Water-Supply and Irrigation Paper No. 77 Series O, Underground Waters, 19

DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

THE

WATER RESOURCES OF MOLOKAI

HAWAIIAN ISLANDS

BY

WALDEMAR LINDGREN

WASHINGTON
GOVERNMENT PRINTING OFFICE
1903

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The publications of the United States Geological Survey consist of (1) Annual Reports; (2) Monographs; (3) Professional Papers; (4) Bulletins; (5) Mineral Resources; (6) Water-Supply and Irrigation Papers; (7) Topographic Atlas of United States, folios and separate sheets thereof; (8) Geologic Atlas of United States, folios thereof. The classes numbered 2, 7, and 8 are sold at cost of publication; the others are distributed free. A circular giving complete lists may be had on application.

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(Continued on 3d page of cover.)

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THE WATER RESOURCES OF MOLOKAI

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DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., October 1, 1902.

SIR: I have the honor to transmit herewith a manuscript by Waldemar Lindgren, geologist of this Survey, with the request that it be published in the series of Water-Supply and Irrigation Papers. This manuscript relates to the water supply of Molokai, one of the Hawaiian Islands. It was prepared from the results of an investigation made unofficially by Mr. Lindgren in 1900. The observations made at that time and the conclusions drawn from them have such general interest, as showing the possibilities and limitations of one of the group of islands, that it is desirable to make them available to the public. Of especial interest are Mr. Lindgren's notes on the gradual decrease of the forested area, the probable effect of grazing, and the intimate relations of these to the available water supply.

The problems of water conservation are here shown to be rather difficult and involved, but are similar in many respects to those of the arid West, the solution being found in combined systems of storage, water-power development, use of the power in pumping, the construction of wells, collecting tunnels, and the economical employment of various devices for lifting water. Opportunity is thus offered for the exercise of skill and mature judgment by the geologist, hydrographer, and civil and mechanical engineer.

Very respectfully,

F. H. NEWELL,
Hydrographer in Charge.

Hon. CHARLES D. WALCOTT,
Director of United States Geological Survey.

Triangulation and Topography by W. D. Alexander and M. D. Monsarrat
Hawaiian Government Survey

MOLOKAI, HAWAIIAN ISLANDS

Scale

1 0 1 2 3 4 5 10 miles

THE WATER RESOURCES OF MOLOKAI, HAWAIIAN ISLANDS.

By WALDEMAR LINDGREN.

INTRODUCTION.

Molokai is the fifth in size of the Hawaiian Islands, and is situated between Oahu and Maui. Oahu is 23 miles distant, and from higher points Diamond Head is in plain sight on clear days. From Maui it is divided by a sound only 8 miles wide. Not much farther to the south rises the dry, rocky coast of Lanai, a still smaller island, chiefly used as a sheep range. Molokai is a narrow strip of land, extending 39 miles from east to west and having an average width of a little less than 7 miles. The area is 261 square miles. The population in 1900 numbered 2,500. The island stands on the submarine plateau from which the whole northern group rises, so that no extreme depths are found in the channel between Oahu and Molokai, nor between Molokai and Maui. Coral reefs fringe nearly the whole south coast of Molokai, but few occur on the north shore. This north shore is the windward side, receiving the full impact of the trade winds and a great amount of moisture. In strong contrast to this the south shore is extremely dry.

Molokai is outside of the ordinary course of travel. No description of the island has ever been published, as far as I know, excepting somewhat stereotyped references to the leper settlement in books of travel. The more easily accessible portions are not attractive, and the northeast coast, which is characterized by wonderful scenery, is hardly ever visited by travelers.

TOPOGRAPHY.[a]

Three natural divisions may be recognized in the relief of the land: (1) The west end, or Kaluakoi; (2) the low gap separating Kaluakoi from the principal mountain range; and (3) the eastern range.

[a] The Hawaiians do not ordinarily designate directions by the four points of the compass. They have instead two very expressive terms: *Mauka*, meaning upward, toward the higher parts of the island, and *Makai*, meaning the opposite, or toward the sea. It also seems that they do not usually designate the water courses by special names, but instead apply to them the name of the subdivision of land through which they happen to flow. As will be seen from the map, each subdivision has its own name.

The west end, or Kaluakoi, comprises about 55 square miles. This area consists of a broad, bare, and grassy ridge, beginning at the light-house at the southwestern extremity of the island and culminating, with an elevation of 1,382 feet, in the round-topped hill of Mauna Loa. Rocky and abrupt ravines lead southward from this backbone to the sea, while long gulches with gentler grade, and separated by broad ridges, reach the north shore. Here a steep cliff has been formed by the action of the waves (Pl. II, *A*). A sharp slope, or pali, a few hundred feet high, runs northward from Mauna Loa, dividing the west end from the low gap.

A low gap separates Kaluakoi from the principal mountain range of the island. The lowest point of this divide is 450 feet above sea level. Gently rolling smooth surfaces characterize this broad gap or saddle; on the south it is cut by shallow gulches and slopes gradually to the sea, while on the north shore the surf has sculptured a low sea cliff gradually merging into the great precipice or pali which from here on follows the northern coast. This gap contains the best and most extensive sugar-cane lands on the island, the total area being about 14,000 acres of deep red, extremely fertile soil. This area is sharply separated from the west end by Mauna Loa Creek on the south side of the island and by the above-mentioned low pali on the north. Eastward the rolling country gradually rises to the plateau of the main mountains of the island.

The eastern range comprises the largest part of the island. This may be briefly described as a segment of a circle, the chord of which extends east and west and has a length of about 25 miles. The line dividing the north-south drainage is, roughly speaking, parallel to the curve of the southern coast. The mountains culminate almost in the center of the island in the peak of Kamakou, which attains an elevation of nearly 5,000 feet. The south slope is gradual, and is furrowed by a great number of straight and narrow, though often deep, ravines (Pl. II, *B*, and Pl. III, *A*). The north slope is abrupt, in places precipitous, and is marked by five most extraordinary recesses or alcoves, cut in the face of the scarp. This great precipice and these alcoves are the most remarkable feature of the island's topography. North of the great gap of the island the great pali has a height of only a few hundred feet, which increases to 900 feet north of Molokai Home ranch and reaches 1,500 feet, where the trail to the leper settlement crosses it. From this point eastward the great precipice is much higher and from Waikolu to Wailau attains elevations of from 2,500 to 3,500 feet; then it gradually decreases again to Halawa, where it ends near the eastern point of the island, having there an elevation of 850 feet. The character of this pali may be seen from Pl. III, *B*, and IV, *A*. When of moderate height, i. e., up to 1,500 feet, it forms practically one continuous slope of from 50° to 70°, with practically no level land below. The surf beats directly against the foot of the escarpment.

A. SOUTH COAST OF MOLOKAI AT KOLO WINDMILL, WEST END OF ISLAND, LOOKING WEST.

Showing seacliff and successive basalt flows sloping down toward the coast.

B. MOUTH OF KAWELA GULCH, SOUTH COAST OF MOLOKAI.

Showing bowlder-filled creek bed and steep side slopes cut in basalt.

At the mouth of the Wailau Valley, and wherever it attains great height, there is usually a vertical or practically vertical cliff from a few hundred to a thousand feet high. Above this a slightly more gradual slope prevails, but for 2,000 feet above sea level the average declivity is often about 70°. Above this the slope flattens to something like 45°. The precipitous rock walls are channeled by a great number of parallel grooves cut by the rain water, and wherever the slopes are not vertical the dark colored rock is covered by a mantle of bright green vegetation. Only in one place is there is any important land mass projecting northward at the foot of the pali. That is the peninsula of the leper settlement, Kalaupapa, a rocky and dry peninsula 2 miles wide and 2 miles long, its highest point rising only a few hundred feet above the sea and marked by the crater of a small extinct volcano.

Next to the great pali itself the most remarkable features of the northern coast are the deep recesses or alcoves which erosion has carved into it, alcoves with exceedingly steep, sometimes perpendicular slopes, of wonderful beauty and grandeur, over the edges of which the waters of the upper drainage basins fall in numberless cascades, increasing to magnificent waterfalls during the rainy season.

West of Waikolu Valley the main divide of the island is close to the northern shore, but here it turns southeasterly and curving follows approximately the central line of the island. The three western alcoves, Waihanau, Waialeia, and Waikolu, have as yet not cut back very far and are therefore most characteristic of their type. All three have a shorter upper high level drainage consisting of small canyons in the high plateau, 200 to 400 feet deep, connected by cascades with the lower straight and deep canyons, 2 to 3 miles in length. The even verdure-clad side slopes descend at angles of from 40° to 60° to the water course in the bottom. At the head of the canyon the declivities become much more precipitous and form an amphitheater in strong contrast to the rolling or level summit plateau. At the head of the alcove and at various places from its sides the waterfalls descend like narrow white threads for 2,000 feet into the black depths of the chasm. Deep grooves and holes have been worn into the rock by the falls, so that in places they disappear altogether from view. More extensive and branching are the two principal streams of the island, Pelekunu and Wailau. They occupy watersheds of 4 or 5 square miles, but they, too, are surrounded by the same precipices, especially near the headwaters at the main divide. They are clearly of the same origin as the smaller alcoves, but a stronger erosive action has widened the valleys and extended their canyons. The grades of the streams are heavy throughout, and except at the north of the canyon there are practically no bottom lands. Pl. IV, *B*, shows the mouth of Wailau, with the broad, almost U-shaped form at the debouchure, and the furrowed slopes descending from the high plateau of the island.

The Halawa, another of the permanent streams of the island, flows in an easterly direction, heading in the swamps of the plateau east of Wailau, descending in a great waterfall to the lower alcove or canyon, and debouching near the extreme eastern end of the island.

From the headwaters of Waihanau to Kamakou, the highest peak on the islands, the summit region consists of gently sloping or hilly plateaus, generally swampy and cut by sharply incised ravines. The elevation of this plateau is only 2,000 feet south of the leper settlement but increases to 3,500 south of Waikolu and to over 4,000 between Waikolu and Pelekunu. Parts of the plateau project between the canyons, contrasting sharply against the precipices of alcoves and pali. From Kamakou for several miles eastward there is no central plateau, or only fragments of it. The drainage from north and south has cut in deeper and left only a sharp and jagged ridge. But between Wailau and Halawa there are again several square miles of the upper surface left.

The south slope of the island is very different from the northern. South of the divide the plateau gradually changes to a sharper slope, over which the water courses find their way in small cascades and falls. This decided slope is most accentuated on the Kawela, but is noticeable all along the south side of the island. The lower declivities, up to an elevation of 800 feet above the sea, are again gentle, having an inclination of from 5° to 8°, and a fringe of narrow flats follows the coast line. Instead of a few great canyons, some forty or fifty gulches and ravines form the drainage ways of the southern slope. All of these have the same characteristics, namely, a straight course, small drainage area, sharp grades, especially in their middle portion, and very abruptly incised sides, rarely, however, cut more than 400 or 500 feet below the slope of the surface. These conditions are the natural result of a comparatively recently established drainage system over the smooth sides of a volcanic cone. East from Kawela the straight, steep gulches are even more numerous than in the western part. Pl. III, *A*, shows the great Kamalo Gulch back of the plantation of the same name. It illustrates well the V-shaped form of the canyons as well as the partially preserved surface of the old lava cone. On the whole, the streams draining north are permanent, while those draining south carry water only during the rainy season, and then intermittently.

GEOLOGY.

Like the other islands of the Hawaiian group, Molokai is almost entirely of igneous origin. It is a volcanic cone built up in the middle of the ocean by a great number of superimposed basaltic flows. The island is, in fact, like Maui, formed by two volcanoes, and these two cones are separated by a low gap on which secular disintegration has reduced the basalt to a deep red soil.

A. KAMALO GULCH, SOUTH COAST OF MOLOKAI.

Showing parts of surface of volcanic cone, deeply dissected by gulches, débris fans at mouth of gulches, and coral reef below shallow water near shore.

B. NORTH COAST OF MOLOKAI, LOOKING WEST FROM THE LANDING AT WAILAU.

Showing fault scarp along northern coast, horizontal basalt flows near base of cliff, and peninsula of leper settlement in the distance.

The west end forms one, separate and complete, though comparatively low cone. Partly obliterated craters are still visible near the summit, between Mauna Loa, Kaana, and Amikopala. The cone is not very regular, and secondary centers of eruption were probably located near the southwest and northwest corners of the island. The steep pali running north from Mauna Loa to the coast indicates a dislocation along which the east side has dropped a few hundred feet.

The main or eastern part of the island is not of so simple a structure. It represents one part, and probably the smaller part, of a large volcano, the northern part having dropped down along a great break or dislocation to a depth of from a few hundred to 3,000 or even 4,000 feet. Thus, the great northern pali, described in the previous pages, is really a break or a fault line, which split the volcano in two. The evidence of this is clear and convincing. The slopes of the lava flows are everywhere to the south, from 4° to 13°; even in the cliffs of the north coast the same inclination is observed. This, in conjunction with the form of the island, shows that a part of the volcano has been removed. Neither wave action nor erosion by running water could possibly have produced such an escarpment as that of the great pali, reaching 3,000 feet in height. The work of erosion on this cliff is shown plainly enough in the great alcoves cut by the water courses and described in previous pages. This erosion is still cutting southward and the divide is no doubt steadily migrating in that direction.

Dana, I believe, was the first to insist that the outlines of these islands have been to some degree determined by dislocations; and in his Characteristics of Volcanoes[a] is the only reference to Molokai which I have found in geological literature. It is as follows:

> Molokai was once, as its lava streams prove, a doublet of volcanoes like Maui, but it has been shaved down to a strip of land. The eastern part has an alcoved precipice facing the north, which rises to a height of 2,500 feet above the sea. Thus, such precipices are rather the rule in the Hawaiian group, and if seashore erosion is not the origin, fractures and subsidence must be.

Dana's view of the causes of the abrupt topography on the eastern coast of Oahu has been disputed by C. H. Hitchcock,[b] who believes that the action of erosion is sufficient to account for it. There is no doubt that deep canyons with very steep walls and almost perpendicular precipices near the heads of the water courses are most characteristic among the forms of erosion on the windward side of the island, and that, therefore, some caution must be exercised in discriminating precipices of erosion from those of fault scarps. However, in the case of Molokai, Dana's statement is undoubtedly true; the great pali is most certainly a fault scarp of magnificent size.

The low peninsula of Kalaupapa, the only land of importance at the foot of the cliff, seems to be a part of this sunken area, still above

[a] 1890, p. 290.

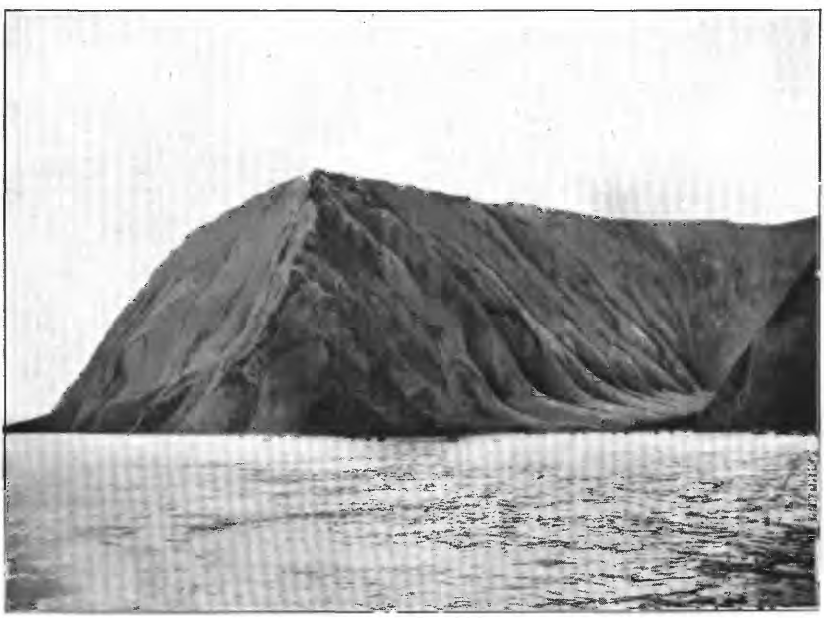
[b] Bull. Geol. Soc. Am., Vol. II, 1899, p. 23.

water. A crater and several lava streams still remain on this peninsula and are better preserved than most of those on the south side. The gently sloping summit plateau does not contain, as far as known, any remaining craters, but it is covered by extremely thick vegetation and few parts of it are accessible. Numerous smaller subcraters or parasitic cones remain, imperfectly preserved, on the long southern slope of the island. They generally have flat tops—the crater funnels being filled in—and intense red or yellow colors due to thermal action on the lavas. Such are Middle Hill, Puu, Luahine, Kakalahale, Maninibolo, and many others.

Similar in general to the other islands, the rocks of Molokai consist almost exclusively of dark basaltic, fine-grained lavas of more or less porous structure. The flows are thin, and range from a few feet up to 50 feet in thickness, but rarely exceed the latter limit. Laterally the flows are ordinarily not continuous over a great distance, hence exposures or wells only a few hundred feet apart may show very differing sections. Harder, more compact lavas alternate with exceedingly porous, loose breccias or agglomerates. The deepest parts of the gulches, the well sections, and the palis at Waikolu, Pelekunu, and Wailau all show the same structure, clearly indicating that the island has been built up by rapidly succeeding thin lava flows. The probability is very strong that this same structure and the same kinds of rocks continue down to a depth of several thousand feet. No petrographic study of the rocks has been undertaken, but a few thin sections make it evident that the rocks chiefly consist of normal feldspar basalt, somewhat glassy, and with olivine, occasionally also containing phenocrysts of soda-lime feldspars. Thus far the only kinds of rocks recognized by petrographers in the Hawaiian Islands are of the type of feldspar basalts, with occasional occurrences of nepheline-basalts or nepheline-melilite-basalts. In exploring the headwaters of Wailau, in the very heart of the dissected volcano of Molokai, however, an interesting occurrence of coarse-grained intrusive rock was found. Crossing the gap north of Mapulehu one descends over a precipice leading down to the valley of Wailau over a difficult and almost dangerous trail, which finally follows the bed of the east fork down to its junction with the larger west fork. Down to the junction only ordinary basaltic rocks are met with, but the west fork is full of heavy bowlders of a dark-green, coarse, granular rock, manifestly different from anything formerly described from the islands. The rock was not found in place, nor was the west fork followed up to its source, where these bowlders must come from. Indeed, in the thick tropical jungle which covers the whole watershed of Wailau, this is a very serious undertaking, but there must be a large mass of this rock in place, too large to have been carried up by the eruption of the lavas, and therefore it is most probably an intrusive body injected into the volcanic masses and there consolidated.

A. NORTH COAST OF MOLOKAI, LOOKING WEST FROM SUMMIT OF TRAIL TO LEPER SETTLEMENT.

Showing summit plateau and fault scarp, exposing a great number of basalt flows. Elevation 1,600 feet above sea level.



B. NORTH COAST OF MOLOKAI, MOUTH OF WAILAU VALLEY, LOOKING EAST.

Showing fault scarp 3,000 feet high and alcove type of eroded valleys.

Upon examination in thin section the rock presents a normal coarse granular structure, without glass, and consists of broad laminæ of a soda-lime feldspar not far from anorthite. Between these lie grains of a pale-violet, slightly pleochroic augite, with which are associated numerous grains of an iron ore. In addition, there are grains of olivine, slightly serpentinized, and in much smaller quantity than the augite. The rock is therefore a very coarse olivine-diabase.

Mr. Monroe, the superintendent of Molokai ranch, gave me a small specimen of a somewhat similar but slightly more decomposed rock which he had broken from a large bowlder in one of the principal streams on Kauai, the most northerly of the large Hawaiian islands. This proved to be very similar to the rock just described, being a coarse-grained diabase. A remarkable feature of the rock from Kauai is the deep purplish color of the augite. It is only slightly pleochroic.

These two coarse-grained rocks are the only occurrences of the kind thus far found in the Hawaiian Islands.

Unlike Oahu, Molokai has no extensive flats of sediment soil underlain by coral and tuffs. The sediments are chiefly confined to small strips and areas of less than 200 acres, and occur at intervals, especially near the mouths of the gulches along the south coast from Palaau to Pukoo. The soil is ordinarily, at no great depth, underlain by basaltic lava. Rarely is there a thin layer of coral rock between the soil and the lava rock.

The gap or the space between the two volcanoes which make up the island is of a rolling character and is covered by soil. A considerable part of this gap is covered by sediment soil, fine red soil, and well-rolled gravel, mixed. This sediment is doubtless chiefly carried down from the east side, and antedates the time when the volcano was split in two and the northern half engulfed in the sea.

As may be expected, the extremely steep gulches from Kawela eastward have brought down big fields of bowlders from the slopes above (Pl. II, *B*).

CORAL REEFS.

A coral reef from one-half to 1 mile wide fringes practically the whole southern coast of the island. The parts adjacent to the main gulches are gradually being filled up by mud. Thus, the island is gradually growing out in this direction. Seen from a high point, the reddish mud flats skirting the shore contrast strongly against the brilliant emerald green of the reef; and beyond this is the dark violet-blue color of the deep sea.

Small amounts of coral rock, indicating a former higher water level, are found all along the southern coast; usually these only reach 25 feet above water level, though in one place—near Puu Maninibolo—

this old coral reef extends up to 130 feet above the sea. The submergence was evidently of short duration.

The coral sand carried up by the waves forms a very narrow fringe all along the southern coast. A large dune wall of coral sand, about 12 feet high, skirts the western coast at Papohaku flats.

Though the coral reefs on the northern or windward side are not extensive, a very large area of dune sand occurs north of the gap and extends for several miles westward, having a width as great as 4,000 feet. The locality is particularly exposed to the full force of the trade winds, and the sand is carried up to the top of a 500-foot hill, where it accumulates in dunes which reach a thickness of 20 feet. Westward the sands finally reach the two creeks emptying near Papohaku, from which repositories the winter floods carry them down to the sea. Part of these dunes are consolidated to hard sandstones. In some of these are seen peculiar footprints which are similar to, and yet somewhat different from, the imprint of a human foot. There are also many obviously recent inscriptions, etc., and, as the Hawaiians are not altogether averse to a practical joke, the real character of these footprints may as yet be left an open question.

CLIMATE.

In regard to temperature, the island possesses the same equable climate as that enjoyed by the others of the same group; frost probably never occurs, even at the highest elevations. The trade winds are strong, especially during the winter months and on the northern coast. During long periods it is impossible to effect a landing at the settlements of Wailau and Pelekunu. Even along the south coast the winds are usually strong in the afternoon, and over the bare west end, or Kaluakoi, and over the gap the breezes sweep without hindrance. There is in general a wet season, extending from October until the end of May, and a dry season including the summer months. On the whole, the west end, the gap, and the south shore as far as Kamalo are included in the arid zone of the island, while the whole northeasterly part may be counted as one of abundant precipitation. All points over 2,500 feet in elevation receive an abundant rainfall. Most of this falls in the winter, but showers occur at intervals all through the summer. Accurate data regarding rainfall extending over any considerable period are not obtainable.

Data collected by Dr. Morritz at Mapulehu, on the southern coast and the eastern part of the island, from 1894 to July, 1899, show an average annual precipitation of 34 inches with but little variation and no apparent decrease. The maximum precipitation is usually in December, with as much as 6 inches, while the minimum monthly precipitation in the summer is 1 inch.

At Kaunakakai no records have been kept except for a month or two in 1900, but it is apparent that the rainfall decreases rapidly west of Mapulehu. The probable annual rainfall at Kaunakakai does not exceed 10 inches, thus indicating a very dry climate. About 2 inches are said to have fallen in January, 1900. About 0.6 of an inch fell April 24, 1900, while since that time, up to July 1, 1900, there were only slight showers at great intervals; a little rain fell June 23, and again a little on June 27 and 28.

There are indications that the rainfall at Palaau, on the south side of the gap, is somewhat larger than at Kaunakakai, and this is, indeed, to be expected, for its position is more open to the northeasterly trade winds. On the north side of the gap precipitation is still further increased, as is indicated by the strong growth of grass, remaining green up to June 1.

At Molokai ranch, at an elevation of 850 feet and only a short distance from the gap, records have been kept by Messrs. Schleifer and Monroe since January, 1899, with the following results:

Rainfall at Molokai ranch.

Month.	1899.	1900.
	Inches.	*Inches.*
January	2	2.69
February	3.75	4.14
March	3	1.36
April	1.90	5.30
May	.50	.83
June	(a)	2
July	(a)	
August	(a)	
September	(a)	
October	1.23	
November	1.29	
December	1.71	
Total recorded	15.38	

[a] No record.

The figures for 1898–99 are incomplete. The season was one of great deficiency in rainfall, and this dry winter was followed by an exceptionally dry summer. The total for the rainy season 1899–1900 is 20.55 inches, indicating an annual rainfall at this place of about 22 inches.

At Meyer's ranch, at an elevation of 1,400 feet, about 2 miles northeast of Molokai ranch, records were kept for some time by Mr. R. W. Meyer, but I have only been able to obtain those of 1891. This year was, as the records show, an exceptionally dry one on Oahu and Maui. At Honolulu 23 inches fell that year against a normal rainfall of 38 inches. It is believed that the latter figure represents the normal rainfall at Meyer's ranch.

Precipitation in 1891 at Meyer's ranch.

	Inches.
January	7.65
February	3.28
March	.36
April	4.35
May	1.63
June	None.
July	None.
August	None.
September	None.
October	4.40
November	.20
December	1.26
Total	23.13

Above an elevation of 2,000 feet in this part of the island almost daily showers occurred from April 1 to May 28, 1900, and this is probably the normal condition during the winter months. Dry and warm weather prevailed from May 28 to June 8, when light showers fell. Again, on June 23, 26, and 27 there was a considerable amount of rainfall.

Regarding the quantity of rainfall in the mountains there is scant information. The annual precipitation probably reaches 100 inches at elevations of 3,000 and 4,000 feet and is not far from this amount over a considerable area on the north slope on the headwaters of Waikolu, Pelekunu, and Wailau.

It has been asserted that the rainfall on Molokai is decreasing. As far as the data go there is nothing to prove such an assertion. It is no doubt true that the island formerly supported a much denser population; this is indicated, for instance, by many old garden patches at streams which are now dry or carry water only intermittently. All this is, however, most probably directly chargeable to the destruction of the forests and the following irregularity or disappearance of the water supply.

SOILS.

The soils of Molokai are similar to those of the other islands of the Hawaiian group and are usually of great fertility. They may be divided into residual and sedimentary soils.

The residual soils result from the gradual decomposition of the basaltic lavas and are usually deep red, very rich in iron and in substances necessary for plant growth.

The sedimentary soils are partly of a deep-red color, partly dark brown, and not very different in character from the residual soils; they consist, in fact, of the same substance merely transported and redeposited. In a few places along the immediate coast line are small areas covered by coral sand, consisting largely of carbonate of lime, usually more or less mixed with detritus from the hills.

The west end of the island contains a very great amount of good, smooth land, with excellent soil. In fact, the larger part of Kaluakoi is of this character, excepting the southern slope of the long ridge extending from Mauna Loa to the light-house, the extreme northern and western portion, and the steep slope extending from Mauna Loa northward to the sea. The soil is residual in character. Unfortunately there is no feasible way of bringing water on this part of the island. It is at present used for sheep ranches and cattle range, being covered by a fine growth of nutritious grasses.

The finest body of agricultural land on the island is situated in the great gap, and has an area of about 14,000 acres. The principal problem of the water supply of the island is how to bring the water from that part which receives an abundant precipitation to this arid portion containing the rich soils. This area of gently rolling hills is covered by a deep-red soil unexcelled for purposes of sugar growing. To a great extent it is a sediment soil, as shown, for instance, along the western plantation fence near Mauna Loa Creek, where it follows the cane planted January, 1900. At this place a depth of from 20 to 30 feet of fine soil and disintegrated washed gravels is observed, resting on basaltic lava. This formation no doubt underlies a large portion of the cane lands. A part, however, of the eastern area on the rising hills is covered by residual soil derived from rock in place.

On the south shore there is a strip of low cane land near the coast at Palaau, but the main body of deep soil does not begin until an elevation of about 200 feet is reached. The total area of cane land at Palaau, below an elevation of 50 feet, is 374 acres.

Above an elevation of 800 feet, on the east side of the gap, there is, between the deeply incised canyons, a considerable amount of smooth land covered by grass and underlain by rich soil; but besides being cut up these areas are, by reason of their elevation, less suited for sugar cane, though well adapted for other crops. Thus, at an elevation of 1,400 feet, on the Meyer ranch, coffee is successfully cultivated in shady places without irrigation.

East of this point the island contains a relatively small amount of economically valuable soils. On the south coast the rocky slopes reach almost to the sea, leaving only in places narrow fringes of level land. On the north side the mountains, as indicated above, are very precipitous, and there is no arable land except small patches along the coast at the mouths of the rivers.

At high elevations the rock is, as a rule, much decomposed and retains water much better than do the stony slopes lower down. In the high swamps the mud is rarely over 2 feet deep, and solid, though decomposed rock comes frequently to the surface. The color of the soil in the swamps is grayish or white, showing that only ferrous oxide, produced by the reducing influences of organic acids, is present. After the swamps have dried up and the trees and ferns die, as has happened over large areas in the high central parts of the island, this ferrous oxide under the influence of the air rapidly changes to ferric oxide. This forms a dark-red, hard-pan area on the surface which is very detrimental to young plants just rooting. This compact, dark-red soil is really an iron ore. A sample examined by Dr. E. T. Allen contained 43.88 per cent of metallic iron. This is one of the reasons why the reforesting of dried swampy areas is such a slow and difficult process.

For some distance east of Palaau there is a strip of sediment land along the coast containing 110 acres. Toward the sea this is joined by a salt marsh and toward the north by a rocky slope, which in part, however, can be planted. Near the cocoanut grove, $1\frac{1}{4}$ miles west of Kaunakakai, are 150 acres of excellent level soil underlain by 5 to 10 feet of coral which again rests on solid lava. At Kaunakakai about 100 acres of level rich soil are available. Between Kawela and Kaunakakai is a narrow strip of soil—mostly coral sand—which is covered by a thick growth of algarobas. At Kawela there is a considerable extent of sandy soil, practically all of which belongs to small native holdings. At Kamalo again several hundred acres of good soil are available, and from this place to the east point of the island a number of more or less extensive flats follow the coast, many of which are cultivated on a small scale. The lower part of the valleys of Halawa, Wailau, Pelekunu, and Waikolu contains a small amount of lands chiefly devoted to the growing of taro on a small scale.

VEGETATION.

In regard to vegetation, the southern side of the island may be separated in several zones. There is first the immediate coast fringe, distinguished by cocoa palms and algarobas; the barren zone; the belt of the grass lands; and finally the high forests.

The southern coast is fringed by a narrow, bright-green zone of thick and luxuriant algaroba trees (a variety of mesquit) which furnishes excellent firewood. The abundant bean pods of the tree are used as forage for cattle and horses. This strip is only a few hundred feet wide, but extends from Kawela Creek, almost without interruption, to a point a few miles west of Palaau. The western coast supports at Papohaku a few small and stunted groves of the same tree; the northern and eastern coast is too humid to permit the growth of this essentially arid-land tree. Occasionally, near springs at the seashore, the lahale trees appear, with clumps of bare trunks and palm-like tufts of leaves. This produces a fiber used for the manufacture of hats, etc. There is a large cocoanut grove one mile west of Kaunakakai. Few groves of this palm are planted east of this on the southern coast, though many places are excellently adapted for this purpose. Big thickets of the obnoxious weed Lantania grow on the coast near Kawela.

The barren zone of rough lava bowlders, with only a few bushes adapted to a dry climate, extends along the south coast, from the western point of the island to beyond Kamalo on the east. At Palaau it reaches an altitude of 200 feet; at Kaunakakai, 1,000 feet; and at Kawela, 2,000 feet. Toward Mapulehu the grasses reach sea level.

The pasture lands are covered by a thick carpet of manania (a variety of Bermuda grass) or delicate tufted Pele grass. Above a certain elevation (about 500 feet on the west end) these give way to annual grasses. Almost the whole of Kaluakoi, or the west end, is covered by pasture land; likewise the gap, excepting the arid strip near Palaau. Both of these areas are practically treeless. During the arid season the grass dries up. In the creeks and canyons east of the gap are found groups of kukui trees, with their smooth trunks and yellowish-green foliage bright with an almost silvery sheen. This is also called the candle tree, on account of producing a nut rich in oil. Many of these groups show signs of damage by cattle.

Isolated wili-wili trees are also noted, with their coral red bean and peculiar habit of shedding their leaves in the summer. Scattered cactus trees and hau bushes complete the meager flora of this zone. The finest and healthiest groves of kukui trees are found in the different branches of Meyers Creek above Meyer's ranch at elevations of about 1,000 feet. Parasitical ferns grow in profusion on the tree trunks. Papaia trees and coffee bushes do well wherever planted in these shaded canyons.

As the elevations increase, the grassy ground gradually becomes more swampy. Near Meyer's ranch the pastures are diversified by thick bushes of wild guavas, and ferns grow luxuriantly in the little gulches. Going upward from Meyer's ranch over swampy pastures and partly decayed forests, sometimes crossing little canyons thick with a growth of ferns, one is suddenly and unexpectedly stopped by the great precipice, the northern pali, here descending abruptly 1,500 feet to the sea, and showing along its steep escarpment the broken succession of the dark lava flows (Pl. IV, *A*). Far below, a silvery white fringe of breakers marks the shore. A rocky peninsula extends at the foot of the pali, and on its western side we notice a prosperous-looking town with regular streets and white cottages. Several churches and larger buildings are also seen, and many of the houses are surrounded by bright green gardens. This is the leper settlement of Molokai. A steep and somewhat dangerous trail leads down to the town. The inmates of the settlement are not allowed south of the pali, and at the little gate at the summit of the trail the unfortunates confined in the settlement often meet their friends.

In this vicinity the forests begin at an elevation of 2,500 feet, but the trees are in poor condition and on large areas are dying. It should be observed that all forests on this island grow on swampy ground. Open forests with trees growing on dry ground do not exist. The lehua, a myrtaceous tree, in several varieties is most abundant. It has dark-green foliage and bright-red flowery tassels during the spring months. The height is usually up to 30 to 40 feet. More common on the north slope is the ohia or mountain apple, and the koa with its exceptionally hard wood. Around the moss-covered roots, frequently branching above ground, cluster the thick ului ferns (*Glauchenia*), and intermingled with the lehuas rise the pulu ferns (*Cibotium*) with their widespreading fronds up to 15 feet high. The whole is interwoven with a mass of tough eea vines (a kind of *Pandanus* or climbing screw pine) to a thicket which usually is almost impenetrable except along the beaten trails.

From Meyers Lake to east of Kaulahuki the forests, once said to be thick and healthy, are in a decaying condition. Kalamaula swamp is now partly dried. Around Kaulahuki extends a comparatively dry high plateau, and the peak itself is easily accessible. Going up over this plateau, rolling, grassy, and cut by sharply eroded little canyons, one comes suddenly to the great alcove canyon of Waikolu. The plateau is cut off sharply as with a knife; the eye sweeps down the black abyss of the precipices of the Upper Waikolu, and then down the V-shaped canyon to the sea. Narrow streams of water descend the faces like silvery threads on a black background. But at every place where there is a possibility of foothold a rank vegetation covers the rocks, and where the walls become a little less abrupt there is a solid area of dark-green foliage. At the brink of the canyon the mornings are often calm and clear, but before noon the sky and the sea mingle in one hazy bank and the strong trades drive dripping mists and intermittent showers over the swampy highlands.

A short distance east of Kaulahuki the horse trail ends and the whole country is covered by thick, healthy vegetation. Above Kawela the forests formerly descended far below Kolekole hill to an elevation of 3,000 feet. In its normal healthy condition the forest now extends along a width of only one-half mile on the southern slope. Traversing this thick swamp, clambering over slimy, moss-covered roots, and wading through deep mud, one suddenly emerges on the Pelekunu pali at an elevation of 4,500 feet. From this point can be seen the whole of Pelekunu drainage and part of Wailau, a green, impenetrable wilderness bordered by nearly perpendicular cliffs. Trails are said to cross the island into Waikolu and Pelekunu, but they are dangerous and difficult.

From Mapulehu an exceedingly bad though not particularly dangerous trail leads over into Wailau. Guided by Mr. Theodore Meyer I ascended the steep grassy slopes from Mapulehu to a more gently sloping path between narrow canyons, along which kukui, wild orange, and guava grow in profusion. We made camp at the edge of the forest 1,550 feet above Mapulehu. The next morning at sunrise a magnificent view was obtained of Haleakala, Maui's great volcano, with its gigantic crater, seemingly only a few miles distant, but within a short time the usual clouds again hid the summit of the mountain. The track now enters the forest and ascends 1,200 feet in 1 mile, through lehua roots and mud, to Wailau Gap, which has the comparatively low elevation of 2,750 feet. The forest seems healthy, but Mr. Meyer states that it is much more open than formerly, probably due to grazing of cattle. In this part of the island there are, however, few cattle compared to the number kept in the western part. From the summit the extensive view over Wailau Valley reveals the same impenetrable sea of dark-green forest relieved by bright patches of wild bananas and kukui groves. Over slippery moss-covered rocks the trail descends 2,000 feet in 1 mile to the east fork, which may be followed for half a mile, by wading through water or jumping from rock to rock, down to the junction of the two forks, at an elevation of about 600 feet. Some distance before the east fork is reached we passed an abandoned kuliana, or native settlement, with a taro patch and a few exceedingly welcome orange trees.

The Wailau is a comparatively large stream, and its waters rush with torrential force in the narrow canyon. There is no further cultivated ground until near the mouth of the river, where considerable taro is grown and sent over by steamer to the leper settlement, partly whole, partly crushed to so-called "paiai" and packed in ti leaves. Pl. III, *B*, represents the native crew of the little steamer *Mokolii* engaged in loading paiai. We returned the same day to the camp above Mapulehu. The excursion makes an extremely arduous day's work.

CAUSES OF DECREASE OF FOREST AREA.

Many theories have been advanced as explanations of the decay of the forest. It has been attributed to cattle, deer, and goats, to decrease of rainfall, and to a disease of the trees.

It is evidently true that for many years the island has been overstocked, especially the good pastures at higher elevations, and it can easily be understood how the damage to the trees is effected. The cattle do not kill the trees directly, but they destroy the thick growth of ferns and grass which protects the roots and which is evidently essential to the life of the lehua tree. They also eat the young trees just coming up from seed. This has assuredly been the most prominent cause. But in many canyons where cattle scarcely can find their way, as well as in some parts of the swamps near the Pelekunu pali, the lehua trees are also dying, which indicates that the tree is besides suffering from some insect or fungus. The deer do less harm than the cattle, but it may nevertheless be well to keep their number within reasonable limits. In lower elevations goats abound, which should be removed as thoroughly as possible, for they completely destroy the already scant vegetation. Sheep have lately been confined to the western end (Kaluakoi), which seems most suited to them.

All in all, I believe that the cattle, in part aided by the disease referred to, are responsible for the decay of the forests and that it is not necessary to assume any material changes in climate. As mentioned, there is no such decay noticeable at Mapulehu, where very few cattle have been pastured. In consequence of the drying up of the swamps, the rainfall runs off rapidly and the streams become more intermittent and torrential in character, as indeed is very clearly marked in the case of Kawela. To remedy these conditions, I can only suggest the exclusion of cattle and other fern-destroying animals from the upper mountain region, which may cause the swamp ferns and lehuas to grow up again. The hard pan mentioned on page 20 is a serious obstacle to reforestation. Planting certain areas of land below the swamps by eucalyptus, acacia, or Monterey cypress would remedy matters to some extent.

FAUNA.

As well known, the native Hawaiian land fauna is exceedingly scant. A number of small birds inhabit the forests. Excepting a few centipedes, the objectionable insects are few in number. Many varieties of tree snails are found, often of beautiful color and delicate shell sculpture. More species of these are said to occur on Molokai than on adjacent islands.

The introduced animals are deer, goats, and cattle. The deer are of the spotted Japanese variety and have multiplied rapidly, so rapidly, indeed, that it has been found necessary to attempt to reduce their numbers, as they do considerable damage to the vegetation. Their principal range is on the high plateaus a few miles east of Meyer's ranch at the edge of the forest. The goats have likewise proved a nuisance, and it is difficult to keep in check their rapidly growing numbers. They chiefly range, practically wild, over the arid portion of the southern slope. It is surprising to observe their gymnastic performances when a band of them is scattered browsing on the ledges of canyon cliffs which a casual observer would pronounce perpendicular. The sheep kept on the Molokai ranch are chiefly confined to the western end of the island. Most of the cattle are now kept on Molokai ranch, including the west end, the gap, and a part of the southern slope as far as Kawela. Some of them run almost wild, but attempts are made to reduce that number, and also to keep them off thc high forest areas. The island has been heavily overstocked with cattle, but the number is now reduced. East of Kawela there are comparatively few. For a limited number the western half of the island is a most excellent range.

CULTURE.

Tradition has it that in former days Molokai supported a far greater number of inhabitants than at present, and, further, that the forest covered much greater areas, even occupying part of the now treeless west end of the island. While, as explained above, it is doubtful whether the rainfall has decreased, it is certain that with the destruction of much of the forest areas an equalizing element of much importance has been eliminated. From one end of the island to the other the coast abounds in stone fences and heiaus or square inclosures of stone connected with the worship of the gods. Evidences of old cultivation are apparent at a number of now arid places. Abandoned farms are found in the valley of Wailau; on the Pelekunu, a mile or two from the coast, old abandoned plantations of pineapples were noted. Such cultivation as now may be carried on by the natives is shiftless and imperfect. Taro is raised in the Lower Wailau and Pelekunu. Rice fields are cultivated by Chinese at intervals along the southern coast. A few small cocoanut groves are planted, but there is only one large grove, near Kaunakakai, said to have been planted by Kamehameha V. Small scattered kulianas contain a few oranges, mangoes, and papaias. On the whole, it is clear that with proper care and industry the island could support a far greater number of people than dwell on it at present. To some extent this undesirable state of affairs is doubtless due to the consolidation of properties into larger holdings for prospective sugar cultivation. But there is also a decided tendency of the natives to sell their small holdings and to move away to centers like Honolulu. The ranch of the Meyer Brothers, located about 5 miles north of Kaunakakai, shows what can be done even with comparatively small holdings when intelligent care is applied. Cattle are raised here, as well as some coffee and other products.

The population of the island aggregates about 2,400; but over 1,000 of this number are located in the leper settlement on the northern coast, established in 1865 and embracing about 8,000 acres. Of the remainder, several hundred are probably Japanese laborers, as the census was taken in 1900, when there were many of this class at Kaunakakai and Kamalo, so that there would remain only about 1,000 people scattered at Pelekunu, Wailau, Halawa, and the southern coast as far west as Kawela, for along the real arid part of the coast there are but few inhabitants. The total assessed value of Molokai was only $250,000 in 1897. In 1900 this figure had increased to about $686,000, due to the projects for sugar plantation advanced that year. In 1901, after the partial failure of these attempts, the assessed value decreased to $427,000. The Molokai Ranch Company, a corporation, controls the larger part of the lands on the western part of the island as far east as Kawela, and make a successful business of raising cattle and sheep on the extensive grass lands.

The American Sugar Company, closely connected with the Molokai Ranch Company, began operations in 1898 and 1899, controlling nearly the whole of the rich body of land in the gap, and the coast as far east as Kawela. It was proposed to bore for water at Kaunakakai, where 10,000,000 gallons per twenty-four hours (15.47 cubic feet per second) were expected, and to raise this by means of pumps to an elevation of 400 feet to a ditch conveying it to the cane lands below the 350-foot level. It was further intended to obtain 20,000,000 gallons (30.94 cubic feet per second) 1 mile east of Kaunakakai and conduct it to a point 2½ miles away, where the water was to be lifted 500 feet to a short ditch conveying it to the lowest point of the gap, whence it could be distributed on both slopes. Eighty acres of seed cane were planted on the Kaunakakai flats and irrigated from a well giving 1,000,000 gallons in twenty-four hours (1.55 cubic feet per second). The failure of the Kaunakakai wells to produce the amount expected caused a change in the plans. It was decided to bore wells at the mouth of Kawela Gulch and raise the water about 70 feet to a cement-lined aqueduct, which should convey it to the high-lift pump mentioned above. Here, too, however, the quantity obtainable at one point seemed insufficient, and difficulty was experienced in avoiding contamination by salt water. Attempts were also made to find water by deep borings. In 1900 the company decided to abandon operations for the time being, and thus the problem how to obtain water for the rich sugar lands at the gap still remains unsolved.

The Kamalo Sugar Company controls the coast from Kamalo to Mapulehu. In this distance there are a number of smaller flats aggregating a considerable area. It was proposed to utilize these for sugar cane by wells bored along the coast and raised to a ditch about 70 feet above sea level. A small area of sugar cane for seed was planted at Kamalo and irrigated by means of a permanent small stream at the head of Kamalo Gulch. The water was taken out a short distance east of Kolekole Peak and temporarily conducted down in a ditch along the ridge. As Kamalo Gulch often contains running water, it was also proposed to utilize this source.

WATER SUPPLY.

GENERAL PRINCIPLES.

The fundamental law governing the water supply is that the only source of fresh water is the rainfall. A part of this rainfall is carried off by evaporation, another part by the streams, while a third and largest part sinks into the ground and gradually finds its way to the ground water, which permanently saturates the rocks below a certain level.

But on this small island, built up of extremely porous rocks, and surrounded by salt water, peculiar conditions result. In the absence of any impermeable stratum or basins filled by clayey material, such as, for instance, exist on Oahu, there is nothing to prevent the sea water from penetrating the rocks freely and assuming a level differing but little from the sea level. Below a certain level there is indeed no reason to expect anything but salt water.

On the other hand, the rain water also sinks freely through the porous rocks until it meets the sea water. Here, at the permanent water level, it is held by the counter pressure of the sea water, and in fact rests like a sheet on the same. Between the underlying salt water and the fresh water on top of it there is an intermediate zone of varying width in which the two mingle to form brackish water. The fresh water, always receiving additions from above, is slowly but steadily moving to the only outlet it can find—that is, to the springs located along the sea shore, just above or a little below sea level.

The surface of salt water is, apparently, near the coast on the south side of the island, about 160 feet below the surface of the ground. Inland this level sinks, and is also doubtless deeper on the north than on the south coast. The permanent surface of fresh water rises inland very slowly, so that a mile or more inland the water in wells may stand only a foot or two above sea level. Only at Kawela, a few hundred feet from the coast line, is the water level from 2 to 3 feet above mean sea level, and in this place a more abundant underground water supply is found than at any other point west of it. This generally low level of ground water is a distinctly unfavorable sign, pointing to small precipitation and water supply.

The one feature favorable to the percolation of the water to the southern coast line is that the lava beds all slope in this direction—that is, toward Palaau, Kaunakakai, and Kawela—thus to some extent guiding the water in this direction.

On the north coast the permanent water level is much higher, as indicated by the number of strong springs coming out at elevations of from 300 to 500 feet above sea level.

Above the surface of the ground water there may be some movement of water in cracks and fissures, but there is no permanent and abundant supply, certainly not on the south slope. Thus, tunneling on this slope is not apt to develop any considerable amount of water, though it may open some small fissures in which water circulates. As a matter of fact, very little water has been developed by the several tunnels driven near springs at higher elevations. If it were possible to drive a tunnel with very slight grade from sea level or from near the same, such an opening might develop a considerable amount of ground water; but this would be attended with many difficulties.

There is considerable irregularity in the amount of water available below the ground-water level. The porosity of the rock changes very rapidly; open, loose agglomerates are laterally adjoined by hard, much more impervious basalts. Further, the drainage conditions vary, the ground-water surface rising higher in one place than in another; thus in closely adjoining wells there may be great difference in the amount of water available from the same level.

The water from the flowing streams and from the springs emerging at high elevations contains practically no chloride of sodium, this being the only saline constitutent necessary to consider.

In the ground water along the coast the salinity is decidedly higher except where the ground water is mingled with water sinking from intermittent streams. The salinity increases with the distance from the center of maximum precipitation. Thus, at Palaau the water contains 90 grains, at Kaunakakai 50 grains, and at Kawela 25 grains per gallon.

In the following pages the available water resources will be described under the head of springs, streams, and wells.

SPRINGS.

The springs coming out on the southern slope of the island may be divided in three classes: First, those emerging at sea level. These are very numerous, and often, by reason of their vicinity to seashore, more salty than the normal ground water. Second, those appearing at elevations from 1,000 to 2,500 feet. Between the sea level and 1,000 feet no permanent springs appear, at least not west of Kamalo. Third, those of the summit region feeding the permanent streams. These will be mentioned under the heading of "Running streams."

On the north coast springs are more numerous and larger and emerge at any elevation. Strong springs appear in the Wailau and Pelekunu at from 300 to 600 feet above sea level.

SPRINGS ON SEASHORE.

No permanent springs are known on the whole north and west coast of Kaluakoi or the west end. A small spring has long been known to emerge on the south side of the ridge, near the summit, 2 miles east of the light-house, at at elevation of 180 feet, but it dried up in 1898 and has not been running since. At Waiakane, well below high tide, a strong spring of fair water appears.

The next important locality is Palaau. In the grassy marsh below the deep well big springs come out for a distance of 700 feet. Many old taro patches indicate that this water has been used. One of these springs flowed about 60,000 gallons a day (0.09 cubic foot per second), and the aggregate flow must be large. A sample yielded 103 grains of sodium chloride per gallon. On Naiwa, between Palaau and Halfway Camp, near a lone cocoanut tree, strong springs emerge from clefts in the basalt rock at the beach, 1 foot above high tide; the total visible flow may be as much as 170,000 gallons in twenty-four hours (0.26 cubic feet per second), and the salinity is 127 grains.

Half way between Palaau and Kaunakakai again a number of smaller springs appear, with a salinity of 86 grains per gallon. They emerge 1 or 2 feet above high-tide level.

The next locality is Cocoanut grove, 1 mile west of Kaunakakai, when very strong springs come out from the sand at the shore for a distance of 150 feet. The total flow is difficult to estimate, but it may be over 200,000 gallons in 24 hours (0.31 cubic foot per second). The water contains 115 grains of sodium chloride per gallon.

Near Kaunakakai there appear to be no springs of importance, but 1 mile eastward, close to the road, a strong spring comes out from the basaltic rock at the foot of a bluff, 1 foot above sea level. Flow, approximately 6,000 gallons in 24 hours (0.01 cubic foot per second). The water contains 76 grains sodium chloride per gallon.

From this place to a point 1,000 feet east of Onini triangulation station no springs were seen at sea level, though wells find water at a depth of a few feet in most places, the sodium chloride in these amounting to about 115 grains. At the locality just mentioned a strong spring appears, and for a distance of several hundred feet much water comes out along the beach. The total flow must exceed 200,000 gallons in 24 hours (0.31 cubic foot per second). The sodium chloride amounts to 72 grains per gallon. A little water comes out east of this point as far as the end of wall around the fish pond. Again, small springs appear at the kulianas, just west of the mouth of Kawela Gulch. All of these springs east of Onini are under water at high tide.

The largest springs noted appear in the rice field east of Kawela Gulch, at the foot of a little bluff; they are 1.5 feet above sea level, and the aggregate volume of water measured by the discharge from the rice field is 450,000 gallons in 24 hours (0.70 cubic foot per second). The water contains 12 grains of sodium chloride per gallon. East of Kawela the coast was not examined in detail. Probably the coast springs continue all the way to Halawa and are fully as strong as at Kawela.

HIGH-LEVEL SPRINGS.

On the south slope, west of Kamalo, the springs issuing between 1,000 and 2,400 feet above sea level are exceedingly few in number.

The gulch heading north of Meyers at Puu Lua and emptying into the sea after flowing a few miles westward contains three springs. The principal one, at an elevation of 1,300 feet, yields at least 30,000 gallons in twenty-four hours (0.05 cubic feet per second), has no salt, and on May 21 flowed on the surface for a distance of at least one-half mile. Water comes out for a distance of about 1,000 feet; at the head two short tunnels have been run into the side hill without increasing the flow. At this place there is a watering trough, but the spring is said to be apt to run dry toward the end of the dry season. Another small spring inclosed by a stone wall is found in the next gulch just below Puu Lua. Lower down in a tributary to the same gulch, at an elevation of 1,000 feet, a little permanent water trickles out from the side and supplies a watering trough.

In the same vicinity, on Meyer's ranch, are two permanent springs. The first, 1,500 feet east of the trail to the leper settlement, at an elevation of 1,500 feet, yields continuously about 20,000 gallons in twenty-four hours (0.03 cubic feet per second). The second, developed by a tunnel 300 feet long, drains toward Meyers Gulch and furnishes about 40,000 gallons (0.06 cubic feet per second), nearly all of which was developed by this tunnel.

A well-defined spring is that of Kapuna, at an elevation of 1,630 feet. This probably yields about 40,000 gallons (0.06 cubic feet per second), which is conveyed in a pipe line to the Molokai ranch. The water contains 3 grains of sodium chloride per gallon. It is permanent in all seasons according to reports. A short tunnel has been run in under the bottom of the gulch, but it failed to develop any additional amount of water.

In that branch of Luahine Gulch heading at Hunter's cabin, at the old wagon road leading up to the summit, a spring appears on the west side at an elevation of 2,400 feet, 30 feet above the bottom of the gulch. Its permanency is indicated by a bunch of wild bananas growing close by. The flow was measured on May 28, and was found to be about 77,000 gallons a day (0.12 cubic feet per second). The water is practically free from salt, but, according to reports, it dwindles down to a fraction of this amount during the driest part of the season. A tunnel 800 feet long has been run in under the hill in a north-northeast direction below the Kalamaula Swamp, but very little additional water was developed. The water comes out from the side and roof for short distance, while the rest of the tunnel is simply moist, giving no flowing water.

The only remaining spring at middle elevations is on Kawela, near its east boundary, in the gulch near Foster's mountain house, at an elevation of 2,500 feet. The water, which is pure and cold, amounted to 10,000 gallons a day (0.02 cubic feet per second), when visited, but the amount is less in very dry weather. From this point to Halawa no detailed examination has been made, but it is probable that springs are somewhat more frequent. At Mapulehu the swampy forests descend to 1,400 feet above the sea, and many springs are found at their lower edge.

RUNNING STREAMS.

STREAMS OF THE NORTH COAST.

On Kaluakoi there are no permanent streams; the gulches contain water only for a short time after heavy rains. Mauna Loa Gulch, emptying near Palaau, is the only one in whose upper course a little water runs during the larger part of the rainy season.

The gulches on the north coast west of the leper settlement are also dry except during heavy rains. The running streams to be considered are as follows: On the north coast, Waihanau, Waialeia, Waikolu, Pelekunu, and Wailau; at the east point, Halawa; on the south slope: Meyers, Kaunakakai, Kawela, Kamalo, Mapulchu, and Waialua gulches.

Waihanau.—The lower part of the Waihanau is a deep recess cut back from the pali, and over the edge of this recess, as indicated on the map, the stream flows in a series of falls. In the lower part of the valley the stream does not run during the summer. The upper part, which alone is considered here, has a drainage area of only about one square mile, but receives a great deal of rain water. Swamps line its borders, and much water comes in from springs on the sides of the abrupt canyon in which it flows, and which has a depth of from 300 to 500 feet. The grade is about 100 feet in 2,000. In the upper portion the stream is permanent though low in the dryest part of the season. I am informed by Mr. D. Center, the manager of the plantation at Kaunakakai, that when at its lowest stage the water will fill a 4-inch pipe lying nearly horizontal. This would correspond to about 80,000 gallons in twenty-four hours, (0.12 cubic feet per second). When visited on April 25, the flow was about 2,500,000 gallons a day (3.87 cubic feet per second), at an elevation of 2,046 feet. The weather was showery. On June 22, after three weeks of uninterrupted clear and warm weather, it flowed 1,500,000 gallons (2.32 cubic feet per second). On June 25, during the beginning of showery weather which continued for three days, the flow was 8,500,000 gallons (13.15 cubic feet per second). These results were obtained, as all of the following, at places where the stream ran with slight grade above and fell over an easily measurable natural weir, and should be accurate within 10 per cent. I conclude that the stream can be relied on for 3,250,000 gallons per twenty-four hours (5.03 cubic feet per second) from November 1 to June 1, for 1,000,000 gallons (1.55 cubic feet per second) from June 1 to August 1, and for at least 100,000 gallons (0.15 cubic foot per second) from August 1 to November 1.

Waialeia.—This stream has formed a deep recess from the pali, shorter but wider than that of the Waihanau. Over the nearly perpendicular wall of this recess it falls in cascades. The water in the lower part of the valley sinks during the dry season. Only the upper part above the precipice is here considered; it forms a small canyon extending back for a mile to Puu Kaeo. The watershed is only one-half of a square mile, but the supply is permanent, being fed by springs.

During the driest part of the season it fills, according to Mr. Center, a 2-inch pipe laid nearly horizontally. This would correspond to about 16,800 gallons in twenty-four hours. Measured May 24, during showery weather, at an elevation of 2,820 feet, a flow of 400,000 gallons (0.62 cubic feet per second) was obtained, which may be taken to correspond to average flow from November 1 to June 1.

Waikolu.—The Waikolu is a still larger and deeply cut canyon, surrounded near its head by almost perpendicular precipices, 2,000 feet in height. From the summit region belonging to its drainage three streams fall in grand cascades over these precipices. The stream carries permanent water, which is used in the bottom of the valley for growing taro, the water rights of the lower part belonging to the leper settlement.

The area drained by the western branch of the Upper Waikolu is only one-half of a square mile, but practically all of it is swampy lands, insuring a good supply, permanent, though small, even through the dry months. The stream has cut a small canyon about 300 feet deep in this swampy plateau. The water was measured at an elevation of 3,645 feet on May 31, after three days of warm, clear weather following showery weather, which are practically normal conditions. The flow was 1,250,000 gallons (1.93 cubic feet per second), which may be accepted as the normal for the rainy season. The two other branches of the Waikolu head on the swampy, almost inaccessible plateau between Waikolu and Pelekunu.

Pelekunu.—Like the others on the north coast, this stream has cut a deep, alcove-like recess from the pali along the coast, continuously surrounded by precipices from 2,000 to 3,000 feet high. The highest part of this precipice is toward Kawela, while a narrow backbone, with an elevation of 2,500 feet, separates it from the headwaters of the Wailau. The watershed has an area of 7 square miles. In its lower course the grade of the stream is about 100 feet per 2,000, but above elevations of 1,000 feet it becomes very steep. The whole area is covered by extremely dense vegetation of ferns, lehuas, kukui, eea vines, and in many places wild bananas and mountain apples. Many large springs swell the lower course of the Pelekunu, coming out at elevations of from 300 to 600 feet. At an elevation of 350 feet the stream forks, the west branch again forking above this at an elevation of 425 feet.

On June 15 I visited the lower course of the river, ascending from the coast, there being no safe trail from the south side of the island to Pelekunu. The landing at Pelekunu is difficult, and on account of the heavy surf, practically impossible during the winter months. The weather for two weeks had been clear and warm, following a period of showers. The east branch of Pelekunu, measured at an elevation of 400 feet, contained 5,300,000 gallons (8.20 cubic feet per second). The middle or main branch, measured at an elevation of 475 feet, contained 11,700,000 gallons (18.10 cubic feet per second), while the west fork at the same elevation contained 4,500,000 (6.96 cubic feet per second), making a total of 21,800,000 gallons in twenty-four hours (33.73 cubic feet per second), from a watershed of 4 square miles. The question of minimum flow is a difficult one to answer without any measurements during the driest part of the season. A total of 5,000,000 gallons (7.74 cubic feet per second) at an elevation of 500 feet is certainly conservative; more probably the least flow would be 6,000,000 or 7,000,000 gallons (9.28 or 10.83 cubic feet per second). More observations during September or October are necessary to settle this point.

Wailau.—This, the largest stream of the island, is in general characteristics very similar to the Pelekunu. Its drainage area is slightly larger and is covered by the same dense vegetation. Precipices like those at Pelekunu, though scarcely as steep, surround the basin, which is narrower toward the sea than toward the head. A difficult foot trail connects Wailau with Pukoo and Mapulehu and crosses the mountain at a pass with the low elevation of 2,800 feet. From the summit gap the trail descends along the ridge between the two principal forks and reaches the east branch at an elevation of 690 feet; then it follows this for some distance and ascending again over the small point Puu o Wailau (elevation 680 feet), it reaches the junction of the forks at 470 feet. At the time of the visit, June 5, clear weather had prevailed for one week over the whole island, following showery weather in the end of May.

At an elevation of 500 feet the east fork contained 7,500,000 gallons (11.60 cubic feet per second), and at the same elevation the west fork contained 14,100,000 gallons (21.82 cubic feet per second), thus giving a total of 21,600,000 gallons in twenty-four hours (33.42 cubic feet per second) from an effective drainage area of 5 square miles. It will be noticed that the Wailau and the Pelekunu differ but little in their total flow; while the drainage area of the latter above 500 feet is slightly smaller, the elevation of its watershed and the precipitation is probably somewhat larger than that of Wailau.

Regarding the minimum flow the same remarks apply as have been made regarding the Pelekunu. Ten million gallons (15.47 cubic feet per second) is a liberal estimate of the least flow; more likely it is 8,000,000 gallons in twenty-four hours (12.38 cubic feet per second).

Several minor streams descend like silvery threads from the pali into the sea between Wailau and the eastern end of the island. Sometimes the strong trade winds dissipate these cascades into mist before they reach the foot of the escarpment.

Halawa.—Very near the eastern promontory the important watercourse of Halawa empties into the sea. Halawa differs from the other streams in flowing in an almost due east direction. Its watershed comprises about 8 square miles; it has its source in the swampy, impenetrable plateaus east of Wailau, and it descends from these in a beautiful waterfall plainly seen from the harbor. For a mile or two above its month it flows in a somewhat open, fertile valley. The minimum flow of Halawa is reported by Mr. O'Shaughnessy, former engineer to the American Sugar Company, to be about 5,000,000 gallons in twenty-four hours (7.74 cubic feet per second).

STREAMS OF THE SOUTH COAST.

Meyers Gulch.—This stream has a drainage area of 16 square miles, the largest on the south coast, but except near the summit it contains no permanent water, not even during the winter months. Its canyon is sharply cut into the grassy plateau to a depth of from 200 to 300 feet, and contains in places thick groves of kukui trees. It empties a short distance east of Palaau. The grade in the lower course is moderate, but above an elevation of 1,500 feet it increases rapidly and the canyon contains many abrupt falls. The uppermost courses of the different branches have again a more gentle grade. At an elevation of 700 feet the creek branches. The east, or Luahine, fork heads with two prongs near the Hunter's cabin, on Kaunakakai land division, at an elevation of 3,000 feet; the main branch continues by Meyer's ranch, where it is joined by several smaller branches extending up toward Meyers Lake, and 1 mile above Meyers divides again into the Kahapakai and the Mokomoka branches, both of which head at elevations of about 2,600 feet in Kalamaula swamp.

During the winter of 1899–1900 the water in this gulch reached the coast four times—in December, April, May, and, lastly, June 27 and 28. The volume is considerable, sometimes 5,000,000 to 8,000,000 gallons in twenty-four hours (7.74 to 12.38 cubic feet per second), but the flow subsides rapidly. On June 27 about 5,000,000 gallons came down in twenty-four hours (7.74 cubic feet per second), while the next day there was but a slight stream trickling along the bed.

The permanent water appears chiefly in the Kahapakai Fork. Near its head, which is separated only by a narrow ridge from the canyon of the Waihanau, it is fed by strong and continuous springs coming in chiefly from the east side. Between 2,000 and 1,500 feet there is a sharp grade. Though the flow is small in summer the water runs permanently as far down as Wahii (elevation, 1,475 feet), where one branch of the water pipe supplying the ranch ends. Below this, on May 26, a little water was running, but only as far as the junction of the two forks.

On May 24, in light showery weather, Kahapakai was measured at an elevation of 1,975 feet, and flowed 281,000 gallons (0.43 cubic foot per second), diminishing at an elevation of 2,200 feet to 192,000 gallons (0.30 cubic foot per second). The same creek, at an elevation of 1,975 feet, contained on June 25 (light showers following three weeks of drought) 155,000 gallons (0.24 cubic foot per second). On May 26, after some pretty heavy showers, the water at Wahii measured only 151,200 gallons (0.23 cubic foot per second), showing that the maximum flow is at a considerably higher elevation.

The Mokamoka Fork does not contain as much water, nor is it permanent during the summer. On May 26 it was running only a little water one-fourth of a mile above the mouth of Kapuna Spring Gulch. Its average flow during the rainy season, at an elevation of 2,000 feet, may be estimated to be 150,000 gallons (0.23 cubic foot per second). The Luahine Fork of Meyers Gulch branches at an elevation of 2,000 feet, the two forks heading on each side of Kalualohe Hill. The west fork carries some water, about 100,000 gallons (0.15 cubic foot per second), in the rainy season, and is said to run some throughout the summer. The east fork contains the spring mentioned above. The flow begins one-half mile above the tunnel and continues for at least the same distance below it. The maximum flow is perhaps 1,000 feet below the tunnel. On May 30 it gave 135,000 gallons (0.21 cubic foot per second).

Kaunakakai Gulch.—This gulch, debouching at Kaunakakai, has cut a long, narrow box canyon, and embraces a watershed of about 8 square miles. It has a very straight course and is from 100 to 400 feet deep, the maximum depth being attained at the junction of the forks below Kaulahuki. From the west it receives some deeply eroded tributaries heading at Hunter's cabin, but these are usually dry, even through the rainy season. The main canyon has near the mouth a grade of about 100 feet in 1,500. In its middle course it is very steep, while on both sides of Kaulahuki lighter grades again prevail. The gulch contains running water in its middle and lower course only after heavy rain storms. Occasionally, very heavy freshets flood the plain at its mouth and bring heavy bowlders from the canyon. It is, in brief, a typical torrential stream. During the winter of 1899–1900 it was in flood in December; again in April, and finally in the last days of June, but each time the volume diminished rapidly, and after twenty-four or twenty-eight hours had dwindled to a very small amount. Below Kaulahuki, at an elevation of 2,500 feet, the main canyon forks—one branch, the Kamiloloa, heading between Kaulahuki and Kaeo, while the other, the Makakupaia, heads in the swamps around Hanalilolilo. Both of these branches carry permanent water. Kamiloloa during the period of examination carried water from its extreme head down to a point 3,500 feet above the junction. It is largely spring fed and its permanency is attested by a big bunch of wild bananas growing in the canyon at an elevation of 3,100 feet. On April 29 there was at least 200,000 (0.31 cubic foot per second) or 300,000 (0.46 cubic foot per second) gallons running. On May 31, after three warm, brighter days following showery weather, a flow of 276,000 gallons (0.43 cubic foot per second) was measured at an elevation of 3,100 feet. According to apparently reliable accounts it dwindles in extremely dry weather to 20,000 gallons (0.03 cubic foot per second). The main bulk of the water comes from the Makakupaia Fork, which is fed partly by springs but largely by the water stored in the swamps about Hanalilolilo. Below this point the Makakupaia forks again, both branches carrying water, though the eastern branch contains the larger part of it. The water, as in all of the streams heading in swampy ground, is of brownish color. The flow is continuous, even in the driest season, but, as in the case of Kamiloloa, it dwindles to a small amount. In the rainy season the water runs for a distance of several thousand feet below the junction, and even in the dry season it usually reaches the junction, according to statements of Mr. Theodore Meyer. The stream was measured May 31, under normal conditions, three days of fair weather following showery weather, at an elevation of 2,510 feet. A flow of 450,000 gallons (0.70 cubic foot per second) was obtained.

Onini Gulch.—Though heading at 3,000 feet this gulch is ordinarily dry up to its head, only flowing after heavy rains.

Kawela Gulch.—The Kawela drains a territory of about 3½ square miles It heads in the swamps near the highest peaks of the island and flows in a narrow box canyon from 100 to 500 feet deep. The grade near the mouth is 100 feet per 2,000, but in the middle course it increases to extremely sharp descents, broken by many perpendicular falls. In its upper course the grade is again less, perhaps averaging 100 feet in 1,000 feet.

Like Kaunakakai, this is a pronounced torrential stream, but it carries considerably more water. During the rainy season its flow very frequently reaches the sea continuously for several days. On an average the Kawela is in flood at least once a month between October and June. There is a great deal of water under its sandy flood plain, and the flow during freshets is depended upon to irrigate the kulianas (small holdings of native settlers) near its mouth. The flood does not stop suddenly, as in Meyers and Kaunakakai gulches, but continues for several days. The volume of water coming down is very large. On May 1, several days after showery weather, the Kawela, 500 feet above the forks, at an elevation of 160 feet, flowed at least 300,000 gallons (0.46 cubic foot per second), which at an elevation of 100 feet diminished to about 100,000 gallons (0.15 cubic feet per second). On May 28 Kawela had been flowing strong for several days; at an elevation of 100 feet there was a flow of 3,000,000 gallons (4.64 cubic feet per second). This gradually diminished, and on June 11 the creek was dry at the junction of the forks. On June 26 the creek was in flood again and continued so for several days, the amount on the day mentioned being at least 6,000,000 gallons (9.28 cubic feet per second).

The Kawela branches three-fourths of a mile above its mouth, and the two canyons have a parallel course only 1,000 to 2,000 feet apart to near their heads. Two miles above the mouth the west fork receives two tributaries which, however, are dry even during rainy season. The main west fork heads near Hanalilolilo and carries a little water, which rarely reaches the main junction. The ordinary winter flow is continuous for 2 miles below the head to a point below the high-water fall at an elevation of 3,000 feet, which may be observed from near Onini station. The flow was measured under normal, average winter conditions at an elevation of 3,350 feet, where its grade is comparatively flat, the result being 190,000 gallons in twenty-four hours (0.29 cubic foot per second). This little stream is probably nearly dry in the fall.

The main or east fork under average winter conditions flows as far down as an elevation of 1,500 or 2,000 feet. By far the greatest volume of its water is collected from the swamps near the head, and during rainy weather its volume reaches 5,000,000 to 7,000,000 gallons (7.74 to 10.83 cubic feet per second). On June 1, after three or four days of dry weather following showery weather, it was measured at an elevation of 3,160 feet, where its canyon has comparatively slight grade. The flow was 1,300,000 gallons in twenty-four hours (2.01 cubic feet per second). On June 19, after three weeks of hot and dry weather, it measured at the same place 350,000 gallons (0.54 cubic foot per second), at about which figure the flow, according to all accounts, remains constant during the summer, though in exceedingly dry weather it may dwindle as low as 50,000 gallons (0.08 cubic foot per second).

Kamalo Gulch.—This stream, together with the two adjoining gulches to the east, receives the drainage of the swamps of the highest mountain region, and in its general characteristics is very similar to the Kawela, though probably carrying a somewhat larger quantity of water. It usually flows at the mouth of the gulch once or twice a month. It is located on the property of the Kamalo Sugar Company, who use it to some extent for irrigation.

East of Kamalo no detailed observations were made. But, as stated above, the rainfall increases steadily in this direction, and grassy slopes descend far toward the sea. Between this place and Halawa the country is comparatively thickly settled. Little flats are common along the shore and little groups of cocoa palms and taro patches appear at frequent intervals. In this distance there are several streams similar to Kamalo and at least one permanent water course, the Waialua. The gulches are numerous and very closely spaced.

WELLS.

The fact that water can be obtained along the coast by shallow wells was recognized long ago, and irrigation on a small scale by means of windmills has been practiced in many places. Water for stock has been obtained in the same manner.

KALUAKOI.

On the western part of the property (Kaluakoi) precipitation is slight and the supply of ground water is accordingly limited and salty in character.

On the north coast, nearly due north of Mauna Loa, is located the Momomie well and windmill, used for watering stock. Here, as at all of the other stock wells, the surplus water is allowed to run back into the well. The depth is 35 feet, water standing at about sea level 30 feet below the surface. The salinity is very high—238 grains per gallon. One mile eastward is an old landing place, where two small houses are still standing. A well 20 feet deep was dug here, but has been allowed to cave.

There are no wells along the coast west of this until Papohaku is reached, at the middle of the west coast. Several wells have been dug in the sandy plain which here follows the coast for about 1 mile. The well and windmill which supplies the stock is one-half mile southeast of Puu o Kaiaka; the depth is 40 feet, the water level, which is equal to the sea level, standing 35 feet below the surface. The water has a salinity of 403 grains to the gallon, thus closely approaching the limit for drinking purposes, even for stock. A quarter of a mile southwest is a smaller well, which probably stands at 200 grains and which is used by the stock men when stopping at Papohaku.

There is no further water until Kamakaipo, where, on the little plain adjoining the sea, a 30-foot well has been dug, the water standing 10 feet below surface. This well proved too salty for use. A smaller well close by, on the trail, is 10 feet deep and contains a little water which has about 150 grains of salt per gallon.

From the light-house to Palaau along the coast fairly good water is much more abundant and the four following wells and windmills are located here on the sandy shore. Alena well and windmill, 1 mile southeast of Waieli, depth 10 feet, salinity about like Kolo; Kolo well and windmill, 5 miles farther east, 7 feet deep, salinity 126 grains per gallon (Pl. II, *A*); Waiakane well and windmill, south of Mauna Loa, 4 feet deep, salinity 150 grains per gallon; Ioli well and windmill, near Palaau, 6 feet deep, salinity 109 grains per gallon, water stands 2 feet below surface.

PALAAU.

A number of wells have been bored near the coast at Palaau, all of them in the vicinity of the proposed site of the mill of the American Sugar Company.

Well No. 1.—This is a 12-inch well at stable 500 feet south of mill site, at an elevation of 22 feet. It is sunk in basaltic lava to a depth of 74 feet, the water standing at about sea level. The water contains 86 grains of salt per gallon. The well was pumped for four days continuously at the rate of 750,000 gallons (1.16 cubic feet per second) without change in water. It supplied the camp with water pumped up to a tank.

Well No. 2.—This is a 12-inch well below the railroad on west boundary of Hoolohua, at an elevation of 125 feet above sea level. It was sunk in basaltic lava to a depth of 140 feet, the water standing at sea level. The water contained 102 grains of salt per gallon when first struck.

Well No. 3.—This well is one-fourth mile east of stable and 100 feet northeast of deep well, at an elevation of 23 feet. It was sunk through basaltic lava to sea level. In bottom 12-inch well sunk to 50 feet below sea level; very little water near surface. The water contained 86 grains of salt per gallon. This well was pumped for some time—just how long I was unable to find out; probably two weeks—at the rate of 750,000 gallons a day (1.16 cubic feet per second) without increasing the salinity.

Palaau deep well.—This well is located about one-fourth mile east of stable at Palaau, at an elevation of 22 feet above sea level. Total depth when work stopped, May, 1900, 250 feet. The surface formation was basaltic lava. At 180 feet some red tuff was met; at about 200 feet the rock was a coarse, open lava.

The first water, at sea level, contained 86 grains of salt per gallon; at 174 feet 90 grains were noted; at 180 feet from surface the well broke into salt water, which continued until the work was stopped.

Well in Meyers Gulch.—This is one of the oldest wells bored. It is located in Meyers Gulch, one-half mile above the railroad bridge and 1 mile east of Palaau, at an elevation of 50 feet above sea level. The total depth is 125 feet. Very little water, but of fair quality, was obtained at sea level; at 125 feet the well broke through into sea water.

Wells at mouth of Meyers Gulch.—There are shallow wells on the level plain at mouth of Meyers Gulch, at an elevation but little above sea level. Water stands 2 feet below surface. Water contained 90 grains of salt per gallon.

NAIWA.

The wells on this land are located near the mouth of a small dry gulch, 1½ miles west-northwest of the cocoanut grove. At 37 feet above sea level a shaft 10 by 10 feet is sunk 33 feet close by a 12-inch bore hole sunk to a depth of 70 feet. The first water, which stood at sea level, contained 74 grains of salt per gallon. Deeper, this increased to 90 grains. There is no record of pumping tests.

This locality was selected as repumping station for the high-lift pump intended to elevate the water to the 500-foot level.

KALAMAULA.

On this land, about 1¼ miles northwest of Kaunakakai, are situated the so-called cocoanut grove wells. They are located near the mouth of a little dry gulch, 2,000 feet from the sea, and in the northeast corner of a fine field of arable land which was plowed in 1900 and which it was intended should be planted to cane to be irrigated from these wells. Many good-sized springs come out on the seashore at the cocoanut grove; hence this was probably considered a good location for wells.

Cocoanut grove deep well.—This well is 27 feet above sea level.

Total depth is 343 feet. Diameter is 12 inches. Strata passed through are as follows:

	Feet.
Soil	10
Coral rock	5
Hard lava	25
Porous lava	75
Hard lava	35
Porous lava	193

Water was struck at sea level and contained 80 grains of salt per gallon. At 150 feet the water contained 91 grains, while at 160 feet the bore hole broke through into what was practically sea water and continued in it the whole remaining distance.

Cocoanut grove shallow well.—About 300 feet west of the deep well, at an elevation of 20 feet, is located another 12-inch well, 60 feet deep. One million gallons were pumped during twenty-four hours (1.55 cubic feet per second), the water containing 102 grains per gallon.

Cocoanut grove pits.—Beginning near the above-mentioned well a series of pits have been dug to below sea level. An excavation about 200 feet long and 15 feet deep has been made, and in the bottom of this 10 wells, 8 by 8 feet, have been dug to a depth of 10 feet, though some of them are not yet completed. While there seems to be a considerable quantity of water, no pumping tests have been made, the discouraging feature being that the water coming in ranged from 102 to 104 grains per gallon.

KAUNAKAKAI.

A number of wells have been bored at or near the mouth of Kaunakakai Gulch. Before the advent of the American Sugar Company there were at the mouth of the canyon several shallow wells on the property, on one or two of which windmills were erected. Water of a salinity of about 35 grains was obtained in sufficient quantities for the local needs of the small kulianas at slight depths, about equal to sea level. When undisturbed for some time the water from the upper part of the ground-water sheet contained only 12 grains of salt per gallon. A well at the Japanese hospital at the foot of the lava bluff, 1,000 feet west of the cane-field wells, was sunk to sea level, yielding water which contained 74 grains of salt per gallon.

The deeper wells bored by the American Sugar Company are as follows:

Cane-field wells.—Two wells have been sunk in the cane field from which during the year the 80 acres of cane at Kaunakakai have been irrigated. These wells are situated on the west side of the gulch at an elevation of 22 feet, have a depth of 60± and 75 feet, and are 40 feet apart. Both have a diameter of 12 inches. Water level was reached after penetrating 22 feet of gravel and soil, the rest of the wells being bored in basaltic lava of varying hardness. Only the 60-foot well is being pumped. A supply of 1,000,000 gallons per twenty-four hours (1.55 cubic feet per second) has been steadily obtained from it for over one year without increase in salinity, which is from 86 to 96 grains. A sample taken May 4 contained 84 grains. In the summer of 1899, however, the water was somewhat less salty than in 1900, for I find a record of July 10, 1899, showing that after two days of pumping from the first well (No. 1) the water contained 68 to 70 grains of salt per gallon. When the centrifugal pump, which now raises the water from the 60-foot well to an elevation of 40 feet, was connected with both wells the salinity increased to over 100 grains, showing that the deeper well had tapped some salty water.

The settlement well.—This is the most southerly of the long row of wells on the east side of the gulch. The elevation of the ground is 25 feet. The 12-inch well is 60 feet deep. The strata penetrated are largely soil, gravel, and soft lava, and there is, indeed, some doubt whether the bed rock was actually reached. A small pump elevates the water from this well to a tank from which the settlement is supplied. The well has yielded about 200,000 gallons a day (0.31 cubic foot per second) continuously. The water contains from 50 to 86 grains of salt per gallon. A sample on May 4 gave 83 gains; on June 11, 80 grains.

The three upper wells.—These are located on the west side of the gulch, 1,000 feet above the main pumping station and at elevations of 50, 60, and 63 feet. The depth of all of them is about 60 feet, water standing at sea level and containing 74 grains of salt per gallon. Except for a few feet of soil the wells are in lava of varying hardness. These wells have not been tested at all as to their capacity, as their high salinity seemed discouraging.

The deep well.—This well is the most northerly of the long row near the main pumping station. It has a diameter of 12 inches. The total depth at end of May, when discontinued, was 500 feet. The mouth has an elevation of 35 feet. Below 15 feet of gravel followed 25 feet of hard lava, below which porous, ashy, and caving lava was met down to 110 feet; from here to 150 feet followed hard lava, and then a porous stratum down to 250 feet. Below 250 feet hard and soft lava alternate, no special record being kept. The first water at sea level contained 50 grains of salt per gallon; at 160 feet the well broke into salt water, which continued until the work was stopped.

The 12 wells for main pumping station.—All of these are arranged in a row parallel to the bluff, and well No. 7, counted from south to north, has an elevation of 31 feet above mean sea level; from this elevation the other wells differ but little. All of the wells are 60 feet deep, except No. 13, which was known as the "donkey-engine well," and which is 75 feet. As in all of the wells bored, the absence of a detailed and reliable record is noticeable. Wells Nos. 7 to 13 reached bed rock at a distance of from 15 to 26 feet, indicating a decided slope southward. Below this only lava was met with, the hardness changing every 15 or 20 feet. In wells Nos. 2 to 6, inclusive, the bed rock was deeper, 26 feet below surface or more, and it is vaguely stated that every well showed a different record. In all wells the water was found at about sea level or, at most, 1 foot above it. The water when first struck contained from 20 to 40 grains of salt per gallon. Wells Nos. 1 to 12 were tested by pumping at the rate of 300,000 or 400,000 gallons in twenty-four hours (0.46 to 0.6184 cubic foot per second) from each for a few hours, the maximum salinity being 40 grains. Only No. 13 was tested somewhat more severely, being pumped four days at the rate of from 500,000 to 750,000 gallons per twenty-four hours (0.77 to 1.16 cubic feet per second). April 5, 1899, a sample from this well contained 11.5 grains of salt per gallon. Pumping at the mentioned rate from May 10 to 13 increased the salinity rapidly to 70 grains, and the last day it reached 83 grains.

After the erection of the 10,000,000-gallon (15.47 cubic feet per second) steam pump to draw from wells Nos. 2 to 13, inclusive, the pumping began in January, 1900. According to Mr. D. Center, at the beginning of the pumping the water contained 50 grains of salt per gallon. The pumps were started at 2,500,000 gallons (3.87 cubic feet per second), and after one week the salt had increased to 110 grains per gallon. After one month it had reached 200 grains and in March 400 grains, though when it went up to the latter figure both pumps were running at a total rate of 5,000,000 gallons (7.74 cubic feet per second). According to Mr. Boller, the engineer in charge, the quantities drawn were larger and for a considerable time varied between 4,000,000 and 5,000,000 gallons (6.19 and 7.74 cubic feet per second).

When it became clear that continued pumping would not bring in fresh water a series of tests were made to find out, if possible, from which wells the salt water came, but the result seemed to indicate that it was derived from all of them. Wells Nos. 2 to 6 seemed to contain better water than the others, the salt amounting to only about 150 grains per gallon. The quantity of water was, however, small, and these wells were easily pumped dry. In whatever way the other wells were arranged the water reached from 270 to 485 grains.

During heavy pumping from wells Nos. 7 to 13 their water level was lowered 1.5 or, at most, 2 feet.

Risdon wells.—These wells, so called because of the intention to erect a 20,000,000-gallon (30.94 cubic feet per second) Risdon pump on them, are located just 1 mile east-southeast of the Kaunakakai wells described above, at the eastern end of the cane fields. There are twenty 12-inch wells 40 feet apart, located in three rows, which are also 40 feet apart with a northeast direction parallel to the dry creek near the mouth of which they are placed. They are bored at the foot of a low, rocky bluff, at the foot of which, 1,000 feet south of the wells, a strong spring appears. The most southerly well has a surface elevation of 28 feet, and a shaft is sunk from the surface to a depth of 20 feet, the well being bored 40 feet below the bottom of the shaft. Well and shaft penetrated 10 feet of soil, 2 feet of bowlders, 25 feet of hard lava, 23 feet of porous lava, below which again comes hard lava. All of the other wells have similar records. Salinity, 70 grains; water level, 1 foot above sea level. The most southerly well was pumped forty-eight hours at the rate of 750,000 gallons (1.16 cubic feet per second), after which the water contained 68 grains of salt per gallon and the water level was lowered 2 feet.

The other wells were tested by pumping with the deep-well pump at the rate of 300,000 gallons (0.46 cubic foot per second), but only for a short time. Maximum amount of salt, 74 grains per gallon.

KAWELA.

Between the Risdon wells and Onini station but little fresh water appears on the coast, but from the latter point to Kawela the indications favor a larger supply. On the sandy flood plain of the Kawela the kulianas find all the water needed in shallow wells, the level standing 6 inches above sea level. The water contains 3 grains of salt per gallon. During floods in the Kawela the ground water stands 1 or 2 feet higher than usual.

Up to June, 1900, 9 wells of an average depth of 55 feet had been bored at Kawela, all of them along the foot of the lava slope from 2,000 to 4,000 feet east of the creek. A number of kulianas or small holdings, usually owned by natives, are located on the sandy plain of Kawela and extend nearly up to the foot of the bluff.

Well No. 1.—This 14-inch well, started 12 feet above mean sea level, is 46 feet deep. The well passed through the following strata: Soil, 4 feet; hard lava, 10 feet; soft porous lava, 34 feet; hard lava at bottom. A good stream of water was met at 14 feet from surface. Water level stands 10 feet 9 inches below surface, giving the water level an elevation of 1 foot 3 inches above sea level. Water contains 15 grains of salt per gallon. Pumped at rate of 1,000,000 gallons in twenty-four hours for twelve hours (1.55 cubic feet per second), the amount of salt rose to 25 grains. Subsequently, at the same time as the heavy pumping took place on well No. 3, this well was pumped for three weeks at the rate of 1,250,000 gallons in twenty-four hours (1.93 cubic feet per second), the amount of salt rising to only 37 grains.

Well No. 2.—This 14-inch well is 40 feet east of No. 1, at an elevation of 12 feet above mean sea level. It is 50 feet deep, and passes through the same rock as No. 1, except that bed rock is at the surface. Water was struck 10 feet below surface, and the level raised to 1 foot below surface (the only instance thus far noted of artesian pressure). On further boring, however, the water level sank to about 2 feet above sea level, showing that some very porous strata had been encountered. Water contained 18 grains of salt per gallon. Pumped at rate of 1,000,000 gallons in twenty-four hours for twelve hours (1.55 cubic feet per second), highest amount of salt was 25 grains per gallon.

Well No. 3.—This 14-inch well is 40 feet east of No. 2, at a surface elevation of 11 feet. The well is 56 feet deep and passes through 2-foot soil, a few feet of porous lava, and then pretty solid lava until 9 feet above bottom, when a porous stratum was met. Water was struck 5 feet below surface, but at 46 feet depth it was easily pumped dry at rate of 1,000,000 gallons per 24 hours (1.55 cubic feet per second). The well was then sunk 10 feet farther, when a large flow of water was encountered. This single well was pumped for thirty days, March 1–30, 1900, at rate of 2,500,000 gallons (3.87 cubic feet per second). The water level was lowered 8 feet and the salinity rose as follows:

Amount of salt in well No. 3.

	Grains per gallon.
March 2	19
March 7	33
March 16	32
March 20	42
March 24	55
March 28	62
March 30	64

On May 16 the water level stood 8 feet 9 inches below surface of ground, or 2 feet 3 inches above sea level.

Well No. 4.—This 14-inch well is 1,080 feet east of No. 3, at an altitude 17 feet above sea level. It is 58 feet deep and passes through the following strata: Soil and gravel 4 to 5 feet, hard lava to 17 feet below surface, where a heavy stream of water was encountered and the water level raised to 13 feet below the surface; then followed a soft streak for 12 to 14 feet, and hard lava was again encountered in the bottom of the hole.

After short pumping with centrifugal pump it was decided to open the water-bearing stratum met 17 feet below the surface.

A pit was excavated about 12 by 24 feet, the longer side being parallel to the coast. The western half was sunk to 8½ feet below the surface, and a double-action two-cylinder 14 by 15 by 10 Worthington pump (strokes 86 per minute) was placed at this level. The eastern half of the pit was sunk deeper. On May 10 it had penetrated 15 feet of hard but porous and open lava agglomerate. The water level stood 14 feet below the surface while pumping at the rate of 2,500,000 gallons (3.87 cubic feet per second). The water level in the deep-bore hole No. 4, situated in the middle of the western end line of the pit, was 1 foot lower. On May 10 the water from pump contained 37.5 to 40 grains of salt per gallon. Pumping began May 8 at 9 a. m. and continued with some intermissions to June 25, when the pumps were removed to well No. 6.

On May 16 the pit was down to 16 feet from surface, while the water stood 14 feet below, and work was becoming difficult. Pumping at the same rate was continued, the water containing 46 grains of salt per gallon. The water could not be handled with the Worthington pump, so a small centrifugal pump was added. On May 28 both were running with a total capacity of 3,500,000 gallons (5.42 cubic feet per second). Water coming into the big pit on northeast side 5 feet below sea level contained 29.5 grains of salt per gallon, while the discharge from the main pipe ran 40.4 grains, but contained up to 60 or 70 grains after some hours of continuous pumping.

In the first days of June a 2,000,000 gallon (3.40 cubic feet per second) centrifugal pump was substituted for the smaller one and total rate of pumping increased to 4,000,000 or 4,500,000 gallons (6.19 to 6.96 cubic feet per second). The water was discharged into a flume and was conveyed to the pond near the eastern boundary of Kawela. Up to the end of May the 20-inch suction pipe had been allowed to remain in the bore hole drawing up salty water all the time, but then this pipe was first shortened and finally placed in the bottom of the pit. The total depth of the pit from surface of upper (north) side is 18½ feet. Tunnels were now started from the northeast and southwest corners of the pit. On June 8, 2 p. m., pumping 4,000,000 gallons continuously, the water in the northeast tunnel ran 40 grains of salt per gallon, while the water in the flume contained 90 grains. On June 11, pumping continued as before, keeping water within 16 feet of bottom, the heavy stream of water from northeast tunnel ran 35 grains of salt per gallon. Another heavy flow, pouring from the well hole, contained 78 grains. The water in the main discharge flume contained 64 grains; later in the day 82 grains. A big stream of salty water also poured out 1½ feet above bottom of pit in southeast corner; a less amount of same on south side of northeast tunnel but only at its mouth, and still another smaller flow near southwest corner of pit. It had now become apparent that salt water came in from the bore hole and from the south side of the pit near the bottom. A futile attempt was made to check the flow from the bore hole by piling bags filled with earth around it. A week later the well hole was filled with cement, but only to a depth of 20 feet below the bottom of the pit, total depth below it being 40 feet. The pumping was continued at same rate and the water contained the amount of salt indicated in the following table:

Amount of salt in water from No. 4 well.

[Grains per gallon.]

Date.	North-east tunnel.	South-west tunnel.	Flume.	South-east flow.
June 12	39	27	120	200
13	48	38	----	----
14—9 a. m	48	38	198	341
12 noon	51	52	----	394
15—2 p. m	57	33	----	----
4 p. m	----	----	----	480
19 [a]	56	65	127	----
20—12 noon [b]	----	----	125	----
4 p. m	45	65	150	225
21 [c]	----	----	----	----
22—9 a. m [c]	52	68	110	162
4 p. m	65	48	150	232
23—9 a. m	49	60	111	----
4 p. m	52	37	142	232
24 [d] } 25 [e] }	57	32	----	----

[a] Pumping stopped for two days.
[b] Running day time only.
[c] June 21 about same as June 20.
[d] No pumping.
[e] Irregular pumping.

All tunnel samples were taken at face.

On this day the tunnel had advanced 32 feet from the pit. The rock, which had been porous and soft, was becoming hard at face, and much water was coming in from the roof. The southwest tunnel had advanced 23 feet in porous rock, but the same was becoming hard, a good stream of water coming in from the floor.

An analysis of above data shows that the two tunnels furnished from 2,250,000 to 2,500,000 gallons (3.48 to 3.87 cubic feet per second) of water, containing on the average 50 grains of salt per gallon, while the southeast flow and the bore hole furnished from 2,000,000 to 2,250,000 gallons (3.10 to 3.48 cubic feet per second), containing from 200 to 400 grains of salt per gallon. Practically all of the salt water comes from these two sources. The rapid increase in salinity from the southeast flow and the bore hole shows that there are leaks in the rocks at these points in almost direct connection with the sea water, while the other parts of the pit had no such connections. It might well have been possible to isolate these sources of contamination.

Well No. 5.—This 14-inch well is located 226 feet east of No. 4, and is 75 feet deep. It passed through the following strata: Soil 3 feet, hard lava to 29 feet from surface, soft red lava tuff to 47 feet from surface, hard lava to 70 feet from surface, soft again from 70 to 75 feet. The water stood 9½ feet below the surface, or 2½ feet above sea level. On May 16 I measured water level to 9 feet 1½ inches below surface. Salinity, 35 grains. Pumped with centrifugal pump at rate of 750,000 gallons (1.16 cubic feet per second) May 8 and 10, but not continuously. On pumping the level immediately fell 2 feet 3 inches. Highest salinity, 35 grains.

Well No. 6.—This 14-inch well is located 255 feet west of well No. 4 and is 60 feet deep. It passed through the following strata: Soil and gravel with bowlders, 40 feet, remainder lava, in part soft. Water contains 25 grains of salt per gallon. Was pumped two days with well pump (capacity, 300,000 gallons, or 0.46 cubic foot per second). Water stands normally 15 feet 6 inches below surface. Pumped also intermittently from June 11 to June 16 at rate of from 500,000 to 850,000 gallons (0.77 to 1.32 cubic feet per second), the water level only being lowered 3 to 4 inches. On June 16 the water contained 31 grains of salt.

Well No. 7.—This 14-inch well is located 240 feet west of No. 6, and is 59 feet deep. It passed through soil and gravel 30 to 35 feet, below this lava of varying hardness. There were no pumping tests up to June 30 on account of lack of available pumps.

Well No. 8.—This 14-inch well is 240 feet west of No. 7 and has a total depth of 58 feet. There have been no pumping tests.

Well No. 9.—This 14-inch well is 195 feet west of No. 1, at an elevation of 20 feet. Down to some feet below water level hard lava prevails. The well was not finished by end of June. There are no special tests of water from the last three wells, but the amount of salt ranges from about 25 to 35 grains per gallon.

On the west side of Kawela Gulch a shaft was sunk at an elevation of 30 feet in a small side gully. Water containing only 3 grains of salt per gallon was found somewhat above sea level. The water came in too fast for bailing, but no pumps being available nothing further was done at this locality.

Other wells.—Since the middle of May, 1900, a series of six shafts (5 by 5 feet) have been sunk to sea level between the wells, but no pumping has been done on these. It was proposed to extend a tunnel from well No. 4 to well No. 1, a little below sea level; this tunnel was to grade toward No. 1, where a central pumping station was to be located, and was to collect the upper stratum of the ground water, to which that from the deeper strata down to 60 feet was to be added by pumping from the wells. As it was shown, however, that tunneling under existing circumstances was quite difficult at well No. 4, it was intended at the time of my departure from Molokai to substitute an open cut and trench for the tunnel.

THEORETICAL AMOUNT OF WATER AVAILABLE.

The rain falling on the island is disposed of in the three following ways: One relatively small part is evaporated from soil and from plants. A second and large part is absorbed by the soil and, continually moving, sinks down to the surface of permanent saturation, which slopes gently seaward; all of this water finds its way to the shore and must emerge from the rocks at or about sea level. A third part runs off in the living streams. On the north coast and in the summit region this amount reaches at least one-half of total rainfall, for the ground here contains much water and only slowly absorbs more. Over the south slope the run-off is very small, for the living streams are here largely absorbed before reaching the sea. The run-off of the total south slope is probably only 30 per cent of the total rainfall. It is greater at Kawela than at Kaunakakai.

Absolute data can not be obtained on account of lack of information as to rainfall; but, taking all conditions known on this and adjacent islands, the following approximate calculation may be made:

Total area of south slope from Meyers Creek to east boundary of Kawela is 54 square miles; average rainfall over this area is 4 feet per year; total annual rainfall over this area, 6,048,000,000 cubic feet, or 45,358,000,000 gallons, or 126,000,000 gallons per twenty-four hours (194.95 cubic feet per second); evaporation, 26,000,000 to 36,000,000 gallons (40.23 to 55.70 cubic feet per second); run off, 20,000,000 to 30,000,000 gallons (30.94 to 46.42 cubic feet per second); ground water, 60,000,000 to 80,000,000 gallons (92.83 to 123.78 cubic feet per second). Of this amount it was proposed to secure nearly one-half, or 30,000,000 gallons (46.42 cubic feet per second), at one place near Kaunakakai, which clearly would be impossible.

The ground water available from one-half mile west to 1 mile east of Kaunakakai and from the coast to the summit, including the drainage of Kaunakakai and small gulches to the east, may be roughly calculated as follows:

Area, 36,000 by 12,000 feet; average rainfall over whole area, 4 feet; total amount of water, 1,728,000,000 cubic feet, or 13,000,000,000 gallons per year, or 36,000,000 gallons in twenty-four hours (55.70 cubic feet per second); evaporation, 8,000,000 to 12,000,000 gallons (12.38 to 18.57 cubic feet per second); run off, 5,000,000 to 10,000,000 gallons (7.74 to 15.47 cubic feet per second); available for ground-water circulation, 14,000,000 to 23,000,000 gallons in 24 hours (21.66 to 35.59 cubic feet per second), which amount must emerge along the coast. It is thus seen that a considerable amount of water is available, though it is probably distributed pretty evenly over the distance, and its long passage through the rocks has rendered it salty. The fact that for a whole year 1,000,000 gallons (1.55 cubic feet per second) has been pumped from the cane-field well goes to prove that there must be a fair amount available along the coast.

A considerable amount of ground water is available at Kawela Gulch. Assuming a drainage area of 24,000 by 12,000 feet for the Kawela property and an average rainfall of 5 feet, for the rainfall is decidedly more than over the Kaunakakai drainage area, we obtain 1,440,000,000 cubic feet, or 10,800,000,000 gallons a year, or 30,000,000 gallons a day (46.42 cubic feet per second). Assuming 6,000,000 to 10,000,000 gallons (9.28 to 15.47 cubic feet per second) evaporation, 4,000,000 (6.19 cubic feet per second) run off, 16,000,000 to

20,000,000 (24.76 to 30.94 cubic feet per second) remain for the ground water that may be considered available near Kawela Gulch. While the total supply is not much larger than at Kaunakakai it is more concentrated and the water is less saline, the normal flow averaging about 35 grains, the flood water on top sometimes going as low as 3 grains.

These calculations of the relative quantities at Kaunakakai and Kawela may not quite express the actual conditions, for from the geologic structure it seems very probable that a large part of the ground water from the headwaters of Kaunakakai Gulch finds its way down to Kawela, thus considerably increasing the amount available there.

The ground water probably available at Kamalo may be roughly estimated as follows:

Assuming a drainage area of 20,000 by 10,000 feet and an average precipitation of 5 feet, we obtain a total of 7,500,000,000 gallons a year or 21,000,000 gallons a day (32.49 cubic feet per second), of which the larger part, perhaps 12,000,000 or 15,000,000 (18.57 to 23.21 cubic feet per second), should be available at or near the mouth of the gulches. Several more favorable locations may be selected between Kamalo and Mapulehu which should aggregate 10,000,000 gallons (15.47 cubic feet per second).

Considering now the high region above with a view to ascertaining how much water may be available for an irrigation system collecting the run-off of the area from the head of Kawela to Waihanau, we may approximately calculate as follows:

Total area involved, 32,000 by 4,000 feet; average rainfall, approximately, 8 feet; total amount of water, 1,024 cubic feet or 7,680,000,000 gallons a year, equivalent to 21,300,000 gallons a day (32.96 cubic feet per second). The run-off, which is here at least 50 per cent of total precipitation, would be 10,500,000 gallons (16.25 cubic feet per second).

The drainage area of the upper Waihanau is 10,000 by 2,500 feet, over which a rainfall of 8 feet may be expected. Total water, 200,000,000 cubic feet, or 1,500,000 gallons per annum; it is proposed to collect the entire run-off of this; the amount estimated by stream measurements is 710,000,000, which is a little less than half of the total precipitation.

UTILIZATION OF THE WATER SUPPLY.

The principal problem on Molokai is how to obtain water for irrigation of the 14,000 acres of deep soil situated in the great gap. Another problem is how to obtain water for the irrigation of the smaller coast flats occurring at intervals from Palaau to Mapulehu.

According to the ordinary estimates of sugar planters, 1,000,000 gallons per twenty-four hours (1.55 cubic feet per second) are needed to irrigate 100 acres of sugar cane. In the opinion of many this is too much, but at that rate 14,000 acres would necessitate 140,000,000 gallons per twenty-four hours (216.61 cubic feet per second). Assuming 1,000 acres of coast flats, 10,000,000 gallons (15.47 cubic feet per second) more would be needed. It is evident that such an amount of water is not available on the island. A certain amount of water can, however, be obtained and it is of interest and importance to attempt to estimate this quantity. Sooner or later the welfare of the island may demand that all possible resources be made available. First of all, the running water at high elevations must be considered. In a few places, as at Kamalo, this water is carried down in steep-grade ditches to irrigate fields at the coast. This plan is probably impracticable in the long run, for these ditches will soon be washed out and there is great loss of water by absorption. If this plan is to be considered, it would be necessary to conduct the water in iron pipes, but the quantity in each place is usually small, so that it would also be an expensive undertaking for the results achieved. Another plan would be to collect the water of the upper region as far east as Kamalo and to carry it by a series of ditches to storage reservoirs above the cane lands. This would be more feasible and such a plan is considered in the following pages. The supply would entail small expense for maintenance. If cemented ditches were used in places the plant would be put on a permanent basis, necessitating no renewal every ten or fifteen years, as is the case with flumes. There is a further source of supply in the ground water along the coast. This can be collected, carried by flumes or cemented ditches to a point near the cane lands, whence it would have to be raised 400 feet by means of a force pump. Few agricultural industries but sugar plantations could bear such a tax, but, as well known, there are many such high-power pumping plants in the islands, especially on Maui. The expense would be still further increased by the necessity of many well plants, for it is certain that no one place will supply a very great quantity of water. There is a possibility of using electric power, which may aid to solve the problem. At any rate, I think it certain that the coast flats could easily be irrigated from wells, which would not necessitate high pumping.

Another point to be considered is the salinity of the waters. The running streams are very pure, but all of the ground water is more or less contaminated by common salt or sodium chloride. There is less of this at Kawela and Kamalo and to the east, but west of Kawela the salinity increases and reaches 90 grains per gallon at Kaunakakai and Palaau. The danger point in using saline water for sugar plantations is stated to be about 100 grains per gallon. Above this the waters become undesirable and their application may spoil the lands, especially if they are low lying.

UTILIZATION OF THE RUNNING STREAMS.

The amount of water which yearly flows to the sea through Meyers, Kaunakakai, and Kawela gulches is not large, though the torrents are violent while they last. To collect this amount at sea level would be difficult in many respects, and this plan is not to be recommended; nor will it be less difficult to collect the water from the streams while running at elevations of 500 to 1,000 feet. Flumes would be long and expensive, and the long seasons during which they must remain dry would necessarily soon destroy them.

The only place to economically collect the running water is near the summit region. Here the streams are more constant and less torrential; here, also, is the region of heaviest rainfall and largest relative drainage area. In their lower course most of the streams are in box canyons which can not collect a large amount of water.

It may be thought that flumes have been used too extensively in the scheme outlined below, and in some places where the soil is very light ditches may possibly be substituted, but the danger of losing water by leakage is great, though not so great as farther down the slope, and in installing the system tests and measurements should be constantly made to make sure that no avoidable losses take place. During the dry part of the season most of the streams will flow only a small amount, and a few will dry up altogether; there will be enough, however, to keep the flumes from drying and shrinking. It is probably not desirable to go beyond Kamalo Gulch for the purpose of collecting water for the region of the gap. Beyond this point the summit region is very precipitous and the expense of construction and maintenance would be very great.

The system of collection is combined with a system of storage by which part of the waters of the rainy season will be stored for summer use. A number of reservoir sites have been selected and surveyed which, it is believed, will be tight and satisfactory.

Referring to the data given above under "Running streams," the following amounts are believed to be available in the different gulches at elevations given below:

	210 days (Nov. 1-June 1).		60 days (June 1-Aug. 1).	
	Gallons per 24 hours.	Cubic feet per second.	Gallons in 24 hours.	Cubic feet per second.
Waihanau	3,250,000	5.02	1,000,000	1.55
Waialeia	300,000	.46	100,000	.15
Waikolu	1,250,000	1.93	300,000	.46
Kahapakai	250,000	.39	150,000	.23
Mokamoka	200,000	.31	100,000	.15
Luahine Fork	200,000	.31	75,000	.12
Kamiloloa	275,000	.43	100,000	.15
Makakupaia	425,000	.66	150,000	.23
West Fork Kawela	200,000	.31	50,000	.08
East Fork Kawela	1,200.000	1.86	300,000	.46
Total	7,550,000	11.68	2,325,000	3.58

This gives a total for two hundred and seventy days of 1,725,000,000 gallons (230,500,000 cubic feet). During the remaining months of the year there will be a varying flow less than 2,000,000 gallons (3.09 cubic feet per second), which may be considered to offset losses by leakage and evaporation. Assuming 500 acres to be irrigated with 5,000,000 gallons a day (7.74 cubic feet per second), or 1,825,000,000 gallons (244,000,000 cubic feet) a year, which amount certainly is ample, a storage capacity of about 577,000,000 gallons (77,000,000 cubic feet) is required in this case to supply about 480 acres with a steady flow of 4,800,000 gallons in twenty-four hours (7.43 cubic feet per second). During part of the winter months the full amount of water is not needed and consequently any increased storage capacity will increase the area which can be irrigated. The water is to be taken out as follows:

Waikolu.—Elevation of dam 3,600 feet; 4,500-foot flume, 2 by 1½ feet; grade 10 feet per mile; capacity 3,000,000 gallons (4.64 cubic feet per second); to cross gap at head of Makakupaia with 2,000 feet of 10-inch riveted pipe, and discharge in Kamiloloa. Probably too much loss of water would result by allowing water to run down into Makakupaia Fork.

Kawela.—Elevation of damming place 3,220 feet; 15,000 feet of flume to Makakupaia Fork; grade 10 feet per mile; capacity 8,000,000 gallons (12.38 cubic feet per second); size 2 by 3 feet; to dump water over edge of canyon into Makakupaia Fork; crosses Onini Gulch in siphon.

Makakupaia.—Elevation of dam 2,650 feet; 17,000 feet to Hunter's cabin; grade 10 feet per mile, dumping water in upper East Fork of Luahine Gulch at elevation of 2,600 feet; capacity 16,000,000 gallons (24.76 cubic feet per second); size 3 by 4 feet; crossing tributary gulches of Kaunakakai Gulch in siphons and receiving tributary flume from Kamiloloa and Waikolu.

Kamiloloa.—Elevation of dam 3,050 feet; 4,500 feet of flume, 2 by 2½ feet carrying; capacity 5,000,000 gallons (7.74 cubic feet per second); sharp grade,

Luahine Fork.—The water from the Makakupaia ditch is dumped into East Fork of Luahine. The latter is dammed at an elevation of 2,350 feet; 9,500 feet of flume to Kahapakai; size 3 by 4 feet; grade 20 feet per mile; capacity 20,000,000 gallons (30.94 cubic feet per second); crossing Mokamoka Fork and West Fork Luahine in siphons, receiving their flows in 2 by 1 foot tributary flumes; dumps at an elevation of 2,300 feet in Kahapakai.

Waialeia.—Damming place at an elevation of 2,760 feet; 4,000-foot flume 14 by 12 inches; 10-foot grade; dumping into Waihanau; capacity 1,000,000 gallons (1.55 cubic feet per second).

Waihanau.—Damming place at an elevation of 2,046 feet; 4,200-foot flume, 2½ by 3 feet; grade 10 feet per mile; capacity 10,000,000 gallons

(15.47 cubic feet per second); 400 feet of tunnel; dumping water into Kahapakai.

Kahapakai.—Damming place at an elevation of 2,000 feet; 3,000-foot flume, 3½ by 4 feet; capacity 30,000,000 gallons (46.42 cubic feet per second); grade 20 feet per mile; dumping into reservoir No. 1 at Meyers Lake.

From reservoir No. 1 there are several ways by which the water can be conducted down to the lower reservoir sites. The simplest would be to let it run down Meyers Creek to an elevation of 1,100 feet, whence it could be taken to the reservoirs in a ditch. This will, however, almost certainly cause large losses, which can not be afforded. A better plan would probably be to let it down to an elevation of 1,600 feet—that is, 300 feet below the reservoir—whence it can be conducted by a sharp-grade flume across the gap below the reservoir and thence to the head of the flat gulch in which the big reservoirs are located. This gulch, it is believed, is fairly tight; at any rate it is worth trying. Should the losses in this gulch be too large it will be necessary to construct a series of ditches at low grade connected with sharp drops which will conduct the water down to the reservoirs. It should be mentioned that all parts of the system are easily accessible. A wagon road extends from Kaunakakai to the gap at Kaohu station above reservoir No. 1; another road is built from Kaunakakai to Waikolu. Still another can be constructed at very slight cost from Kaunakakai by way of Makakupaia station to the headwaters of Makakupaia, and to the edge of the canyon above the West Fork of Kawela. In places the flumes will be difficult to build, but there do not appear to be serious obstacles in any place.

The required storage capacity, 577,000,000 gallons (77,000,000 cubic feet), is to be obtained as follows:

The highest reservoir is known as Meyers Lake, a small natural pond dammed to some extent by Mr. Meyer. It consists of two basins which can readily be dammed to contain 160,000,000 gallons (21,000,000 cubic feet). The elevation is about 1,900 feet. The site is excellent; the ground is evidently very tight and evaporation slight. Considerable wave action may be expected and the main dam must be riprapped and protected by a break water of logs. Abundant and excellent dam material, clayey, decomposed soil close at hand. Large quantities may be loosened by bank blasting. Two different schemes are proposed; if only the lower basin which drains towards Meyers Gulch is utilized, the capacity will be reduced to 91,000,000 gallons (12,000,000 cubic feet). If both basins are utilized they must be connected by a drain or siphon. The upper basin drains toward the north by means of a narrow cut which must be filled by a dam.

Dam No. 2 and No. 3 are natural basins at elevations of about 900 to 1,000 feet, apparently entirely tight and in their present state ready to receive water. They are situated about 2 miles west-northwest of Meyer's ranch on the broad grassy ridge south of Eleuweuwe Point. They must be emptied by means of siphon pipes or drain tunnels.

Most of the gulches and creeks of the island have a very steep grade. Among the exceptions to this rule are the three gulches discharging on the north coast over the 1,000-foot pali, 2 or 3 miles north of Middle Hill. The water courses are from 2 to 4 miles long and meander with relatively low grade through the grassy rolling country here continuing out to the very edge of the pali. Their valleys are from about 100 feet deep up to 800 feet wide; their sides, as a rule, grassy and covered by clayey soil. Receiving but little precipitation they contain but little water, even during heavy rains and are thus excellently adapted for storage. Water can be stored in all three at elevation of from 800 to 1,000 feet. The most southerly of these creeks, flowing just south of Eleuweuwe Point, is best adapted for reservoir sites. There is no difficulty in carrying the stored water out from the reservoirs and down toward the cane lands. Four reservoirs were planned on this creek, though one of these, No. 5, may be dispensed with as the desired capacity is obtained without it. The dams must be carefully constructed of the abundantly available clayey soil, and I believe that the reservoirs will be found water-tight. They are calculated to 10 feet on top with a slope of 3:1 on both sides The surveys for these dams were made for me by Mr. E. Pope, at that time one of the surveyors of the American Sugar Company.

List of reservoirs.

No.	Capacity.		Height of dam.
	Gallons.	*Cubic feet.*	*Feet.*
1 (Meyers Lake)	160,000,000	21,389,000	30
2	62,000,000	8,288,000	(a)
3	73,000,000	9,758,500	(a)
4	117,000,000	15,640,500	54
5	138,000,000	18,448,000	54
6	189,000,000	25,266,000	54
7	100,000,000	13,368,000	52
Total	839,000,000	112,158,000	

a Natural basin.

From the reservoirs at an elevation of 800 feet the water is easily conducted by ditches and drops in shallow ravines to an elevation of 450 feet, the height of the gap, whence it can be applied to any part of the cane lands desired. The distance from the reservoirs to the cane lands is from 2 to 4 miles. It is easily understood that it is not necessary to construct this whole system outlined above at once. The Waihanau, Waialeia, Kahapahai may be first utilized together with reservoirs No. 1 and No. 2 or No. 7. The results of this system, which will irrigate at least 175 acres, will indicate the success to be expected from the installation of the whole system.

In conclusion it may be estimated that collecting and storing the running streams as outlined above will cost about $120,000 and the water collected amounts to a steady supply of nearly 5,000,000 gallons a day (7.74 cubic feet per second) during the whole year. The utilization of this water will interfere but little with the supply to be expected from pumps at sea level.

If it were found practicable to use the lands for cultivation of fruit trees and vines, this quantity of water—5,000,000 gallons in twenty-four hours (7.74 cubic feet per second)—would easily be sufficient to irrigate 1,000 acres. In view of the strong winds prevalent over the area containing good soil such culture may, however, be difficult. Experiments in this direction would be desirable.

In order to develop the water supply by catching some of the underground flow which otherwise would come out at elevations lower than the point of collection, tunnels might be driven at Waihauau, Waialeia, and Waikolu into the hill perpendicularly to the direction of the drainage, just above the damming place and in both directions from the creek; it is rather probable that notable amounts will thus be collected by comparatively short tunnels, say 100 or 200 feet in length.

Similar tunnels at the places where Kawela and Makakupaia forks are caught are not advisable.

Wailau and Pelekunu.—Referring to previous pages, it is estimated that Wailau has a minimum flow of 8,000,000 gallons (12.38 cubic feet per second) and Pelekunu of 7,000,000 gallons (10.83 cubic feet per second), both at an elevation of 600 feet; but measurements during the driest time of the year are necessary to confirm these figures. Only the minimum supply can be considered, for the high-level irrigation system proposed above has exhausted the greater part of storage capacity available.

The utilization of the water supply of these streams involves (1) a high-level ditch reaching the cane lands at an elevation of 450 feet and (2) long tunnels to bring the water to the south side of the island, the northern coast being entirely impracticable. Both ditch and tunnel will be very expensive.

There are two possibilities: (1) Utilization of Wailau alone; (2) utilization of Pelekunu and Wailau.

By the utilization of Wailau alone 8,000,000 gallons (12.38 cubic feet per second) of water will be obtained, and to this must be added water which will be found in the tunnel. The latter quantity is very doubtful, but will probably amount to several million gallons. The tunnel will tap Wailau, West Fork, at an elevation of 670 feet. The water from the East Fork will be added by ditch across gap south of Puu o Wailau. Length of tunnel to point in the canyon 1¼ miles above Dr. Morritz's house at Mapulehu (elevation 660 feet), 12,800 feet. From Mapulehu to the cane fields there will be 17 miles of conduit and flume, with many siphons, the latter causing considerable loss of grade. Elevation of flume at cane fields, 450 feet. The expense of this undertaking would probably exceed $400,000. But it should be remembered that there are many things which may cause increased expense. Among these are the possibility that the tunnel may partly or wholly need cementing in order to become tight. Further, that loose strata may be met, which may largely increase the expense. Further, the difficulty of working the tunnel from both ends on account of descending grade and large quantity of water probably met with. Lastly, the difficulty of landing coal and machinery at Wailau. Time needed, if only worked from one end, three years.

By the utilization of Pelekunu and Wailau 14,000,000 gallons (21.66 cubit feet per second) should be secured, besides the large flow which will almost certainly be met in the tunnels. Ditches and flumes must be correspondingly enlarged, and a tunnel 14,500 feet long driven from Pelekunu to convey the water after it is collected from the different branches. The expense would be at least $800,000.

By tunneling the range from Kawela to Pelekunu the long and difficult conduit from Mapulehu to Kawela would be avoided and there would be also considerable saving of grade. The tunnel from Wailau (elevation 650 feet) to Pelekunu (elevation 635 feet) would be 15,000 feet long, while the tunnel from Pelekunu (elevation 635 feet) to Kawela (elevation 610 feet) would be 26,500 feet. All of the previously stated objections apply with still greater force. The enterprise would consume several years and require at least $1,200,000.

In conclusion, I consider it feasible to bring the water from Wailau and Pelekunu to the cane fields, but do not believe that the enterprise would be a paying investment.

UTILIZATION OF THE GROUND WATER.

This plan contemplates the pumping of water from shallow wells at suitable places along the coast up to a low flume, say 50 to 75 feet above sea level, and the further raising of it up to a level of 300 to 500 feet by means of reciprocating pumps. Considering the conditions fully outlined above, it is clear that a large volume of water, say 30,000,000 gallons (46.42 cubic feet per second), is not obtainable in any one place. The only way is to utilize all the resources as far as possible and to collect the water wherever found. It is true that this may be somewhat more expensive than if the water were found in one place, but it is the only plan possible, except if the supply from Wailau and Pelekunu be used.

When the ground water is concentrated about sea level, trenches, pits, or tunnels may offer the best means of collecting the same, the trenches and tunnels as a matter of course being extended parallel to the shore. Even in this case difficulties may occur, for the heavy pumping necessary to prosecute the work is apt to bring in sea water, and leaks may be found which will admit large quantities of the same. If the water is more evenly distributed through the strata down to 30 or 40 feet below sea level, or if the bulk of it is found at the latter depth, sinking and tunneling become impracticable, for if it is attempted to keep the workings dry, the sea water, being under heavy pressure, is almost sure to find its way in. In such case groups of 14-inch bore holes should be used, and even when the water occurs at sea level they may become preferable. In these porous rocks the capacity of a single bore hole may be comparatively great and amount up to 1,000,000 gallons in twenty-four hours. There is great temptation to overdraw the capacity of wells, and this has been done both at Kaunakakai and at Kawela. Just as soon as a steady increase in salinity is noted the quantity drawn must be decreased. In these rocks one well has a large suction area. If one well will give 1,000,000 gallons (1.55 cubit feet per second), 20 wells surrounding it, say at the corners of each 40 feet square, will probably give at most 3,000,000 to 4,000,000 gallons (4.64 to 6.19 cubic feet per second). While many of these conditions seem discouraging, it should be borne in mind that one single well, that at Kaunakakai, has for over one year furnished a steady flow of water with a salinity of 85–90 grains per gallon, and that many similar places can doubtless be found along the coast.

At Palaau.—According to the data given above (wells and springs) there is probably a considerable amount of ground water available at Palaau at a depth of about 80 feet—how much is difficult to say; there is at least 1,000,000 gallons, possibly as much as 3,000,000. The wells bored have not been adequately tested, and this should first of all be done with the well and shaft near the deep well. If this will yield a steady stream for about a month or two of from 750,000 to 1,000,000 gallons (1.16 to 1.55 cubic feet per second) in dry season, I recommend that two or three more wells be sunk parallel to the coast, about 40 feet apart. If it should be found that these would yield 2,000,000 or 2,500,000 gallons (3.09 to 3.87 cubic feet per second) of water containing less than 100 grains of salt per gallon, this should be utilized to irrigate the bottom lands at Palaau, as well as part of the slopes above, which, though rocky, can be cleared and planted. About 1 mile of small flume will be needed. If the water is elevated to 100 feet by a reciprocating pump driven by electricity, it would require 44 horsepower, or 52 horsepower delivered at the motor. The salinity would be high—i. e., about 90 grains per gallon—and this may in the long run interfere with its use on the lowlands.

Cocoanut grove wells.—The 60-foot well at this place should be tested, which has not been done up to date. Should it be found that this well, with or without adjacent pit, will furnish 1,000,000 gallons per twenty-four hours (1.55 cubic feet per second) of salinity of 100 grains, this water may be used to irrigate the bottom lands adjacent, amounting to 150 acres, less water being needed on these low-lying lands than on the higher ground. This would require 8 theoretical horsepower, or 10 delivered at the motor if electric power be used. Should the water prove too salt, water from Kaunakakai must be used.

Kaunakakai.—One well at Kaunakakai is clearly proved to be able to deliver a steady stream of 1,000,000 gallons per twenty-four hours (1.55 cubic feet per second). It is probable that 2,000,000 gallons (3.09 cubic feet per second) more may be obtained from shallow wells to sea level between this well and the so-called Risdon wells, 1 mile eastward.

Risdon wells.—These 20 wells have never been adequately tested, and their capacity is in doubt. Such incomplete tests as have been made are encouraging, and the conditions seem to indicate that they may furnish 2,000,000 gallons of water (3.09 cubic feet per second) at 80 grains of salinity. The water is contained in a well-defined stratum of porous rock from 9 feet to 34 feet below sea level.

Kawela.—Between Risdon station and the west boundary of Kawela the ground water does not appear along the coast in notable quantities, and the prospect of obtaining water from wells is not encouraging. But one-fourth of a mile east of Onini station very large springs appear on the beach, and I believe that there is 2,000,000 gallons (3.09 cubic feet per second) of ground water available at this place. The wells should be sunk at the foot of the bluff, just east of the rock point which extends to the sea. Preliminary exploration by means of pits or shafts would be necessary to decide at what level the water will be found; possibly most of it is held above sea level, but this is a point which can not be decided at present.

On the west side of Kawela Gulch for a distance of 2,000 feet from the creek a considerable amount of water is probably available. I think 3,000,000 gallons (4.64 cubic feet per second) can be secured here, but whether at sea level or 30 or 40 feet below it is impossible to say at present.

The flood plain of Kawela Gulch at present contains much water in its gravelly bed, but this amount will probably be notably diminished by the diversion of its headwaters into the irrigation system as proposed above. Nearly all of the recent well boring and pumping has been done on the east side of Kawela Gulch. The total quantity of water proved seems to be 4,500,000 gallons (6.96 cubic feet per second). Of this, 2,000,000 gallons (3.09 cubic feet per second) of 40 grains salinity have been shown to be available at wells Nos. 1, 2, and 3; 2,500,000 gallons (3.87 cubic feet per second) of 60 grains salinity may be considered proved at well No. 4, with its pit and tunnels, if the flow of salt water is shut off, which probably can be done by filling the salty bore hole with cement and constructing a cement wall around the leak in the southeast corner of the pit (see p. 44).

Tunneling at about 4 feet below water level has proved a difficult undertaking, and will become more so in the loose gravelly material which will be encountered near wells Nos. 6, 7, and 8. It would probably be better to run an open cut 6 feet wide in the bottom and 4 feet below water level in a line of about 15 feet south of the wells, thus collecting all of the ground water available at sea level into one central station, whence the water could be pumped. But to this must be added such amounts of the ground water as is stored in lower strata, as, for instance, 55 feet below the surface at well No. 3. This deeper water may be secured by connecting the bore holes with the main cut at its level—i. e., 4 feet below the sea level—but each bore hole must first be very carefully tested as to capacity and lowering of water level. If necessary, the open cut must be extended west of well No. 1, and a tunnel run through the bluff of well No. 9. It is almost impossible to outline a plan which in its details can be strictly adhered to, for the conditions change almost from day to day and the work requires the personal supervision of a very skilled and experienced engineer. In conclusion, it is believed that 10,000,000 gallons (15.47 cubic feet per second) may be expected at Kawela, east of the creek, and 3,000,000 gallons (4.64 cubic feet per second) west of the same. At Kamalo a quantity of water almost equal to that at Kawela may be expected; and a few million gallons may doubtless be obtained at intervals between Kamalo and Mapulehu.

To collect these waters will doubtless prove an expensive undertaking, owing to the many small pumping stations. Should it be desired to pump a smaller quantity for purposes of irrigation along the coast, some of the small streams at high elevations could be used to generate electric power to drive the pumps below.

Recapitulation.—While the estimate of waters available below the surface is necessarily very uncertain and difficult, I should place the probable amounts as follows:

Probable amount of water available.

	Million gallons per 24 hours.	Cubic feet per second.
Palaau	3	4.64
Cocoanut grove wells	1.5	2.32
Kaunakakai	3	4.64
Risdon wells	2	3.09
Onini Station	2	3.09
Kawela (west)	3	4.64
Kawela (east)	10	15.47
High-level irrigation system	4.8	7.43
Total	29.3	45.32

ELECTRIC POWER AVAILABLE.

As stated before, the irrigation system from the running streams outlined above should furnish at an elevation of 800 feet a steady supply of 4,800,000 gallons a day (7.43 cubic feet per second), or 3,333 gallons a minute. If the water is applied below 425 feet on the south slope of the gap, 375 feet of fall will be available, giving a theoretical horsepower of 314, which if converted into electrical power by means of Pelton wheel and dynamo and transmitted with high potential to Kawela should be sufficient to raise 13,000,000 gallons 66 feet; length of pressure pipe, 15,000 feet; length of transmission to Kawela, 10 miles. The greatest item of cost is the pressure pipe, which should be 14 inches in diameter, riveted, and of wrought iron, and which would not cost less than $50,000. The transmission would offer no difficulties, nor would the loss in transmission with high voltage be large. The great cost of pressure pipe diminishes the value of this proposition. More electric power could be obtained by utilizing the upper reservoir, which has a capacity of 160,000,000 gallons (247.56 cubic feet per second). Quantity of water available, 1,000,000 gallons per twenty-four hours (1.55 cubic feet per second), or 700 gallons per minute; fall available, 700 feet; total theoretical horsepower available, 123; horsepower available at pumps 5 to 10 miles distant, 75. Pressure pipe from reservoir to power station in Meyers Gulch, at elevation of 1,100 feet, would be 10,000 feet long; diameter of 8 inches should be sufficient. Here, again, the pressure pipe forms the principal item of cost, being not less than $15,000.

This proposition is more favorable, but still very expensive in comparison with the advantages obtained. On the whole, it seems more advisable to depend upon steam for motive power.

Electric power from Pelekunu, Waïlau, and Halawa.—According to a preliminary report by Mr. M. M. O'Shaughnessy, dated December 5, 1899, the following approximate power could be generated by utilizing these streams:

Stream.	Normal flow (gallons per 24 hours).	Cubic feet per second.	Fall available for power	Horsepower (theoretical).
Halawa	5,000,000	7.74	300	263
Wailau	10,000,000	15.47	400	701
Pelekunu	5,000,000	7.74	200	210
Waikolu	3,850,000	5.96		

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SERIES O—UNDERGROUND WATERS.

[See last page of this cover.]

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PAPERS RELATING ESPECIALLY TO UNDERGROUND WATERS.

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