SOIL SURVEY

Territory of Hawaii

Islands of Hawaii, Kauai, Lanai, Maui, Molokai, and Oahu

Series 1939, No. 25

Issued September 1955

UNITED STATES DEPARTMENT OF AGRICULTURE
Soil Conservation Service
In cooperation with the
HAWAII AGRICULTURAL EXPERIMENT STATION

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Soil Survey of the

TERRITORY OF HAWAII

Islands of
Hawaii, Kauai, Lanai, Maui, Molokai, and Oahu

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UNITED STATES DEPARTMENT OF AGRICULTURE
In cooperation with the
HAWAII AGRICULTURAL EXPERIMENT STATION

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Summary

THE SOIL SURVEY of Hawaii covered the six major islands of the Territory—Oahu, Hawaii, Kauai, Lanai, Maui, and Molokai—or an aggregate area of about 4,000,000 acres. It was a cooperative effort of the United States Department of Agriculture and the University of Hawaii Agricultural Experiment Station. It was made primarily for agricultural interpretations, although the basic information gathered will serve many kinds of users. Consequently, the soils were mapped in varying degrees of detail among areas of different agricultural potential. The range was from detailed foot traverses, on which soil boundaries were seen throughout their length, to compilations involving few field observations. The intensity of the survey of each area is indicated on the Reliability of Data map that accompanies this report.

The report incorporates the efforts of scientists who are authorities on Hawaii, its material and cultural setting, its agriculture, and its soils. Although the soil mapping was completed in 1939, World War II prevented publication, and these scientists wrote the report in 1947–48. Unless otherwise specified, statements in the report refer to conditions at that time.

THE NATURAL AND CULTURAL SETTING

The Hawaiian Islands are the tops of great volcanic mountains built up from the ocean floor, the highest rising more than 13,000 feet above sea level. Moisture-laden northeast trade winds rise against the mountain masses and drop their moisture in an orographic pattern. The northeastern sides of the mountains receive high rainfall; the southeastern sides are dry. The mean annual rainfall ranges from almost none to more than 400 inches. Temperatures decrease with increasing elevation. Distinct vegetation zones of highly contrasting kinds are related to the climatic zones that result from systematic variation of rainfall and temperature. Agriculture is related to these climatic zones, to the soil and topographic conditions in these zones, and to the economic framework of land as property peculiar to the Islands. These factors of the natural and cultural setting are described in considerable detail.

The principal Island exports are sugar and fresh and processed pineapple. Though the Hawaiian economy is based on agriculture, nearly two-thirds of the food consumed and much of the livestock feed are imported. The economy of the Islands is closely keyed to the continental United States. Invisible exports, such as services rendered and goods sold to the Federal Government, tourists, and shipping and air lines have brought about a balance of payments favorable to the Islands. This balance is partly dependent on military expenditures, however, and the need for developing more exports and producing more food on the Islands is recognized.

SOILS AND THEIR ENVIRONMENT

Shown on the detailed soil map accompanying this report are 400 mapping units, each of which has some characteristic or combination of characteristics of practical significance to agriculture, engineering, or other pursuits that made separate delineation necessary. To point out the relationships among these units and the interaction of soil-forming factors that have created them, the units have been classified into successively broader groups—series, families, great soil groups, suborders, and orders—according to the system of classification used by the United States Department of Agriculture. Many of the great soil group names used, however, were introduced specifically for this area because recognized groups would not properly accommodate the soils involved. The generalized soil map, showing great soil groups and member families, will aid the reader in understanding broad land use patterns on the Islands and the way soils change with change in environment.

The Hawaiian Islands are volcanic, and the parent materials of the soils are dominantly from basic igneous rocks—basalts or andesites, or their pyroclastic equivalents. Only small areas of trachyte and coral occur. Parent material, one important factor of soil formation, is therefore relatively uniform. Relief generally is sloping to steep, so drainage is good throughout most of the Islands. Age varies because there have been successive flows of lava and eruptions of ash and cinders, and because some of the material so discharged weathers more rapidly than others. Nevertheless, climate and vegetation—the active factors in soil formation—account for the major differences among broad groups of soil in Hawaii. The influence of climate on the zonal (or normal) soils of the Islands is strikingly apparent. The zonal soils occur in definite belts that correspond closely with climate and vegetation zones.

The variation in climate and vegetation are very great. The average annual rainfall ranges from less than 10 to more than 400 inches. The average annual temperature ranges from 78° F. at sea level in dry regions to less than 60° on the highest mountains. Elevations range from sea level to almost 14,000 feet. The vegetation ranges from dense tropical forest to semidesert types, and from warm-temperate grasslands to temperate deserts.

Zonal soils.—This soil order is represented on the Islands by seven great soil groups: Low Humic Latosols, Humic Latosols, Hydrol Humic Latosols, Humic Ferruginous Latosols, Red Desert soils, Reddish Brown soils, Reddish Prairie soils, and Latosolic Brown Forest soils. The first four named are definitely lateritic zonal groups of soils. All these soils are characterized by clays that are low in plasticity and stickiness and by a profile consisting of an A_1 horizon underlain by a B horizon that is transitional to the parent materials. The first three of these lateritic groups occur at successively higher elevations on the mountains in belts that conform with the low, medium, and high rainfall belts. The fourth lateritic group, Humic Ferruginous Latosols, occurs in regions occupied by both the Low Humic and Humic Latosol groups and apparently represents extreme eluviation under the environment of those climatic zones. Humic Ferruginous Latosols occur principally on the older parent materials.

The Red Desert, Reddish Brown, and Reddish Prairie great soil groups occur on the younger volcanic ash on the leeward, or southwestern, sides of the Islands. They occur in belts at successively higher elevations, the Red Desert group at the lowest. Although these three groups have many properties in common with great soil groups in the southern part of the continental United States, they also have striking differences, and the names are used as expedients in absence of recognized groups that would be more appropriate.

Intrazonal soils.—In this order are soils of the Latosolic Brown Forest, Gray Hydromorphic, Paddy, Bog, Dark Magnesium Clays, Solonchak, and Solonetz great soil groups. The Latosolic Brown Forest group consists of young soils with dark-colored A_1 horizons relatively high in bases and organic matter that grade through lighter colored B horizons to young volcanic ash high in bases. This group of young soils is on rapidly weathering material high in bases that occurs in regions where the normal soils are acid.

The Gray Hydromorphic group of soils occurs on the coastal plains or alluvial lowlands, as do the man-made Paddy soils. The true Bog soils are on the highest mountains where rainfall is extremely heavy, and on the lowlands where the water table is high. The Dark Magnesium Clays occur on lowland influenced by seepage waters from the basic lavas and have some properties in common with the Regur soils of India. Near sea level are small areas of Solonchak, and one small area of Solonetz.

Azonal soils.—This order is represented by soils of the Alluvial, Regosol, and Lithosol great soil groups. The Alluvial soils are in the valleys; the Regosols on beaches and the high mountains; and the Lithosols on the rough, broken, stony uplands that occupy a very large part of the Islands.

AGRICULTURE AND THE SOILS

The important crops of Hawaii have patterns of distribution related to the distribution of the great soil groups.

Sugarcane has first priority on Low Humic Latosols where irrigation water is available; otherwise pineapple has first choice. These soils are low in total nitrogen and generally fix phosphorus in unavailable forms very quickly, but are relatively well supplied with bases, including potassium. They are very responsive to good management.

On the Humic Latosols, sugarcane, pineapple, and grazing compete for land. Humic Latosols are higher in total nitrogen than the Low Humic Latosols but fix large amounts of phosphorus in forms not available to plants and are generally deficient in potassium.

In the climatic zone occupied by Hydrol Humic Latosols, cane production and forestry meet. These areas are mostly too wet, cloudy, and cool for efficient growing of cane. The soils have very large amounts of organic matter but require nitrogen fertilizer under intensive cropping.

The Humic Ferruginous Latosols, which are found in the wettest part of the region occupied by Low Humic Latosols and in all the area occupied by Humic Latosols, are used in much the same way as the groups with which they occur. Generally, however, they are

more nearly marginal as cropland. Humic Ferruginous Latosols are very low in bases in their uppermost horizons and have low exchange capacities. They are moderately supplied with organic matter and nitrogen, but require nitrogen fertilizer if cropped.

Grazing dominates on the Red Desert and Reddish Brown soils. On the Reddish Prairie soils, grazing dominates but vegetable growing competes for use of the land. The soils of these three great groups are the most fertile on the Islands. They are high in bases, including potassium, and, except for the Red Desert soils, are relatively well supplied with total nitrogen. They normally do not fix phosphorus to so great a degree as soils of the Latosols suborder.

The Latosolic Brown Forest soil group is used almost entirely for grazing. The best grazing land on the Islands is on soils of this group and on the Reddish Prairie soils. Latosolic Brown Forest soils are very high in total nitrogen but somewhat more depleted of bases than Reddish Prairie soils.

The Gray Hydromorphic soils are used mainly for sugarcane if irrigation water is available. Otherwise they are used for pasture. In spite of their poor physical properties, the Dark Magnesium Clays are used in the same way as the Gray Hydromorphic soils. Supplies of magnesium are generally high in both groups, but exceptionally high in the Dark Magnesium Clays. The high concentration of magnesium is commonly associated with potash deficiency. In most places soils of both these groups need nitrogen, phosphorus, and potassium.

Paddy soils are still used to a limited extent for wet-land culture or rice and taro. Use of the Alluvial soils is conditioned largely by availability of water. The plant nutrient requirements of the Alluvial soils vary from place to place, but they are generally more fertile than the zonal soils with which they are associated.

Regosols, in the main, are poor grazing land. The Lithosols are grazed or in forest. The steep, stony, and shallow soils that occur in cropped areas are either used for grazing or are left idle.

Prospects for future land use.—Increased costs of production have led to mechanization of the cane and pineapple industries and to abandonment of some land not suitable for machine cultivation. Some of this abandoned land has been converted to pasture or other crops. Some soils not cropped at present, principally Low Humic Latosols, could be brought into cane production if irrigation water were available. The water supplies of the Islands have been rather thoroughly explored, however, and prospects of developing new sources of water for cane are limited. It is possible that the pineapple acreage might be expanded on the Low Humic Latosols.

Areas of soil suitable for vegetable production are far in excess of the acreage needed to meet Island consumption. With irrigation, very large acreages of Low Humic Latosols could be used for a number of different vegetable crops. Various kinds of vegetables, fruits, and nuts could be produced on the Humic Latosols and Hydrol Humic Latosols. The regions occupied by Reddish Prairie soils are exceptionally well suited to vegetables, and, in themselves, could produce vegetable crops far in excess of what could be used on the Islands. The acreage in fruits and nuts could be greatly expanded. Macadamia

nuts is a particularly promising crop for Humic Latosol and Hydrol Humic Latosol soils on which production of sugarcane is marginal.

GEOGRAPHY AND CHARACTERISTICS OF SOILS

The last part of the report, with the accompanying soil maps, contains the basic data of the soil survey of Hawaii. The material is organized around the soil family. The general environment and soil characteristics of a family are described. Next, the mapping units of this family are regrouped to show suitability for mechanized agriculture, and use and management are described for these groups. Then each mapping unit of the family is described in relation to the profile of the parent soil series, and use and management peculiar to the unit are discussed.

Part I

The Natural and Cultural Setting of Hawaiian Soils

MAN'S USE OF the soil is conditioned by the natural and cultural environment in which the soil occurs. The authors of this part present some of the important features of the Hawaiian setting as a background for applying knowledge about the soils.

The authors first broadly outline the Hawaiian geographic setting and the sequence of geologic events that produced the Islands as we see them today. Next, they present the climatic environment and its relation to the geographic setting. With this perspective, they provide rather detailed information on water supply, which so greatly affects use of Hawaiian soils. Next, discussed is the distribution of vegetation in relation to climate and elevation.

The authors then turn to man's activities within this setting. First they explain the ways in which Hawaiian land is used and describe in some detail the operation of major agricultural enterprises. Finally they tell about the people themselves—where they live, what they do, and how they meet physical and cultural needs of everyday living.

***THIS SECTION** describes the physical environment in which the soils of Hawaii occur. Special attention is given to water supplies on the Islands for man's use of the soils. The soil itself is a function of the elements of the physical environment. Man's use of the soil is conditioned by the factors involved.*

NATURAL ELEMENTS OF THE LANDSCAPE

By CHESTER K. WENTWORTH, Former Principal Geologist, Honolulu Board of Water Supply

PHYSICAL GEOGRAPHY AND GEOLOGY

THE EIGHT inhabited islands forming the Territory of Hawaii lie at the southeastern end of a chain of islands and shoals more than 1,600 miles long. These islands are the summit parts of a range of volcanic mountains. This range has been built above an ocean floor 15,000 to 18,000 feet in depth through the outpourings of basaltic lava flows at various points along the line of a crustal rift having a northwest to southeast trend. No evidence yet discovered indicates that any of the islands were formed earlier than the late Tertiary, so they are possibly 5 million years old.

The islands are of the sort known as high islands of the central Pacific area. The main mass of each is wholly volcanic and consists of basalt derived from the subcrustal magmatic material normal to the Pacific basin. The fissure giving rise to their linear arrangement is not clearly related to lateral thrusting. In structural origin, this line of islands is therefore quite dissimilar to the various lines of islands from the Marianas westward and around other Pacific margins. One important result of this dissimilarity in origin is that the crustal floor in the Hawaiian area is a highly stable unit; no tilting or other general crustal deformation has been demonstrated. The shifting of shorelines in the area is best explained by changes in the level of the sea, which result chiefly because of increase or decrease of glaciers over the world.

The building of the islands began at the northwest, and, in general, volcanic activity moved from northwest to southeast. The larger islands have been formed by eruption from more than one vent. The largest island, Hawaii, has been formed by the successive growth and merging of five different volcanoes, two of which reach nearly 14,000 feet above the sea. Northwest of the eight inhabited islands are a number of islands showing either basaltic remnants or coral reefs and shoals. These remnants or the coral indicate that the volcanic masses probably had ceased growth and been partly cut away at sea level before the main history of the eight islands began. In consequence, the eight islands still stand as high islands; whereas the older ones to the northwest have been worn down.

The geologic history and characteristics of the Hawaiian Islands have been summarized by Stearns (*16*). Various contributions on the petrography have been presented by MacDonald (*7, 8*). Recently, Zimmerman (*33*) compiled a summary of the geological history of Hawaii as a prelude to his work on insect fauna. It has been shown

that there is some variety of rock composition and diversity of structure in various islands. On some islands, for example, Maui and Molokai, an older dome of primitive basalt is overlain by a cap of andesitic lavas; on others there are small amounts of late, ultrabasic lavas such as the Honolulu series of southeastern Oahu (*32*). In explaining topography and soil formation, however, these minor petrographic differences should be considered against a background of surprising uniformity. The volcanic rocks of which the islands are composed are very largely in the general range of olivine basalt, with silica about 50 percent. Moreover, with very minor exceptions, the volcanic mass above, and presumably below, sea level consists of thin basic lava flows. Each flow came from vents at the crater or on the various rift lines at lower elevations and poured down the irregular surface formed by earlier similar flows. The existing soils should be considered in relation to this general lava, the surface and structural features of the flows, and the extreme variety of microclimates at various elevations.

Each of the chief islands was originally built as one or more lava domes.[1] Slopes were determined by the fluidity of the lava flows and the radius and area at sea level consistent with the elevation of the summit vent. Some of the domes are nearly circular (West Maui) and show the dominance of a central vent; others have been built by flows coming from vents along subequal fissure lines (Koolau dome, Oahu). The outlines of domes and the islands portray much of the successive activity of the various vents.

Subaerial erosion of the domes started as soon as they got above sea level and took on the patterns of orographic rainfall as they grew higher. The most active attack was on the windward slopes of islands that had grown to heights of 3,000 to 6,000 feet. Some of the domes may have undergone considerable erosion before the building by a given volcanic series stopped, but there is little evidence to support this conclusion. It is difficult to find an eroded terrain that has been overlapped by lavas of the same character as those of the eroded terrain. There are marked erosional unconformities at the bases of late volcanic formations or at places where lavas from one dome overlap those from another.

On some domes erosion is now most active on the leeward slope because the maximum rainfall is leeward of the crest. On most such domes, however, the windward slope has been greatly dissected by subaerial and marine erosion and has suffered the most active initial erosion.

The domes owe their form to successive lava flows down existing slopes. The drainage net on the slopes of these domes is made up of stream channels following the courses of the lava flows. Practically all of the drainage in Hawaii follows the original radial pattern of the lava flows. There is only limited integration into dendritic arrangements. The mesh of the drainage pattern of Hawaii varies widely. It is conditioned largely by the intensity of local rainfall and the character of the local rock and soil. Large areas on some slopes show few fixed drainage lines because dryness resulting from low rainfall is

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[1] Although many volcanologists prefer the term "shield," the word "dome" seems more suitable for general, popular use to denote the rounded shapes of the major volcanic accumulations.

enhanced by the high porosity of both the little-weathered surfaces of lava and the subordinate cinder and ash deposits. In wetter areas the formation of soil accompanies the development of more systematic drainage patterns. In some wetter places (Hamakua coast), ashes and cinders deposited as a parent rock have given rise to a remarkable close-spaced system of subequal channels that are only slightly integrated as they pass down the slope. In some sections, there are two elements in the drainage system: (1) Major streams that have cut deep enough into the main rock structure to be perennial, and (2) smaller channels that are developing on interfluvial facets in soil or ash and are related only to surficial ground water. The wide mesh of the major pattern cut into the permeable rock structure leaves room for the subordinate drainage pattern on the facets (*24*).

Only a few small areas subject to special conditions have a stage of erosion that can be called late in maturity. Parts of all the major and higher domes except the younger ones on the island of Hawaii are deeply dissected to a mature or early mature topography of extraordinary declivity. Lower islands of equal age or islands partly in the lee of others (Lanai, Kahoolawe, west Molokai, and so on) are less dissected. These lower and protected islands, with large areas on Maui and Hawaii, make up a large part of the area in the Hawaiian Islands where the form of the volcanic construction has been but little modified.

Marine erosion has cut away exposed parts of all the islands and produced some striking coastal cliffs. Some of these cliffs rise directly from the water's edge to heights of 1,000 feet or more. Coastal escarpments as high as 3,000 to 4,000 feet are found on the islands of Molokai and Kauai. To some extent these cliffs may have been caused by faulting, but discussion of that subject is not appropriate here. Along the cliffed coasts the major valleys are shortened, and their canyon forms are aggravated. Nevertheless, the same transverse profiles occur in all the larger valleys of Hawaii, whether or not they embouche on a cliffed coast. Despite the impressive forms it produces, marine erosion plays a rather subordinate part in the removal of volume from masses of this size.

As previously mentioned, the Hawaiian Islands owe their shape primarily to volcanic building. Parts of islands have been more or less modified by erosion under strongly localized climatic conditions. Davis' formula of structure-process stage is admirably applicable here and has led to the outlining of some 83 physiographic provinces (*25*). No extended description of these provinces has yet been compiled; their major character will be evident on scrutiny of the topographic maps of the Islands. Many of the lines are inescapable natural boundaries reproduced on the soil maps and on other maps (*25*).

CLIMATE

The three dominant factors in the climate of Hawaii are (a) the position of the several islands in north latitude from 19° to 22°, (b) the insular position within the largest ocean of the world, and (c) the elevation and topography of the several islands. Because the third factor—elevation and topography—is minutely varied, we may say that the microclimates of Hawaii are largely induced on an oceanic

base by the orographic effects of the local physiographic features. We must recognize that these microclimates, each with its own amounts and distribution of rainfall, cloudiness, and temperature and moisture resulting from the effects of slope and elevation, not only are of great contemporary importance but also are among the primary factors of soil development.

Because of great local variations, climatic averages convey only part of the picture. No brief, systematic text on the climates of Hawaii exists; when a full-length text is written it will be a very large book. In 1949 Leopold and Stidd (*6*) offered a review of the literature on Hawaiian climatology; their review briefly surveys the state of published work up to that date. In this section we can only offer some averages and extremes and suggest the types and directions of some of the many deviations.

Temperature.—The general range of temperature is shown in table 1.

TABLE 1.—*Temperatures at representative stations in Hawaii*

Station	Elevation	Mean annual	Lowest monthly mean	Highest monthly mean	Lowest monthly mean minimum	Highest monthly mean maximum	Extreme minimum	Extreme maximum
	Feet	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*
Hilo (Hawaii)	40	72. 8	70. 4	75. 4	62. 6	82. 6	51	91
Mahukona (Hawaii)	11	77. 6	74. 2	80. 6	65. 5	89. 4	52	98
Honolulu (Oahu)	12	74. 6	71. 5	78. 3	64. 0	84, 5	56	88
Waianae (Oahu)	10	75. 9	71. 7	80. 0	63. 7	89. 4	50	96
Kahuku (Oahu)	25	74. 6	71. 0	78. 2	64. 0	84. 5	49	95
Kealia (Kauai)	11	74. 9	70. 9	78. 7	63. 0	85. 7	44	93
Mana (Kauai)	11	73. 9	69. 8	77. 9	61. 0	88. 5	48	95
Waimea (Hawaii)	2, 669	63. 9	62. 1	66. 8	53. 5	75. 3	([1])	87
Volcano observatory (Hawaii)	3, 971	60. 3	58. 0	63. 8	50. 5	71. 1	38	84
Kula (Maui)	3, 004	64. 0	60. 5	67. 0	52. 0	76. 8	41	89

[1] Weather Bureau office considers the extreme minimum temperatures at this station to be questionable.

As shown in table 1, the mean annual temperatures at sea level in Hawaii range from about 72° to 78° F. The range depends rather more on exposure to ocean breeze than to latitude. The range between the means for the coldest and warmest months at any station is from 5° to 8°. The widest ranges between coldest and warmest months occur on the northernmost islands. Mean temperatures decrease at the rate of about 2.5° to 3° F. per 1,000 feet increase in elevation. At some stations daily temperature ranges are little if any greater than 10°; at others the range may reach 25°.

Maximum temperatures at sea level go above 95° at only a few places; minimum temperatures go below 50° only on the northern islands. Ranges between extremes may be as great as 50° at some stations and as little as 30° at others. The leeward stations ordinarily have the greater ranges in temperature.

No systematic records of temperature have been kept for elevations above 7,000 feet, but it is known that night temperatures at Lake Waiau on Mauna Kea, Hawaii (elev. 13,007 feet) fall below 32° practically

every night in the year. No exception is known. Temperatures of 19° have been recorded in July and August. It is probable that 15° is common in winter at Lake Waiau, but temperatures as low as 10° are very likely uncommon.

According to measurements made in the Honolulu region, temperatures of soil and shallow ground waters follow closely the mean air temperatures at comparable elevations. Temperatures of basal ground water, at sea level, and 100 feet or more below the surface, approximate 70°. Differences caused by geographic location may change this approximate temperature by about 1°. For the first thousand feet below sea level in water-saturated rock, the increase of temperature with depth is probably about 1° for every 300 feet. This very low geothermal rate probably results because of the large amount and the active circulation of both meteoric and ocean water. In the Honolulu area the annual temperature range at 600 feet below sea level is of the order of 0.04° F.

Warm or hot ground waters do occur in the Hawaiian Islands, but in general, ground water bodies do not exist or are not accessible near active volcanic areas.

Wind.—The prevailing winds at nearly all the stations are the northeasterly trades. At Honolulu, where the most complete record has been kept, the wind has come from easterly and northeasterly sectors about 82 percent of the time. During the period 1908–37, the central direction for these preponderant winds shifted systematically from about N. 52° E. to N. 87° E., and by 1945 it had shifted back as far as N. 62° E. (*30*) (fig. 1). The cause of this cyclical shift is not

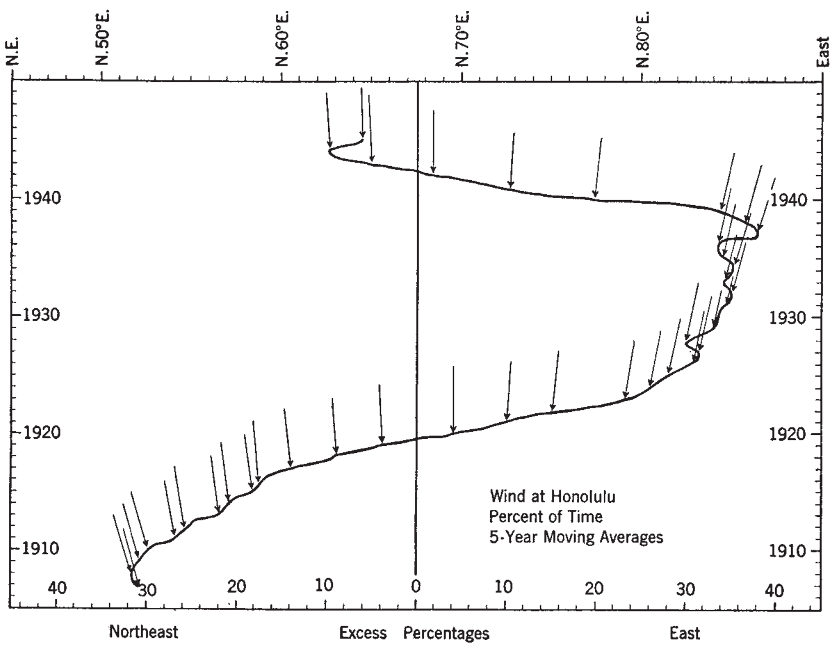

FIGURE 1.—Change in direction of prevailing wind at Honolulu from 1907 to 1945.

known, nor is the effect it has on rainfall. We cannot doubt that the amount and pattern of rainfall has been modified at some stations, particularly those dominated by orographic rainfall.

The islands lie near the northern limit of the tropics, near the permanent high-pressure belt. It is therefore possible at all seasons, and more commonly in winter, to have winds from a direction opposite to the trades or from various directions. These spells of varied winds are known as *kona* storms. In the Hawaiian language *kona* means southern, but more particularly leeward. In any one district the special characteristic of the kona storms is the cessation of the trade winds and the coming of varied winds related to pressure patterns that overlap from the permanent high-pressure belt to the north.

Records on wind directions at high elevations are not adequate, but rainfall records and many observations show that the strength of the trade winds is reduced above 5,000 or 6,000 feet. Cumulative records of wind directions at higher altitudes show that the preponderance of northeasterly winds is relatively low at 10,000 feet. The boundary between the trade winds and the westerlies fluctuates continually in elevation. Above 10,000 feet, the westerly winds prevail for days or weeks.

Island masses up to 6,000 or 7,000 feet high appear to be overtopped and generally bathed in trade-wind air movement. In contrast, high masses such as Haleakala, Mauna Kea, and Mauna Loa are barriers that the trade winds do not drive over. On the trade-wind sides of these masses the average maximum rainfall is much lower than on the summits of such islands as Kauai. The trade winds tend to split, or go around, the larger mountains. They converge again, particularly on slopes between such masses as Mauna Kea and Mauna Loa, and at the place of convergence the rainfall frequently is greater than on the windward side of the mountains.

Also, on the lee slopes of Haleakala, Mauna Kea, and Mauna Loa there is a daily, strongly marked, sea-to-land breeze. The persistence and importance of this breeze is indicated by the rainfall maximum belt, which is shown best on the leeward, or kona, slope of Mauna Loa. There is usually a marked reversal of the sea-to-land breeze at night. On these coasts protected by high land masses the trade winds are weak or nonexistent during much of the year. The high summits such as Mauna Loa are foci against which trade winds, sea-to-land breezes, and less frequently, the westerlies move. Accounts of the daily patterns of cloud growth around these mountains have been given (*12*), but more systematic recording and further study are needed before even a general description of the microweather for any given high-level site can be written.

Rainfall.—Because of the effect of land masses, it is difficult to estimate annual rainfall on the open ocean in the latitude of Hawaii. It is thought to be about 29 inches. Much of the leeward coast of Oahu in the Honolulu section receives 20 to 22 inches. Parts of the lower islands and such leeward sections as the Waianae coast of Oahu get materially less. The Waianae coast probably gets less because of the rain-shadow effect of the Waianae Range (fig. 2).

The precipitation at any given station in Hawaii is made up of three components—orographic, cyclonic, and convectional rainfall.

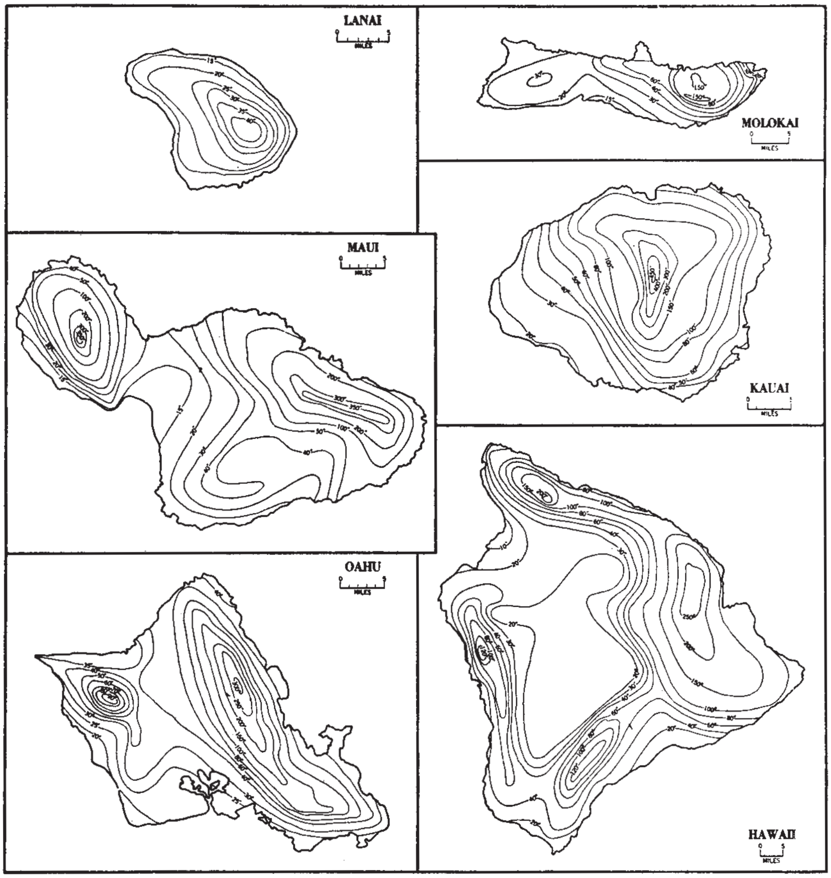

FIGURE 2.—Isohyetal maps for larger islands in Territory of Hawaii. (Redrawn from maps in U. S. Weather Bureau office, Honolulu.)

OROGRAPHIC RAINFALL.—This kind of rainfall is induced through movement of trade winds or other winds against the mountains. The mountains deflect the air upward; it cools as it rises, and the cooling leads to condensation of moisture and rainfall. Persistent clouds hanging over or enveloping the peaks and range summits are a part of the permanent landscape of Hawaii. The height, size, and position of the cloud formations are clearly related to the strength of the trade winds and general temperature conditions. In any given windward-leeward profile through such a peak or range, the clouds seem more or less anchored to the summit. Nevertheless, depending on wind and temperature conditions, the cloud zone may be extended and lowered on the windward side, the leeward side, or both.

If the mountain range is not too high, the maximum rainfall may be several thousand feet to leeward of the summit, as on the Koolau Range. This results because the effect tends to drift beyond the cause. Higher summits may block this drift, and maximum rainfall may remain at the summit or on the windward side. The extraordinary

annual rainfall of about 450 inches at the summit station of Kauai (Waialeale) has been explained as the result of winds blowing up radial valleys and converging at the summit. If the summit were elongated rather than pointed, rainfall would be less. The high rainfall at the summit of West Maui (Puu Kukui) may also be caused by convergence of winds from radial valleys.

It is evident that a great variety of rainfall mechanisms can be considered as orographic, and that orographic rainfall accounts for practically all the precipitation at some stations. Among these orographic mechanisms are (1) direct uplift against a transverse barrier of moderate height, (2) valley-funneling of winds to a pointed summit such as that on Kauai, and (3) convergence of trade winds after splitting around high masses that rise above them.

Orographic rainfall is dominant most of the time for most stations in Hawaii. The total rainfall at any one station is therefore roughly determined by its position in a profile drawn from the windward to the leeward coast along the trade-wind azimuth. Once the position and shape of the maximum rainfall zone is known for a given island mass or major dome, the pattern for the rest of the profile can be inferred. There is a fairly uniform decrease in rainfall outward from the zone of maximum precipitation to the coast. (See fig. 2.) The cloud zone continually expands and contracts from a mean position near the maximum rainfall zone but it tends to huddle against the summits.

Cyclonic Rainfall.—The rainfall caused by cyclonic conditions has an entirely different distribution than that caused by orographic. During a cyclonic spell, a lowland or leeward station having one-fifth to one-tenth the annual rainfall of a mountain station in the same sector may receive as much or more rain than the mountain station. The amounts of rainfall received at various stations during a cyclonic period are commonly unequal in an irregular fashion quite inconsistent with the systematic pattern of orographic rainfall. These periods of kona, or cyclonic, rainfall come haphazardly in any part of the year; they cause variability in total rainfall out of proportion to the total precipitation they contribute. The leeward stations get less orographic rainfall and are more influenced by cyclonic rainfall. They therefore have much greater overall variability in precipitation (*9*, *26*).

Convectional Rainfall.—This form of rainfall is common in various lowland areas where heating of the land gives rise to convection and cloud formation. It is in such areas, and in relation to such a rainfall pattern, that experiments have been conducted on artificial production of rain by the dry-ice method.

Rainfall prediction.—Frequency distribution curves for total rainfall for periods of any specified length, months or years for example, show a marked skewness. This skewness may simulate a logarithmic-probability distribution, but no method yet formulated indicates that the skewness of the rainfall curve conforms to the logarithmic scale. In statistical theory, this effect would probably be explained as the result of the Poisson condition, which is also known as the law of small numbers (*13*).

Frequency distribution for monthly or annual rainfall is more skewed for dry and leeward stations, and there is also larger variation (*9*). If a frequency distribution curve for annual rainfall is plotted for wet

sites in any given years, the probable variation from the mean may be as low as 12 percent. In contrast, some dry stations may show a probable variation as high as 40 percent.

Because of skewness and difference of variation, Halstead and Leopold (*3*) have commenced compilation of monthly median maps. Isohyetal lines on these maps show the median rainfall for each calendar month. The median rainfall is materially less than the mean rainfall in parts of the islands having low to moderate rainfall, and particularly in all the marginal agricultural areas. For agricultural planning in such areas, the median is clearly a better index than the arithmetic mean. It is the amount which may or may not be exceeded in a given month. The mean is affected by exceptionally wet years and is therefore not so useful in defining the normal prospect (*22*).

Where the interest is in the contribution of rainfall to supplies accumulated in the ground or in large reservoirs, the median is less useful than the arithmetic mean. The arithmetic mean has the advantage that it can be directly converted into a total water quantity. Moreover, an arithmetic mean, even for a short period, has an immediate factual value. A longer time is required to determine a median of sufficient reliability for making inferences. A probability chart using arithmetic means is shown in figure 3.

Rainfall cycles and the possibility of prediction on that basis are now receiving much attention (*28*). It is simple to find some evidence of successive higher and lower values in examining past records of monthly or annual rainfall. One is conscious of a somewhat systematic behavior in following a moving average of rainfall for months and years, and this invites an attempt at prediction. Nevertheless, systematic analysis has so far failed to develop a method by which rainfall can be reliably predicted for future years. Possibly some highly specialized studies now in progress will lead to prediction of rainfall a month in advance. However fascinating the study of rainfall figures may be, it must be emphasized that individuals having data from only a few gages cannot hope to make predictions of high or low rainfall that will justify serious business consideration in agriculture or other enterprises.

WATER SUPPLY

Large acreages of arable soils in Hawaii do not regularly receive enough rain to support a profitable plant cover. Other large acreages have high rainfall but are so steep and inaccessible they cannot be cropped. Yet other acreages have soil, surface configuration, and rainfall favorable to productive agriculture. The arable dry soils, the wet steep soils, and the arable soils with sufficient rainfall occur as small units, as the soil map well shows. The land pattern of Hawaii is close-meshed. Rainfall or arability range from favorable to unfavorable, often in reciprocal fashion, in short distances. The water and rainfall economy is extraordinarily complex (*2*).

The economic and engineering problem of developing and distributing water supplies so as to permit profitable use of the soils over a period of years is not a subject for discussion here. It should be mentioned, however, that the haul of water from a high rainfall site to the point of most profitable application is usually short—not more

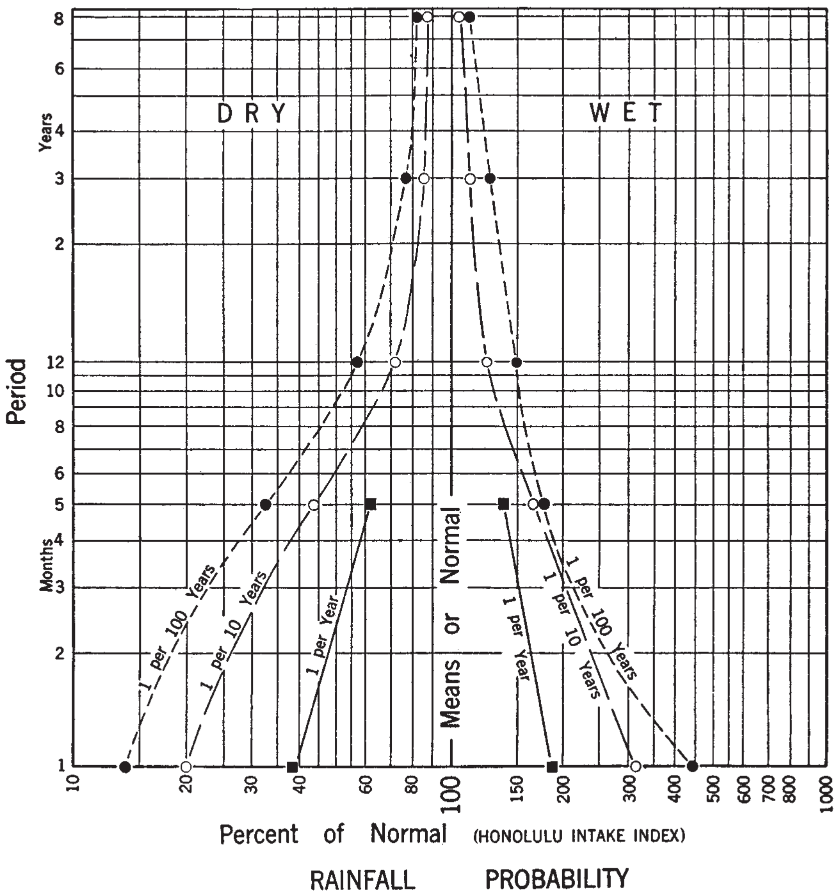

FIGURE 3.—Duration-deviation probability chart for Honolulu intake area. Graph is based on data from 10 stations representing a district of about 50 square miles. Individual gages in Hawaii might show somewhat greater deviations, particularly for short periods, but the type would be similar. (Twelfth biennial report, Board of Water Supply, 1949).

than 4 or 5 miles, and rarely more than 10. In many instances the water would go farther to drier areas if it were not taken up in areas nearer the source that need supplementary water and produce enough to pay for it.

As shown in table 2, the estimated total rainfall for the eight islands of Hawaii is about 20,000 million gallons a day. This rainfall is disposed of in four main ways: (1) Evaporation from the surface of land and plants; (2) transpiration from plants through their life processes; (3) runoff over the land, into streams, and thence into the sea; and (4) infiltration into the ground and downward by various routes until it eventually merges with sea water in the rocks or in the open ocean.

The percentage of rainfall disposed of in each of these four ways depends on the nature of the rock, steepness of slope, character of the vegetation, and the time and pattern of rainfall. The percentage of

infiltration is usually rather high, for the rocks of Hawaii are generally highly permeable, and the main water table is very low. Local variations are enormous, however, and there is some interchange. Infiltrated water, for example, may reappear as seeps and springs that empty into stream channels. Some runoff may later pass underground. Really valid inventories of water disposal are nearly impossible to make (*27*).

Of the four main categories of disposal, surface water and ground water are the sources of supply for man. Neither evaporated nor transpired water can be called sources. It is realized, however, that evaporated water is of utmost importance in maintaining atmospheric humidity, and that transpired water makes the same contribution after already having been used by plants.

TABLE 2.—*Estimated rainfall in Hawaii* [1]

Island	Area	Rainfall			
		Average	Total	Million gallons per day	Million gallons per day per square mile
	Square miles	*Inches*	*Mile-inches*		
Hawaii	4, 030	65. 4	263, 600	12, 550	3. 11
Maui	728	85. 6	62, 350	2, 970	4. 08
Oahu	604	68. 0	41, 100	1, 957	3. 24
Kauai	555	87. 8	48, 700	2, 320	4. 18
Molokai	260	45. 9	11, 900	570	2. 18
Lanai	141	22. 6	3, 190	152	1. 08
Niihau [2]	72	16. 0	1, 160	55	. 76
Kahoolawe [2]	45	12. 0	560	27	. 60
Total	6, 435	(3)	432, 560	20, 601	(3)

[1] Based on planimeter measurements of latest available isohyetal maps.

[2] Data inadequate. Estimate provided on basis of available data and general knowledge of rainfall behavior so that small quantity of rainfall on this island could be added to get a total for the Islands.

[3] Total mile-inches divided by total square miles equals 67.2 inches. Ton column six, total million gallons per day divided by square miles equals 3.2 m. g. d.

It is the purpose of the following discussion to explain the principles of water occurrence and the methods of use. No attempt will be made to present data on water quantities. Tables showing quantities and qualities of water used on various islands will be found in reports by the Territorial Division of Hydrography (*15, 17, 18, 19, 20, 21*). Data for more recent years can be obtained from the files of that office.

Surface water.—The most immediate and direct use of rainfall is by plants. No doubt, plants obtain more water from direct rainfall than from all other sources. For many areas, this is the only use of rainfall. In the most primitive pattern, this direct use entails no cost. If direct use is to be continued on the most profitable basis, however,

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there are costs for maintaining suitable field conditions and, particularly, costs for soil conservation. In some places these costs must be incurred even for survival.

Water for domestic use and livestock is caught on roofs of buildings and carried to cisterns in large areas and isolated places throughout Hawaii. This somewhat less direct use of rainfall probably will continue indefinitely. Storage in surface reservoirs is not economic in most places. Only small reservoirs can be made in the rugged terrain; there is heavy seepage into porous rocks, and the large amounts of silt and gravel carried in Hawaiian streams can soon fill a reservoir.

In most places surface runoff is highly variable, and only a fraction of the Hawaiian Islands is drained by perennial streams. Runoff is used in a few places for irrigation, and there are a few small hydroelectric plants. Surface water is used to a relatively limited extent on the island of Oahu. Larger amounts are used on Maui, windward Hawaii, and Kauai, but this use has reached a maximum and probably will decline (*23*).

Ground water.—In Hawaii ground water occurs in three principal forms: (1) High-level water, which is perched above some water-resistant layer or confined between dikes; (2) basal water, which has a level only slightly above that of the sea; and (3) basal water under artesian pressure because it is held under an impervious cap (*14*).

The process of downward movement is gradual. When it first infiltrates, the rainfall may take the form of shallow ground water, which is the source of moisture for most plants. This ground water extends down several feet, sometimes 20 feet or more, but normally it cannot be tapped. The soil is ordinarily tight enough that it will not yield water into a pit or shallow well. In Hawaii practically no water is obtained from shallow wells driven into an upland surface. With few exceptions, wells dug in upland areas having 50 to 150 inches of rainfall will first penetrate moist surface soil and subsoil that yields no moisture and then pass down into more permeable, progressively less weathered rock that contains no visible moisture.

The mass of rock beneath the moist soil is mostly dry all the way down to near sea level. This is attested by hundreds of well borings, as well as thousands of feet of tunnel not specially driven to pass through known bodies of water. It is true that ground water is reached at high levels, but this is in rainy areas where dikes form vertical barriers or where sills or other tight strata cause perched water.

We cannot doubt that water continually percolates downward through the porous rock masses several hundred to 3,000 feet thick and feeds the body of basal water lying near sea level. Calculation will show why water is not more evident in the rock. If we assume that 50 inches of rain passes vertically downward each year, as it must on the average, we have an average daily total of about 80 gallons to pass through 100 feet of tunnel 10 feet wide. Eighty gallons a day is only about a cup a minute. Such an amount dispersed in each 100 feet of tunnel hardly would be discernible. The impression would be that water was completely absent.

The foregoing shows why random, "wildcat" wells and tunnels, even in rainy areas, have small prospect of success. Tunnels and wells must penetrate where there are natural concentrations of water.

High-Level Water.—On several dissected volcanic cones more or less parallel dikes have pushed up along linear rift zones in areas of fairly high rainfall. These dikes may confine water to the normal volcanic rock between them. The excess water overflows, sometimes over steep cliffs, and gives rise to springs and perennial streams. Large amounts of water have been developed in Hawaii by driving tunnels through high ground to penetrate one of these dike barriers. Water so reached may be under pressures equivalent to 100 feet or more of head and often discharges in large quantities at first. The ultimate flow—commonly but a fifth to a tenth of the original—depends on the amount of rainfall available to replenish the body of ground water that has been tapped. Often the period of declining flow lasts several years, or even 20 or 30 years.

Decline in flow from tunnels that tap high-level water should be considered in terms of the relationship between storage volume and annual net yield. Few tunnels in Hawaii have been recorded accurately enough to justify elaborate analysis, but the importance of the basic relationship is now realized and methods are gradually being improved. Experience with progressive decline has led to the placing of bulkheads after tunnel driving is completed. The bulkheads allow limiting the water drawn to the amount needed. During tunnel construction, of course, much water is often unavoidably wasted, especially if the project is for domestic supply.

In the Pahala area of Hawaii, a considerable supply of perched water has been developed by driving tunnels at the top of an impervious layer of ash. This suggests that similar ground water might be captured elsewhere on the islands. Some promising studies have been made, but it does not appear that relatively large amounts of water will be recovered in this way.

In southeastern Oahu, late volcanic eruptions took place at more than thirty vents. Lava flows and cinders from these vents were added to the valley fill in a number of valleys that had been cut much deeper than their present levels during the earlier great erosion interval. At a number of places in these valleys—chiefly those occupied by these late volcanic rocks—there are perched bodies of ground water only a few feet below the surface.

On East Maui there are numerous occurrences of perched ground water resulting from various structures in volcanic rocks (*18*).

Basal Water.—By far the largest source of ground water is the great lens of fresh water that floats on sea water within the rocks of all the larger islands. This water accounts for the larger part of the infiltration derived from rainfall. It floats on the sea water because it has less density; it collects in the permeable rocks because of capillary resistance to lateral discharge to the sea; it accumulates to a height above sea level such that the rate of escape can equal the rate of rainfall infiltration.

This fresh water, though it is discharged slowly, is a floating body. Like all floating bodies it must displace a weight of fluid equal to its own weight. Sea water has a specific gravity of about 1.025, or one-fortieth greater than fresh water. It follows that a body of fresh water will be in floating equilibrium with sea water when its volume above sea level is about one-fortieth its volume below.

If because of its resistance to dispersal, fresh water is maintained slightly above sea level for any length of time, it will gradually move downward in the rocks until it forms a lens having the outlines of the island or the outlines of the permeable rocks of that island. This lens of fresh water will have a depth below sea level about forty times its height above sea level. This principle of floatation has been called the Ghyben-Herzberg hypothesis. It was discovered in lands bordering the North Sea late in the last century and has been verified in other parts of the world (*1, 11, 27*).

A great amount of information on the relationship between fresh and salt water has been collected in Hawaii during the past 70 years. Though local conditions are quite variable, there is no doubt that the Ghyben-Herzberg relationship chiefly accounts for the occurrence and availability of fresh water around the margins of islands and at low levels through much of the Hawaiian Islands (*29*).

Two conditions have made the Ghyben-Herzberg principle especially important in Hawaii. First, as a rule, the relatively permeable rock formations through which the ground water infiltrates extend upward and downward from sea level a thousand feet or more without notable change in character. Because this flow formation is so deep and uniform in permeability, the fresh-water lens in Hawaii tends to take the symmetrical geometric form required by the Ghyben-Herzberg principle to far greater extent than lenses on most coasts of the world. The other condition is caused by a thick, effective caprock formation in some places, especially in the Honolulu-Pearl Harbor area and in several others on Oahu. The caprock retards the outflow of fresh water, so the head—or amount above sea level—is increased to 10, 20, or even 40 feet. The increase in amount of water above sea level means an increase below sea level in the proportion of 40 to 1, so below-sea-level water may be hundreds or even a thousand feet deep. This condition is not known in such degree in any other part of the world. It means an enormous storage of water that has well served the Honolulu community. This abundance, however, has obscured the fact that rainfall is the source that must ultimately be relied on, and that supplies are less copious than they first appeared.

Artesian wells can be drilled where coastal caprock of weathered sediments and late volcanics holds a thick lens of fresh water. Wells drilled at a surface elevation lower than the elevation of the head, or top, of the lens will flow because of artesian pressure. In developing water near the coast, wells have been drilled hundreds of feet below sea level before reaching the base of the caprock and entering the aquifer. By such practical tests, the limit below which fresh water cannot be developed has been determined. The depths revealed by such borings confirm the broad principles of Ghyben and Herzberg.

Unfortunately these principles were not earlier understood. The drilling of wells on low ground or near the place of desired use has required drawing water from depths in the lower third or fourth of the fresh water zone that existed at the time of drilling. Lowering of the head through excessive draft has thinned the lens and allowed the saline zone at the bottom to rise. In consequence, many wells originally fresh now draw salt water (*10*).

Wherever basal water is exploited by drilled wells, the temptation is to drill too deep, either to get sufficient yield, or in the case of

artesian wells, to reach the aquifer where the caprock is relatively thick. In selecting sites for wells it should be assumed that heads of fresh water will be reduced as flow continues and that the zone of transition between fresh and salt water will rise. Water cannot be taken artificially from such a ground water body without causing some shrinkage. Even under ideal use, some shrinkage may be desirable to reduce the amount lost by natural leakage. Because these facts are not considered, many wells quickly become untenable as sources of fresh water. Nearly all such drilled wells face this eventual possibility, though the supply of basal water may still obscure the fact.

There is now a well established trend toward use of so-called skimming tunnels rather than drilled wells in getting water from the basal lens (*10, 21*). These tunnels are driven near sea level; their bottoms, as conditions warrant, are some inches or feet below the basal water level. The tunnels lead into a sump, from which the water is pumped. Because a larger yield area is exposed in a tunnel than in a well, the required drawdown is smaller, and furthermore, is applied near the top of the water body rather than in its deeper part. For these reasons, it is practically certain that more water containing less salt can be obtained from a skimming tunnel than from a drilled well. Moreover, well casings become corroded and eventually must be replaced, both to be effective and to conform to Territorial law.

Progressively more and more single wells, as well as groups of 2 to 20 wells that have served larger pumping stations and plantation systems, are being replaced by basal tunnels of the skimming type that are located farther inland. It is believed that by 1978—100 years after the first artesian well was drilled on Oahu—there will be little water produced from artesian wells.

To some extent, replacement of artesian wells by skimming tunnels will permit safe operation at lower heads of basal water. According to hydraulic theory, operation at lower heads should produce somewhat larger amounts of water because less would be lost by outward leakage. The gain of usable water through this change, which necessarily will be a slow one, will be partly offset by a slow decline in the amount of water in the deeper part of the Ghyben-Herzberg lens. Shrinkage of the lower part of the lens can be expected as operation at lower basal heads increases.

It is not evident to this author that building of additional basal stations and retirement of deeper artesian wells will produce more water annually in the Honolulu-Pearl Harbor sector or similar fully developed areas. The basal stations may only ease conditions of operation and better assure safe passage through recurrent dry periods.

Skimming tunnels offer the only suitable method yet devised for developing water where the basal lens is thin, but are not a complete solution. The larger outlines of geologic structure and ground-water supply are now well established. We cannot escape the fact that large areas on all the bigger islands, as well as most of the extent of the smaller islands, have low rainfall and no perennial streams. In these areas the lens of basal water is commonly thin, is already somewhat saline, or will become saline when subjected to artificial draft. This is reasonable to expect. Contrasts in annual rainfall are large among the various areas in Hawaii. Rainfall is the source of ground water,

so its contrasts are more than matched by those in supplies of basal water.

In evaluating thin basal lenses as sources of water, it should be remembered that the Ghyben-Herzberg doctrine requires merely that the land water be substantially lighter than the salt water. It does not imply or guarantee that such land water will be so free of saline contamination that it will be suitable for household use or agriculture (*27*). Also, experience in the chief artesian areas of Oahu has shown (1) that the zone of transition between salt and fresh water is commonly 100 to 300 feet in half width, and (2) that adequately fresh water does not commonly come from a depth below sea level close to 40 times the height of the head above sea level. These facts are considered in exploring coastal areas with little or no caprock. If the basal head in such an area is not more than 1 or 2 feet it cannot be expected that the 40 to 80 feet of fresh water floating below sea level will escape being somewhat brackish. Nevertheless, exploration of coastal supplies and development of marginally brackish water will become increasingly necessary as efforts to utilize land in the drier parts of the Islands are made.

WATER SUPPLY BY ISLANDS

The most compact statistics on water supply for the whole Territory are in reports of the Territorial Planning Board (*4*). These statistics are based on data collected by the United States Geological Survey, (*23*) the United States Weather Bureau, the Board of Water Supply, and various other agencies. The Territorial Division of Hydrography, in collaboration with the United States Geological Survey, has issued reports on geology and water resources for several islands.

In this section the chief interest is in amount of rain falling directly on the soils and supplies of surface and ground water that can economically be applied to the soils. An attempt will be made to summarize the existing and controlling conditions of water supply for the larger segments of each island. Effort will be made to define the fundamental rainfall supply, to show to what degree that supply is concentrated in large perennial streams or in bodies of ground water that can be tapped, and to mention pipelines delivering water for domestic use. The rainfall distribution for the eight islands of the Territory is given in table 3.

Oahu.—Water supplies on Oahu have been more completely developed and are better known than those of any other island (*31*). The various kinds of water supply on Oahu exemplify the kinds on other islands, but because of great differences in geologic history and structure, the methods of development used on Oahu should not be followed closely on the other islands.

Most important in the Oahu water supply is the exceptional lens of basal ground water in the Honolulu-Pearl Harbor area. Paralleling the shoreline in this area for a distance of 20 miles is a head of fresh water currently 20 to 30 feet above sea level. This area contributes a large fraction of the total ground water discharged on Oahu. The total ground water discharged on the island is probably nearly 20 percent of the rainfall.

TABLE 3.—*Rainfall distribution in Hawaii*

Island	Area	Annual rainfall						
		Mean	300 inches +	200 inches +	100 inches +	50 inches +	25 inches +	Total
	Square miles	*Inches*	*Square miles*	*Square miles*	*Square miles*	*Square miles*	*Square miles*	*Million gallons per day*
Hawaii	4, 030	65. 4	------	157	876	1, 710	1, 120	12, 550
Maui	728	85. 6	34	95	193	350	200	2, 970
Oahu	604	68. 0	2	29	108	283	92	1, 957
Kauai	555	87. 8	11	26	190	368	48	2, 320
Molokai	260	45. 9	------	------	32	77	102	570
Lanai	141	22. 6	------	------	------	------	89	152
Niihau	72	16. 0	------	------	------	------	72	55
Kahoolawe	45	12. 0	------	------	------	------	45	27
Territory	6, 435	[1] 67. 2	47	307	1, 399	2, 788	1, 768	20, 601

[1] Total mile-inches divided by total square miles; hence, 432,560÷6,435=67.2 inches.

The ground water in the Honolulu-Pearl Harbor sector was first developed by artesian wells. Flow from the wells, eventually more than 300 of them, caused depletion of the basal head and some shrinkage of the deeper, sub-sea-level, part of the basal lens. In various places the basal head is now 5 to 15 feet lower than it was originally. Depletion of the basal head has caused fatal saline encroachment in many deeper wells in a belt along the coast. It has brought increased salinity to a large number of the wells in the Pearl Harbor area and to a smaller number of those farther inland in the Honolulu area.

It is evident that all the artesian wells eventually will have to be abandoned. The changeover to basal skimming tunnels is now well underway; nearly a third of the total draft is now taken from skimming stations.

If all artesian wells are sealed and water from the free-flowing springs at Pearl Harbor is salvaged, it appears that the basal head at its present level might maintain production at somewhere near 270 million gallons a day. Some additional production—it is not known how much—might be achieved by operating at lower heads. In the opinion of this author, however, the ultimate safe yield of the Pearl Harbor-Honolulu sector was closely approached during the period 1940–49. Supporting this opinion is the decline in yield from the shrinking bottom storage and the decrease in operating head. New skimming stations no doubt will be built. Apparently they will provide additional water, but in reality they will allow only more flexible access to the same supply.

There are smaller basal water accumulations with heads ranging from 10 to 15 feet in the Waialua and Kahuku areas on Oahu. Each was originally tapped by artesian wells. Each is destined to produce increasingly saline water as the head is lowered. To hold the discharge near its present value, the wells eventually will have to be

replaced by basal skimming tunnels. The basal supply in some parts of the Waianae area is less promising than those in the Waialua and Kahuku areas.

Occasional exploration for basal water continues in Oahu, but the main sources already have been outlined. Except in artesian areas heretofore mentioned, the basal water around much of the coast has heads of only 1 or 2 feet. In some areas, as in the Koolaupoko, basal water does not exist in any known systematic balance with sea water. Locally, small amounts of basal water may be obtained for livestock or limited irrigation, but in the sense of municipal supply or commercial agriculture, the supply is practically nonexistent.

The Waiahole tunnel system of Oahu is one of the best examples of exploiting high-level water confined within a dike complex. This system has furnished upward of 25 million gallons of water per day for several decades. The dike complex extends southward from the Waiahole area several miles. A total of some 7 or 8 million gallons per day is now developed from this complex at Kahaluu, Haiku, Luluku, and Waimanalo.

In the Koolau area inland from Kalihi, Nuuanu, or Manoa, the dike complex lies in low ground on the windward, or dry, side of the crest. In consequence, tunnel systems in this area could not be expected to produce as much as those south of Waiahole. It is unlikely that a total of more than 10 or 12 million gallons per day can be developed from a dike complex south of the Waiahole system. The territory eastward from Diamond Head on the leeward coast and eastward from the Maunawili area on the windward coast will continue to be water-poor because both rainfall and favorable geologic structures are lacking. Water will have to be piped to these areas from farther west.

On the plateau that extends a short distance north and south of Wahiawa and Schofield Barracks there is a body of ground water standing about 275 feet above sea level and, according to geophysical measurements, in balance with sea water. It is not known why this body appears at such a high level, or what area of watershed it draws upon. This body has been exploited by the United States Army shaft south of Wahiawa and by 3 or 4 other wells north of that point. The body has not been tested beyond 5 or 6 million gallons per day, so its regional capacity is not known.

In the Waianae area relatively low rainfall warns us not to expect large amounts of ground water. Some of the valleys on the leeward slope are almost without water; others, such as Waianae, have some springs at high levels and a moderate amount of basal water, part of it artesian. The high-level springs and tunnels are fed from a dike complex and yield materially less water than would be obtained from a similar complex on the more rainy Koolau Range. Dissolving of the Waianae Company and abandonment of sugarcane growing in this part of the island have encouraged homesteading and subdivision. This brings new problems of water supply that will not be solved for many years.

The need for domestic and agricultural water likely will be acute in the Waianae area indefinitely. Considering the homesites that will be laid out, it is not yet evident that sufficient water for domestic use can be provided. Still less evident are means whereby water can

be provided in amounts sufficient for effective agriculture over the whole area of arable land. Importing of water from the Pearl Harbor or Schofield area has been discussed, but the writer does not know of a sound economic plan or of a crop that would pay the charge.

Considering Oahu as a whole, the water-supply situation is much the same as for the Honolulu-Pearl Harbor area. The present measured water discharge is not far from the ultimate total. The problem of water supply has passed from one of discovery and exploitation to one of hydrologic management and control. The success of hydrologic control, voluntarily or otherwise achieved, will determine the limits for agricultural and municipal growth on Oahu. Probably attempts will be made to exploit some of the brackish basal water for special purposes, but there is extremely small prospect of getting significant supplies that will meet present standards of potability.

Kauai.—The island of Kauai receives an average annual rainfall of about 88 inches, the highest rainfall of the island group. About 34 percent of its area gets more than 100 inches annually. A segment at the southwest, measuring about 48 square miles, receives less than 25 inches; the eastern and southeastern coastal strips receive 35 to 40 inches.

On Kauai a large part of the rainfall—probably a larger part than on any of the other islands—is discharged as runoff. The amount of ground water is relatively less than on Oahu or parts of Maui. Free basal ground water occurs on the north, the east, and south coasts. There is sufficient caprock to produce artesian water along the southeastern coast, and to small extent along about 5 miles of the eastern coast. Nevertheless, the total developed ground water on Kauai is less than 20 million gallons a day, or less than 1 percent of the rainfall. Further exploration no doubt will reveal some additional ground water, but the geologic structure of Kauai indicates that the total yield in relation to rainfall will not approach that in the more productive parts of Oahu.

When ultimate water utilization is reached on Kauai, direct rainfall and irrigation for surface flow will contribute a larger percentage of the total supply than on Oahu, and the percentage from ground water will be less than on Oahu. The total measured use from surface and ground water supplies probably will be less than on Oahu.

Niihau.—The island of Niihau has generally low rainfall and no perennial streams. On the basis of incomplete records, it nowhere receives more than 25 inches per year. In table 2, the average is estimated at 16 inches, but data needed for drawing isohyetal lines are lacking.

Only two or three small high-level springs have been found on Niihau. Of the more than 50 waterholes and drilled wells entering basal water, only 3 show a salinity of less than 25 grains of salt to the gallon. These three wells are in tuff or dune sand. More than half the wells and waterholes analyzed have 100 to 500 grains of salt to the gallon (*17*). The entire basal lens on Niihau is brackish. It is possible that small amounts of fresh ground water may be found on this island. It is certain, however, that water supplies for irrigation or keeping of more than a limited number of livestock do not exist.

Molokai.—This island has a wet eastern and dry western part. About a fifth of the island receives more than 60 inches of rainfall annually, but this area is mostly rugged and not readily accessible. On the island the larger part of the arable land lies where annual rainfall ranges from less than 10 inches to about 40 inches. Data on water supply and modes of occurrence have been summarized by Stearns and Macdonald (*20*).

Various springs and test wells show that basal ground water derived from rainfall underlies much of the island. It is evident that the Ghyben-Herzberg condition exists in fairly stable form, but the accessible margins of the lens are already somewhat contaminated by salt or would soon become so under moderate pumping. Recent borings and more complete understanding of hydrologic conditions suggest that some fresh ground water can be taken from properly designed and operated wells and skimming tunnels. Considering the greater expense of development imposed by the thin basal lens, it is hard to estimate how far economical exploitation can go. The earlier water exploitation on Molokai under methods similar to those used on islands such as Oahu and Maui was quite discouraging. The measured ground-water discharge on Molokai is probably less than five-tenths percent of the rainfall.

It is thought that about 50 million gallons of water per day can be obtained by tunneling in the dike complex in the dissected part of East Molokai (*5*). The ruggedness of this area and its distance from points where water can be practically utilized makes exploitation of this possible source a large-scale operation. So far, acceptable financing for such development has not been found.

Western Molokai is one of the areas in Hawaii where atmospheric conditions occasionally appear favorable for production of rain by the dry-ice method. It is not yet clear that such atmospheric conditions can be considered a water resource.

On much of the southern shore of East Molokai, rainfall supplemented by local springs supports a fringe of population living largely in the old Hawaiian pattern. The area is classified as grazing land. Eventual water supply will determine whether this area will support the same or a larger population practicing a varied cash-crop agriculture and served by piped community water.

Lanai.—This is the smallest island that has what can be called a rain forest near its summit. This forest area is quite small and does not receive a maximum of more than 40 inches of rainfall annually. Rainfall on most of the arable land ranges from 25 inches down to less than 20 inches annually. Maunalei is the only stream that generally shows perennial flow. Surface water is diverted to reservoirs for watering stock. Stearns has presented a sketch of water utilization on the island (*15*). He estimates the average total ground-water infiltration at about 21 million gallons per day, or approximately 15 percent of the rainfall. Probably only a small fraction of this infiltration can be developed.

Various seeps, springs, and shallow pits along the shores of Lanai yield water that is derived mainly from rainfall. These show that the rocks of the island contain a lens of basal water floating on salt water. The basal water is too saline for drinking. The performance of the

lower Maunalei shaft, dug with much care to avoid unnecessary salting, indicates that no significant quantity of water suitable for agriculture or household use can be recovered from the basal lens.

A tunnel driven under the floor of Maunalei Gulch at an elevation of 1,100 feet yields an average of about one-fourth million gallons daily. It is believed that this flow comes from water confined between dikes that have been cut by the stream valley. Higher up in the same valley several tunnels have been driven in or near the dike complex, but only one—the upper Maunalei shaft—has yielded substantial amounts of water. This inclined shaft penetrates to the water-bearing rock between the dikes, and the flow is drawn from a well that reaches nearly 400 feet lower than the portal in Maunalei Gulch. Annual draft from this tunnel was around 10 million gallons during the period 1937–39, with pumping at 144,000 gallons per day. According to Stearns, the total high-level water developed on Lanai is about one-half million gallons per day (*15*).

In summary, Lanai shows accumulations of fresh ground water in all the places where it can be expected on basaltic islands, but generally in small quantities and limited areas. The various sources of supply are smaller, show water of poorer quality, and are more expensive to develop than comparable ones on larger islands. This fact must be faced. Recoverable water goes down as the size of the island, total rainfall, and rainfall per square mile go down. Kauai, Oahu, and Maui may be considered the most favorable type of high island; they have heavy rainfall, deep dissection, dike complexes, and at least local areas of coastal plain. The large development of coastal plain on Oahu places it far ahead of the other islands in ground-water production.

Kahoolawe.—Without question, this is the driest island of the group. It has a long history of attempted stock raising. Adequate records are not available, but the maximum rainfall at any point may not exceed 25 inches annually. General rainfall over the smoother parts is probably less than 15 inches. Also, in all areas of low rainfall such as this, the rainfall is extremely variable by the month or year. This should be remembered when grass and trees show encouraging greenness following favorable rains. Even small amounts of ground water would be of great value on Kahoolawe, but neither geologic survey nor the electrical resistivity survey of 1939 is encouraging. The basal lens is apparently less than 1.5 feet above sea level. The prospect of getting supplies of usable water from this lens hardly justifies the high cost of an adequate, full-scale exploration (*15*).

Maui.—The island of Maui receives heavy rainfall over large areas. A maximum fall of 350 inches is reached both on East Maui and West Maui. Parts of each of these domes are deeply dissected and have geologic structures favoring high-level accumulation of water. Basal, nonartesian, water is found at the eastern end of East-Maui and across the Maui isthmus, as well as around the whole margin of West-Maui. A large area on the northeastern slope of East-Maui has perched water in lava-filled valleys. No artesian water has been discovered.

The general outlines of ground-water occurrence on Maui are known. Further exploration likely will not materially change the picture. Parts of East-Maui are of complex geologic structure, however, and

complete disclosure of details by drilling and complete exploration will take a long time. The total known ground-water discharge on Maui approximates 11 percent of the rainfall (*18*).

Hawaii.—The island of Hawaii, nearly six times the size of Maui, presents such varied water supply conditions that its ultimate potentiality can be forecast only in the most general terms. First we must recognize that only three areas on the island have rainfall adequate for varied agriculture. The first of these is the Hamakua-Puna part, measuring about one-fourth of the island area, that receives 80 to 240 inches annually. A large part of this area is in forest. The second area is Kohala, measuring nearly 150 square miles and receiving 60 to 200 inches annually. The third is the upper Kona area, a strip 30 miles long that receives 60 to 100 inches through the action of sea-to land winds in the trade-wind lee of Mauna Loa and Puu Hualalai.

The Hamakua-Puna and Kohala rainfall areas give rise to an important area of basal water stretching from Pahoa northward to Kohala. This basal supply has been exploited only locally. The Kohala Mountains rainfall also supports an interior area of dike-confined, high-level water, some perched ground water, and, in the Waipio Bay area of the windward slope, several relatively large perennial streams. Numerous smaller perennial streams occur along the entire windward coast southward as far as Hilo.

The third area of favorable rainfall, the Kona, is apparently too small to produce a strictly fresh Ghyben-Herzberg lens along the Kona coast. Nevertheless, general occurrence of brackish water indicates that the lens exists. There is no geologic structure in this area producing concentrations of fresh water or perennial streams.

In total effect, rain in the Kona area does the following: (1) Supports sectors of fine forest in the zone between 1,000 and 5,000 feet if cattle are excluded and (2) permits some subsistence agriculture and homesteading by use of roof catchment. Probably attempts will be made to exploit some of the brackish basal water for special purposes, but there is extremely small prospect of getting significant supplies that will meet present standards of potability.

Substantially all the available information concerning ground-water supplies on Hawaii has been compiled by Stearns and Macdonald (*19*), whose text should be consulted for details. As they have pointed out, large amounts of water await development in the Kohala and Hamakua-Puna sections. The interior of Hawaii, however, in large part receives rainfall ranging from 40 inches down to less than 20 inches. Water will always be scarce in this interior area from elevations of a few hundred feet up to 10,000 feet or more. The total ground-water discharge on the island of Hawaii is only about 6 million gallons per day, or approximately one-twentieth percent of the rainfall.

GENERAL SUMMARY OF WATER SUPPLY

A hydrologic inventory of the islands would set up outside limits of water supply that could not be ignored. Unfortunately, we cannot start with total rainfall, subtract evaporation, transpiration, and runoff, and then assign the remainder as water infiltrating the ground. Because we lack precise knowledge of transpiration and evaporation, we cannot determine the ground-water residue for any island or large

section of an island. The discussion following therefore will point out only marked differences in rainfall and resulting water supply that are well established.

The total rainfall for the eight islands is about 20 thousand million gallons daily (see table 2). Hawaii gets 12.6 thousand million gallons of this total; Maui, 3.0; Kauai, 2.3; and Oahu, 2.0. These four islands account for 19.9 thousand million gallons of the total. The relatively small remainder falls on the other islands—Molokai, Lanai, Niihau, and Kahoolowe. Amounts falling on Molokai and Lanai are fairly well established. Only rough estimates are available for Niihau and Kahoolawe; they may be in error by 20 or 30 percent, but this still does not appreciably affect the rainfall total for the Territory.

Differences in geologic structure of the various islands cause fairly large differences in the way the rainfall is dispersed. On Kauai, for example, totals of average flow from many large streams indicate that runoff from the island exceeds half the rainfall. No other island has such a large percentage of runoff. West Maui is probably the only area having runoff anywhere approaching that on Kauai. Large parts of the Islands, including at least half the island of Hawaii, have no runoff at all. Another large fraction has no perennial streams. Only about a fourth of the Hawaiian Islands has runoff during most of the year. This does not mean the other three-fourths has no runoff; it simply means runoff is small and surface water is not available for domestic use or agriculture. Lack of surface water emphasizes the importance of ground water as a source of supply.

On Oahu, the measured ground water is very close to 25 percent of the total rainfall; for Maui, it is around 10 or 11 percent of the rainfall. All the other islands have percentages falling below these. Some change in amount of ground water exploited and measured can be expected, but is evident that broad contrasts will not be changed materially. Kauai, with high surface runoff, will continue to have low supplies of ground water. Oahu, with low surface runoff, will have large supplies. In relation to total area, the island of Hawaii cannot approach Kauai, Oahu, or Maui in percentages of rainfall accounted for in either surface runoff or ground water.

In the foregoing discussion of water supply, the emphasis has been on water resources for land areas rather than municipalities. Those interested in data on water supplies for town and villages should refer to reports of the Territorial Division of Hydrography. The sources of water for exploited municipal use follow the general patterns of water supply development for the various islands. The tendency is to use ground water more than other sources for municipal supply. This trend will continue as more areas are supplied with metered water and as the suppliers meet Territorial health and quality standards.

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***THIS SECTION** describes the broad distribution patterns of Hawaiian plants in terms of relationships to climate and elevation. It serves as a background for considering vegetation as a factor in soil formation and as a product of the soil.*

VEGETATION

By WILLIAM CROSBY, Territorial Forester, and E. Y. HOSAKA, Specialist in Pasture Management

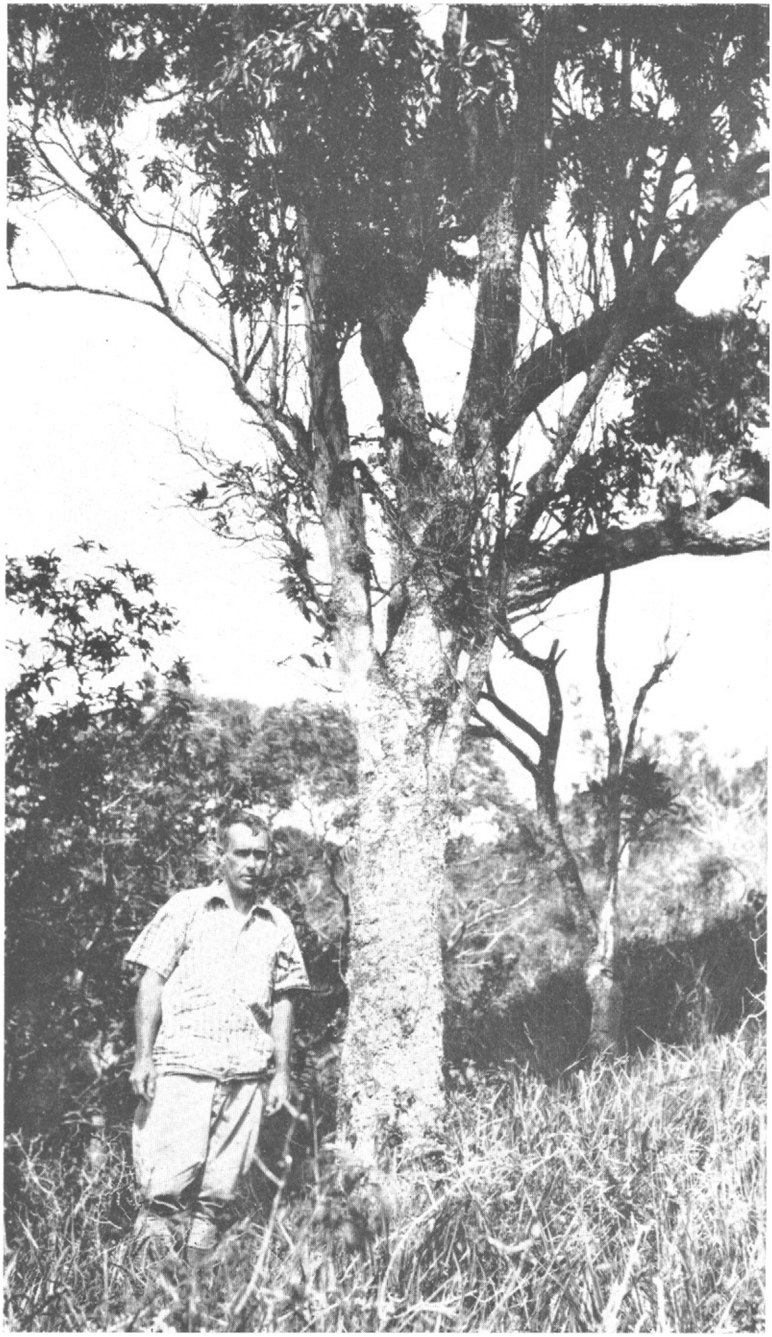
VARIOUS remnants of native forest indicate that the first Polynesian settlers found trees growing on all parts of the Hawaiian Island except a few very dry leeward areas and recent lava flow. The Polynesians cleared only limited areas for cultivation and made little use of forest products, so forest must have occupied most of the land when the islands were discovered by Captain Cook in 1778.

Growing contacts with European and American countries brought great changes in the peoples of Hawaii and their occupations and customs. The forests were rapidly destroyed as land was cleared for an expanding agriculture. Plant introductions were made in large number and great diversity. Many of the introduced plants became established as part of the natural, or wild, vegetation and profoundly changed the plant composition of both cleared and uncleared areas.

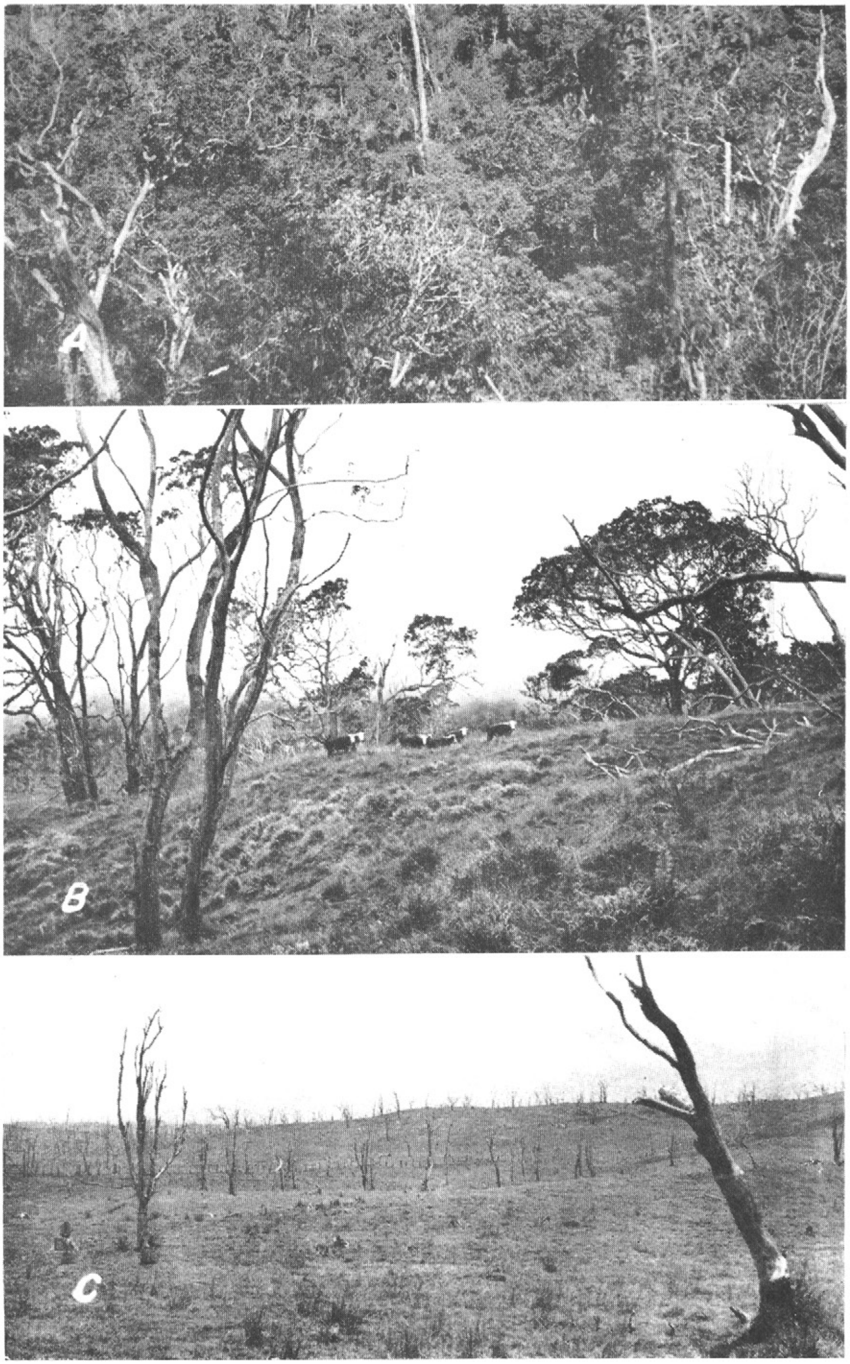
Grazing animals—cattle, sheep, and goats—were the foremost cause of forest destruction. They were first introduced by Captain Vancouver during his voyage of 1792–93. The Hawaiians were delighted to have this additional source of food. The chiefs restricted slaughter of the few animals liberated. They ran free, multiplied prolifically, and spread over the greater part of the accessible forested areas. The forest flora had developed in total absence of animal life, and the sharp-hooved animals feeding on the leaves and injuring the root systems soon destroyed the native forest in large areas.

At the time of Captain Cook's visit, about 3 million acres of the approximate 4 million acres of land in the Hawaiian Islands must have been forested. Today, remnants of the native forest measure less than one million acres, and these occur almost entirely in the Territorial Forest Reserve, which is protected from grazing and other exploitation.

Early use of timber was not excessive. Ohia lehua, most abundant and widespread of the native Hawaiian trees, furnished a moderately hard and durable wood used by the early Hawaiians for posts and poles and by the early white settlers for flooring and general construction. Koa—principal source of logs for the Hawaiians' dugout canoes and an excellent interior-finish and furniture wood—was cut for local use but was not available in quantities sufficient for export. Cutting of sandalwood brought forest utilization to its peak during the first half of the nineteenth century. In this period the great sandalwood trade with China developed and continued until all the readily accessible stands were completely cut.

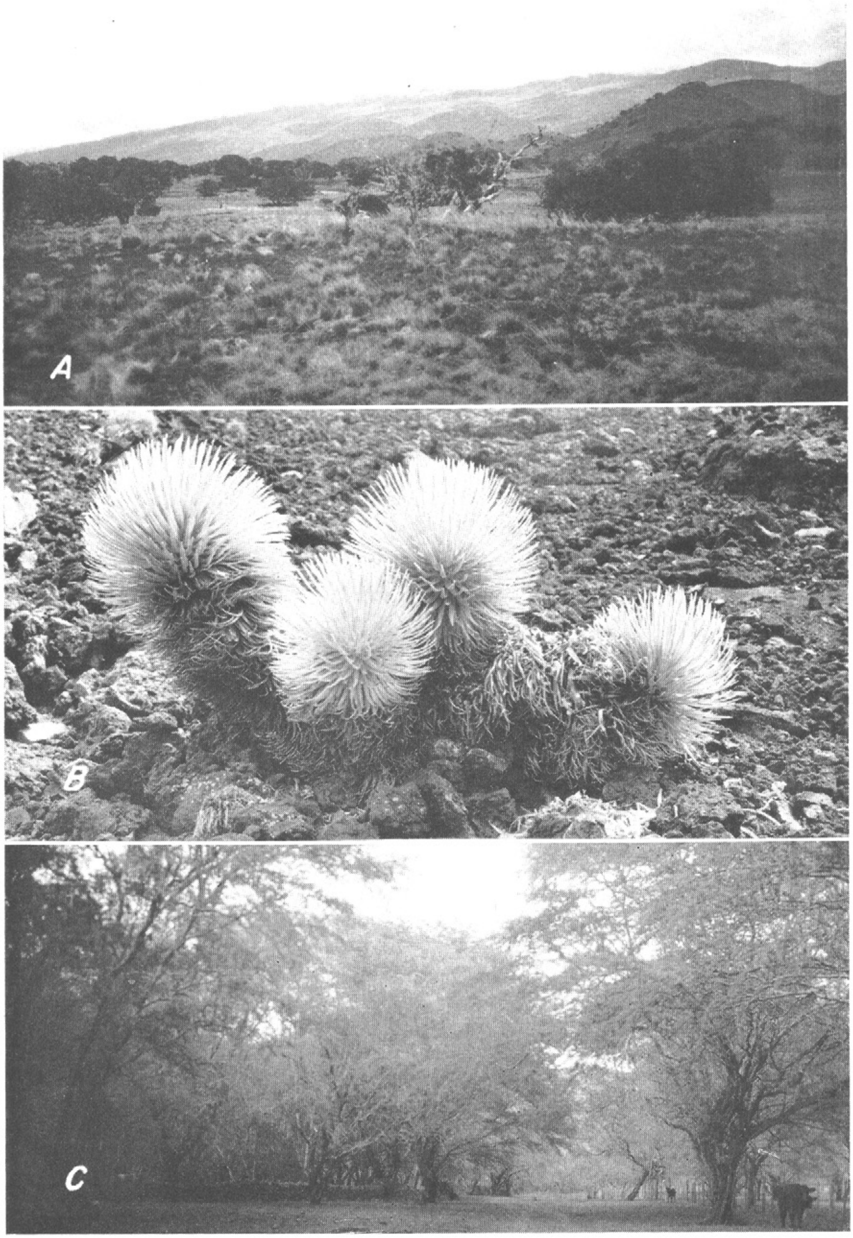


Sandalwood (*Santalum freycenetianum*) in kukui type forest.



A, Ohia type forest at elevation of 3,500 feet.
B, Remnants of Ohia and large koa trees being killed by grazing in Ohia type forest at elevation of 5,000 feet.
C, Ohia type forest, at 5,000 to 6,000 feet elevation, that has been killed by grazing.

Koa type forest.



A, Mamani type forest at elevation of 6,500 to 7,500 feet.
B, Silversword (*Argyroxyphium sandwicensis*) at elevation of 10,000 feet.
C, Introduced forest (*Prosopis chilensis*) on leeward costal plains.

As the forest line receded under the attack of increasing numbers of wild cattle, sheep, goats, and hogs, large areas once forested became sites for cattle ranches and sugarcane plantations. This brought a new chief use of timber. Firewood was needed for sugar mills and household use. As the number and size of the mills increased, the cost and difficulty of getting firewood grew rapidly. Considerable planting of trees for firewood was done before fuel oil and kerosene were generally adopted for use in furnaces and stoves.

An island vegetation is delicately balanced. A slight disturbance of equilibrium often leads to its partial or complete destruction. This happened in Hawaii. Many of the introduced trees, grasses, and herbs found their new habitat so ideal that they became dominant in many locations and almost completely forced out the native species. Such are the vegetation zones now dominated by algaroba, lantana, cactus, pamakani, koahaole, and guava. Large areas such as the Waimea plateau on the island of Hawaii that probably were forested now appear as natural grasslands because ranchers have persistently eliminated trees and shrubs and established improved pasture species. The result of all these changes is a present vegetation markedly different from the original in dominant species and often in vegetation type.

VEGETATION TYPES

Using the general classification of vegetation, five formations can be pointed out on the Hawaiian Islands: Shrub, forest, parkland, bog, and moss-lichen. These formations do not exist on all the islands, nor are the altitude limits of the formations the same on all the islands.

Shrub formation.—This formation occurs in varying widths along the coastal lowlands. On the lee, or dry, sides of the islands it extends farther up the slopes than on the windward, or wet, sides.

The shrub formation is characterized chiefly by guava (*Psidium guajava*), lantana (*Lantana camara*), koahaole (*Leucaena glauca*), klu, (*Acacia farnesiana*), cactus (*Opuntia megacantha*), and piligrass (*Heteropogon contortus*). In wet places along streambeds and on shaded slopes, guava forms a dominant cover, but in dry areas and rocky places other species are common. In certain localities cactus and koahaole form homogenous thickets. Other vast areas are spotted with clumps of lantana, with Bermudagrass (*Cynodon dactylon*) and Natal redtop (*Tricholaena repens*) covering the interspaces. Pili occurs in solid to scattered areas in the open, rocky places.

Forest formation.—This formation is found above the shrub formation on the leeward dry areas and down to sea level on the windward areas. Forest cover extends from an altitude of about 1,000 to 9,000 feet. Within this formation, however, there is considerable variation resulting from the varying aspects of topography in relation to prevailing winds, rainfall, and differing temperatures produced by altitude, lava flows, cultivation, and grazing.

In this formation there are tall trees and an undergrowth of shrubs and ferns intermixed with tangling vines. At higher altitudes where fogs are common, the trees are covered with epiphytes. At the lower elevations, kukui trees (*Aleurites moluccana*) 25 to 50 feet tall form a conspicuous light-colored canopy along the gully bottoms. On the

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lower island, koa (*Acacia koa*) forms a prominent part of the forest from about 1,000 to 6,500 feet elevation. Koa is usually scrubby and heavily branched at lower elevations, but grows into large trees at elevations between 4,000 and 6,500 feet. Mamani (*Sophora chrysophylla*) is found at elevations ranging upward from 5,000 feet to the timberline at 9,000 feet. Ohia lehua (*Metrosideros polymorpha*) is the characteristic tree in the wet forests at altitudes of 1,500 to 4,000 feet and on new lava flows at lower altitudes. Along the dry coastal alluvial flats and gullies, algaroba (*Prosopis chilensis*) trees 40 to 50 feet tall form a good growth. These algaroba trees form a solid stand on the flats and a rather open growth on the slopes. Swollen fingergrass (*Chloris inflata*) makes excellent growth where the stand of algaroba trees is somewhat open, and where the trees are thick, bristly foxtail (*Setaria verticillata*) is dominant. The growth of these grasses is most conspicuous during the rainy season.

Parkland formation.—This formation occurs on the upper slopes of the high mountains on the islands of Maui and Hawaii. It is dominant at an altitude of about 7,000 feet, where the climate is dry and cool.

The vegetation characteristically consists of scattering clumps of trees and occasional shrubs. Common plants are naenae (*Raillardia* sp.), mamani (*Sophora chrysophylla*), naio (*Myoporum sandwicense*), ohelo (*Vaccinium reticulatum*), puakeawe (*Styphelia tameiameiae*), aalii (*Dodonaea eriocarpa*), bracken fern (*Pteridium aquilinum* var. *decompositum*), heu pueo (*Trisetum glomeratum*), and mountain pili (*Panicum tenuifolium*).

Bog formation.—This formation is found in areas of extremely high rainfall at altitudes ranging from 4,000 to 6,000 feet. The topography is normally level. Drainage is poor, and channels of water occur between hummocks of generally low and stunted plants. Common plants in this specialized type of vegetation are violets (*Viola* sp.), sundew (*Drosera longifolia*), ohia lehua, plants of the *Plantago*, *Lobelia*, *Cyperus*, and *Panicum* species, and moss. The bigger plants, such as ohia lehua and those of the *Lobelia* species form small clumps on the tops of isolated hummocks and are completely or partly covered with moss. Plants of the *Cyperus* and *Panicum* species form tufts in colonies.

Moss-lichen formation.—This formation is found above timberline on the summits of high mountains. It is alpine in character. Rainfall is low and frost is frequent. Snow covers the ground occasionally during the winter months but seldom persists except in depressions near the summits. This formation is above the zones occupied by seed-bearing plants. The ground is barren of higher plants. Occasional chance clumps of silversword (*Argroxiphium* sp.) (see pl. 4, *B*) and kalamaloa (*Deschampsia nubigena*) have been recorded.

FOREST TYPES

The original native forests may be classified into four types: (1) Dryland, (2) Ohia, (3) Koa, (4) Mamani.

Dryland forest type.—On the leeward areas and on old lava flows ranging from sea level to about 2,000 or 3,000 feet, there is a distinct dryland type of forest cover dominated by native Hawaiian species—

wiliwili (*Erythrina monosperma*), ohe makai (*Reynoldsia sandwicensis*), and olopua (*Osmanthus sandwicensis*) (pl. 1).

In the gully bottoms and moist locations, kukui (*Aleurites moluccana*) often forms distinctive stands. It occurs on both windward and leeward sides of the islands and merges into some parts of the Ohia forest type.

Ohia forest type.—Semimoist to wet areas at altitudes ranging from 500 to about 6,000 feet are occupied by this forest type (pl. 2). It replaces the Dryland forest type as increased elevation and gaps in the mountain formations bring more rainfall. Ohia lehua is the dominant species, but in this type are found Hawaiian ebony (*Diospyros sandwicensis*), loulu palm (*Eupritchardia* sp.), kolea (*Myrsine lessertiana*), kopiko (*Straussia kaduana*), and tree fern (*Cibotium chamissoi*).

Within the Ohia forest type are found bog areas such as the Alakai Swamp on Kauai, and Eke Crater and Puu Kukui on the island of Maui. In these areas *Metrosideros* persists as small trees or shrubs and is accompanied by various species of *Lobelia* or by other plants.

Koa forest type.—The koa, largest and best known of the Hawaiian trees, generally reaches its best development at elevations between 4,000 and 6,500 feet on the islands of Maui and Hawaii (pl. 3). These trees grow as much as 60 feet high and have diameters of 10 to 12 feet. The rainfall is about 40 to 50 inches annually. Remnants indicate there must have been an excellent stand of koa around the south and west slopes of Mauna Loa, Mauna Kea, and Puu Hualalai before large development of cattle ranches began.

It is interesting to note that the two trees outstanding in number and commercial value—ohia lehua and koa—show their best development on the island of Hawaii, which is considered the most recent geologically, and particularly on the slopes of Mauna Loa, which still has periods of volcanic activity. Koa will often show vigorous root sprouting and prolific seed germination where light fires have occurred, but growth on the geologically older soils tends to be twisted and scrubby. In contrast, young, well-formed, vigorously growing koa trees are noted on the new soils on the slopes of Mauna Loa.

Koa is one of the few native Hawaiian trees that will handle satisfactorily in nurseries and was therefore used for several years in an effort to reestablish koa forests. Results on older soil formations have been uniformly disappointing. Frequently the trees die out after 15 or 20 years.

Ohia lehua is difficult to handle and not satisfactory for nurseries and planting. The natural regeneration shows the same tendencies as for koa. The more recent soil formations produce large well-formed trees; the older formations, small scrubby ones.

Mamani forest type.—At about 5,000 feet on the islands of Maui and Hawaii the stands of ohia lehua begin to thin out, and mamani (*Sophora chrysophylla*) becomes the dominant tree (pl. 4, *A*). In many areas it continues to an elevation of 9,000 feet, and to limited extent, up to 10,000 feet. Some of the trees commonly found with mamani are naio (*Myoporum sandwicense*) and koa (*Acacia koa*).

Introduced forest type.—In addition to the native forest types already described, there is an introduced, distinct, dryland forest type

TABLE 4.—*Classification of introduced trees as to suitable climate, planting site, and uses in the Hawaiian Islands*

[[1] Normally trees will not grow satisfactorily in areas receiving less than 25 inches of annual rainfall, but many species do excellently in areas averaging around 30 inches. Distribution of rainfall and the presence of underground water flow from areas of higher rainfall affect this in some areas. Because of frequent concentration of rainfall and prolonged dry periods, it is considered advisable to list areas of 20 to 40 inches of rainfall as arid.

[[2] Spacing of trees in the field: (1) In forest planting, trees normally should be planted 8 by 8 to 10 by 10 feet for good form and growth for timber; this spacing requires thinning when the trees are 25 to 30 feet high to prevent crowding of crown space and reduced growth rate; (2) for purely watershed planting, spacing can be spread to 15 by 15 or 20 by 20 feet; (3) on areas subject to heavy winds, spacing should be reduced to 8 by 8 or 8 by 12 feet for mutual support in young stages]

Species	Common name	Climate [1]											Planting sites [2]					Tree class [3]				Special use
		Arid		Semidry		Semiwet			Wet		Very wet		I	Ia	Ib	II	III	1	2	3	4	
		Low	*High*	*Low*	*High*	*Low*	*Medium*	*High*	*Low*	*High*	*Low*	*High*										
Acacia confusa	Formosan koa	x [4]		x		x	x						x		x			x				
Acacia melanoxylon	Blackwood			x	x		x	x					x	x	x	x		x	x		x	
Albizzia moluccana	Siris			x		x							x			x		x				
Alnus nepalensis	Nepal alder						x	x		x		x			x	x	x	x			x	
Araucaria excelsa	Norfolk pine			x		x	x		x	x			x		x	x		x			x	
Bischafia javanica	Tuai			x		x			x				x			x		x			x	
Bucida buceras	Jucaro			x		x			x							x			x	x	x	
Casuarina equisetifolia	Beach ironwood	x		x		x			x				x					x				Beach windbreak.
Casuarina glauca	She oak	x		x		x	x		x					x	x			x				Scar planting.
Casuarina montana	Mountain ironwood		x		x		x	x		x				x	x			x				Scar and windbreak.
Cedrela australis	Australian redcedar			x		x	x		x							x		x		x		Furniture-pattern lumber.
Cedrela mexicana	Cigar-box cedar			x		x	x		x							x		x		x		Do.
Chamaecyparis lawsoniana	Port Orford cedar				x		x	x		x		x	x			x			x	x	x	Cedar chests, ship plank, poles.
Cinnamomum camphora	Camphor			x		x	x		x							x				x		
Cryptomeria japonica	Sugi				x		x	x		x		x	x		x	x		x	x		x	
Cupressus lusitanica	Portuguese cypress				x		x	x		x			x		x	x		x	x		x	
Cupressus macrocarpa	Monterey cypress				x		x	x		x		x	x		x	x		x			x	
Enterolobium cyclocarpum cyclocarpum	Earpod			x		x			x				x			x		x			x	
Eucalyptus citriodora	Lemon gum	x		x		x	x		x				x			x		x	x		x	
Eucalyptus pilularis	Black butt			x		x	x		x		x		x		x	x		x	x		x	
Eucalyptus deanei	Silky gum		x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x			
Eucalyptus saligna	Flooded gum		x	x	x	x	x		x	x	x	x	x		x	x	x	x	x		x	
Eucalyptus sideroxylon	White ironbark	x	x	x	x	x	x						x	x	x	x		x	x		x	
Eucalyptus robusta	Swamp mahogany			x	x	x	x	x	x	x	x	x	x		x	x	x	x	x			
Eucalyptus botryoides	Bangalay		x	x	x	x	x	x					x		x	x		x	x		x	
Grevillea robusta	Silk oak			x		x	x	x					x			x		x			x	
Juniperus bermudiana	Juniper		x	x	x		x			x			x			x		x	x	x		Posts, cedar chests.
Melaleuca leucadendron	Paperbark			x	x	x	x		x		x		x			x	x	x	x		x	
Ochroma lagopus	Balsa			x		x			x							x		x		x		Lightest wood known
Pinus caribaea	Slash pine		x		x		x	x		x			x		x	x		x			x	
Pinus patula	Softleaf pine		x		x		x	x		x			x		x	x		x			x	

Pinus pinea	Stone pine	-----	x	-----	x	-----	x	x	-----	x	-----	-----	x	-----	x	x	-----	x	-----	-----	x	
Pinus taeda	Loblolly pine	-----	x	-----	x	-----	x	x	-----	x	-----	-----	x	-----	x	x	-----	x	-----	-----	x	
Quercus suber	Cork oak	-----	-----	x	-----	x	x	-----	-----	-----	-----	-----	-----	-----	-----	x	-----	x	-----	x	-----	Bark is the source of cork.
Samanea saman	Monkey pod	-----	-----	x	-----	x	-----	-----	x	-----	-----	-----	x	-----	-----	x	-----	x	-----	x	-----	
Santalum album	Indian sandalwood	x	-----	x	-----	x	-----	-----	-----	-----	-----	-----	x	-----	-----	x	-----	x	-----	x	-----	
Sequoia sempervirens	Redwood	-----	-----	-----	x	-----	x	x	-----	x	-----	x	x	-----	-----	x	-----	x	x	-----	x	
Swietenia mahogani	Mahogany	-----	-----	x	-----	x	-----	-----	x	-----	x	-----	x	-----	-----	x	-----	x	x	x	-----	
Tamarindus indica	Tamarind	-----	-----	x	-----	x	-----	-----	x	-----	-----	-----	x	-----	-----	x	-----	x	-----	-----	-----	
Tecoma pentaphylla	Yokewood	-----	-----	x	-----	x	-----	-----	x	-----	-----	-----	-----	-----	-----	x	-----	x	-----	x	x	
Tabebuia Donnel-Smithi	Primavera	-----	-----	x	-----	x	-----	-----	x	-----	-----	-----	-----	-----	-----	x	-----	x	-----	x	x	
Tectona grandis	Teak	-----	-----	x	-----	x	-----	-----	x	-----	-----	-----	-----	-----	-----	x	-----	x	x	x	-----	Ship plank.
Terminalia myriocarpa	Jahlna	-----	-----	x	x	x	x	-----	x	x	x	-----	-----	-----	-----	x	-----	x	x	-----	x	
Thuja plicata	Western redcedar	-----	-----	-----	x	-----	x	x	-----	x	-----	x	x	-----	-----	x	-----	x	x	-----	x	Shingles, posts, poles.
Tristania conferta	Brush box	-----	-----	x	x	-----	x	x	-----	x	-----	-----	x	-----	-----	x	-----	x	x	-----	x	

[1] Climate is roughly divided by elevation and rainfall into the following zones:

Type:		*Elevation*	*Rainfall*
Arid	Low	0 to 2,000 feet	20 to 40 inches.
	High	2,000 to 7,000 feet	
Semiarid	Low	0 to 3,000 feet	40 to 60 inches.
	High	3,000 to 7,000 feet	
Semiwet	Low	0 to 1,000 feet	60 to 80 inches.
	Medium	1,000 to 3,000 feet	
	High	3,000 to 7,000 feet	
Wet	Low	0 to 2,000 feet	80 to 150 inches.
	High	2,000 to 5,000 feet	
Very wet	Low	0 to 2,000 feet	150 to 500 inches.
	High	2,000 to 5,000 feet	

[2] Planting sites are divided as follows:

- I Shallow ridge tops and slopes.
- Ia Erosion areas exposing subsoil.
- Ib Windswept ridges.
- II Deep soil in valley bottoms and on lower ridge slopes.
- III Poorly drained and swampy soils.

[3] Trees are listed in four classes according to their best use:

1. Trees for watershed cover that will reproduce themselves, maintain high shade, grow rapidly, and encourage growth of low cover.
2. Trees suitable for general planting that will produce high-quality fence posts and telephone poles.
3. Trees suitable for planting outside watersheds that will produce high-quality hardwood, veneer woods, or have other special qualities of economic importance.
4. Trees suitable for rough construction lumber.

[4] Symbol "x" indicates that species is suitable for the climate and planting site indicated at the head of the column in which it occurs, and also the tree class to which the species belongs.

at elevations ranging from sea level to about 1,500 feet (pl. 4, *C*). Dominant in this forest type is the algaroba (*Prosopis chilensis*). This tree started from a few seeds brought by Father Bachelot, a French priest who came to the Islands in 1820. His planting at the Catholic Church grounds in Honolulu has been spread over the major part of lower dry areas on all the islands, partly by planting and partly by cattle feeding on the beans.

REFORESTATION

Need for reforestation grew as vast areas of native forest were destroyed by grazing. Difficulties encountered in attempting reforestation with native species led to introduction of many foreign species and their trial in general plantings and in arboreta. During a period of about 25 years, some 200 introduced species have been tried under varying conditions, and from these 45 species have been selected as giving generally most satisfactory results. Table 4 lists selected species according to the climatic-elevation zone and the usefulness of the trees and products.

The problem of water supply has given reforestation its main impetus, but growing attention to land classification and removal of marginal sugar and pineapple areas from cultivation have stimulated interest in planting for timber production. Estimates for early plantings and records of later years show that some 34,000 acres of Government forest land and 58,000 acres of private holdings have so far been planted.

***SOILS ARE** used and managed in a cultural and economic environment. The authors of this section describe the use of land as property so we may know the pattern into which soil use and management must fit.*

LAND UTILIZATION

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THE LAND area of the Hawaiian Islands, about 4,100,000 acres, is broken down by various uses in table 5, and by ownership, in table 6. By calculating percentages from acreages given in table 6 and adding figures on valuation from the 1948 report of the Tax Commissioner (*10*), we arrive at a tabulation of ownership and assessed valuation as follows:

HAWAIIAN ISLANDS

Class of ownership:	*Ownership (percent)*	*Assessed valuation (percent)*
Government agencies:		
Territorial	33. 0	8
Federal	5. 5	33
Hawaiian Homes Commission, city and county	4. 2	1
Private	57. 3	58

As indicated in the foregoing tabulation, the area of Government-owned land is large, about 42.7 percent of the Hawaiian Islands. Most of the land owned by the Territorial Government is used for forest reserves or grazing, or is wasteland. The primary purpose of the forest reserve is to provide plant cover that will prevent rapid runoff and erosion during rains. The Territorial land has a low assessed value. The Federal agencies own a proportionally small acreage, but the area owned by the Armed Forces has a high assessed valuation. The Hawaiian Homes Commission, established in 1920 for resettling Hawaiians on the land, has the smallest acreage and a very low assessed valuation. The high-value lands are mainly those privately owned or held by the Federal Government.

Most of the private lands are held by a few trusts, corporations, and individuals. In 1948, 15 percent of the privately owned land was held by the largest owner, and 69 percent, by the 50 largest owners. All private owners, other than the 50 largest ones, held only 31 percent of the private lands in the Islands (*6*).

UTILIZATION OF AGRICULTURAL LAND

The acreages of agricultural land used for plantation crops, diversified crops, and pasture are given in table 7. As therein shown, the 1951 acreage in cultivated crops was only about 18 percent of the total agricultural land; the rest was in pasture. Also, of the proportionately small acreage cultivated, 95 percent was used for two crops—sugarcane and pineapple. The value and volume of sugarcane, pineapple, and other crops produced in the Hawaiian Islands are given in table 8, and the number of commercial agricultural enterprises and number of farms, in table 9.

TABLE 5.—*Land utilization in Hawaii, by islands and for the Territory, 1951*

[Sources: For agricultural land, forest reserve, and total land area, University of Hawaii Agricultural economics report (*14*), for land use by Army, Navy, Air Force, and National parks, the Surveyor of the Territory.]

Item	Territory		Hawaii		Maui and Kahoolawe		Lanai and Molokai		Oahu		Kauai and Niihau	
	Acres	*Percent*	*Acres*	*Percent*	*Acres*	*Percent*	*Acres*	*Percent*	*Acres*	*Percent*	*Acres*	*Percent*
Agricultural land	1, 706, 000	41. 6	1, 100, 000	42. 7	204, 000	41. 3	125, 000	48. 7	90, 000	23. 9	187, 000	46. 9
Forest reserve	1, 210, 155	29. 5	716, 250	27. 8	160, 055	32. 4	52, 805	20. 6	120, 425	31. 9	160, 620	40. 3
Army, Navy, and Air Force land	58, 367	1. 4	727	(1)	1, 341	0. 3	24	(1)	54, 195	14. 4	2, 080	0. 5
National parks	[2] 213, 403	5. 2	[2] 196, 273	7. 6	17, 130	3. 5	0	------	0	------	0	------
Other land [3]	911, 915	22. 2	560, 190	21. 8	[4] 111,554	22. 6	78, 811	30. 7	112, 340	29. 8	49, 020	12. 3
Total land area	4, 099, 840	100. 0	2, 573, 440	100. 0	494, 080	100. 0	256, 640	100. 0	376, 960	100. 0	398, 720	100. 0

[1] Less than 0.1 percent.
[2] Of this total 48,652 was authorized by Congress but has not yet been officially turned over by the Territory to the National parks.
[3] Cities, towns, campsites, roads, wasteland, and land not otherwise specified.
[4] Includes the whole area of Kahoolawe, or 28,800 acres.

TABLE 6.—*Government and privately owned lands in the Hawaiian Islands, 1948* [1]

Item	Territory	Hawaii	Maui	Molokai	Lanai	Kahoo-lawe	Oahu	Kauai	Niihau	Molo-kini, Lehua, and Kaula
Federal land:	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*
U. S. Army	30, 917	727	18	10	-------	-------	28, 082	2, 080	-------	-------
U. S. Navy	29, 728	-------	2, 682	275	-------	-------	26, 764	7	-------	-------
Department of Interior (National park)	164, 891	147, 621	17, 270	-------	-------	-------	-------	-------	-------	-------
Other Federal lands	1, 207	249	209	77	11	23	156	78	-------	404
Total	226, 743	148, 597	20, 179	362	11	23	55, 002	2, 165	-------	404
Territorial land:										
Board of Agriculture and Forestry	670, 620	448, 355	103, 503	14, 013	-------	-------	27, 955	76, 795	-------	-------
Other territorial lands	685, 389	552, 668	45, 265	10, 375	71	28, 800	17, 208	30, 986	15	-------
Total	1, 356, 009	1, 001, 023	148, 768	24, 388	71	28, 800	45, 163	107, 781	15	-------
Other Government-owned land:										
Hawaiian Homes Commission	169, 385	91, 535	20, 108	25, 976	-------	-------	3, 027	28, 739	-------	-------
Honolulu City and County and other counties	4, 083	478	623	341	-------	-------	764	1, 877	-------	-------
Total	173, 468	92, 013	20, 731	26, 317	-------	-------	3, 791	30, 616	-------	-------
Total Government-owned land	1, 756, 220	1, 241, 633	189, 678	51, 067	82	28, 823	103, 956	140, 562	15	404
Privately owned land	2, 362, 607	1, 337, 567	276, 242	115, 333	90, 158	-------	282, 604	214, 638	46, 065	-------
Territorial total [2]	4, 118, 827	2, 579, 200	465, 920	166, 400	90, 240	28, 823	386, 560	355, 200	46, 080	404

[1] Based on Report of the Commissioner of Public Lands and Surveyor of the Territory of Hawaii for the 2 years ending June 30, 1948 (*9*)
[2] Island totals in this table and table 5 based on different surveys.

TABLE 7.—*Utilization of agricultural lands in Hawaii, by islands and for the Territory, 1951*

[Source. University of Hawaii agricultural economics report (*14*)]

Item	Territory		Hawaii		Maui		Molokai and Lanai		Oahu		Kauai and Niihau	
	Acres	*Percent* [1]	*Acres*	*Percent* [1]	*Acres*	*Percent* [1]	*Acres*	*Percent* [1]	*Acres*	*Percent* [1]	*Acres*	*Percent* [1]
Plantation crops:												
Sugarcane [2]	221, 215	13. 0	101, 380	9. 2	38, 925	19. 1	0	------	35, 230	39. 2	45, 680	24. 4
Pineapples [3]	73, 600	4. 3	400	0	12, 600	6. 2	32, 100	25. 7	21, 800	24. 2	6, 700	3. 6
Total plantation crops [4]	294, 810	17. 3	101, 780	9. 2	51, 520	25. 3	32, 100	25. 7	57, 030	63. 4	52, 380	28. 0
Diversified crops: [5]												
Coffee [6]	3, 500	------	3, 500	------	0	------	0	------	0	------	0	------
Corn, field [7]	625	------	312	------	218	------	80	------	0	------	15	------
Fruits, tree [6]	1, 932	------	294	------	228	------	92	------	1, 292	------	26	------
Nuts, macadamia [8]	2, 197	------	1, 476	------	276	------	2	------	180	------	263	------
Rice [7]	166	------	0	------	0	------	0	------	0	------	166	------
Taro [6]	871	------	153	------	95	------	50	------	411	------	162	------
Vegetables [7]	4, 703	------	1, 323	------	1, 484	------	56	------	1, 595	------	245	------
Total diversified crops [4]	14, 000	0. 8	7, 060	0. 6	2, 300	1. 1	280	0. 2	3, 480	3. 9	880	0. 5
Total land in crops [4]	308, 810	18. 1	108, 840	9. 9	53, 820	26. 4	32, 380	25. 8	60, 510	67. 2	53, 260	28. 5
Pasture land [4]	1, 397, 000	81. 9	991, 000	90. 1	150, 000	73. 5	93, 000	74. 4	29, 000	32. 3	134, 000	71. 5
Total agricultural land [4]	1, 706, 000	100. 0	1, 100, 000	100. 0	204, 000	100. 0	125, 000	100. 0	90, 000	100. 0	187, 000	100. 0

[1] Percentage of total agricultural land.
[2] Acreage at end of 1951 is rounded.
[3] Acreage at end of 1951, including fallow land, campsites, and roads, is rounded.
[4] Figures are rounded.
[5] Commercial acreage only; acreage of flowers and a few unimportant crops such as cotton and grapes not included.
[6] Average acreage during 1951.
[7] Plantings for 1951 harvest.
[8] Acreage at end of 1951.

TABLE 8.—*Wholesale value and volume of agricultural products produced commercially in the Hawaiian Islands, 1952* [1]

Item	Volume	Value
		1,000 dollars
Sugar, raw [2] ... tons	1, 020, 450	[3] 138, 860
Molasses [2] ... do	250, 000	
Pineapples: [4]		
Canned fruit ... cases	13, 905	[5] 100, 000
Canned juice ... do	9, 650	
Total plantation crops	----------	238, 860
Fruits, fresh (except pineapples) ... 1,000 pounds	15, 700	1, 125
Vegetables, fresh ... do	47, 080	4, 582
Taro (for manufacture) ... do	12, 180	542
Coffee, green [6] ... do	7, 700	3, 900
Corn, field, shelled ... do	380	22
Macadamia nuts, unshelled ... do	965	165
Rice, milled ... do	845	136
Flowers	----------	3, 000
Total diversified crops	----------	13, 472
Beef cattle ... head	34, 200	8, 662
Dairy products:		
Butcher cows and calves ... head	2, 620	655
Milk ... 1,000 quarts	37, 442	7, 301
Sheep products:		
Mutton ... head	2, 460	40
Wool ... 1,000 pounds	55	35
Swine ... head	66, 900	3, 951
Poultry products:		
Eggs ... 1,000 dozens	4, 753	3, 722
Meatbirds ... number	793, 000	1, 345
Bee products:		
Honey, extracted ... 1,000 pounds	584	56
Beeswax ... do	7	3
Total livestock, poultry and bee products	----------	25, 770
Total livestock and diversified crops	----------	39, 242
Total agricultural marketings	----------	278, 102

[1] All data are for calendar year 1952, unless otherwise indicated.
[2] Data from Hawaiian Sugar Planters' Association.
[3] Approximate value of raw sugar, molasses, and Sugar Act Conditional Payments to Hawaiian sugarcane producers.
[4] Pineapple data are for fiscal year ended May 31, 1952.
[5] Approximate value of total pack.
[6] Estimates for crop year ended June 30, 1952.

SUGAR

Growing and processing of sugarcane is the oldest and largest agricultural industry in the Hawaiian Islands. Sugarcane was indigenous to Hawaii at the time of its discovery, but production had reached only 2 tons in 1837. By 1876, production had increased to 13,036 tons of raw sugar per year (*8*). Production reached a peak of slightly more than 1 million tons a year in the early 1930's, and then gradually

TABLE 9.—*Number of commercial agricultural enterprises and number of farms, by islands and for the Territory of Hawaii, 1952*

[Sources: U. S. Department of Agriculture, Production and Marketing Administration, for number of sugar growers; Pineapple Research Institute of Hawaii for number of pineapple growers; University of Hawaii agricultural economics report (*14*) for all other enterprises.]

Enterprise	Territory	Hawaii	Maui	Molokai and Lanai	Oahu	Kauai and Niihau
Beef cattle [1]	405	226	90	21	20	48
Sheep [1]	3	2	0	0	0	1
Dairy [2]	76	20	6	2	44	4
Hogs [2]	588	96	71	37	344	40
Poultry [2]	378	132	33	5	184	24
Bees [1]	25	3	12	3	5	2
Total livestock	1, 475	479	212	68	597	119
Taro	280	92	87	11	33	57
Other vegetables	1, 465	308	360	48	659	90
Fruits	343	104	81	8	144	6
Coffee	706	705	1	0	0	0
Macadamia nuts	99	63	9	3	4	20
Rice	53	0	0	0	0	53
Flowers	632	334	45	0	240	13
Total diversified crops [1]	3, 578	1, 606	583	70	1, 080	239
Total commercial diversified enterprises [3]	5, 053	2, 085	795	138	1, 677	358
Total diversified farms [4]	3, 642	1, 396	583	83	1, 325	255
Sugar:						
Plantations	28	13	3	0	4	8
Small planters	1, 501	1, 489	0	0	0	12
Pineapple:						
Plantations	15	1	3	4	3	4
Small growers	111	0	74	0	1	36
Total sugar and pineapple [1]	1, 655	1, 503	80	4	8	60
Total commercial enterprises [3]	6, 708	3, 588	875	142	1, 685	418
Total farms [4]	5, 249	2, 883	638	87	1, 333	308

[1] Dec. 31, 1952.
[2] Aug. 31, 1952.
[3] Some farms have more than 1 enterprise.
[4] In this estimate, each farm is listed only once, regardless of number of enterprises.

declined to 680,000 tons in 1946. Since then it has increased steadily and exceeded one million tons in both 1952 and 1953. The acreage in sugarcane increased from 127,000 in 1900 to 252,000 in 1934 and then declined to 222,000 in 1952 (*5*).

The increase in sugarcane production following 1875 has been encouraged by favorable Federal policies. The United States signed

a reciprocal trade agreement with Hawaii in 1875. Annexation of Hawaii in 1898 brought the islands within the United States tariff system. A series of Federal acts such as the Jones-Costigan Act of 1934, the Sugar Act of 1948 and the 1951 amendment, all included Hawaii within the sugar quota system of the United States.

Capital invested in the sugar industry was estimated at more than 175 million dollars in 1952 (*5*). The wholesale value of 1,020,000 tons of raw sugar and the 250,000 tons of molasses produced that year amounted to almost $139,000,000 (table 8). Close to 222,000 acres was in cane in 1952. The crop requires 18 to 24 months to mature, so the area harvested that year was about 108,000 acres, with an average yield of 9.44 short tons of sugar per acre (*5*).

Most of the land now occupied by sugarcane consists of former forested areas, useless arid areas, or semiarid pasture land. The sugarcane acreage is in lowland tracts; attempts to grow it at levels above 2,000 feet are seldom made. About 2,000 tons of water is needed to produce a ton of sugar. Slightly more than half of the cane area is irrigated, and this irrigated part produces a little less than two-thirds of the total sugar. The rest of the sugarcane is grown on the wet windward sides of the Islands and is entirely dependent on rainfall (*5*).

Organization of the Industry.—From the beginning, sugar production has been a larger scale operation than typical Mainland farming. The unit of organization is the plantation, which grows the cane and manufactures it into raw sugar. Historically, there has been a steady decrease in the number of plantations, offset by a corresponding increase in their size. In 1952, 28 plantations were in operation (table 9), and the average area planted to sugarcane per plantation was 7,900 acres. The smallest plantation had 600 acres in sugarcane, and the largest, 25,000 acres (*5*). Together, these 28 plantations owned 122,800 acres of caneland and leased 89,800 acres from the government and private owners (*5*).

Five large agencies, called sugar factors, serve the plantations. These factors handle the fiscal matters of the plantations, much of their purchasing, and the shipping of sugar and molasses. The Hawaiian Sugar Planters' Association is the central organ that coordinates policy, planning, and research for the Hawaiian sugar industry.

Physically, each plantation consists of the land controlled by the company, the sugar mill, shops and central offices, a transportation system, the plantation town, and villages for plantation employees. In addition to the land used for growing sugarcane, many sugar companies hold considerable acreages of nonarable land used mainly for water conservation or grazing.

The plantation town usually has a business district with stores, a motion picture theater, a recreation field and gymnasium, a hospital, and such public services as electric lighting, a water system, and police and fire protection (*7*).

Growing and Processing.—Sugarcane has to be milled within a few days after it is cut. Production schedules therefore must be planned carefully so that cane will be continuously delivered in quantities large enough, but not too large, to keep the mill at full operating capacity. Field operations are highly mechanized; tractors, heavy mechanical

harvesting equipment, and large trucks or narrow-gage railways are used.

The optimum ripening period for cane lasts from the latter part of March to the end of July. By proper control of cultural practices, sugarcane can be ripened and harvested any month of the year in Hawaii. To keep the permanent labor force employed, plantations harvest their cane during 9 to 11 months of the year. During off-season months, the labor force is employed at repair and upkeep work, as well as regular agricultural operations.

In 1952 approximately 1,500 small sugar growers had under cultivation about 24,000 acres, or about 11 percent of the total sugarcane acreage. All but 12 of these family-sized farms were located on the island of Hawaii.

The small sugar growers have two types of agreements with the plantations: as adherent planters or as independent growers. Under the adherent planter arrangement, plantations have the right to make many basic decisions in the operation of the small cane farms, such as the timing of planting and harvesting. They also furnish fertilizer, weedkillers, seed cane, and other supplies at a charge approximating cost, and finance the farming operations of the adherent planters. The planters usually care for the crop from planting until harvesting.

In 1951 the plantations offered to small growers a so-called independent grower contract which gave the small growers greater independence in the management of their farms. In most instances, they are being financed by commercial banks. Early in 1953 almost 80 percent of the small sugar planters were operating under the new arrangement. This constitutes the first break in the long trend of centralization and integration in the Hawaiian sugar industry.

Developments in the Industry.—Until the early 1930's the sugar plantations found it profitable to intensify cultivation in terms of labor, fertilizer, and irrigation, and to extend acreage to areas less suited to sugar production. The rise in wages between 1933 and 1940, the wartime labor and equipment shortage, the further sharp rise in wages since 1944, and the increase in other production costs have forced the industry to make many changes.

The plantations are combating higher labor costs with more mechanization, labor-saving practices, and efforts to increase yields per acre. Fields that cannot be worked with mechanical equipment have largely been abandoned. Small isolated plantations have been liquidated. Overhead costs per ton of sugar have been reduced by merging adjoining companies and thus increasing the size of plantations. New varieties of cane have been introduced. More scientific and efficient agricultural methods have been developed, and the handling of sugar in bulk rather than in sacks has become more and more common.

Hawaiian sugarcane growers, like other domestic cane and beet producers, receive Federal subsidies, the so-called conditional payments, from the United States Department of Agriculture. Under the assumption that sugar prices and Federal subsidies remain near present levels, the leaders of the Hawaiian sugar industry expect to stabilize production at about 1.1 million tons of raw sugar. In the 1951 amendment of the Sugar Act of 1948, Hawaii's quota for the continental United States was continued at 1,052,000 tons of raw

sugar. An additional quantity of refined sugar is annually allowed to Island producers for sale in Hawaii, amounting to 42,000 tons in 1952.

PINEAPPLE

Pineapple production is the second most important agricultural industry in the Hawaiian Islands (pl. 5, *A*). Canned pineapple juice and fruit are the major products. Pineapple producers proudly point out that practically all of the fruit is used in the cannery processes. Some of the byproducts are pineapple pulp and pineapple bran, both used as stock feed, citric acid, alcohol, sugar sirup, and natural sugar. In the postwar period several frozen pineapple products have been developed, such as fresh frozen pineapple chunks and frozen pineapple juice concentrate. Mainland shipments of fresh pineapples are expanding.

Pineapples were exported from Hawaii to the Mainland occasionally in the 1890's, but only 5,000 acres was used by the industry as late as 1909. The ginaca machine for peeling and coring, patented in 1913, gave great impetus to the canning of the fruit. Carefully planned advertising greatly stimulated the demand for the canned pineapple. In 1916 it was found that spraying with solutions of iron sulfate prevented the chlorosis of pineapple plants. This made possible the growing of pineapple in areas well adapted to the crop but high in manganese, as those on the Wahiawa plateau on Oahu. By 1920 the land owned or leased by pineapple companies amounted to about 47,000 acres.

The most productive pineapple areas on the Islands are those within limits of 25 to 60 inches of rain a year. Areas with an average of less than 25 inches of rain annually are usually too arid for the crop, and in most areas with more than 60 inches of average rainfall both the yield and quality may be adversely affected. Irrigation water, if available, is supplied to pineapple fields in some of the drier districts.

On most of the islands, pineapples are grown at altitudes ranging from near sea level to about 1,200 feet. On Lanai and Maui, however, plantings extend to about 2,000 feet. Pineapples make it possible to use many areas not adapted to sugar, including semiarid tracts which would not be economically feasible to irrigate.

Organization of the Industry.—The pineapple industry, like the sugar industry, has developed in the direction of large-scale plantations. In 1952, 9 pineapple companies operated 14 plantations and 9 canneries. A minor portion of the 1952 pineapple crop was raised on about 110 small, nonplantation farms, most of which had made contracts with canneries. About 73,600 acres was used for pineapples; this total included land occupied by fallow fields, roads, campsites, and so on (table 7). In 1946, about 33 percent of the land used for pineapples was owned by the 9 companies, 61 percent was leased by them from various estates, and a small area was leased from the government. The small percentage of pineapple land not owned or leased by the companies was held by homesteaders or small independent growers (*13*).

Some cooperation exists between the various companies, such as in their joint sponsorship of the Pineapple Research Institute of Hawaii, and a certain amount of joint advertising. However, on the whole, the several companies are highly competitive.

Growing and Processing.—The first pineapple crop requires approximately 18 to 22 months to mature. The second and third crops, known as ratoon crops, grow on the already matured plant and require only about 12 months each to mature. The greater the number of ratoon crops, the smaller the average size of the pineapples. The present practice is to grow one ratoon crop, or occasionally two. Before a new crop cycle is begun, the soil is fumigated against nematodes. The field may then be replanted at once or it may be left fallow for periods of 8 to 9 months.

Large-scale machinery is used—crawler tractors, heavy-duty plows, big spraying outfits, harvesting machines equipped with conveyor belts extending over several plant rows, and double-bin truck trailers for transport to the canneries. Day-by-day volume of harvesting must be closely coordinated with operating levels in the canneries. In contrast to the sugar industry, pineapple harvesting and canning tend toward sharp seasonal peaks. There is a major fruiting season in summer, a minor one during winter, and limited sporadic harvesting throughout the year (*7*).

Seasonal workers are essential to the industry. Most of these are housewives and high school and university students. During the postwar years, the industry employed approximately 22,000 persons in the peak seasons and 10,000 in the slack seasons.

Developments in the Industry.—The value of the pineapple output has greatly fluctuated from year to year. Insect pests and plant diseases have made repeated inroads, and climatic factors, particularly variable rainfall, affect quantity and quality of production at times. Market forces have been the major cause of the industry's instability in recent years. Price fluctuations of competing canned fruits and juices, such as canned peaches and grapefruit juice, and lately of concentrated frozen orange juice, are important. Another reason for unstable marketings is the fact that pineapples are a luxury food item. Sales, therefore, are severely reduced by declines of consumer purchasing power during business recessions. The value of the pineapple pack had reached a high of 50 million dollars in 1930 but sank to less than 10 million only 2 years later (*8*). This low was followed by a marked recovery to 59 million dollars in 1937, which was only 4 million dollars less than the total value of sugar shipments in that year (*12*). The following year, however, the value of pineapple and juice declined 36 percent (*7*).

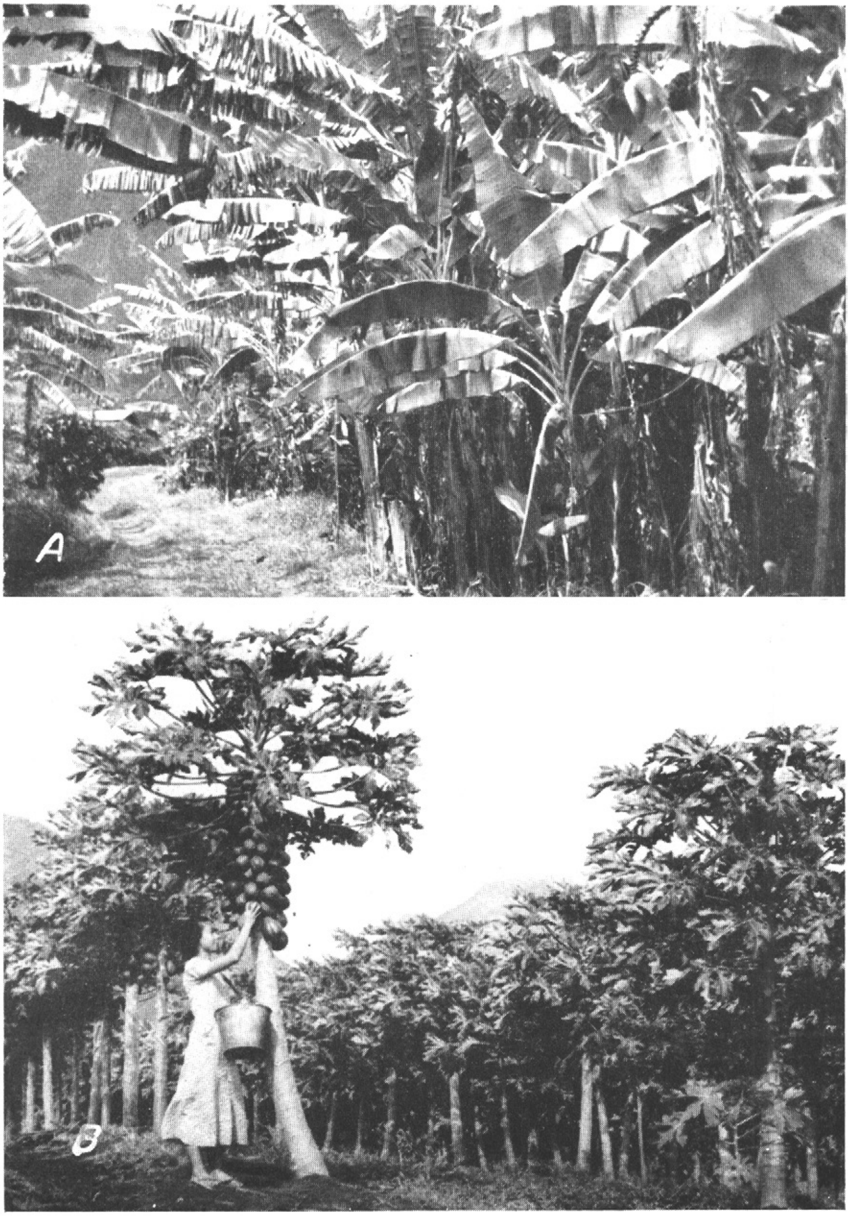
Most of the Island pineapple pack is being consumed within the United States; only a small portion is exported. Hawaii now produces about 80 percent of the Mainland consumption of canned pineapple products. The Island industry may expect more competition on the Mainland, mainly from the Philippines, Cuba, Mexico, and Puerto Rico.

DIVERSIFIED CROPS

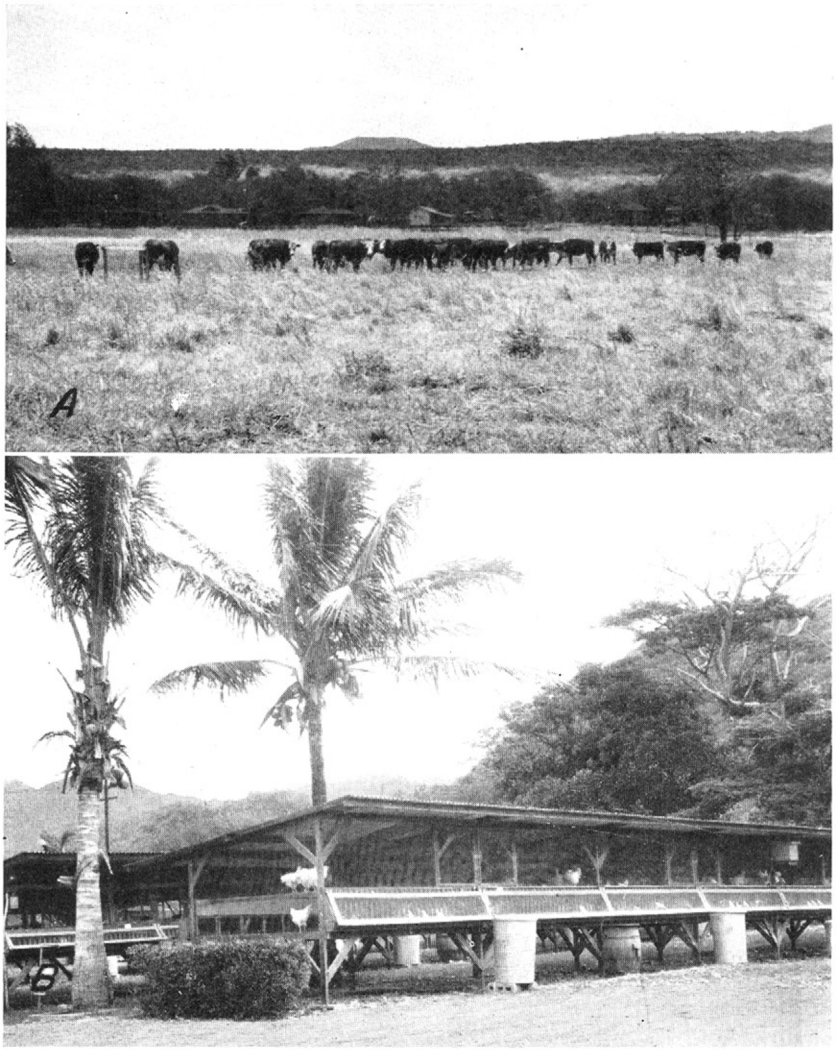
Crops other than sugar and pineapple occupied only about 14,000 acres in 1951, or 0.8 percent of the total agricultural land in the Hawaiian Islands (table 7). Nevertheless, the wholesale value of these crops was high—about 13.5 million dollars (table 8).

Coffee.—The most important of the diversified crops is coffee, which is grown as a family enterprise by about 700 small farmers

A, General view of pineapple field showing terrace and control-grade planting.
B, Tomato production in Hawaii.



Among leading commercial fruits in the Hawaiian Islands are: *A*, bananas; and *B*, papayas.



A, This 10-acre pasture on the island of Molokai accomodates 20 head of cattle for 3 weeks.
B, Most chickens are kept in wire-floored houses such as these on the Hawaii Agricultural Experiment Station.

High school students in Hawaii.

operating groves which are mostly from 5 to 10 acres in size. The total area in coffee was 3,500 acres in 1952, and all of this was on the island of Hawaii.

The prosperity of the Hawaiian coffee industry depends largely on world prices. The industry was hard hit during the depression of the 1930's but became profitable during and after World War II because of high coffee prices. With continuing strong demand and high prices for coffee in 1953, and lagging production in foreign countries, the coffee industry in Kona is expanding.

Macadamia nuts.—These nuts were grown on about 2,400 acres in 1953, and the area is increasing. The nut is of excellent quality, and at the present time the Mainland demand exceeds supply. So far, Hawaii is apparently the only place where macadamia nuts are produced commercially on a significant scale. Up to now production costs were such that the nuts had to be marketed as a luxury item. However, higher yielding varieties might bring costs down to the place where macadamia nuts can compete on a price basis with other nuts on the Mainland market. Macadamia nuts are being planted mostly in areas previously used for grazing or forest. Both corporations and small farmers on all the major islands are engaged in growing macadamia nuts.

Fruits and vegetables.—Of the total consumed in the Islands, about half the fresh fruits and vegetables are grown locally; the rest, as well as most canned, frozen, and dried fruits and vegetables, are imported from the Mainland. Some of the main reasons for these imports are the following:

1. Cost of importing some crops, potatoes and onions, for example, is often less than the cost of producing them in Hawaii.
2. Some crops, such as most deciduous fruits, grow better on the Mainland than in present Island farming districts.
3. Seasonal scarcity of irrigation water is a severe handicap in many districts where vegetables and fruits are now grown.
4. Scarcity of long term leases and of fee simple land at prices low enough for use of crop farmers discourages production.

Commercial orchards.—About 1,900 acres was in commercial fruit orchards in 1951. Bananas accounted for a little less than half of this acreage (pl. 6, *A*), and papayas for slightly more than a fourth (pl. 6, *B*). The rest was mainly in avocados, mangoes, and citrus fruits. A few orchards are owned by corporations, but most of them belong to small-scale farmers. In addition to the commercial acreage, there are many different kinds of tropical- and temperate-zone tree crops grown mainly for home consumption.

Some fresh fruits, particularly bananas and papayas, were exported to the Mainland before World War II. Introduction of the oriental fruit fly (*Dacus dorsalis*) after the war stopped all exports to the Mainland for a time. Sterilization treatments were perfected, however, and nearly 400,000 pounds of fresh papayas were shipped to the Mainland in 1952 (*4*). Mainland exports for canned and frozen tropical fruits and fruit products and jams and jellies are gradually expanding.

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Vegetables.—About 4,700 acres was in vegetables in 1951 (table 7). Taro occupied an additional area of about 900 acres. This is the plant from which poi, the Hawaiians' staff of life is made. The 1951 acreage of taro was less than one-tenth the acreage of this crop at the time Hawaii was discovered (*8*). Most of the taro is grown by the wetland method; that is, the soil is covered by several inches of water most of the time. Some taro, however, is produced in the moist uplands without irrigation.

Great differences in climate in the various areas of the Islands make it possible to grow many different truck crops, but insects and diseases, need for irrigation, and high fertilizer requirements make production costs high. Another factor contributing to high cost is the small scale of most operations. Nevertheless, cabbage, watermelons, tomatoes (pl. 5, *B*), cucumbers, and many other Mainland crops are produced commercially, as well as vegetables preferred by Orientals, such as gobo (burdock), daikon, or watercress.

Most vegetable farms are primarily family operated, only a few are of larger than family size. About four-fifths of the farmers are full-time and the rest part-time operators. A little more than one-third own their farms; the others lease. The majority use tractors and other farm machinery. Most of the farmers are of Japanese extraction.

Export of vegetables to the Mainland is limited to a few specialities such as ginger, lotus root, and dasheen. Some observers believe that prospects are good for winter shipments of such vegetables as snap beans, cucumbers, or green corn to the west coast of the Mainland if production and marketing cost can be kept low enough.

Floral products.—The export of floral products has grown rapidly since World War II and amounted to 410,000 pounds in 1952. The main exports are vanda orchids, anthuriums, and tropical foliage. Many other floral products are produced commercially, mainly for consumption in Hawaii. An estimated 600 acres was used for flower production in 1952. The wholesale value of the commercial floral production in Hawaii was believed to approach 3 million dollars in 1952. Flower growing is largely a part-time enterprise for most growers, particularly those in or near Hilo and Honolulu.

Rice.—Growing of rice was once the second largest agricultural enterprise in Hawaii. The crop occupied 9,400 acres in 1909, but only 160 acres in 1952 (*11*, *4*). Development of the large-scale mechanized rice industry in California doomed the Hawaiian industry, which is limited in the degree of mechanization feasible because of small paddies.

Field corn.—In 1920, during a period of high prices, corn occupied 10,000 acres. The area in this crop was down to less than 400 acres in 1952.

Other crops.—Many crops, including cotton, wheat, tobacco, rubber, silk, and sisal, have been tried in Hawaii. Some of these, such as cotton, are now grown on only a few acres; others, such as silk, rubber, and sisal, proved economically unsound and were abandoned. Wheat and cotton growers were not able to withstand Mainland competition. Tobacco production was tried for many years but never became commercially successful (*3*).

LIVESTOCK

About 82 percent of the agricultural land in Hawaii was used for grazing in 1951 (pl. 7, *A*). The total grazing land was about 1,400,000 acres, and approximately 95 percent of this was used by more than 400 beef ranchers, who ran close to 150,000 head of cattle. Most of the grazing land was used by large-scale ranches. The grazing land not used by cattle ranchers served mainly as pasture for dairy cattle and for two sheep ranches, which together had about 14,000 head of sheep.

Cattle.—The first cattle were brought into Hawaii by George Vancouver in 1793. The cattle industry has been commercially important since about 1830.

Beef.—Production of dressed island beef amounted to 18.6 million pounds in 1952, but this was not sufficient to meet demand. Twenty-eight percent of the fresh, chilled, or frozen beef and veal and all canned, pickled, and cured beef was imported (*4*).

Herefords are the most commonly raised beef breed. Compared to the systems of raising beef cattle in the temperate zones, ranching in Hawaii requires fewer facilities and operations. Haymaking for winter feeding, and substantial storage buildings for feed, are not required in the Islands. Other costs, such as pasture clearing and stock watering, are probably higher in Hawaii than in many Mainland sections.

On the average, one beef animal required about 10 acres of grazing land in 1951. The carrying capacity of rangeland increases in proportion to rainfall until about 60 inches a year is reached. As rainfall increases above 60 inches, pasture decreases in value.

Seasonal or controlled grazing should be practiced in most of the drier sections, due to the seasonal distribution of the rainfall, most of which falls during the winter months. Recent advances in mechanical and chemical methods of clearing land overridden with noxious shrubs and weeds, as well as other improvements in range management, are expected to bring some expansion in beef production.

Dairying.—Hawaiian milk production was nearly 38 million quarts in 1952 (table 8), as compared to 2 million quarts in 1900. In spite of this expansion, consumption of fresh milk in Hawaii is low by Mainland standards. Nearly all of Hawaii's milk output is consumed as fluid milk. A small portion is used for coffee cream and, occasionally, for ice cream. Almost all other dairy products such as butter, cheese, canned, and dried milk are imported.

The 76 dairies operating in Hawaii in 1952 had a total of 10,800 mature dairy cows. For many years the dairies have steadily decreased in number but increased in size. In 1952, 4 of the dairies operating, had more than 800 mature cows each, and another 12 had more than 150 cows each. A good portion of the large dairies are operated by corporations. Most of the dairies are located on Oahu and supply the Honolulu market. Holsteins are the most numerous, followed by Guernseys, Jerseys, and Ayreshires. Dairies have become more efficient by using improved techniques for disease control, weeding out low-producing cows, and using modern dairy equipment.

On Oahu, the usual practice is to keep dairy cows in feed lots. Small acreages are used for growing soiling crops, particularly Napier-

grass. Except for molasses and pineapple bran and pulp, almost all concentrate feeds have to be brought from the Mainland. Some pasturing is done on outlying islands, but little on Oahu. A large portion of the replacement cows are imported from the Mainland.

Swine.—The total number of swine in Hawaii was 8,000 in 1900, but by 1940 this rose to 32,000 head 4 months old and older. Large amounts of garbage available at low prices from Army and Navy kitchens during the war caused a further increase in the swine population to a total of 60,000 head. After the war a scarcity of garbage and its high price resulted in a decline to 39,000 swine past weaning age by 1949. As a result of more grain feeding, the number of weaned swine on Island farms exceeded 60,000 head in 1952, and annual liveweight production reached 11 million pounds (*4*).

The Hawaiian market prefers soft Island-produced pork, but because of lower prices almost half of the fresh, chilled, and frozen pork was imported in 1952 (*4*). All pork provisions as well as all smoked and canned pork were also imported.

Swine production is largely in the hands of people of Okinawan parentage. Duroc, Hampshire, and Tamworth are the predominant breeds. Nearly all the hogs are raised on small farms, the farm family furnishing most of the labor. Most of the hogs are raised in concrete or wooden pens; few are pastured.

Poultry.—In 1952 there were about 380,000 laying hens on 380 commercial farms. These farms produced nearly 4.8 million dozen eggs and about 793,000 meatbirds. The flocks averaged 156 eggs per hen in 1952, slightly lower than the Mainland average. In addition to the commercial flocks, there were many backyard flocks scattered throughout the Islands. Nevertheless, poultry production does not meet Hawaiian demand. In 1952, 2.4 million dozen eggs in the shell, substantial amounts of frozen, dried, and otherwise preserved eggs, and 3.6 million pounds of dressed chickens were imported. The per-capita consumption of poultry products in the Islands is only about half of that on the Mainland (*6*).

Most of the poultry farms in Hawaii are family enterprises. In 1952 only 22 farms had flocks of more than 3,000 hens; 166 farms had flocks of 500 to 3,000 layers; and all the rest had less than 500 hens (*4*).

Most of the chickens are raised in wire-floored houses that keep them off the ground (pl. 7, *B*). Production costs are higher than on the Mainland, but local poultrymen are making strong efforts to reduce them.

Little poultry feed is produced in Hawaii. Practically all the grains and mashes are imported from the Mainland.

LAND USE BY ISLANDS

In this section, land utilization is discussed for the eight major islands of the Territory, beginning with Hawaii in the southeast and ending with Niihau and Kauai in the northwest.

Hawaii.—This island, the largest in the Territory, has a land area of 2,573,000 acres. As shown in table 5, about 43 percent of it was agricultural land in 1951; about 28 percent was forest reserve; approximately 8 percent was in National parks; and the rest was waste-

land or land occupied by cities, towns, roads, and so on. The Kilauea-Mauna Loa sections of the Hawaii National Park contain the two active volcanoes in the Territory—Mauna Loa and Kilauea—and some adjoining extinct craters and lava flows. The Territorial forest covered about 716,000 acres.

Most of the agricultural land is used for grazing. In 1951 only 109,000 acres, or 4 percent, of the island was cultivated. Aside from the sugar plantations, the amount of cropland per farm is small. In the Waimea district the average amount of cropland is 20 acres, and in the other districts often even less. Most farmers use tractors, except those in the Kona district, where the land is too rocky and stony.

Crops.—Sugarcane was grown on 101,000 acres in 1951, or on about 93 percent of the land in crops. The main sugar-growing districts are Kohala, the Hamakua coast, Hilo, Puna, and Kau, all on the windward side of the island. Former sugar acreages on the leeward side of the island in the Kona and Puako districts were abandoned before 1910. Only about 6,000 acres of the sugar acreage is irrigated; the remaining acreage depends entirely on rainfall. There were 13 plantations on the island in 1952; they ranged from 4,000 to 14,000 acres in size and averaged 8,000 acres (*5*).

Pineapples were not produced commercially on the island in 1953 though test plantings in 1951 showed that they are doing well in the Kohala district.

Coffee is grown on the leeward side of the island in the Kona district at altitudes between 800 and 2,200 feet. A belt 2 miles wide and 25 miles long in this area favors coffee production because of its excellent climate, freedom from storms most of the year, and well-drained though shallow soils. Coffee occupied 3,500 acres in 1951.

Macadamia nuts were grown in about 60 orchards covering approximately 1,500 acres in 1951 (table 7). Most of the bearing acreage is on the Hamakua coast and in the Kona district. Major new plantings have been made in the Hilo and Puna districts.

Commercial fruit orchards covered about 300 acres in 1951. Of this total, about 190 acres were in avocados and bananas, mainly in the Kona district. Papayas are of commercial importance in the Puna and Hilo districts, and some citrus is grown in Puna, Hilo, and Kona.

Field corn was grown on about 300 acres in the Kohala district, and in rotation with pasture grasses on the Parker ranch located on the northwestern slopes of Mauna Kea. Some wetland taro is grown on the windward side of the island. Farmers grow about 100 acres of dryland taro in the moist upland areas of the Kona district.

Fresh vegetables were planted on about 1,300 acres in 1951. One of the major truck-crop areas in Hawaii is the Waimea district (2,700 feet) where farmers grow primarily lettuce, cabbage, celery, and other cool-climate crops. Another high-elevation vegetable area (3,000 to 4,000 feet) is on the road from Hilo to Kilauea Crater near the boundary of Hawaii National Park; this area produces mainly cabbage, lettuce, cucumbers, and Italian squash. Smaller vegetable acreages are scattered throughout the Kohala, Hamakua, Hilo, Puna, and Kona districts.

Livestock.—In 1951, more than 200 ranches used about one million acres of grazing land. Most of this land was held by 20

corporations or large individual ranchers that each used 10,000 acres or more. The remaining area was used by family-operated ranches, many of which were operated on a part-time basis.

The carrying capacity of pastures was 9 acres per head of cattle in northern Hawaii, 11 acres in western Hawaii, and 14 acres in eastern Hawaii (*14*). The low carrying capacity in eastern and western Hawaii results because some of the rangeland consists largely of lava flows or is located in very dry areas. The Hilo area is the center of poultry, swine, and dairy production on the island.

Maui.—This island lies to the north northwest of Hawaii. It has a land area of about 465,000 acres divided as follows: Agricultural, 44 percent; forest reserve, 35 percent; parkland, 4 percent; and the rest, towns, campsites, roads, wasteland, and so on.

The Territorial forest reserve (160,000 acres) covers the mountains in the western part of the island, and in the eastern half includes most of the slopes of Haleakala except those on its western side. The Haleakala section of the Hawaii National Park covers about 17,000 acres and includes mainly the vast crater of the dormant volcano, Haleakala.

Crops.—About 54,000 acres were under cultivation in 1951, and of this, 72 percent was occupied by sugarcane. Nearly all the cane is grown under irrigation. Two sugar plantations operate in the lowlands in the center of the island; a third is near Lahaina on the leeward side. Sugar production at Hana, on the eastern end of the island, was abandoned in 1946.

Pineapples were grown on nearly 13,000 acres in 1951 by 3 plantations and about 70 small farmers. One pineapple area is located on the northwestern slopes of Haleakala, and the other on the west end of the island near Lahaina. All the pineapple canning is done by three canneries on the island.

Fruits and nuts, particularly mangoes, bananas, and macadamia nuts, occupied about 500 acres. Wetland taro was grown on about 100 acres along the coast on the windward side of the island. About 1,500 acres was in vegetables. Most of this acreage was in the fertile Kula area on the western slope of Haleakala at elevations of from 2,000 to 3,500 feet. Cabbage, tomatoes, and onions were the major crops, but many other vegetables were produced. The vegetable farms in the Kula area average 15 acres and are mostly cultivated with tractors. Vegetable farms in most other areas on the island are smaller.

Livestock.—Maui had 71 hog farms, 33 poultry farms, and 6 dairies in 1952 (table 9). Rangeland for beef cattle covered about 150,000 acres Most of this range was on 6 ranches, none of which had less than 12,000 acres. The rest of the pastureland was in small ranches, many of which provided only part-time employment.

Kahoolawe.—The island of Kahoolawe, with a land area of about 29,000 acres, is owned by the Territory. It is now uninhabited, unused, and severely wind eroded. Before World War II it was used for cattle grazing. During the war it served as a range for aerial target practice.

Lanai.—Until about 30 years ago, the island of Lanai was a windswept waste supporting about 40 people who tended 400 cattle and a few patches of taro. Then a pineapple company bought practically

the whole island of 90,200 acres. With an investment of about 6 million dollars it developed a modern pineapple plantation (*2*), which covered about 15,000 acres in 1951. The fruit is shipped to Honolulu for canning. The Territorial forest reserve covers 6,100 acres.

Molokai.—The island of Molokai, with a land area of 166,400 acres, had 21 cattle ranches occupying an area of about 93,000 acres in 1951. The Territorial forest reserve covers most of the mountain area on east Molokai, or 46,700 acres.

In 1927 a pineapple company started production on the island. Three pineapple plantations were operating in the central and southern sections in 1953. All the fruit is sent by barge to Honolulu for canning, as there are no canneries on the island. The total area used for pineapples on the island was about 17,000 acres.

Only about 300 acres on Molokai was in crops other than pineapples in 1951. These crops were primarily corn, taro, and mangoes. Lack of irrigation water in arable areas is the main reason for this low acreage. The few hog and poultry farms on the island produce mainly for local consumption.

The Kalaupapa peninsula on the windward side of Molokai, isolated from the rest of the island by a 1,000-foot precipice, is a settlement for people with Hansen's disease.

Oahu.—Two excellent harbors—Honolulu and Pearl—have made Honolulu the largest city in Hawaii and brought the island of Oahu most of the Navy installations. The city of Honolulu proper covers about 53,000 acres, or 82.2 square miles (*1*). It is located in the southeastern, leeward, part of the island. The total land area of the island is only 377,000 acres and all parts of it are within commuting distance of Honolulu. Land values on Oahu are consequently based partly on the actual or potential value as residential property and generally are higher than on the outlying islands.

Large residential districts have developed on the northeastern side of the island. A tunnel through the Koolau Mountain range is being built to reduce travel distance from these areas to the city.

The Armed Forces possess about 54,000 acres scattered all over the island (table 5). Major military installations include areas in the district of Honolulu proper, the Pearl Harbor Naval base and adjoining airfields, Schofield Barracks in the center of the island, a communications center in the Lualualei valley on the southwestern side, and two airfields—Kaneohe Marine Corps Air Station and Bellows Field—on the northeastern side of the island.

Much of the Waianae and Koolau mountain ranges is held as a Territorial forest reserve.

Crops.—Four sugar plantations had about 35,000 acres in sugarcane in 1951. Two of these, with a total of about 21,000 acres, are located in the Ewa district on the leeward side. The two others operate on an area of 14,000 acres in the Waialua and Koolauloa districts on the windward side of the island (*5*). Except for a small area in the Kualoa district, all of the sugarcane acreage is irrigated. Two sugar plantations discontinued production in 1947. One of these was in the Waimanalo district in the southeastern corner of the island; the other, in the Waianae district on the western side. Land in these plantations is now used mainly by small farmers or as residential areas.

Pineapples were grown on about 22,000 acres in 1951 (table 7). This area is on the high plateau between the Waianae and Koolauloa mountain ranges in the center of the island.

Production of fresh fruits and vegetables is encouraged by the proximity of the Honolulu market. Fruit and vegetable farmers on the island of Oahu produce about 45 percent of the total produced in Hawaii. In 1951 about 400 acres of wetland taro was grown in the lower areas of several valleys on the windward side. About 400 acres of papayas and 850 acres of bananas were also grown, mainly on the windward side.

Fresh vegetables were grown on nearly 1,600 acres in areas widely scattered throughout the island. Most of the vegetable and fruit farms are from 5 to 15 acres in size, and are mostly cultivated with tractors. Some farms, particularly near Honolulu are even smaller. Of the nonplanatation crop farms, only one in ten on Oahu is owned by the operator; this is a much lower percentage of ownership than on the other islands.

LIVESTOCK.—Two-thirds of all the poultry and four-fifths of all the dairy cows and hogs in Hawaii are kept on the island of Oahu (*4*). The majority of the poultry and hog farms are in the vicinity of Honolulu. The dairymen on the island keep their cows mostly in paddocks. On the windward side, particularly in the Koolaupoko district, and on the leeward side in the Waianae district, some land is used for dairy pastures. About 30,000 acres on the island were used for beef and dairy pastures in 1951.

Niihau.—This island, measuring about 46,000 acres, is owned by one family that tries to preserve the original way of life of the native Hawaiians. Nonresidents are allowed on the island only by special permission. Nearly all the island is used for grazing beef cattle and sheep and for beekeeping.

Kauai.—On this island the Territorial forest reserve covers 161,000 acres in the mountainous interior and amounts to nearly half the total island area of 353,000 acres.

Kauai had the second largest sugar acreage in 1951—about 46,000 acres, which was divided among eight plantations. The sugarcane is grown in the coastal areas, from Kilauea in the north, with few interruptions, around the island to Mana in the west. Only about 5,000 acres of sugarcane on the island is not irrigated.

Pineapples were produced on about 7,000 acres in several areas, from the vicinity of Anahola in the northeast to the vicinity of Lawai in the south.

Kauai is the only island still producing rice. Approximately 170 acres each of taro and rice were grown in an area extending from Hanalei valley in the north to the Waimea and Hanapepe valleys in the southwest. About 250 acres was planted to miscellaneous vegetables, and approximately 260 acres was in macadamia nuts.

Cattle ranches used about 90,000 acres in 1951. Of this the largest portion was held by 5 ranchers, each of which had an area of 7,000 acres or more. The remaining pasture acreage was used by about 40 cattlemen, the majority of whom were part-time operators.

IMPROVEMENTS IN AGRICULTURE

Many public and private agencies are engaged in the development of agriculture in Hawaii. The Hawaii Agricultural Experiment Station does extensive research in improving present agricultural industries and developing new ones. The sugar and pineapple industries finance and operate their own research institutions. The Agricultural Extension Service of the University of Hawaii and the Territorial Department of Public Instruction provide education and training in agriculture.

Federal and Territorial agencies such as the Territorial Board of Agriculture and Forestry and the United States Department of Agriculture try to prevent the introduction of new pests and diseases. The United States Department of Agriculture gives financial aid to the agricultural industries of the Territory.

Mountainous topography, heavy tropical rainfall, and strong winds make soil erosion a serious problem on Hawaiian pastures and croplands. Pineapple and sugar planters, small-crop farmers, and ranchers have given erosion increasing attention during the last 15 years. Federal and local agencies, including the Soil Conservation Service and the Agricultural Extension Service, are active in soil conservation. In 1947, the Territorial Legislature passed an enabling act for the creation of soil conservation districts in the Territory. By the middle of 1953, 12 districts had been formed on the islands of Hawaii, Oahu, Kauai, Maui, and Molokai. Other districts are being established.

Efforts are being made to improve public land laws and the leasing practices for both public and private lands. Particular emphasis is placed on lengthening the time of leases and on providing for equitable reimbursement to tenants for long-range improvements.

Several proposals have been made for developing additional irrigation projects. One project on the island of Molokai was approved by the legislature of Hawaii in 1941, but during 1942 the Congress of the United States failed to pass legislation providing for the project. The Waimea Plain Project on the island of Hawaii called for the irrigation of 1,500 acres, well suited to temperate-climate crops. The project was endorsed by the United States Department of Interior, but a resolution in the 1949 Territorial Legislature to authorize construction of the project did not pass. However, the 1951 Territorial Legislature appropriated one million dollars for developing a new irrigation project at Waimea.

The recreation resources of the Territory are being increased by improving and enlarging the Hawaii National Park and local parks.

A planning board for dealing with the development of resources in the Territory was in existence before World War II but was discontinued during the war. The 1949 Territorial Legislature created the Farm Advisory Board, which is less broad in scope than the prewar agency. The board is to study the maximum utilization of the public and private lands of the Islands and to make recommendations regarding the future development of lands suitable for farming.

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***THE ECONOMIC** and cultural institutions of the people of Hawaii influence the use and management of the soils. The authors of this section describe the people of Hawaii and their institutions.*

HAWAII AND ITS PEOPLE

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POPULATION

AT THE TIME Capt. James Cook discovered the Hawaiian Islands in 1778, the population is estimated to have been about 300,000 (table 10). The natives had been isolated so long that they had little resistance to the diseases brought by the white men. By 1872 only about 57,000 people were left in the Islands, of whom approximately 50,000 were native Hawaiians, and the rest mainly Americans, British, and Chinese (*6*).

The expanding sugar industry created need for labor, and large numbers of workers were brought in between 1870 and 1930, first from China and Portugal, then from Japan, and still later from the Philippines. Smaller groups of immigrants came from many other countries, including Korea, Puerto Rico, Spain, and Germany. In addition there was slow but steady immigration from the continental United States that increased greatly just before and during World War II.

The 1950 total population of the Territory was 499,794 (table 10). This population was made up of various racial groups as follows: Japanese, 37 percent; Caucasian, 23 percent; part Hawaiian, 14.8 percent; Filipino, 12 percent; Chinese, 6.5 percent; full-blooded Hawaiian, 2.5 percent; and all other races, including Korean, 4.2 percent. Of all these groups, Part Hawaiians are increasing most rapidly. (See table 11.) The land area and density of population per square mile are given for the various islands in table 12, and the population by islands, in table 13.

TABLE 10.—*Changes in population of the Hawaiian Islands by counties*

[Figures from sources as follows: 1778, estimates by R. Adams *In* interracial marriage in Hawaii (*1*); 1832 to 1896, Hawaii Board of Education (*3*); 1900 to 1950, U. S. Census (*8*)]

Year	Hawaiian Islands	County of Honolulu [1]	County of Kauai [2]	County of Maui [3]	County of Hawaii [4]
	Number	*Number*	*Number*	*Number*	*Number*
1778 [5]	300, 000				
1832	130, 313				
1836	108, 579	27, 809	9, 927	31, 479	39, 364
1853	73, 138	19, 126	7, 781	21, 781	24, 450
1860	69, 800	21, 275	7, 134	19, 910	21, 481
1866	62, 959	19, 799	6, 624	16, 728	19, 808
1872	56, 897	20, 671	5, 194	15, 031	16, 001
1878	57, 985	20, 236	5, 811	14, 904	17, 034
1884	80, 578	28, 068	8, 935	18, 584	24, 991
1890	89, 990	31, 194	11, 859	20, 183	26, 754
1896	109, 020	40, 205	15, 392	20, 138	33, 285
1900	[6] 154, 001	58, 504	20, 734	26, 743	46, 843
1910	[6] 191, 909	82, 028	23, 952	29, 762	55, 382
1920	255, 912	123, 527	29, 438	38, 052	64, 895
1930	368, 336	202, 923	35, 942	56, 146	73, 325
1940	423, 330	258, 256	35, 818	55, 980	73, 276
1950	499, 794	353, 020	29, 905	48, 519	68, 350

[1] Coextensive with island of Oahu except for 1930 and 1940, when outlying islands of Palmyra, Baker, Canton, Enderbury, Howland, Jarvis, Johnston, and Midway are included.

[2] Includes islands of Kauai and Niihau.

[3] Includes islands of Maui, Molokai, Lanai, and Kahoolawe.

[4] Coextensive with island of Hawaii.

[5] Various estimates for this year range from 250,000 to 400,000 people.

[6] Totals for 1900 and 1910 include population of Kalawao County, which in following reports is included in Maui County figure: 1900, 1,777; 1910, 785.

TABLE 11.—*Population of the Hawaiian Islands by racial antecedents for stated census years (8)*

Race	1900	1910	1940	1950
	Number	*Number*	*Number*	*Number*
Hawaiian	29, 799	26, 041	14, 375	12, 206
Part Hawaiian	7, 857	12, 506	49, 935	73, 885
Puerto Rican	(1)	4, 890	(2)	(2)
Caucasian	28, 819	39, 158	103, 791	114, 793
Chinese	25, 767	21, 674	28, 774	32, 376
Japanese	61, 111	79, 675	157, 905	184, 611
Korean	(2)	4, 533	(2)	(2)
Filipino	(2)	2, 361	52, 569	61, 071
All others	648	1, 071	15, 981	20, 852
Total	154, 001	191, 909	423, 330	499, 794

[1] Puerto Ricans included under Caucasians.

[2] Included under all others.

TABLE 12.—*Area and population density of the Hawaiian Islands, by islands, for stated years (8)*

Island	Land area	1900	1930	1940	1950
	Square miles	*Number per square mile*	*Number per square mile*	*Number per square mile*	*Number per square mile*
Oahu	589	99. 3	344. 5	437. 5	599. 4
Hawaii	4, 021	11. 6	18. 2	18. 2	17. 0
Maui	728	34. 9	67. 0	64. 4	55. 1
Kauai	551	37. 3	65. 0	64. 7	53. 9
Molokai	259	9. 7	19. 4	20. 6	20. 4
Lanai	141	(1)	16. 7	26. 4	22. 2
Niihau	72	2. 4	1. 9	2. 5	3. 1
Kahoolawe	45				
All islands [2]	6, 406	24. 0	57. 5	66. 0	78. 0

[1] Lanai population density for 1900 not available; population density in 1910 was 0.9 per square mile.
[2] Figure for 1930 does not include 36 people living on Midway; figures for 1940 and 1950 do not include people living on outlying islands of Palmyra, Baker, Canton, Enderbury, Howland, Jarvis, Johnston, and Midway.

TABLE 13.—*Population of the Hawaiian Islands by islands, for stated census years (8)*

Island	1900	1930	1940	1950
	Number	*Number*	*Number*	*Number*
Oahu	58, 504	202, 887	257, 664	353, 020
Hawaii	46, 843	73, 325	73, 276	68, 350
Maui	[1] 25, 416	48, 756	46, 919	40, 103
Kauai	20, 562	35, 806	35, 636	29, 683
Molokai	2, 504	5, 032	5, 340	5, 280
Lanai	(1)	2, 356	3, 720	3, 136
Niihau	172	136	182	222
Kahoolawe		2	1	
Total all islands [2]	154, 001	368, 300	422, 738	499, 794

[1] Census of 1900 gives only one figure for the combined populations of Maui and Lanai. Census for 1910 shows a population of 131 people on Lanai.
[2] Figure for 1930 does not include 36 people living on Midway; figures for 1940 and 1950 do not include people living on the outlying islands of Palmyra, Baker, Canton, Enderbury, Howland, Jarvis, Johnston, and Midway.

The two largest cities in the Territory are Honolulu (pop. 248,034 in 1950) on the island of Oahu, and Hilo (pop. 27,198) on the island of Hawaii. As shown in table 14, the growth of Honolulu has been spectacular. Honolulu owes its expansion to several advantages. It is the seat of the Territorial Government and its agencies, and most business firms have their main offices there. The majority of the Armed Forces installations, the docks and ship repair-yards, the

storage warehouses, and the construction companies are in this city. Manufacturing industries, including pineapple and fish canneries, are located nearby. The city is also the center of the tourist industry and is a major air and water transportation hub. In addition it possesses most of the educational and cultural institutions of the Islands. People who look for employment, desire an education, seek greater opportunities, or are simply attracted by city life tend to congregate in Honolulu.

TABLE 14.—*Population growth of the cities of Honolulu and Hilo, Hawaiian Islands* [1]

Year	Honolulu	Hilo
	Number	*Number*
1890	22, 907	(2)
1900	39, 306	(2)
1930	137, 582	19, 468
1940	179, 326	23, 353
1950	248, 034	27, 198

[1] Figures for 1890 taken from Hawaii Board of Education Census (*3*); figures for 1900 to 1950 from U. S. Census (*8*).
[2] Population less than 5,000 persons.

EMPLOYMENT

The 1950 census reports that the civilian labor force makes up 52.7 percent of the total number of people in the Hawaiian Islands 14 years of age or older (*8*). Employment of persons 14 years old or older is given for 1940 and 1950 as follows:

	In 1950		*In 1940*	
	Number	*Percent*	*Number*	*Percent*
Civilian labor force	185, 155	100. 0	161, 232	100. 0
Employed	167, 588	90. 5	153, 796	95. 4
Unemployed	17, 527	9. 5	7, 436	4. 6
Experienced workers	16, 078	8. 7	6, 464	4. 0
New workers	1, 449	0. 8	972	0. 6

The labor force is broken down by industry groups for 1940 and 1950 in table 15. As shown therein, the number of people employed on sugar plantations has dropped sharply since 1940 because of mechanization of the industry. Increase in the labor force resulting from increased population and decrease in sugar-farm employment since 1940 have been partly offset by increased employment in other occupation groups. The part of the labor force unemployed was 4.9 percent greater in 1950 than in 1940.

The industrial and financial structure of the Islands is controlled by a highly unified management. In spite of this, Hawaii is strongly unionized. In contrast to conditions prevailing in most mainland areas, agricultural labor in the two major agricultural industries of the Islands—sugar and pineapple—is also unionized. Both the CIO and AFL have locals in the Islands.

TABLE 15.—*Industry group of employed workers in Hawaii (8)*

Industry group	1950		1940	
	Number	*Percent distribution*	*Number*	*Percent distribution*
Total employed	167, 588		153, 796	
Agriculture	30, 418	18. 2	55, 365	34. 7
Sugar farms	17, 146	10. 2	37, 762	24. 6
Pineapple farms	4, 374	2. 6	} 15, 603	10. 1
Coffee farms	981	. 6		
Other agriculture	7, 917	4. 7		
Forestry and fisheries	1, 371	. 8	1, 249	. 8
Mining	168	. 1	256	. 2
Construction	11, 662	7. 0	10, 807	7. 0
Manufacturing	21, 292	12. 7	15, 454	10. 0
Durable goods	5, 661	3. 4	2, 509	1. 6
Nondurable goods	15, 544	9. 3	12, 887	8. 4
Sugar processing	4, 389	2. 6	3, 018	2. 0
Pineapple canning	5, 360	3. 2	} 7, 509	4. 9
Other food industries	2, 805	1. 7		
Other nondurable goods	2, 990	1. 8	2, 360	1. 5
Not specified manufacturing industries	87	. 1	58	
Transportation, communication, and other public utilities	13, 179	7. 9	8, 397	5. 5
Wholesale and retail trade	31, 650	18. 9	21, 816	14. 2
Wholesale trade	5, 521	3. 3	2, 602	1. 7
Retail trade	26, 129	15. 6	19, 214	12. 5
Finance, insurance and real estate	3, 951	2. 4	2, 112	1. 4
Business and repair services	4, 123	2. 5	2, 896	1. 9
Personal services (including domestic)	10, 883	6. 5	15, 365	10. 0
Entertainment and recreational services	2, 712	1. 6	1, 605	1. 0
Professional and related services	16, 722	10. 0	11, 402	7. 4
Medical and other health services	6, 517	3. 9	3, 396	2. 2
Educational services	7, 390	4. 4	6, 058	3. 9
Other professional and related services	2, 815	1. 7	1, 948	1. 3
Public administration	18, 438	11. 0	7, 661	5. 0
Postal service	742	. 4	341	. 2
Federal public administration	12, 209	7. 3	4, 714	3. 1
Territorial and local public administration	5, 487	3. 3	2, 606	1. 7
Industry not reported	1, 019	. 6	1, 411	. 9

TRADE AND INDUSTRY

Hawaii has a highly developed trading economy heavily dependent upon the Mainland. The Islands possess no mineral resources that are used commercially at present, except for some sand, stone, and lime. Forest reserves are maintained primarily to prevent rapid runoff and soil loss following rain and are not an important source of forest products.

The people of the Islands import most construction materials, as well as equipment, fuel, and supplies to keep their industries going. They also import nearly all consumer goods such as clothing, shoes, cars, and household equipment. Though the Hawaiian economy is based on agriculture, nearly two-thirds of the food consumed and much of the livestock feed are imported.

Exports of merchandise, primarily agricultural products and fish, pay for part of these imports. Manufacturing industries in the Islands are relatively unimportant, producing mainly for local consumption or processing waste products of sugar mills and pineapple canneries. One export product is the insulating fiberboard, called Canec, made of a byproduct of sugarcane milling. Some Island-style clothing and Hawaiian handicraft products, such as lauhala weavings and woodenware, are also being exported.

In addition to these visible exports, there are invisible exports such as services rendered and goods sold to the Federal government, to tourists, and to shipping and airlines. A record number of 60,500 visitors stayed 2 days or longer in Hawaii during 1952. The combined payroll of the Armed Forces, including both servicemen and civilians, was approximately 128 million dollars in 1950. This compares to 33 million in 1940, and 377 million in 1945. The preparedness program brought about a payroll expansion to 195 million in 1952.

By comparing the value of exports and imports, both visible and invisible, it is possible to obtain the balance of payments. Up to 1940 Hawaii's annual balance of payments was, with few exceptions, favorable. In other words, the people of Hawaii received more money from exports than they spent on imports. Throughout World War II, the balance of payments continued strongly in favor of the Islands despite an excess of imports over exports of goods. This was the result of local purchases of materials and services by the Armed Forces, the USO, the Red Cross and similar agencies, and individual servicemen and war workers. With the end of the war, Federal expenditures were sharply reduced and the number of servicemen and civilians employed by the Government declined greatly. At the same time, merchandise imports continued to exceed in value exports of Hawaiian goods. As a result, Hawaii's postwar balance of payments was unfavorable until 1952. In that year the balance of payments was 39 million dollars in favor of the Islands, mainly because of an increase in Federal expenditures and a decrease in imports (table 16). However, when world tension subsides a reduction in the expenditures of the Armed Forces in Hawaii can again be expected. To maintain its present population and standard of living, Hawaii must find ways of increasing its exports of goods and services or of substituting local production for imports.

TRANSPORTATION

Ocean transportation to the Mainland is vital to the economy of the Islands. A large fleet of ships regularly plies back and forth between island harbors and ports in California, the Pacific Northwest, the Gulf of Mexico, and the east coast of the United States. Speedy passenger liners cover the distance from Honolulu to the West Coast in 4½ days. Fast freighters make the trip from the Islands to California and the Pacific Northwest ports in 5½ days, and to North Atlantic ports in about 18 days.

In addition, Honolulu is a regular port of call for some ships traveling from the Mainland to Japan, China, and other parts of the Orient. Some steamers sailing from North America to New Zealand and Australia also stop at Honolulu. Incoming overseas freight of island

TABLE 16.—*1952 Balance of payments, Hawaiian Islands (2)*

Exports and other income received from overseas		Imports and other expenditures made overseas	
Items	Million dollars	Items	Million dollars
Hawaiian products:		Goods purchased:	
Sugar and molasses	134	Mainland	329
Pineapple products	92	Foreign countries	20
Coffee, floral products, canned fish, sportswear, and metal scrap	11	Total	349
Hides, petroleum products, papayas, and other products	3		
Total	240		
Expenditures of the Federal Government:		Payments to the Federal Government	154
Armed Forces	254		
Civilian agencies	17		
Other (grants, transfer payments, tax refunds)	35	Services from Mainland or foreign businesses:	
Total	306	Ocean and air freight	30
Mainland firms and individuals:			
Tourists and transients, including crews of commercial carriers	35	Travel expenses of Hawaiian residents overseas	24
Shipping and air lines, national advertisers and other mainland business	27	Other services (net cost of insurance, entertainment, advertising, and miscellaneous expenses)	24
Total	62	Total	78
Dividends, interest, and profits from overseas investments	22	Dividends, interest, and profits paid to overseas investors	16
Remittances from workers in forward areas and other personal gifts	15	Personal remittances sent overseas and money taken out by outmigrants	9
Total for all export and other income received from overseas	645	Total imports and other expenditures made overseas	606
Balance of payment favorable to Hawaii			39

ports, excluding petroleum products shipped by tankers, was approximately the same as outgoing freight in 1951, each amounting to about two million tons. This made full loads possible on both the incoming and outgoing trips, which is a basic requirement for low tariff rates.

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Scheduled barges now transport most of the interisland freight. Before World War II, when four steamers served the interisland trade, passenger service provided a sizeable portion of steamship revenue. Nearly all travel between the islands is now by air. In 1952 the only remaining ship that carried freight regularly between Honolulu and the island of Hawaii discontinued operation (*4*).

Honolulu airport is a stopover for transpacific flights from North America to New Zealand, Australia, and the Orient. The departure of a plane from this airport to Manila, Tokyo, or Sidney is as routine as a flight to the neighboring island of Kauai. Three regularly scheduled United States and three foreign airlines, as well as nonscheduled air carriers, offer transportation from Honolulu to several airports on the West Coast of the Mainland and Canada.

As mentioned before, nearly all travel between the islands of the Territory is done by air. Sixteen airports were in operation in 1953. Interisland air freight, particularly in vegetables and fruit, is far more important than on the Mainland. Two scheduled airlines and two charter air services carry passengers and freight between the islands.

GOVERNMENT

Under the Organic Act, which established Territorial government, the governor and secretary as well as the Territorial supreme and circuit court judges are appointed by the President of the United States with the consent of the United States Senate. The governor appoints the heads of the various executive departments and the members of policy-making boards and commissions, such as the Commissioners of Labor and Industrial Relations and the Commissioners of Agriculture and Forestry. These appointments are subject to the approval of the Territorial Senate.

Hawaii is represented in the United States Congress by one elected delegate who has no vote. The Territorial Legislature consists of a Senate, the members of which are elected by popular vote for a 4-year term, and of a House of Representatives, elected every 2 years. The Territorial Legislature meets biannually for a period of 60 legislative days. Counties are governed by an elected Board of Supervisors. The City and County of Honolulu, which is classed as the only organized municipal government, also has an elected mayor.

SCHOOLS, HOSPITALS, AND OTHER PUBLIC FACILITIES

Educational opportunities in Hawaii compare well with those on the Mainland. Interracial cooperation is continuously enhanced by the schools, in which children of all races learn to work and play together (pl. 8).

The public schools are operated as one educational unit administered by the Territorial Department of Public Instruction. There is one standard for all public schools, both rural and urban, and all receive the same benefits. About half of all the teachers have 5 years of training above the high school level. The majority of the private schools are in the urban areas. Many of them enroll students who do not fall within the compulsory attendance years. Parochial schools, kindergartens, and trade and commercial schools make up a large section of the total private school enrollment. About 101,000 students were enrolled in public and 26,000 in private schools in 1953.

The University of Hawaii has an enrollment of about 4,500 students, and many well-known educators and research men are on its faculty. Public libraries exist in the major city of each island, and branches are located throughout the rural districts.

Seven daily newspapers and ten weeklies or semiweeklies were published in Hawaii in 1953. Twelve radio stations were in operation, all but four of which started since World War II. Eight of these stations were located on Oahu. In addition two television stations operated on Oahu.

Medical services have attained a high level of efficiency, and preventable communicable diseases have been largely eliminated. The ratio of number of hospitals, physicians, and dentists to the total population is roughly equivalent to Mainland standards. The mortality rate compares well with that of the United States as a whole. In 1952, the rate for the Hawaiian Islands was 6.1 deaths per 1,000 civilian population, whereas the rate for the United States as a whole was about 9.6 per thousand.

Electric power lines have been extended to most towns and villages, and gas is being piped to domestic and commercial consumers in the cities of Honolulu and Hilo. The use of household appliances such as electric irons, washing machines, refrigerators, and electric or gas stoves follows the Mainland pattern. Nearly 123,000 phones were in operation, and there was nearly one automobile for every three persons in the islands in 1953. Public services such as social welfare, fire and police protection, public recreational facilities, and water supply systems, are of the same character as in any comparable Mainland State, and so are the stores and theaters.

LIVING COSTS AND RACIAL RELATIONS

People in Hawaii have to pay higher prices for most products than Mainland consumers because so large a portion of consumer goods, equipment and supplies is imported. This disadvantage is to some extent offset by a mild climate that reduces expenditures for fuel, heavy clothing, and similar items, and by easier access to beaches, mountains, and other recreational areas. Everything considered, the cost of living in Hawaii is slightly higher than on the Mainland.

The general trend toward a decrease in interracial barriers is shown by the fact that 31 percent of all marriages in Hawaii were interracial in 1951 (*7*). There is not much segregation of races into well-defined residential areas. In most residential districts a family is likely to find a racial variety of neighbors. The mixture of racial influences has had a unique effect on diets. Each race has borrowed menus from the others to the point that about 70 percent of all families use a mixed cuisine according to a recent survey (*5*).

The word "Hawaiian" is now used in two senses, one to mean of Hawaiian blood, and the other to mean a person who has accepted the Hawaiian heritage regardless of his racial background. Although Hawaiians now constitute a relatively small percentage of the total population, many of their hospitable customs and friendly manners have been widely adopted by the other races. The use of the "lei" as an "aloha" gift is only one example. Their dances and songs are enjoyed equally by all races. In general it may be said that racial consciousness is diminishing and race barriers are crumbling in Hawaii.

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