WATER SUPPLY IN HAWAII

WENTWORTH AND OTHERS

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A Symposium Presented Before the Hawaiian Academy of Science,
First Session, Seventeenth Annual Meeting, November 14, 1941

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RAINFALL AND WATER SUPPLY
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MUNICIPAL WATER SUPPLY
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Reprinted from the
Paradise of the Pacific,
Febrary, March, April and May,
1942

HONOLULU, HAWAII
1942

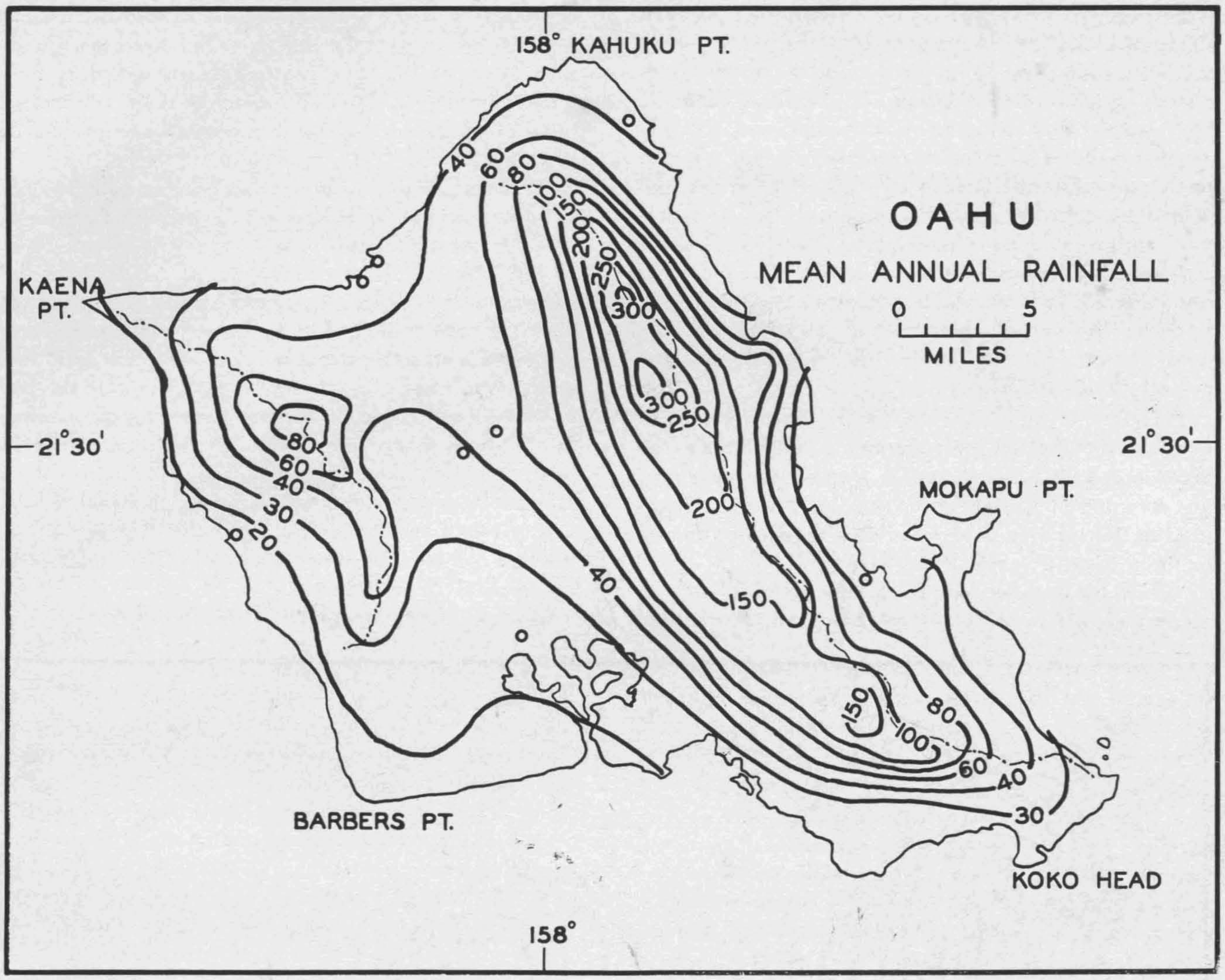
Foreword

Why should Hawaii, with its torrential rains, widespread liquid sunshine, and lush tropical vegetation, have a water supply problem? This is a perennial question which newcomers ask and which not all oldtimers are able to answer. But there is an answer, found in the nature of Hawaii's various climates, volcanic rocks, and rugged mountains, and the complete story is a long and complex one. The four papers which follow are intended as a brief and simple, but authentic introduction.

CHESTER K. WENTWORTH,
Chairman and Editor.

Rainfall and Water Supply

By Max H. Carson



Editor's Note: This is the first of a series of four papers on Water Supply which were presented as a symposium before the Hawaiian Academy of Science under the chairmanship of Dr. Chester K. Wentworth, Senior Geologist, Board of Water Supply. The other three will appear in future numbers of the Paradise of the Pacific.

NEXT TO OXYGEN, water is the most immediate requirement for the sustenance of all forms of life, including ourselves and all our sources of food supply. A very large part of the life on our planet is dependent on fresh water; that is, water containing less than one part in a thousand of chlorides. In addition to its use in sustaining life, water serves for transportation, recreation and power, and to a considerable degree as a solvent and many other less generally recognized purposes. Water supply signifies the occurrence of water which is available or can be made available for these purposes. All usable fresh water appears first as moisture condensed from the atmosphere as rain.

Of the rain that falls, some is evaporated again or carried away by the wind, some is used by plant life, some runs off the surface in streams and some sinks into the ground to fill the voids in the rocks or to move through them and appear later as springs. Where little rain falls on the surface of the earth, most of it is lost in evaporation and transpiration and little if any becomes available either as surface or ground water for future use. Wherever the rainfall is heavy, both evaporation and transpiration are relatively low so that much of the water runs off or sinks into the ground. To what extent it does the one or the other depends on the character and structure of the rock on which it falls, the topography and to some extent the vegetative cover.

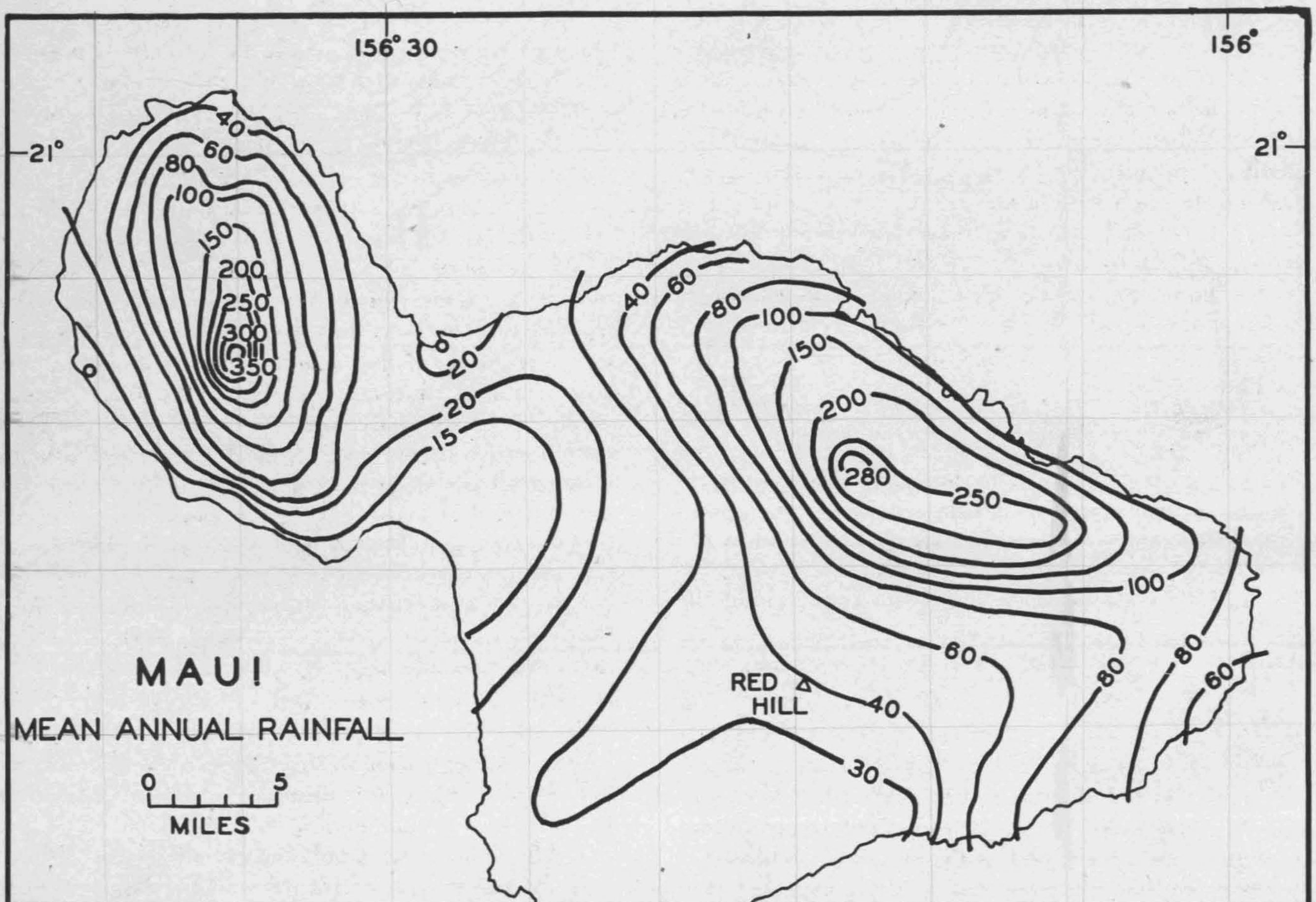
In Hawaii, there are areas where the rainfall is very light and others where it is extremely heavy, as well as localities with all intermediate intensities. The extremes vary from as low as six or seven inches in a year to more than six hundred inches. And these respective areas are consistently low and high in rainfall. This is not to deny that there is much variation from year to year, season to season, or month to month at any given locality; for as we all know such variations do exist. On Waialeale the range is from about 250 to 600 inches annual rainfall while in some of the dry areas a single storm may equal or exceed the yearly average. But Waialeale is always very rainy and Mana on Kauai or Barber's Point on Oahu are always very dry. The areas of high rainfall are not desirable as human habitations or adaptable to agriculture, both because of the direct effects of high rainfall and deficiency of sunshine and also because they lie in localities of extremely rugged topography at high altitudes which are difficult of access and difficult to cultivate, and with uniformly low temperatures unfavorable to common food crops. Hence the problem of water supply is one of transporting the water from where it falls as rain to where we want to use it. In doing this, natural channels and storage systems are used wherever practicable, the final distribution being made by artificial means.

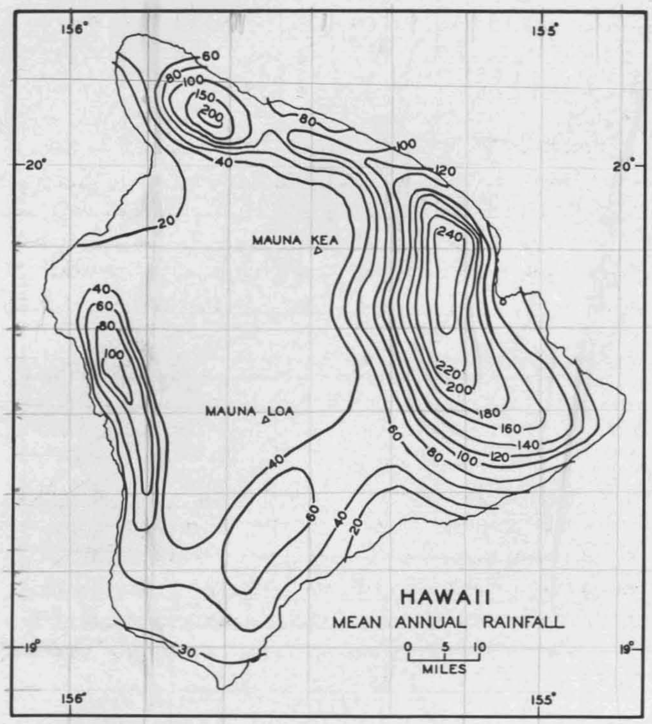
Therefore, in studying water supply, we are concerned with the distribution and quantity of the rainfall, the location and discharge of surface streams, the movement and quantity of ground water and the artificial devices used in transporting it to where it is needed for domestic, industrial and agricultural use.

While the general features of the weather such as warm and cold fronts, cyclones and anti-cyclones, pressure gradients, etc., may be significant with respect to whether the rainfall is above or below normal, these do not explain why the average annual rainfall is less than 20 inches in some parts of each island while on other parts of the same islands it amounts to 200, 300 or even 450 inches. Such differences must be ascribed to topography and exposure to the prevailing winds, which blow some 95 per cent of the time from the northeast quadrant, except on the Kona coast of Hawaii which is sheltered from the trade winds and has daily reversal of wind direction due to alternate heating and cooling of the land surface.

Although, so far as I know, there are no good records of rainfall over the open ocean, it is probably safe to say that the average in this vicinity does not exceed 20 or 30 inches a year. However, when the wind strikes the mountains it is deflected upward against the cooler air above. Condensation of its burden of moisture as rainfall rapidly increases till at between 2000 and 3000 feet on the windward or northeast slopes the rainfall reaches an intensity of some 200 inches or more a year. Above this altitude, where the mountains continue to rise in fairly smooth slopes, forcing the air still higher as on Haleakala and Mauna Kea it seems to have lost its heaviest load and the rainfall gradually decreases till on the tops of Mauna Kea and Mauna Loa it is reduced to the original 20 or 30 inches.

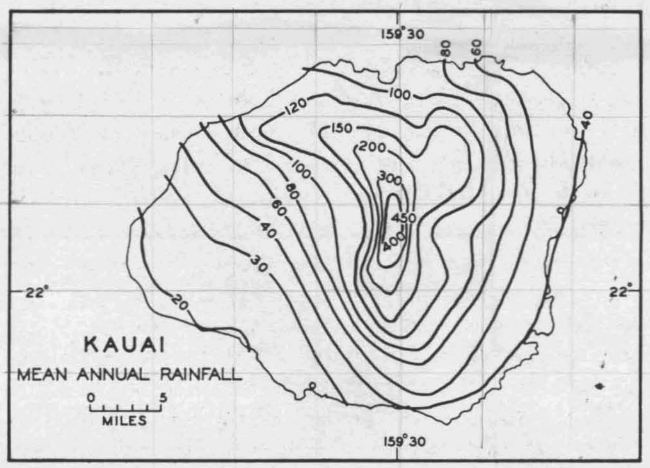
In some places topographic features other than alti-





tude come into play to change the general picture. When the rising air currents reach the crest of the mountains and pass the obstruction which has deflected them upward, their direction changes to horizontal or slightly downward, and the rain drops just beyond the crest. If this release in upward pressure coincides with an altitude at which maximum condensation takes place due to cooling, the combination results in high precipitation. Where there are deep valleys, broad at their mouths and narrowing toward the summit the winds blowing up these valleys increase in velocity and carry the rain to higher levels than on relatively smooth planes or surfaces cut by parallel valleys. At the same time the increase in pressure produces greater condensation. Again if the topography is such that the valleys converge toward the same summit from all directions, the resulting rainfall is extremely high, as on Waialeale, Kauai (average over 450 inches), and on Kukui, Maui (average over 390 inches a year). After dropping their moisture the winds travelling down the leeward slopes become warmed, expand and dry out till as they pass off the lee coast to the sea they are robbed of moisture and like the winds that pass over the tops of Mauna Kea and Mauna Loa produce only 20 inches or less of rainfall annually. Niihau, Lanai, and Kahoolawe are sheltered from prevailing winds by other islands and are therefore normally exposed to winds that have unloaded their moisture and are relatively dry. Hence there is little rainfall on these islands.

The accompanying isohyetal maps illustrate this distribution of rainfall. Attention is called to the Kona rainfall which is only about half the fall at comparable altitudes on the windward side since the wind blows inland only about half the time. In general the stream flows reflect this distribution, and the streams are more numerous and larger where the rainfall is heaviest. This is modified by the type of rock or soil on which the rain falls. If these are tight and relatively impervious, a large proportion of the rainfall runs off in streams. If they are loose and pervious the larger portion of the rain sinks into the ground and in spite of heavy rains the streams are small and unimportant. The wide variation in Hawaiian rocks in this respect results in wide divergences in runoff per square mile of drainage area which are not attributable to differences in rainfall. On Kauai, where the soil is relatively tight, we have large streams, Wainiha, Lumahai, Hanalei, Anahola, Wailua, Hanapepe, Olokele and the Waimea river system, besides many smaller streams supplying something



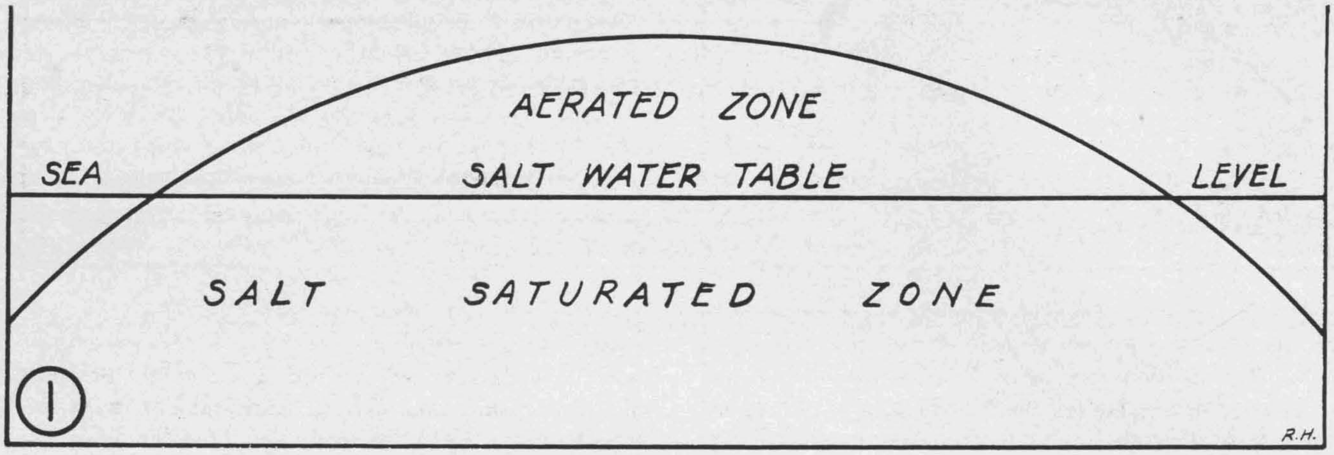
like 400 to 500 million gallons a day of surface water, of which only a part can be practically utilized at present. This is yield comparing favorably with the yield of the entire bulk of east Maui, and greater than the runoff from the whole Island of Hawaii.

Thus most of our rain falls on relatively small areas high on the mountain sides, generally on the northeast side of the islands, or on the lower ranges, just to the lee of the crests. Our streams flow from still smaller areas in the same regions and in many places actually decrease in volume as they flow seaward. On the contrary, the homes of the majority of our population and most of our agricultural areas are in the drier, sunnier regions along the sea coasts. To bring the water from the streams to these areas, chiefly for irrigation, ditches have been built along the sides of the mountain ranges and they collect water from the streams and deliver it to the growing fields. A few of these ditches divert from single streams, such as Hanapepe and Olokele on Kauai. But most of them cross and divert water from a great many small streams, and on East Maui several ditches at different levels parallel each other and collect from the same streams at the several levels.

However the surface water supply is neither sufficient nor uniform enough in quantity to supply all the requirements of our agricultural developments. Because it is subject to contamination, such surface water is less desirable for domestic supply than ground water. Moreover, the topography of the Hawaiian Islands is such that large surface storage reservoir sites are not available. Hence the development of ground water supplies has become of major importance in this Territory. This subject will be discussed in a later paper by Dr. Palmer.

Geologic Structure and Water

By Harold S. Palmer



The concurrence of only salt ground water in a rainless island

OF THE WATER that falls as rain, some (the "fly-off") returns to the asmosphere, some (the "run-off") flows as surface streams, and some (the "run-in") seeps into the ground. Part of the run-in stays near the surface of the ground as soil-water accessible to roots, but some goes on downward to become ground-water, which is the water supplying wells and springs.

It is clear that most ground-water is derived from rainfall (or melted snow). For one thing, regions of abundant rainfall are also regions of abundant ground-water. For another, at any given place, ground water is most abundant during and after heavy rains and decreases during droughts. Thirdly, rainfall is sufficient in amount to be an adequate source. The average rainfall on the 37 square miles back of Honolulu is about 95 inches a year. If one-fourth of this seeped into the ground and was fully recovered, it would yield about 40 million gallons a day if uniformly distributed throughout the year.

HYDROLOGIC PROPERTIES OF ROCKS.—Different kinds of rock differ in hydrologic properties, or abilities to store or transmit water, or to restrain its movement underground.

Rocks can contain and transmit water if they have suitable voids, or non-rock spaces, of fair size and abundance, such as the gas pores in lavas or the chinks between sand grains or pebbles. The amount of such pore space varies from a negligible amount up to about 50 per cent of the total volume of the rock. The ability of a rock to store water is proportional to its porosity.

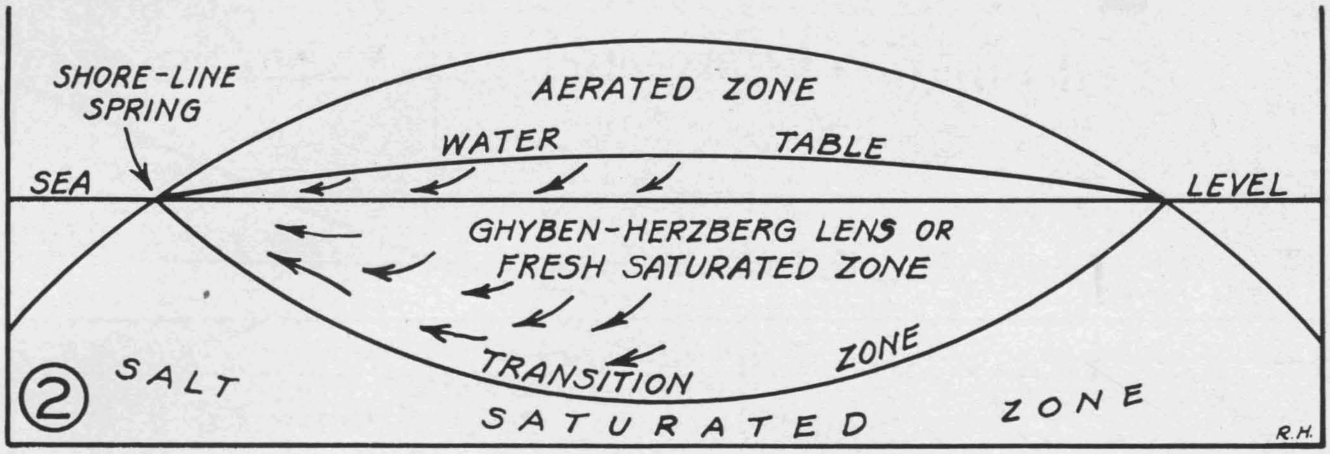
Pervious rocks have at least a fair abundance of voids, which are of good size, and which are inter-connected. Probably there are nowhere large bodies of rock that are more pervious or porous than the lava rocks and fresh volcanic ash of Hawaii. Parts of the emerged reef-rock of Hawaii are pervious because solution has enlarged cracks in the relatively soluble limestone.

Impervious rocks have voids that are so small as to offer great frictional resistance to the passage of water, or that are few, or that do not inter-connect. Hawaiian lava rocks weather and rot easily, so that sediments composed of their debris soften and mash down, thus destroying the chinks between the grains. Thus sediments derived from basalts, whether laid down as valley-fill by streams or as shore deposits by waves, become rather impervious. Old soils and old beds of volcanic ash, formed between lava flows, also become impervious by the same rotting and mashing process.

During the building of our volcanic mountains, lava often made its way into vertical cracks that radiate from the central volcanic conduit, or into horizontal openings between buried lava flows. Since they solidified under pressure, the lava rock of these tabular bodies is nearly free of gas pores, and is therefore nearly impervious. The vertical, tabular bodies that cut across the older lava flows are "dikes," and are far more abundant than "sills," which are the ones that lie between and parallel to flows.

DISTRIBUTION OF GROUND WATER IN IMAGINARY ISLANDS.—With a knowledge of the effect of pervious and impervious rocks on the movement of water, and with reasonable assumptions as to the distribution, shapes, and interrelations of such bodies of rock underground, we can figure out where and how water may exist underground. Such deduction is attempted in the following paragraphs for several kinds of imaginary oceanic islands.

A symmetrical, uniformly pervious, rainless island offers a simple problem with which to begin. In such an island, as suggested by the vertical cross section of Diagram 1, salt sea water would eventually seep into the island and fill all the accessible voids below sea level, forming what may be called a "salt saturated zone." It must be borne in mind that the accompanying diagrams are only diagrams and are not drawn to



The Ghyben-Herzberg lens of fresh water, supported on denser salt water, in a rainless island

scale. The depth to which fresh water extends below sea level is shown far too small in Diagrams 2, 3, and 4, because of limited space. The part shown above sea level will contain only air and is the "aerated zone." The boundary surface between a saturated zone and an aerated zone is a "water table," and in this situation is a "salt water table."

A symmetrical, uniformly pervious, but rainy island will involve the interaction of fresh water and salt water, which is heavier by one fortieth, so that a given depth of salt water will cause one-fortieth more pressure than the same depth of fresh water.

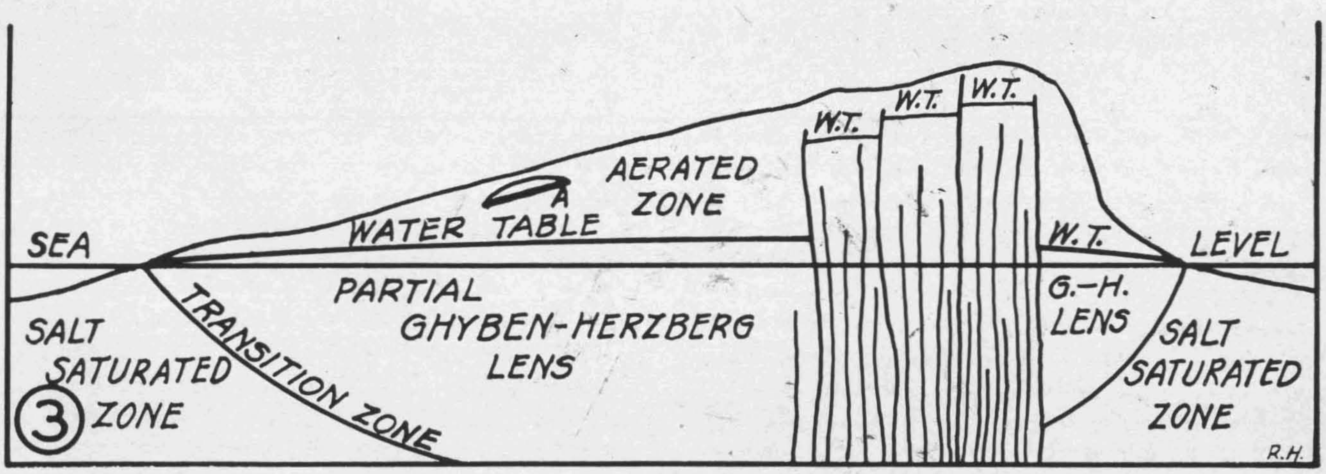
Let us consider what would happen if a formerly rainless island had its climate change to one of considerable rainfall. The run-in will move downward by gravity until it reaches the salt water table. If abundant, the water will spread laterally and some will escape at the edge of the island as shore-line springs. But some will pile up and press down on the salt water and will displace some of the salt water until an equilibrium is reached. Thus, fresh water will saturate a body of rock shaped like a bi-convex lens, known as the "Ghyben-Herzberg Lens," in honor of two Europeans who first studied it. The lower surface of the lens, or "transition zone," will bulge downward about forty times as far below sea level as the upper surface, or water table, bulges above sea level. From the ground surface downward, as suggested by Diagram 2, we would find first an aerated zone, then a fresh water table, a fresh saturated zone, a transition zone, and, finally, a salt saturated zone.

An island cut by tabular bodies of impervious rock will have some ground water at higher levels. The tabular bodies may be dikes that cut more or less vertically across the laval flows or they may be sills or weathered soils or weathered ash beds that lie between and parallel to rows.

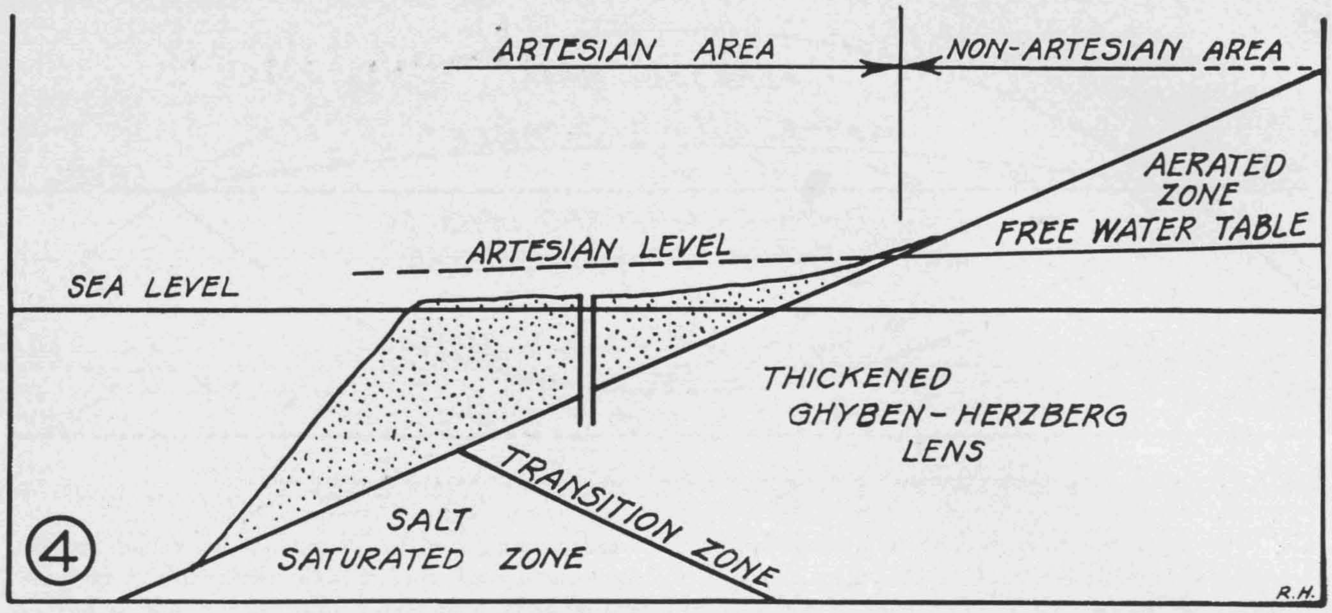
Downward movement will be stopped by impervious sills or beds of weathered ash or soil, and the water will collect as small "perched" ground water bodies, as suggested at "A" in Diagram 3. The heavy line represents the impervious body. The perched water rises a little above it. Below it is part of the aerated zone.

At the right of Diagram 3, the vertical lines represent dikes, which form the impervious walls of what might be likened to huge underground "boxes." Within the boxes, of course, are flow lavas whose abundant voids may be filled by water derived from the mountain rainfall. A good many tunnels driven horizontally so as to pierce such dikes have obtained large flows of water behind the dikes. Little success has been had with tunnels that do not cut dikes.

A coastal capping of impervious rocks along one



The concurrence of ground water at higher levels in an island cut by tabular bodies of impervious rock.



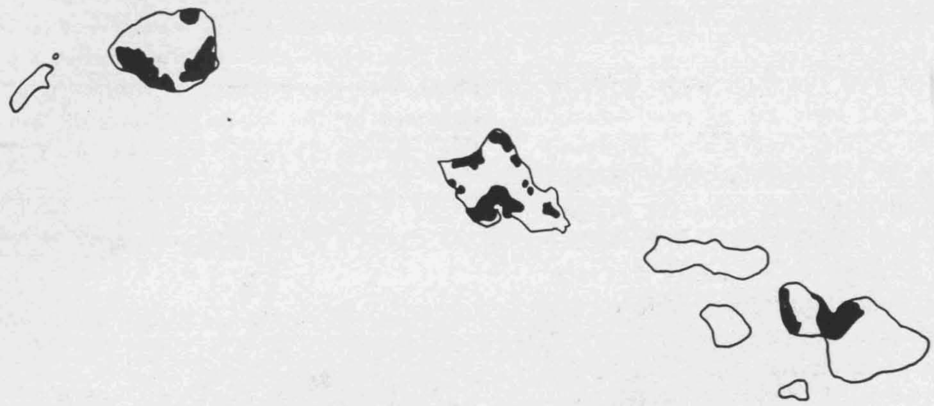
The origin of artesian pressure where there is a coastal capping of impervious rock.

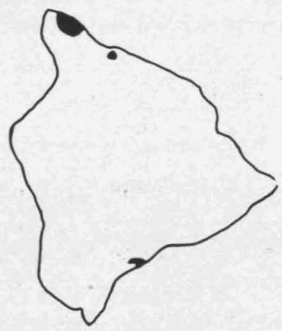
shore of an island, otherwise composed of pervious rocks, is shown in stipple in Diagram 4. The impervious capping prevents discharge of fresh water as shore-line springs, and backs up the fresh water in such a way as to thicken the edge of the Ghyben-Herzberg Lens. Water below the impervious capping will have a pressure corresponding to the height of the nearest part of the free water table, and will rise to about that level (the "artesian level") in a bore hole drilled down through the capping into the saturated, pervious rock. In other words, the water will have artesian pressure, as shown by the dashed line in Diagram 4. Wells too near the shore and wells that are too deep will get more or less salty water instead of fresh water, as can be read from Diagram 4.

At Honolulu and elsewhere, the cap rock, considered as a unit, is a relatively impervious body, but it does contain, especially in its upper part, layers of reef-rock, or gravel, and of volcanic ash that are water bearing. This water is, of course, not artesian. It is in serious danger of becoming polluted since it is derived in part from rain that has fallen on the inhabited lowland areas.

Water and Hawaiian Agriculture

By Joel B. Cox





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IRRIGATION IN HAWAII — 1938

	AREA IN ACRES				AVERAGE M. G. D.	INVESTMENT IN DITCHES, WELLS, PUMPS AND POWER
	SUGAR CANE	RICE	TARO	TOTAL		
OAHU	44,641	294	831	45,766	537	$ 11,083,908
KAUAI	38,384	982	114	39,480	374	5,841,135
MAUI	37,125	0	103	37,228	524	11,631,970
HAWAII	10,653	0	118	10,771	136	1,333,885
TOTAL	130,803	1,276	1,166	133,245	1,571	$ 29,890,898

The ancient Hawaiians identified one of the greatest gods of their mythology with the eternal beauties, endless fascination and life-giving qualities of water. The worship of Kane, the great god of nature, was at the same time the most elevated and mystical in tone of Polynesian religious observances and directed toward one of the most essential practical aspects of their culture and civilization.

The last verse of *He-mele no Kane,* an ancient traditional poem from Kauai is:

"E ui aku ana au ia oe,
Aia i-hea ka Wai o Kane?
Aia i-lalo, i ka honua, i ka wai hu,
I ka wai kau a Kane me Kanaloa—
He wai puna, he wai a inu,
He wai e mana, he wai e ola.
E ola no, ea!"

"I ask you
Where is the water of Kane?
There—deep in the earth in the gushing waters,
In the water of Kane and Kanaloa that is flowing in all seasons,
It is spring water, it is water to drink.
It is water of divine power, it is the water of life.
It is life itself."

Even in those ancient days the life of the land was supported and preserved by the wise and careful use of water in irrigation. Taro irrigation called forth engineering skill of no mean order, and the hanging terraces of Wainiha, Kalalau and Nualolo, the long route of the native ditch at Wahiawa on Kauai, the evidences that flumes built from hollowed logs were used to cross gulleys, all show the resource and skill of the Polynesian engineer. It is significant that even such alien skill in stone masonry as is shown in the construction of the Menehune Ditch (at Waimea) of squared stone, should have at once been put to the service of the essential art of irrigation. It is also perhaps significant that much of ancient hydraulic engineering was ascribed to the work of Menehunes.

Taro, and later rice in the inundated valley flats, and since 1856 an increasing percentage of the cane sugar of Hawaii have been irrigated crops. It is a striking condition where in a land of verdure and high rainfall the principal agriculture has always been dependent upon irrigation. Hawaii's living has always been gained from the soil, and has always depended upon irrigation to an extent only equalled by the arid regions of most lands.

The causes of this dependence upon irrigation are two-fold. First, that localization of rainfall discussed in the preceding papers, with its accompanying rugged topography, leached soils, and decreased sunlight in the rainy zones. This difference of habitat of the rich soils demanded by the rapid growth of plants in our tropical climate from the areas which are heavily and constantly bathed in showers has called for great investments and for skill on the part of the hydraulic engineers responsible for the developing of our modern systems for the conveyance of water. In the same manner the irregularity of the distribution of rainfall in time has placed a high premium of water storage, but this in a country where such storage is difficult and costly.

The second feature is that the three main irrigated crops, taro, rice, and sugar cane are all semi-aquatic plants, natural swamp-growing vegetables, requiring and able to use and profit by enormous concentrations of water. A contributing factor has been the prevailing looseness of structure characteristic of Hawaiian soils. The usual high permeability has meant that rainfall has not remained long in the root zone of our plants.

During the periods of profitable expansion in the sugar industry, 1900-1910 and 1920-1928, most of the principal water-yielding areas on the windward slopes were tapped for use in cane irrigation. Those that remain have been too far away from suitable arable land

ECONOMIC EQUATION FOR AN IRRIGATED SUGAR PLANTATION

P = Returns from one ton 96° Sugar at Market including Molasses and Compliance Payments

I = Investment in Mill, Buildings, Equipment, Field Ditches etc. per acre

O = Operating Cost (including Depreciation) but not including water supply or land rent or taxes on land: Per ton of 96° Sugar

L = Land Value per Acre

V = Value of Water delivered to the Distribution Ditches: Per million gallons

s = Tons of 96° Sugar produced per Acre per Year

t = Tons of 96° Sugar produced per million gallons of Water measured at delivery to Distribution System

i = Annual Return on Investment per $1.00 of Invested Capital

r = Rent and Taxes per $1.00 Value of Land

$$P = O + \frac{V}{t} + \frac{rL}{s} + (I + 2sO)\frac{i}{s}$$

$$V + \frac{Lrt}{s} = tP - tO - (I + 2sO)\frac{ti}{s}$$

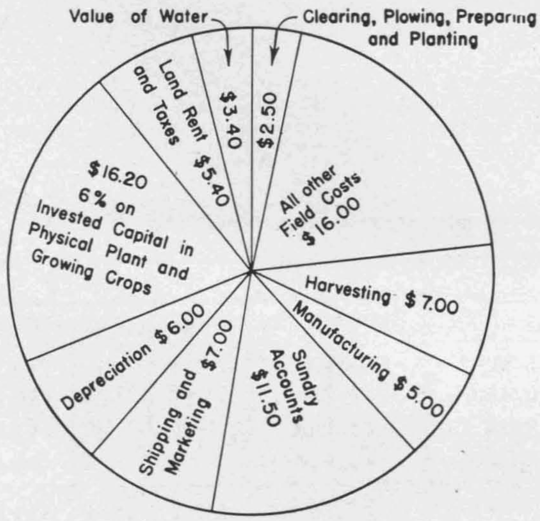
②

or the tunneling cost too high (for there is a relationship between the cost per foot of tunnels and the distance between adits).

There is no general shortage of arable land and it is rather generally true that the sugar production of the Islands has tended to be limited by the expense in developing water supply justified at any time by the future prospects of the sugar industry. Irrigation is therefore an economic problem, the finding of a balance between the cost of water delivered to a plantation and the earning power of such water.

No good study of ancient Hawaiian taro areas seems available. The 1938 tax data listed 3,801 acres as wet land. Perhaps twice this or 6,000 to 8,000 acres was the maximum ever in inundated crops. Recent figures on the areas under irrigation for cane, taro and rice are shown in the accompanying table.

Such statistics lead to a crucial point of this discussion, the irrigation requirements of a given area in terms of water supply. This is partly a problem in plant physiology, and it would be well to consider all that this science can contribute. But it must be recognized that the quantity of water supplied is largely governed by the losses in transportation and application. About 45 inches per year or 3,350 gallons per



③ TYPICAL DISTRIBUTION OF EARNINGS PER TON OF 96° SUGAR
Sugar at 3.45¢ per lb.
Compliance Payments and Molasses $11.00 per ton

acre per day may be transpired, while three times this much must be provided for cane and perhaps ten times as much for taro. For rice the water requirements are practically the same as those for taro except that for rice the operation of the patches is seasonal. The demand for water inflow to a group of taro patches includes also a requirement for circulating water, which will later be returned to the stream. The total inflow will carry from 25,000 gallons per acre per day to 80,000 gallons per acre per day or even more.

It is not well known or easily determinable what is the exact value of water for taro cultivation. It is probably not more than $5.00 per million gallons. It is of the same order of magnitude as the value of water for truck gardening. I think that no irrigated diversified farm on a large scale can be made profitable where water costs more than $5.00 per million gallons. The plans for such irrigation require heavy subsidization either because of an assumed general social necessity or the demands of national defense. They do not fit into an orderly economic scheme of free enterprise for profit or for production at minimum cost.

For cane the water requirements are also highly variable. First of all remember that most of our cane lands are in regions of appreciable rainfall and that only the deficiency in rainfall must be supplied by irri-

ECONOMIC EQUATION APPLIED TO A TYPICAL PLANTATION

P variable (includes $11.00 per ton sugar compliance payments and molasses returns)

I = $800.00

O =	
Clearing and Plowing	$ 1.50
Preparing and Planting	1.00
Water Distribution	1.00
Cultivating	11.00
Fertilizer and app.	4.00
Harvesting	7.00
Manufacturing	5.00
Sanitation	1.50
Repairs	2.00
Sundries	5.00
Taxes, except on Land	3.00
Shipping and Marketing	7.00
Depreciation	6.00
	$ 55.00

s = 5
t = 1.8
i = 0.06
r = 0.09

④ $V + 0.0324\,L = 1.8\,P - \$128.16$

gation. The water supplied depends also upon the seepage from ditches and watercourses, and the permeability of the soil, upon the temperature and sunlight, the variety of cane and the amount of fertilizer applied, the age of the crop and upon whether it is being grown for a short cycle of harvesting of from 12 to 14 months or for a long cycle of 16 to 24 months. The topography of the field has an important influence upon the field losses, as also the method of irrigation employed and the skill of the irrigators.

The statistics just presented give an average consumption for the entire Territory of 11,500 gallons per acre per day. The seasonal variation is very marked, with a mid-winter consumption of about half the mean and a mid-summer demand of about one and a half times the mean.

This leads to the most important consideration of application of water to Hawaiian crops. The art of irrigation, like all engineering, deals with an economic problem, and it is the knowledge of what cost is justifiable in the development of a plantation water supply that governs all decisions as to whether such agricultural use shall be extended. Now this value of water for agricultural use is at all times a delicate balance between many factors. The principal ones are shown on the accompanying chart. Each of these is affected by many others such as geographical location and cost of transportation, competition in the use of land, topography and extent of the plantation area, all the factors of soil and climate, and social conditions affecting the supply of labor and its cost and efficiency.

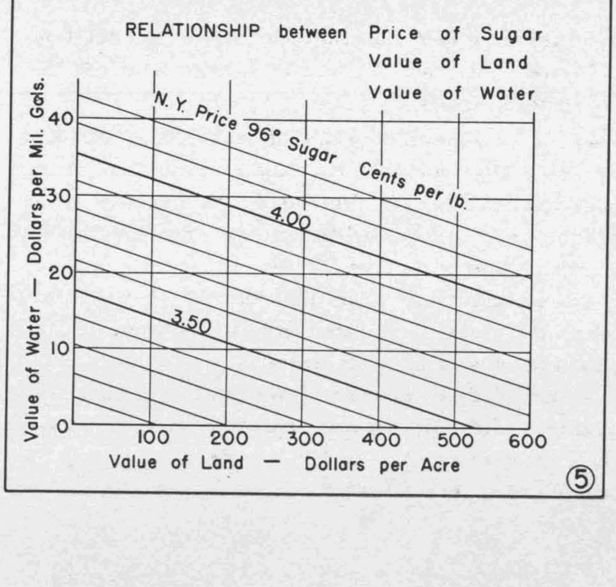
Above all these there is the highly variable factor of the price of sugar. At any time the decision as to whether to develop more water is dependent on the value of all these economic factors as forecast for the future, not as they have existed in the past. The engineer and the businessman must be forecasters, must have a sound basis for judgment of future trends in the economic factors of the industry. The development of industry and the fulfillment of the principal function of the engineer are therefore highly dependent on an orderly condition in the social and economic world. I do not say a *static* condition, I say an orderly evolution in which trends may be safely measured and changes foreseen. No proper carrying out of the functions of engineer or entrepreneur is possible in a world of chaos, and that it what we have today. It is therefore of conditions in the past that I am forced to speak, of the recent past it is true, but I warn you that they may not hold in the future that is to come.

So I shall attempt only to give you an economic scheme with an illustration from typical (rather than average) 1938 plantation conditions. The various factors change materially throughout the sugar-growing area of Hawaii, and each case must be separately considered. The general features of the conomic scheme may be outlined with simplicity as is done in the accompanying tables and charts.

The important thing is to grasp clearly the intimate reciprocal relationship between land and water values. The other factors are largely determined by economic factors in the external world, and determine a total value for both land and water. How this value is to be distributed between the two co-factors is an internal problem. The value may be nearly all ascribed to the land, as where water is abundant and cheap, or nearly all to the water, as where competitive use for the land is absent and the water supply is limited. I have tried to show this relationship by my arrangement of equations and charts.

This type of analysis refers to the average, year-round value of a water supply. It does not refer to the marginal value of an additional million gallons of water during some definite time of shortage, such as a mid-summer month of drought. Nor does it refer to the value of water to an already operating plantation which is suffering from a shortage of water supply. These latter problems are more complicated and involved and while of great interest the details are too elaborate to be given in the space that we now have available. The resulting values are high. Frequently such water is worth from $75 to $100 per million gallons.

It is only in this latter zone where competition for



water can be felt by a municipal demand for domestic purposes. The three principal uses for water:

(1) For domestic consumption, with usual values greater than $100 per million gallons;

(2) For sugar cane irrigation, with usual values from $5 to $100 per million gallons;

(3) For taro, rice and diversified crops, values less than $5 per million gallons;

are in different zones of value. Only under exceptional conditions can there be any real question of competition between them. The higher valued use will always govern.

So in Hawaii our great irrigation systems have been built to fit the needs of the industry and of the time. The total cost of water, including interest on the investment, depreciation of all non-permanent items of construction or investment, operation and maintenance, must needs have fallen within the economic zone for each plantation. Where error has been made, as at Kihei or McBryde in the days of steam pumping, disaster has followed. A few pictures will show the character of construction of such water supply systems. Tunnels, dams, high flumes and steel pipelines have all their parts to play. Add to these pictures the great pumping plans which deliver up to forty millions of gallons daily from a single shaft, and remember that this fabric of remarkable construction has been erected in a land where stream valleys are cut to depths measured by thousands of feet, and where our geologists have had a secret source of pleasure in watching us poor engineers struggle with underground conditions where anything may be expected in the next foot of heading progress, and where everything frequently does happen, and you will perhaps join me in paying tribute to those great contributors to American engineering progress who have built our irrigation systems in Hawaii. M. M. O'Shaughnessy, Alonzo Gartley, Jorgen Jorgensen, J. H. Foss and many others have contributed greatly to the wealth of Hawaii, and to the knowledge of the engineering world.

Municipal Water Supply

By *Walter H. Samson*

Water falling in the hills eventually reaches Honolulu's artesian basins.

Foreword

THE problems of a municipal water supply vary in different regions, depending upon the type and source of available water supply, the terrain and climatic conditions, and according to the water requirements of the domestic, agricultural, and industrial users. The problems to be met by the municipial water system are those mainly connected with the growth of the city and the increasing dependence of city dwellers on the public agencies. Many isolated, one-family dwellings in rural Hawaii are served by roof catchment of rain which is stored in wood or metal tanks holding from 10 to 100 days' supply for the family. At the other extreme is the municipal water system which serves the city of Honolulu, a complex modern plant with an inventory value of almost 13 million dollars. Between these lie the systems of various sizes serving smaller villages and towns. Much of the following discussion applies particularly to the Honolulu system but many of the problems have not been encountered by some of the smaller communities. As these communities become larger, since they depend on the same climatic and geographic background, their expanding water systems will face more of these similar conditions and difficulties.

Fundamental Requirements

Three main requirements in any municipal system, whether public or private, are that the supply must be *dependable*, sufficient in *quantity*, and of high *quality*.

Dependability

Water is more immediately essential to human life than is food. When the old Hawaiians found their water supply failing, they either packed fresh water from distant mountain springs, or moved downstream, or perished. The dweller in a modern city lacks such adaptability; he cannot, for various reasons, move; and he is rarely able legally or economically to dig a well. He has, through no direct choice of his own, surrendered the right and the native skill to deal with this problem. The responsibility rests with the city, of which such a man is a part, to have water continuously available for drinking, cooking and sanitary uses. This service is not rendered wholly for the individual families, for in addition, the community must be provided with an adequate supply at all times for agricultural and industrial purposes and for fire protection. This is recognized by individual and community alike; it is the necessary standard of community life, just as truly a matter of existence and survival as were more simple individual requirements in more primitive times.

Quantity

Necessary quantities of water are determined by racial, local and personal customs and by climatic and economic conditions. It is impossible to draw a sharp line between domestic and industrial and agricultural uses. Water used by hotels, civic centers and organizations, parks, and most of the business establishments of a community is as essential to the particular standard of living established there as water used in homes for drinking and cooking.

In cities in mainland United States, where high standards of domestic life and sanitation prevail, the per capita daily use of water averages about 100 gallons. In England, 40 gallons per capita is considered high, and many parts of Europe use still less water. Farm life with the farmhouse well or pump, the Saturday night bath, had a per capita use of water of about 10 gallons daily per person. In Honolulu the per capita use started at a low value when shore wells were dug by the missionaries over a century ago, rose progressively when the first pipe line was constructed about 1850, and skyrocketed after 1880 when the artesian supply was tapped. In 1916, the net per capita use, including water supplied from privately operated artesian systems was about 350 gallons daily. This rate had probably been reduced to 305 gallons in 1928 and was 205 gallons in 1940.

The problem of further reduction in the daily per capita requirement is not solved by lowering the present standards of living, but by devising the most beneficial utilization of industrial and agricultural water or by substituting a non-potable source of water supply wherever conditions permit and provided a suitable supply is available.

Quality

Water for all-around municipal use must be low in mineral content, free from color, odor, objectionable taste, and sediment, as well as from bacterial or other organic contamination. While it is fully recognized that in the isolated rural areas these standards are not fully met and much local contamination may occur, the consequences have not been so widespread and such conditions have been tolerated. Small streams and springs in country districts often do carry water which is free from pathogenic bacteria. But in a town or city, the only safe assumption is that all surface water and most shallow ground water is dangerously contaminated, and in view of the dangers of widespread epidemic conditions which may arise from contaminated supplies, all surface water must be either filtered or chemically treated before being considered safe to supply to any community.

Local conditions determine, both in Hawaii and elsewhere, what source should be tapped. The best available natural water which occurs in sufficient quantity, with a minimum of treatment, is not only the most economical but is often the only supply that will avoid serious disaster.

Sources of Water in Hawaii

Each island of the Territory is dependent strictly on its own rainfall for a water supply. Large, dependable supplies of surface water of good quality are unknown in Hawaii, and recourse to water from large rivers, fed by rainfall and groundwater hundreds of miles away is impossible. This is due to the relatively small size of the islands, their steepness of slope, and the lack of large perennial streams. The shape and nature of the grounds is such that the storage of large amounts of surface water is not generally practicable and the quality of such water is not dependable. For small supplies in certain parts of Hawaii, surface water may serve for public use but it does not appear that the needs of medium or large systems will be satisfactorily met as to dependability and quality by surface sources. Permanent satisfactory water supplies for the larger public systems will come from ground water sources, the general character of which has been outlined by others in this discussion. In this restriction to ground water supplies, public systems of large size are much more limited than agricultural systems which can tolerate certain deficiencies of quality and dependability. Honolulu depends primarily on ground water supplies with a small amount, approximately 5 per cent, being obtained from mountain springs and tunnels.

Operating and Service Requirements

Uses of water from a municipal system are varied. One of the problems is that of agricultural water. Because of the high requirements in dependability and quality, in pressures and in adaptation to fire protection in a system built chiefly for domestic supply, it is not generally practicable to furnish such water at rates which will permit small farmers to make a profit in strictly commercial agriculture. There is nothing strange about this; the municipal system is engaged in delivering a product of higher grade and under stricter service conditions than is required for commercial farming, and it is not possible to duplicate the system or to furnish two different grades of water through the same pipes. This is a permanent problem and it is no doubt desirable to encourage diversified and subsistence farming by use of cheap water where that can be had or by some form of subsidy, but it has been held by the Honolulu Board of Water Supply that it is not the duty of other water rate payers to pay the excessive cost of furnishing water through the city system for agricultural uses at rates less than the cost of production.

Another problem is often posed by the peculiar conditions of fire protection. Water for fire protection may be needed by any consumer and it may be needed by non-consumers or by consumers in amounts that are not in proportion to normal uses. The chief cost of fire protection is not in the amount of water used but in the high momentary rate of delivery demanded and the required installation for fire protection of water mains of capacity generally two to three times larger than would be required for all other domestic uses. The investment charges for such oversize construction, while it is absolutely necessary for the community, forms a considerable fraction of the water rate.

An important factor in the problem of equitable application of fire protection costs in Honolulu is the problem of privately owned and operated artesian wells. At present, about 40 per cent of the water taken from the artesian structure is by privately owned and operated artesian well systems. The bulk of this water is used for agricultural and industrial purposes. In view of the increasing difficulty of meeting public demand for domestic water from the artesian structure, I cannot justify the use of such water for agricultural irrigation within the urban area. Moreover, the users of water from these wells pay no water rates, and take no part in meeting the costs of various measures designed for general conservation. Finally, they bear no part of the cost of providing water in quantities sufficient for fire protection. The permitting of the users of water from private wells to use that water in ways and in quantities that are denied to users from the public system, without supporting various overhead costs connected with the protection of the supply system or in paying even for their own fire protection, is one of the reasons why the cost of domestic water to the remaining rate payers precludes its general use for commercial crop production, even if that were otherwise feasible, which it is not.

Much of the responsibility of a public agency for water supply can be consolidated under the first term, *dependability.*

Not only must water be available day and night, with service and repair crews on call to reestablish service and protect the system and neighborhood against further damage in case of accidents, but your water agency also must be constantly alert to prevent failure of the water supply at its source — in other words, to prevent waste or other overdraft that would imperil the community water supply. This is particularly true in Honolulu where the ultimate water supply is by no means unlimited; where the margin is not such that the system can take care of itself; where, in fact, the supply is limited to that portion of the rainfall that can be conserved and utilized.

Municipal water needs must be anticipated and planned long in advance, a very difficult, and at times impossible thing to do. Population growth and the shift of population centers must be predicted with all possible accuracy in the development and expansion of a water distribution system, a problem second in importance to that of foreseeing the quantity demand for water and making provision for its production when required. We have had an example of this in the past two years when a drought of exceptional duration has further complicated an unpredictable increase in the demand for water service that has come with national defense activities in Hawaii. This set of circumstances telescoped the Board of Water Supply's six year long-range plan, calling into the immediate program activities that under normal conditions would not have fallen due until six years hence. The existence of a long-range plan in such form as to be immediately adaptable, saved the situation and proved to be an effective demonstration of the outright necessity for a policy of forehanded preparation for whatever the future may have in store.