Site Selection for Concentrated Solar Thermal Systems in Hawaii

Hawaii Natural Energy Institute
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PREFACE

This HNEI technical report was originally submitted to Sandia National Laboratories under contract No. 56-6959. The project, Technical Support for the Small Community Solar Thermal Experiment at Molokai Electric Company, was sited on the island of Molokai, Hawaii; Patrick Takahashi served as principal investigator.

ACKNOWLEDGEMENTS

This report was largely put together by Arthur Seki, project manager for the Molokai Small Community Solar Thermal Experiment. Much of the data collection and analysis was provided by George Curtis. D. Richard Neill provided information about wind regimes and political concerns. Special thanks to Zhou Gong for tabulating the insolation data; Sean Kurizaki for reducing data; and Warren Tyau for providing some of the graphics in this report. The project thanks Dean Graves for guidance and support.

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ABSTRACT

This report identifies areas on the five major islands (Oahu, Maui, Molokai, Hawaii, and Kauai) that have the potential for concentrating solar thermal applications. The locations are based on existing solar insolation (mostly global and some direct normal) data, other meteorological information, land use, potential end-use, and existing facilities. These areas are:

- Western coast of Oahu, especially near Kahe Point
- Maui plains area
- South-central Molokai
- Kona Coast of the Big Island, especially Natural Energy Laboratory of Hawaii
- Western and southern areas of Kauai

Monitoring stations are recommended at some of these sites to obtain direct normal insolation data for future evaluation.

I. INTRODUCTION

The State of Hawaii has a variety and abundance of natural energy sources such as geothermal, ocean thermal, wind, biomass, and solar. The development of renewable non-polluting natural energy sources has great potential for meeting Hawaii's present and future demands.

Radiation from the sun is the ultimate source of energy that is essential for the maintenance of plant (biomass) and animal life on the earth. Solar radiation is also related to ocean thermal energy conversion (the sun heats the ocean surface waters that act as a heat source, while the deep cold water acts as a heat sink) and wind energy, where thermal differences on the earth's surface coupled with its rotation produce the movement of air.

In direct solar applications, two distinct areas are being examined: photovoltaics and solar thermal. Photovoltaic energy converts direct sunlight to DC electricity though a semi-conductor device or silicon cell. Research has also expanded to include other materials (i.e. gallium arsenide, indium phosphide, etc.) as the collective cell. Solar thermal applications are most frequently identified with flat plate water heaters primarily for household and commercial use. However, to achieve higher operating temperatures, concentrating systems must be used. The temperatures achieved in these systems would provide the energy necessary to drive an organic rankine or steam engine.

The primary objective of this report is to identify, with the best available data, a guide to site selection for locating concentrating solar thermal systems in Hawaii. The analysis includes the evaluation of solar insolation, land area, utility interface, and other concerns.

II. BACKGROUND

In Hawaii, three concentrating solar thermal projects have either gone through preliminary design or have been or are in the process of being tested: Solar Repowering at Pioneer Mill Co. Ltd.; Wilcox Hospital Solar Photovoltaic Energy System; and the Small Community Solar Experiment at Molokai Electric Company (see Figure II-1). All three projects were supported primarily by the U.S. Department of Energy.

The Solar Repowering project at Pioneer Sugar Mill, located in Lahaina, Maui on the leeward (dry side) lowlands of West Maui, called for a preliminary design initiated in 1980 to examine a solar power tower concept on sugarcane lands adjacent to the sugar mill. This power tower concept had a field of mirrors or heliostats directing sunlight to a centrally located receiver for steam production which was to be used in the sugar mill process and for power generation. A conceptual drawing of the general process is shown in Figure II-2. The preliminary design was for an 8 megawatt system with about 568 heliostats directing sunlight to a 260-foot tower. The area required for this system was about 60 acres of sugarcane land. The overall cost was estimated to be about $40 million. The recommendation from this study called for third party financing with an aggressive power sales

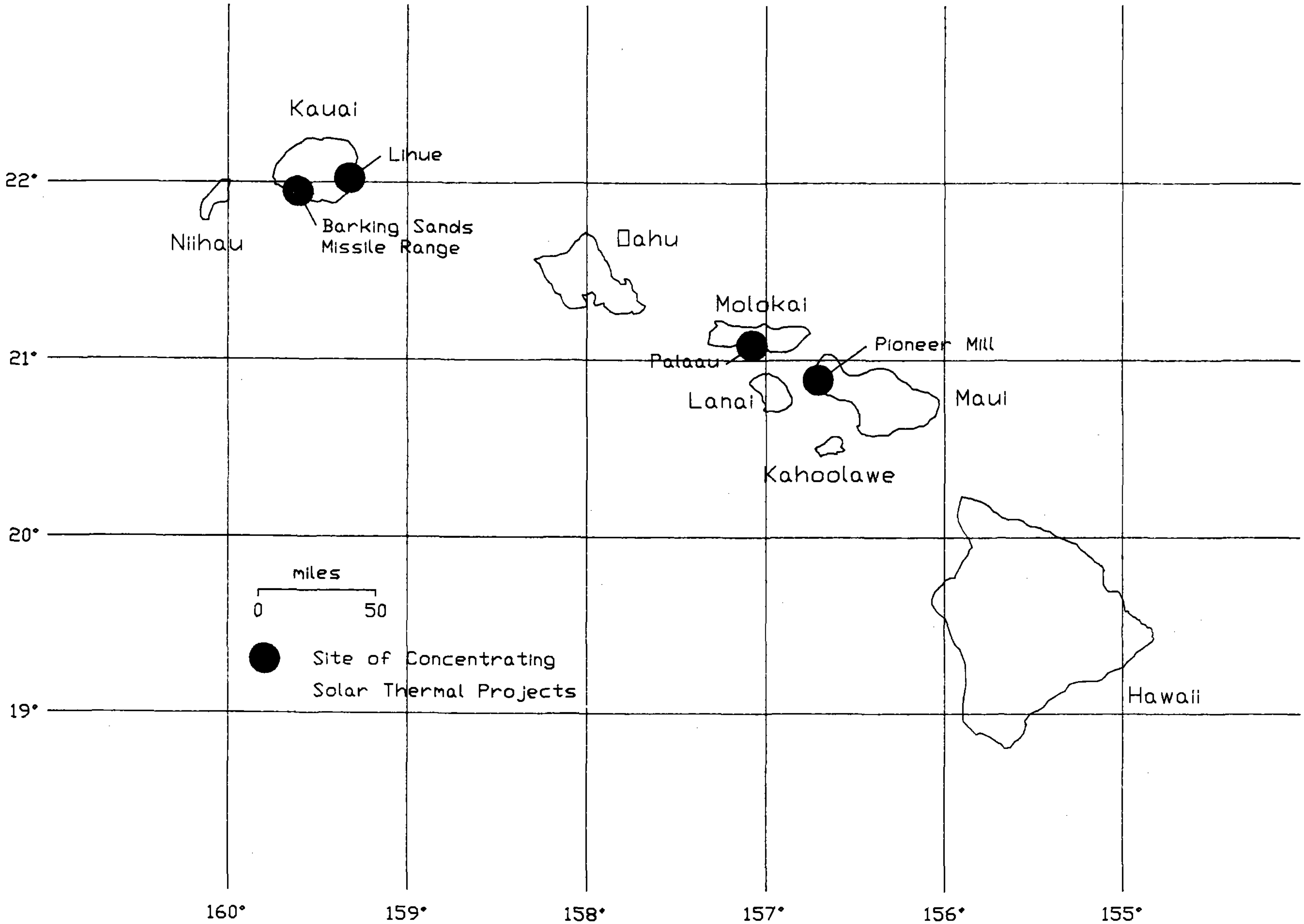


Figure II-1 Map of the State of Hawaii

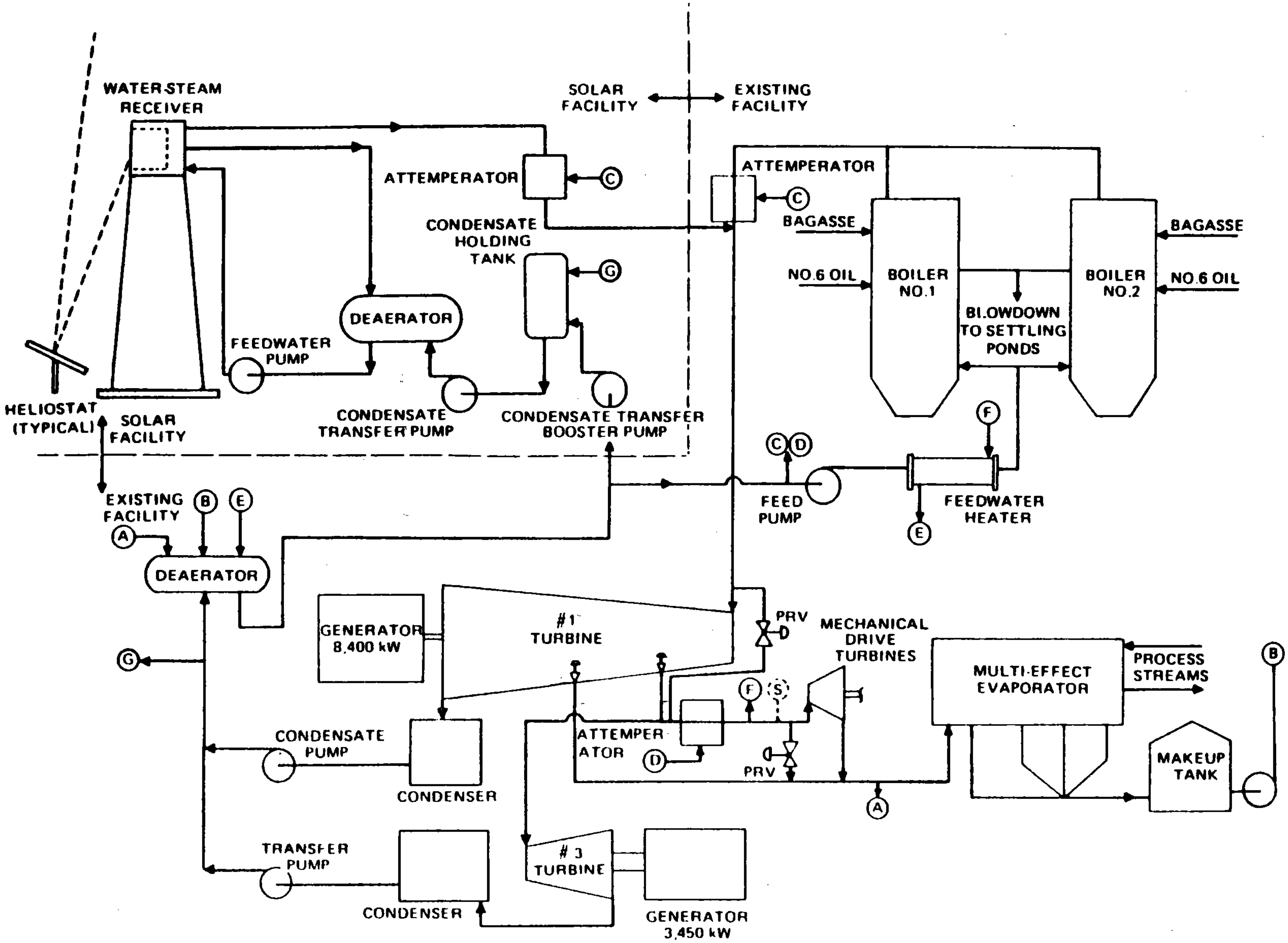


Figure II-2 Repowered Facility Schematic Diagram at Pioneer Mill

Source: (Amfac Energy 1983)

agreement from the local utility (Amfac Energy 1983). The project has been put on hold until financing backing can be attracted (St. John 1987).

The G.N. Wilcox Memorial Hospital and Health Care Center, located in Lihue on the island of Kauai, was the site for the United States' largest parabolic concentrator photovoltaic/thermal solar system from 1982-1983. The system was rated at 35 kilowatts and designed to produce 22,000 net kilowatt-hours of electricity and 620,000 gallons of 180°F water (about 900 million Btu) annually. A field of 10 rows of eight parabolic collectors, each 6 feet by 10 feet in aperture was used. The collectors tracked the sun by rotating about their north-south horizontal axis. These collectors concentrated the incident sunlight on photovoltaic cells on the receivers mounted at the collector's focal lines. For optimal system operation, the photovoltaic cells are cooled by water passing in series through the hollow centers of all 80 aluminum receivers. This water, part of a closed, continually recirculating system with a 3,000-gallon storage tank, took the excess thermal energy away from the photovoltaic cells and transferred it through a heat exchanger to the hospital's hot water supply (see Figure II-3).

The solar system at Wilcox Hospital did not perform well because of two factors: inclement weather (1982 was the wettest and least sunny year in the state over the past 50 years) and photovoltaic cell deterioration. At the end of the project, the solar system was transferred to the Barking Sands Missile Range, outside Kekaha, on the leeward side of Kauai. The system is currently providing thermal energy at the facility's local cafeteria (Yuen, Seki, and Curtis 1983).

The third concentrating solar thermal project is the Small Community Solar Experiment at Molokai Electric Company's Cooke Generating Station in the Palaau area (a few miles outside of Kaunakakai) on the island of Molokai. The system is designed for 250 kilowatts output from five point focus concentrating collectors. Each concentrating collector will have about 400 separate mirrors focussing sunlight at the point focus about 60 feet away. The working fluid is water, as it is converted to steam at the collector receiver for transfer to a converted air-cooled, 4-cylinder, diesel engine (see Figure II-4). This unique system has been proven in White Cliffs, Australia with a smaller converted diesel engine. Construction of this facility is scheduled for the 1987-1988 time frame. (Rogers and Bilodeau 1985).

III. ENERGY PROFILE

Despite these solar projects and other renewable energy projects, the State of Hawaii remains highly dependent on imported petroleum - only 10 percent comes from coal and indigenous, non-petroleum sources (biomass, hydroelectric, geothermal, wind power) compared to the entire United States, where petroleum constitutes about 42 percent and renewables contribute 5 percent (see Figure III-1).

The end-use distribution of the energy is shown in Figure III-2 for Hawaii and the entire United States. Because of Hawaii's geographical location in the middle of the Pacific, tourism, and thus transportation,

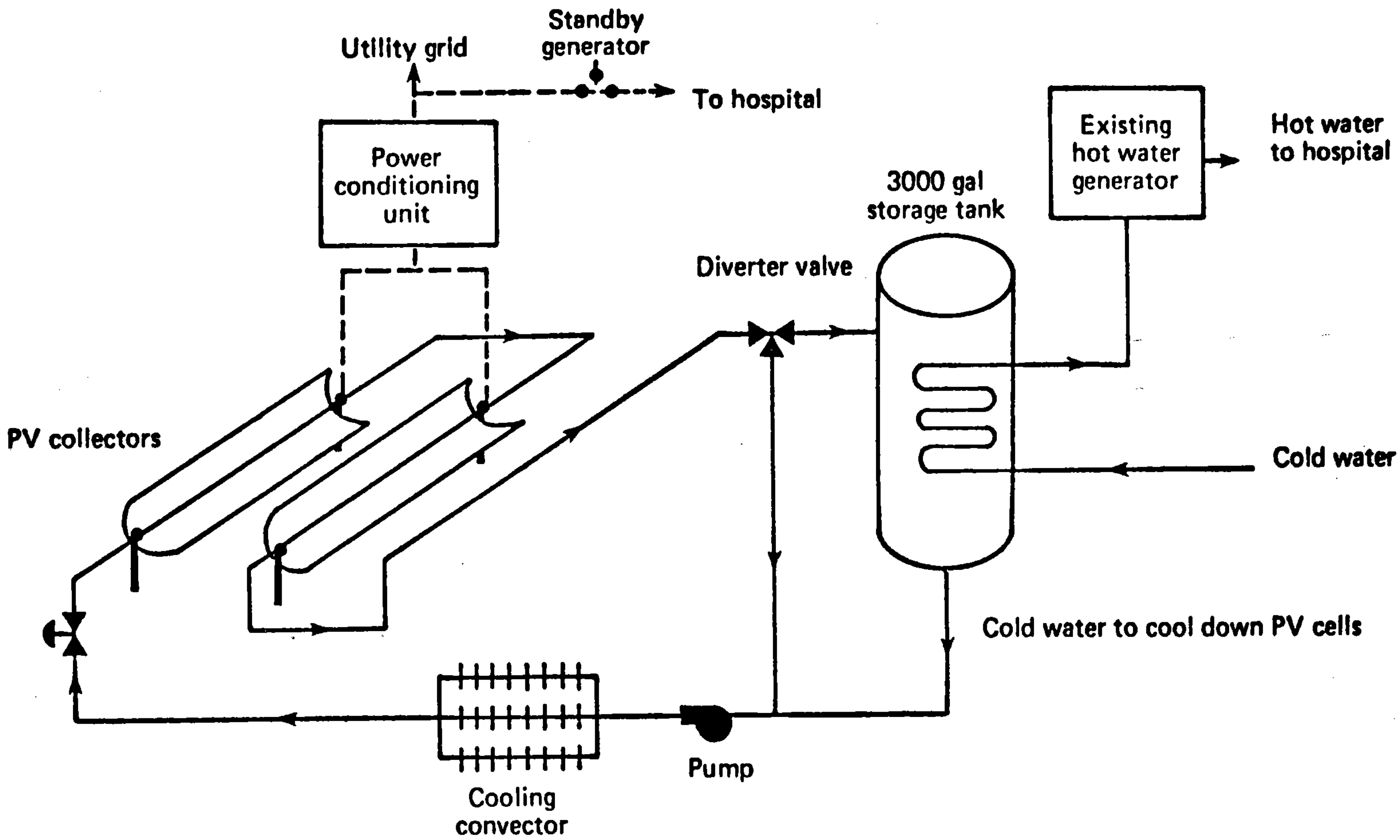


Figure II-3 Schematic of Wilcox Hospital Solar Energy System

Source: (Yuen, Seki, and Curtis 1983)

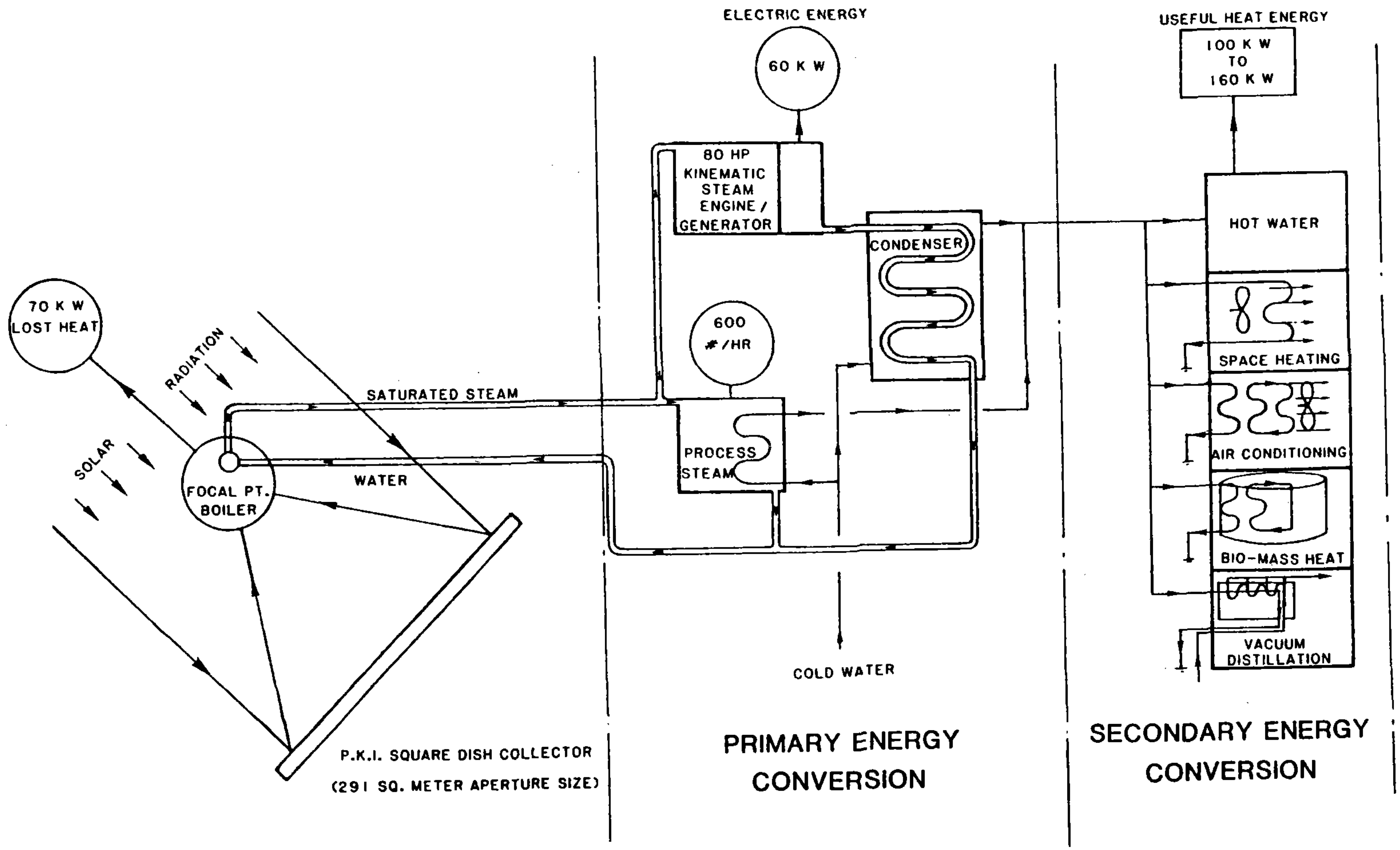


Figure II-4 Flow Diagram of Molokai Small Community Solar Experiment

Source: (Rogers and Bilodeau 1985)

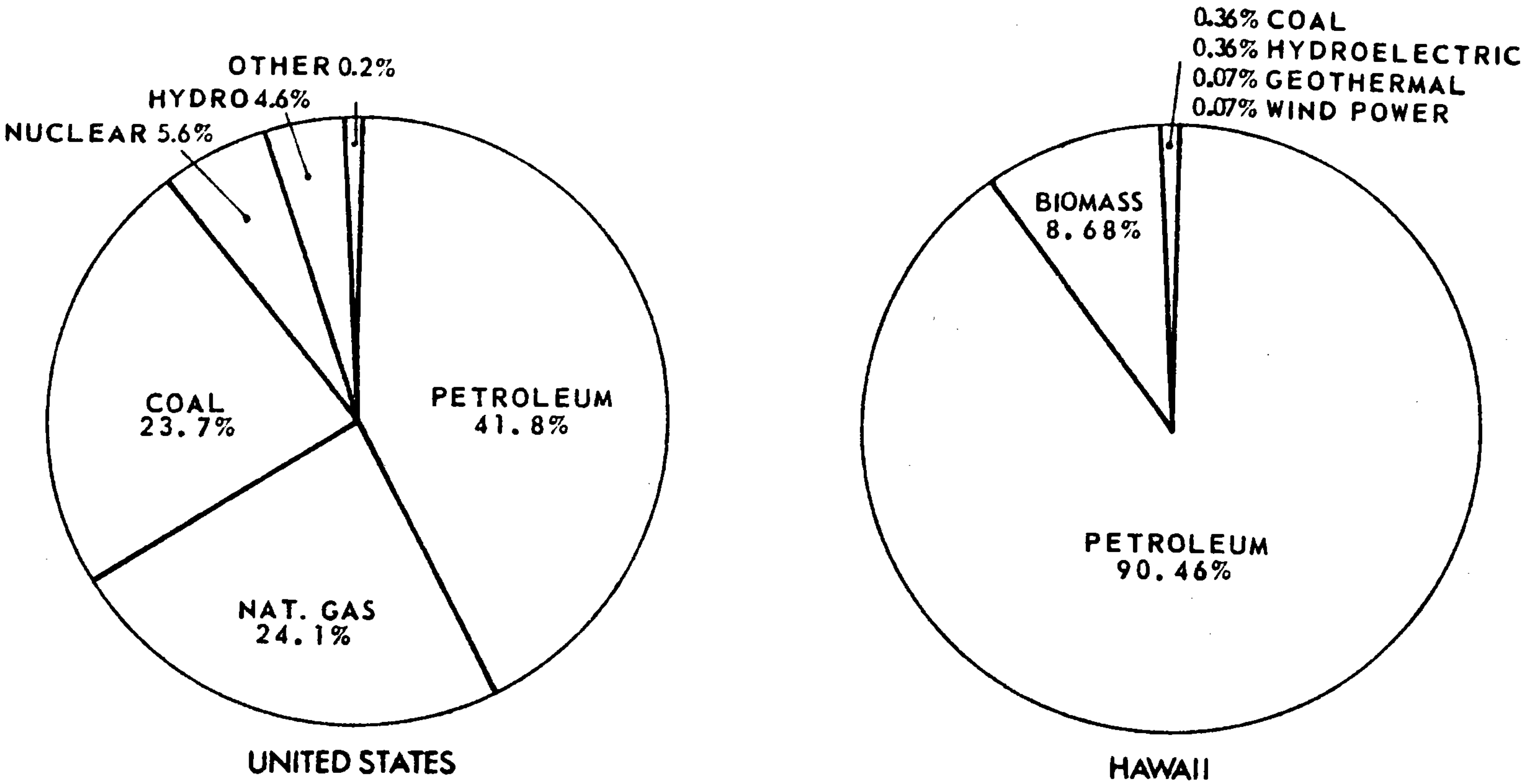


Figure III-1 Energy Use by Source, U.S. & Hawaii: 1985

Source: (Zane 1986)

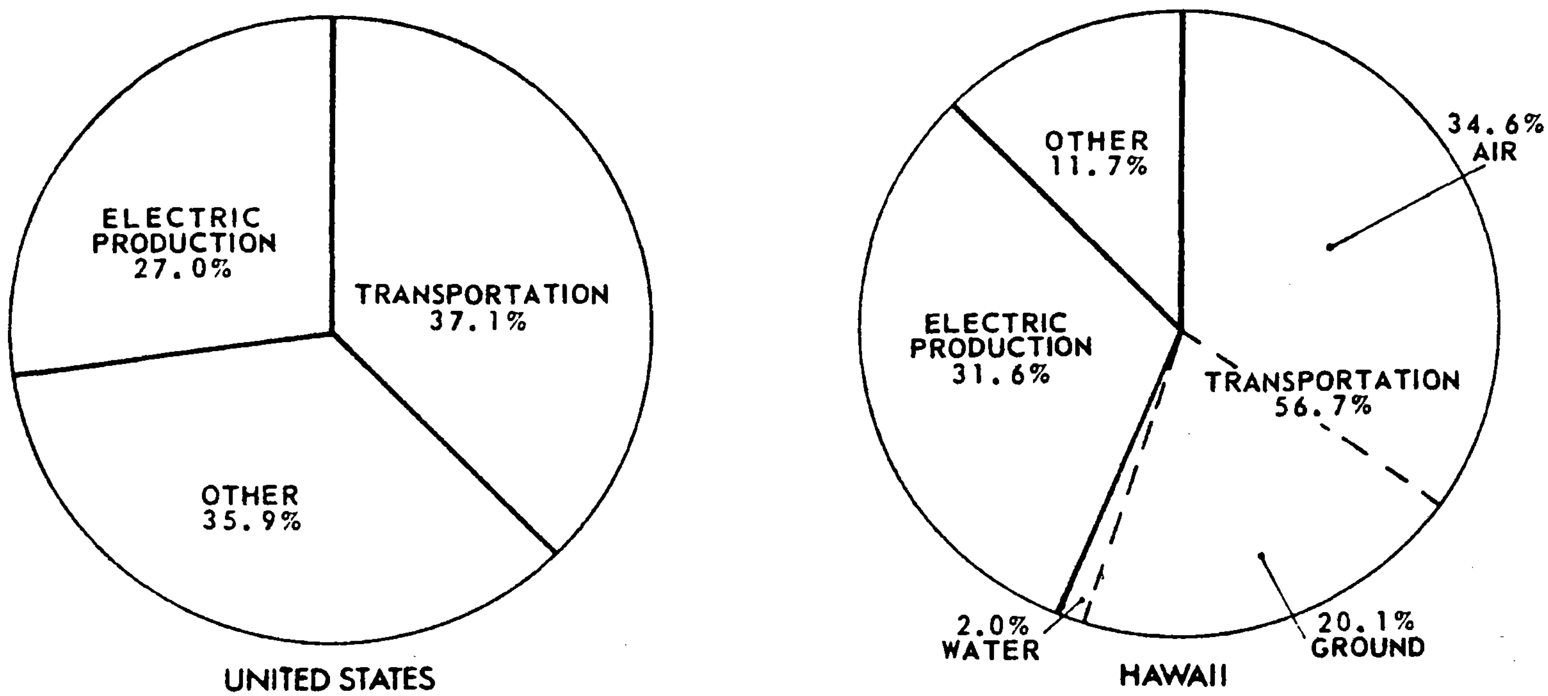


Figure III-2 Energy Use by Sector, U.S. & Hawaii: 1985

Source: (Zane 1986)

play an important factor in the economy. With limited local manufacturing capabilities, most domestic products must be transported to the islands. Almost 57 percent of the energy goes towards transportation (ground, air, and water), of which air transportation consumes about 35 percent. On the mainland, the end use is evenly distributed for electrical production, transportation, and other uses. Appendix A (page 41) presents a table of petroleum fuel use in Hawaii for 1985. The primary consumption sectors of petroleum are aviation fuel, electrical generation, ground transportation, military, and commercial/industrial. The military uses kerosene and naphtha for aviation, diesel for electrical generation, and gasoline for ground transportation. Appendix B (page 45) is a table of import and export of crude oil and petroleum products for 1985. Surprisingly, some of the petroleum refined locally in Hawaii is exported to foreign destinations.

As shown in Figure III-3, about 90 percent of Hawaii's electrical energy is generated from oil, as compared to 4 percent nationwide (primary sources include coal, natural gas, nuclear, and hydroelectric). However, the state's proportional use of biomass, wind, and geothermal energy is significantly greater than the mainland U.S. The neighbor islands have achieved a large degree of independence from oil generated electricity. Oahu, which accounts for over 80 percent of the state's electricity demand (The State of Hawaii Data Book 1985), is 98 percent dependent on oil generated electricity. Maui County is over 74 percent dependent on petroleum for electrical generation, while Hawaii is about 51 percent, and Kauai roughly 45 percent (Figure III-4). Table III-1 shows population and electrical information for the major islands.

III.1 Electrical Generation in Hawaii

The island of Oahu is, by far, the largest island in terms of electrical generation, population, and industry in Hawaii. Eighty percent of the state's total power generation was consumed by 75 percent of the state's population (based on de facto population). Hawaiian Electric Company (HECO) is the utility company responsible for Oahu, and produces over 90 percent of the total power generated on the island. HECO has the newest, largest, and the most efficient generating equipment in the state. This efficiency, together with long-term fuel supply contracts lasting until the '80s, have kept the cost of electricity to consumers low compared to the neighbor islands.

There are three significant private producers of electricity on Oahu who interact with HECO to both buy and sell power. They are: Oahu Sugar Company; Waialua Sugar Company; and Hawaiian Independent Refineries, Inc. Together, these plants produced about 2 percent of the island's total electricity, but consume the majority of it themselves for irrigation and industrial processing (Kinoshita 1985).

Like the other islands, Oahu grew from an agriculture base. However, other industries such as military, tourism, and light industry have developed much faster on Oahu; thus, the sugarcane plantations have a much smaller part of the total electrical generation. The transition from agriculture to other industries is also the largest single reason for the

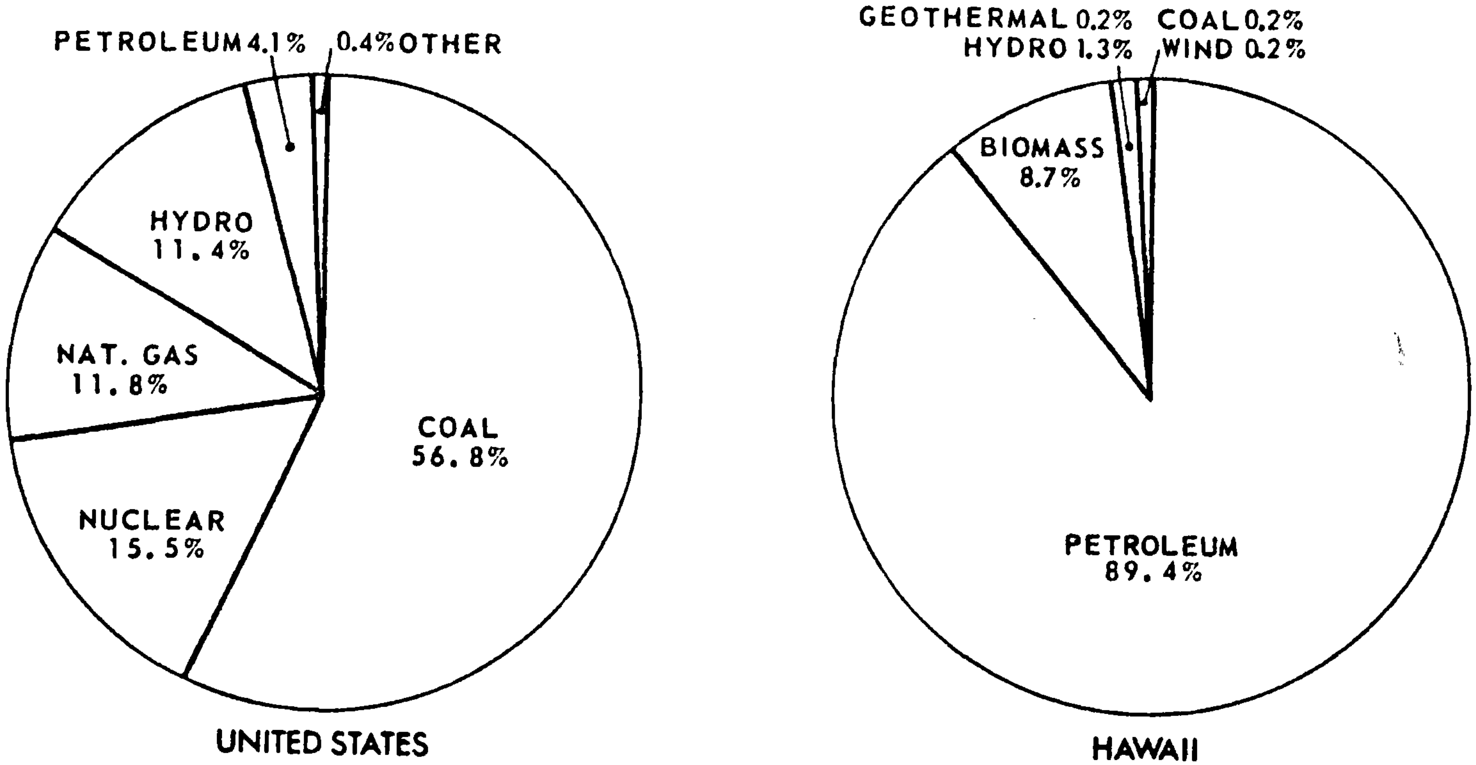


Figure III-3 Electricity by Source, U.S. & Hawaii: 1985

Source: (Zane 1986)

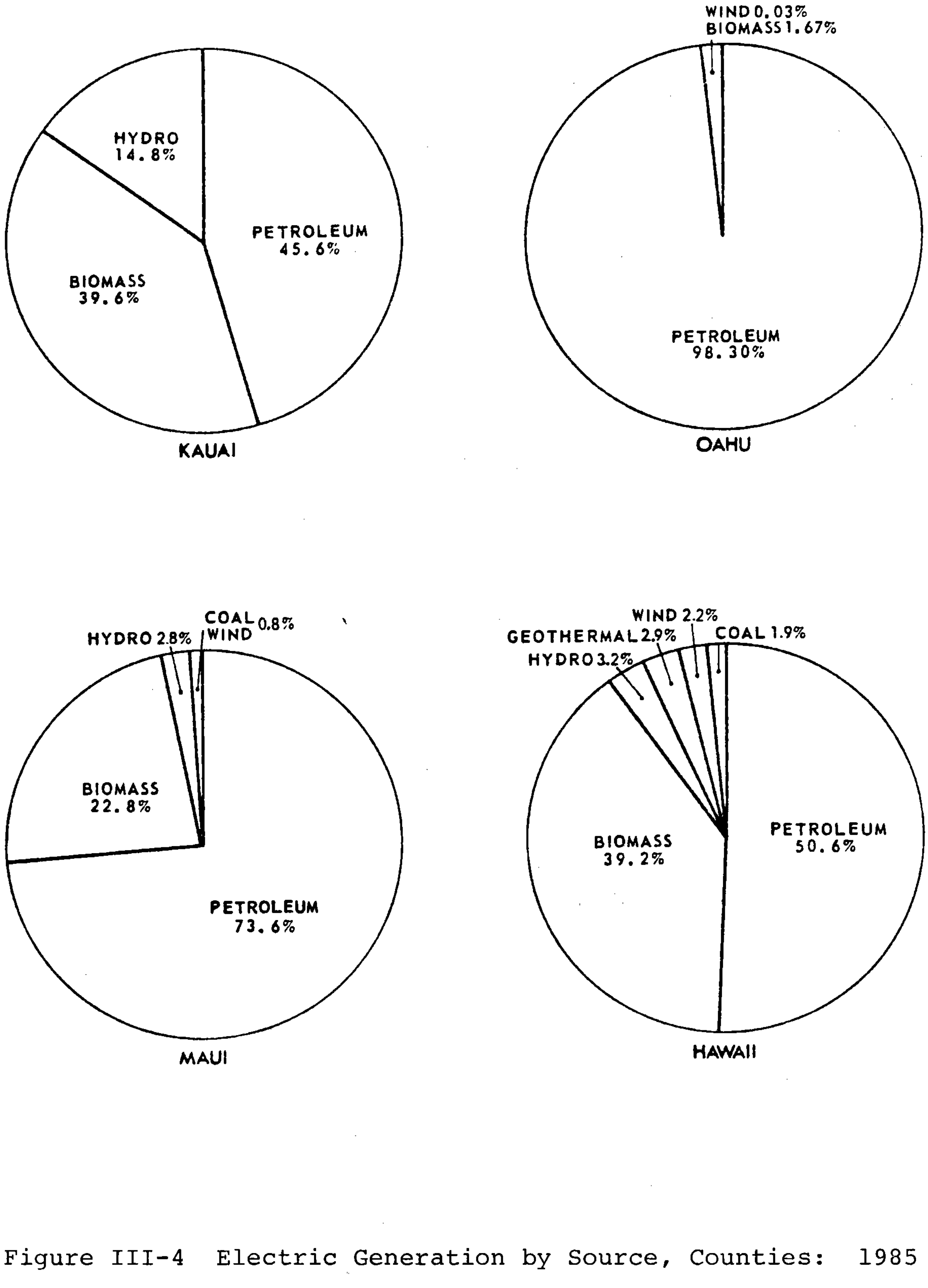


Figure III-4 Electric Generation by Source, Counties: 1985

Source: (Zane 1986)

TABLE III-1
COMPARATIVE ENERGY DATA - 1984

	State	Oahu	Maui	Molokai	Hawaii	Kauai
Population						
Total (1000)	1,039	805	83	*	106	44
de facto (1000)	1,141	860	115	*	113	54
Electricity Sold (1000 kwh)	6,606	5,330	529	24	488	229
Ave. Elec. Rate ($/kwh)						
Residential	0.118	0.110	0.139	0.216	0.137	0.153
Other	0.102	0.095	0.130	0.219	0.128	0.151

* included in Maui figures

Source: (The State of Hawaii Data Book 1985) heavy dependence on oil as fuel to generate electricity on Oahu and in the state.

The three generating plants run by HECO are located at Honolulu, Waiau, and Kahe. They were built in this same order. The Kahe plant site is the newest and largest plant with all near-future planned increments to be built on this site (Appendix C, Figure C-1, page 51).

The islands of Maui and Lanai are served by the same electric utility, Maui Electric Company (MECO), a subsidiary of HECO. The two islands are separate systems entirely, with the Lanai division being for distribution of power only. Both islands support a major agriculture industry with a large amount of electricity being used for irrigation. Tourism has increased significantly on Maui in recent years, helping to make it the second largest power generating island.

The MECO generating facilities are located at two sites: Kahului has a steam plant, and Maalaea has diesel units. These two, together with the firm power supplied by Pioneer Mill Company and Hawaiian Commercial & Sugar Company (HC&S) make up the utility system on Maui. Several hydropower sites are found on the plantations at Pioneer and HC&S (Appendix C, Figure C-2, page 52).

The Lanai system is supplied entirely by power generated by the Dole (Pineapple) Company generation plant, which is all diesel. Dole also owns most of the distribution lines on the island.

Molokai Electric Company (MOECO) is the only generator and distributor of power on Molokai, the least developed of the five largest islands. Generation is by diesel units, gas turbine, and steam boiler located at the Cooke Generating Station (Appendix C, Figure C-3, page 53). Growth on this island has been very slow, thus only a small increase in power generation was necessary over the last few years.

The largest island in the Hawaiian chain, the Big Island (Hawaii), has the highest portion of generation by private companies of any island, reflecting the large sugarcane agricultural base of the island. Hawaii Electric Light Company (HELCO), the utility which serves the island, is a subsidiary of HECO. HELCO has several generating stations which include steam, diesel, hydrogenerators, and gas turbine units. HELCO is also the only utility company that owns hydropower plants. The much larger distances on this island cause problems with power line transmission and associated losses, particularly to the growing Kona Coast region (Appendix C, Figure C-4, page 54).

The private producers are, in several cases, modernizing their sugar production by consolidating and redesigning plants for maximum efficiency of electrical power production as well as sugar processing in mind. Hamakua Sugar Company's two sugar mills (soon to be consolidated into one), Hilo Coast Processing Co., and Ka'u Agribusiness Co., all provide energy to the local utility through their sugarcane operations. The Puna Sugar Co., which shut its sugar operations, is still obligated to provide electricity to HELCO, and burns an assortment of fuel to meet their contractual demands.

These fuels include residual oil, coal, wood chips, bagasse, and municipal solid waste (Kinoshita 1985; St. John 1987).

Hydropower sites on the island are found only on the northern part. Two of them are operated by HELCO, one by a private ranch owner, and the remainder are operated by the sugar companies and are part of the irrigation system. These sites are all dependent, to some extent, on seasonal rainfall and crop irrigation priorities.

Kauai, the northernmost of the inhabited and developed islands in the State of Hawaii, is also called the Garden Island because of its lush beauty. Sugar plantations were established early, but only Kekaha Sugar Co., The Lihue Plantation Co., McBryde Sugar Co., and Olokele Sugar Co. remain. These sugar mills were the start of the island's electric generating capability and, in fact, were the only producers of electricity on the island until 1964.

In January 1969, Amfac, Inc. sold Kauai Electric Company Ltd. (KECO) to Citizens Utilities Company. In the first twelve years, KECO installed more generating capacity than the sugar mills and, at the same time, reduced the amount of power that the plantations supply to the utility grid by 50 percent (see Appendix C, Figure C-5, page 55). Many sugar mills have the original machinery in place, including all of the hydropower stations and bagasse burning plants, which form the largest part of the plantations' energy sources (Kai 1986; Kinoshita 1985).

IV. METEOROLOGICAL INFORMATION

Solar insolation has been recorded in Hawaii from as early as 1932, by 140 observation stations over various periods of time. Almost all of the data were collected by the sugar industry, which at the present time maintains a network of approximately 100 stations located on the four sugarcane growing islands in the state, for the evaluation of the amount of solar energy available for photosynthesis by sugarcane. The use of several types of instruments limits the accuracy of radiation observation to 10 percent (How 1978). Since the values are used for agricultural purposes, only global insolation was collected and reported.

Scientists at the University of Hawaii at Manoa have also been monitoring the solar insolation values for a number of years. With the advent of the oil crisis, renewable energy became an important issue for Hawaii because of its natural energy resources, and large dependence on petroleum products. Background data on solar insolation were collected at various sites in the state. Since equipment and instrumentation for these were limited, only a few sites could be monitored and even fewer sites measured direct insolation (Ekern 1986; Falicoff, Koide and Takahashi 1979; Law 1976; and Yoshihara and Ekern 1977, 1978). Conversion between diffuse/direct (direct horizontal) values and direct normal (via a normal incidence pyrheliometer) values for typical conditions are discussed in Curtis and Soloman (in preparation). Tables of global, diffuse, and direct insolation are shown in Appendix D (pages 57-72).

Figures IV-1 to IV-5 show the annual average global insolation values for various islands in the state (adapted from Energy Division 1985). As mentioned, the global values were collected at many sites due to the presence of the sugarcane industry, thus insolation contours for each island could be made. On the other hand, direct insolation is only now being recorded with any regularity, so the number of recording stations is minimal. These figures also show the direct insolation measuring stations in the state with average annual values in parentheses. The monthly values for each site are plotted in the figures in Appendix E (pages 73-88).

Appendix F (pages 89-95) shows the rainfall maps for Oahu, Maui, Molokai, Hawaii, and Kauai. In general, the areas of highest rainfall are usually poor solar sites. However, it isn't unusual to have dramatic changes in the local climate due to island geography. For example, Waikiki receives about 10-15 inches of rainfall a year, but just a few miles inland in Manoa Valley (site of the University of Hawaii) about 100-150 inches of rain fall annually.

High wind regimes also indicate potential cloud cover and rainy areas. The wind energy map for each island is shown in Appendix G (pages 97-103). Prevailing trade winds from the northeast usually push clouds towards the island which accumulate at the mountain ranges and deposit their moisture. Thus, the leeward sides of the islands are dry, cloudless, and sunny. However, Kona winds from the south sometimes deposit rain in these dry areas. These conditions occur only for brief periods during the year.

V. LAND USE

Agriculture is the predominant land use in the state. About 75 percent of the total land area (4,045,511 acres) is used for forestry, grazing, plantations, and diversifed agriculture. Forests and forest reserves account for about 50 percent of the area in this broad use category and embrace primarily those lands of importance for watershed protection. Grazing lands comprise more than 33 percent and normally include areas rated poor in overall agricultural productivity. Plantations use less than 10 percent of the total agriculture land area, but this is more than 75 percent of the state's "prime" agricultural land. The acreage in sugarcane plantations is declining as operators seek to remove the most costly and lowest yielding areas from production. Diversified crops, consisting primarily of orchard crops, flowers, foliage and nursery products, and vegetables, are produced on slightly more than 1 percent of the area in the broad agricultural land use category. Most of the orchard crops are found on the island of Hawaii. Oahu has about the same acreage in vegetables as Hawaii and Maui, but leads the major islands in area devoted to dairy, poultry, and swine farms. Table V-1 presents the total land area for each county in the state and the land use category percentage (The State of Hawaii Data Book 1985).

On the county level, Honolulu County (Oahu) shows a more developed and evenly distributed land use than the other counties. Maui County (Maui, Molokai and Lanai islands) is similar to Oahu, except the urban development isn't as large, while the Big Island of Hawaii is predominately broken into the same percentages as the state since it covers over half the land mass in

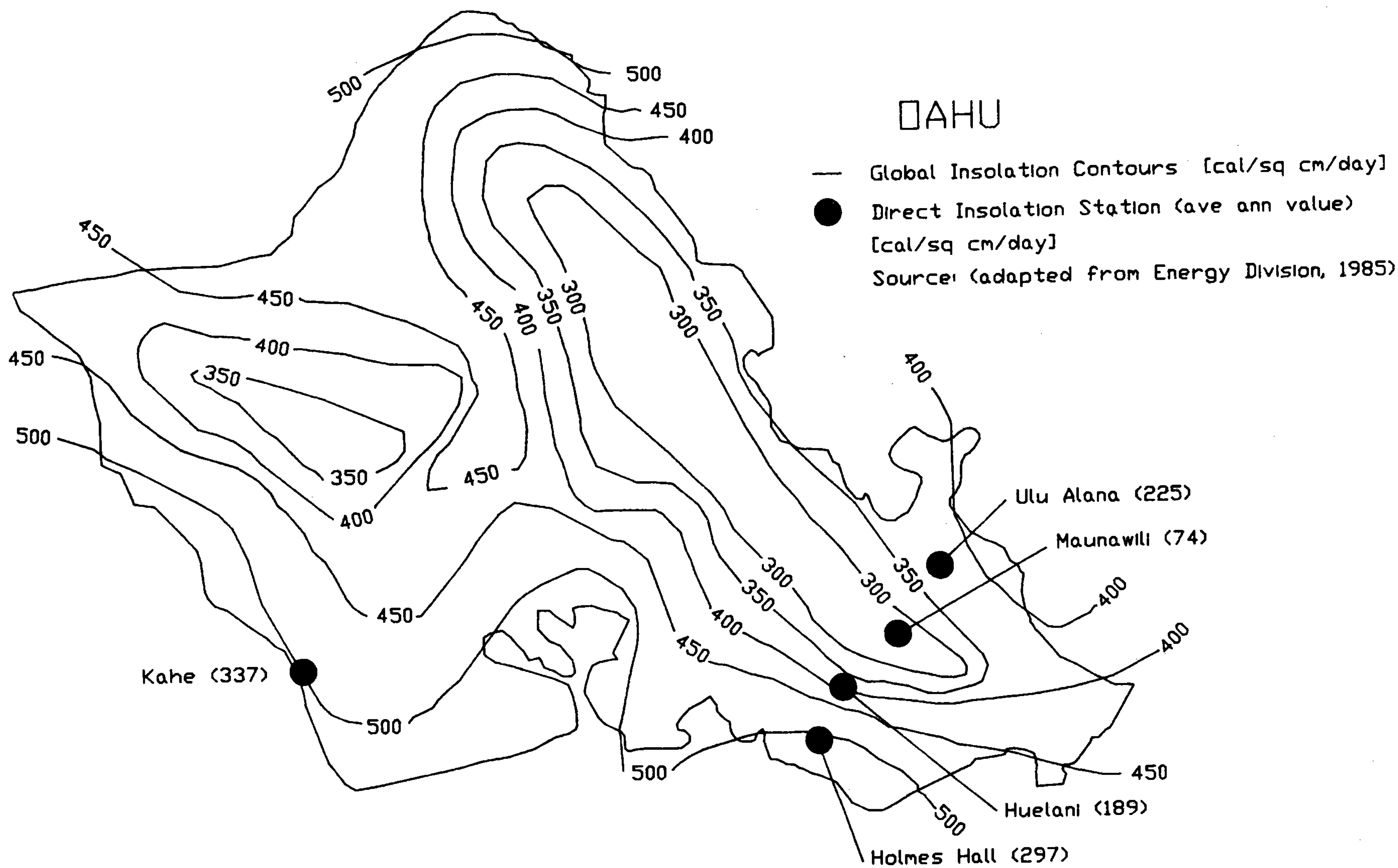


Figure IV-1 Oahu Solar Insolation Map

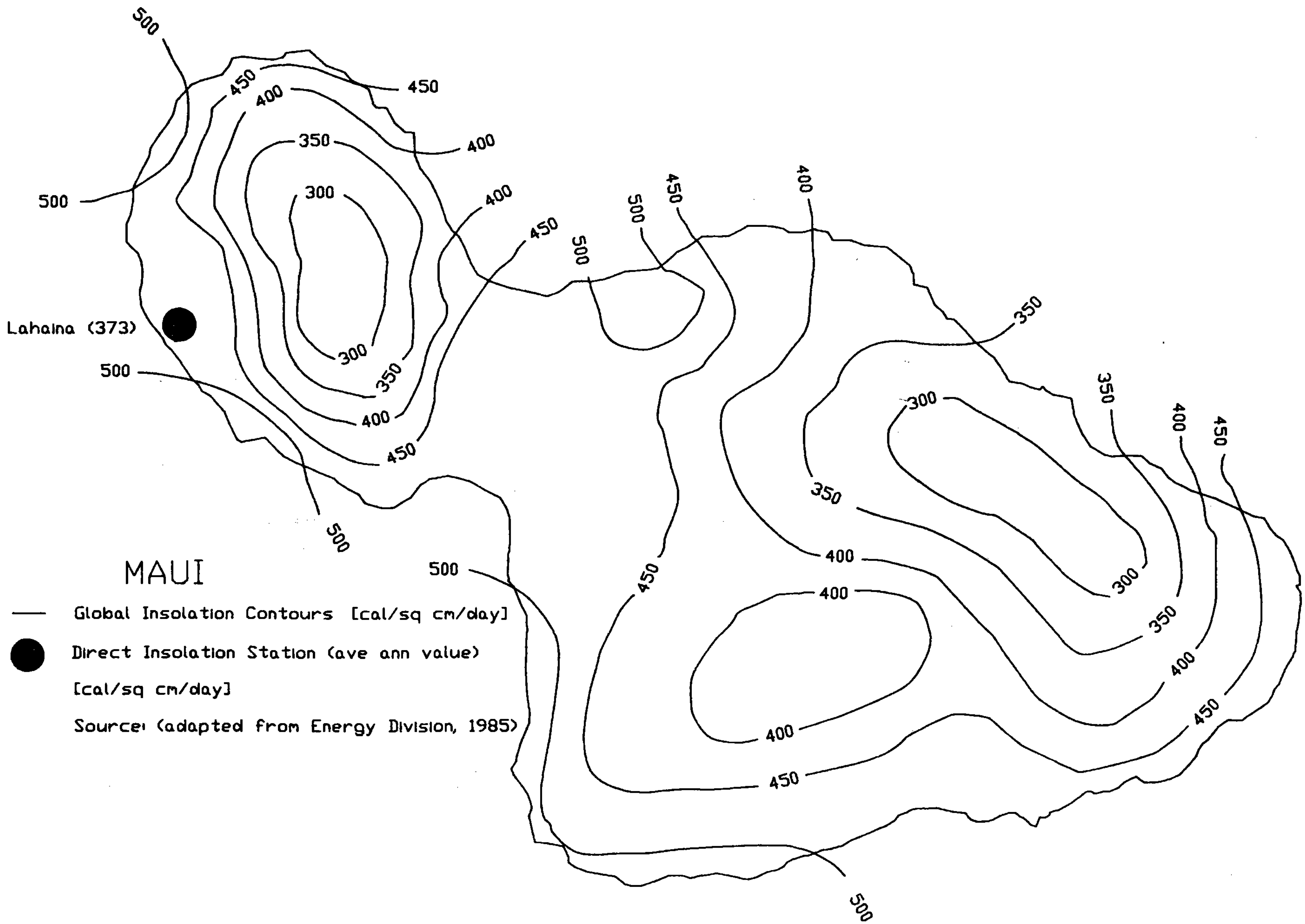


Figure IV-2 Maui Solar Insolation Map

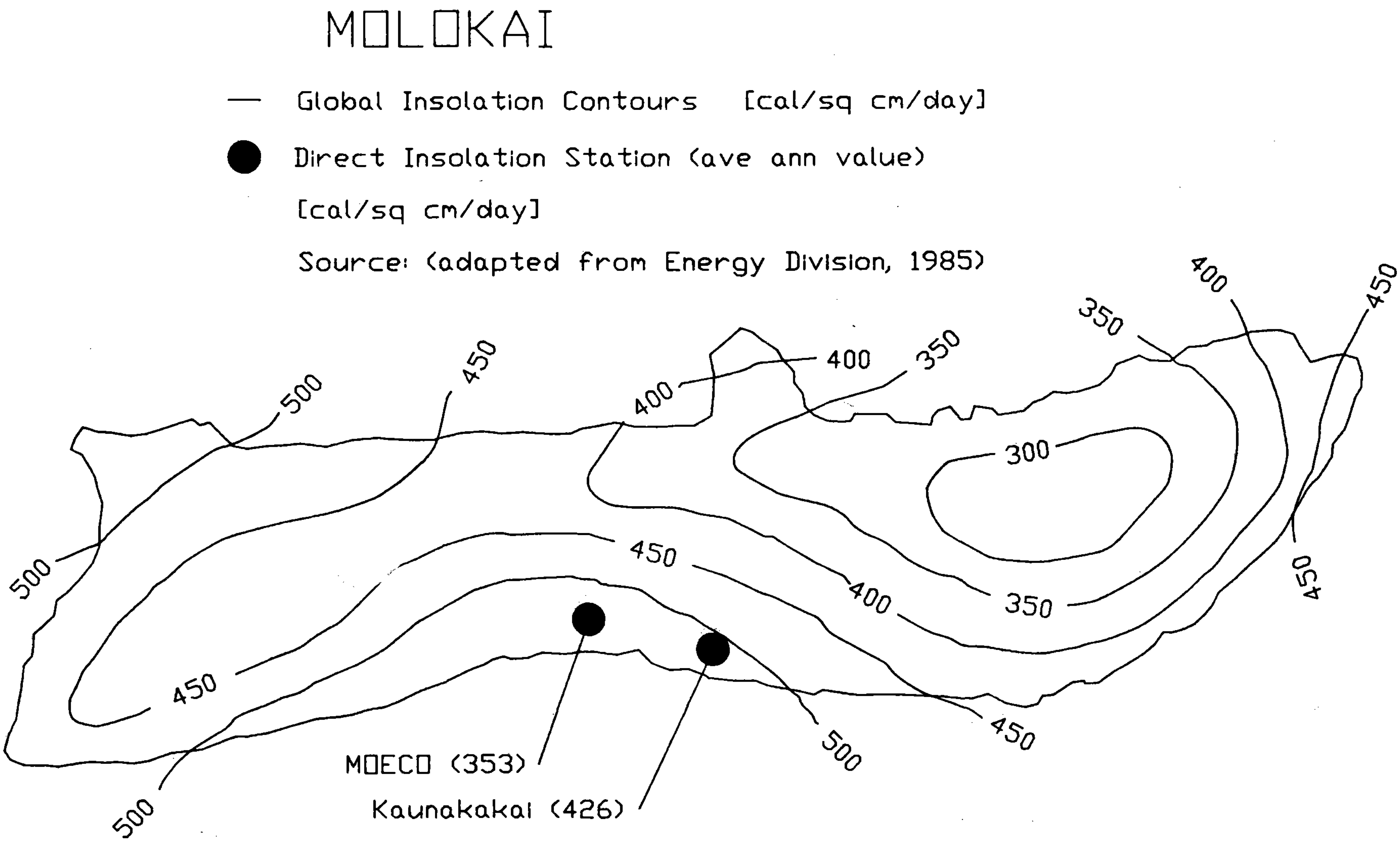


Figure IV-3 Molokai Solar Insolation Map

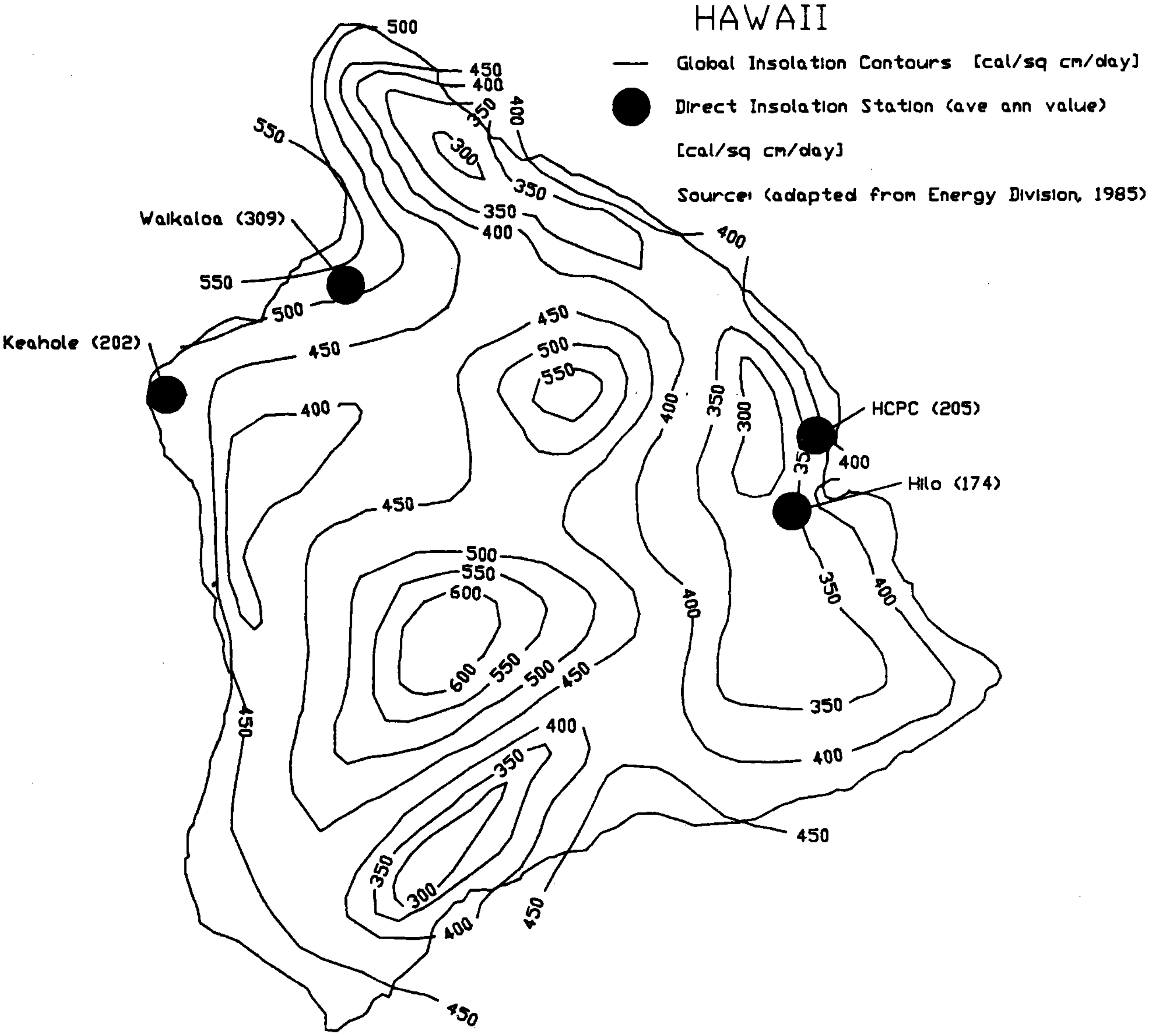


Figure IV-4 Hawaii Solar Insolation Map

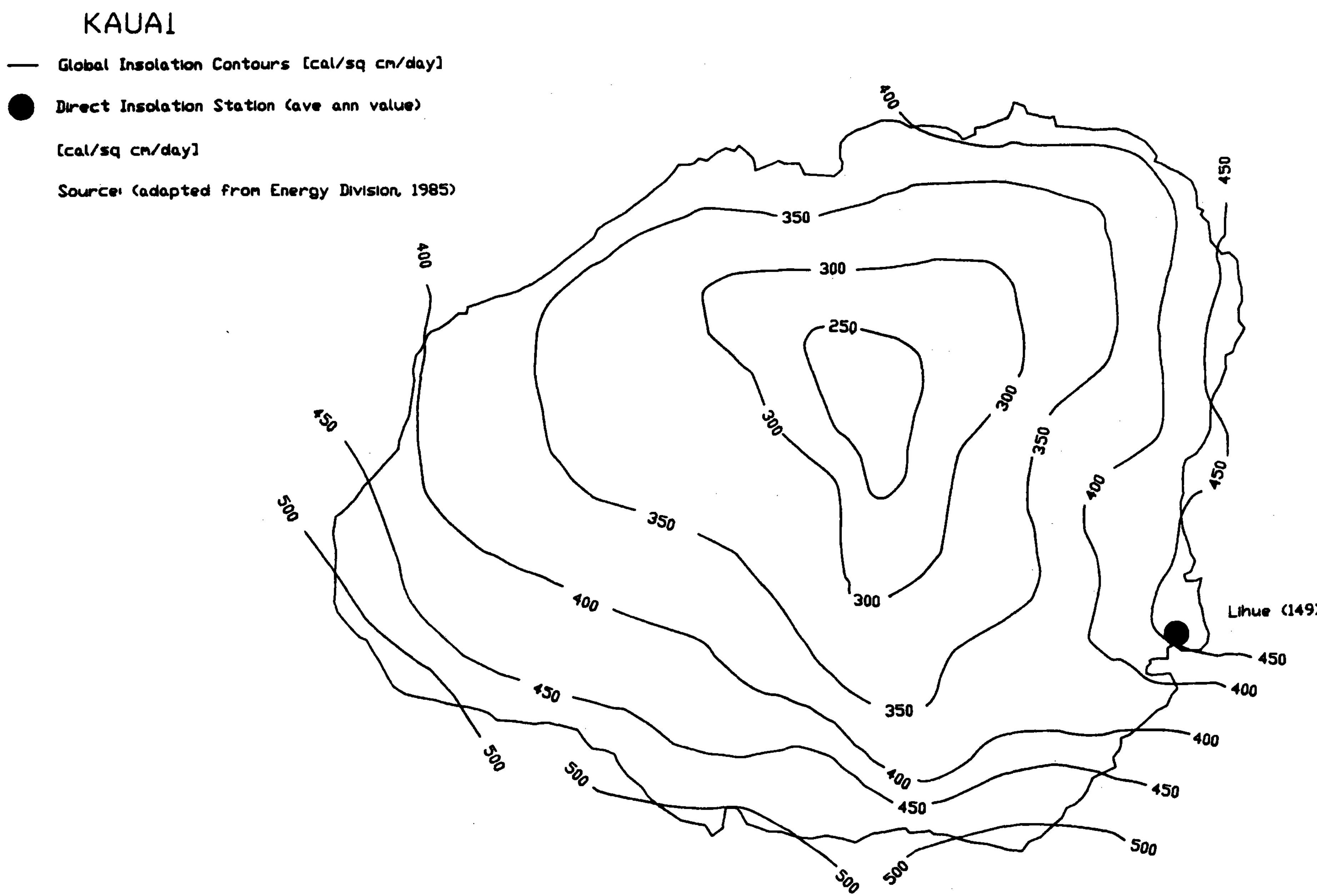


Figure IV-5 Kauai Solar Insolation Map

TABLE V-1
LAND USE IN HAWAII

Category	State of Hawaii	Honolulu	Maui County	Hawaii County	Kauai County
Federal Land	8.25	12.87	7.37	8.98	0.65
Cropland	8.05	18.78	12.01	3.30	20.42
Pastureland	23.52	19.66	29.71	24.07	12.11
Forest Land	35.58	26.26	32.53	34.53	57.25
Minor Land Cover	20.02	2.77	14.58	26.72	4.27
Urban	3.04	14.33	2.24	1.63	2.43
Rural Transportation	0.55	1.18	0.62	0.40	0.77
Small Water Areas	0.30	0.25	0.07	0.34	0.52
Census Water	0.71	3.90	0.87	0.03	1.59
Percent Total	100	100	100	100	100
Total Acreage (1000)	4,414.3	397.2	758.6	2,582.5	403.0

Source: (The State of Hawaii Data Book 1985) the island chain. Kauai County (island of Kauai) shadows the Maui County land use. Maps of land use and land use districts of the islands of Oahu, Maui, Molokai, Hawaii, and Kauai are displayed in Appendix H (pages 105-116). The land use zone districts can be categorized into four groups: urban, rural, agriculture, and conservation. Urban districts are locations of most development whether it be residential, commercial, resort, or industrial, with reserve to accomodate foreseeable growth. Rural districts which occupy a very small amount of land in Hawaii, are land primarily in small farms mixed with low density residential lots. The two main districts are agriculture and conservation. Agriculture lands include sugarcane, pineapple, grazing, and other crops, while conservation lands encompass existing forest and water reserves, lands in national and state parks, lands with a general slope of 20 percent or more, and marine waters and offshore islands.

Maps of major landowners are shown in Appendix I (pages 117-123). Large private landowners make up 42 percent of the state's total acreage, while the state (including Hawaiian Homes Lands) controls 37 percent. Small private landowners occupy 12 percent, and the remainder is under federal jurisdiction.

Hawaii is by no means the smallest state of the Union. Three others (Rhode Island, Connecticut, and Delaware) are smaller and the largest of Hawaii's islands, the island of Hawaii, is more than three times as large as the state of Rhode Island. Table V-2 presents geographical information about the islands of Hawaii, and Appendix J shows the general topography of the major islands (pages 125-131). Landforms in Hawaii are the result of construction by volcanoes, living organisms (reef building by coral, etc.), and sedimentary processes, and the destruction by erosion. The Hawaiian Islands are wholly volcanic with sedimentary rocks forming only a narrow fringe.

VI. SOLAR THERMAL APPLICATIONS

Solar or global radiation from the sun is made up of two components: diffuse and direct. Diffuse radiation is due primarily to the earth's atmosphere, clouds, and large bodies of water which "rob" energy from the sun by reflecting and redirecting the rays in all directions. Radiation which escapes all these obstacles and reaches the earth's surface in a parallel or uniform direction is called direct normal.

Direct radiation has the property of being uni-directional. The diffuse rays of the sun are not directional, as they come from all parts of the sky and cannot be focussed. Certain types of solar collectors cannot make use of the diffuse energy from the sky and require clear sky conditions for their successful operation (see Figure VI-1). They are called concentrating collectors (Duffie and Beckman 1974; Meinel and Meinel 1976; and Falicoff, Koide and Takahashi 1979).

Solar thermal systems require concentration of the thermal properties of absorbed sunlight to attain temperatures sufficiently high to drive a heat engine. Concentration can be achieved with linear (parabolic trough) or point (dishes or power tower) focussing systems. Figure VI-2 shows solar

TABLE V-2

GEOGRAPHICAL INFORMATION OF HAWAII

Parameter	State	Oahu	Maui	Molokai	Lanai	Hawaii	Kauai
Total Area (square miles)	6,450.4	607.7	728.8	261.1	139.5	4,038.0	553.3
Coastline (miles)	750.0	112.0	120.0	88.0	47.0	266.0	90.0
Highest Elev. (feet)	--	4,020.0	10,023.0	4,970.0	3,370.0	13,796.0	5,243.0
Extreme Length (miles)	--	44.0	48.0	38.0	18.0	93.0	33.0
Extreme Width (miles)	--	30.0	26.0	10.0	13.0	76.0	25.0
Percent of Area with Elevation							
<500 feet	20.8	45.3		37.3	24.8	12.0	35.6
>2000 feet	50.9	4.6	68.4	17.8	6.3	68.4	24.0
Percent of Area with Slope							
<10%	63.5	42.5	38.5	53.0	61.0	76.0	33.5
10-19%	19.5	12.0	25.5	21.0	23.0	20.0	16.0
>20%	17.0	45.5	36.0	26.0	16.0	4.0	50.5

Source: (Atlas of Hawaii 1973)

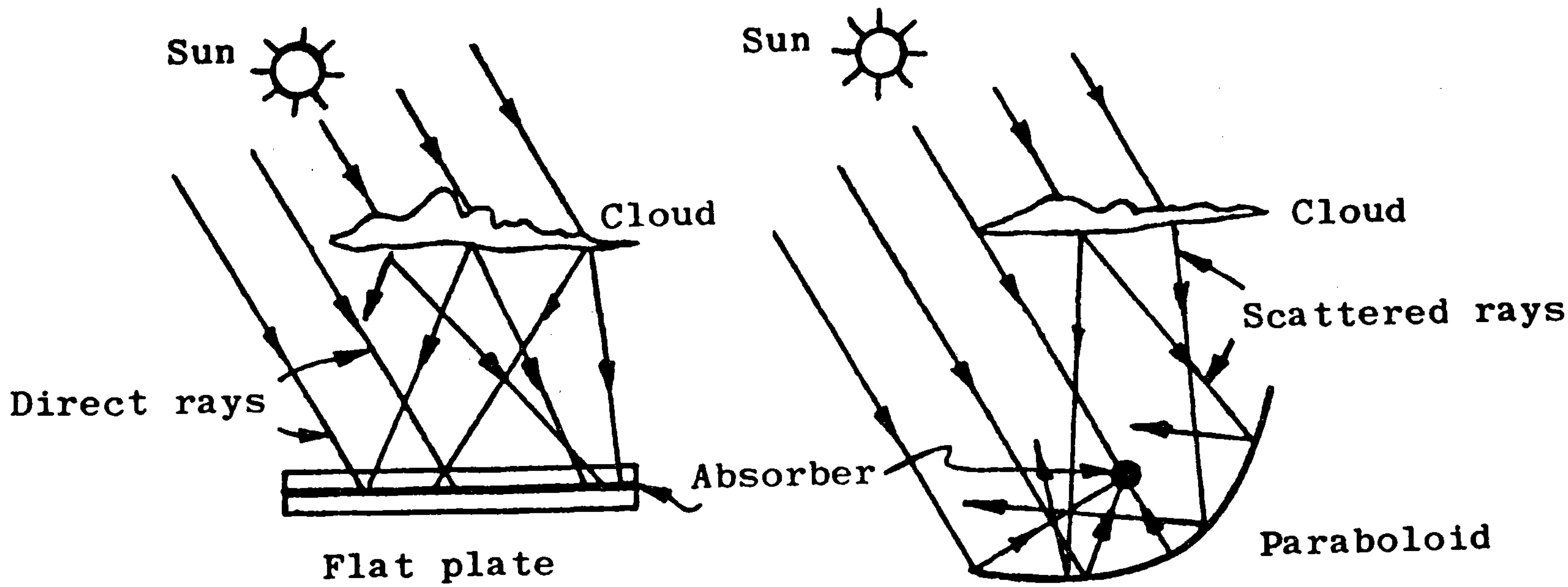


Figure VI-1 Diagram of Two Basic Types of Solar Collectors

Source: (Duffie & Beckman 1974)

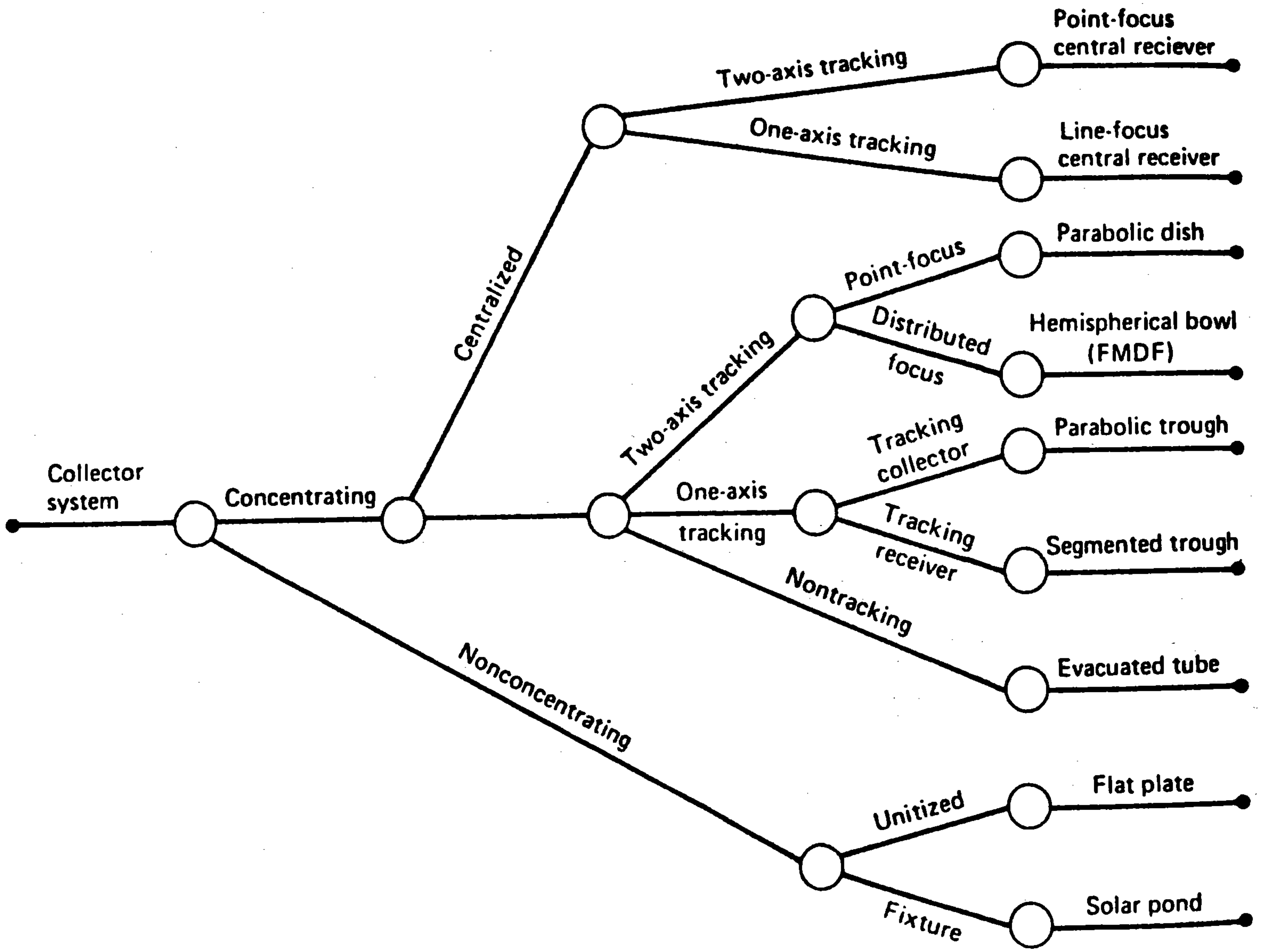


Figure VI-2 Solar Collector Classification Based on Optical Properties

Source: (Thorton, et al. 1980)

collector classification based on optical properties. Acceptable engine efficiency requires the high temperatures associated with high concentration ratios. Figure VI-3 shows the operating temperature ranges for various solar thermal systems.

The key elements of a concentrating solar thermal power system are concentrator, receiver, energy converter, and electrical generator. Solar energy collected by a tracking collector focusses the energy on a receiver. The working fluid in the receiver is raised to a high temperature and is transported to a heat engine, which converts the thermal energy into mechanical energy. This energy is used to generate electricity in a conventional manner. Energy storage may be incorporated as thermal storage in the thermal transport system, as mechanical storage following conversion, or as electrical storage following generation. Figures VI-4 to VI-6 show schematics of three concentrating solar thermal systems: line focus with parabolic troughs; point focus dishes; and central receiver.

For high temperature operation, the two types of concentrators suitable for solar thermal plants are heliostats and point focussing parabolic dishes. A field of heliostats focussing on a tower-mounted receiver functions in much the same manner as a parabolic dish collector focussing on a receiver at its focal point. Just as the same segments of a parabolic dish are relatively flat, so are the heliostats in a central receiver. The distance between a heliostat and the central receiver in a 1 megawatt plant may be several hundred feet.

Point focussing dish collectors are typically paraboloids which concentrate direct insolation and focus it on a receiver located at the focal point. A tracking mechanism with a sensing device keeps the dish pointing at the sun.

Concentrators must have structural integrity sufficient to withstand adverse meteorological conditions. Wind is a problem to all concentrator designs, but especially to heliostats because of their flat shape and precise focussing requirements.

Solar thermal technologies use the sun's radiant energy to produce heat that can be converted to mechanical or electrical power, or used directly in industrial and agricultural operations. In Hawaii, electrical production and process heat are used throughout the major islands. A point of increasing concern is the availability of fresh water. With growing demands and dwindling resources, coupled with chemical contamination, other sources must be found. Desalination with the use of solar systems is a good match for the following applications: multistage-flash or multi-effect; solar powered electrodialysis or reverse osmosis; and freezing (Rogers, Siebenthal, and Battey 1983; McVeigh 1977).

VI.1 Areas with Potential in Hawaii

In the background discussion (section II, page 1), three concentrating solar thermal projects in Hawaii are discussed. A power tower concept to produce steam for industrial processing and electrical production is examined. The Kauai Wilcox hospital project field used parabolic troughs to

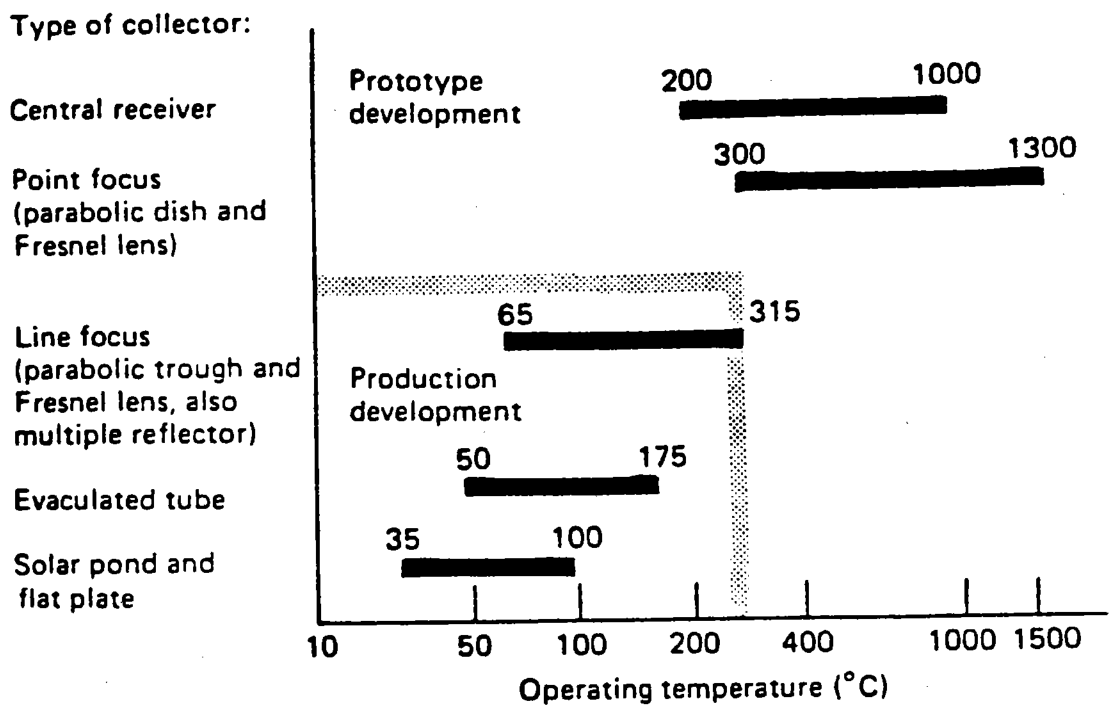


Figure VI-3 Typical Operating Temperature Ranges for Solar Thermal Systems

Source: (Brown 1980)

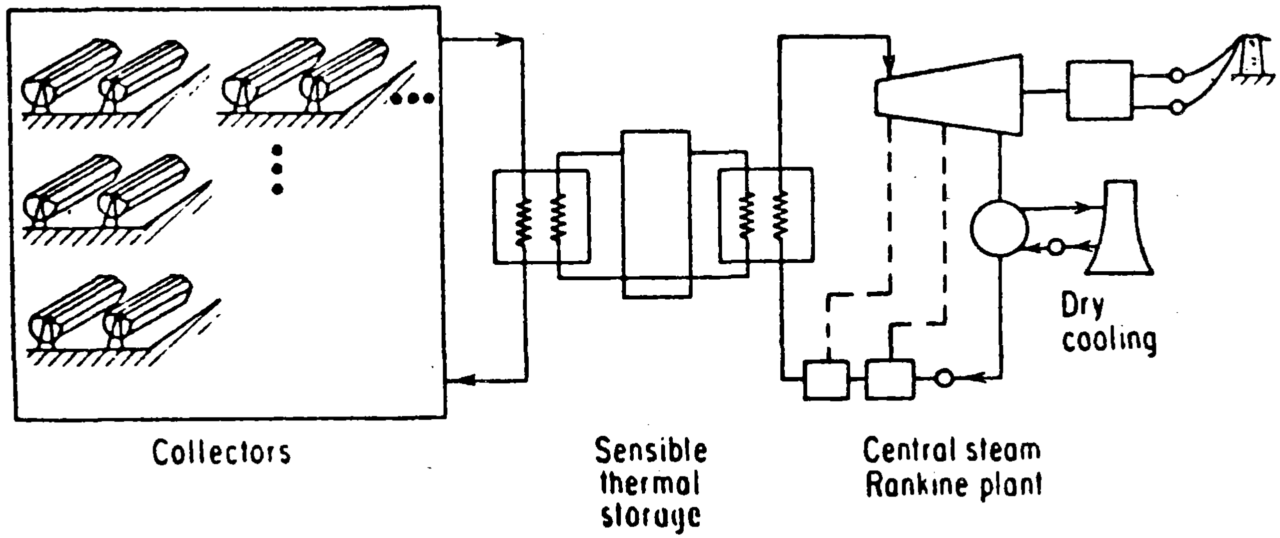


Figure VI-4 Parabolic Trough-Steam Transport and Conversion System

Source: (Kreider and Keith 1981)

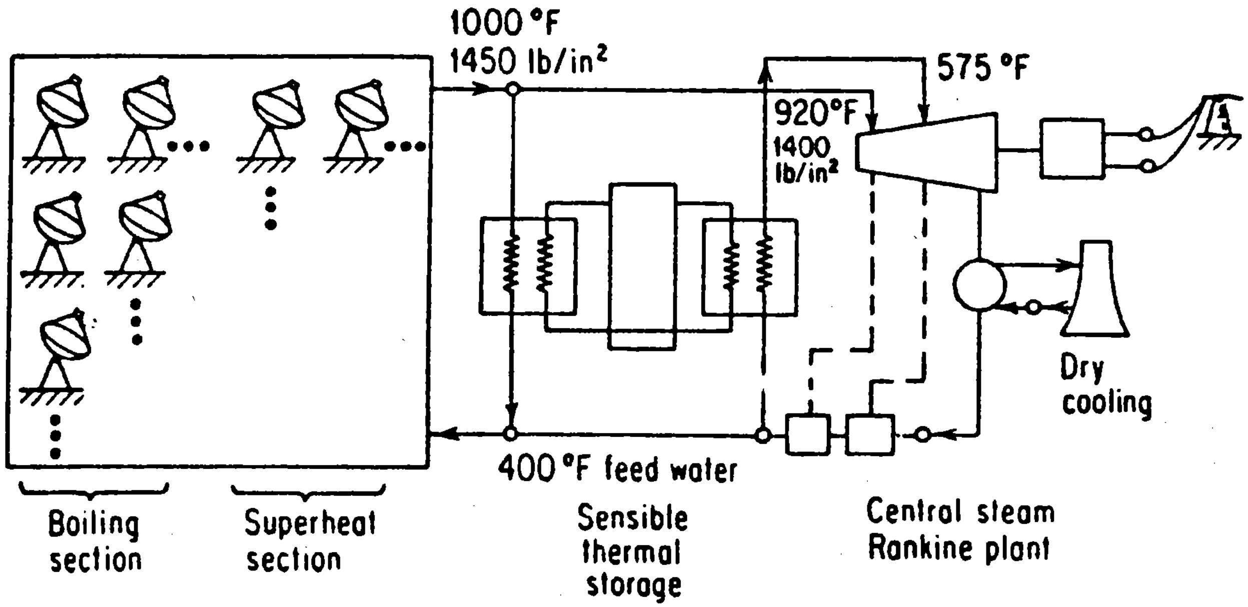


Figure VI-5 Parabolic Dish-Steam Transport and Conversion System

Source: (Kreider and Keith 1981)

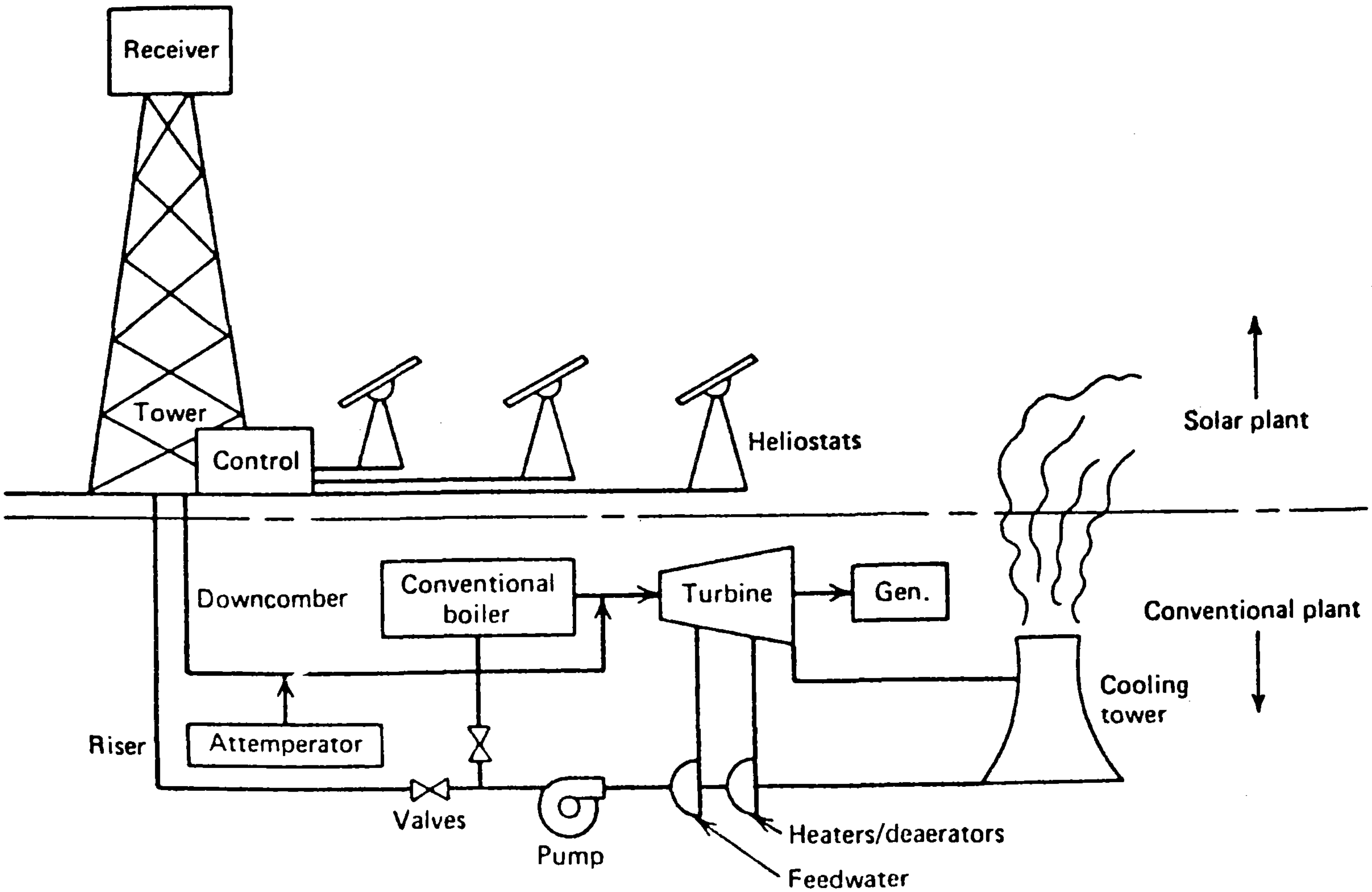


Figure VI-6 Central Receiver Solar Thermal-Electric Power Plant

Source: (Kreider and Keith 1981)

concentrate the sunlight onto a line source for electrical and thermal energy. Finally, a new project under design for 1987-1988 construction, will examine point focus dishes for steam production to a converted diesel engine for electrical generation on Molokai.

The common elements for these projects and future projects are sufficient direct normal insolation, adequate land area, and end use of the solar generated energy. Based on existing global and direct insolation information, land area available or in-use, and end user, areas for potential application have been identified (see Figure VI-7). Direct insolation is the key factor, since if it is not available in sufficient quantity, no concentrating solar thermal system will perform to expectations. Available land area is important, especially in Hawaii, since it is at a premium. This factor is critical for power tower systems, since these systems tend to require a large land area. Lastly, a market or need must be available or established for the system product. Electricity is, by far, the easiest product to market since it has widespread use in Hawaii; however, other applications such as process heat (i.e. sugar mill operations), heating, desalination or others (space cooling, dehumidifying) could turn out to be just as, or even more, valuable.

On Oahu, the western area of the island from HECO's Kahe power plant up the coast to Makaha is generally quite dry, sheltered from the prevailing trade winds by the Koolau and Waianae mountain ranges. Limited direct insolation measurements at Kahe Point have shown high insolation with an annual average of 337 calories per square-centimeter per day. The area averages about 20 inches of rainfall a year.

Land use is primarily croplands, limited forestry, and urban development (residential, commercial, resort, and industrial), and is zoned urban and agricultural. Major land ownership is dominated by the James Campbell Estate, Hawaiian Homes Land, Federal Government, State of Hawaii, and a host of small private owners.

This rural area has a community noted for its strong activism against any kind of major development. However, any project or solar thermal system which is environmently benign to the local environment, not in conflict with the local lifestyle, and which produces jobs, would probably be acceptable. The potential products for the concentrating solar thermal systems would be electricity, fresh water, and other heating applications.

The Ewa plains site is another potential area on Oahu. Sugarcane dominates with a long history, with increasing urban development designated for this region. The match of solar potential and need for electricity, process steam, and fresh water are all common elements for the area.

On Maui, the potential area for concentrating solar thermal systems is in the valley or plains area (see Figure VI-7), where global insolation is excellent. Land use in the valley is predominately agriculture (sugarcane and grazing) with a little forest land. The land use districts fall in this order, with area also zoned for agriculture, conservation, and development. C. Brewer and Co., Ltd. and Alexander and Baldwin, Inc. are the major landowners in this area with the state controlling conservation land.

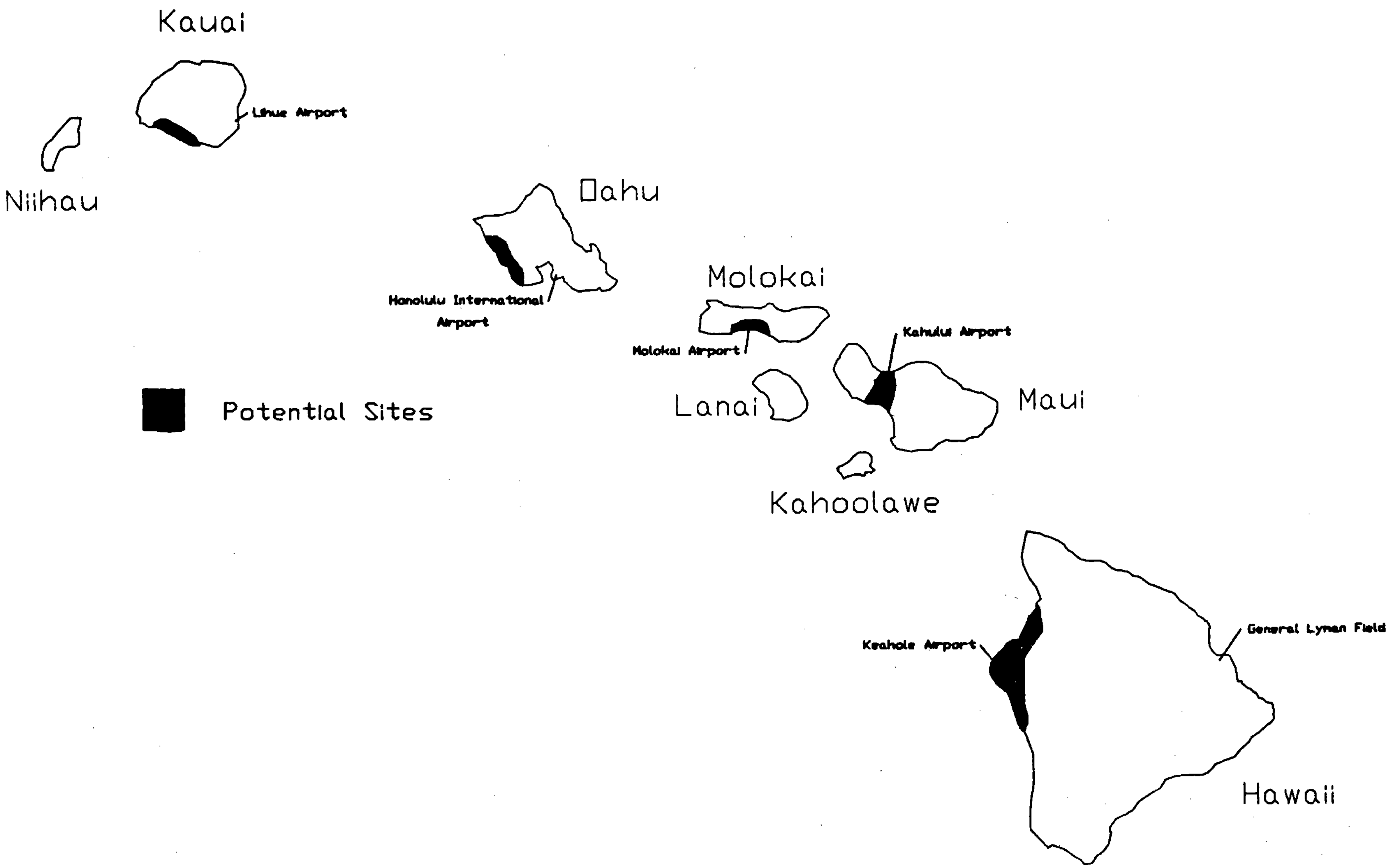


Figure VI-7 Potential for Concentrating Solar Thermal Systems

The Maui Renewable Resources Research Facility and the Maui High Tech Park Facility, sponsored by the State of Hawaii and the County of Maui, are scheduled for construction in 1988. The laboratory will be a test bed for renewable energy research and development, and a possible site for concentrating solar thermal systems. Electricity, process steam, and fresh water should be valuable in this area.

A major factor to consider in designing any concentrating solar thermal unit at this site is the wind load. The two Maui mountain groups (Haleakala and the West Maui Mountains) tend to funnel winds through the valley making it an excellent site for wind energy; however, strong winds can be detrimental to concentrating solar thermal systems structures. Appropriate design in the solar systems could help prevent any problems. The Kahului Airport is located in the northern section of the valley or plains, thus height restrictions are present. This could affect the location of any power tower type system in the neighboring area.

The Lahaina area of West Maui has excellent direct insolation for concentrating systems according to recorded data (Maui's only station at the Pioneer Mill has an annual average of 373 calories per square-centimeter per day). The discussion in the background section (section II page 1) mentions that Lahaina was the site for the proposed Solar Repowering Project at Pioneer sugar mill. This area is also one of recent rapid resort development, thus land value could be a problem.

The Molokai potential for concentrating solar thermal systems includes the site for the Small Community Solar Experiment (see section II, Background). This south-central section of Molokai is good for concentrating solar thermal systems. The Small Community Solar Experiment project, which records direct insolation in this area, shows an excellent resource (353 to 426 calories per square-centimeter per day).

Land use here is primarily grazing with small amounts of cropland and development, and is zoned for agriculture use and development with some conservation acreage. The two main landowners are the Hawaiian Homes Land and Molokai Ranch, Inc.

As mentioned earlier, Molokai is the least developed of the five largest islands. Residential electricity rates average about 20 cents per kilowatt-hour and the unemployment rate is the highest in the state over the past 10 years, averaging 13.9 percent (The State of Hawaii Data Book 1985). Thus, any development that has potential for less costly or steady electricity rates and jobs would be appealing to the local community. However, as with any development project, community education or awareness is very important, especially on Molokai, where there is a strong activist element.

In locating a concentrating solar system on the grounds of the Cooke Generating Station (Molokai Electric), steam could also be provided to their steam turbine.

Water for irrigation is a problem on Molokai. Currently, it is being transported through tunnels from the wet eastern mountain region to a man-made reservoir (1.4 billion gallon capacity) and distributed to the low-lying farm lots in the central region.

The Kaunakakai Airport is located in central Molokai. Thus, depending on the actual location of the concentrating solar thermal system, there may be height limitations on central receiver units.

With limited information on Big Island insolation, the west side, or Kona district, appears to be the best side for concentrating solar thermal systems. Sparse data collected at the site of the Natural Energy Laboratory of Hawaii (NELH) in 1982 show uncharacteristically low direct insolation (about 202 calories per square-centimeter per day), which can be explained by it being the wettest year in the last 50 years, and the year that the state was hit by Hurricane Iwa (Yuen, Seki and Curtis 1983). Further insolation information is needed to conclusively determine the site potential. NELH was created by the Hawaii State Legislature in 1974 as a facility for natural energy research and could be ideal for a concentrating solar thermal system. NELH is also the site of various alternate energy projects such as open-cycle ocean thermal energy conversion (OC-OTEC) and peripheral aquaculture activities, not only on the 324-acre site occupied by NELH, but also the neighboring Hawaii Ocean Science and Technology (HOST) park's 547 acres. Strong state support for this location is evidenced by the state's administration of the two sites.

The Keahole Point area is currently zoned and split between conservation and agriculture (forest land and crops) use, with proposed resort development for areas south and north. Major landowners include the State of Hawaii, Bishop Estate, and other small private owners.

With recent development in the Kona district, electricity and water are needed for further economic expansion. Land area is generally wide open on barren lava rock. The NELH and HOST park facilities are adjacent to the Keahole Airport, thus there are height restrictions near and around the surrounding area. This would again affect the location of power tower systems.

Finally, on Kauai, the city of Lihue in the southeast region of the island, has record of the only direct insolation measuring station. The potential, however, exists in the southern and western sections of the island. As mentioned in section II, the Wilcox Hospital concentrating solar system was eventually transferred to the Barking Sands Missile Range. The average annual rainfall is about 20-30 inches with high global insolation. Sugarcane growing and grazing dominate the land use, consequently, the area is zoned for agriculture. The major landowners are the State of Hawaii and Gay and Robinson (sugarcane), with small private owners. The scenario is similar to Maui, where electricity and process steam could be used in existing sugar mill operations. Water again is a primary concern in the area.

VII. CONCLUSIONS

The three important parameters needed for a solar thermal concentrating system are adequate direct normal insolation, land area, and a market for the product. Historically, Hawaii has an abundance of solar data on record. Unfortunately, most of this information is for global insolation. New equipment has been installed within the past few years to measure or calculate the direct component of solar radiation at various sites. However, more stations are needed to record this information if concentrating solar thermal systems are to be taken seriously.

Land requirements for a solar thermal concentrating system are dependent on the system to be used and the size of the installation, ranging from a few hundred square feet to several acres. In Hawaii, because land is at a premium, minimal system size is an important consideration.

Finally, the market for this solar product must be examined. Hawaii has a need for electricity, process heat, fresh water, and other "niche" applications (space cooling and dehumidifying). Taking these factors into account, the best sites for solar thermal concentrating systems in the state are as follows:

- Western coast of Oahu, especially near Kahe power plant
- Maui plains area
- South-central Molokai
- Kona Coast of the Big Island, especially Natural Energy Laboratory of Hawaii
- Western and southern areas of Kauai

These sites are all located on the leeward or dry side of the island (normal trade winds blow in from the northeast), thus cloud cover would only be a problem during stormy periods and Kona weather conditions (southerly winds about 10 percent of the year). Direct insolation is being collected from a few of these sites, where good insolation has been shown. Land area should not pose a major problem since these sites tend to be in or near non-developed areas. Finally, electrical generation could be used at all sites, but just as important is fresh water production, which would be very attractive in these dry areas.

REFERENCES

Amfac Energy, Inc. 1983. Preliminary Design for Solar Repowering at Pioneer Mill Co., Ltd. - Final Report. U.S. Department of Energy COntract No. DE-FC03-82SF11676. November.

The University Press of Hawaii. 1973. Atlas of Hawaii. Honolulu.

Brown, K.C. 1980. Use of Solar Energy to Produce Process Heat for Industry. Solar Energy Research Institute. SERI/TP-731-626.

Curtis, G. and M. Soloman. Theoretical and Emperical Comparison of Normal and Derived Direct Insolation Values for Hawaii. In preparation, Hawaii Natural Energy Institute, University of Hawaii.

Duffie, J.A. and W.A. Beckman. 1974. Solar Energy Thermal Processes. John Wiley and Sons, New York.

Ekern, P. Soils & Agronomy, University of Hawaii. Personal communication, Dec. 1986.

Energy Division. 1985. Island Sunshine Maps. Department of Planning and Economic Development, State of Hawaii.

Falicoff, W., G. Koide, and P. Takahashi. 1979. Solar/Wind Handbook for Hawaii: Technical Applications for Hawaii, the Pacific Basin and Sites Worldwide with Similar Climatic Conditions. Department of Architecture, College of Engineering, and Hawaii Natural Energy Institute, University of Hawaii.

How, K. 1978. Solar Radiation in Hawaii: 1932 - 1975. Hawaiian Sugar Planters' Association Experimental Station, Report R57. Honolulu, Hawaii.

Kai, K. Kauai Electric Company. Personal communication, Dec. 1986.

Kinoshita, C. 1985. Hawaiian Sugar Planters' Association. Unpublished HSPA Data.

Kreider, J.F. and F. Keith, eds. 1981. Solar Thermal Power Systems. Solar Energy Handbook. R.R. Donnelly & Sons, Co. pp. 20-1 to 20-41.

Law, H.K. 1976. Characteristics of Solar Radiation in Hawaii. Senior Honors Thesis, Department of Civil Engineering, College of Engineering, University of Hawaii. December.

McVeigh, J.C. 1977. An Introduction to the Applications of Solar Energy. Pergamon Press.

Meinel, A.B. and M.P. Meinel. 1976. Applied Solar Energy - An Introduction. Addison-Wesley Publishing Co., Menlo Park, California.

Neill, D.R. 1985. Guidebook on Wind Energy Conversion Applications in Hawaii. Hawaii Natural Energy Institute, University of Hawaii and Department of Planning and Economic Development, State of Hawaii.

Rogers, A., C. Siebenthal, and R. Battey. 1983. Desalinatio Technology - Report on the State of the Art. Bechtel Group, Inc., San Francisco. February.

Rogers, R. and E. Bilodeau. Power Kinetics, Inc. Personal communication, Nov. 1985.

The State of Hawaii Data Book - 1985 - A Satistical Abstract. 1985. Department of Planning and Economic Development, State of Hawaii. November.

St. John, G. Amfac Energy. Personal communication, Jan. 1987.

Thornton, J.P. 1980. A Comparitive Ranking of 0.1-10 MW_e Solar Thermal Power Systems. Solar Energy Research Institute. SERI/TR-351-461.

Yoshihara, T. and P. Ekern. 1977. Solar Radiation Measurements in Hawaii. Hawaii Natural Energy Institute, University of Hawaii. September.

Yoshihara, T. and P. Ekern. 1978. Assessment of the Potential of Solar Energy in Hawaii - Final Report. Hawaii Natural Energy Institute, University of Hawaii. January.

Yuen, P., A. Seki, G. Curtis. 1983. Operation and Maintenance of Wilcox Hospital Solar Photovoltaic Energy System on Kauai - For the period from May 1, 1982 to February 28, 1983 - Final Report. Hawaii Natural Energy Institute, University of Hawaii. April.

Zane, L. Energy Division, Department of Planning and Economic Development. Personal communication, Dec. 1986.

APPENDIX A

Table of Petroleum Fuel Use in Hawaii for 1985

TABLE A-1
PETROLEUM FUEL USE, HAWAII: 1985
(BARRELS)

CONSUMPTION SECTORS	MOTOR GASOLINE	NAPHTHA	KEROSENE	ALCOHOL FUELS	DIESEL	OTHER DISTILL	AVIATION GASOLINE	JET KEROSENE	JET NAPHTHA	RESIDUAL FUEL OIL	ASPHALT	PROPANE	FUEL GAS	TOTAL	TOTAL LESS ASPHALT
Civ Serv Stations	6,156,824	185	0	0	76,132	584	0	0	0	0	10	0	0	6,233,735	6,233,725
Military Serv Stat	467,800	0	0	0	2,742	4	0	0	0	0	0	0	0	470,546	470,546
Trucks & Buses	174,229	0	0	2,090	215,049	61	0	0	0	0	0	0	0	391,429	391,429
Aviation, IntraState	8,026	0	0	0	457	0	17,035	2,988,400	0	0	0	0	0	3,013,918	3,013,918
Aviation, Overseas	1,123	6	0	0	100	0	42,511	9,274,076	0	0	0	0	0	9,317,816	9,317,816
Water, IntraState	441	3	0	14,746	387,479	0	0	0	0	15,598	0	0	0	418,267	418,267
Water, Other	28	4	0	0	480,643	10	0	447	0	43,444	0	0	0	524,576	524,576
Construction	89,877	361	0	0	155,701	3,940	234	0	0	29,479	0	0	0	279,592	279,592
Commercial-Industr'l	659,240	490	0	0	223,837	31,952	0	0	754,762	1,199,490	277,226	535,576	0	3,682,573	3,405,347
Electric Generation	0	0	0	0	811,882	0	0	0	0	10,599,202	0	0	0	11,411,084	11,411,084
Gas Utilities	0	485,735	0	0	0	0	0	0	0	0	0	269,141	50,402	805,278	805,278
Agri, Agri Produc	106,168	249	0	0	242,806	12,056	4,138	0	0	149,390	0	0	0	514,807	514,807
Military	120,117	0	0	0	1,821,814	232	561	983,819	2,667,025	44,140	0	0	0	5,637,708	5,637,708
Federal Government	14,499	0	0	4,380	17,614	0	609	0	0	31	0	0	0	37,133	37,133
State Government	80,948	0	0	0	27,450	2,095	0	0	0	5,139	0	0	0	115,632	115,632
County Governments	120,326	270	0	0	137,275	176	0	0	0	2,333	0	0	0	260,380	260,380
Total.......	7,999,646	487,303	0	21,216	4,600,981	51,110	65,088	13,246,742	3,421,787	12,088,246	277,236	804,717	50,402	43,114,474	42,837,238
Transportation use:	7,999,646				2,984,416	584	65,088	13,246,742	3,421,787	59,042				27,777,305	27,777,305
Electric generation:	0	0	0	0	811,882	0	0	0	0	10,599,202	0	0	0	11,411,084	11,411,084
Other direct use:	0	487,303	0	21,216	804,683	50,526	0	0	0	1,430,002	277,236	804,717	50,402	3,926,085	3,648,849
Btu per barrel:	5253000	5248000	5670000	5253000	5825000	5825000	5048000	5670000	5355000	6287000	6636000	3836000	3963000		
Total Btu by prod..	4.2022140e13	2.557e12	0	1.114e11	2.68007e13	2.977e11	3.286e11	7.510903e13	1.832367e13	7.599880e13	1.840e12	3.087e12	1.997e11	2.4667582e14	2.448361e14
Btu transpor:	4.2022140e13	0	0	0	1.73842e13	3.4018e9	3.286e11	7.510903e13	1.832367e13	3.711971e11	0	0	0	1.5354222e14	1.535422e14
Btu elec gener:	0	0	0	0	4.72921e12	0	0	0	0	6.663718e13	0	0	0	7.1366396e13	7.136640e13
Btu other direct:	0	2.557e12	0	1.114e11	4.68728e12	2.943e11	0	0	0	8.990423e12	1.840e12	3.087e12	1.997e11	2.1767204e13	1.992747e13

Source: Zane (1986)

APPENDIX B

Table of Import and Export of Crude Oil and

Petroleum Products for 1985

TABLE B-1
IMPORT AND EXPORT OF CRUDE OIL
AND PETROLEUM PRODUCTS: 1985
(BARRELS)

Product	Imports Total	Imports Domestic	Imports Foreign	Exports Total	Exports Domestic	Exports Foreign
Crude oil	38.489,614	17,713,569	20,776,045	0	0	0
Motor gasoline	240,538	145,623	94,915	0	0	0
Distillates	121,061	31,201	89,860	560,259	0	560,259
Jet fuel	1,242,715	2,157	1,240,558	0	0	0
Aviation gas	0	0	0	0	0	0
Residual fuel	5,282,917	5,160,936	121,981	4,639,915	0	4,639,915
Naphtha	537	537	0	0	0	0
Refined products	6,887,768	5,340,454	1,547,314	5,200,174	0	5,200,174
Total all prod	45,377,382	23,054,023	22,323,359	5,200,174	0	5,200,174

Source: Zane (1986)

APPENDIX C

Maps of Electricity Producers and Transmission Systems for Oahu, Maui, Molokai, Hawaii, and Kauai

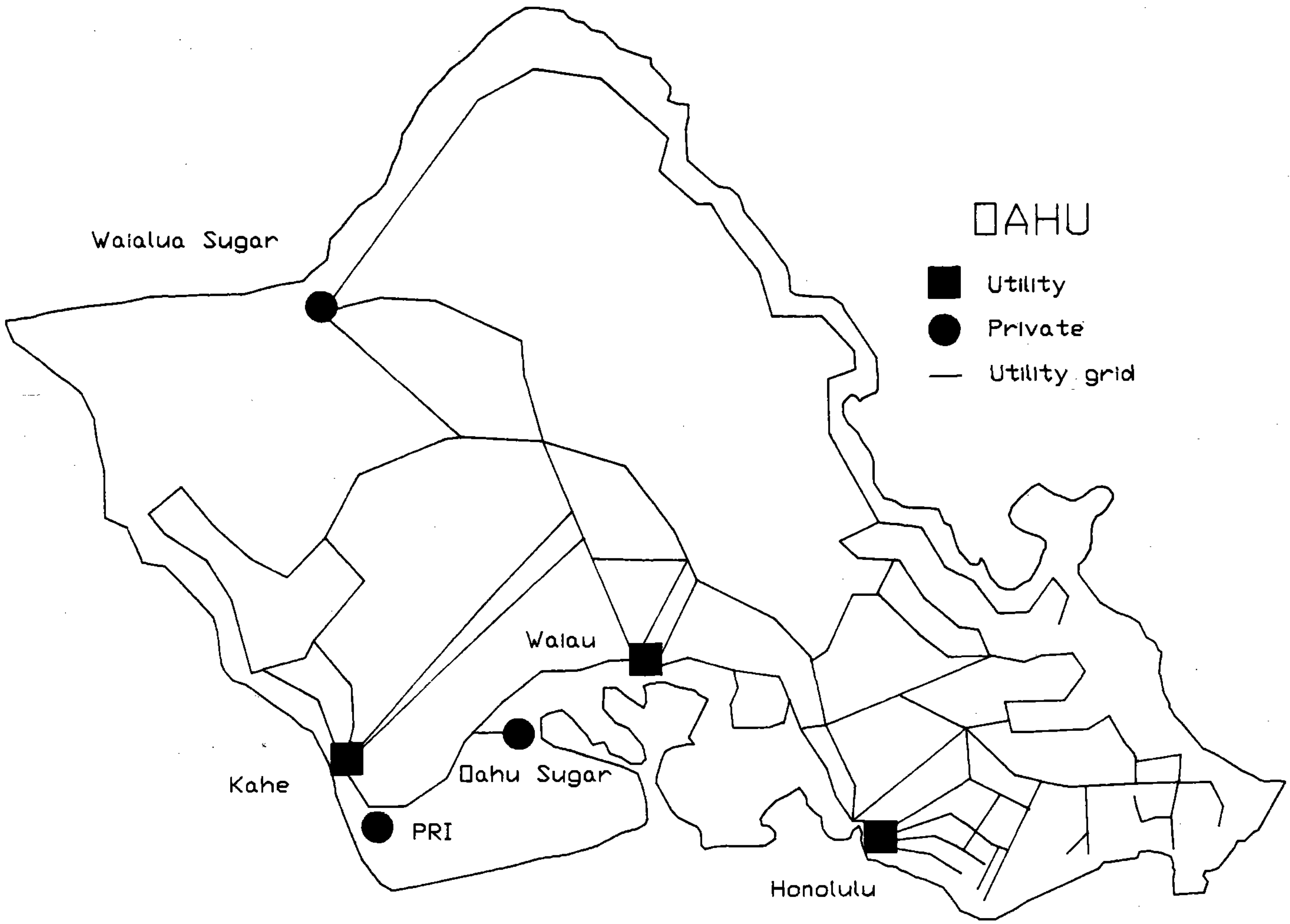


Figure C-1 Oahu Electricity Producers and Transmission System

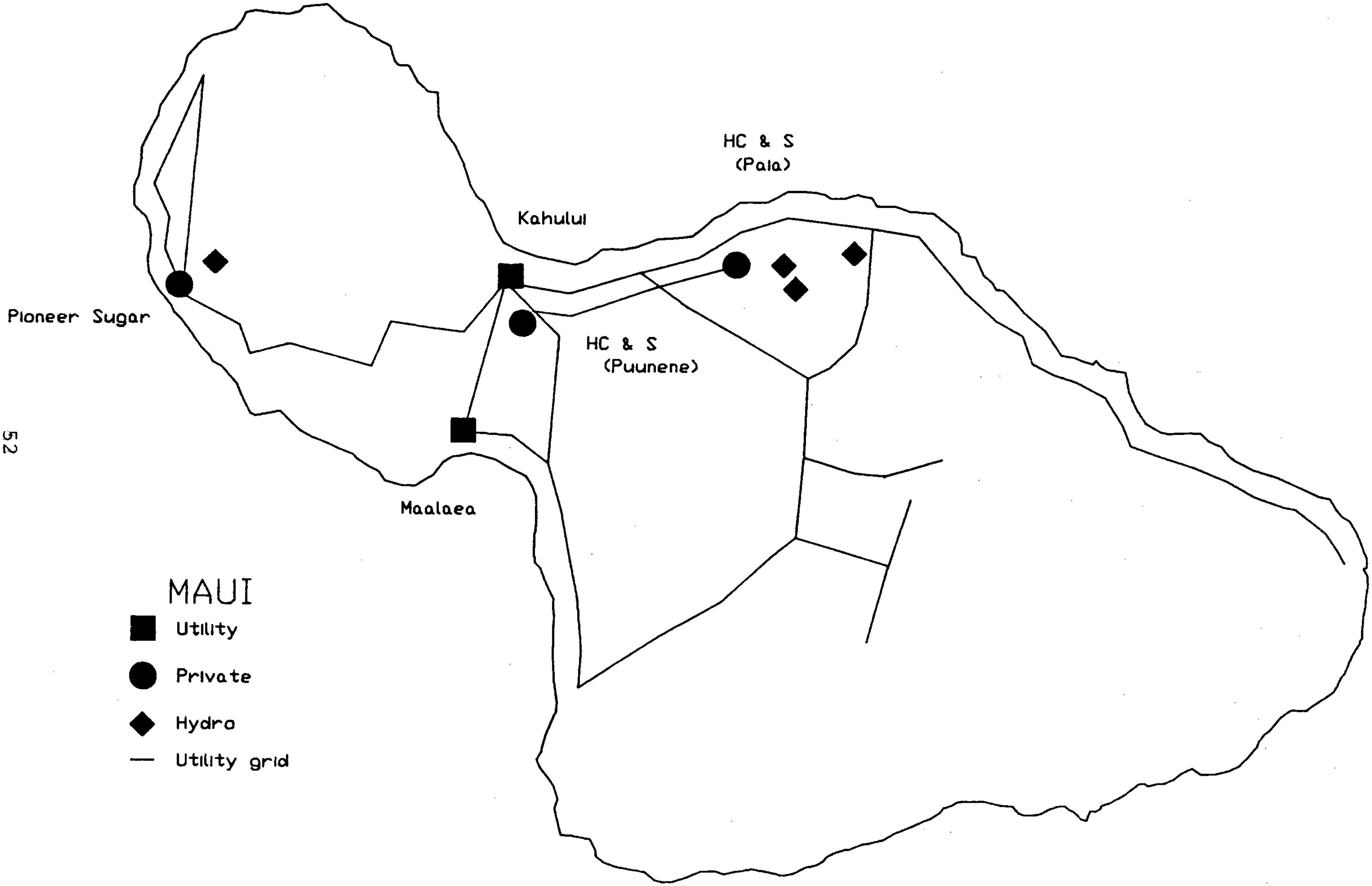


Figure C-2 Maui Electricity Producers and Transmission System

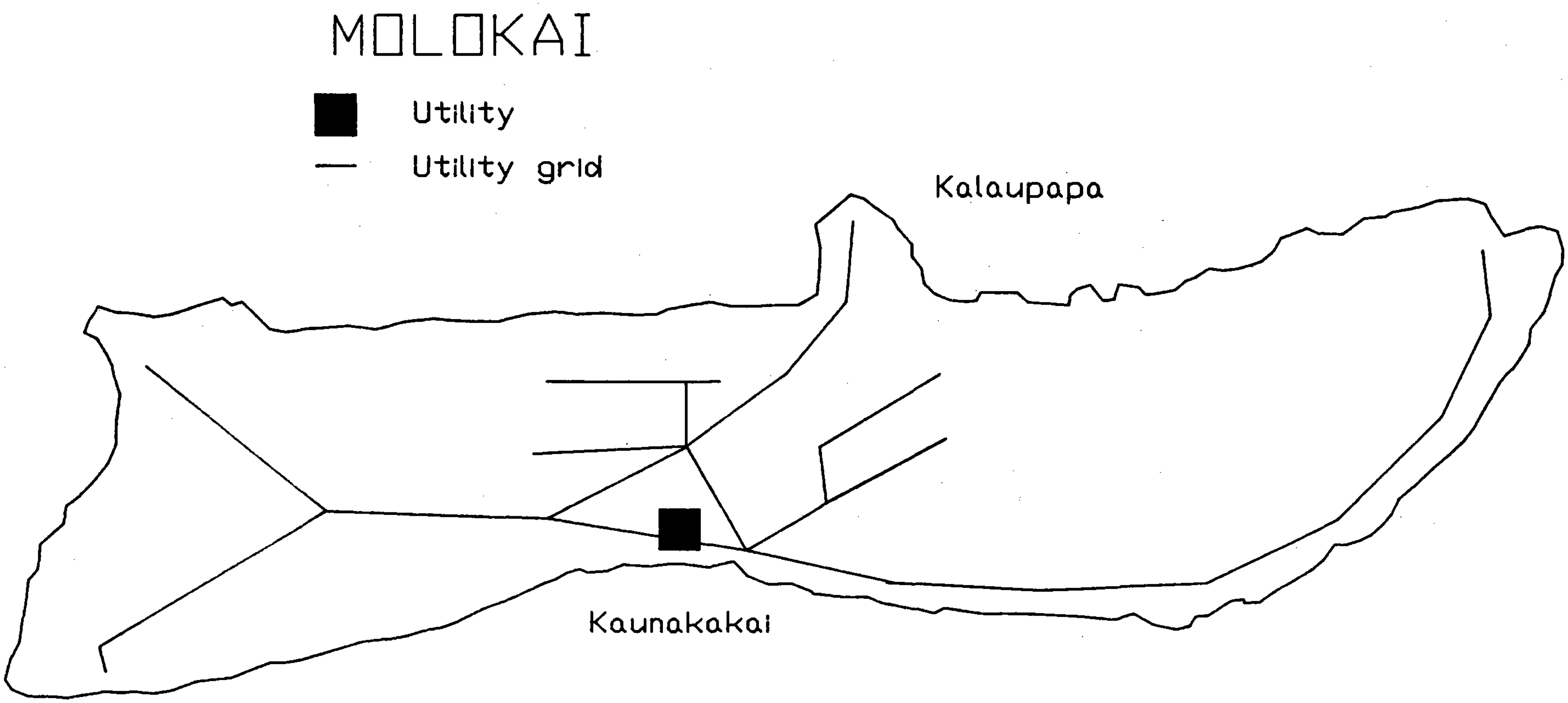


Figure C-3 Molokai Electricity Producers and Transmission System

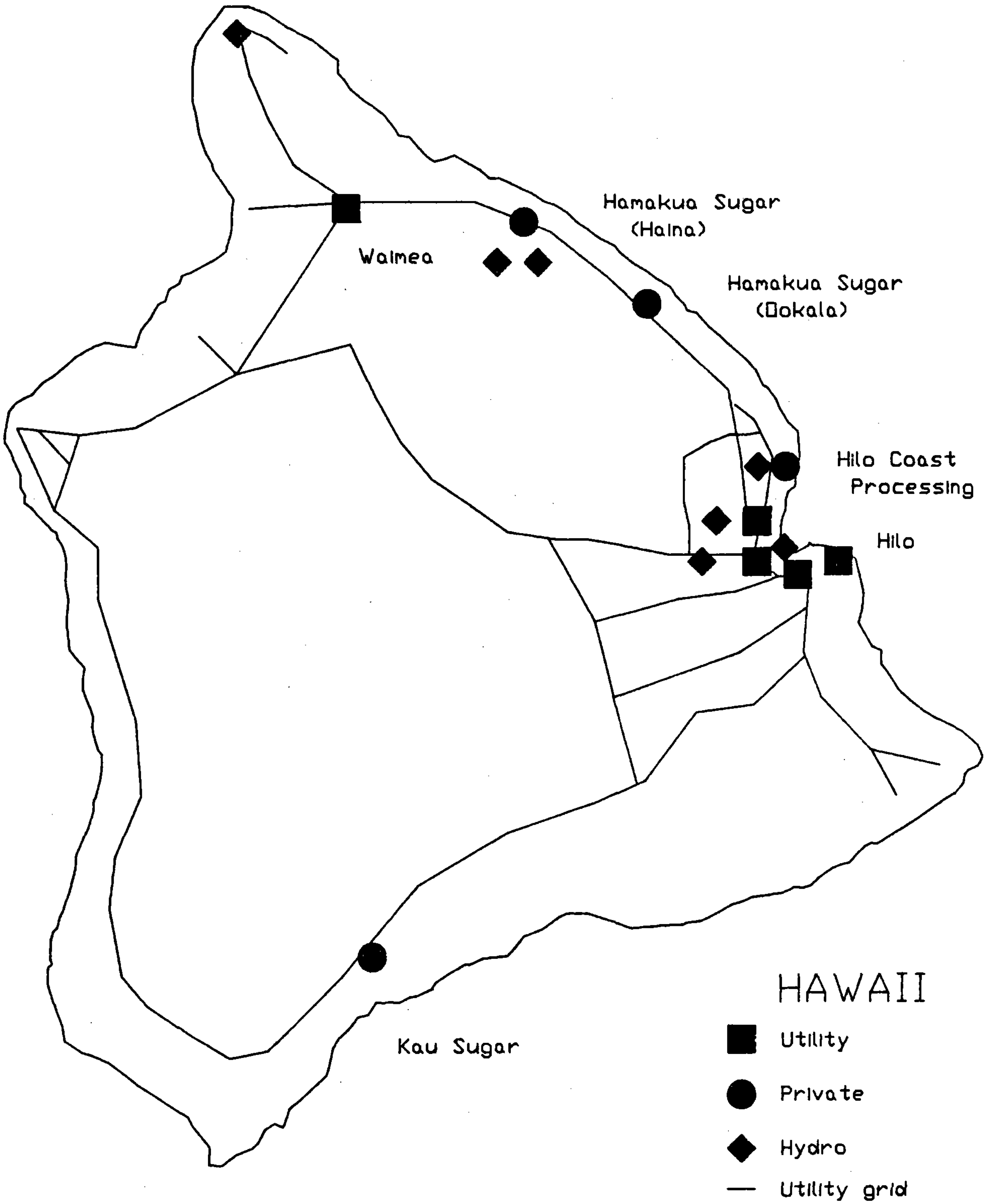


Figure C-4 Hawaii Electricity Producers and Transmission System

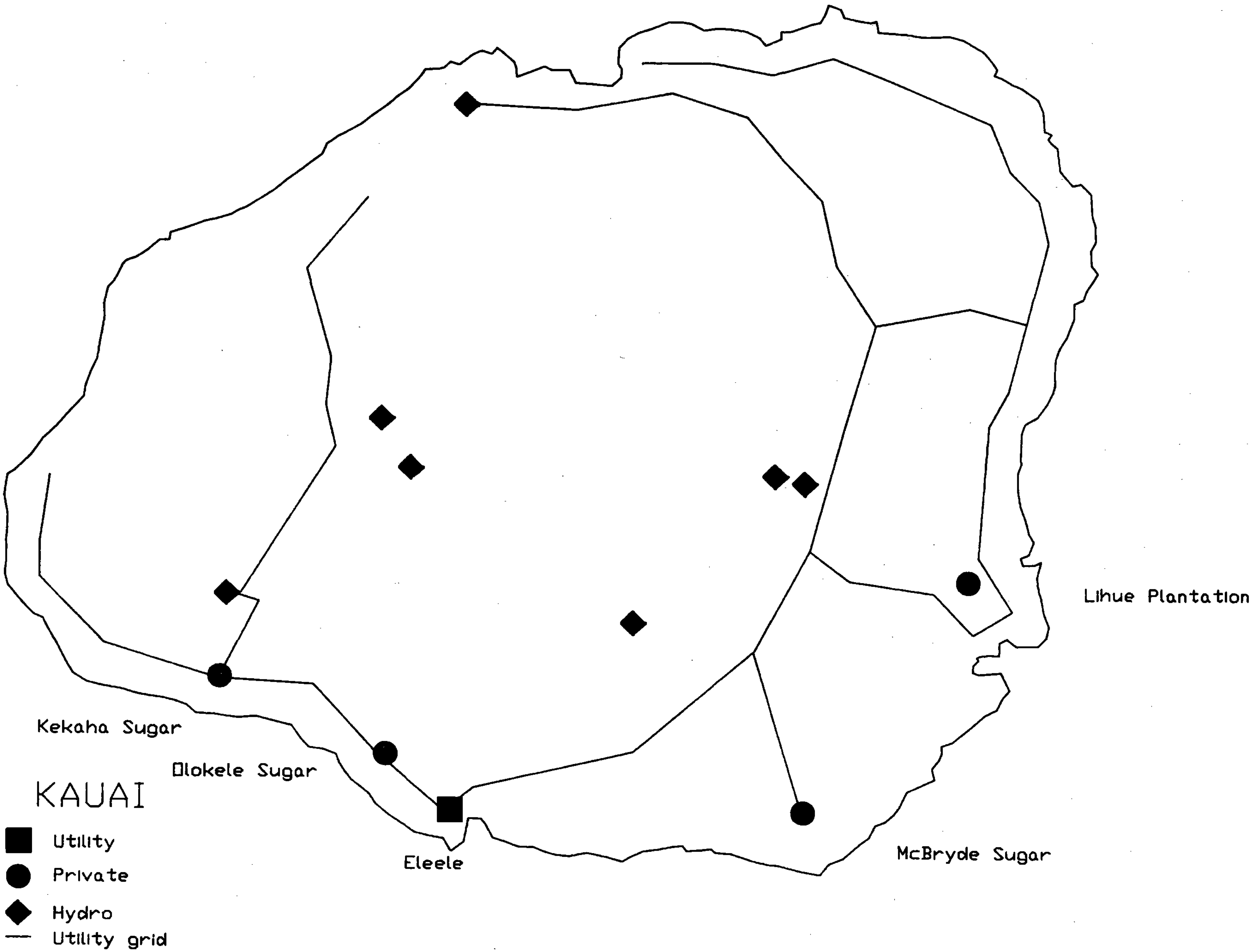


Figure C-5 Kauai Electricity Producers and Transmission System

APPENDIX D

Tables of Global, Diffuse, and Direct Insolation for Various Sites in Hawaii

TABLE D-1

1977 HAWAII SOLAR RADIATION DATA

(cal/cm^2/day)

Sites	Test Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annu
Oahu	Global	382.3	457.1	490.0	546.1	552.4	527.4	576.9	550.4	532.0	453.5	390.7	334.7	482.8
Holmes	Diffuse			165.1	163.0	173.4	180.2	168.2	151.6	155.9	132.7	120.1	124.3	153.5
Hall	Direct			290.2	345.6	342.6	313.0	375.1	367.0	341.8	296.9	253.8	195.5	312.2
Oahu	Global	386.3	458.8	493.8	555.8	560.4	544.2	602.5	567.4	503.0	450.6	393.6	341.3	488.1
Honolulu	Diffuse													
Airport	Direct													
Oahu	Global	342.5	433.8	414.0	457.2	436.5						344.4	285.7	387.7
Huelani	Diffuse													
	Direct													
Oahu	Global	342.5	379.3	446.8	441.6	519.8	582.8	560.1	520.4	480.9	415.1	333.7	302.0	443.8
Kahuku	Diffuse													
	Direct													
Oahu	Global	331.0	374.7	423.0	431.8	430.3	415.6	455.7	411.6	377.6	361.2	322.9	313.4	387.4
Kaena	Diffuse													
	Direct													
Oahu	Global	315.9	363.6	279.7	374.2	316.9	341.0	339.0	366.8	334.9	366.0	280.1	280.4	329.9
Lyon	Diffuse													
Arboretum	Direct													
Oahu	Global	387.9	464.8	497.9	542.2	553.7	531.6	593.7	569.5	550.2		383.9	346.8	492.9
Makiki	Diffuse													
Arcadia	Direct													
Oahu	Global	254.6	265.2	243.2	230.1	315.8	346.5	316.2	300.9	295.5	263.8	222.9	209.3	272.0
Maunawili	Diffuse													
	Direct													
Oahu	Global	329.5	428.2	440.6	507.6	496.7	517.6	550.5	535.1	463.9	413.1	336.3	309.8	444.1
Mililani	Diffuse													
	Direct													
Oahu	Global	329.9	393.8	469.9	512.0	503.1						347.1	320.3	410.9
Palehua	Diffuse													
	Direct													
Oahu	Global	266.1	274.4	262.5	361.5	386.5			411.3		443.9	315.2	377.1	344.3
Tantulus	Diffuse													
	Direct													
Oahu	Global	396.0	477.7	523.9	547.6	578.0			598.7			406.0	353.4	485.2
Waikiki	Diffuse													
	Direct													
Oahu	Global	362.7	426.0	451.6	511.1	479.3						363.7	332.2	418.1
Waimano	Diffuse													
Home	Direct													

Maui C.C.	Global	410.5	469.8	493.3	457.0	564.9					439.4	415.1	320.0	446.3
	Diffuse													
	Direct													
Molokai	Global	396.4	453.5	503.8	522.0	545.3	566.3	582.9	579.6	507.7	459.8	409.0	361.0	490.6
Kaunakakai	Diffuse													
	Direct													
Hawaii	Global	406.0	435.8	450.5	526.7		495.2	515.3	543.4	497.7	406.0	409.2	364.0	459.1
Keahole	Diffuse													
Airport	Direct													
Hawaii	Global	353.6	337.7	364.3	401.4	387.3	328.2	374.8	405.2	359.3	342.9	409.4	280.9	362.1
Kealakekua	Diffuse													
	Direct													

TABLE D-2

1978 HAWAII SOLAR RADIATION DATA

(cal/cm^2/day)

Sites	Test Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annu
Oahu	Global	367.3	433.3	496.8	507.3	529.1	568.5	545.2	545.6	632.6	424.7	412.9	320.1	482.0
Holmes	Diffuse	118.9	103.4	151.4	173.4	167.7	141.5	145.8	161.0	147.8	129.4	117.2	138.6	141.3
	Direct	232.9	313.4	313.6	294.0	326.2	400.1	370.2	350.8	452.3	272.0	279.3	164.9	314.1
Oahu	Global	379.7	456.0	489.6	516.8	578.9								484.2
Honolulu	Diffuse													
Airport	Direct													
Oahu	Global	354.5	409.9	418.4	416.4	427.3	439.3	461.1				378.8	286.5	399.1
Huelani	Diffuse				208.5	175.8	182.0	179.7				129.8	126.2	167.0
	Direct				159.9	214.6	222.7	245.5				230.8	145.2	203.1
Oahu	Global	330.5	419.2	386.9	373.3	371.0	312.0	307.5	331.8	285.5	350.5	334.7	250.6	337.8
Lyon	Diffuse													
Arboretum	Direct													
Oahu	Global	261.0	339.8	295.0	296.4	325.7	312.9	308.8	284.0	303.3	261.5	223.0	171.1	281.9
Maunawili	Diffuse										176.4	137.7	138.6	150.9
	Direct										53.3	66.0	15.9	45.1
Oahu	Global	348.9	427.6	444.1	456.0	460.4	509.5	538.0	520.2	515.7	396.3	354.9	299.0	439.2
Mililani	Diffuse													
	Direct													
Oahu	Global	376.4	465.5	490.8	481.2									453.5
Tantulus	Diffuse													
	Direct													
Oahu	Global	393.6	459.7	497.6	543.3	556.1	601.3	622.3	589.2	558.0	432.2	393.6	338.8	498.8
Waikiki	Diffuse													
	Direct													
Oahu	Global	355.5	444.0	456.8	464.7	448.4	475.8	514.4	503.6	492.7				461.8
Waimano	Diffuse													
Home	Direct													
Maui	Global							589.6	532.0	457.3	421.9	362.0		472.6
Lahaina	Diffuse													
	Direct													
Molokai	Global	411.4	462.9	523.3	519.8	547.5	568.4	560.0	550.5	509.2	431.3	394.8	387.6	488.9
Kaunakakai	Diffuse													
	Direct													
Hawaii	Global						410.7	376.9	366.4	437.8	331.3	276.3	207.4	343.8
Hilo CPO	Diffuse						220.1	239.2	205.4	201.3	176.6	95.7	109.1	178.2
	Direct						148.8	89.9	117.9	192.2	122.9	167.2	85.2	132.0
Hawaii	Global	410.1	512.1	524.8	551.8	615.1	562.7	565.7	544.0	520.1	475.2	382.5	360.1	502.0
Keahole	Diffuse													
Airport	Direct													

Hawaii	Global	367.1	428.9	388.3	448.7	364.8	366.1	356.5	346.1	346.1				379.2
Kealakekua	Diffuse													
	Direct													
Hawaii	Global						385.0	451.1	427.6	392.6	339.7	277.0	243.1	359.4
Kulani	Diffuse													
	Direct													
Kauai	Global							516.1	465.1	496.6	387.0	340.3	310.6	419.3
Lihue	Diffuse							208.9	212.1	221.1	182.0	164.4	147.4	189.3
	Direct							265.4	208.5	226.9	172.2	152.9	145.5	195.2

TABLE D-3

1979 HAWAII SOLAR RADIATION DATA

(cal/cm^2/day)

Sites	Test Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annu
Oahu	Global	317.8	325.0	483.7	545.8	550.3	548.7	558.4	565.5	524.6	425.7	371.9	334.1	462.6
Holmes	Diffuse	119.2	146.7	149.1	157.8	157.8	188.5	158.2	139.7	132.3	148.8			149.8
	Direct	183.1	154.8	303.3	351.7	359.4	324.4	368.6	396.6	363.2	250.1			305.5
Oahu	Global	291.2	289.6	414.1	448.7	449.1	396.1	426.9	491.8	434.0	386.2	373.8	340.7	395.2
Huelani	Diffuse	121.3	145.7	139.6	165.7	169.9	185.3	187.1	152.1	196.2	158.3	147.9	112.9	156.8
	Direct	154.1	120.6	245.2	244.9	243.5	175.6	202.4	307.8	194.6	199.4	205.2	214.3	209.0
Oahu	Global	251.2	247.6	384.4	417.2	381.0	274.3	361.4	408.6	395.6	296.7	299.2	303.7	335.1
Lyon	Diffuse													
Arboretum	Direct													
Oahu	Global	190.3	159.2	332.4	353.2	356.8	319.0	333.5	365.2	345.6	253.8	207.5	199.4	284.7
Maunawili	Diffuse	141.7	134.9	207.3	207.4	210.5	222.5	228.4	200.5	199.6	158.3	139.9	122.6	181.1
	Direct	30.2	2.7	81.6	98.1	102.1	54.2	59.4	122.6	102.1	67.0	48.0	62.1	69.2
Oahu	Global	318.4	303.6	468.9	516.7	525.1	560.5	564.0	545.5	508.4	395.6	363.8	327.2	449.8
Mililani	Diffuse													
	Direct													
Oahu	Global		199.7	416.3	438.1	497.8	479.8	503.1	474.3	466.3	329.9			422.8
Ulu Alana	Diffuse	70.5	81.1	94.0	167.3	201.7	225.6	217.7	171.4	165.7	152.8	134.9		153.0
	Direct		105.6	302.6	232.2	253.7	211.3	241.9	266.9	264.1	149.6			225.3
Oahu	Global	349.4	343.7	526.7	569.9	592.2	604.4	629.8	605.6	540.8	445.5	395.2	366.2	497.5
Waikiki	Diffuse													
	Direct													
Maui	Global	342.6	336.6	544.8	583.8	608.2	584.0	612.8				409.2	363.7	487.3
Lahaina	Diffuse													
	Direct													
Molokai	Global								528.4	502.7	440.8	385.3	330.2	437.5
Kualapuu	Diffuse													
	Direct													
Molokai	Global	361.9	315.9	551.4	511.9	555.5	538.1	603.7	592.1	532.1	450.5	423.7	381.4	484.9
Palaau	Diffuse													
	Direct													
Hawaii	Global										262.1	306.0	325.0	297.7
HCPC	Diffuse										160.8	129.9	118.3	136.3
	Direct										72.4	157.9	192.5	140.9
Hawaii	Global	236.7	236.5	354.2	331.2	389.2	360.1	366.9	411.4	408.9	297.2	254.6	271.8	326.6
Hilo CPO	Diffuse	91.2	115.9	128.2	163.8	166.7	175.4	174.3	145.0	129.0	106.4	103.8	93.7	132.8
	Direct	133.6	102.1	199.1	129.7	187.5	151.4	157.7	236.0	251.5	171.6	136.3	166.9	168.6
Hawaii	Global	279.5	210.3	376.1	316.7	375.7	384.8	465.6	452.9	447.7	318.8	286.2	322.4	353.1
Kulani	Diffuse													
	Direct													

TABLE D-4

1980 HAWAII SOLAR RADIATION DATA

(cal/cm^2/day)

Sites	Test Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annu
Oahu	Global	314.8	363.5	464.1	498.0	512.2	551.6	530.5	581.2	537.8	476.4	388.3	319.0	461.5
Holmes	Diffuse	106.4	102.5	146.9	153.2	186.9	172.7	216.3	157.0	186.9	122.9	113.4	93.2	146.5
	Direct	194.6	244.6	286.4	309.6	286.1	346.1	270.9	391.2	309.8	331.4	259.0	214.6	287.0
Oahu	Global	303.9	363.8	366.2	434.3	402.1	394.2	385.7	486.1	471.1	416.8	384.5	307.8	393.0
Huelani	Diffuse	127.2	135.0	182.1	221.4	265.4	173.6	190.0	156.5	153.2	133.7	113.6	102.2	162.8
	Direct	106.2	207.2	145.9	162.0	81.0	187.6	157.7	296.7	284.2	259.0	255.0	193.3	194.7
Oahu	Global				287.1	280.7	237.9	253.7	337.8	390.2	321.7	337.9	279.7	303.0
Lyon	Diffuse													
Arboretum	Direct													
Oahu	Global						498.4	473.8	538.3	495.0	425.8	329.6	254.2	430.7
Mauka	Diffuse													
Campus	Direct													
Oahu	Global	259.8	272.2	189.1	252.2	287.7	310.9	287.8	325.6	312.5	279.2	241.3	220.2	269.9
Maunawili	Diffuse	144.8	148.4	145.1	154.6	178.2	183.0	163.0	139.1	127.3	134.8	123.8	85.5	144.0
	Direct	96.2	100.1	13.5	62.0	72.1	93.1	92.2	157.3	157.2	120.1	100.2	124.4	99.0
Oahu	Global	291.3	380.3	462.2	487.1	511.6	572.7	526.3	541.7	487.3	381.5	352.2	261.6	438.0
Mililani	Diffuse													
	Direct													
Oahu	Global	365.6	406.2	497.8	547.0	575.6	615.7	605.2	611.1	544.1	492.7	417.3	333.4	501.0
Waikiki	Diffuse													
	Direct													
Maui	Global										457.4	395.3	290.8	381.2
Pioneer	Diffuse													
Mill	Direct										506.2	586.3	383.3	491.9
Molokai	Global	365.9	436.3	483.9	538.9	536.6	528.3	535.0	544.4	545.2	506.2	436.8	344.7	483.5
Palaau	Diffuse													
	Direct													
Hawaii	Global	297.4	318.1	223.7	360.4	384.3	333.5	384.7	368.3	335.4	311.1	294.1	299.5	325.9
Hilo CPO	Diffuse	85.0	114.1	124.5	147.1	173.5	174.9	175.8	163.7	133.4	124.0	99.5	82.8	133.2
	Direct	201.4	185.4	73.1	179.5	174.4	125.4	173.7	170.2	172.7	164.8	180.7	206.8	167.3
Hawaii	Global	378.3	394.4	319.5	504.1	526.4	516.4	521.8	487.0	468.8	469.5	422.5	358.0	447.2
HCPC	Diffuse	115.7	141.0	174.4	195.3	218.3	184.7	158.0	153.9	142.4	104.2	91.2	113.9	149.4
	Direct	247.6	230.8	108.5	263.9	262.3	296.6	332.2	300.8	295.1	346.5	318.5	230.4	269.4
Hawaii	Global	341.2	305.2	245.3	459.3	432.7	374.3	428.2	411.6	418.5	399.9	379.0	340.8	378.0
Kulani	Diffuse													
	Direct													
Kauai	Global	308.8	392.3	380.2	454.7	488.7								404.9
Lihue	Diffuse	148.3	271.2	340.3	421.6									295.4
	Direct	160.5	121.1	39.9	33.1									88.7

TABLE D-5

1981 HAWAII SOLAR RADIATION DATA

(cal/cm^2/day)

Sites	Test Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annu
Oahu	Global	379.8	422.0	521.2	542.1	560.4	594.8	588.2	559.4	545.2	448.7	390.8	310.4	488.6
Holmes	Diffuse	98.9	134.9	120.6	137.2	147.2	169.8	145.4	142.8	142.8	97.9	102.5	127.6	130.6
	Direct	268.0	265.5	375.3	373.3	382.3	392.7	413.7	386.6	371.0	333.2	274.0	167.5	333.6
Oahu	Global	376.6	379.9	473.3	491.6	470.0	428.2	491.5	490.5	465.4	426.2	380.3	279.4	429.4
Huelani	Diffuse	113.2	144.5	145.0	170.4	163.6	171.8	171.2	154.3	152.0	132.8	134.5	123.8	148.1
	Direct	248.7	212.3	297.9	282.0	272.0	223.8	286.1	303.8	280.0	269.5	227.0	140.9	253.7
Oahu	Global	333.1	301.0	348.7	406.3	330.9	323.9	389.6	399.1	391.7	354.0	305.5	262.9	345.6
Lyon	Diffuse													
Arboretum	Direct													
Oahu	Global	312.1	358.7	463.8	490.2	495.8	510.3	528.3	519.5	482.8	426.4	335.2	260.7	432.0
Mauka	Diffuse													
Campus	Direct													
Oahu	Global	269.1	295.0	328.5	341.2	356.7	373.8	388.8	343.0	367.4	275.7	211.8	179.3	310.9
Maunawili	Diffuse	133.6	154.4	193.8	196.5	183.3	216.8	215.3	197.2	187.2	164.8	124.1	114.9	173.5
	Direct	118.1	115.9	94.0	99.5	134.9	115.8	130.4	104.4	139.0	81.2	70.3	50.6	104.5
Oahu	Global	311.1		434.2	467.7	494.4	513.1	517.4	519.4	519.7	421.4	338.8	329.3	442.4
Mililani	Diffuse													
	Direct													
Oahu	Global	400.2	448.7	544.4	560.1	599.6	598.7	649.8	587.4	566.8	477.9	399.2	346.5	514.9
Waikiki	Diffuse													
Sheraton	Direct													
Maui C.C.	Global	406.0	428.9	531.5	559.6	578.9	607.9	599.4	566.7	541.1	450.4	375.7	328.9	497.9
	Diffuse													
	Direct													
Maui	Global	370.0	407.2	519.7	555.5	553.4	553.1	559.5	527.3	501.9	435.5	360.7	309.1	471.1
Pioneer	Diffuse													
Mill	Direct	297.2	297.1	434.2	456.2	430.3	407.4	436.1	486.2	427.6	362.8	266.4	227.1	377.4
Molokai	Global	423.2	471.8	568.9	561.3	576.4	552.6	557.6	565.1	533.1	480.8	387.3	345.7	502.0
Palaau	Diffuse													
	Direct													
Hawaii	Global	318.4	335.4	384.8	401.5	382.0	453.6	467.0	383.6	372.1	314.2	262.0	271.2	362.2
Hilo CPO	Diffuse	81.4	114.2	125.7	139.8	164.0	157.4	147.2	138.9	123.8	111.7	97.4	87.4	124.1
	Direct	226.4	202.9	232.7	362.0	183.6	266.3	290.4	215.5	221.1	182.4	151.0	173.3	225.6
Hawaii	Global											365.4	387.1	376.3
Keahole	Diffuse											148.1	180.1	164.1
	Direct											196.6	185.4	191.0
Hawaii	Global	371.4	385.8	400.0	450.4	397.9	525.1	508.9	453.3	445.5	296.1			423.4
Kulani	Diffuse													
	Direct													

TABLE D-6

1982 HAWAII SOLAR RADIATION DATA

(cal/cm^2/day)

Sites	Test Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annu
Oahu	Global	315.3	384.0	363.1	475.6	549.3	538.6	550.3	546.0	519.2	442.3	316.4	256.9	438.1
Holmes	Diffuse	124.3	158.3	175.5	252.6	215.2	227.6	234.7	219.9	183.2	169.0	156.7	148.5	188.8
	Direct	174.8	200.4	150.7	164.9	288.9	267.8	279.9	295.7	295.7	242.9	137.5	90.6	215.8
Oahu	Global	300.9	356.6	329.6	409.2	468.4	454.9	417.4	442.0	450.3	389.8	290.8	249.1	379.9
Huelani	Diffuse	106.2	132.2	142.3	191.0	165.4	159.2	188.0	153.2	189.1	155.9	141.8	127.0	154.3
	Direct	180.9	203.2	157.4	174.3	286.3	265.5	191.8	256.6	219.6	205.8	129.1	106.9	198.1
Oahu	Global	276.2	341.2	312.1	344.9	402.2	405.5	349.3	306.8	355.2	315.1	245.0	249.7	325.3
Lyon	Diffuse													
Arboretum	Direct													
Oahu	Global	276.4	343.8	327.1	426.6	498.5	483.3	495.8	497.5	520.4	416.1	384.5	258.5	410.7
Mauka	Diffuse													
Campus	Direct													
Oahu	Global	201.0	258.7	208.1	252.6	334.5	293.7	267.9	223.1					255.0
Maunawili	Diffuse	120.0	136.9	133.5	182.5	217.4	200.6	190.5	176.7					169.8
	Direct	65.4	99.9	46.6	28.1	71.4	55.0	39.3	9.3					51.9
Oahu	Global	322.9	407.7	386.2	505.8	588.9	612.8	584.7	547.5	456.8				490.4
Waikiki	Diffuse													
Sheraton	Direct													
Maui	Global	281.0	358.0	394.7	489.3	531.5	522.9	505.8	482.6	505.8	398.7	382.0	304.1	429.7
Pioneer	Diffuse													
Mill	Direct	167.7	219.6			363.3	337.0		218.2	352.5		171.9	182.7	251.6
Molokai	Global	285.9	413.4	357.4	507.3	596.0	528.8	611.5	562.4	540.9	433.2	354.0	336.7	460.6
Electric	Diffuse													
Site	Direct													
Molokai	Global	320.0	390.8					548.2	497.4	515.4	446.6	329.0		435.3
Palaau	Diffuse													
	Direct													
Hawaii	Global	270.8	312.0											291.4
Hilo CPO	Diffuse	101.7	105.8											103.8
	Direct	155.9	189.3											172.6
Hawaii	Global													
Keahole	Diffuse													
	Direct	179.7	205.3	182.0	179.4									186.6

TABLE D-7

1983 HAWAII SOLAR RADIATION DATA

(cal/cm^2/day)

Sites	Test Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annu
Holmes	Global	336.3	464.5	510.0	499.3	566.2	573.8					361.9	319.2	453.9
(Oahu)	Diffuse	168.3	168.1	201.2	172.7	215.8								185.2
	Direct	168.0	296.4	308.8	326.6	350.4	371.5	363.5	370.2	373.6	248.4	221.8	189.9	299.1
Huelani	Global	346.3	421.3	452.2	423.7	479.3	460.1	452.7	525.7	499.5	379.3	361.7	340.2	428.5
(Oahu)	Diffuse	141.2	138.3	147.7	160.3	168.9			145.5	133.1				147.9
	Direct	186.7	260.9	273.5	226.5	274.9			349.6	337.1				272.7
Lyon	Global	321.2	419.9	422.8	358.0	472.9	350.0	289.9	335.4	372.4	312.4	317.7	313.6	357.2
Arboretum	Diffuse													
(Oahu)	Direct													
Mauka	Global	346.7	433.0	495.6	485.8	524.1	571.2	557.7	539.3	560.7	426.6	365.6	321.7	469.0
Campus	Diffuse													
(Oahu)	Direct													
Pioneer	Global	353.1	421.2	479.8	522.3	537.1	555.2	498.8						481.1
Mill	Diffuse													
(Maui)	Direct													
Molokai	Global	389.3	434.1	481.4	581.3	634.7	679.5	633.0	596.0	524.5	488.2	388.4	355.0	515.5
Electric	Diffuse													
Site	Direct													
Kahua	Global						622.7	594.9	568.8	511.0	494.7	404.0	323.1	502.7
Ranch	Diffuse													
(Hawaii)	Direct													
Keahole	Global			554.1	547.4	605.3		580.8	544.6	528.3	474.6	436.5	403.8	519.5
(Hawaii)	Diffuse													
	Direct													

TABLE D-8

1984 HAWAII SOLAR RADIATION DATA

(cal/cm^2/day)

Sites	Test Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annu
Holmes	Global													
(Oahu)	Diffuse													
	Direct	190.7	232.6	327.5	314.1	395.6	353.9	418.2	451.8	415.7	294.1	209.2	195.2	316.6
Huelani	Global	370.1	455.3	478.7	438.3	469.2								442.3
(Oahu)	Diffuse													
	Direct													
Lyon	Global	314.4	356.2	413.4	311.8	333.1								345.8
Arboretum	Diffuse													
(Oahu)	Direct													
Mauka	Global	346.3	468.8	507.8	507.3	578.1								481.7
Campus	Diffuse													
(Oahu)	Direct													
Molokai	Global	388.0	448.7	548.6	550.9	536.7	470.2	559.3	576.6	488.9	493.5	397.9	349.7	484.1
Electric	Diffuse													
Site	Direct	283.1	351.7	382.9	302.8	327.4	264.4	423.3	174.3	353.7	378.9	302.1	273.0	318.1
Kahua	Global	383.1	460.5	498.2										447.3
Ranch	Diffuse													
(Hawaii)	Direct													
Keahole	Global	422.6	510.3	522.1	470.8									481.5
(Hawaii)	Diffuse	129.7	114.2	158.3	210.1									153.1
	Direct	276.0	377.8	330.6	212.4									299.2

TABLE D-9

1985 HAWAII SOLAR RADIATION DATA

(cal/cm^2/day)

Sites	Test Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annu
Holmes	Global	318.8	385.6	446.9	531.5	506.8	526.1	564.5	534.8	480.2	418.7	318.4	340.9	447.8
(Oahu)	Diffuse													
	Direct													
Kaunakakai	Global							534.6	530.4	516.0	433.4			503.6
Sewage	Diffuse													
Pump	Direct							412.8	480.9	445.8	363.3			425.7
Station														
Site														
Molokai	Global						467.1	503.6	480.9	472.7	394.2	352.9	352.3	432.0
Electric	Diffuse													
Site	Direct						372.1	381.8	348.8	352.9	249.7	241.5	269.7	316.6

TABLE D-10
1986 HAWAII SOLAR RADIATION DATA
(cal/cm^2/day)

Sites	Test Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annu
Holmes	Global	365.0	419.0	472.0	488.0	514.0	518.0	490.0	515.0	425.0	423.0	403.0	325.0	446.4
(Oahu)	Diffuse													
	Direct													
Oahu	Global	353.5	384.5	440.3	460.9	452.7	483.7	469.2	398.9	384.5	386.5	326.6		412.8
Kahe	Diffuse													
	Direct	312.1	303.8	370.0	376.2	353.5	392.7	376.2	328.7	295.6	322.4	270.8		336.5
Molokai	Global	390.1	433.4	474.7	466.5	528.4	520.1							468.9
Electric	Diffuse													
Site	Direct	317.9	266.3	336.4	317.9	394.2	388.0							336.8

APPENDIX E

Plots of Monthly Values of Direct Insolation for Various Sites in Hawaii

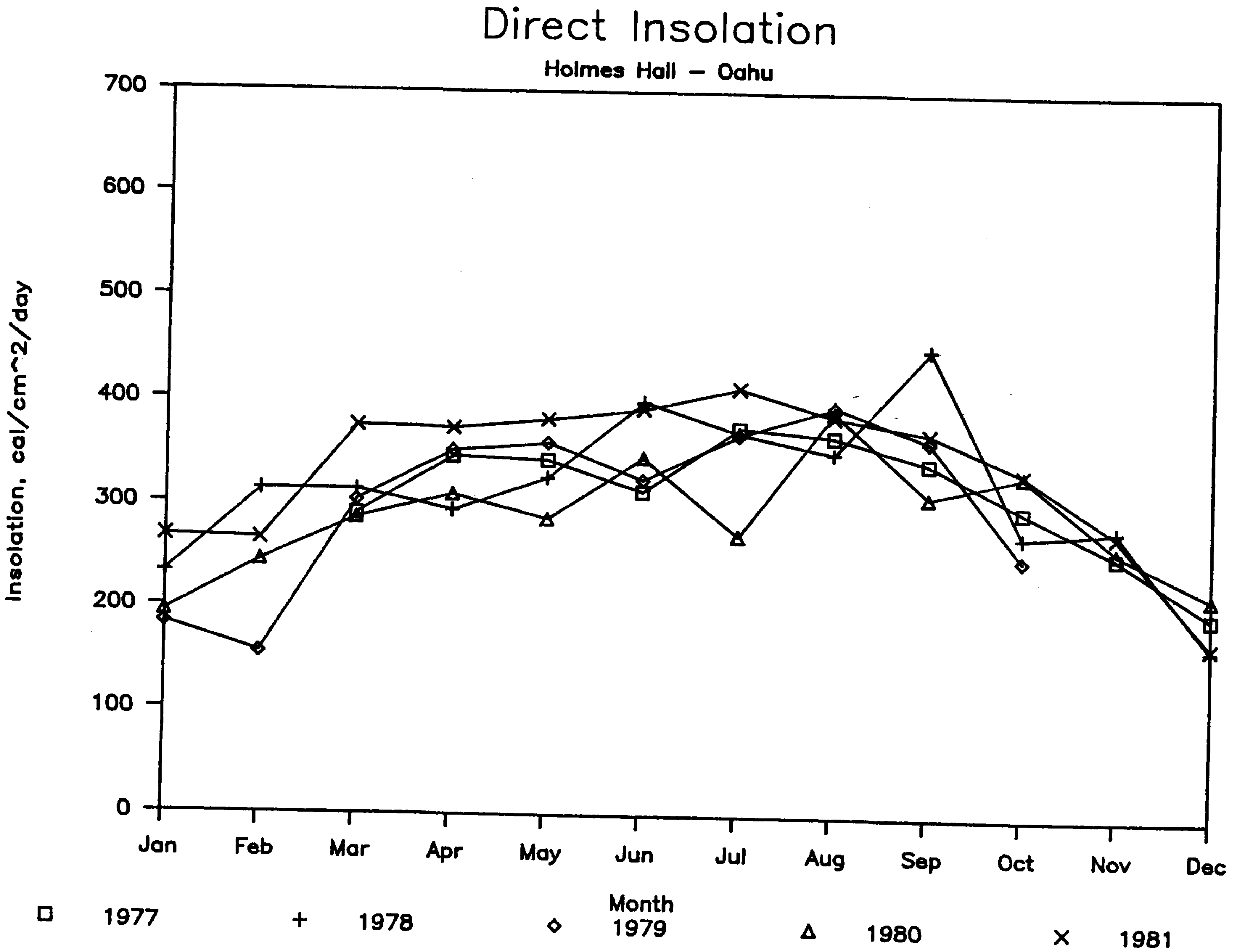


Figure E-1 Direct Insolation - Holmes Hall, Oahu (1)

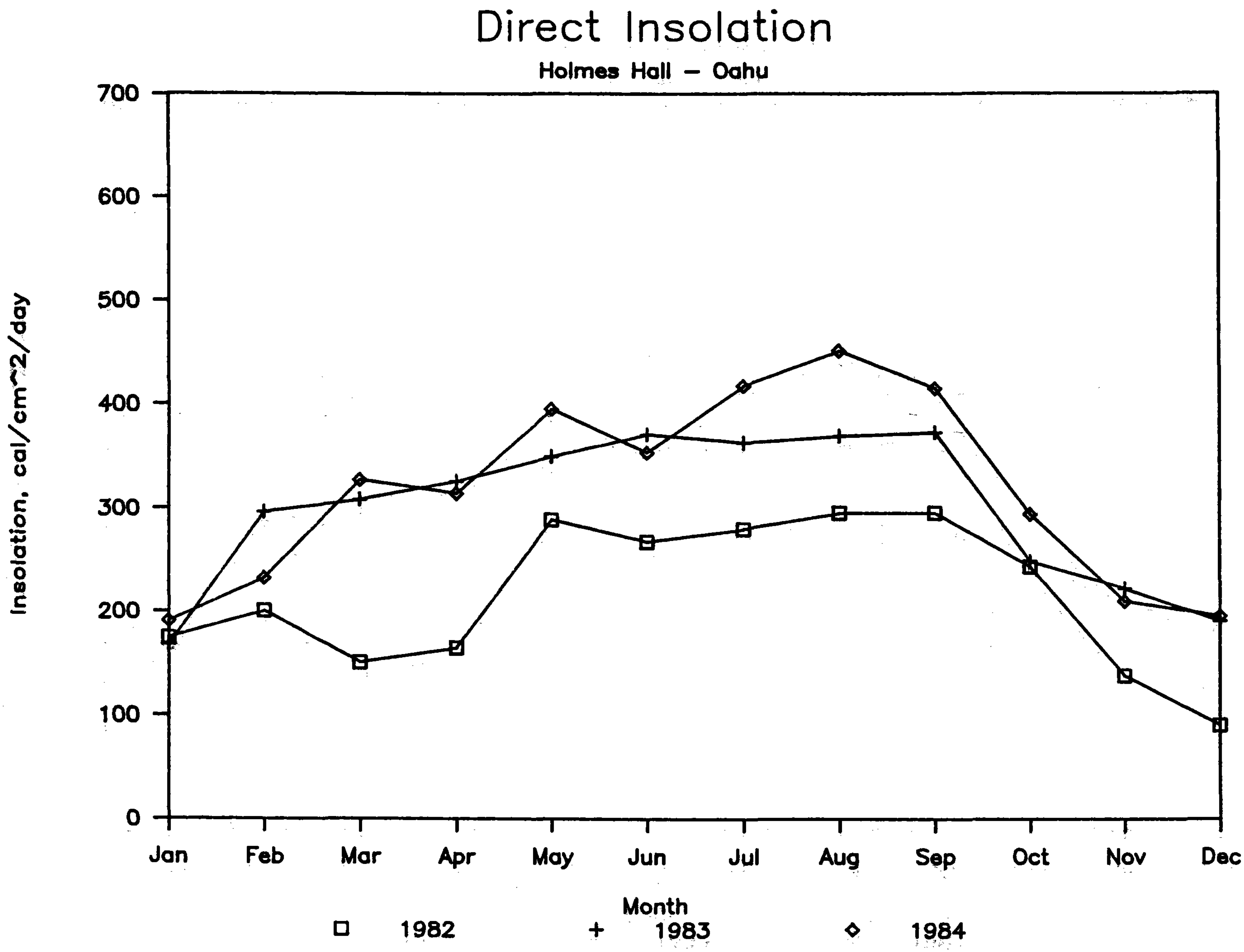


Figure E-2 Direct Insolation - Holmes Hall, Oahu (2)

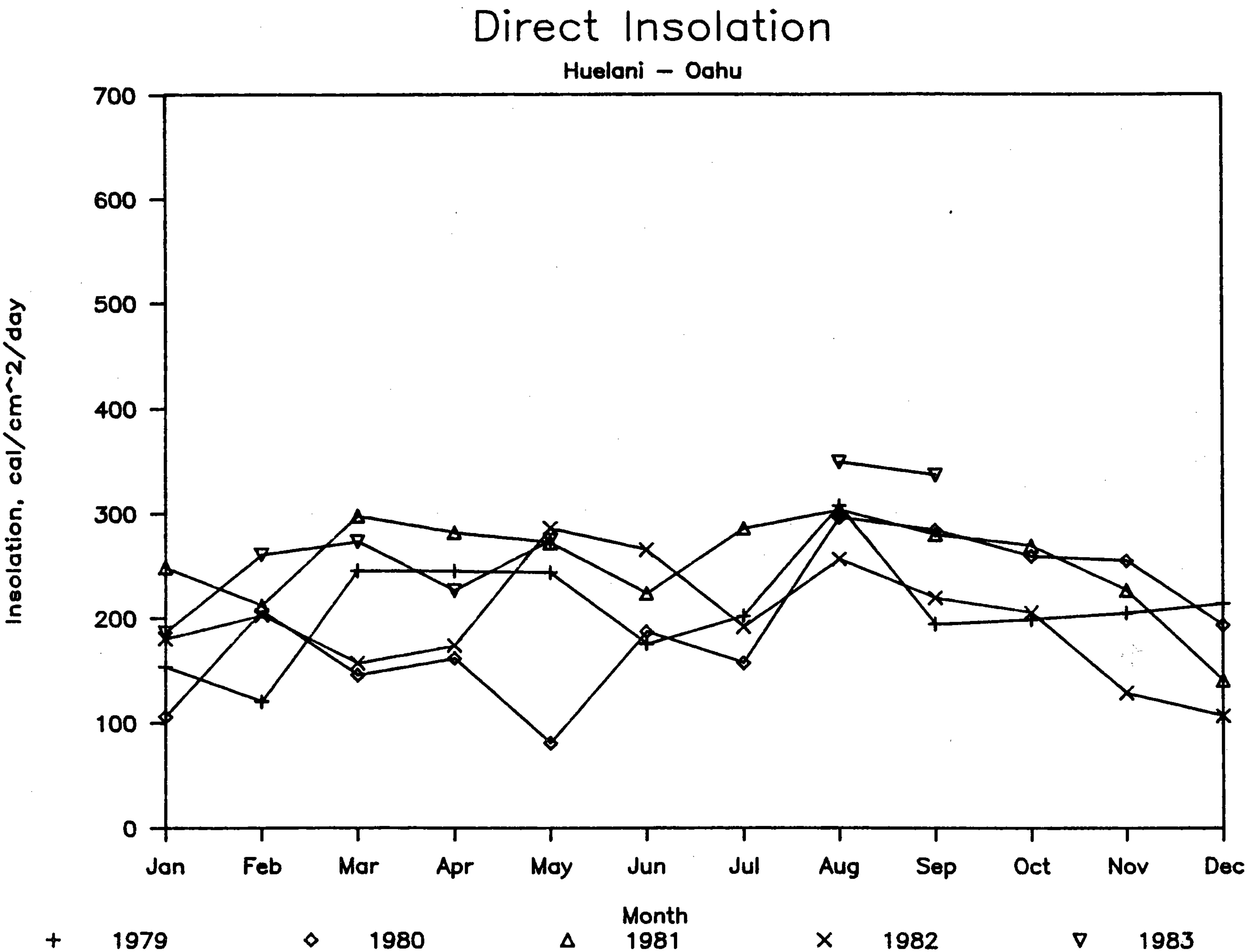


Figure E-3 Direct Insolation - Huelani, Oahu

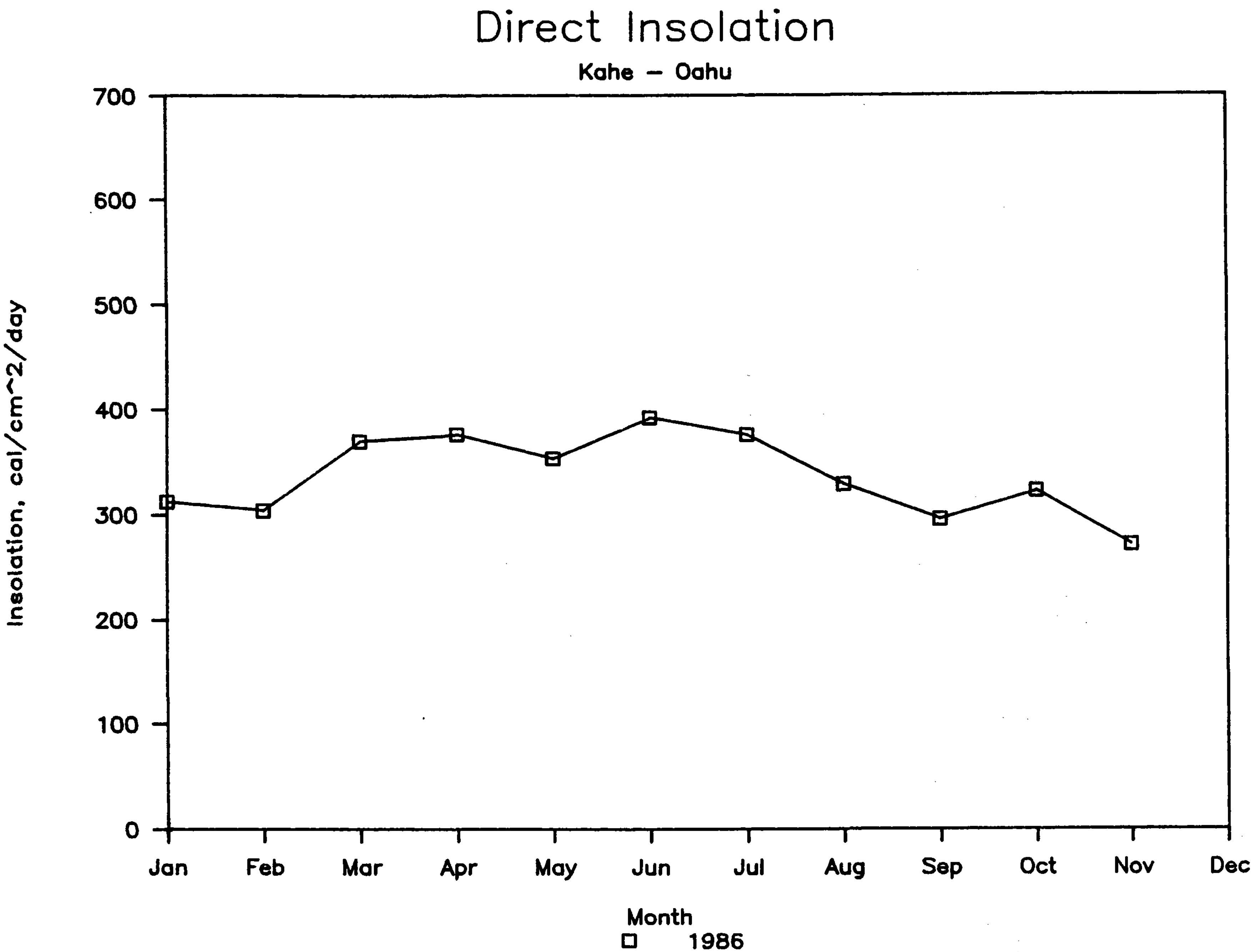


Figure E-4 Direct Insolation - Kahe, Oahu

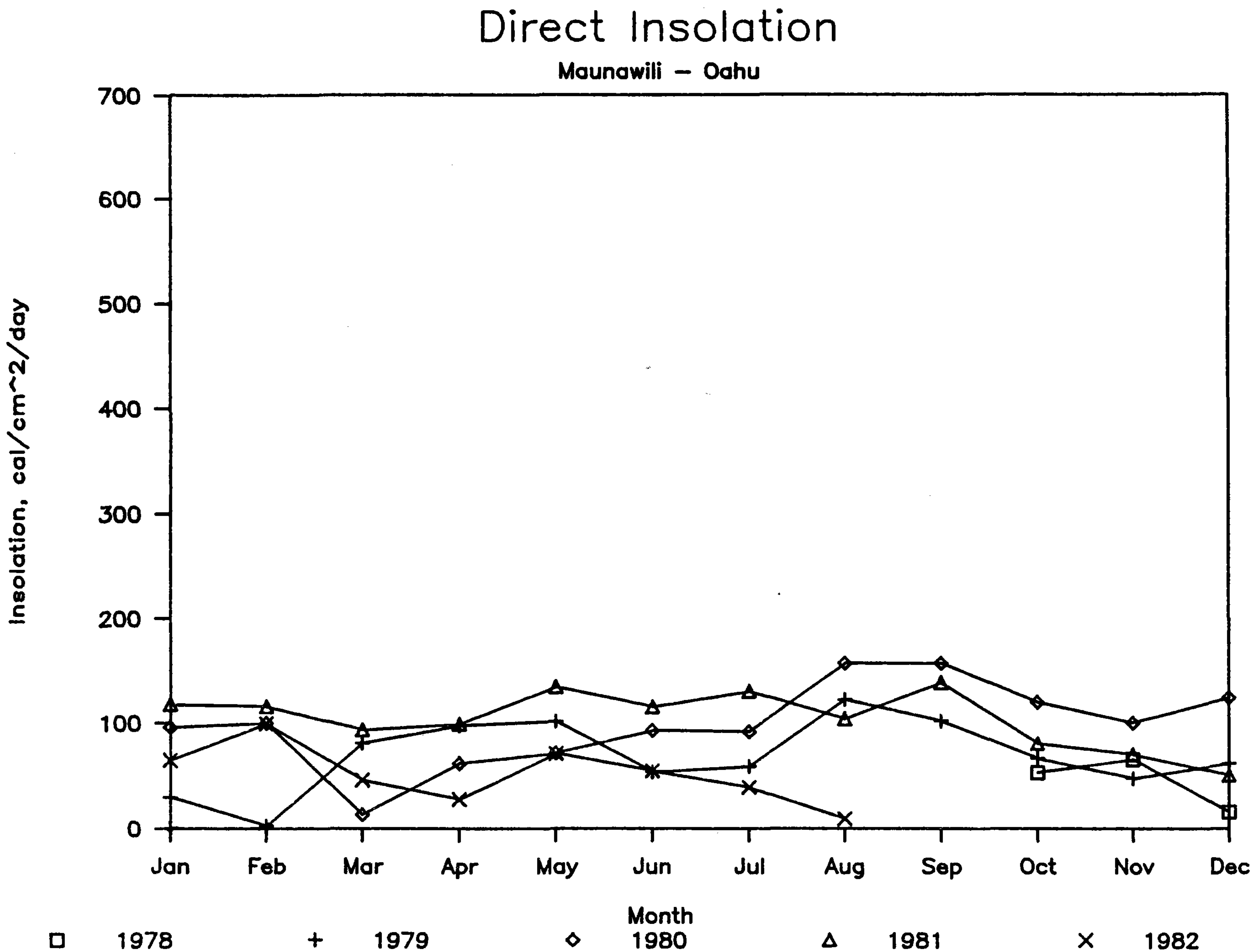


Figure E-5 Direct Insolation - Maunawili, Oahu

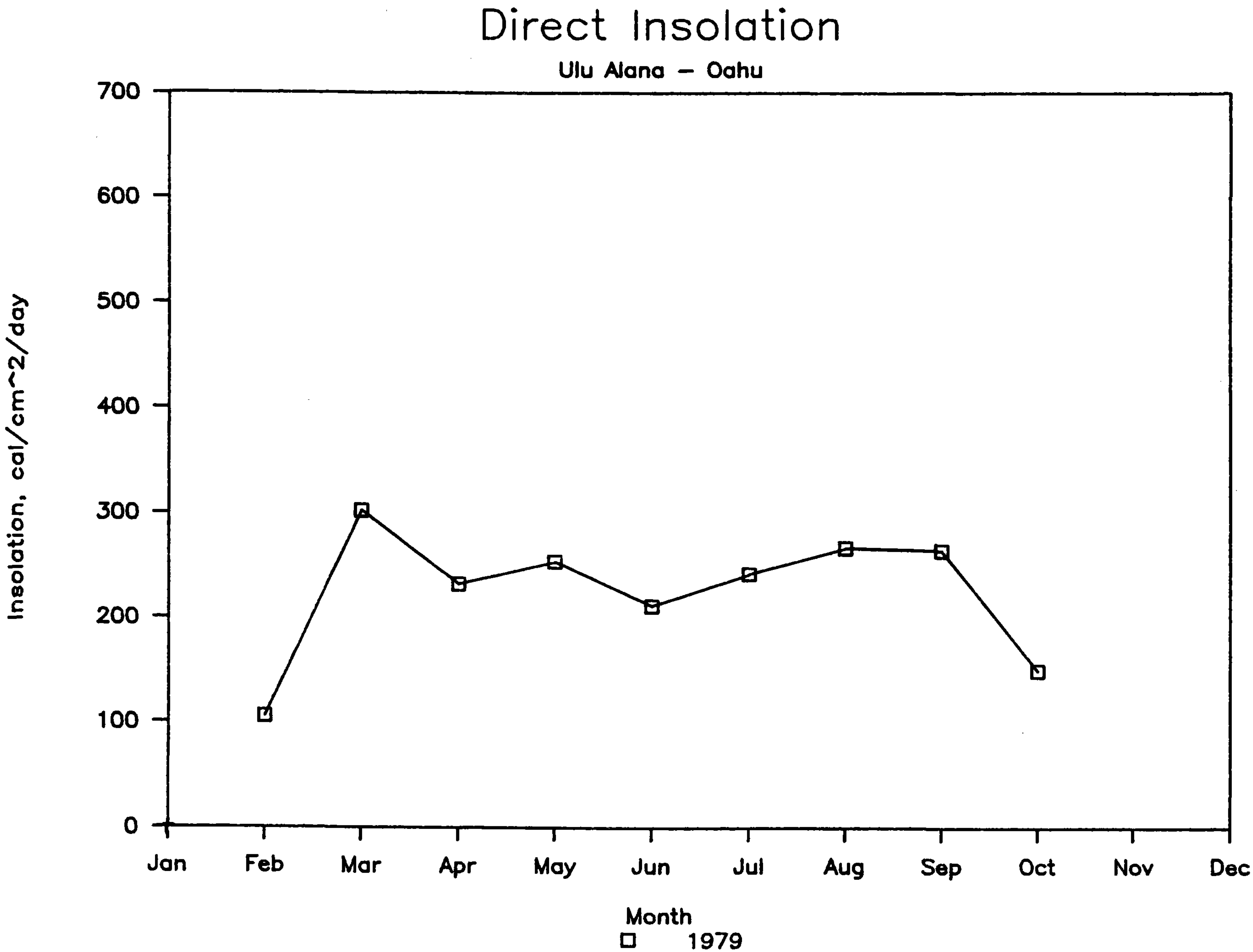


Figure E-6 Direct Insolation - Ulu Alana, Oahu

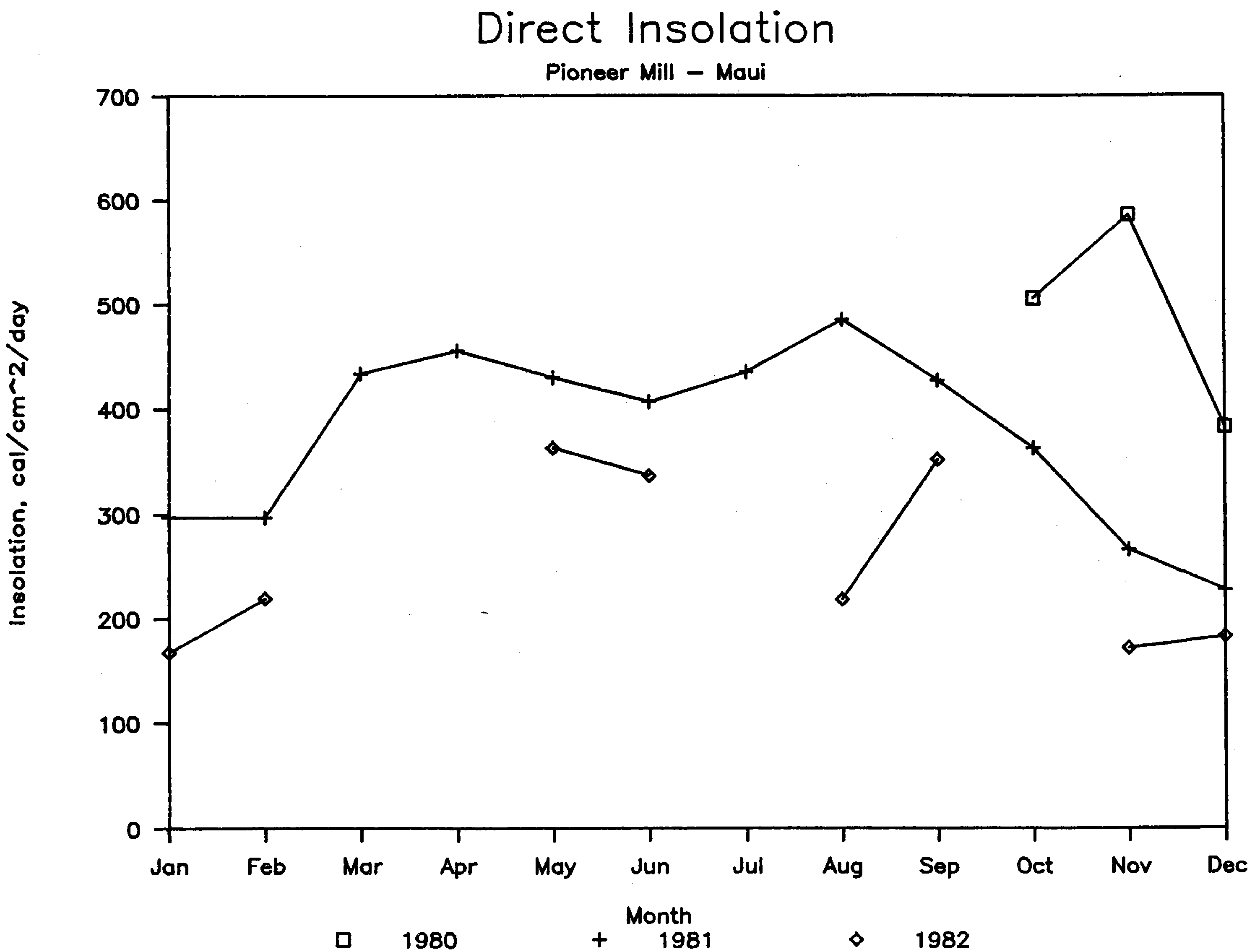


Figure E-7 Direct Insolation - Pioneer Mill, Maui

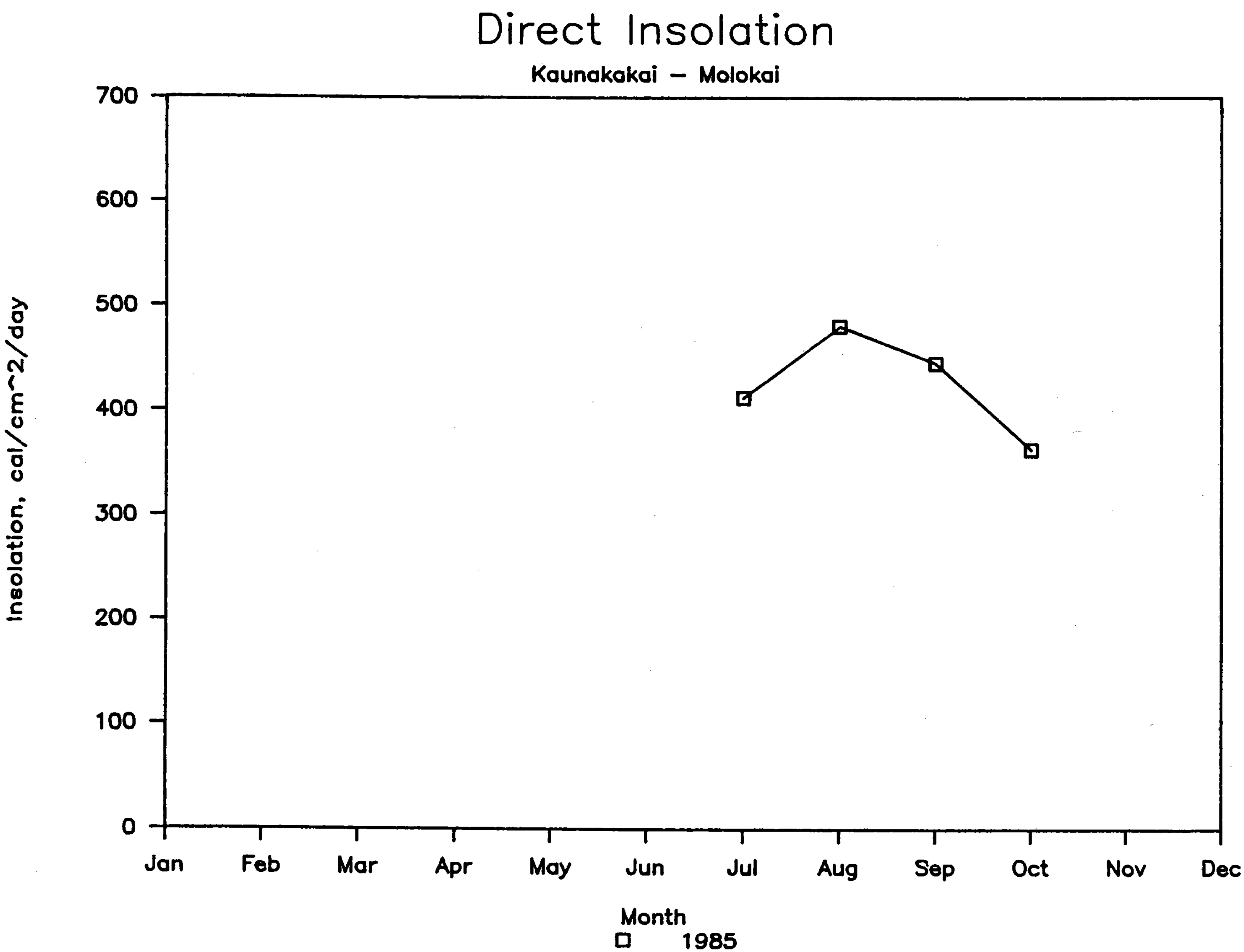


Figure E-8 Direct Insolation - Kaunakakai, Molokai

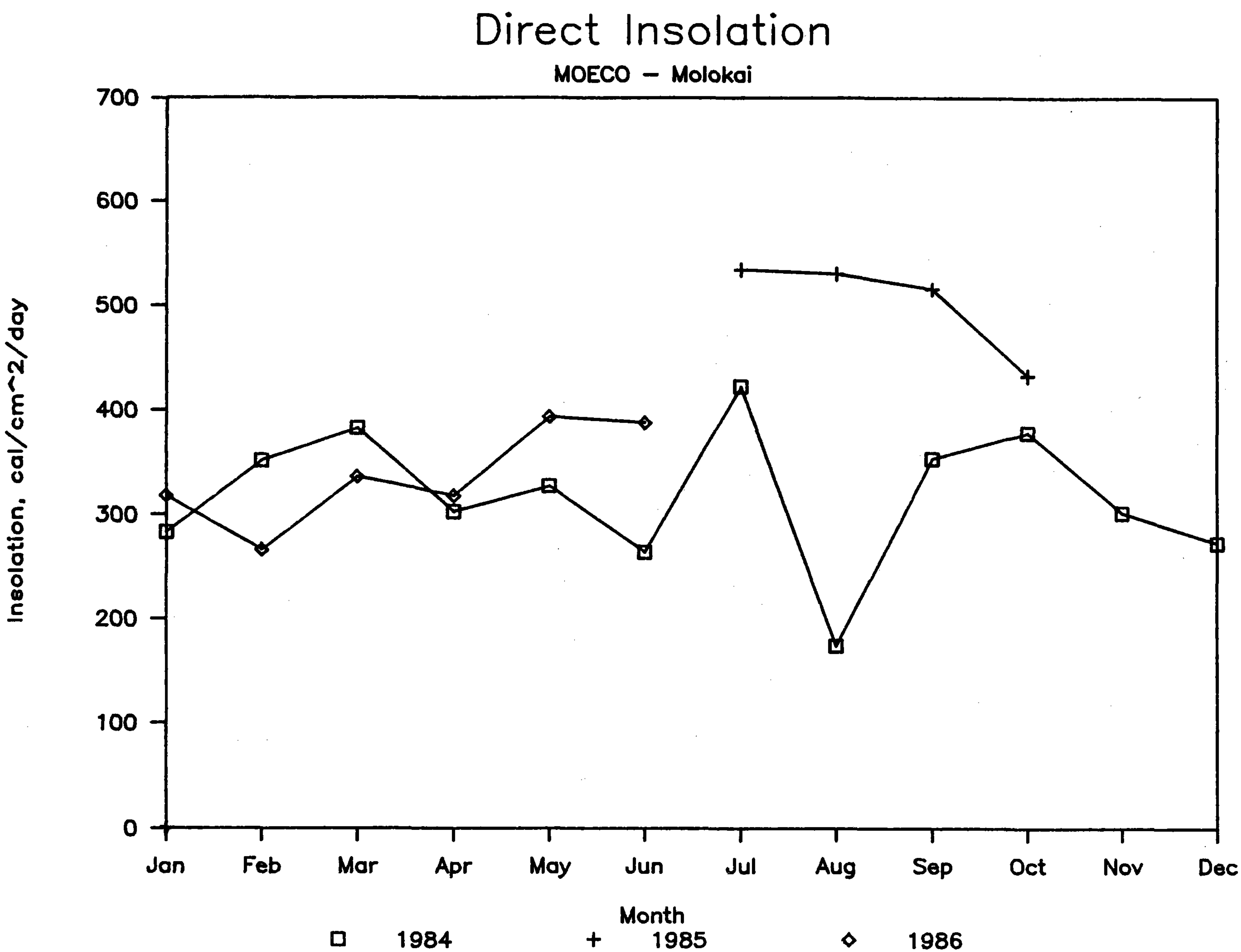


Figure E-9 Direct Insolation - MOECO, Molokai

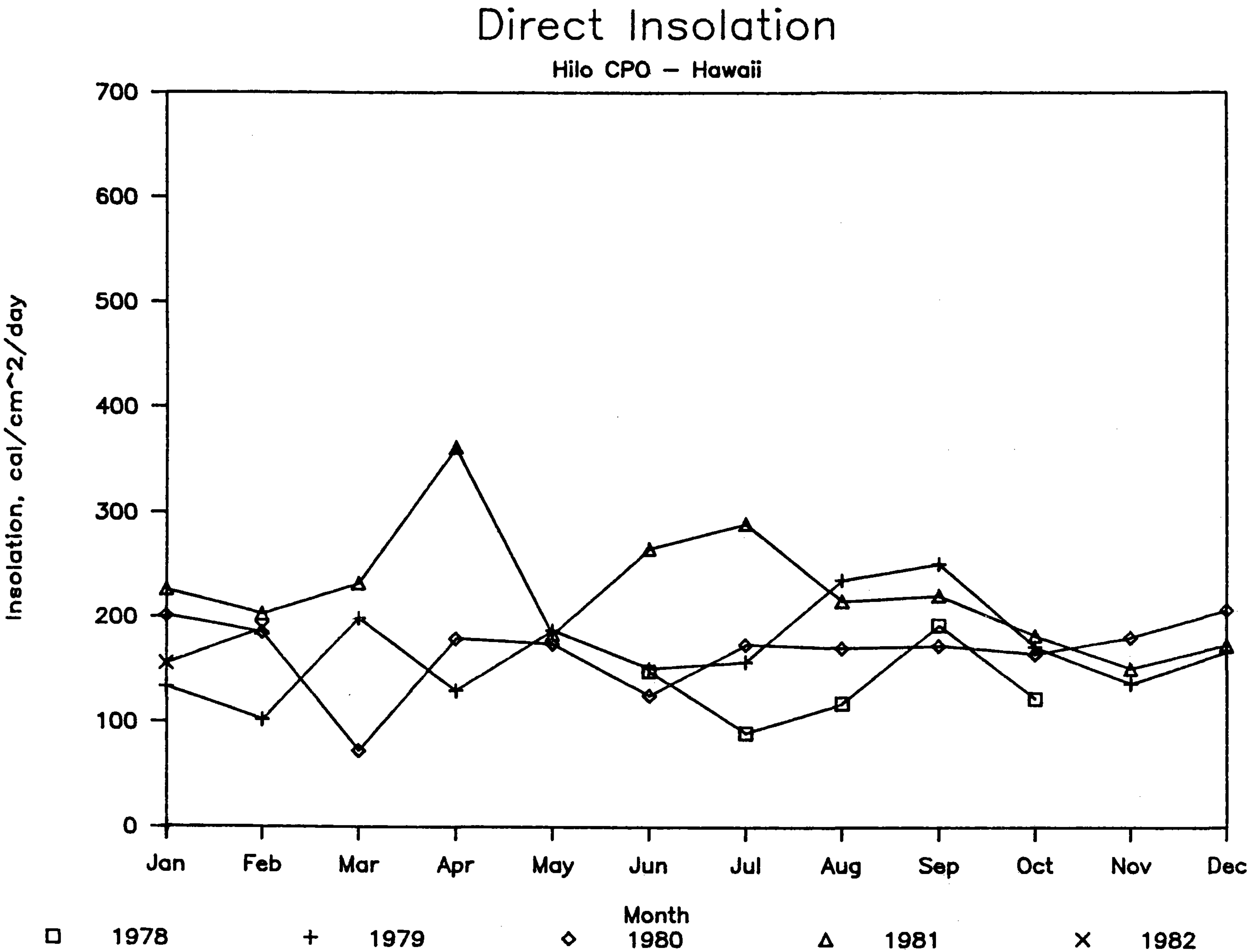


Figure E-10 Direct Insolation - Hilo CPO, Hawaii

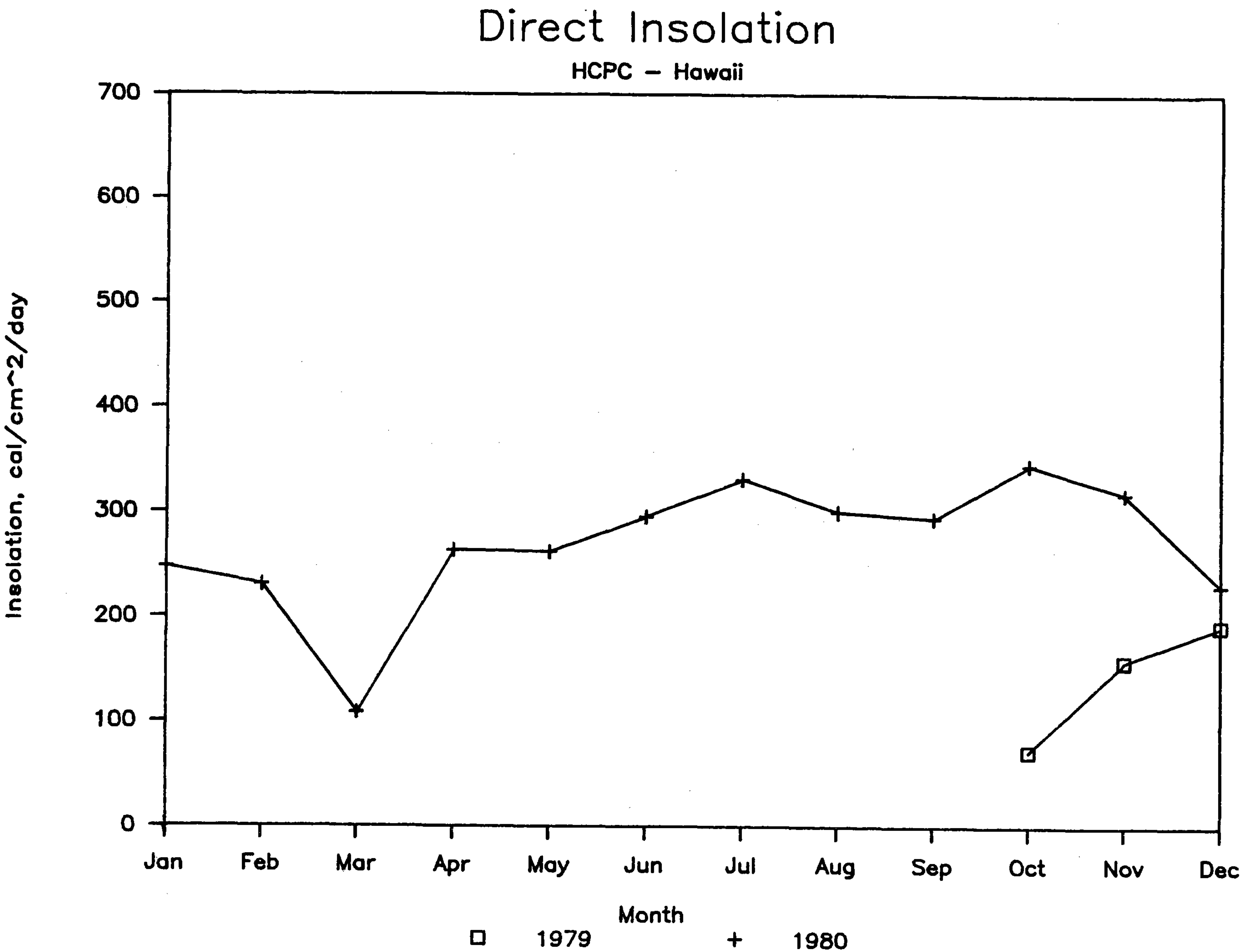


Figure E-11 Direct Insolation - HCPC, Hawaii

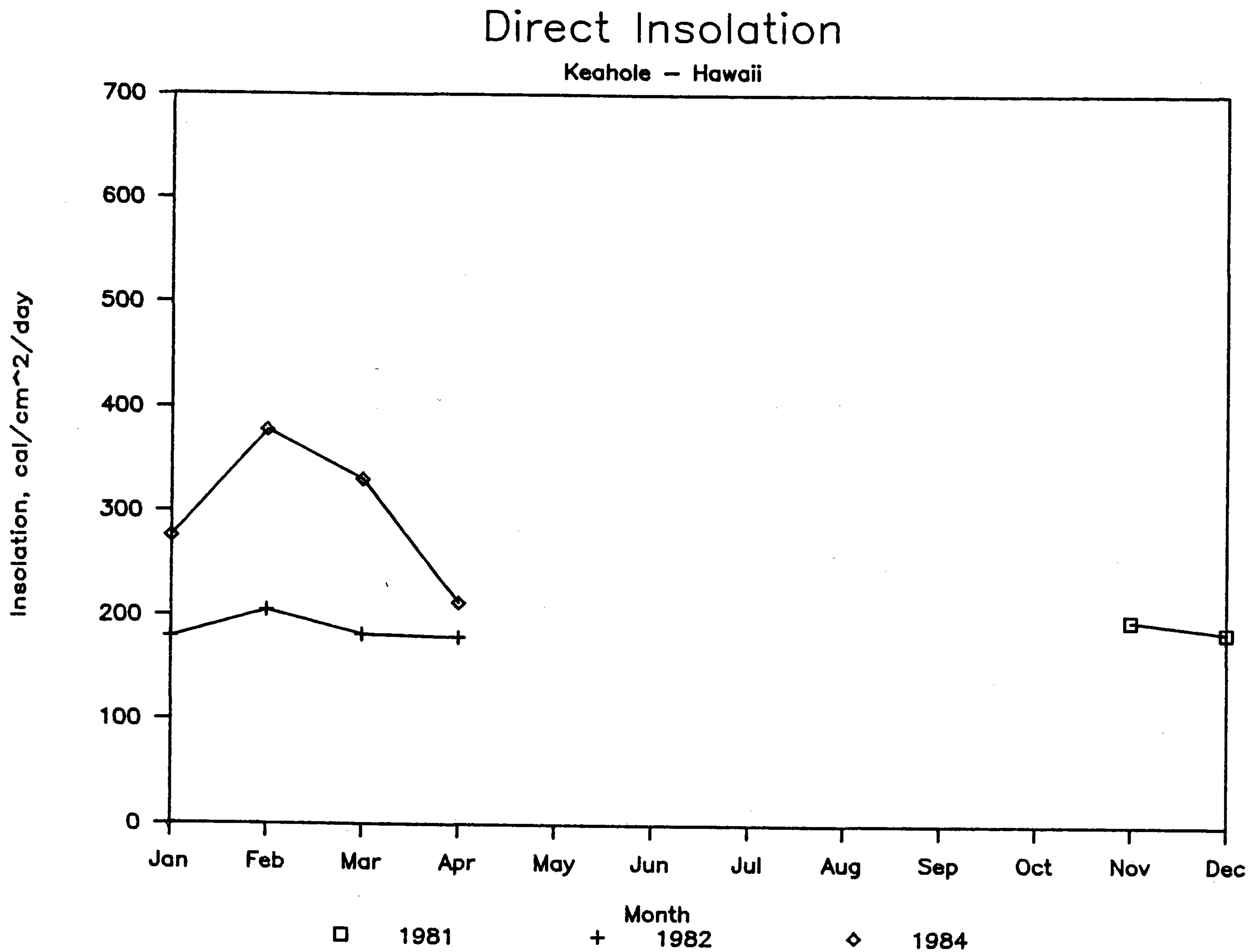


Figure E-12 Direct Insolation - Keahole, Hawaii

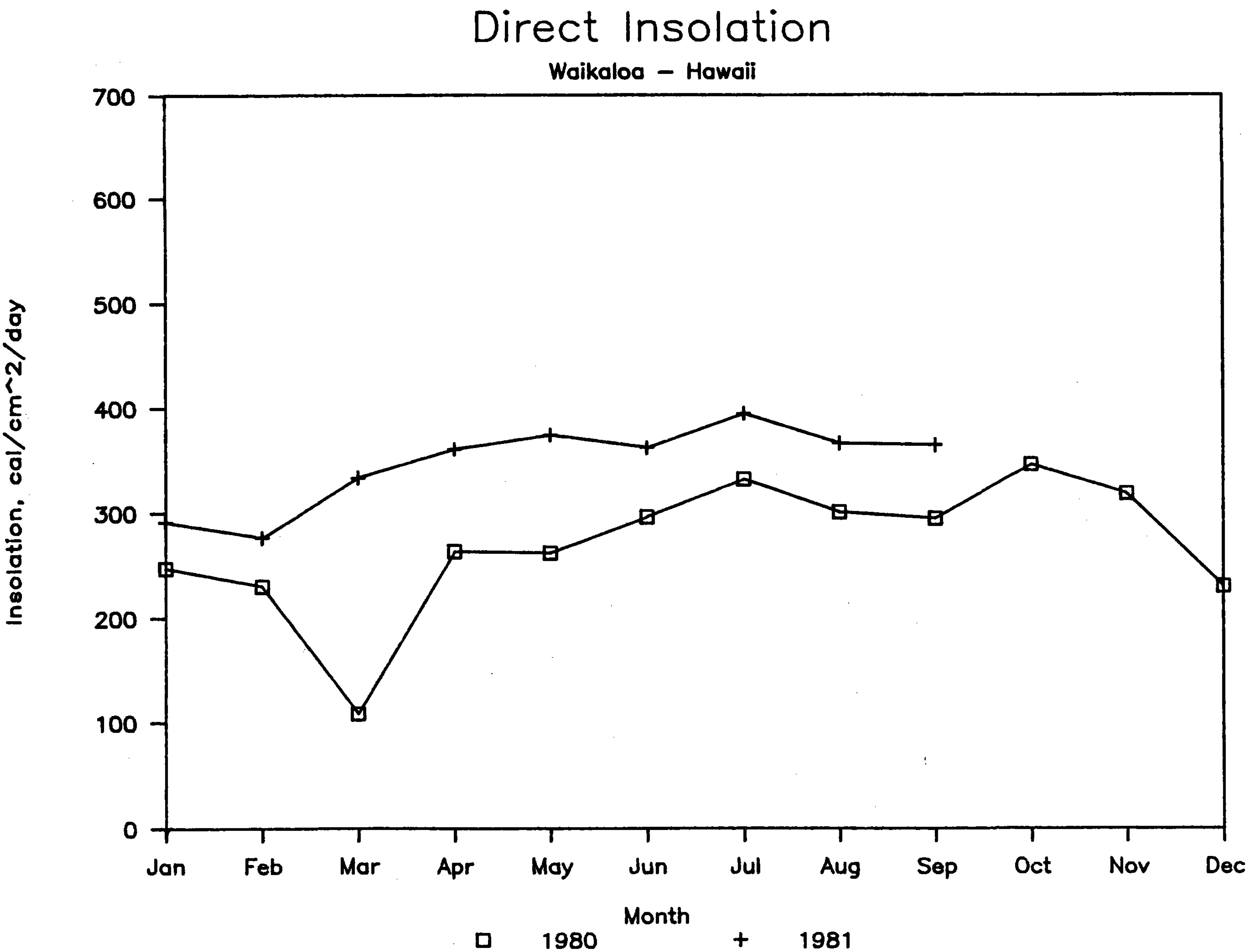


Figure E-13 Direct Insolation - Waikaloa, Hawaii

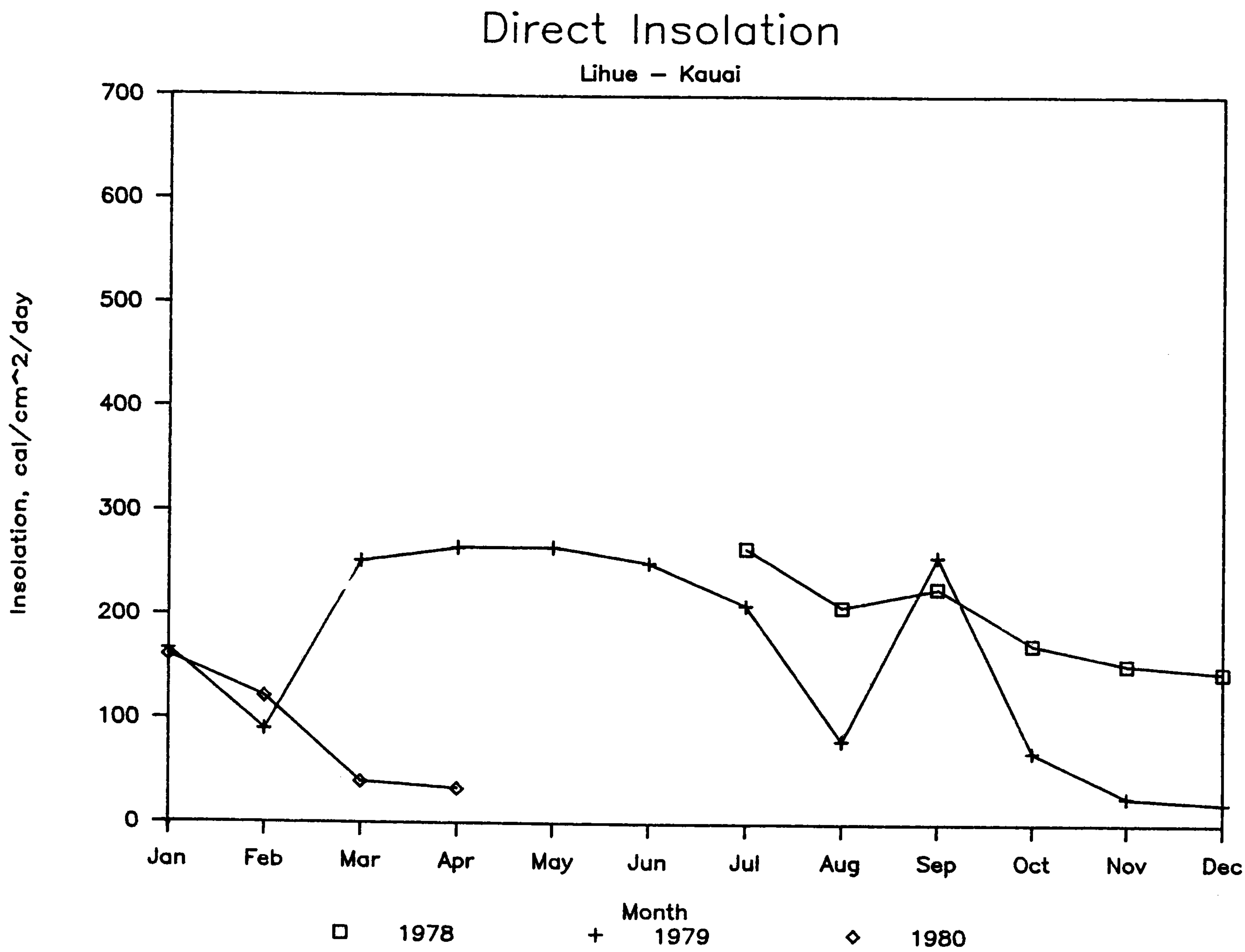


Figure E-14 Direct Insolation - Lihue, Kauai

APPENDIX F

Plots of Rainfall Contours for

Oahu, Maui, Molokai, Hawaii, and Kauai

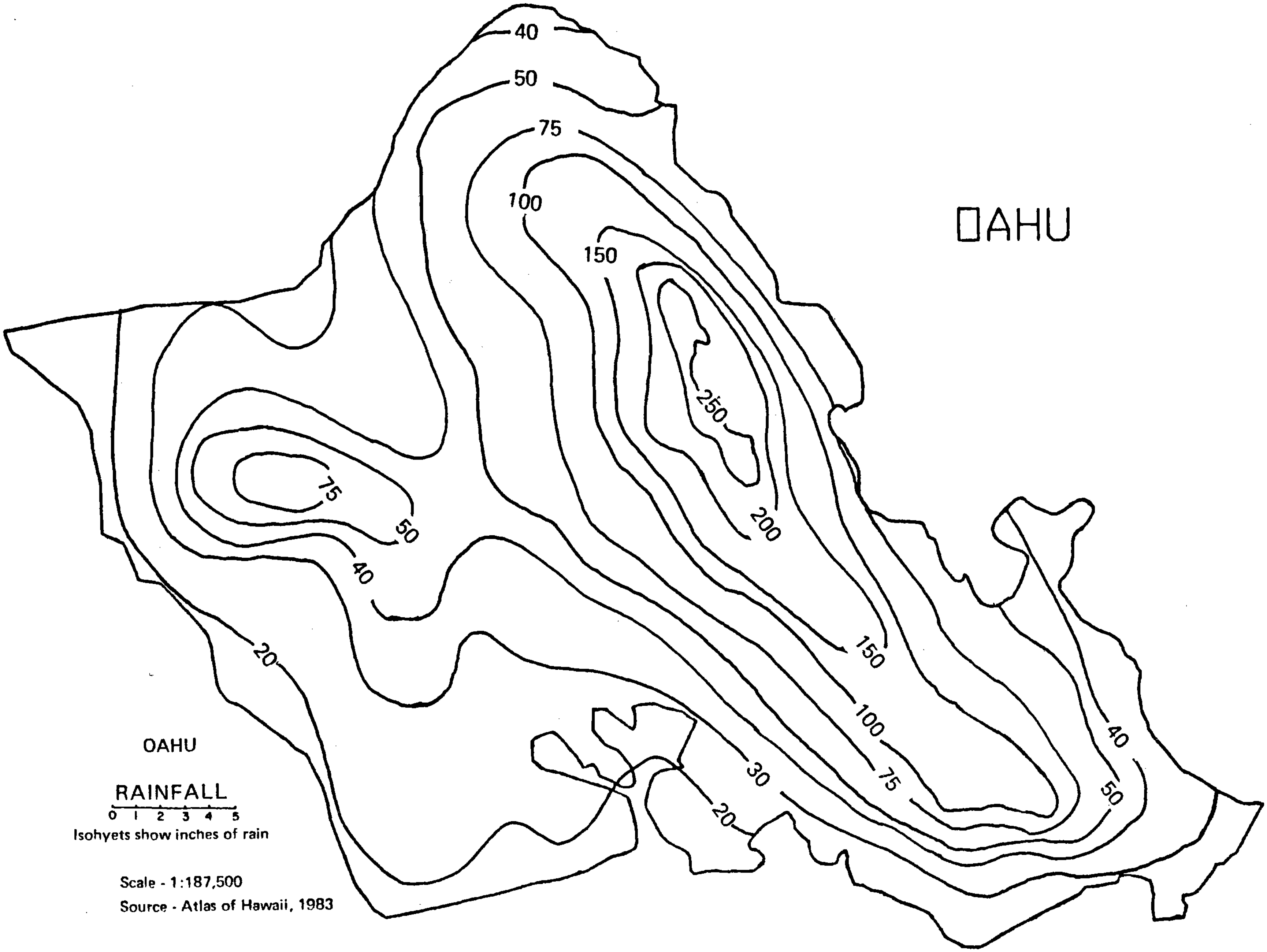


Figure F-1 Rainfall Map of Oahu

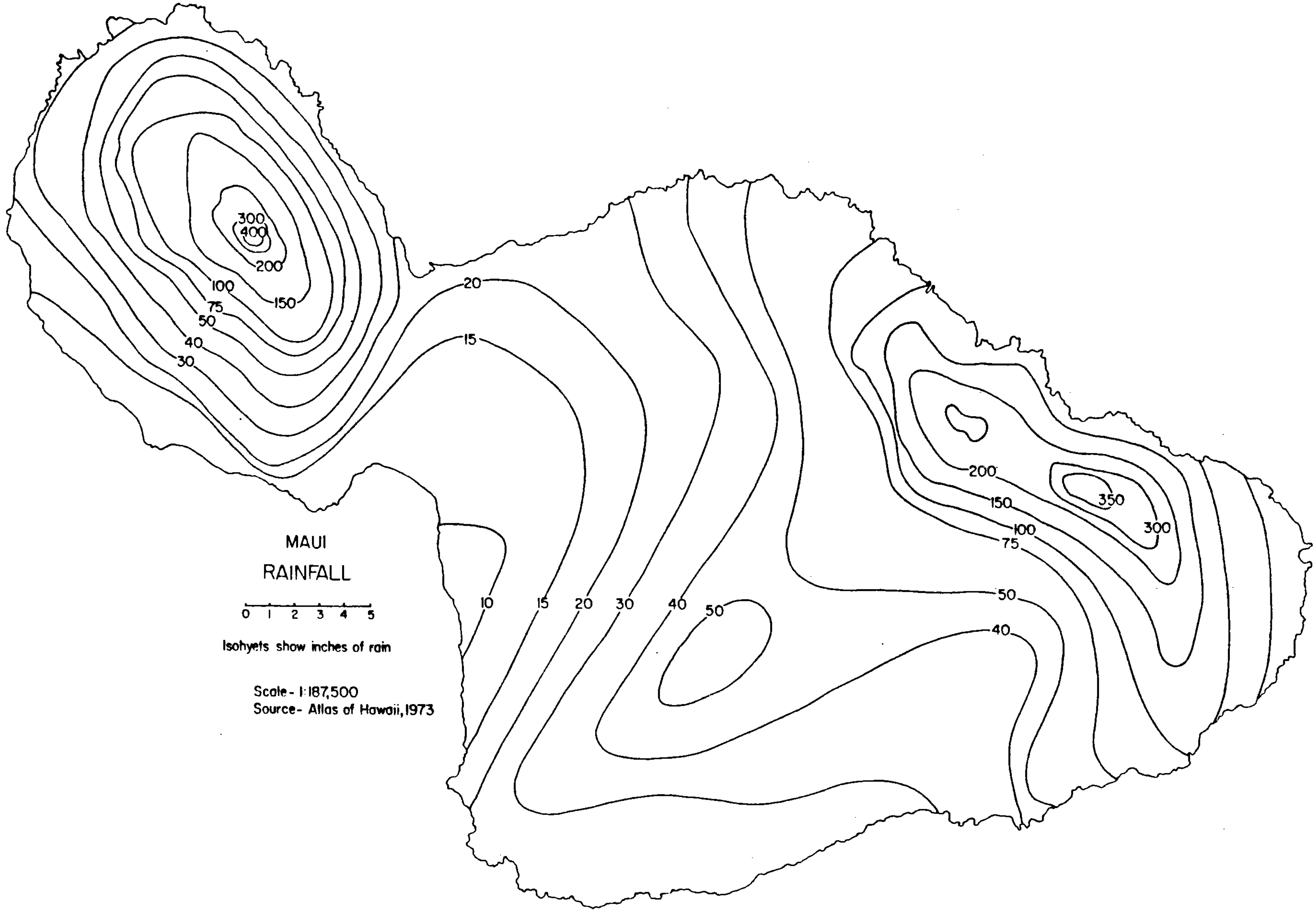


Figure F-2 Rainfall Map of Maui

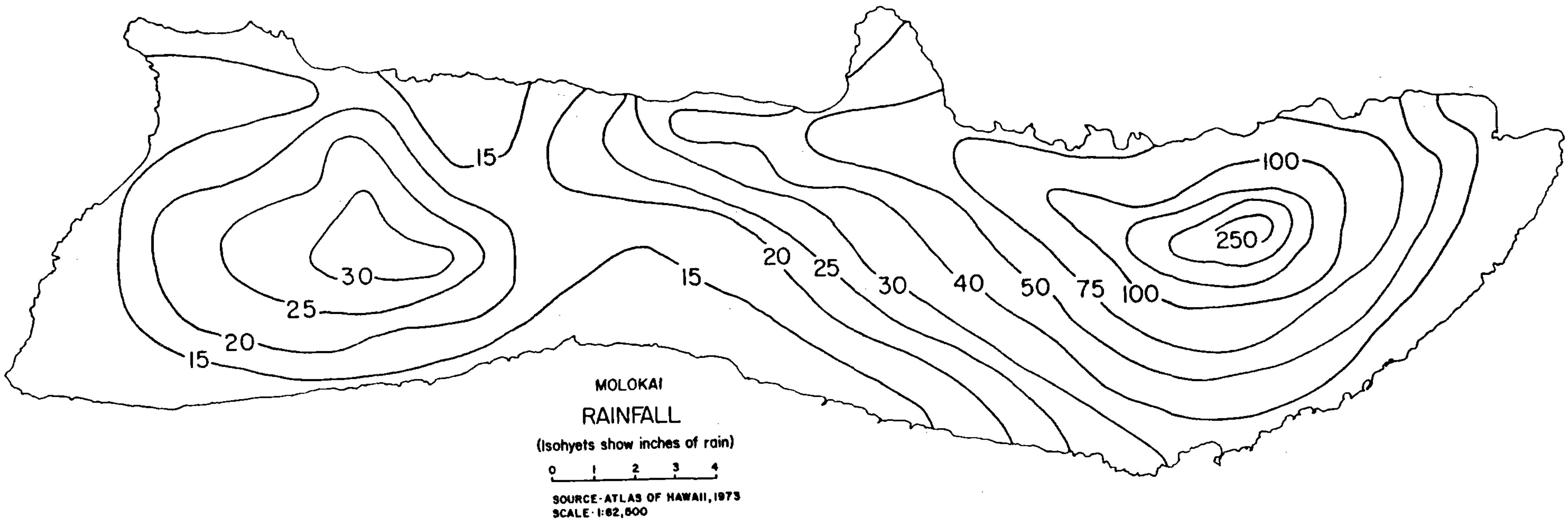


Figure F-3 Rainfall Map of Molokai

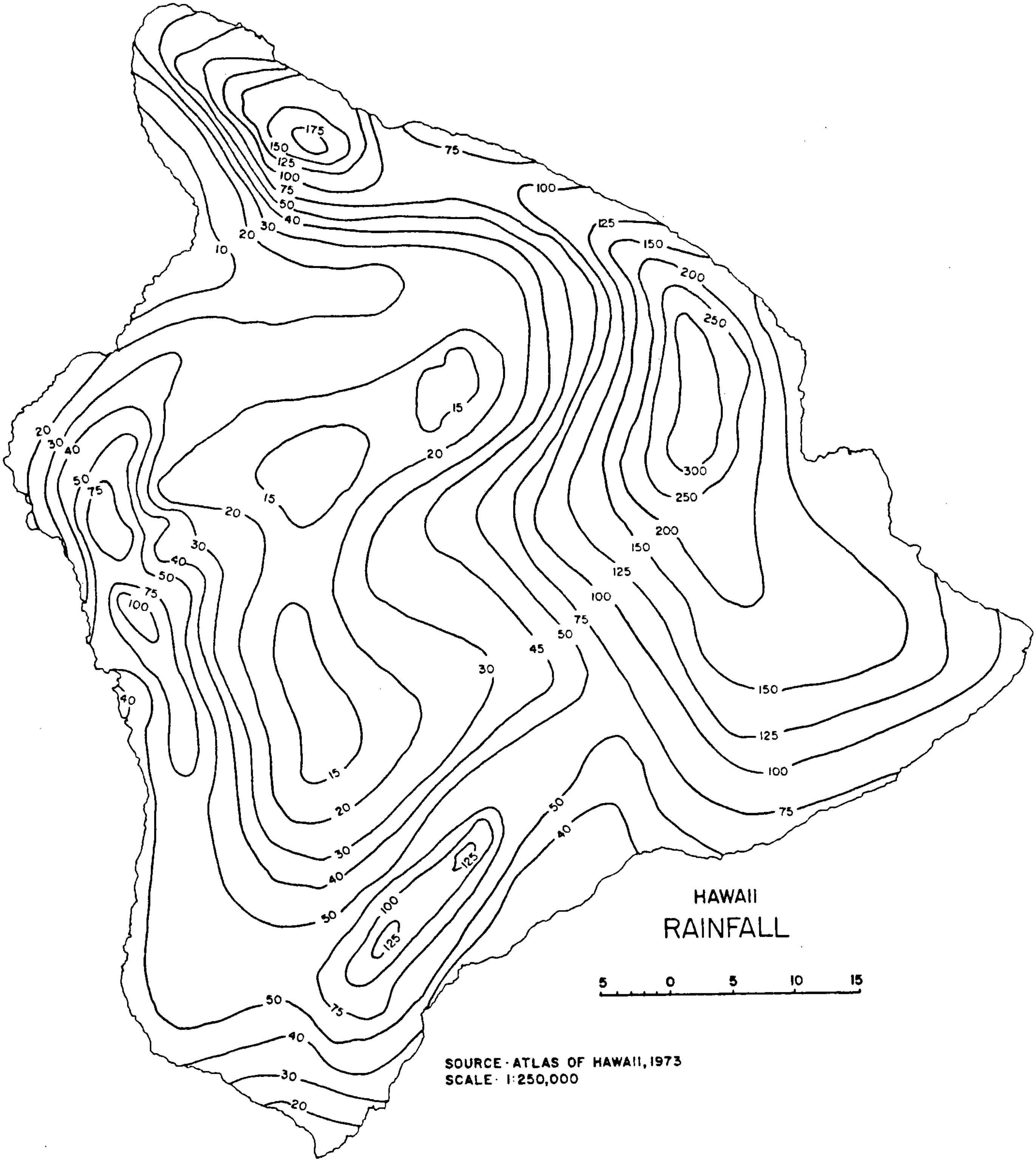


Figure F-4 Rainfall Map of Hawaii

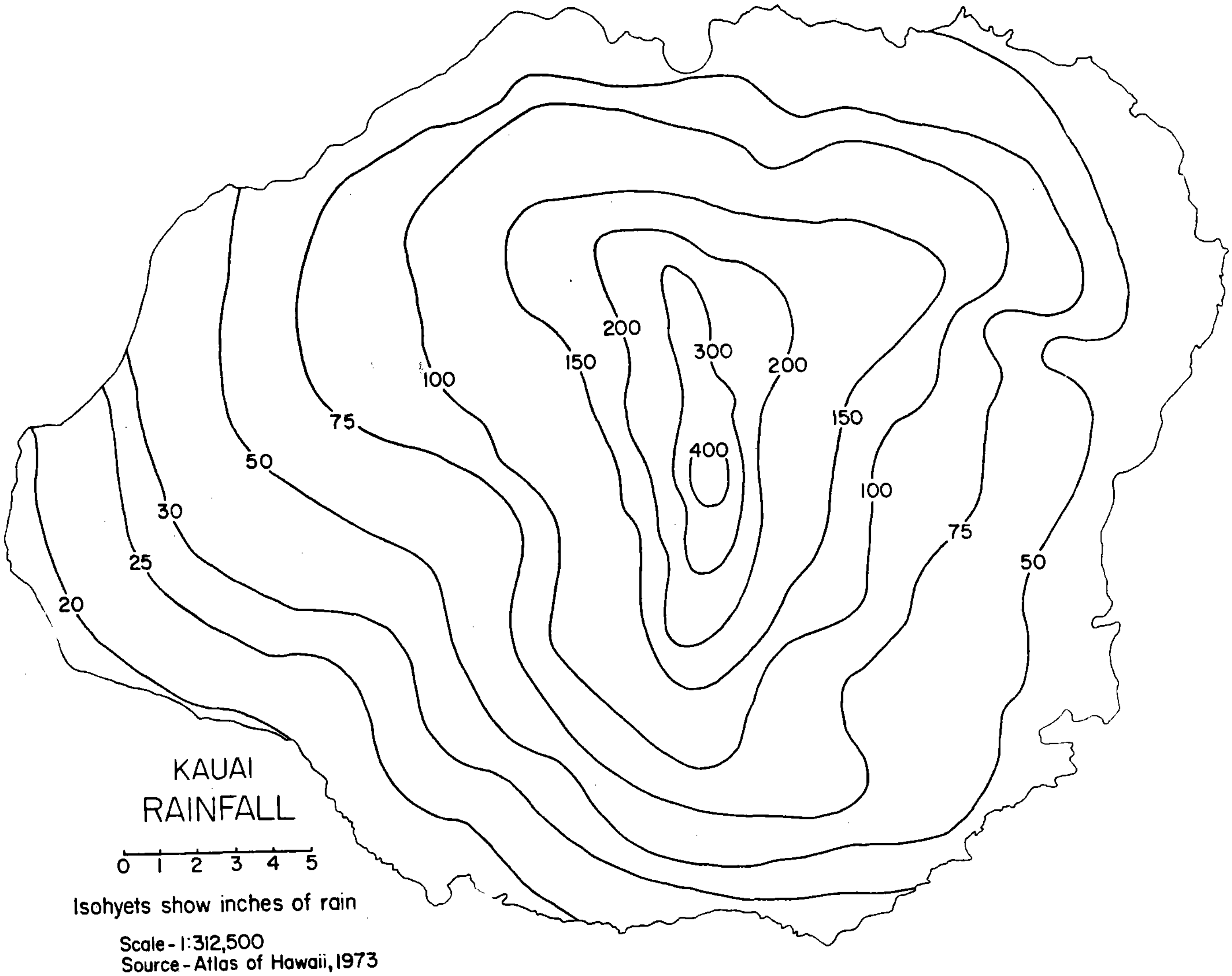
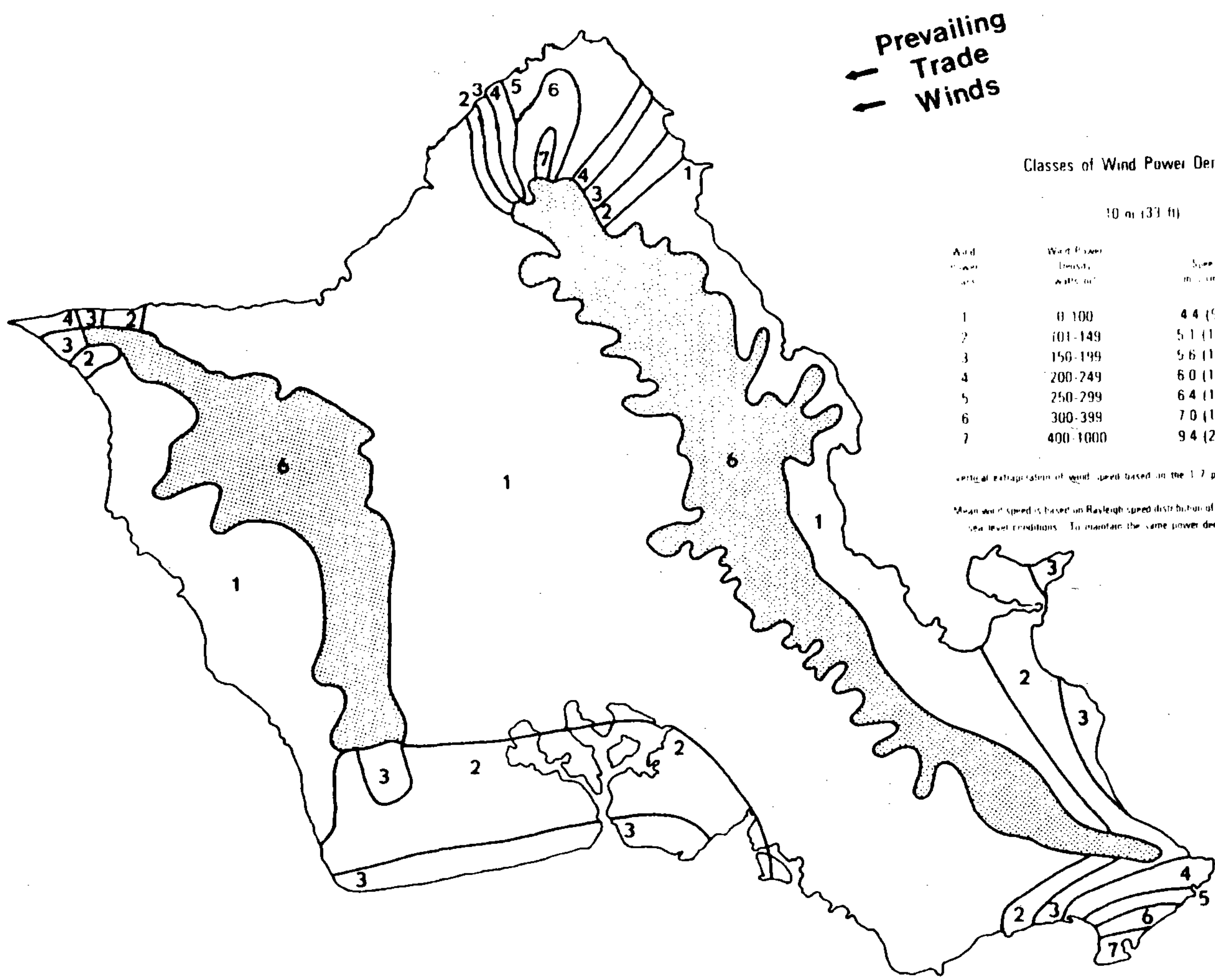


Figure F-5 Rainfall Map of Kauai

APPENDIX G

Wind Energy Maps for Oahu, Maui, Molokai, Hawaii, and Kauai



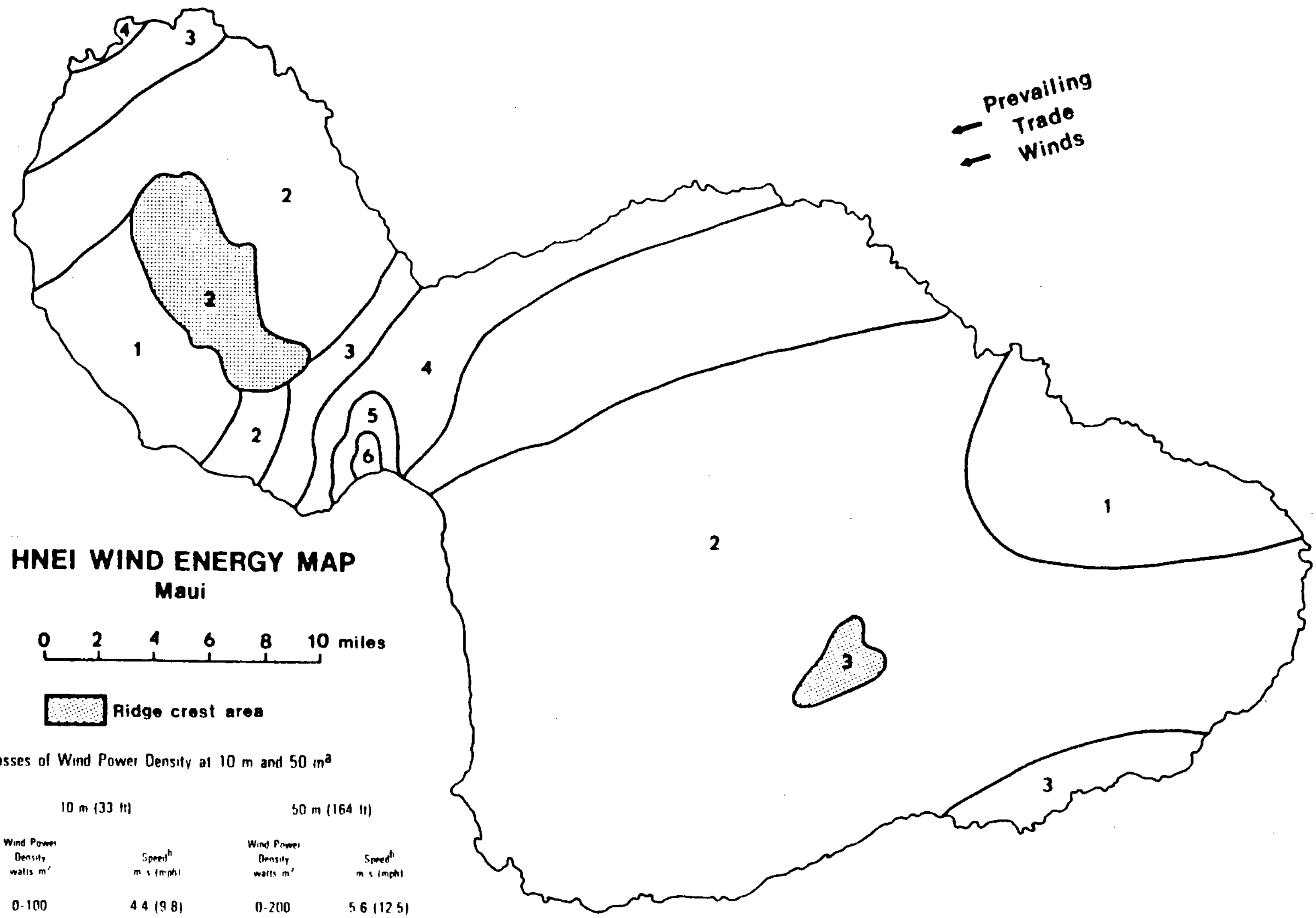
Classes of Wind Power Density at 10 m and 50 m[a]

	10 m (33 ft)		50 m (164 ft)	
Wind Power Class	Wind Power Density watts/m²	Speed[b] m/s (mph)	Wind Power Density watts/m²	Speed[b] m/s (mph)
1	0 100	4 4 (9 8)	0-200	5 6 (12 5)
2	101-149	5 1 (11 5)	201-299	6 4 (14 3)
3	150-199	5 6 (12 5)	300-399	7 0 (15 7)
4	200-249	6 0 (13 4)	400-499	7 5 (16 8)
5	250-299	6 4 (14 3)	500-599	8 0 (17 9)
6	300-399	7 0 (15 7)	600-799	8 8 (19 7)
7	400-1000	9 4 (21 1)	800 2000	11 9 (26 6)

[a] Vertical extrapolation of wind speed based on the 1/7 power law.

[b] Mean wind speed is based on Rayleigh speed distribution of equivalent mean wind power density. Wind speed is for standard sea level conditions. To maintain the same power density, speed increases [illegible] 1000 m of elevation.

Figure G-1 Wind Energy Map of Oahu



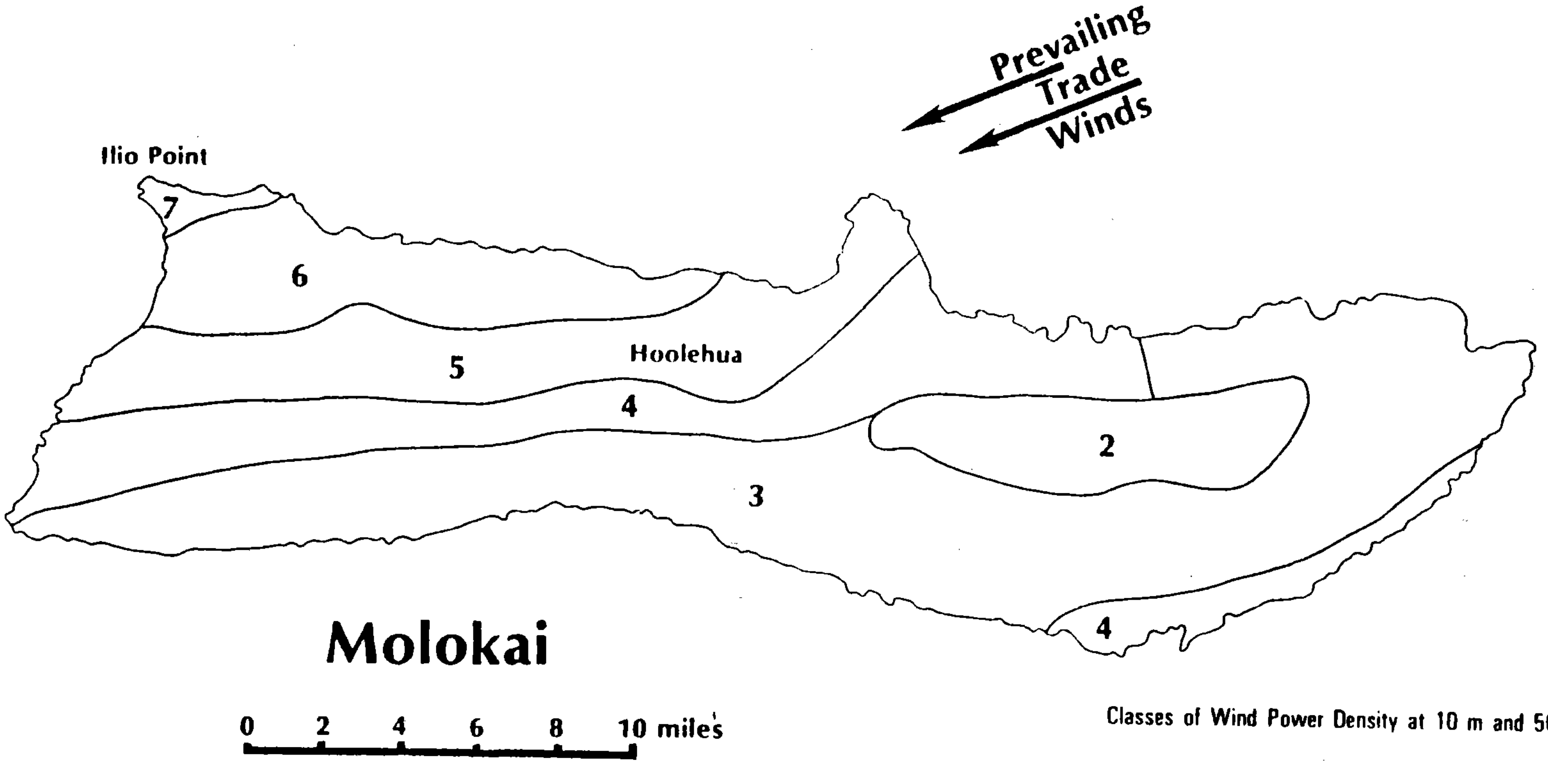
Classes of Wind Power Density at 10 m and 50 m[a]

	10 m (33 ft)		50 m (164 ft)	
Wind Power Class	Wind Power Density watts/m²	Speed[b] m/s (mph)	Wind Power Density watts/m²	Speed[b] m/s (mph)
1	0-100	4 4 (9 8)	0-200	5 6 (12 5)
2	101-149	5 1 (11 5)	201-299	6 4 (14 3)
3	150-199	5 6 (12 5)	300-399	7 0 (15 7)
4	200-249	6 0 (13 4)	400-499	7 5 (16 8)
5	250-299	6 4 (14 3)	500-599	8 0 (17 9)
6	300-399	7 0 (15 7)	600-799	8 8 (19 7)
7	400-1000	9 4 (21 1)	800-2000	11 9 (26 6)

[a] Vertical extrapolation of wind speed based on the 1/7 power law

[b] Mean wind speed is based on Rayleigh speed distribution of equivalent mean wind power density. Wind speed is for standard sea level conditions. To maintain the same power density, speed increases 5%/5000 ft (3%/1000 m) of elevation

Figure G-2 Wind Energy Map of Maui



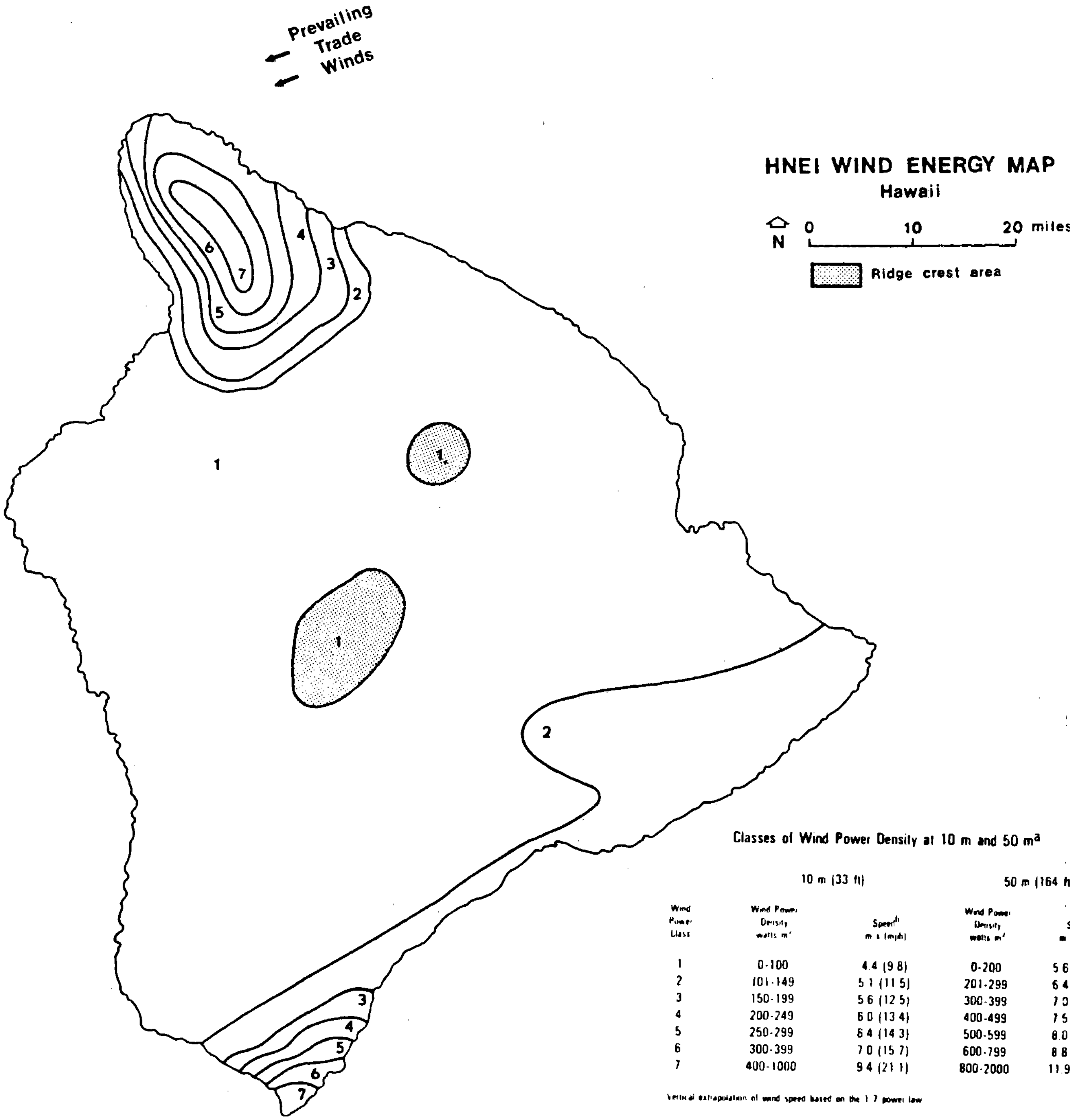
Classes of Wind Power Density at 10 m and 50 m[a]

	10 m (33 ft)		50 m (164 ft)	
Wind Power Class	Wind Power Density watts/m²	Speed[b] m/s (mph)	Wind Power Density watts/m²	Speed[b] m/s (mph)
1	0-100	4.4 (9.8)	0-200	5.6 (12.5)
2	101-149	5.1 (11.5)	201-299	6.4 (14.3)
3	150-199	5.6 (12.5)	300-399	7.0 (15.7)
4	200-249	6.0 (13.4)	400-499	7.5 (16.8)
5	250-299	6.4 (14.3)	500-599	8.0 (17.9)
6	300-399	7.0 (15.7)	600-799	8.8 (19.7)
7	400-1000	9.4 (21.1)	800-2000	11.9 (26.6)

[a] Vertical extrapolation of wind speed based on the 1/7 power law

[b] Mean wind speed is based on Rayleigh speed distribution of equivalent mean wind power density. Wind speed is for standard sea-level conditions. To maintain the same power density, speed increases 5%/5000 ft (3%/1000 m) of elevation.

Figure G-3 Wind Energy Map of Molokai



Classes of Wind Power Density at 10 m and 50 m[a]

Wind Power Class	10 m (33 ft) Wind Power Density watts/m²	10 m (33 ft) Speed[b] m/s (mph)	50 m (164 ft) Wind Power Density watts/m²	50 m (164 ft) Speed[b] m/s (mph)
1	0-100	4.4 (9.8)	0-200	5.6 (12.5)
2	101-149	5.1 (11.5)	201-299	6.4 (14.3)
3	150-199	5.6 (12.5)	300-399	7.0 (15.7)
4	200-249	6.0 (13.4)	400-499	7.5 (16.8)
5	250-299	6.4 (14.3)	500-599	8.0 (17.9)
6	300-399	7.0 (15.7)	600-799	8.8 (19.7)
7	400-1000	9.4 (21.1)	800-2000	11.9 (26.6)

[a] Vertical extrapolation of wind speed based on the 1/7 power law.

[b] Mean wind speed is based on Rayleigh speed distribution of equivalent mean wind power density. Wind speed is for standard sea level conditions. To maintain the same power density, speed increases 5%/5000 ft (3%/1000 m) of elevation.

Figure G-4 Wind Energy Map of Hawaii

HNEI WIND ENERGY MAP
Kauai

N 0 2 4 6 8 10 miles

Ridge crest area

Classes of Wind Power Density at 10 m and 50 m[a]

Wind Power Class	10 m (33 ft) Wind Power Density watts m²	10 m (33 ft) Speed[b] m s (mph)	50 m (164 ft) Wind Power Density watts m²	50 m (164 ft) Speed[b] m s (mph)
1	0-100	4 4 (9 8)	0-200	5 6 (12 5)
2	101-149	5 1 (11 5)	201-299	6 4 (14 3)
3	150-199	5 6 (12 5)	300-399	7 0 (15 7)
4	200 249	6 0 (13 4)	400-499	7 5 (16 8)
5	250-299	6 4 (14 3)	500-599	8 0 (17 9)
6	300-399	7 0 (15 7)	600-799	8 8 (19 7)
7	400-1000	9 4 (21 1)	800-2000	11 9 (26 6)

[a] Vertical extrapolation of wind speed based on the 1 7 power law

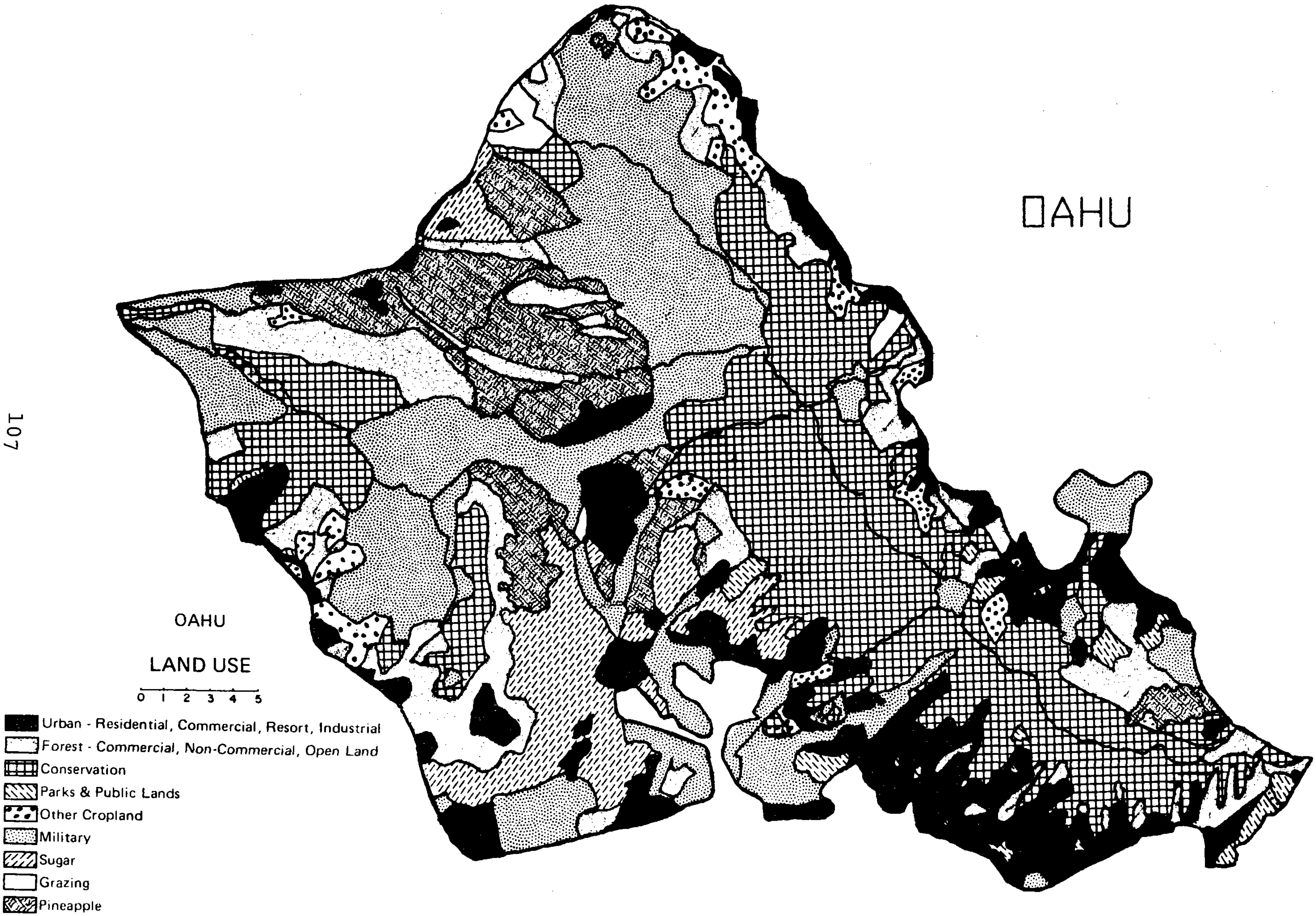
[b] Mean wind speed is based on Rayleigh speed distribution of equivalent mean wind power density. Wind speed is for standard sea-level conditions. To maintain the same power density, speed increases 5% 5000 ft (3% 1000 m) of elevation

Figure G-5 Wind Energy Map of Kauai

APPENDIX H

Maps of Land Use and Land Use Districts for

Oahu, Maui, Molokai, Hawaii, and Kauai



Scale - 1:187,500

Source - Atlas of Hawaii, 1983

Figure H-1 Oahu Land Use

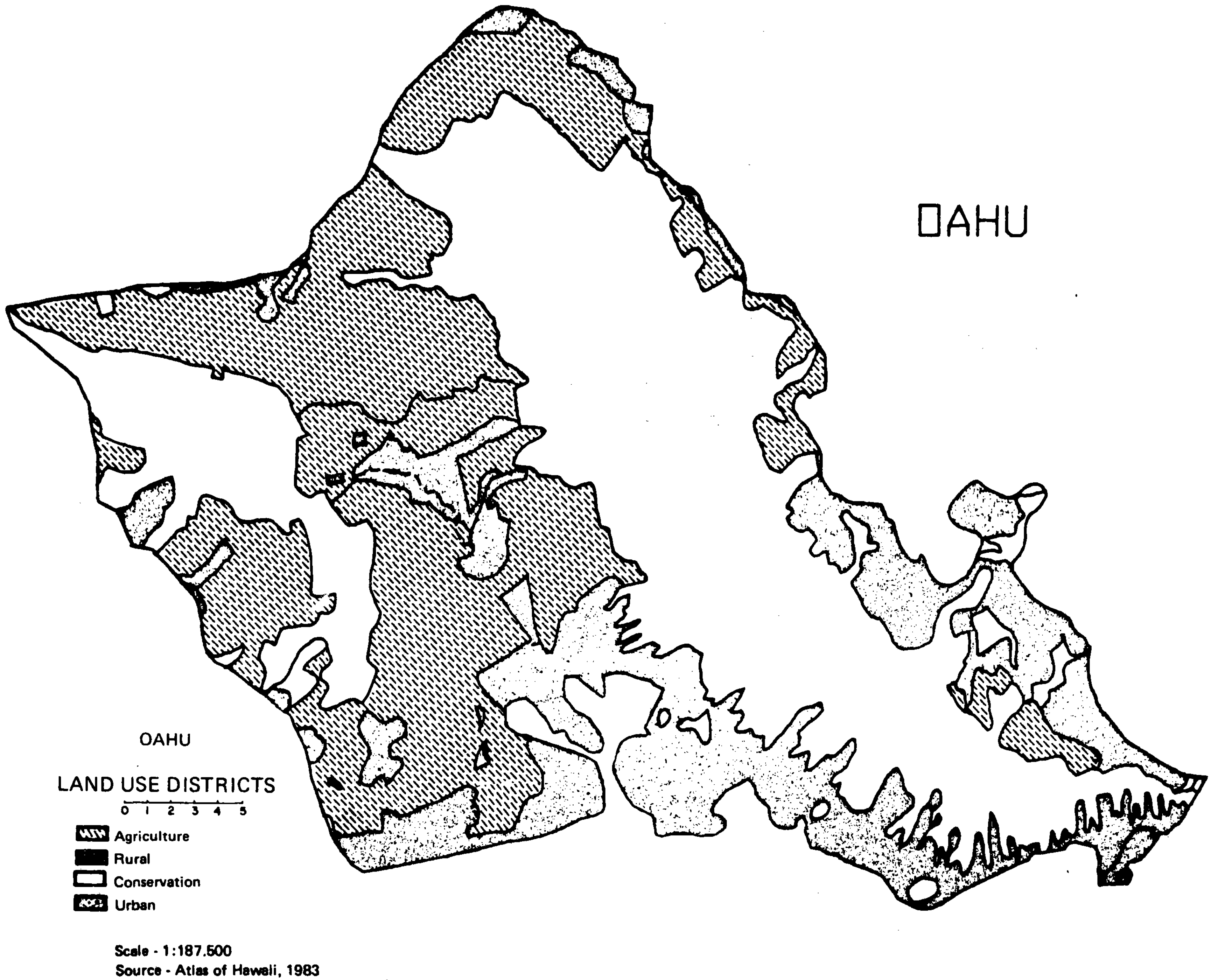


Figure H-2 Oahu Land Use Districts

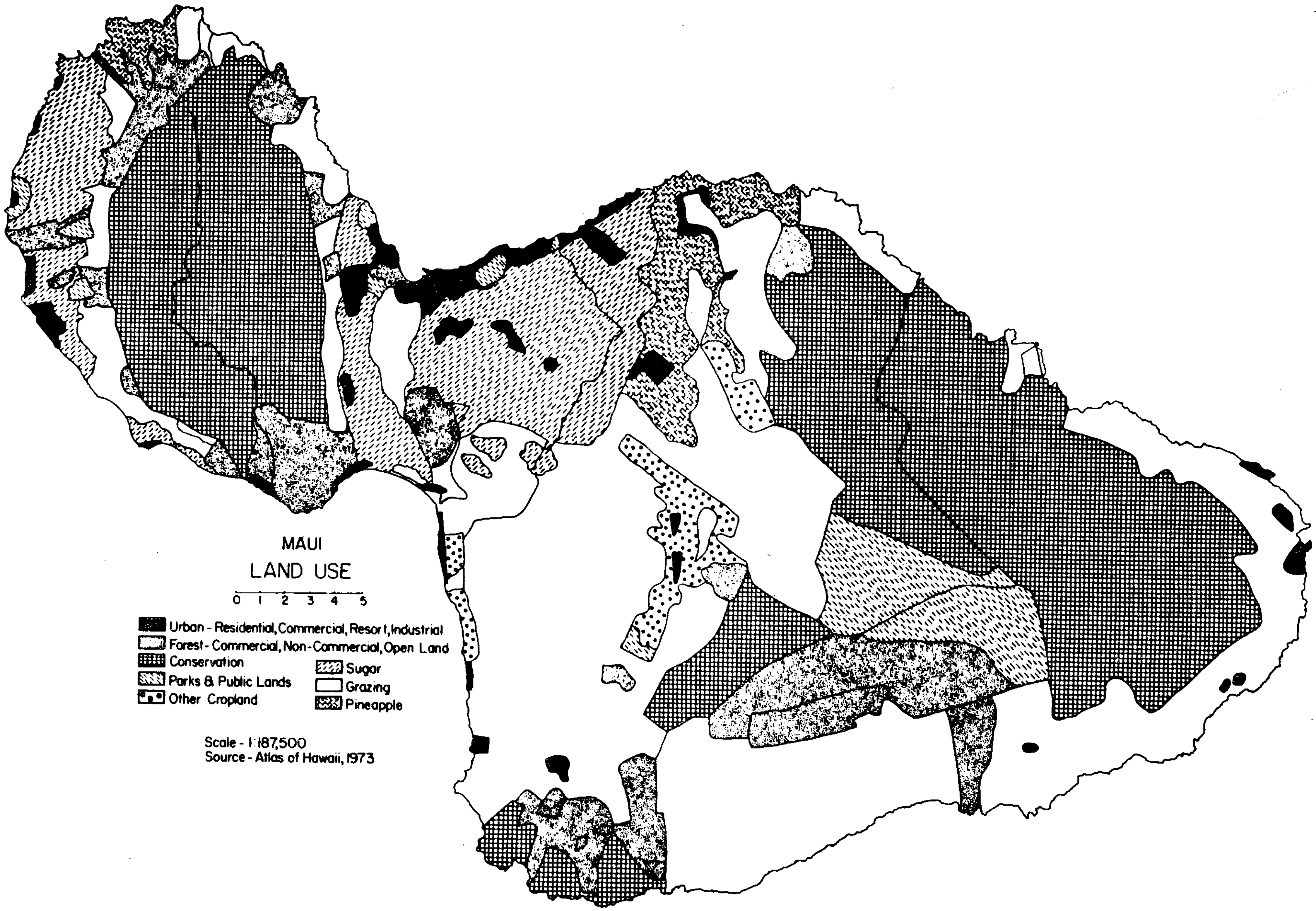


Figure H-3 Maui Land Use

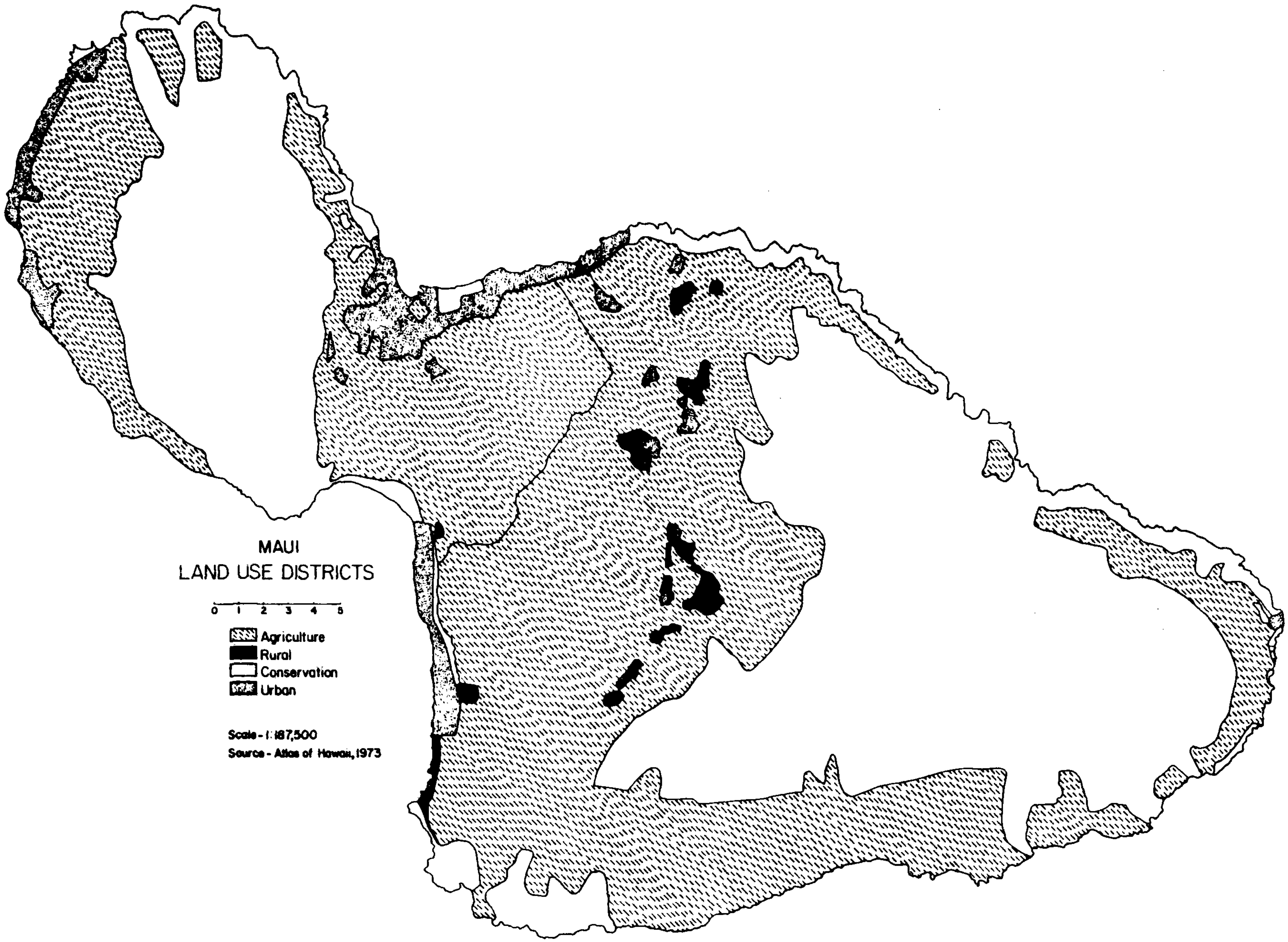


Figure H-4 Maui Land Use Districts

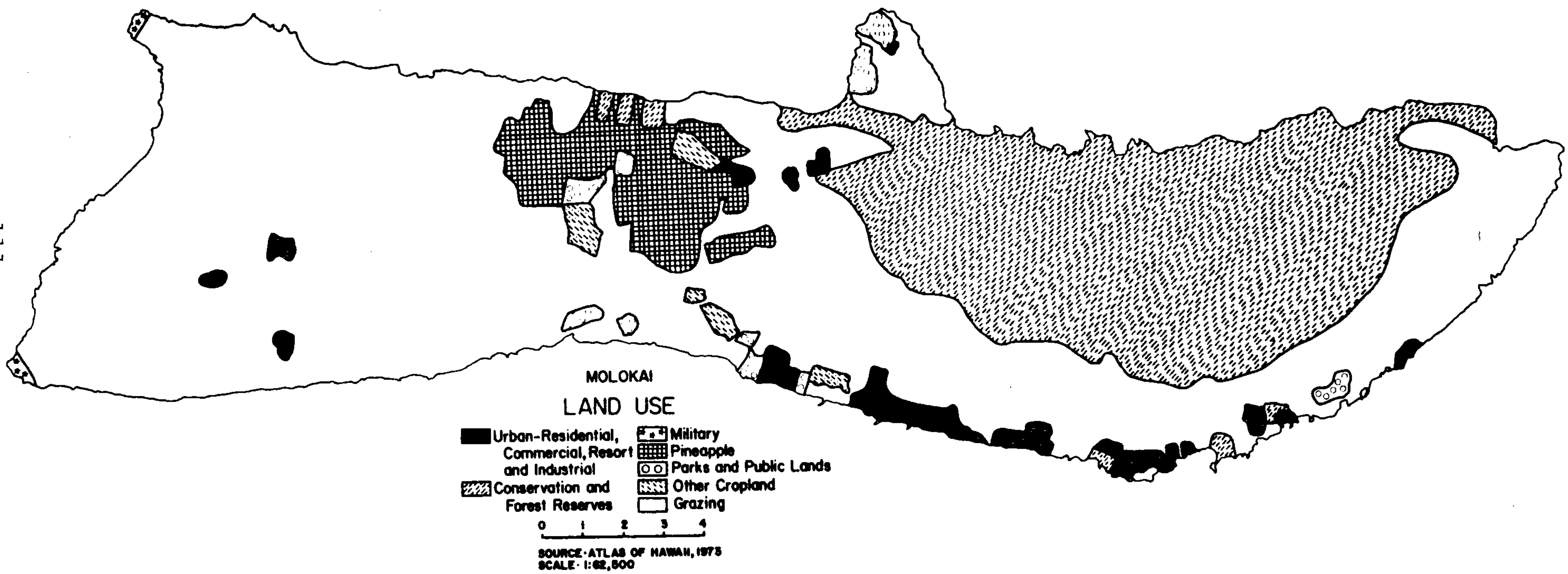


Figure H-5 Molokai Land Use

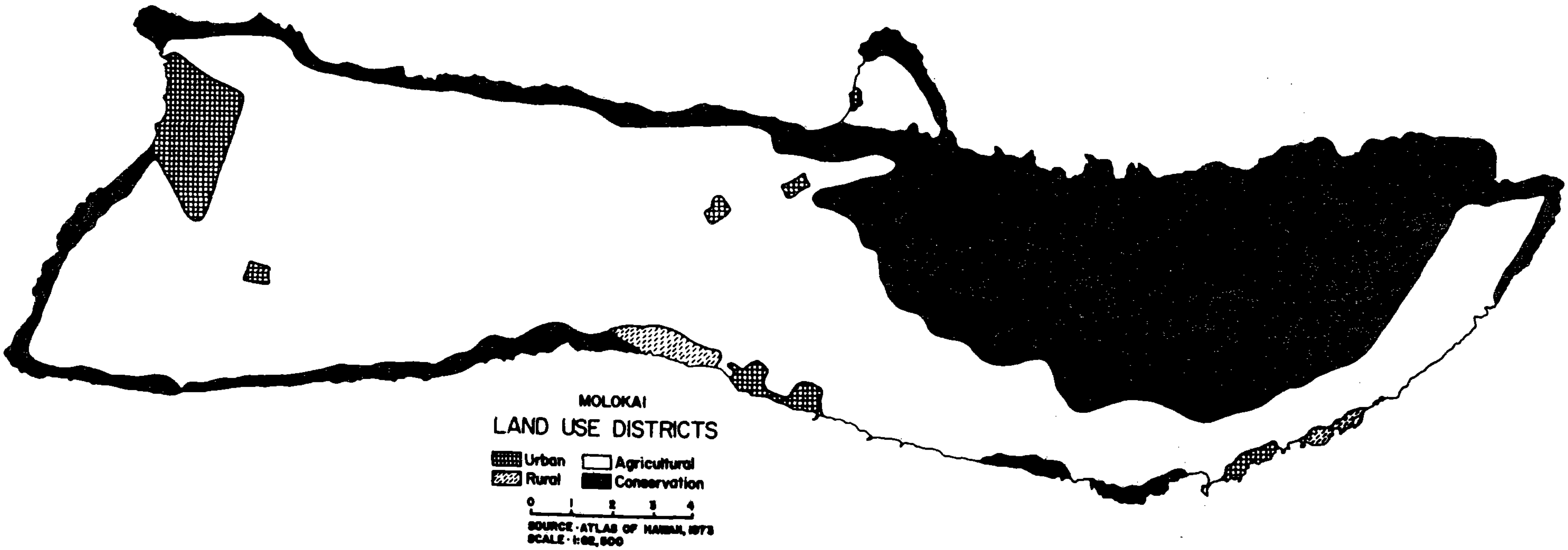


Figure H-6 Molokai Land Use Districts

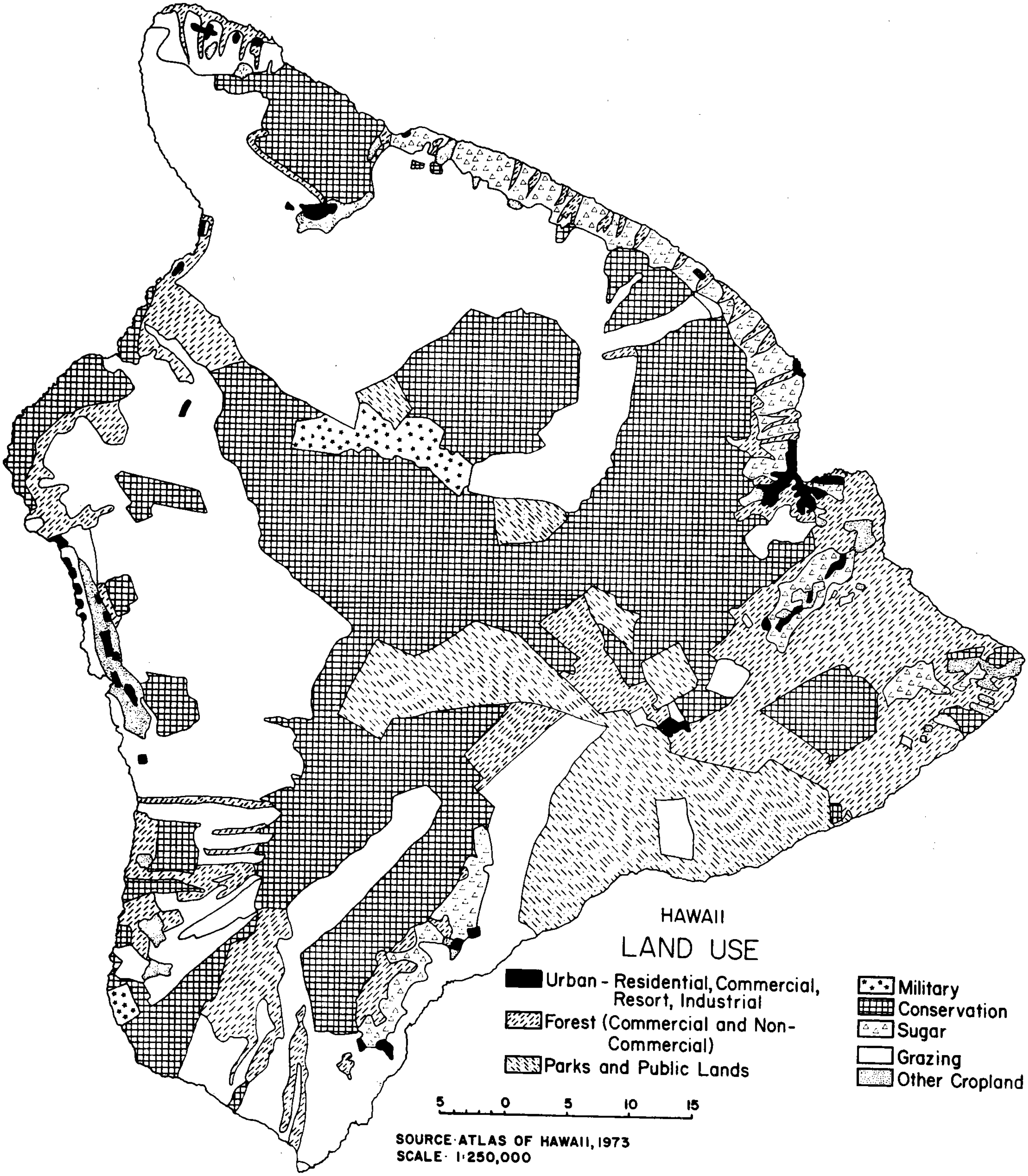


Figure H-7 Hawaii Land Use

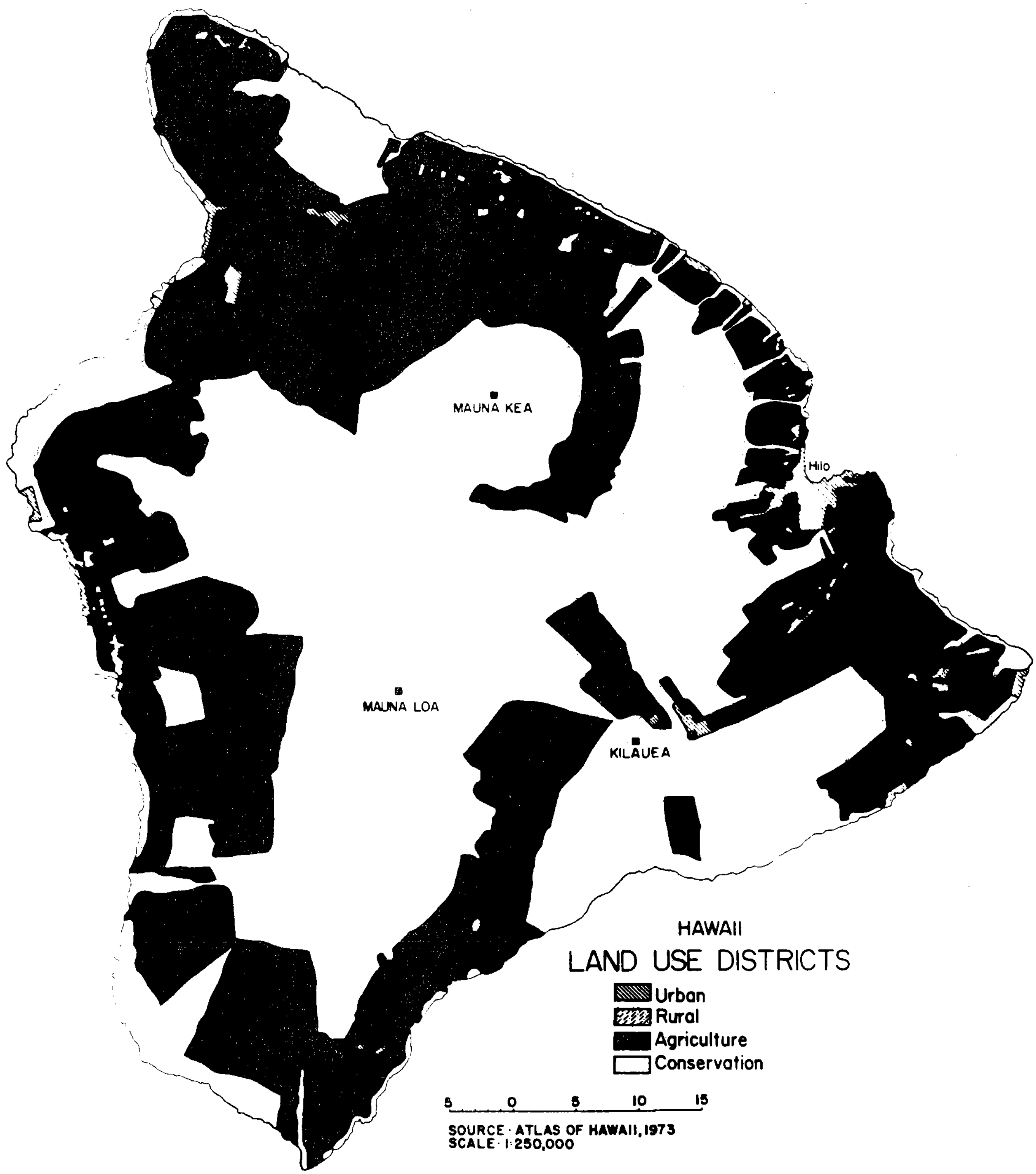


Figure H-8 Hawaii Land Use Districts

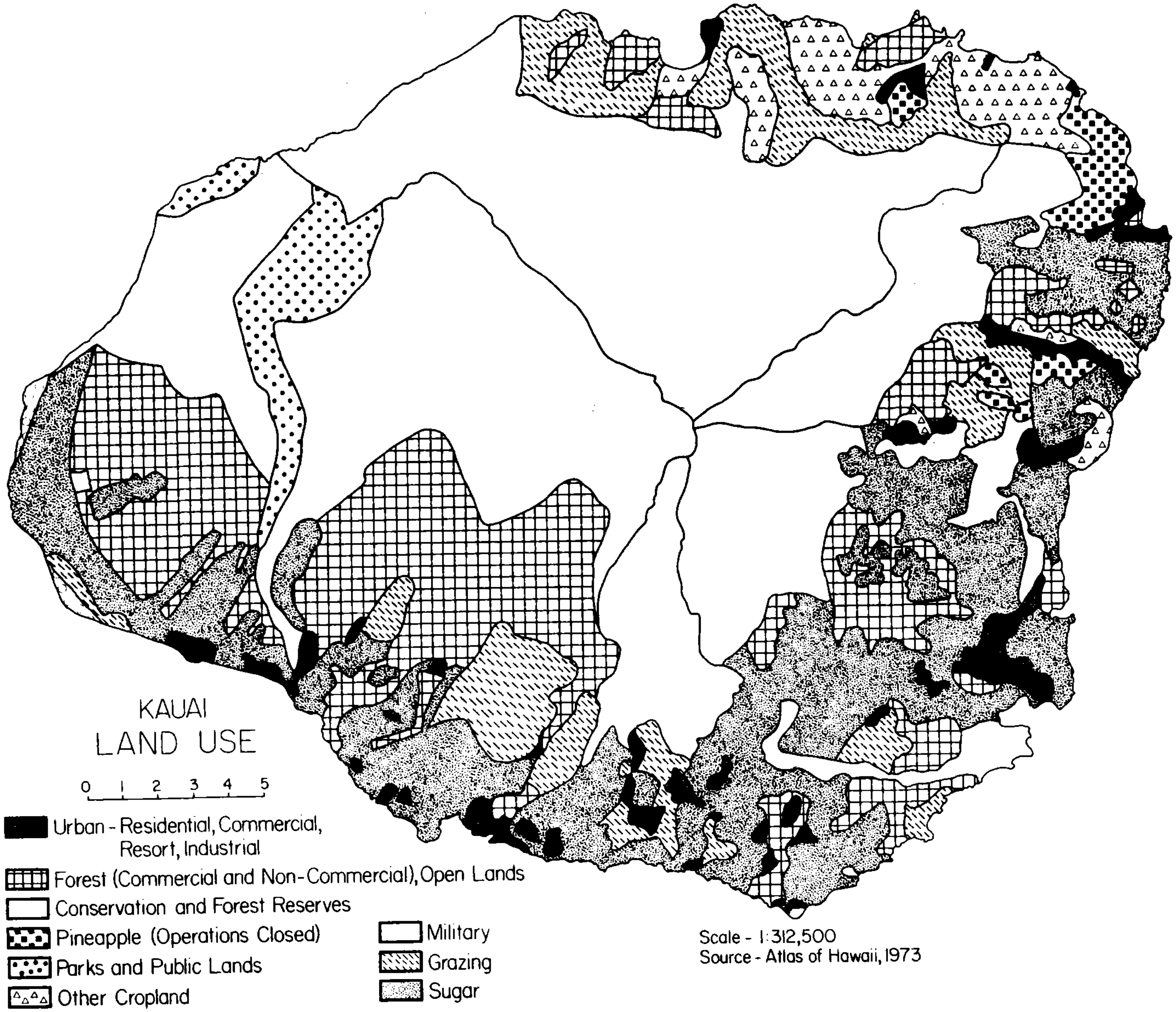


Figure H-9 Kauai Land Use

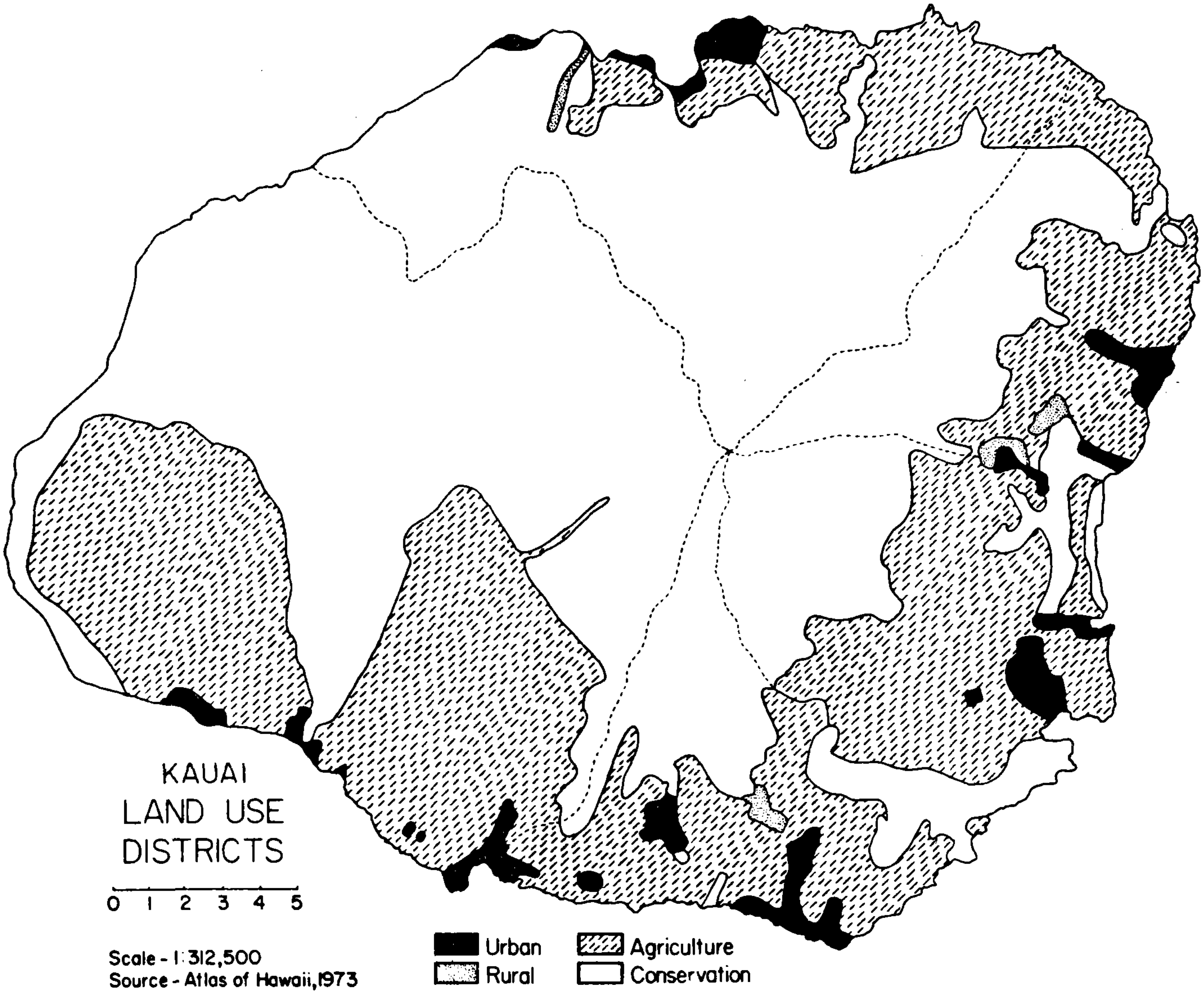
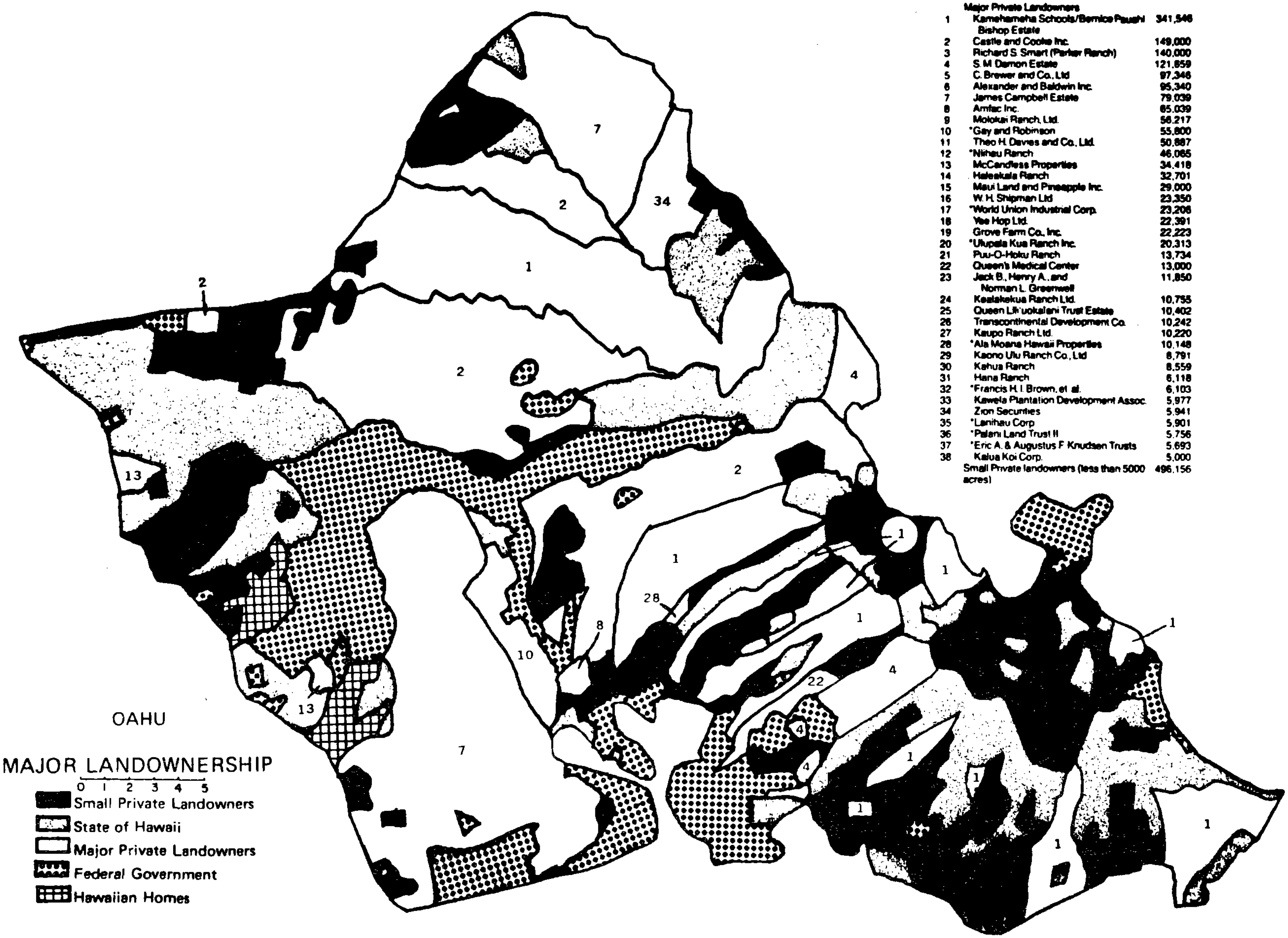


Figure H-10 Kauai Land Use Districts

APPENDIX I

Maps of Major Landownership for

Oahu, Maui, Molokai, Hawaii, and Kauai



LAND OWNERSHIP

		acreage
	State of Hawaii	1,477,886
	Hawaiian Home Lands	
	Federal Government	408,939
	Major Private Landowners	
1	Kamehameha Schools/Bernice Pauahi Bishop Estate	341,546
2	Castle and Cooke Inc.	149,000
3	Richard S. Smart (Parker Ranch)	140,000
4	S. M. Damon Estate	121,659
5	C. Brewer and Co., Ltd	97,346
6	Alexander and Baldwin Inc.	95,340
7	James Campbell Estate	79,039
8	Amfac Inc.	65,039
9	Molokai Ranch, Ltd.	56,217
10	*Gay and Robinson	55,800
11	Theo H. Davies and Co., Ltd.	50,887
12	*Niihau Ranch	46,065
13	McCandless Properties	34,418
14	Haleakala Ranch	32,701
15	Maui Land and Pineapple Inc.	29,000
16	W. H. Shipman Ltd	23,350
17	*World Union Industrial Corp.	23,206
18	Yee Hop Ltd.	22,391
19	Grove Farm Co., Inc.	22,223
20	*Ulupalakua Ranch Inc.	20,313
21	Puu-O-Hoku Ranch	13,734
22	Queen's Medical Center	13,000
23	Jack B., Henry A., and Norman L. Greenwell	11,850
24	Kealakekua Ranch Ltd.	10,755
25	Queen Lili'uokalani Trust Estate	10,402
26	Transcontinental Development Co.	10,242
27	Kaupo Ranch Ltd.	10,220
28	*Ala Moana Hawaii Properties	10,148
29	Kaono Ulu Ranch Co., Ltd	8,791
30	Kahua Ranch	8,559
31	Hana Ranch	6,118
32	*Francis H. I. Brown, et al.	6,103
33	Kawela Plantation Development Assoc.	5,977
34	Zion Securities	5,941
35	*Lanihau Corp	5,901
36	*Palani Land Trust II	5,756
37	*Eric A. & Augustus F. Knudsen Trusts	5,693
38	Kalua Koi Corp.	5,000
	Small Private landowners (less than 5000 acres)	496,156

Scale - 1:187,500

Source - Atlas of Hawaii, 1983

Figure I-1 Oahu Major Landownership

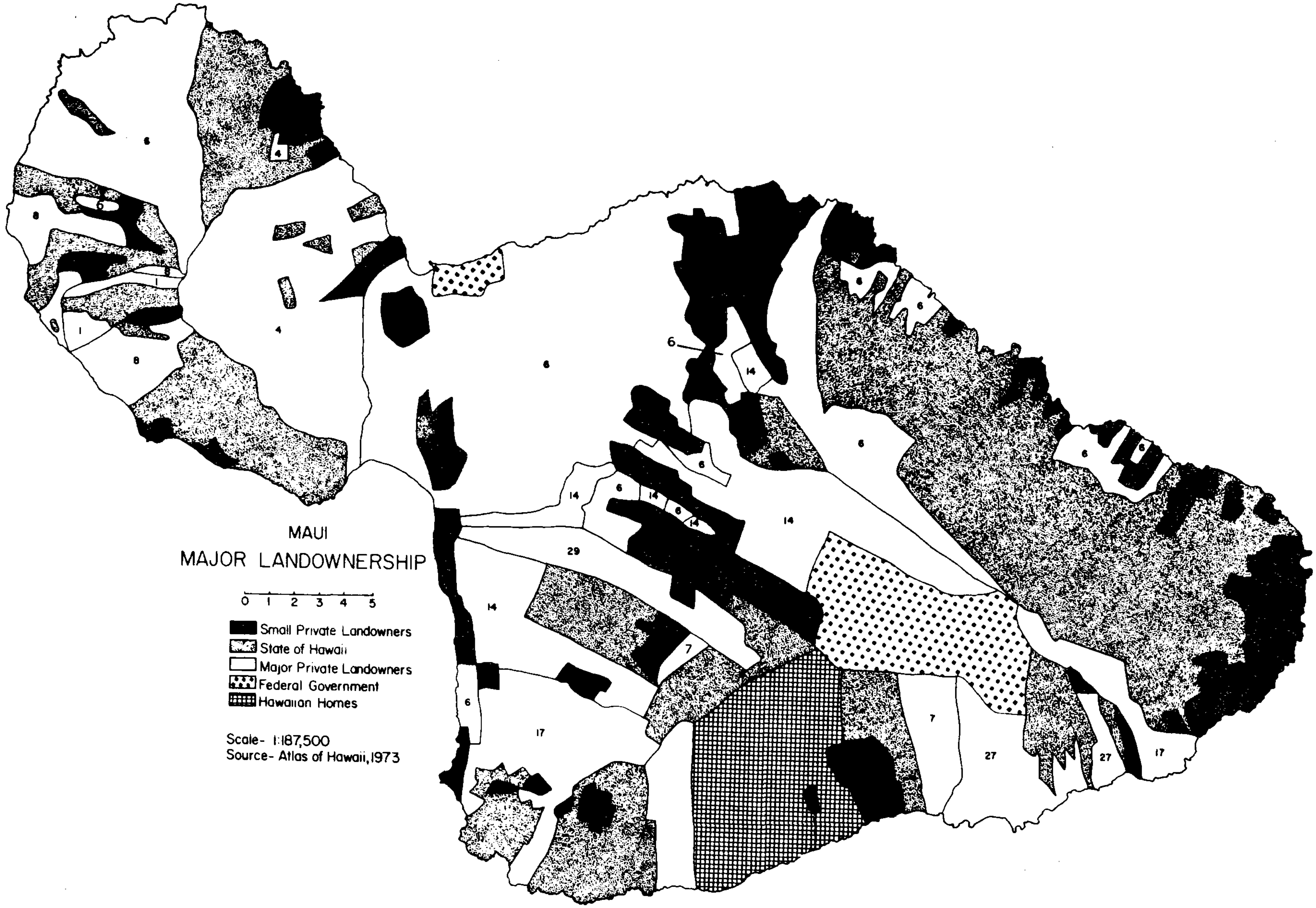


Figure I-2 Maui Major Landownership

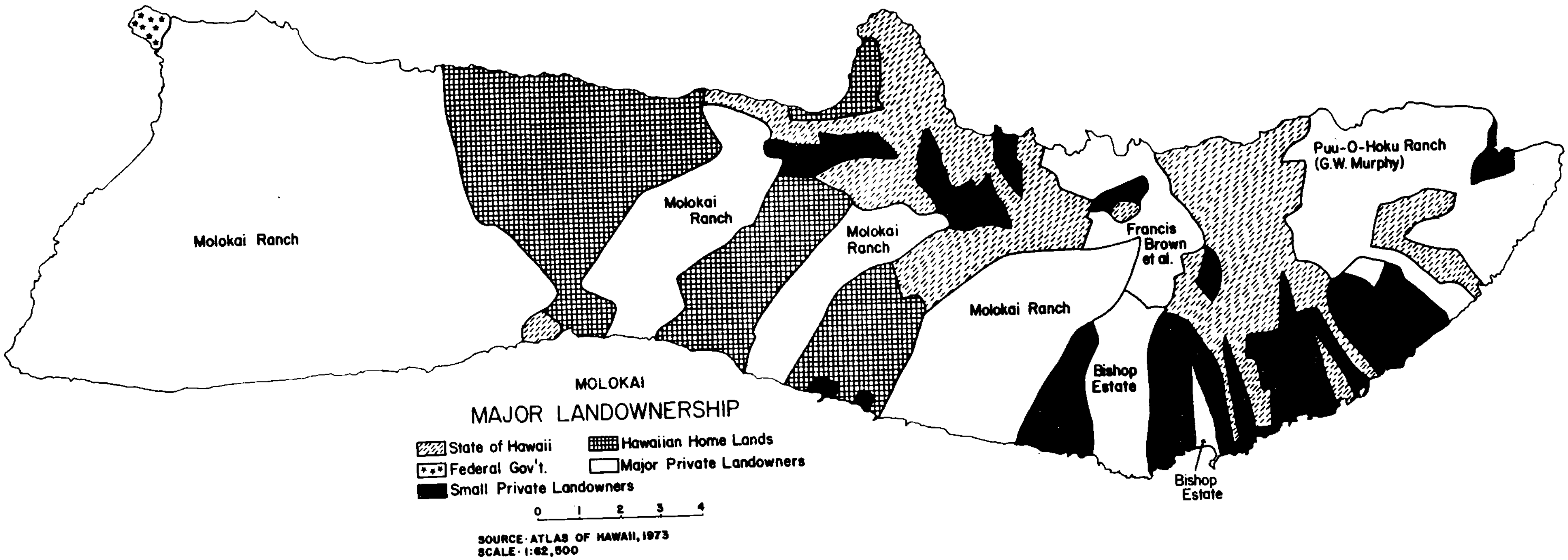


Figure I-3 Molokai Major Landownership

LAND OWNERSHIP

		acreage
	State of Hawaii	1,880,532
	Hawaiian Home Lands	
	Federal Government	402,084
	Major Private Landowners	
1	Bernice P. Bishop Estate	369,462
2	Richard S. Smart (Parker Ranch)	185,940
3	Castle and Cooke, Inc.	153,912
4	C. Brewer and Co., Ltd.	145,147
5	Samuel M. Damon Estate	143,842
6	Alexander and Baldwin, Inc.	126,790
7	James Campbell Estate	81,549
8	Amfac, Inc	81,417
9	Molokai Ranch, Ltd	73,975
10	Gay and Robinson	55,800
11	Niihau Ranch	46,065
12	Theo H. Davies and Co., Ltd	43,490
13	McCandless Heirs	37,622
14	Haleakala Ranch Co.	30,041
15	Grove Farm Co., Inc.	22,616
16	Yee Hop, Ltd	21,830
17	Ulupala Kua Ranch, Inc.	21,557
18	W. H. Shipman, Ltd	20,599
19	Thelma K. Stillman Trust (Huehue Ranch)	15,438
20	Puu-O-Hoku Ranch (G. W. Murphy)	14,262
21	Kahua Ranch, Ltd.	14,013
22	Queen's Hospital	13,065
23	W. H. Greenwell, Ltd	12,149
24	Dillingham Investment Corp.	11,471
25	Kealakekua Ranch (S. Greenwell)	11,136
26	Hawaiian Ocean View Estate	10,642
27	Kaupo Ranch, Ltd	10,037
28	Queen Liliuokalani Trust	9,794
29	Kaonoulu Ranch Co., Ltd.	8,813
30	Estate of H. K. L. Castle (Kaneohe Ranch)	8,806
31	Frank R. Greenwell (Palani Ranch)	6,917
32	Zion Securities Corp.	6,514
33	Francis H. Ii Brown, et al	6,164
34	Eric A. and August F. Knudsen Trust	5,879
35	Hawaiian Paradise Park Corp	5,503
36	Bernice P. Bishop Museum	5,257
37	Austin Heirs	5,255
38	Capital Investment Co., Ltd	5,182
39	Kapoho Land & Development Co., Ltd	5,174
	Small private landowners (less than 5000 acres)	257,059

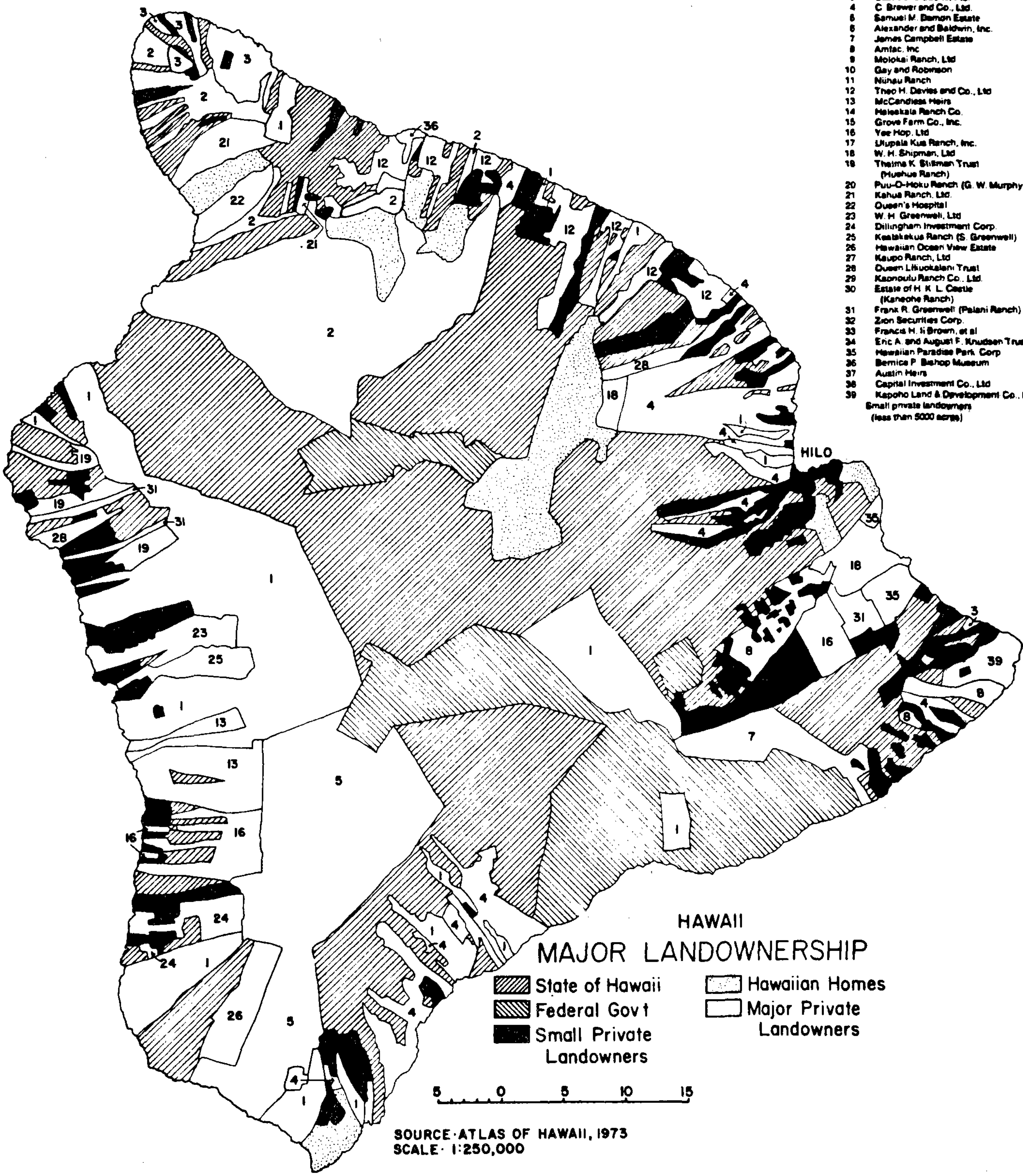


Figure I-4 Hawaii Major Landownership

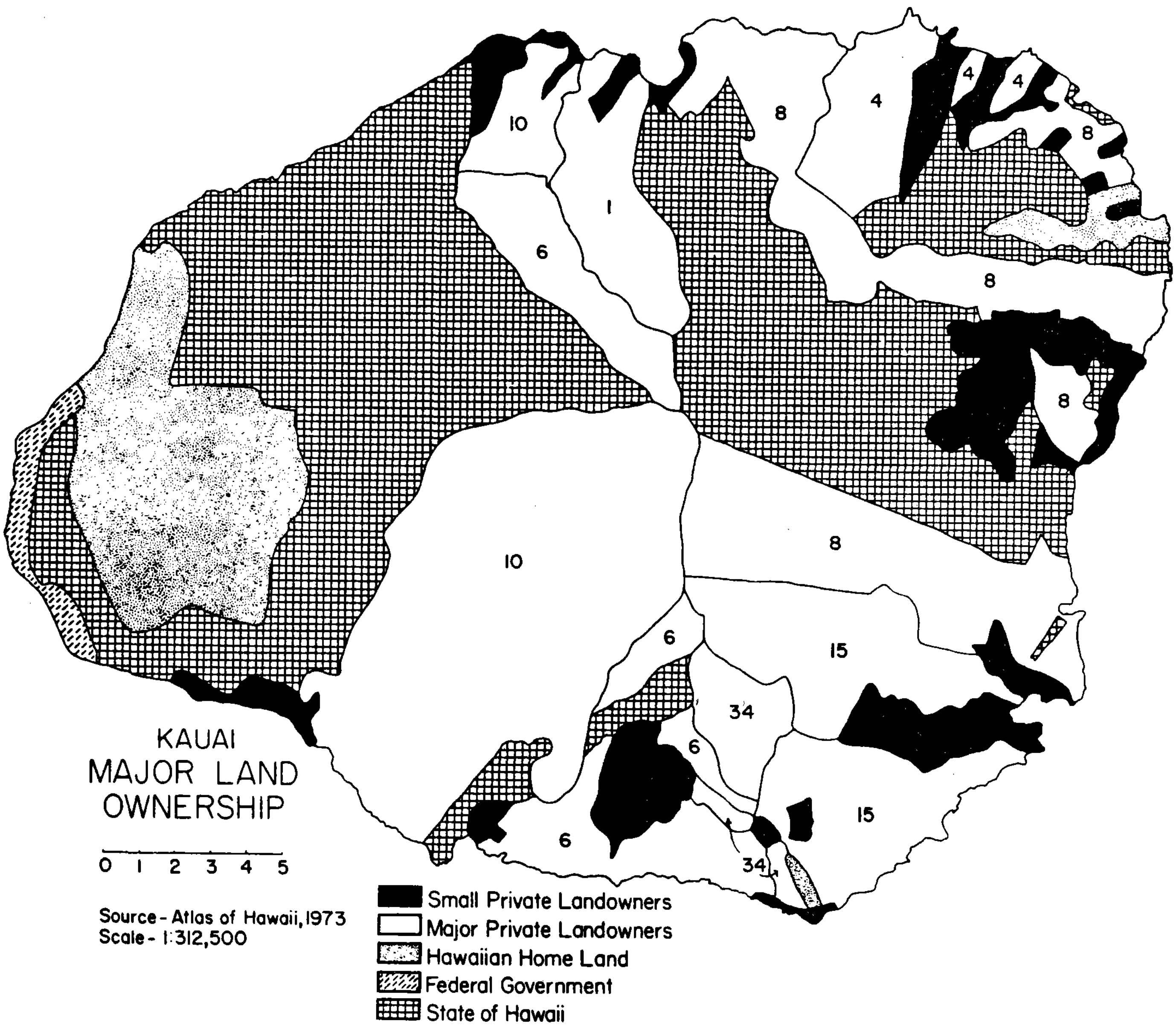


Figure I-5 Kauai Major Landownership

APPENDIX J

Maps of General Topography for

Oahu, Maui, Molokai, Hawaii, and Kauai

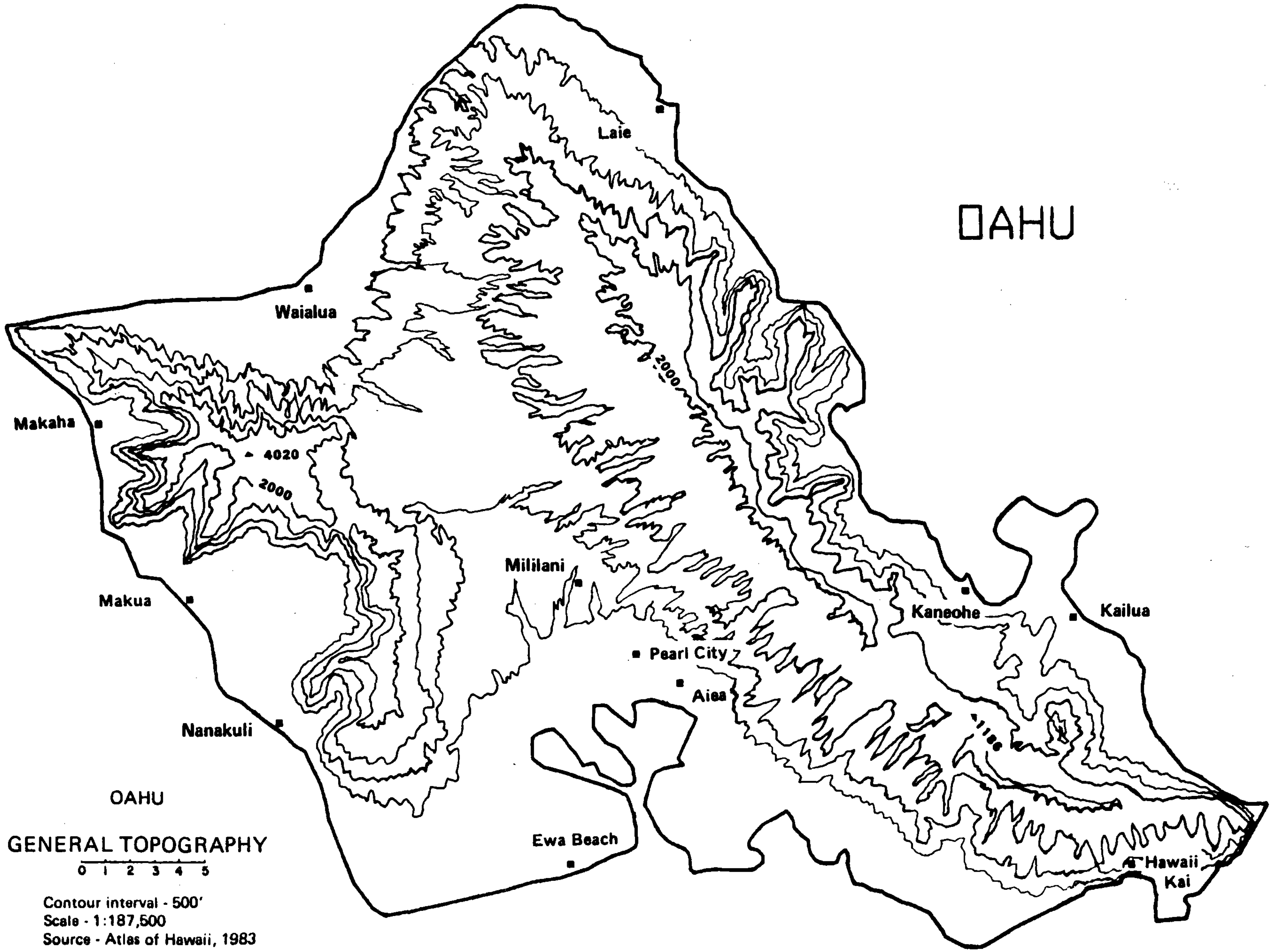


Figure J-1 Oahu General Topography

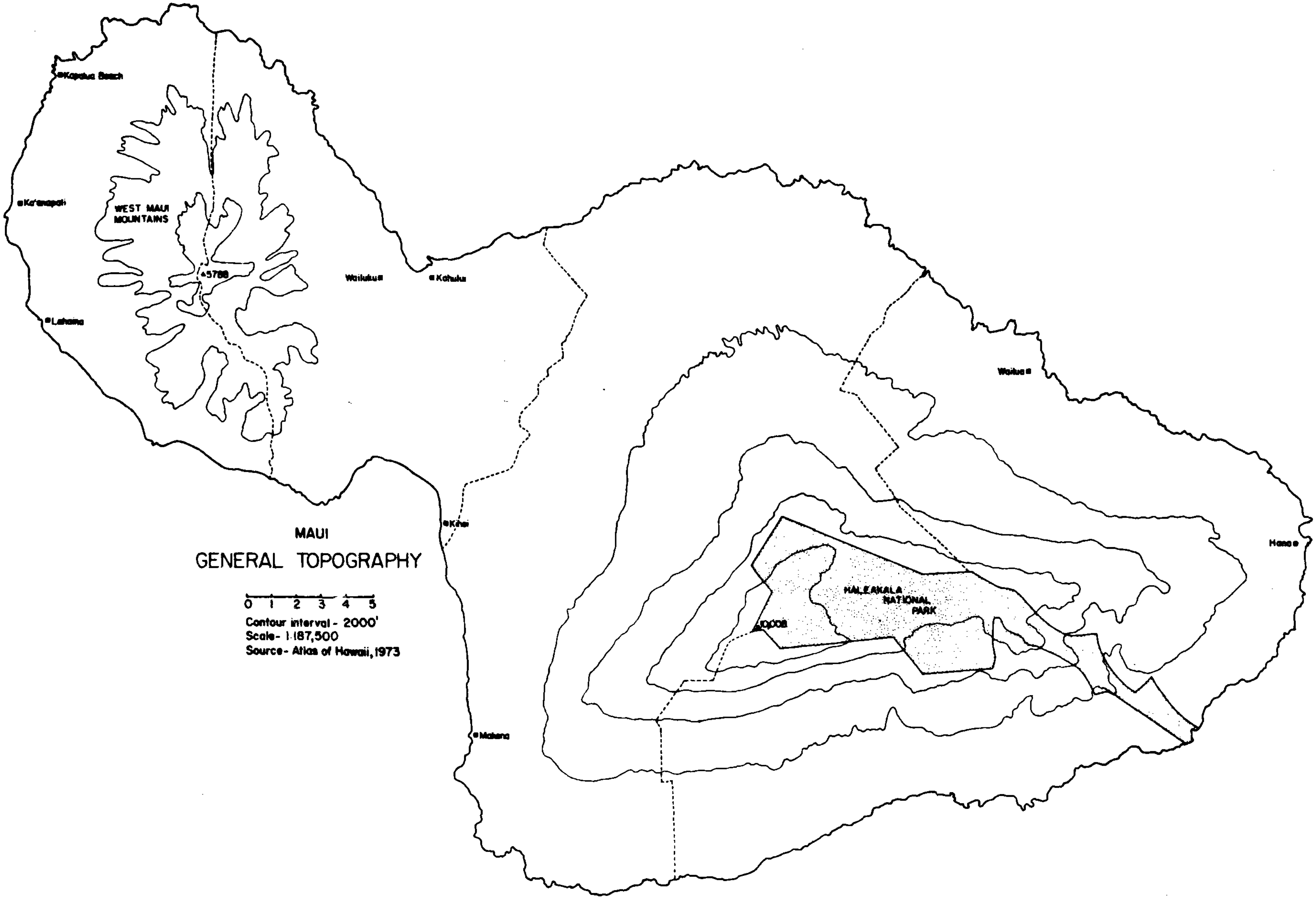


Figure J-2 Maui General Topography

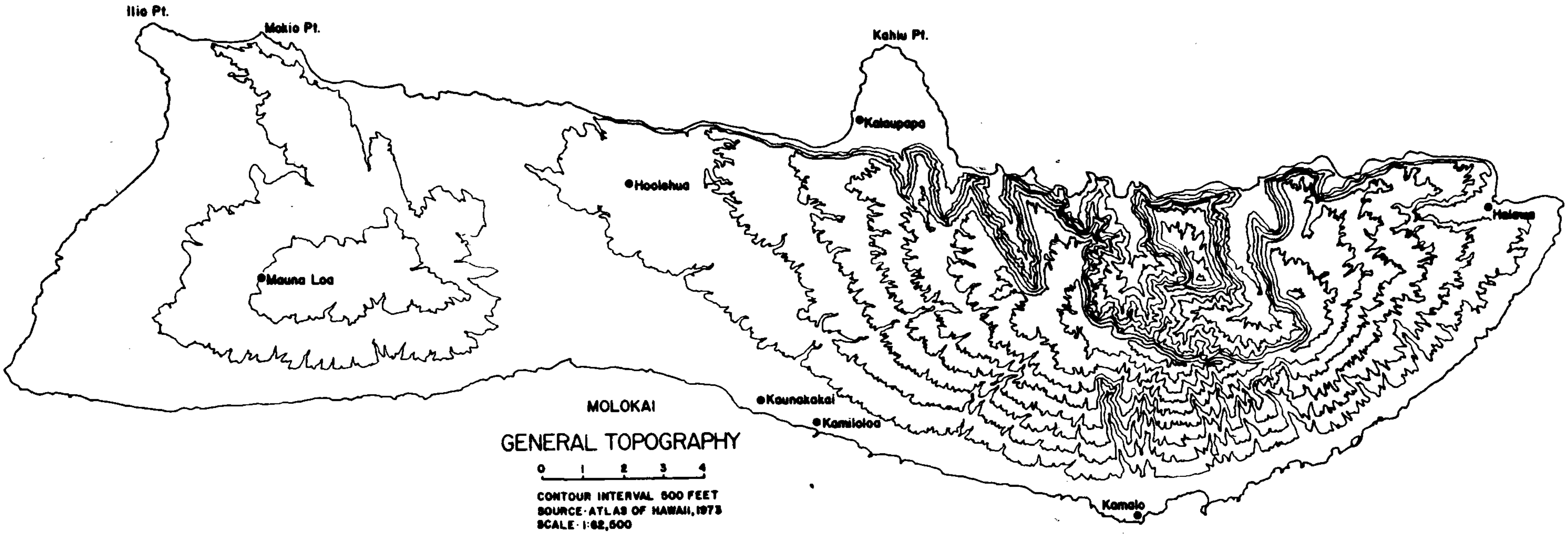


Figure J-3 Molokai General Topography

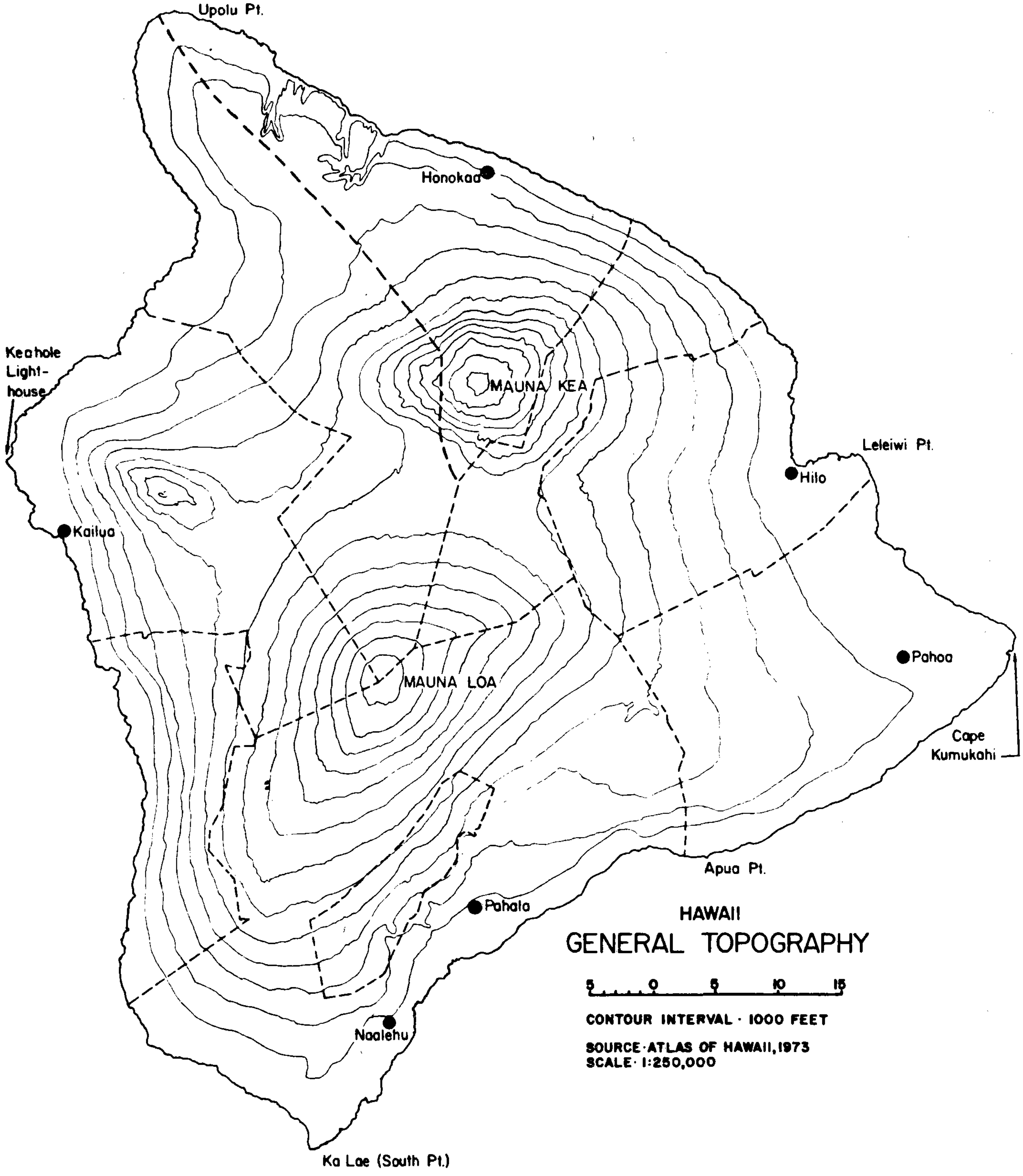


Figure J-4 Hawaii General Topography

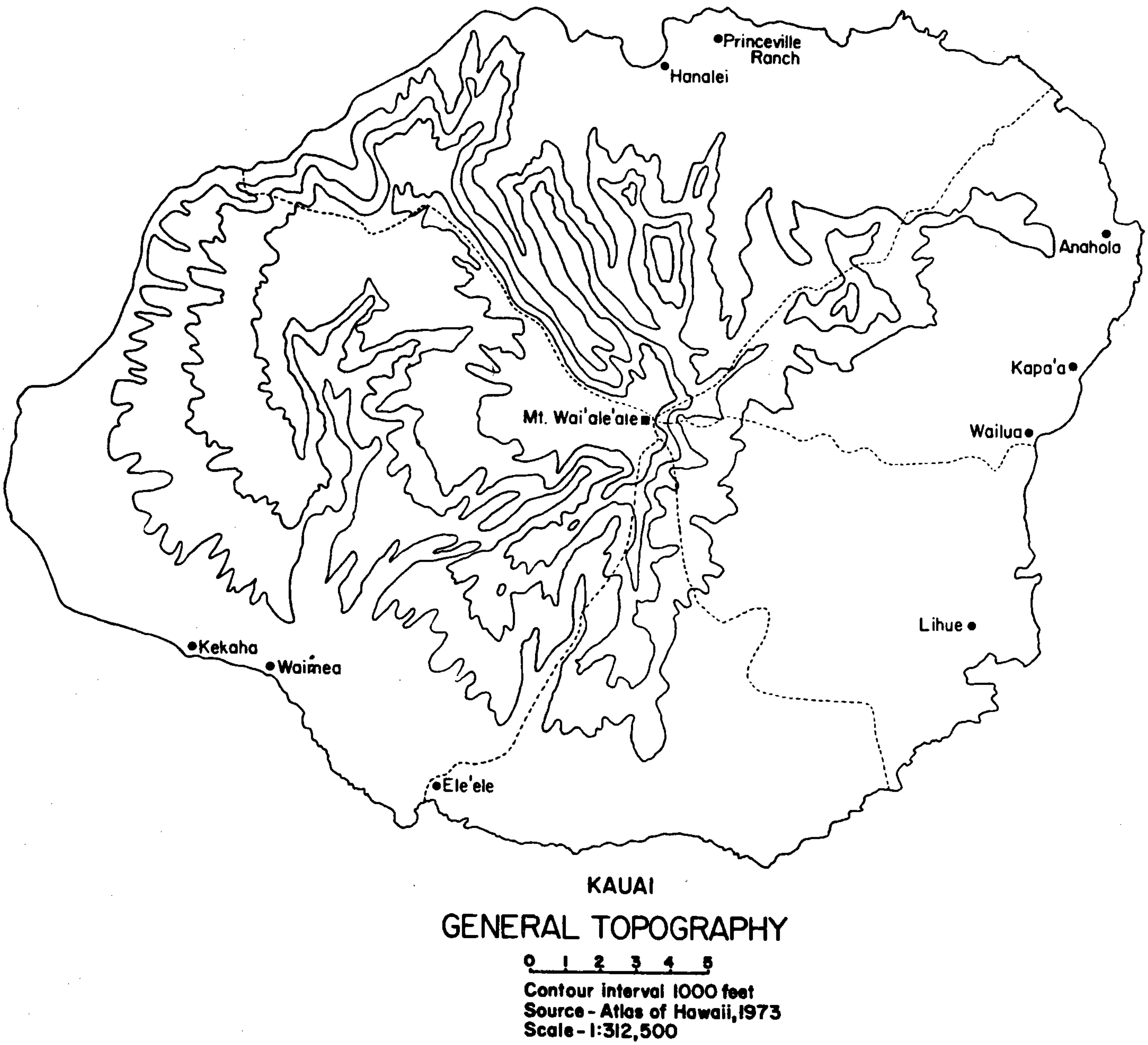


Figure J-5 Kauai General Topography