

Hydrology of the ALAKAI SWAMP Kauai, Hawaii

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COVER PHOTO

By R. WENKAM

Hydrology of the Alakai Swamp, Kauai, Hawaii

BESSEL D. VAN'T WOUTD and ROBERT E. NELSON

INTRODUCTION

One of the rainiest areas on earth is in the center of the island of Kauai, in the Hawaiian island chain. The raingage on top of Mount Waialeale, 5,080 feet in elevation, at 160 degrees west longitude and 22 degrees north latitude, has measured average annual rainfall as 466 inches. Northwestward from Waialeale extends a dissected plateau, approximately 9 miles in length and 2 to 3 miles in width, at approximately 4,000 feet elevation. It is referred to as the Alakai swamp. The average annual rainfall in this area is 200 inches or more. The area, as shown on the geologic and topographic map of Kauai (Macdonald *et al.*, 1960), covers approximately 20 square miles. The area included in the computation is outlined in figure 7 (see pp. 16-17).

Until recently, little was known of the area because of difficult access due to topography, swamp, and densely entangled jungle growth. The Alakai swamp is bounded on three sides by steep cliffs (palis) with few approaching ridges. It is known that in bygone days Hawaiians climbed Waialeale along these ridges for worship (a place of worship, a stone heap or "heiau," is still found today at the summit—figure 1), and to collect a red clay found near the summit of Waialeale (allegedly after mixing with common salt, used as a condiment). However, these ridges have been found unclimbable in recent years.

The swamp is accessible, however, from the southwestern side where the terrain slopes down to the Waimea river basin. In the last 50 years a few hardy hikers have visited Waialeale, but for one day only, following an almost indistinguishable trail across the swamp. (Alakai in Hawaiian means "one-file track.") Away from this trail the area appears to have remained unexplored and unmapped.

The present-day plateau features of the Alakai swamp can be explained from the geologic history of the area. Macdonald *et al.* (1960) reported that: "the plateau has been built up by successive dense and massive flows of basalts and associated pyroclastics laid in almost horizontal beds within an existing large and central caldera of the Kauai shield volcano. At the head of the Olokele Valley, the beds are 2,000 feet thick. The basic formations underlying the Alakai-Waialeale area are reported to be moderately to poorly permeable." . . . "Locally, ash beds perch small bodies of water at high levels but they are of no economic significance. High-level springs



Figure 1. Expedition members gather around the heiau on top of Waialeale.

in most areas are rare because of the scarcity of dikes and the absence of beds that are less permeable than the average beds.”

For many years the possibility has been discussed of utilizing the waters of Alakai swamp for expansion of hydro-electric power production or irrigation. A study of this subject has been hampered by a lack of knowledge on:

- 1) rainfall on the swamp;
- 2) rainfall dissipation as surface runoff or subsurface runoff, or as deep seepage to the basal water table below the center of the island; and
- 3) water storage at the surface of the swamp.

In November, 1958, a group of specialists in various fields made a 7-day survey of the central and southeastern part of the swamp. This group was made up of representatives of the University of Hawaii, the Board of Agriculture and Conservation, the U. S. Forest Service, the U. S. Soil Conservation Service, the U. S. Weather Bureau, and the Pineapple Research Institute of Hawaii.

During this survey, a new trail was cut from the Koaie camp site to the Wainiha rim. Three days were spent near the Waialeale summit—two nights in the Keaku cave, man-hewn in the steep bank of an intermittent stream, approximately 1 mile from the summit of Waialeale. Aided by aerial photographs, this survey has provided an opportunity to obtain in-

formation on the topography of the swamp, on depth of the organic deposits at the surface, and on streamflow behavior.

Because of the significance of the swamp in the water economy of Kauai, and because of an academic interest in this area of unusually high rainfall, the information collected has been worked up in conjunction with available information on rainfall and streamflow, as described on the following pages.

OBJECTIVE

The objective of this study has been to arrive at a better understanding of the dissipation of rainfall falling on the Alakai swamp.

PROCEDURE

Four approaches to this study were followed:

1) *Aerial photographs*

Aerial photographs of the swamp had been taken, prior to the field survey, on one of the few days of the year the swamp was not clouded in.

Topographic features of the swamp were studied in the field and on the aerial photographs through stereoscopic technique. The field survey allowed the aerial photographs to be interpreted more satisfactorily than would have been possible in the absence of field work. Aided by information collected during the survey, a map was subsequently prepared from the aerial photographs showing vegetative and topographic features of the swamp.

2) *Field survey*

During the field survey, information was collected on:

- a) topography, as mentioned under 1);
- b) the vegetative pattern in relation to topography;
- c) the depth of organic deposits in relation to topography in some 50 locations; and
- d) streamflow behavior in relation to rainfall near the Waialeale summit.

3) *Soil analysis*

Some soil samples were collected during the survey. These were supplemented at a later date by additional samples collected by Mr. J. Souza, Forest Ranger, Kokee area, Board of Agriculture and Conservation, who made a special trip for this purpose to the central part of the Alakai swamp.

These samples have been analyzed by routine methods for moisture-holding capacity, mineral content, and mechanical properties.

4) *Rainfall and streamflow analysis*

Pertinent rainfall and streamflow data collected by the U. S. Geological Survey have been analyzed and compared.

RESULTS AND DISCUSSION

Topography

The map prepared from the aerial photographs (figure 7) allows areas to be defined as: dissected, flat to gently sloping, open bog, or slips. Because of lack of control points, details on the map are not accurately to scale; moreover, only simple stereoscopic equipment was used in plotting. However, the relative location and extent of areas covered by forest or bog and the differences in nature of the terrain shown are approximately correct. Aided by the field observations, the analysis of the aerial photographs has given the following information:

- 1) The area can only partly be called a swamp. Approximately 59.5 percent of the area is dissected and is reasonably well drained a few days after rain (figure 2). However, fog, almost daily rain, and dense, dripping vegetation provide a swamplike atmosphere.
- 2) The gently sloping and flat land occupies approximately 29 percent of the area. This land generally exhibits a peaty layer at the surface and supports a more typical swamp forest. The few trails through



Figure 2. There are a number of well-drained ridges in the Alakai swamp, which remain passable even during rain.



Figure 3. Most of the treeless area of Alakai swamp is adjacent to the summit of Waialeale. The soil is a sticky, gray clay from which water runs off as it falls. Half the soil is bare; scattered tufts of grass and dwarf ohia form the main ground cover.

the Alakai swamp tend to follow the flat grades where bogs are found.

- 3) Treeless areas with low swamp vegetation occupy approximately 11.5 percent of the Alakai swamp. Of this, 8 percent is situated adjacent to the summit of Waialeale on land with slopes up to 20 degrees. No peat layer is present here and the name "mountain barren" could be applied to this summit area (figure 3). The other 3.5 percent consists of patches of typical bog on flat land, with peat layers up to 4 feet deep.
- 4) A few barren areas, shown on the map (figure 7), are the result of large slips on steep mountain sides.
- 5) There are a number of well-drained ridges, which stay well drained even during rain. One such ridge was visited during heavy rain on the Wainiha rim (pali), east of the Koaie camp site. Figure 7 shows a number of ridges in the area, which have not been previously recorded.
- 6) The aerial photographs show that the central divide (drainage boundary) follows the Wainiha rim from Mount Kilohana southeast to the head of Koaie stream only. From there the divide lies southwesterly of the rim. Consequently, more of Alakai swamp drains northward into the Wainiha river than is indicated on the geologic and topographic map of Kauai.



Figure 4. On poorly drained sites the forest is low, stunted, and almost impassable because of branch entanglement and prostrate logs. (Photo by R. Wenkam.)

Vegetation

The predominant vegetative cover on the Alakai swamp is ohia (*Metrosideris polymorpha*) forest, covering approximately 88 percent of the area. Associated with ohia are many other species forming the undergrowth, many of which were described by Rock (1913).

In most places the tree canopy cover ranges from less than 50 percent in a few areas to a general 80 percent or more. On the steeper sites the canopy tends to be more open. On the better drained sites the forest reaches maximum height. Ohia height ranges here from 30 to 50 feet, with a few trees more than 60 feet tall. On the poorly drained sites in the northwestern and central part of Alakai swamp and on most sites within 3 miles of Wai-aleale the forest is lower, much stunted, and almost impassable because of entangled and prostrate branches (figure 4). Many undecomposed logs at the surface and poor visibility (partly due to foot-thick moss cover on most branches) add to travel difficulties. This forest is "fog-saturated" much of the time.

At the edge of the treeless summit area, some 1,500 feet northwest from the peak of Wai-aleale, the forest has died in a belt a few hundred feet wide (figure 5). This dieback has already been reported by Selling (1948) for this summit area and another on Maui. According to Selling, the distribution of buried pollen suggests that this has been due to a recent change to a wetter climate.



Figure 5. At the edge of the treeless summit area, some 1,500 feet northwest from the summit of Waialeale, ohia forest has died in a belt a few hundred feet wide. (Photo by R. Wenkam.)

Soil properties

The soil below the organic deposits at the surface, probably throughout the area, consists of a gray, puggy clay. X-ray diffraction of two subsoil samples collected from about 4,000 feet elevation in the vicinity of the Koaie cabin showed substantial quantities of illite and kaolinite, with minor quantities of anatase, gibbsite, and hydrated illite. The bulk, however, appeared noncrystalline.

Four subsoil samples from the same area were analyzed for plastic limit (yielding values of 46.5, 50.8, 46.5, and 49.8 percent moisture on the basis of the oven-dried weight of soil) and liquid limit (yielding values of 84.0, 84.4, 76.7, and 74.4 percent moisture, on the same basis). This gives an average value for plasticity index of 31.6. On plotting (figure 6), the plasticity index fell above the "A-line," which implies that the permeability of the soil is "very-low" (U.S. Bureau of Reclamation, 1960, p. 30). The presence of the plate-shaped minerals as well as hydrated illite (Baver, 1961, p. 112) explains the high plasticity index observed.

Table 1 shows results of determinations of moisture content of the surface soil and subsoil made on bulk samples weighing 1 to 2 pounds each, collected from three locations at about 3,750 feet altitude, approximately 1½ miles west of the Koaie camp. The samples of the top layer of peat were taken from the 0- to 6-inch depth; those of the bottom layer of peat, from approximately 1½-foot depth.

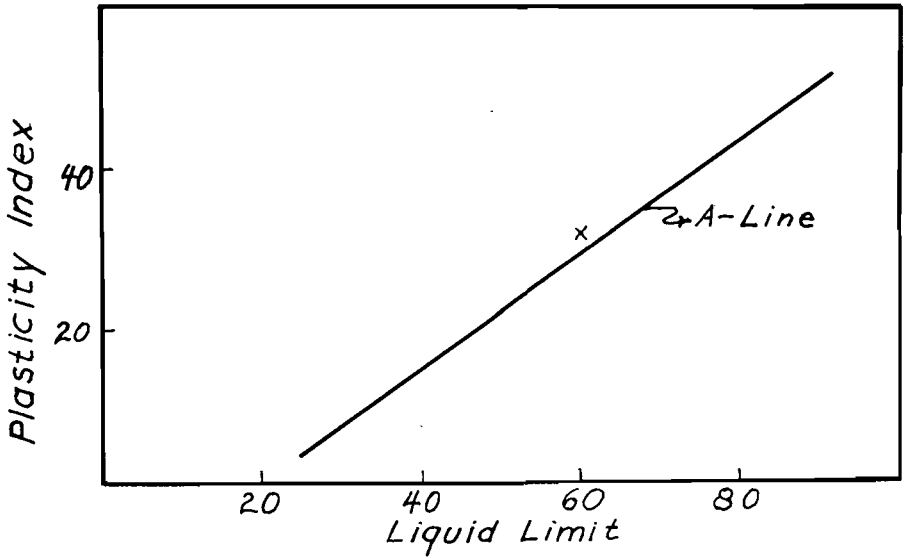


Figure 6. Plasticity index versus liquid limit, in relation to A-line, of subsoil of Alakai swamp.

It is seen that at the time of collecting, the samples from the surface layers were below saturation, but those from the bottom layers were at or near saturation. According to the data on loss of ignition, the surface layers consisted almost completely of organic matter, but from one-half to one-quarter of the bottom layers consisted of mineral matter.

Volume-weight determinations were made on air-dried lumps of peat by water displacement. This method could be applied because of the un-wettability of dried-out samples. The values obtained in this way need to be adjusted for shrinkage for which 20 percent has been taken (Baver, 1961, p. 3). The average value adjusted in this manner comes to 0.84, which is close to the average value of 0.8 given by Mitscherlich (1923, p. 22) for sodden peat and in line with values for woody peat given as 0.77 and 0.90 by Dachnowski (1933).

The data on moisture content reported in table 1 for the two batches of peat samples show the considerable variation which is normally observed in peat soils (Feustel and Byers, 1930).

The saturation values (82, 105, 347, and 227 percent) average 190 percent. Although this figure forms an insecure basis for further computation, it is of interest to note that it approaches the average saturation value of 171 percent determined by Campbell and Richards (1950) for 19 peat samples. The individual values were: 136, 142, 236, 337, 186, 215, 272, 300, 90, 102, 137, 228, 97, 106, 148, 92, 128, 156, and 147.

TABLE 1. Moisture content of surface soil and subsoil samples from Alakai swamp, on collection, on saturation, and on ignition*

SAMPLE	(1) MOISTURE ON COLLECTION, %	(2) MOISTURE ON SATURATION, %	(3) DIFFERENCE BETWEEN (1) AND (2), %	LOSS ON IGNITION, %	AVERAGE APPARENT SPECIFIC GRAVITY
<i>Location 1</i>					
Surface peat	50	82	32	90	0.94
Bottom peat	105	105	—	50	1.15
<i>Location 2</i>					
Surface peat	261	347	86	90	0.94
Bottom peat	187	227	40	73	1.15
<i>Location 3</i>					
Gray subsoil	12	12	—	5	—

* All values expressed as percentage moisture on the basis of the oven-dried weight of soil.

A determination of "field capacity" in the Alakai swamp is a difficult task. A scrutiny of the literature shows that between one-half and two-thirds of the water contained in peat is lost between saturation and moisture equivalent (determined by centrifuging at 1,000 g) or between saturation and moisture content at 1 atmosphere (Feustel and Byers, 1930; Campbell and Richards, 1950; Davis and Lucas, 1959).

The moisture content by weight, P_w , \times apparent specific gravity, A_s , gives moisture content by volume. On the basis of $P_w = 190$ and $A_s = 0.8$, the moisture content of the peat at saturation is estimated at $190 \times 0.8 = 150$ percent of the volume of solid matter. For 1-foot depth of peat this will give 4.8 inches of solid matter and 7.2 inches of water. If from one-third to one-half of the water is released between saturation and "field capacity," from 2.4 to 3.6 inches in depth would be released as streamflow from a 1-foot depth of saturated peat.

Rainfall assessment

Only two rainfall stations have been established on the Alakai swamp, one at Kilohana and the other on Waialeale. Records have been collected by the U. S. Geological Survey. For the first station they have been collected at intervals of several months and for Waialeale, at annual intervals. However, incomplete float records of daily rainfall are available for Waialeale from 1949 to 1956.

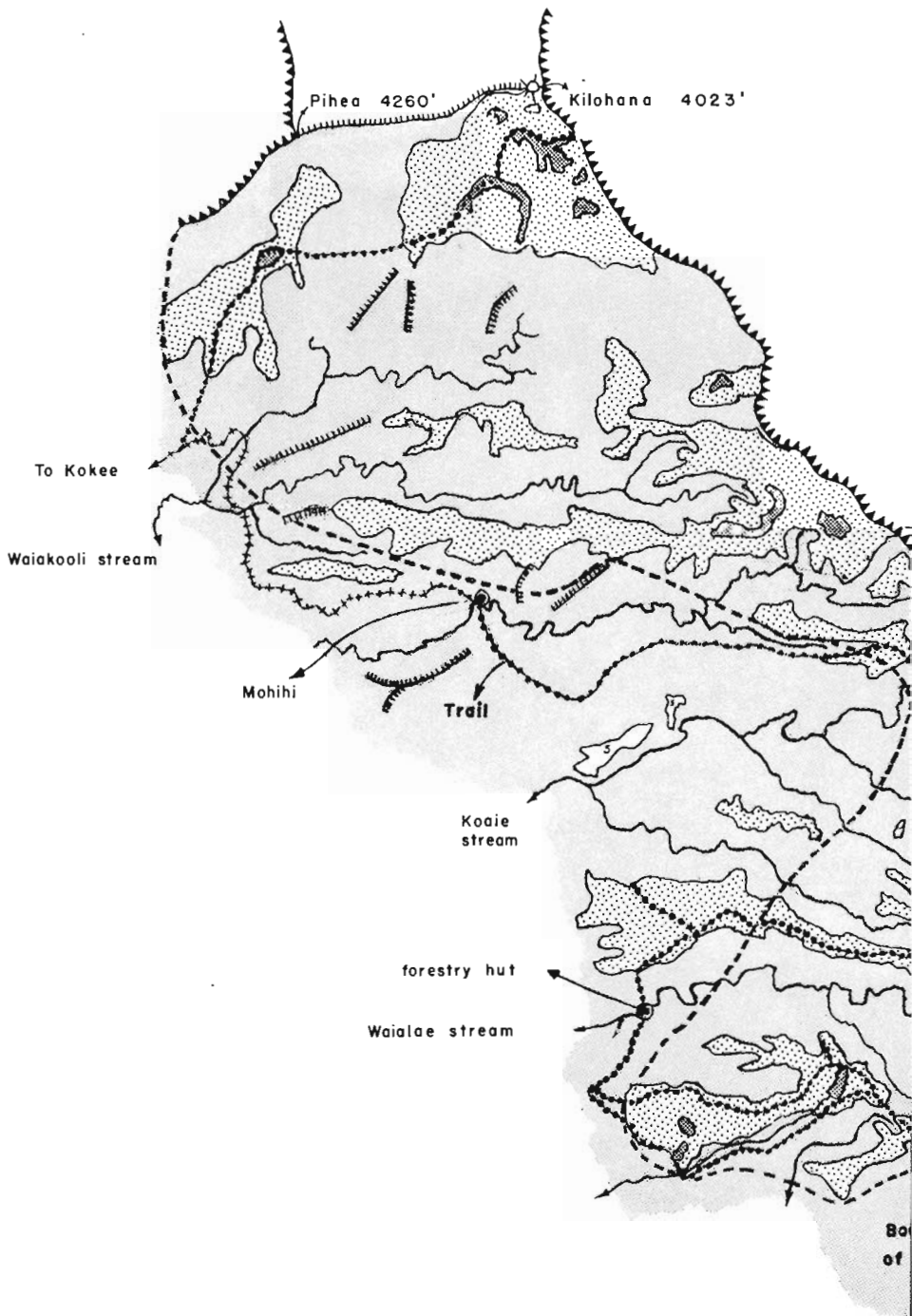



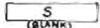





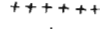




Figure 7. Topography, vegetation, and drainage of Alakai swamp.

SCALE: APPROX. 1:66,000

DATE: 1958

-  Dissected, covered by Ohia forest
-  Flat or gently sloping, covered by Ohia forest
-  Open bog
-  Steep, barren area (Slips)
-  Divide
-  Cliff
-  River
-  Approximate boundary of swamp
-  Track
-  Road, accessible by jeep
-  Mountain peak
-  Camp site

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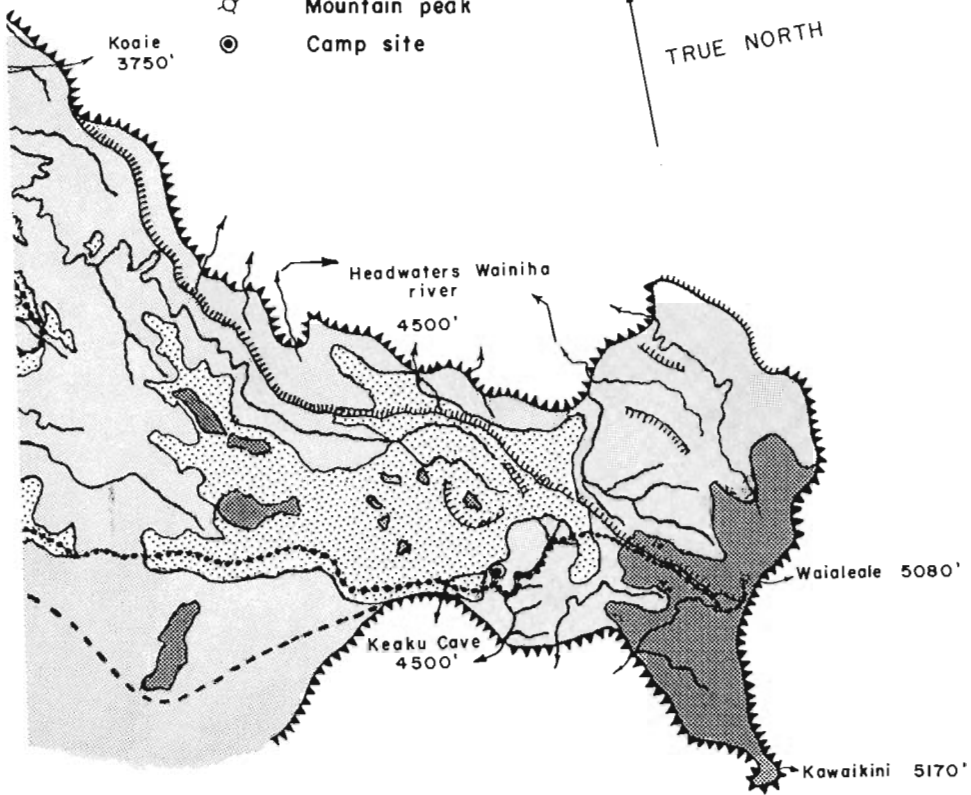


TABLE 2. Rainfall records for Alakai swamp and surrounding area¹

GAGE (SITE)	GAGE NO.	SITE NAME	ELEVATION, FEET	PERIOD OF RECORD (UP TO 1958)	NUMBER OF COM- PLETE YEARS	ANNUAL RAINFALL, INCHES			
						max.	median	min.	
1	1047	Waialeale	5,075	1911-	46	624	466	218	*
2	990.4	Olokele, mauka	2,100	1911-1941	29	307	133	74	**
3	1044	Keanakua	4,450	1920-	28	337	129	66	*
4	1042	Waialae	3,600	1911-	12	148	90	47	*
5	1083	Upper Mohihi	3,500	1919-	31	120	81	41	*
6	1082	Waiakoali	3,450	1919-	33	117	70	36	*
7	1080	Paukahana	3,723	1919-	35	129	72	42	*
8	1084	Kilohana	4,023	1918-	19	296	194	104	*
9	1086	Wainiha Power Intake	700	1907-	51	249	160	73	**
10	1115	Wainiha Power House	101	1907-	50	198	125	64	**

* No monthly totals available.

** Detailed records given below.

GAGE (SITE)	GAGE NO.	SITE NAME	MONTHLY RAINFALL, INCHES												
			Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
2	990.4	Olokele, mauka	max.	32.4	38.7	25.0	32.3	25.0	22.0	32.6	28.7	25.5	24.7	37.8	37.7
			med.	14.3	8.3	10.5	9.5	9.8	7.6	10.4	10.2	9.8	9.9	12.0	13.0
			min.	0.9	2.0	2.4	1.7	2.0	4.0	3.5	2.9	1.9	4.0	2.5	0.7
9	1086	Wainiha Power Intake	max.	73.5	49.8	42.9	45.2	43.5	25.5	27.6	39.2	37.2	28.1	47.7	42.8
			med.	14.1	9.6	18.2	13.4	10.4	7.1	10.8	10.7	7.2	9.2	14.3	17.8
			min.	0.3	1.9	0.8	0.3	-	0.8	2.5	0.8	1.7	2.2	4.3	0.2
10	1115	Wainiha Power House	max.	51.7	71.9	33.3	30.0	32.1	17.6	26.0	39.7	34.3	17.8	28.1	44.7
			med.	10.8	8.0	12.3	9.8	7.4	5.4	7.3	7.7	5.0	6.8	9.6	12.1
			min.	2.5	0.1	3.2	2.8	0.3	0.3	2.5	1.1	1.0	1.6	1.9	0.3

¹Data derived from: Rainfall of the Hawaiian Islands. Hawaii Water Authority, 1959.

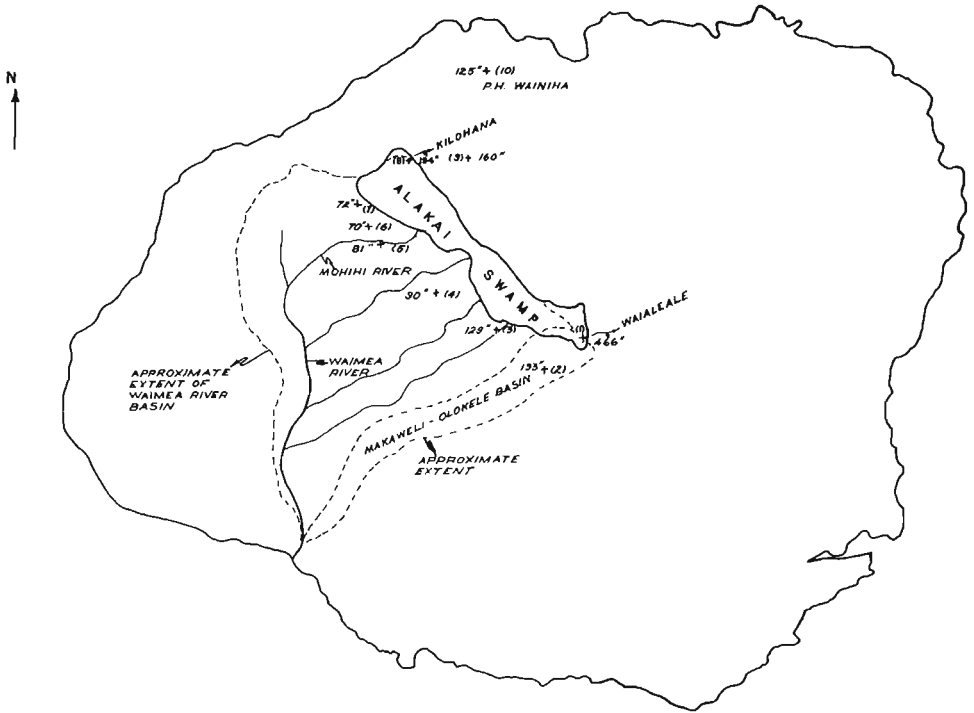


Figure 8. Location of Alakai swamp on Kauai, sites of relevant raingages, and the approximate location of the two river basins analyzed for streamflow.

Much of the rainfall pattern must be inferred from raingages placed in more accessible sites adjacent to Alakai swamp. Figure 8 shows the distribution of these gages and table 2 summarizes the mean annual and monthly rainfall measurements.

At Waialeale the records show a median annual rainfall of 466 inches, with a maximum of 624 inches and a minimum of 216 inches. This is probably an underestimate, as:

- 1) The raingage is at a site where much of the rainfall falls horizontally on a vertically exposed gage, so that there is a reduction in catch due to the effect of very strong winds in the vicinity of the gage (figure 9).
- 2) The rainfall is likely to be heavier just below the mountain top on the leeward side, as was shown by Mink (1960) for the Koolau range on Oahu.
- 3) The gage is unscreened so that there is no measure of fog drip.



Figure 9. Raingauge of 900 inches capacity at summit of Waialeale. Much of the rain falls horizontally, being driven by strong winds coming over the cliff just beyond the gage. The gage is "unscreened."

At Kilohana the median annual rainfall is shown as 194 inches. Here too the gage is unscreened. Measurements on a foggy mountain site on the island of Lanai in the Hawaiian island chain showed at least 30 percent more "precipitation," due to fog condensation, than was indicated by measurements by an unscreened raingauge (Ekern, 1960).

It is considered likely that an average moisture supply of 250 inches per year for the whole of the Alakai swamp is a conservative estimate.

Data available from a site a few miles windward of Waialeale, at 500 feet elevation, show annual evaporation to be approximately 45 inches (van't Woudt, 1961). For the foggy, high-altitude Alakai swamp it probably does not exceed 25 inches. Such an estimate is supported by an analysis by Davis (1960) of rainfall and streamflow for the major rivers draining the central portion of Kauai, shown in table 3. This table compares total rainfall computed from isohyets over the drainage area and streamflow from that drainage area. Even though isohyets are difficult to define with the restricted number of rainfall measurements, it is of interest to note that the calculations lead to an estimate of 38 percent of measured rain lost by evapotranspiration or by deep seepage.

The data in figure 8 further illustrate that on the windward side (side of predominant trade winds), the Alakai swamp receives more rain than on the leeward side. Westward of the sites shown, rainfall tapers off rapidly and to such an extent that the west-facing slopes of the Waimea river basin support desert vegetation.

TABLE 3. Mean annual rainfall computed from isohyets in drainage basin compared with mean annual streamflow expressed as depth of water over area of drainage basin (after Davis, 1960, p. 152)

RIVER	MEAN ANNUAL RAINFALL, INCHES	MEAN ANNUAL RUNOFF, INCHES	RECOVERY OF RAINFALL IN STREAMFLOW, %
Waimea river	70	48	68
Makaweli river	110	76	69
Hanapepe river	150	87	58
Wailua river, south fork	150	109	73
Wailua river, north fork	185	116	63
Hanalei river	275	209	76
Wainiha river	235	194	83
Total	1,375	839	
Average	172	105	62

Water storage at the surface of Alakai swamp

Relatively little water is stored on the peatless soil of the steep slopes and that of the summit area. The bulk of the surface storage is on the flat and gently sloping land. The measurements made indicate that the thickness of the peat on the latter sites is generally between 6 inches and 1 foot. In some pockets peat has accumulated up to 4 feet. Selling (1948) reported that the peat near Kilohana never exceeded 18 inches. Near the summit of Waialeale he was unable to take samples for pollen analysis, as "the peat had washed by runoff." However, several kilometers from the summit he was able to collect samples from a 4-foot-deep peat profile. The impression that the Alakai swamp is covered by hip-deep muck (figure 10) seems to have arisen from the very limited area which has been visited in the past. One can sink knee-deep, and in one or two places even hip-deep, in mud on the gouged-out trails; yet a few yards away from the site shown in figure 10, the depth of peat was only a few inches.



Figure 10. The impression that the Alakai swamp is hip-deep seems to have arisen from the very limited area which is normally visited via the few gouged-out trails. In a few places on these trails one can sink knee- or even hip-deep in the mud; a few feet away the depth of peat may be only a few inches. (Photo by R. Wenkam.)

On the basis of the study of the aerial photographs and the field observations made, it is estimated that significant peat formation is restricted to 29 percent of the area outlined in figure 7. Furthermore, there is reason to assume that the average depth of peat does not exceed 1 foot.

Therefore, the significant storage area is estimated at 29 percent of 20 square miles = 3,700 acres, and the volume of the storage area, at 3,700 acre-feet. At saturation the total surface storage of Alakai swamp is estimated at $7.2/12 \times 3,700 = 2,200$ acre-feet of water and the release from it for streamflow between 730 and 1,100 acre-feet of water ($2.4/12$ and $3.6/12 \times 3,700$).

Rainfall and streamflow

A close relationship between rainfall and streamflow would follow from the observations on a low permeability of the subsoil and a commonly saturated condition of the surface soil. This last condition should cause the Alakai swamp to act as a collecting and overflow basin during much of the time. This hypothesis is supported by the following observations:

- 1) An obviously saturated swamp was encountered, in November, 1958, on reaching the Keaku cave, 1 mile from the summit of Waialeale.

The track ran through a creek bed with merely a few pools of water and a trickle of flow in it. This was at a time when no rain was falling. A few hours later, moderate rain caused the stream to increase to many times its original size. The next morning, without rain, the creek subsided again to a mere trickle. At that time, following of other creek beds for about a quarter of a mile to the summit of Waialeale was a relatively easy task. However, upon return during rain in the afternoon, the same creeks had become rushing torrents.

Sizeable creeks run on the "barrens" near the summit of Waialeale, only a few hundred feet below the top. The poorly drained, saturated soil has practically no additional storage capacity and the creeks represent current rainfall accumulated as surface runoff. (The Hawaiian word "Waialeale" means "rippling waters.") The waters of these summit creeks are clear, as are the creeks several hundred feet down the slope, indicating low soil erodibility and lack of organic matter at the surface. Some thousand feet below the summit and lower, the creeks and rivers turn brown due to organic matter.

- 2) Rainfall at Waialeale during 1950 (the only year for which a complete record of daily rainfall is available) shows a close relationship with streamflow in the Olokele-Makaweli river, particularly during the wetter part of the year (figure 11). Most of the discharge in this river is derived from the summit area of Waialeale (figure 8).
- 3) No daily rainfall data are available for Kilohana on the opposite side of the swamp. The nearest site at which detailed data are taken is Wainiha Power House at 101 feet elevation. The rainfall pattern at Kilohana may be different from that at Wainiha Power House or at Waialeale. At Waialeale the trade winds approach over low-lying country, while they reach Kilohana after having crossed three mountain ridges. A comparison has been made to test the validity of using rainfall data from Wainiha Power House for assessing rainfall on the central and northern part of Alakai swamp (figure 12). The data for 1950 show that while, on the whole, a close relationship exists, on some days rain at Wainiha Power House even exceeds that at Waialeale. However, the relationship is close enough to warrant plotting the Wainiha rainfall against streamflow in the Waimea basin, as done by Davis (1960), shown in figure 13.

It is seen that the streamflows of the Mohihi and Waimea rivers run parallel. As the Mohihi river is a tributary of the Waimea river (figure 8), this is to be expected since both rivers derive most of their waters from the Alakai swamp.

During one period in April, streamflow was lower than would be expected from rainfall at Wainiha Power House. This can be explained from figure 12, since in mid-April more rain fell at the Wainiha Power House than at Waialeale and, therefore, probably also on the central and northern part of the Alakai swamp.

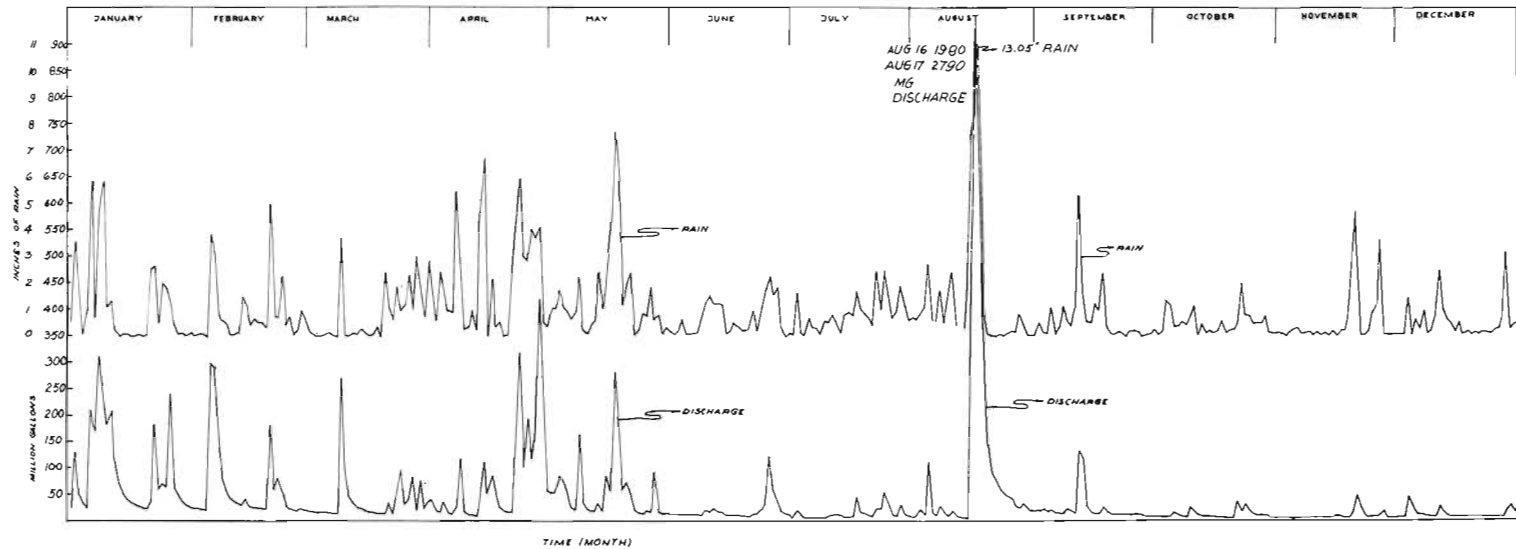


Figure 11. Comparison of daily rainfall at Waialeale with discharge in the Makaweli river during 1950.

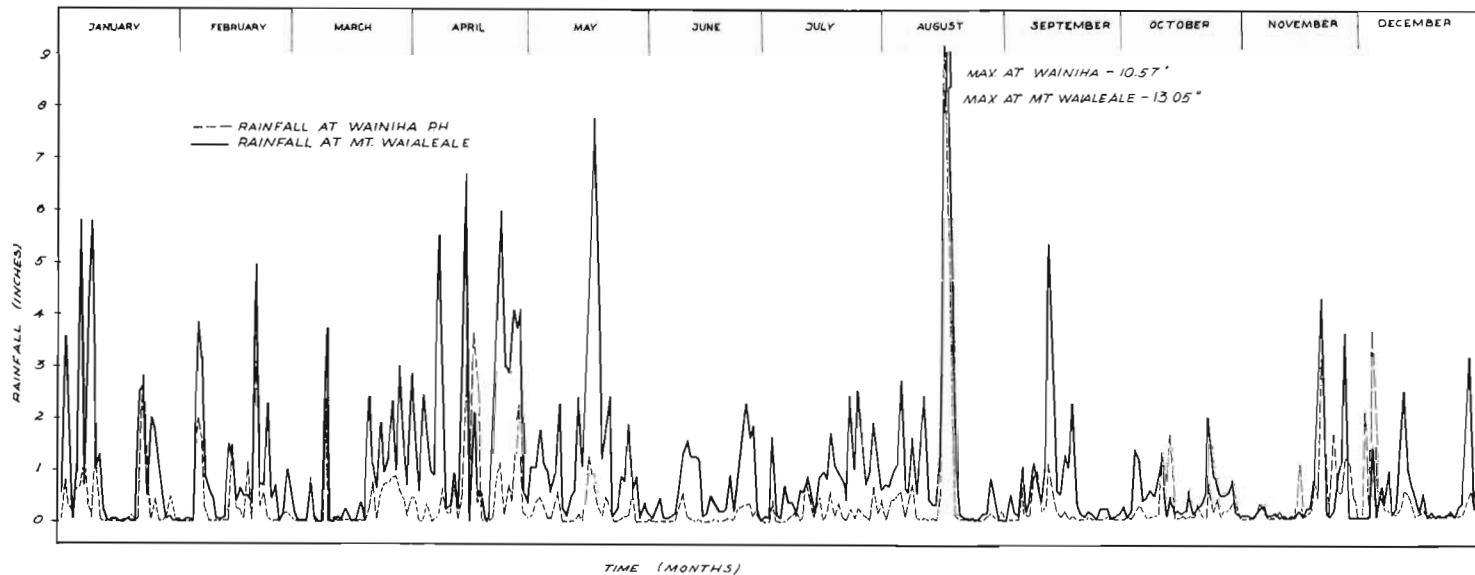


Figure 12. Comparison of rainfall at Wainiha Power House with rainfall at Waialeale during 1950.

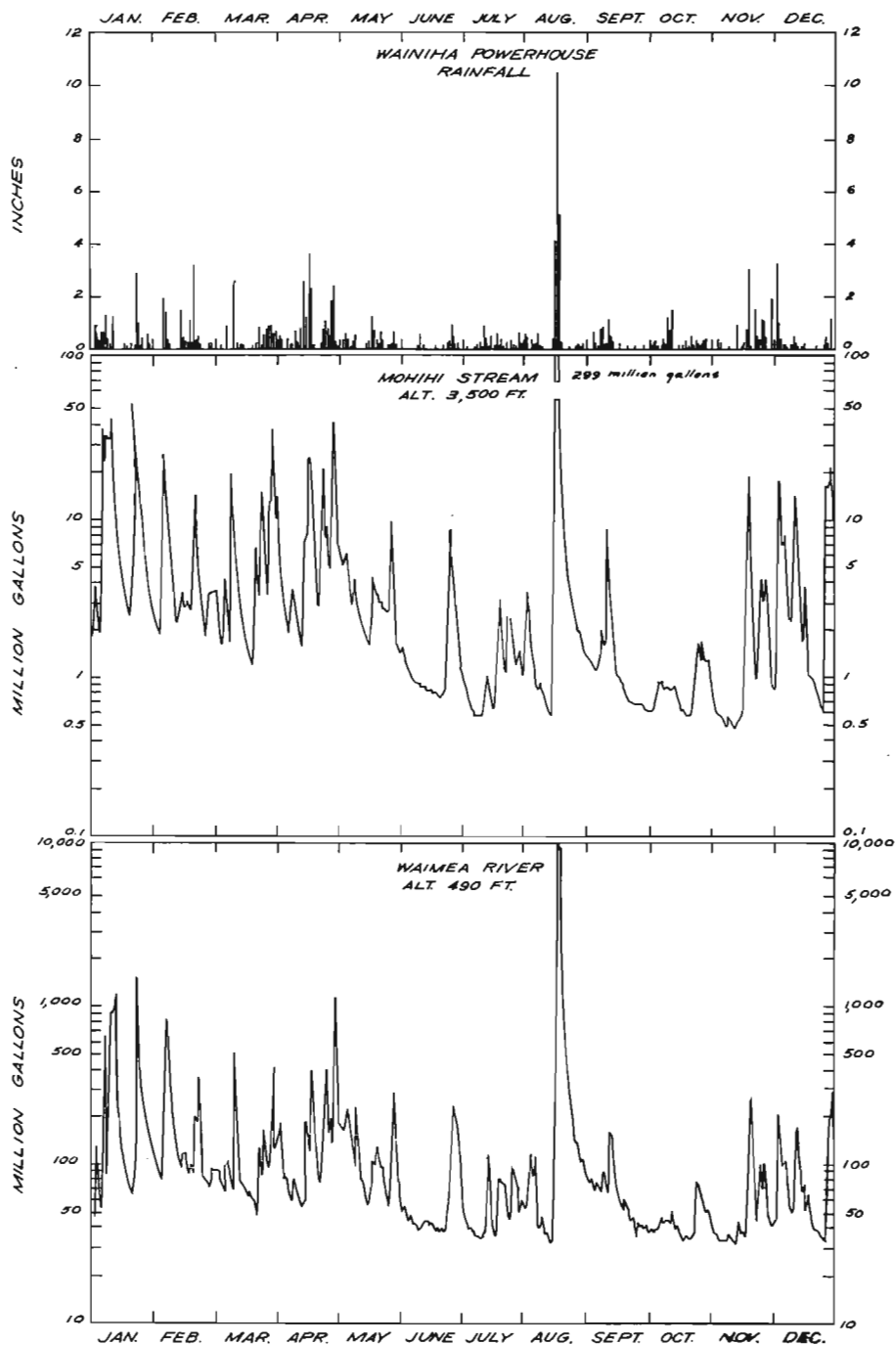


Figure 13. Comparison of daily rainfall at Wainiha Power House with daily discharge of the Mohihi stream and of the Waimea river during 1950 (from R. T. Davis, 1960).

In December more streamflow was measured than would be expected from rainfall at Wainiha Power House. This cannot be explained from the rainfall data in figure 12; it seems that during December more rain fell on the central and northern part of Alakai swamp than at either Waialeale or the Wainiha Power House. Therefore, with minor reservations, streamflow in the Waimea river can be predicted from rainfall data at Wainiha Power House.

The analyses support a conclusion that the Alakai swamp acts primarily as a collecting and overflow basin.

Storage release and river base-flow

From 1949 to 1956 the taking of daily rainfall records at Waialeale was attempted by the U. S. Geological Survey on 1,616 days, but only on 942 days were records obtained. The available data give an opportunity to assess the effect of relatively dry spells on streamflow. The dry spells that occurred are recorded in table 4. Data for the longest dry period show a total discharge of 1,848 acre-feet during the 11 days after rain became negligible (table 5). This was followed by 9 days with a 1,169 acre-feet discharge.

The discharge taken into account consists of two fractions: (1) most of the drainage water of Alakai swamp and (2) drainage water from the drier area west of it (figure 8). During the dry period under consideration, the second fraction is probably small in comparison to the first.

On the basis of extrapolation of lowland data, the assumption is made that from January 23 to February 14 evapotranspiration on the swamp was 0.08 inch per day. (Clear skies tend to prevail during mid-winter dry periods.) This would make the rainfall, as measured at Waialeale, of negligible significance during this period.

TABLE 4. Periods of relatively low rainfall at Waialeale from 1949 to 1956*

PERIOD	TOTAL RAINFALL, INCHES	DURA- TION, DAYS	PERIOD	TOTAL RAINFALL, INCHES	DURA- TION, DAYS
May 18 - 25, 1949	1.40	8	Oct. 29 - Nov. 17, 1950	1.55	20
Jan. 12 - 20, 1950	0.35	9	Jan. 18 - Feb. 13, 1951	2.75	24
Mar. 10 - 19, 1950	0.90	10	Jan. 20 - Feb. 8, 1952	1.60	20
May 29 - June 7, 1950	1.60	10	Jan. 5 - 16, 1954	0.60	12
Aug. 19 - Sept. 3, 1950	2.55	15	Jan. 30 - Feb. 11, 1954	1.10	13
Sept. 18 - Oct. 3, 1950	1.90	16	Sept. 19 - 28, 1956	1.95	10

* This does not represent all periods of low rainfall from 1949 to 1956, as records are available on only 942 out of 1,616 days.

TABLE 5. Comparison of rainfall at Waialeale with streamflow in the Waimea and Makaweli rivers from January 18 to February 14, 1951

DATE	WAIALEALE RAINFALL, INCHES	STREAMFLOW, M.G.D.*				Total Flow of 3 Gages
		Waimea River, below Kekaha Ditch Take-off	Kekaha Ditch	Makaweli River		
Jan. 18	0.05	100	51	72		
19	0.05	46	48	31.5		
20	0	31.5	44	21.5		
21	0.20	21.5	41	18.5		
22	0.65	140.0	36.5	33		
23	0.10	115	13.7	29.5		
24	0	102	0	20		
25	0.05	75	0	16.4		
8 days subtotal	1.10					
26	0	65	0	14.4	79.4	} Total flow: 601.9 m.g.d. = 1,848 acre-feet
27	0.10	45	0	13.4	58.4	
28	0	40	0	12.4	52.4	
29	0.15	37	0	12.4	49.4	
30	0.05	40	0	16.9	56.9	
31	0.05	7.9	26	15.9	49.8	
Feb. 1	0	0.7	54.5	13.4	68.6	
2	0.05	0.5	34.5	12.4	47.4	
3	0.05	0.5	34.5	11.9	46.9	
4	0.05	0.5	34.5	11.4	46.4	
5	0.05	0.4	34.5	11.4	46.3	
11 days subtotal	0.55					
6	0.10	0.4	32	11.0	43.4	} Total flow: 380.7 m.g.d. = 1,169 acre-feet
7	0	0.2	32	10.0	42.2	
8	0.05	0.2	32	9.5	41.7	
9	0.05	0.2	30	9.1	39.3	
10	0	0.2	30	8.8	39.0	
11	0.50	0.9	31	8.1	40.0	
12	0.15	7.7	40	8.6	56.3	
13	0.25	0.1	32	8.6	40.7	
14		0	30	8.1	38.1	
9 days subtotal	1.10					
Total	2.75					3,017 acre-feet

* Million gallons per 24-hour day.

The measured discharge of 3,017 acre-feet over 20 days is in excess of the estimated maximum release-from-surface storage, which has been given as 1,100 acre-feet. While some allowance must be made for drainage from the area west of Alakai swamp, it is yet likely that close to 2,000 acre-feet, or 100 acre-feet per day, were derived from subsurface storage. Such a conclusion is supported by observations, made by Morris (1962), that springs at about 3,000 feet elevation flow unabated during dry spells.

The above analysis and data earlier presented in table 3 and figures 11 and 13 support further a conclusion that there is little deep seepage to the basal water table below the center of the island.

CONCLUSIONS

- 1) The Alakai swamp acts primarily as a collecting and overflow basin.
- 2) The surface-storage capacity probably does not exceed 2,200 acre-feet.
- 3) The release from surface storage during dry spells is probably less than 1,100 acre-feet.
- 4) During prolonged dry spells a continued base-flow of 100 acre-feet per day in the Waimea and Makaweli rivers can probably be counted upon, derived from subsurface storage below the Alakai swamp above 3,000 feet elevation.
- 5) There is little deep seepage to the basal water table below the central portion of Kauai.

SUMMARY

An analysis of aerial photographs in combination with field observations has revealed that the Alakai swamp consists of approximately:

- 59.5 percent dissected land;
- 29 percent flat to moderately sloping land; and
- 11.5 percent treeless area.

Of the treeless area, 8 percent is a "mountain barren" near the summit of Waialeale, and the other 3.5 percent is typical swamp.

Eighty-eight percent of the area is covered by ohia, ranging from open forest on well-drained sites to dense swamp forest.

Subsoil analysis shows low permeability, explaining peat formation on approximately 3,700 acres out of an assumed 20-square-mile extent of the Alakai swamp.

The Alakai swamp is continuously moisture-saturated, the result of approximately 250 inches of rainfall well distributed throughout the year. The swamp acts as a collecting and overflow basin during most of the time. This explains the close relationship between rainfall and streamflow in the area.

The volume of the peat deposit is estimated at 3,700 acre-feet, from which an estimated 1,100 acre-feet of water or less is released during dry spells. This, added to an estimated 100 acre-feet per day release from subsurface storage above 3,000 feet elevation via springs, accounts for a small base-flow in the Waimea and Makaweli rivers during dry spells. These spells normally do not exceed 1 or 2 weeks per year.

There seems to be little seepage to the basal water table below the center of the island.

REFERENCES

1. BAVER, L. D. 1961. SOIL PHYSICS. 3rd ed., 3rd print. John Wiley & Sons, Inc., New York.
2. CAMPBELL, R. B., and L. A. RICHARDS. 1950. SOME MOISTURE AND SALINITY RELATIONSHIPS IN PEAT SOILS. *Agron. J.* 42: 582-585.
3. DACHNOWSKI-STOKES, P. P. 1933. GRADES OF PEAT AND MUCK FOR SOIL IMPROVEMENT. U. S. Dept. Agr. Circ. 290.
4. DAVIS, J. F., and R. E. LUCAS. 1959. ORGANIC SOILS. Michigan State Univ. Spec. Bull. 425.
5. DAVIS, R. T. 1960. MAJOR STREAMS OF KAUAI AND THEIR UTILIZATION. M. S. Thesis. Univ. of Hawaii, Honolulu.
6. EKERN, P. C. 1960. THE IMPORTANCE OF FOG DRIP ON WATER SHED. Report, Pineapple Research Institute of Hawaii, Honolulu. (Mimeo.)
7. FEUSTEL, J. C., and H. G. BYERS. 1930. THE PHYSICAL AND CHEMICAL CHARACTERISTICS OF CERTAIN AMERICAN PEAT PROFILES. U. S. Dept. Agr. Tech. Bull. 214.
8. HAWAII WATER AUTHORITY. 1959. RAINFALL OF THE HAWAIIAN ISLANDS.
9. MACDONALD, G. A., D. A. DAVIS, and D. C. COX. 1960. GEOLOGY AND GROUND-WATER RESOURCES OF THE ISLAND OF KAUAI, HAWAII. Hawaii Div. Hydrog. Bull. 13. 212 pp.
10. MINK, JOHN F. 1960. DISTRIBUTION PATTERN OF RAINFALL IN THE LEEWARD KOOLAU MOUNTAINS, OAHU, HAWAII. *J. Geophys. Res.* 65(9): 2869-2876.
11. MITSCHERLICH, E. A. 1923. BODENKUNDE FÜR LAND- UND FORSTWIRTE. P. Parey, Berlin.
12. MORRIS, F., HYDROLOGIST, U. S. GEOLOGICAL SURVEY, KAUAI. 1962. (Personal communication.)
13. ROCK, JOSEPH F. 1913. THE INDIGENOUS TREES OF THE HAWAIIAN ISLANDS. Honolulu, Hawaii.
14. SELLING, O. H. 1948. STUDIES IN HAWAIIAN POLLEN STATISTICS. PART III. Bernice P. Bishop Museum Spec. Publ. 39.
15. U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU. (Various years.) CLIMATOLOGICAL DATA, HAWAII.
16. U. S. DEPARTMENT OF INTERIOR, BUREAU OF RECLAMATION. 1960. EARTH MANUAL.
17. U. S. DEPARTMENT OF INTERIOR, GEOLOGICAL SURVEY. 1954. SURFACE WATER SUPPLY OF HAWAII, 1949-50. *Geol. Surv. Water-Supply Paper* 1185.
18. ———. 1955. SURFACE WATER SUPPLY OF HAWAII, 1950-51. *Geol. Surv. Water-Supply Paper* 1219.
19. VAN'T WOUTD, B. D., and G. UEHARA. 1961. EROSION BEHAVIOR AND CONTROL ON A STRIPMINED LATOSOLIC SOIL. Hawaii Agr. Exp. Sta. Tech. Bull. 46.

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