ESTIMATED WATER USE IN 1990, ISLAND OF KAUAI, HAWAII

By Patricia J. Shade

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CONTENTS

FIGURES

TABLES

Conversion factors and abbreviation

Multiply	By	To obtain
acre	4,047	square meter
foot (ft)	0.3048	meter
gallon (gal)	3.785	liter
gallon per day (gal/d)	3.785	liter per day
gallon per acre per day [(gal/acre)/d]	0.8593	liter per square meter per day
million gallons (Mgal)	3,785	cubic meter
million gallons per day (Mgal/d)	0.04381	cubic meter per second
million gallons per year (Mgal/yr)	3,785	cubic meters per year
inch (in.)	25.4	millimeter
inch per year (in/yr)	2.54	centimeter per year
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
ton	0.9072	megagram
cubic yard (yd^3)	0.7646	cubic meter

Abbreviation used:
Units of power are given in gigawatthours (GWh)

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Abstract

The estimated total quantity of freshwater withdrawn on the island of Kauai, Hawaii, in 1990 was 370.84 million gallons per day of which 46.29 million gallons per day (12 percent) was from ground-water sources, and 324.55 million gallons per day (88 percent) was from surface-water sources. An additional estimated 40.94 million gallons per day of saline water was withdrawn for thermoelectric power generation. Agricultural irrigation was the principal use, accounting for 66 percent of the total freshwater withdrawals. Irrigation accounted for about 40 percent of the fresh ground-water withdrawals, followed by public supply, thermoelectric power generation, self-supplied domestic, self-supplied commercial, and self-supplied industrial withdrawals. Agricultural irrigation accounted for 69 percent of the total fresh surface-water withdrawals, followed by hydroelectric power generation, self-supplied industrial, public-supply and self-supplied livestock withdrawals.

A comparison of water-use data for 1980 and 1990 shows total freshwater uses decreased during 1990 by slightly more than 100 million gallons per day because of decreased withdrawals for sugarcane irrigation and processing. During this time, increased domestic, commercial, and thermoelectric power usage reflects increases in the resident population and in tourism on the island.

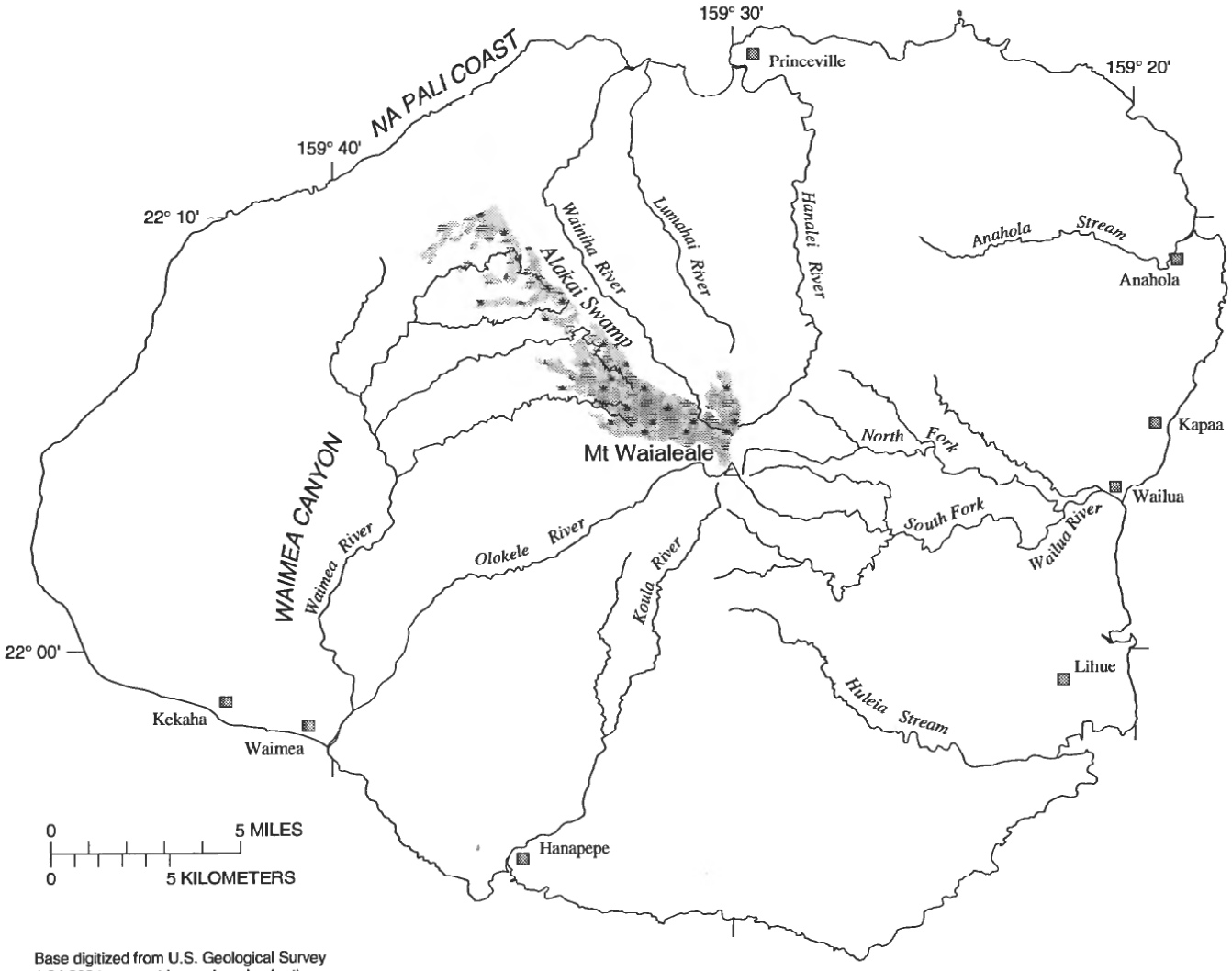
INTRODUCTION

Tremendous growth and change have occurred in the State of Hawaii since the 1960's. By 1990 the population had grown from about 634,000 in 1960 (State of Hawaii, 1967) to more than 1 million residents. Tourism has become one of the principal economic activities in the State. Agricultural companies have begun to decrease the amount of acreage planted in sugarcane, to diversify the type of crops grown, and to improve the methods of irrigation. Urban development has rapidly expanded on the island of Oahu, and residential and commercial development is increasing on the outer islands of Maui, Kauai, Molokai, and Lanai.

Coinciding with these changes is an increased demand and competition for water among all users and a need for governmental agencies to compile accurate, uniform, and timely water-use data for planning purposes. At the national level, the United States Congress, in 1977, recognized the need for water-use information and directed the U.S. Geological Survey to establish a National Water-Use Information Program (Solley and others, 1988). This program became a part of the U.S. Geological Survey's Federal-State Cooperative Program. This report is a product of that program between the U.S. Geological Survey and the Kauai County Department of Water.

PURPOSE AND SCOPE

The purpose of this report is to present 1990 water-use estimates for the island of Kauai, Hawaii. Estimates of water withdrawn from surface- and ground-water sources were made from data provided by the Kauai County Department of Water and the principal self-supplied users. These data were categorized by type of use including domestic, commercial, industrial, power generation, and agricultural as outlined by the National Water-Use Information Program. These data are presented on an island-wide basis and by aquifer-system areas that were delineated by the State of Hawaii for water-management purposes. A geographic information system (GIS) was used to disaggregate these water-use data by aquifer-system areas and to perform spatial analyses of agricultural data. Water-use estimates for 1980 and 1990 were compared to determine the effects from population growth, increased tourism, and changing agricultural practices.



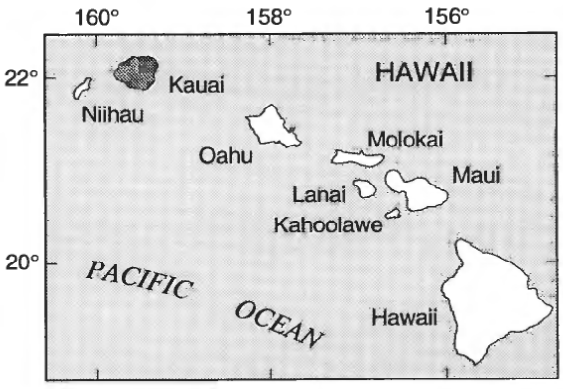


Figure 1. Hawaiian islands and island of Kauai.

ACKNOWLEDGMENTS

The author acknowledges the cooperation and assistance of personnel from the Kauai County Department of Water and Department of Public Works, the State of Hawaii Department of Land and Natural Resources, and the University of Hawaii. The cooperation of the principal water users in providing data is greatly appreciated.

STUDY AREA

The island of Kauai encompasses 553 mi^2 and is located at the northwest end of the chain of major Hawaiian islands (fig. 1). The topography is varied and ranges from spectacular sea cliffs and beaches along the Na Pali coast to mountain peaks higher than 5,000 ft in the interior of the island. The magnificent Waimea Canyon is in some places 2,600 ft deep, and the Alakai Swamp covers more than 10 mi^2. This varied and dramatic topography is the result of an equally extreme distribution of rainfall. Mean annual rainfall ranges from less than 30 in. along the coast near Kekaha to more than 400 in. at Mt. Waialeale (Giambelluca and others, 1986) (fig. 2).

Several perennial streams (fig. 1) flow from the summit area in the interior of the island to the shore. These streams supply substantial amounts of water for the generation of hydroelectric power and are the predominant sources of agricultural irrigation water.

ECONOMIC SETTING

Kauai is one of the more rural islands in the State of Hawaii and has a resident population that has increased from about 39,000 in 1980 to about 51,000 in 1990 (State of Hawaii, 1991a). The population centers (fig. 2) at Kekaha, Waimea, Hanapepe, Lihue, Wailua, and Kapaa are mostly along the coast where rainfall, topography, and temperatures are moderate and port facilities are available nearby.

There also are residential and resort developments at Princeville in a tropical setting on the north shore. Resorts are similarly located along the southeast and east coasts where beaches are plentiful and the climate is mild.

Tourism has more than doubled between 1980 and 1990, as represented by the average number of visitors per day present on the island, from about 7,300 in 1980 to 17,600 in 1990 (State of Hawaii, 1991b). Statewide data show that visitor expenditures more than tripled from 1980 to 1990 (State of Hawaii, 1991b), making tourism a major source of income for the islands.

Plantation agriculture is the other major economic activity on Kauai. Five companies have grown sugarcane on the island since the early 1900's. From 1980 to 1990 there was a decrease of almost 8,000 acres in cultivated sugarcane and a decrease in the value of total production of raw sugar and molasses of almost 50 million dollars (Hawaii Agricultural Reporting Service, 1981; Hawaii Agricultural Statistics Service, 1991). To increase efficiency, plantations have continued to shift from furrow- to drip-irrigation methods. Recently, one of the plantations started to diversify by replacing about 5,000 acres of sugarcane with lower-water-demand crops of coffee and macadamia nuts. The sugarcane processing mills are the major industry on the island and most of the power used on the plantations is generated at hydroelectric plants owned and operated by the plantations.

WATER USE

Water uses are defined as either offstream, instream, or miscellaneous (Solley and others, 1988, p. 8). Offstream use includes water that is withdrawn from ground-water sources or diverted from streams and conveyed to a place of use. Instream use is water that is essentially used on-site as for hydroelectric power generation. The miscellaneous-use category includes return flows to the environment from wastewater-treatment facilities and water that has been recycled from the use for which it was originally withdrawn to another use.

OFFSTREAM USE

PUBLIC SUPPLY

Water withdrawn by the Kauai County Department of Water and delivered to many users for domestic, commercial, agricultural, industrial, and thermoelectric purposes is considered public supply. Because pumpage was not adequately metered, the total 1990 withdrawal by the Department of Water was estimated as the average of the 1989–90 and 1990–91 fiscal year metered deliveries plus 15 percent as estimated unaccounted-for water (Gregg Fujikawa, Kauai County Department of Water, oral commun., 1991) due to conveyance losses, and public uses such as firefighting and street cleaning. The estimated total withdrawal by the Department of Water was 12.86 Mgal/d of which 12.54 Mgal/d was from ground-water sources and 0.32 Mgal/d was from a single surface-water source, Alexander Reservoir (fig. 3).

The total deliveries (withdrawals minus unaccounted-for water) made by the Department of

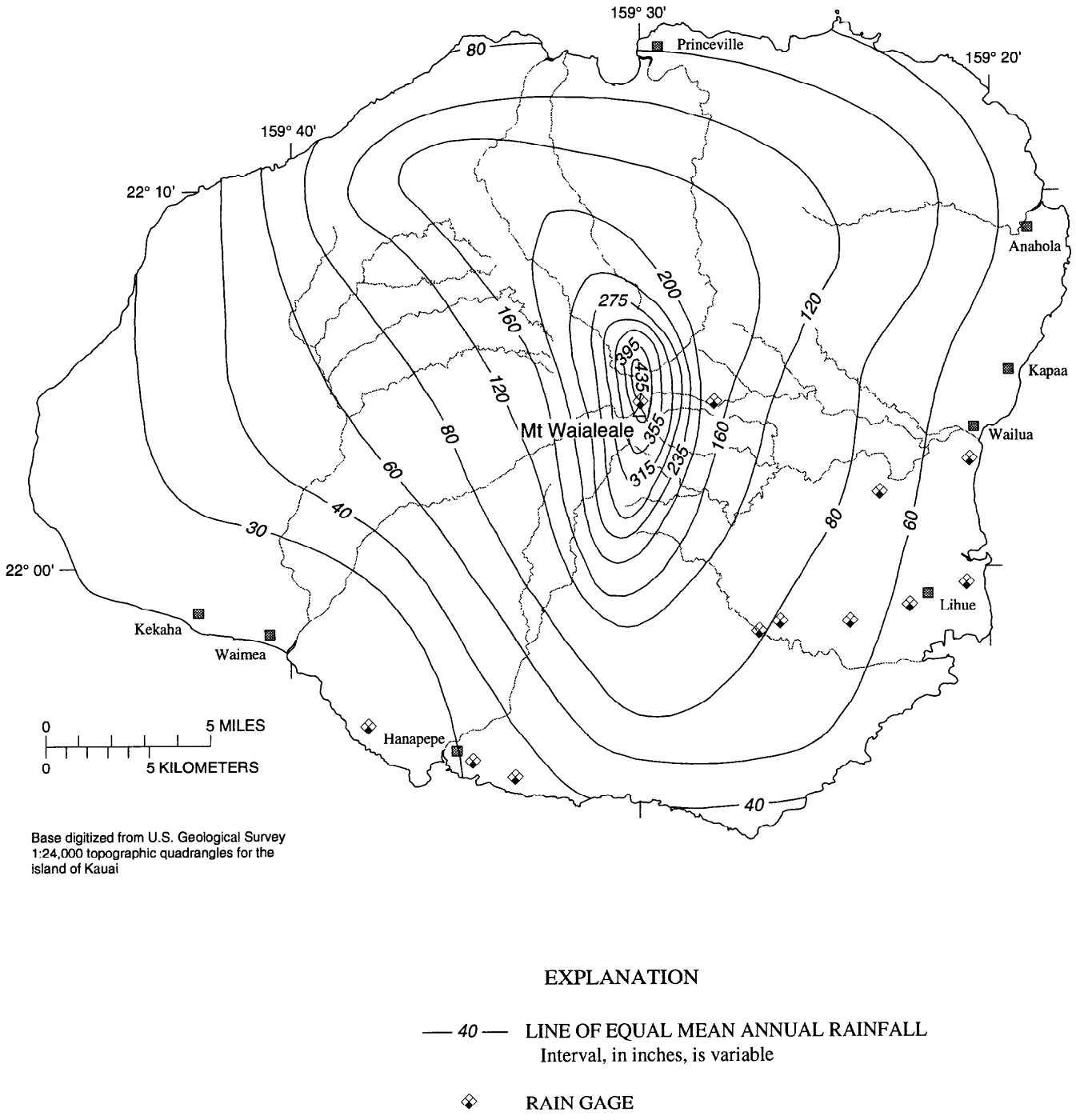
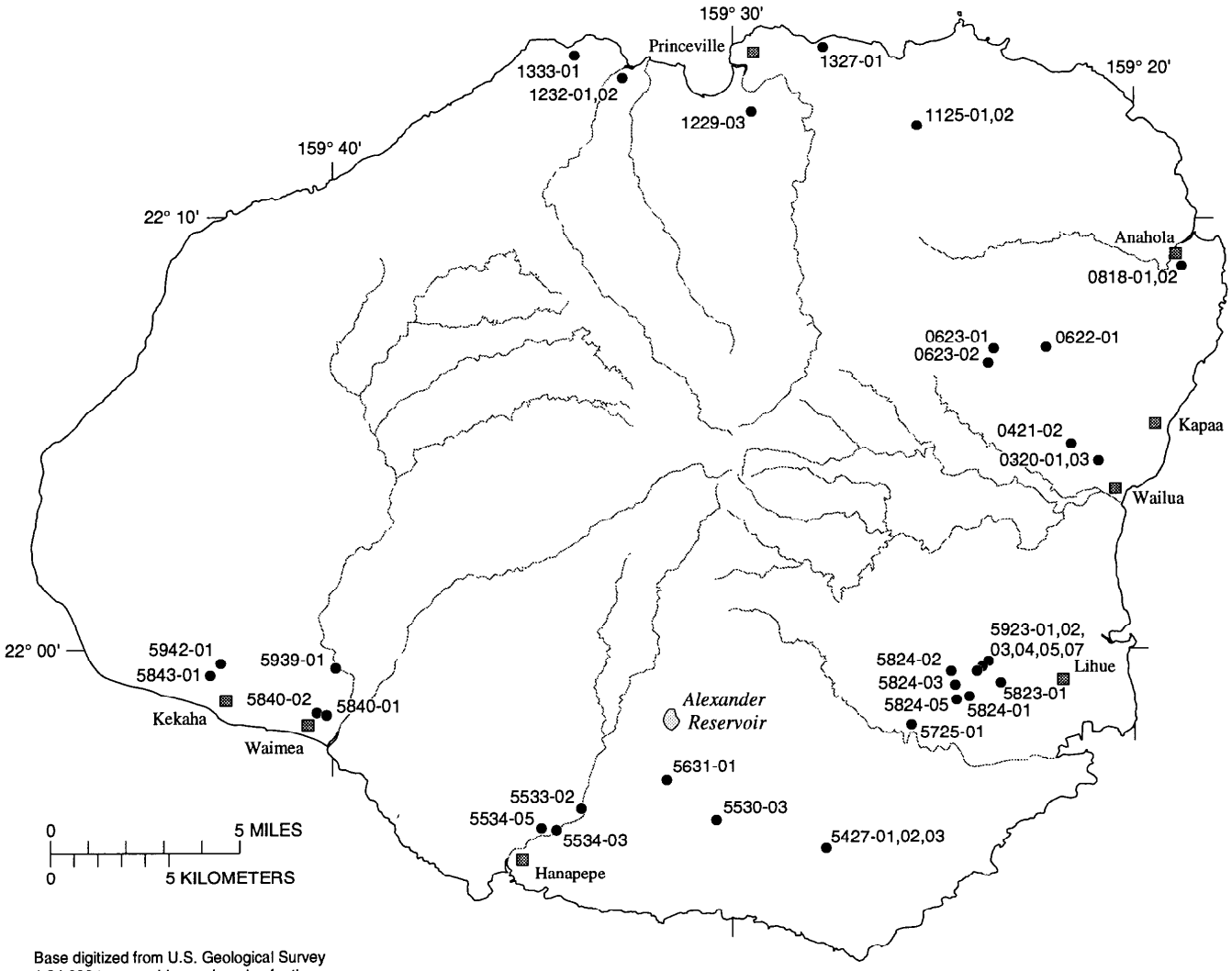


Figure 2. Mean annual rainfall, island of Kauai (modified from Giambelluca and others, 1986).

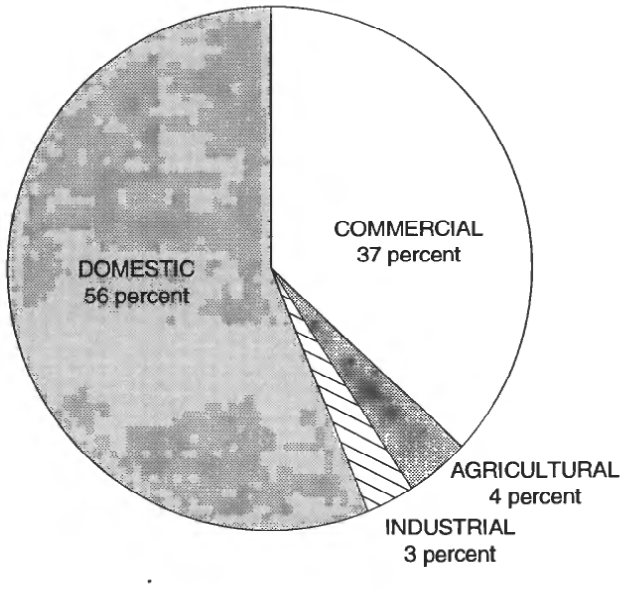


EXPLANATION

5843-01 ● KAUAI COUNTY DEPARTMENT OF WATER WELL AND NUMBER

Figure 3. Locations of public-supply wells and reservoir, island of Kauai, 1990.

Water for 1990, 11.18 Mgal/d, were calculated by averaging the deliveries reported in the 1989-90 and 1990-91 fiscal year metered delivery records. The deliveries were apportioned by water-use category using the sewer class codes listed in the records. Domestic deliveries were 56 percent of the total (6.23 Mgal/d), commercial deliveries were 37 percent (4.17 Mgal/d), agricultural deliveries were 4 percent (0.45 Mgal/d), industrial deliveries were 3 percent (0.33 Mgal/d), and thermoelectric deliveries were zero (fig. 4). Unaccounted-for water was estimated to be 1.68 Mgal/d (15 percent of deliveries); thus, estimated total withdrawals equaled 12.86 Mgal/d).



TOTAL: 11.18 million gallons per day

Figure 4. Percentages of public-supply water deliveries, island of Kauai, 1990.

DOMESTIC

The 1990 census data (State of Hawaii, 1991a) indicate a resident population of 50,947 on Kauai. The Department of Water supplied domestic water to about 90 percent of this total population, about 46,000 residents. Separate systems on the major plantations and at Princeville supplied most of the remaining 5,000 residents.

Domestic water use includes water used for drinking, washing clothes, bathing, food preparation, watering residential lawns, and flushing toilets. The Department of Water withdrew 7.16 Mgal/d, 6.84 from ground water and 0.32 from surface water, for domestic purposes on the island. Subtracting conveyance losses of 15 percent (Gregg Fujikawa, Kauai County Department of Water, oral commun., 1991), the domestic public-supplied water use was 6.23 Mgal/d, 0.27 Mgal/d from surface-water sources and 5.96 Mgal/d from ground water. There were self-supplied domestic users on the major plantations and in the Princeville development. The estimated self-supplied domestic withdrawals were from ground-water sources, and in 1990 were 2.77 Mgal/d on the plantations, 0.35 Mgal/d at Princeville (estimated as 30 percent of the total withdrawal, Gregg Fujikawa, Kauai County Department of Water, oral commun., 1991), and 0.01 Mgal/d for all other small self-supplied users on the island for a total of 3.13 Mgal/d. Subtracting 15 percent as an estimate of conveyance losses, the quantity of water used by self-supplied users for domestic purposes on the island in 1990 was estimated to be 2.66 Mgal/d. The total domestic usage for all users was 8.89 Mgal/d.

Using a resident population of 50,947, the per capita water use for domestic purposes was about 174 gal/d, of which 135 gal/d was for public-supplied users and more than 500 gal/d was for self-supplied users. The extreme value for self-supplied users indicates the possibility of error in the reported withdrawal data from the plantations. Most likely some water reported for domestic use was used for irrigation or other purposes. The public-supplied domestic per capita use of 135 gal/d is comparable to the use reported for several states in 1990 (Solley and others, 1993, p. 29), such as Arizona, California, Florida and Nevada, which had per capita public-supplied domestic uses of 150 gal/d, 147 gal/d, 111 gal/d, and 213 gal/d, respectively.

COMMERCIAL

Commercial water use includes water for hotels, office buildings, restaurants, government buildings, military installations, and other commercial activities. Allowing for 15 percent conveyance losses, the 1990 Department of Water commercial withdrawals were estimated to be 4.80 Mgal/d. The average of the Department of Water 1989–90 and 1990–91 delivery figures shows 37 percent of total deliveries, 4.17 Mgal/d, was for commercial purposes. Hotel use accounted for 2.07 Mgal/d, 50 percent of this commercial delivery. At the self-supplied Princeville development, it was estimated that 70 percent (Gregg Fujikawa, Kauai County Department of Water, oral commun., 1991) of the water withdrawn, or 0.83 Mgal/d, was for commercial activities, and allowing for 15 percent losses, 0.71 Mgal/d was used. The total

estimated commercial withdrawals on Kauai in 1990 were 5.63 Mgal/d from ground-water sources, and the total commercial use was 4.88 Mgal/d.

INDUSTRIAL

Industrial water use includes water for purposes such as processing, washing, and cooling. On Kauai, the major industrial process is the milling of sugarcane. Estimated industrial self-supplied withdrawals for 1990 were 0.03 Mgal/d from ground-water sources and 6.34 Mgal/d from surface-water sources. Applying a 15 percent conveyance loss, 5.41 Mgal/d was the estimated self-supplied industrial use. From the Department of Water delivery records, 0.38 Mgal/d was the estimated industrial withdrawal from ground-water sources, and 0.33 Mgal/d, or 3 percent of total Department of Water deliveries, were delivered to industrial users. The total industrial use was estimated to be 5.74 Mgal/d.

MINING

On Kauai, the only activities considered in the mining category are rock quarrying and concrete production. Water used in these operations is for washing, dust control, and in the production of concrete. Data from users on Kauai in this category were not available; however, estimates were made from information compiled from a ready-mix concrete operation on the island of Oahu. These data indicate that the water used in concrete production was 15 percent of the total water delivered to the facility from the public supply, and that 40 gal was required per cubic yard of concrete. The estimated quantity of concrete produced in 1990 on Kauai was 100,000 yd^3. Therefore, 4 Mgal/yr was used in concrete production, a quantity which is 15 percent of the estimated total water required at the facility. With the additional 85 percent, the estimated total water used in mining was about 27 Mgal/yr (0.07 Mgal/d).

LIVESTOCK

Livestock water use is a small part of Kauai's total water use that includes drinking water for animals and washing water for dairy cattle. Water used in slaughterhouse operations and egg washing are considered industrial and commercial uses, respectively. Livestock water use was estimated from statistics on the number of beef and dairy cattle, hogs, and chickens (Hawaii Agricultural Statistics Service, 1991) and from estimates by University of Hawaii animal science professors (B.A. Buckley, G.G. Gomez, C.N. Lee, and P.H. Patterson, University of Hawaii, oral communs., 1991) of the drinking-water requirements of these animals (table 1). The estimated total livestock use was 0.2 Mgal/d. Of this total, the estimated self-supplied livestock use in 1990 was 0.13 Mgal/d from surface-water sources. The Department of Water deliveries for livestock use were estimated from applications for lower-price agricultural water rates, about 10 percent of which indicated some livestock use. The estimated delivery for these users was 0.07 Mgal/d in 1990.

Table 1. Estimated livestock water use, island of Kauai, 1990

Livestock type	Number of animals	Water use (gallons per day per animal)
Dairy	850	80
Beef	11,150	10
Hogs	3,300	5
Poultry	42,400	0.055

IRRIGATION

Water used for irrigation includes water used by plantations for crop irrigation, small farm irrigation of fruits, vegetables, flowers, grains, and horticultural products, and golf course irrigation. Irrigation was the largest use of water on Kauai in 1990. Data sources included the Department of Water 1989–90 and 1990–91 metered delivery records, data from the plantations on the amount of surface- and ground-water withdrawals, plantation field maps that indicate location and size of cultivated areas, type of crop, and method of irrigation (figs. 5–9), cultivated acreage statistics from the Hawaiian Sugar Planters' Association (HSPA) printed in the 1990 agriculture report (Hawaii Agricultural Statistics Service, 1991), and private user withdrawals reported in the Kauai Water Use and Development Plan (R.M. Towill Corp., 1992).

The total ground-water withdrawals by the plantations for irrigation was estimated to be 16.62 Mgal/d of which 0.26 Mgal/d was sold to small farmers. Another 0.45 Mgal/d of ground water was estimated to be withdrawn for irrigation by the Department of Water. Estimated total ground-water withdrawals by self-supplied users other than the plantations, including small farms and resorts using water for hotel grounds and golf course irrigation, was 2.15 Mgal/d. The total ground-water withdrawal for irrigation was estimated to be 19.22 Mgal/d in 1990. Allowing for conveyance losses of 15 percent, the net estimated ground-water supplied irrigation water use was 16.34 Mgal/d.

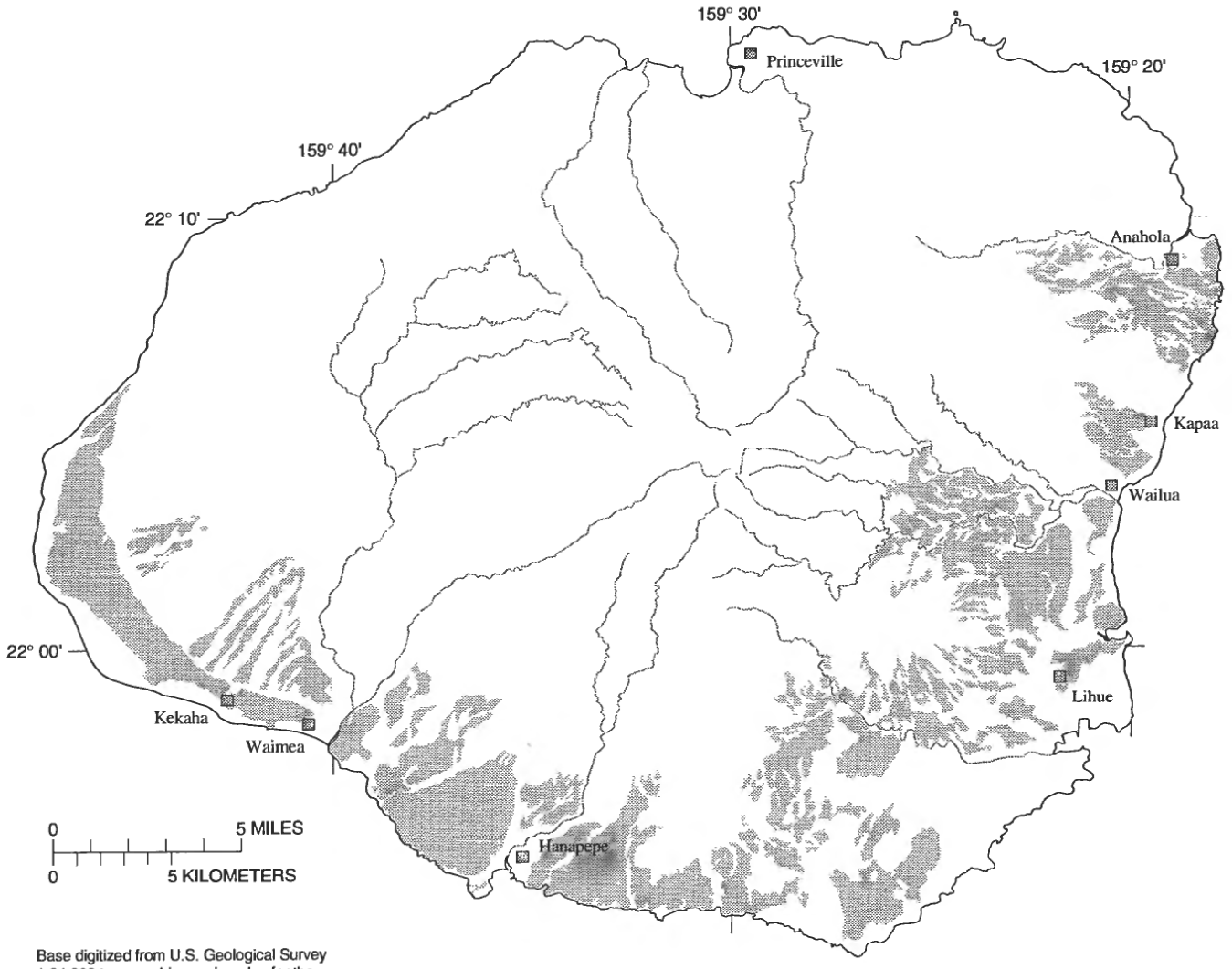


Figure 5. Areas of plantation agricultural fields, island of Kauai, 1990.

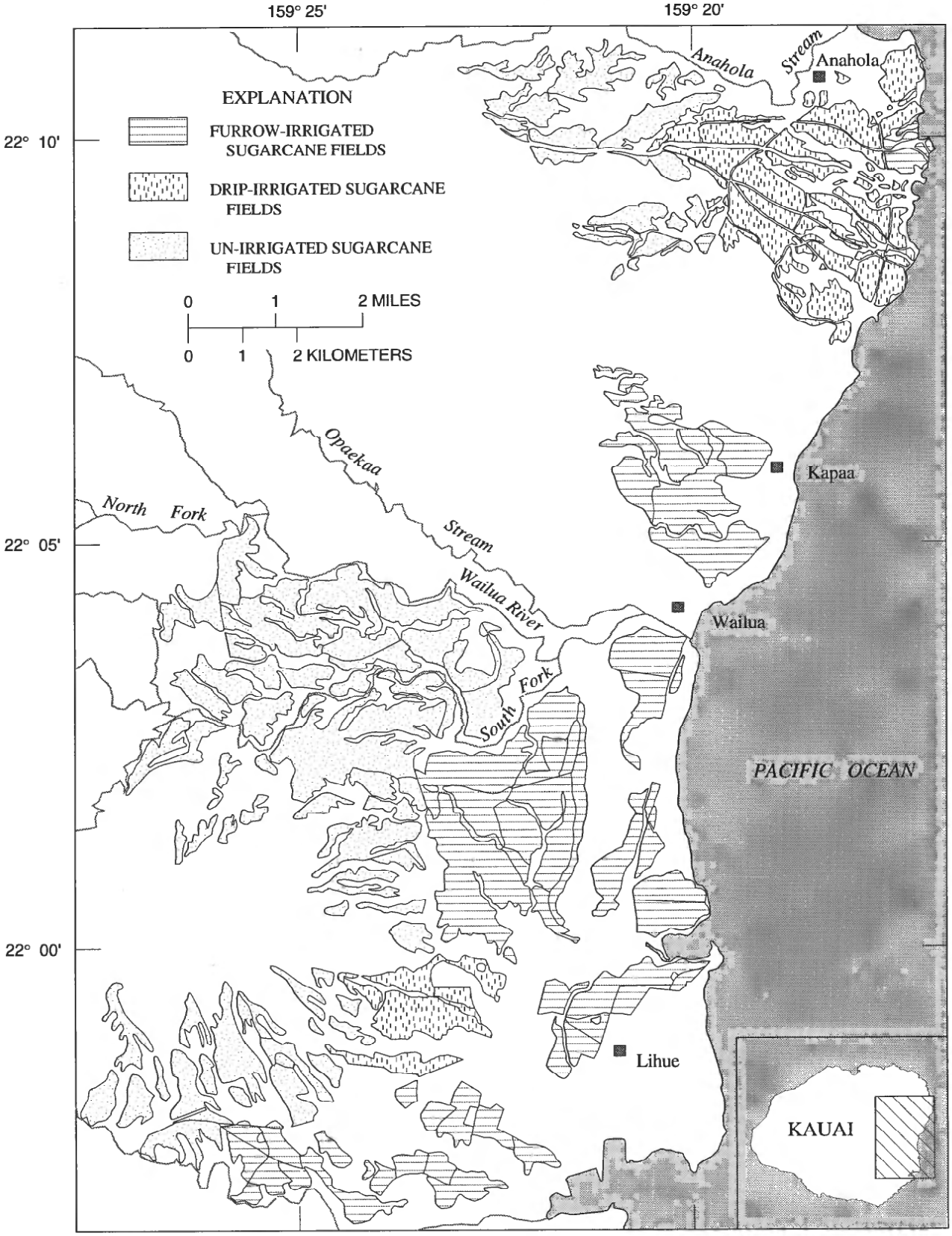
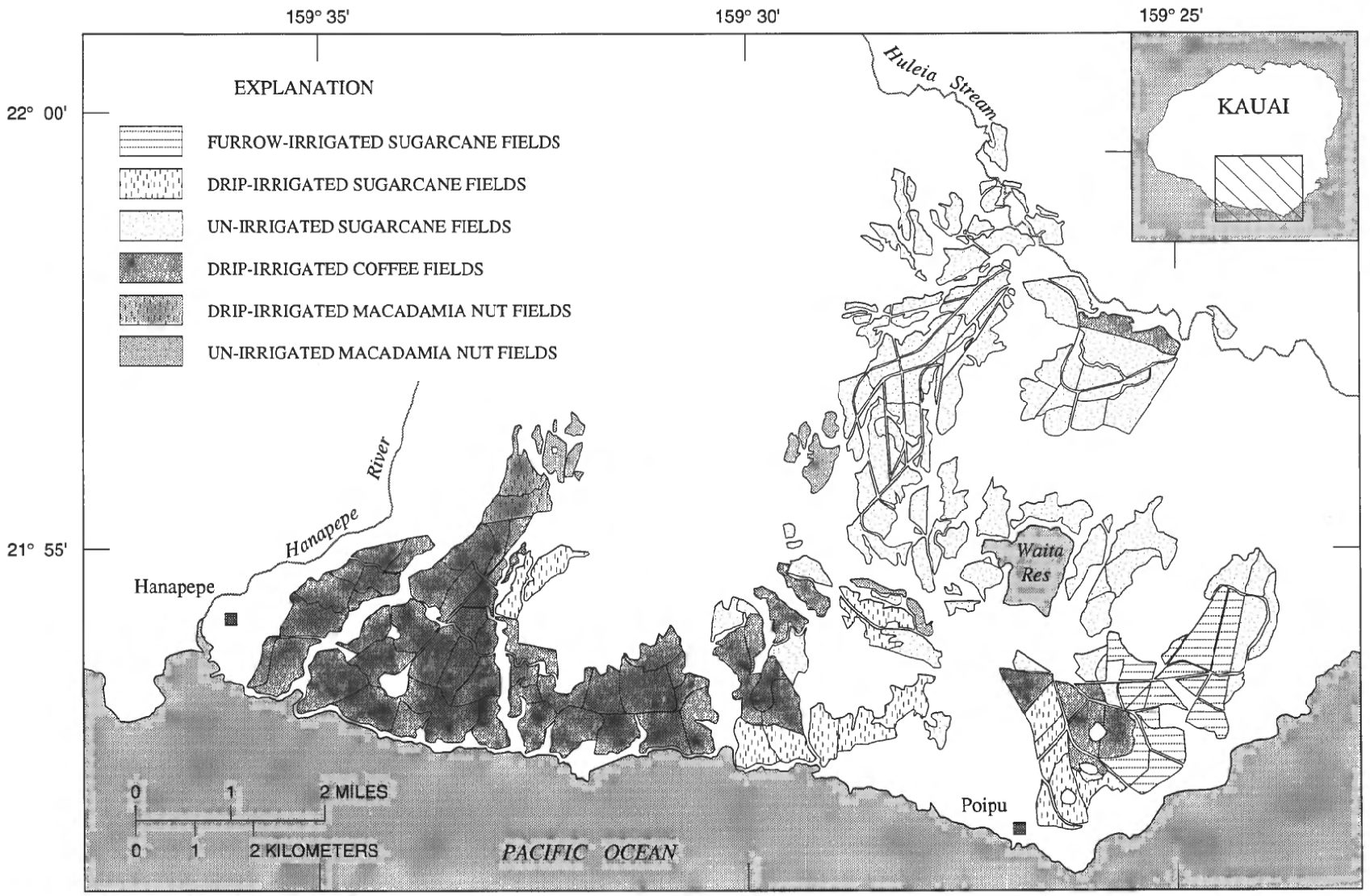


Figure 6. Types of agricultural fields and irrigation, eastern Kauai, 1990.



Base digitized from U.S. Geological Survey 1:24,000 topographic quadrangles for the island of Kauai

Figure 7. Types of agricultural fields and irrigation, southern Kauai, 1990.

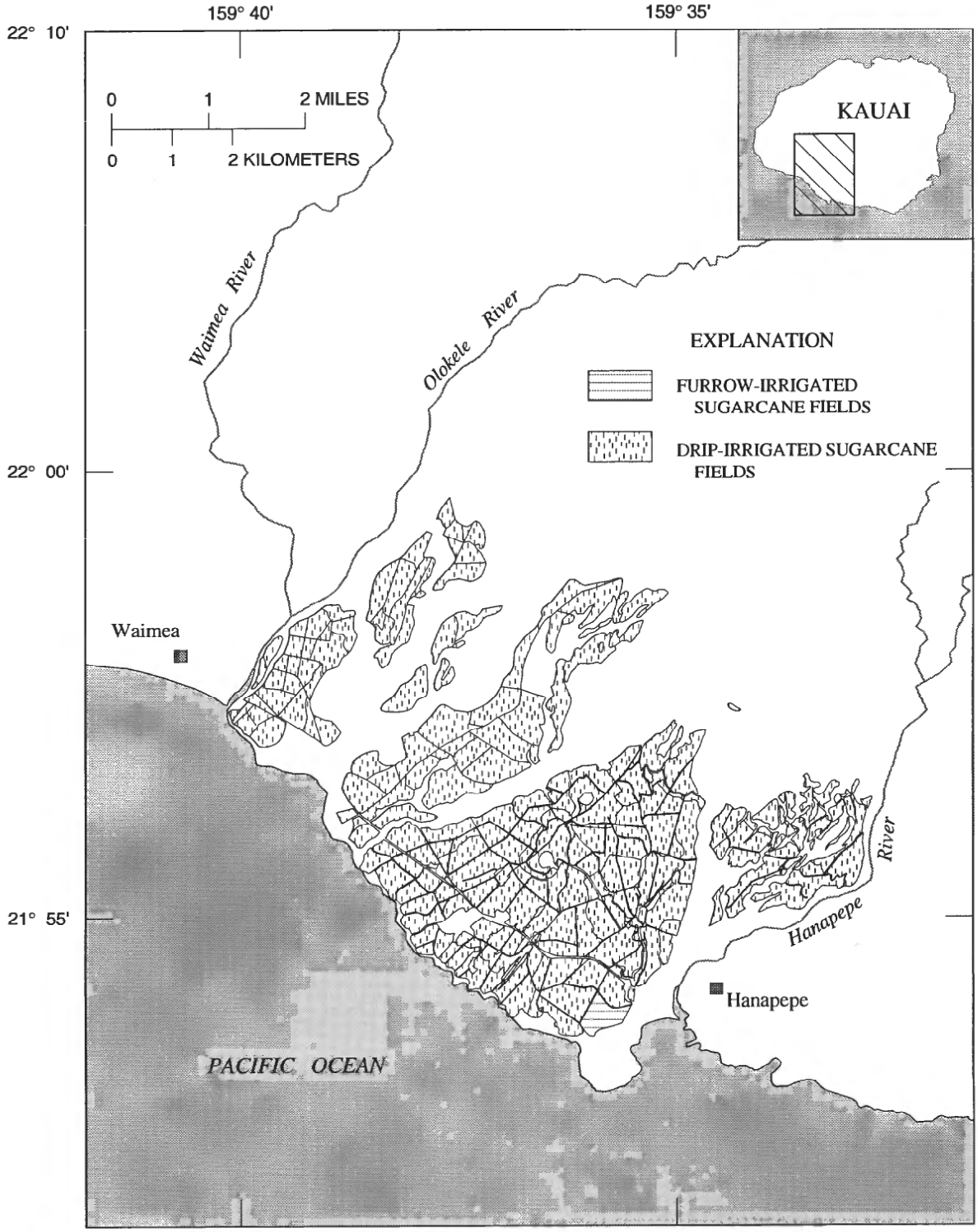


Figure 8. Types of agricultural fields and irrigation, southwestern Kauai, 1990.

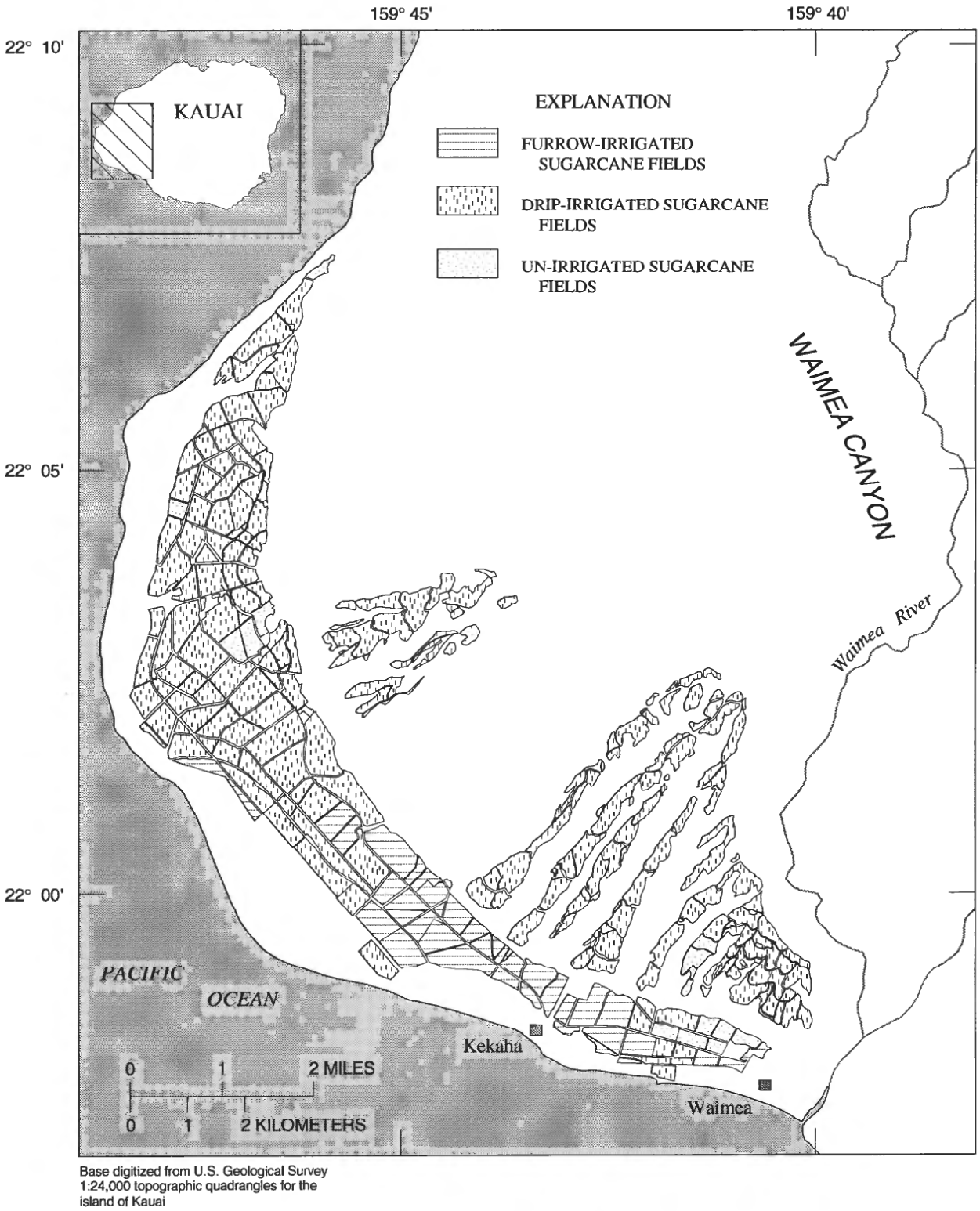


Figure 9. Types of agricultural fields and irrigation, western Kauai, 1990.

The total surface-water withdrawals by the plantations for irrigation was estimated to be 194.04 Mgal/d. Surface-water withdrawal data were provided by four of the five major plantations. Withdrawal estimates were generated for the fifth plantation by comparing withdrawal data from a neighboring plantation using similar irrigation methods to grow sugarcane. The analysis showed for a plantation irrigating 4,740 acres of sugarcane, using drip-application methods for 95 percent of the acreage, the withdrawal was about 8,685 (gal/acre)/d. Using this value, a withdrawal of 23.81 Mgal/d was estimated to irrigate 2,742 acres of drip-irrigated cane. The total surface-water withdrawals by other small self-supplied users was estimated to be about 30 Mgal/d (R.M. Towill Corp., 1992) for an unknown amount of acreage, although the area is probably at least 1,500 acres. Some of these smaller operations were growing taro, which requires a tremendous amount of water, an estimated 47,000 (gal/acre)/d (University of Hawaii Tropical Agriculture Experimental Station, K. Gooding, oral commun., 1992) for the wetland variety. The total surface-water withdrawals for irrigation were estimated to be 224.04 Mgal/d for 1990. Subtracting conveyance losses comparable to those estimated for the public-supply system of 15 percent, the estimated surface-water use was 190.43 Mgal/d.

Some differences exist regarding the amount of irrigated acreage. HSPA data for 1990 showed 19,264 acres of drip-irrigated sugarcane, 8,837 acres of furrow-irrigated sugarcane, and 10,019 acres of unirrigated sugarcane. These numbers included 4,337 acres that were fallow. Using a GIS and digitizing the field maps from the five plantations the following acreages were calculated in this study: 18,637 acres of drip-irrigated sugarcane; 9,414 acres of furrow-irrigated sugarcane; 12,229 acres of unirrigated sugarcane; 225 acres of drip-irrigated macadamia nuts; 318 acres of unirrigated macadamia nuts; and 5,008 acres of drip-irrigated coffee. The difference between the HSPA and GIS-calculated numbers is probably because some field maps did not represent 1990 plantings. However, because the difference in irrigated acreage estimated by GIS was only about 5 percent compared with the HSPA totals, the following analysis is valid for estimating plantation irrigation withdrawals.

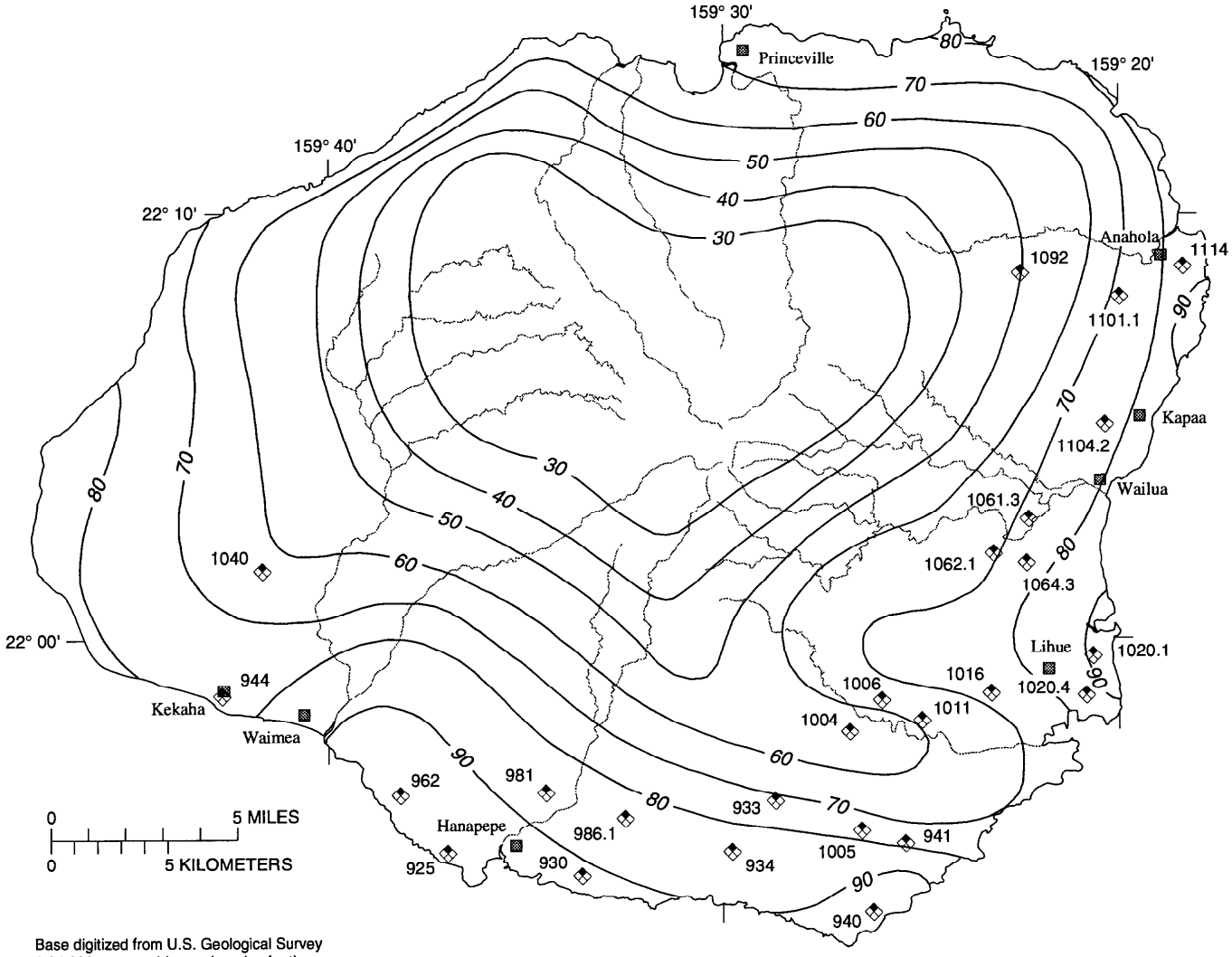
The probable irrigation requirements on plantations where only sugarcane was being cultivated can be estimated by using mean annual pan evaporation data (Ekern and Chang, 1985) (fig. 10) and a sugarcane irrigation application rate equal to a pan coefficient of 1.2 (Michael Furukawa, Vice President and Manager Lihue Plantation, Kauai, oral commun., 1992). This analysis showed calculated application amounts (column A) were within 16 percent of the withdrawal amounts reported by the plantations (column B) (table 2). Considering that unaccounted-for water such as conveyance losses, estimated at 15 percent throughout this study, needs to be subtracted from the amount of water withdrawn to represent the actual applied irrigation amount, this method of irrigation and withdrawal estimation seems to be an accurate technique.

Table 2. Estimated sugarcane irrigation requirements, island of Kauai, 1990

[GIS, geographic information system; HSPA, Hawaiian Sugar Planters' Association; pan, mean annual pan evaporation; Mgal/d, million gallons per day; (gal/acre)/d, gallons per acre per day]

Plantation	(A) Estimated need (pan × 1.2) (Mgal/d)	(B) 1990 withdrawal (Mgal/d)	1990 estimated irrigation (Mgal/d)	GIS area (acres)	HSPA area (acres)	Water use [(gal/acre)/d]
1	58.48	67.76	57.60	8,450	8,413	6,847
2	68.53	81.49	69.27	9,933	7,933	8,732
3	38.63	41.96	35.67	4,705	4,740	7,525
4	22.51	25.25	21.46	2,831	2,742	7,826

Note: The 1990 estimated irrigation values are determined by subtracting 15 percent from the withdrawal value as a representation of conveyance loss. The values for water use are determined as the estimated irrigation value divided by the HSPA area. No calculations were made for plantation 5 because withdrawal data were not available for comparison.



EXPLANATION

— 60 — LINE OF EQUAL MEAN ANNUAL PAN EVAPORATION--Interval 10 inches

981 PAN-EVAPORATION STATION AND NUMBER

Figure 10. Mean annual pan evaporation, island of Kauai (modified from Ekern and Chang, 1985).

THERMOELECTRIC POWER

The thermoelectric power category includes water used in the production of electricity generated from fossil fuels. The public utility company operates a thermoelectric plant at Port Allen near Hanapepe cooled by saline ground water. Using a ratio developed from pumpage data and power generated in 1985, an estimated 40.94 Mgal/d of saline ground water was withdrawn in 1990. The power produced from this plant was 251.83 GWh. A single fossil fuel power plant on one of the plantations used 10.98 Mgal/d from a ground-water source in 1990. The power produced at this plant was 19.89 GWh. Most of the other plantations have hydroelectric power plants which are discussed in this report as an instream use. The total thermoelectric power production in 1990 was 271.72 GWh.

INSTREAM USE—HYDROELECTRIC POWER GENERATION

Water used for hydroelectric power production is the only instream use accounted for in this report. From five hydroelectric power plants on the plantations, 47.12 GWh were produced from withdrawals of 93.72 Mgal/d. Of this total withdrawal, 28.4 Mgal/d was recycled to other uses on the plantations and the remainder, 65.32 Mgal/d, was discharged back into the streams.

The various methods used to account for withdrawals for hydroelectric power can lead to large differences when comparing various water-use studies. For example, a recent report (R.M. Towill Corp., 1992) shows a withdrawal and use of almost 54 Mgal/d for hydroelectric power generation at one of the plantations. Two hydroelectric-power plants are at that plantation, and at one plant all water is returned to the stream. Therefore, with no accounting for a return to the stream, there is no accounting for potential use downstream. This is an example of how applying a uniform water-use accounting method could result in consistent data for those making management decisions.

MISCELLANEOUS USE

WASTEWATER TREATMENT

The final element in the water-use cycle of withdrawals, deliveries, and consumption is the return of water to the environment either as discharge to streams, the ocean, or underground by use of injection wells. Attempting to calculate the quantity of irrigation water recharging the ground-water sources or the quantity infiltrating from individual septic systems was beyond the scope of this study. About 20 percent of the resident population was served by sewer systems in 1990. Water-quality considerations are becoming increasingly important, and quantifying releases of treated wastewater to surface- or ground-water sources is an important element in the resource management.

Data from wastewater treatment facilities also are useful for estimating consumptive use. For well-defined small systems such as resorts or military installations that have their own sewage treatment facilities and little infiltration of ground water into the sewers, estimates of consumptive use can be readily determined by subtracting the amount of inflow to the treatment plant from deliveries made to users.

Wastewater-discharge quantities and locations are important to know for health reasons and for potential recycled-water uses. In 1990, Kauai had two sites of release to surface water and one site of release to ground water by injection well (fig. 11). The major sewage-discharge site into the ocean was at Wailua where 0.66 Mgal/d was released at a depth of about 30 ft and about 680 ft offshore. On the basis of data provided by the three treatment facilities, the total surface-water releases in 1990 were estimated to be 0.68 Mgal/d and ground-water releases 0.22 Mgal/d. In addition to these releases was 1.71 Mgal/d recycled to golf-course irrigation and sugarcane irrigation at one of the plantations.

RECYCLED WATER

An estimated total of 46.2 Mgal/d of water was recycled to various purposes on Kauai in 1990 (fig. 12). Of the water withdrawn for hydroelectric power generation, 28.4 Mgal/d was recycled on the plantations for use first in the sugar mills and then to irrigation, or directly from the power plant to the fields. The 10.68 Mgal/d of ground water withdrawn for thermoelectric power generation was recycled to the mill at one of the plantations and then to the fields. A total of 5.41 Mgal/d was used directly in the mills and then recycled to the fields. Thus, all the water discharged from the plantation sugar mills, about 28.71 Mgal/d, was recycled to irrigation. An additional 1.71 Mgal/d was recycled to plantation and golf course irrigation from three wastewater treatment plants. The total recycled water used for irrigation was 46.2 Mgal/d.

CONSUMPTIVE USE

Consumptive-use estimates were made for the domestic, commercial, industrial, thermoelectric power generation, and irrigation categories. Consumptive use

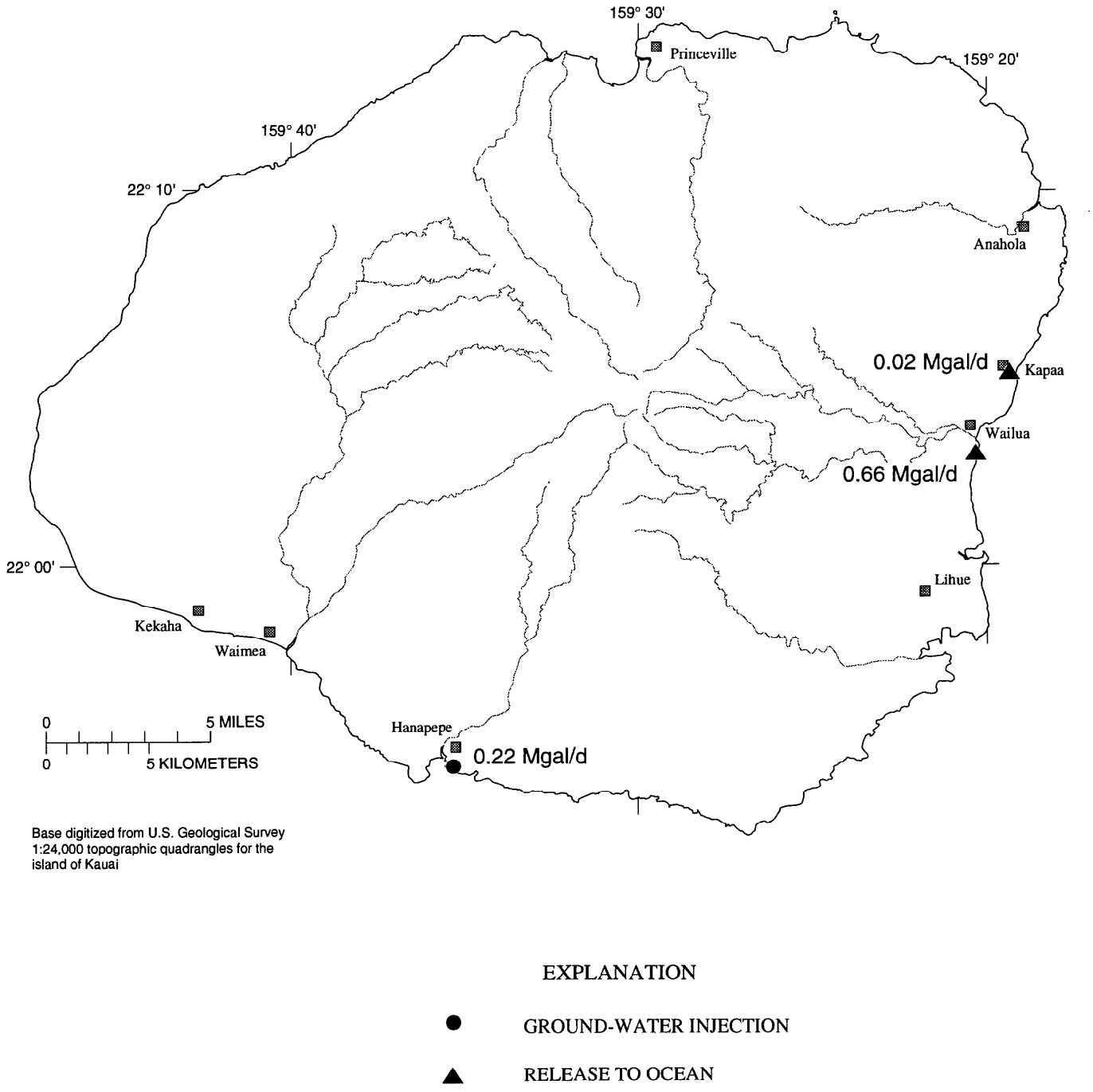


Figure 11. Locations of wastewater-discharge sites, island of Kauai, 1990.

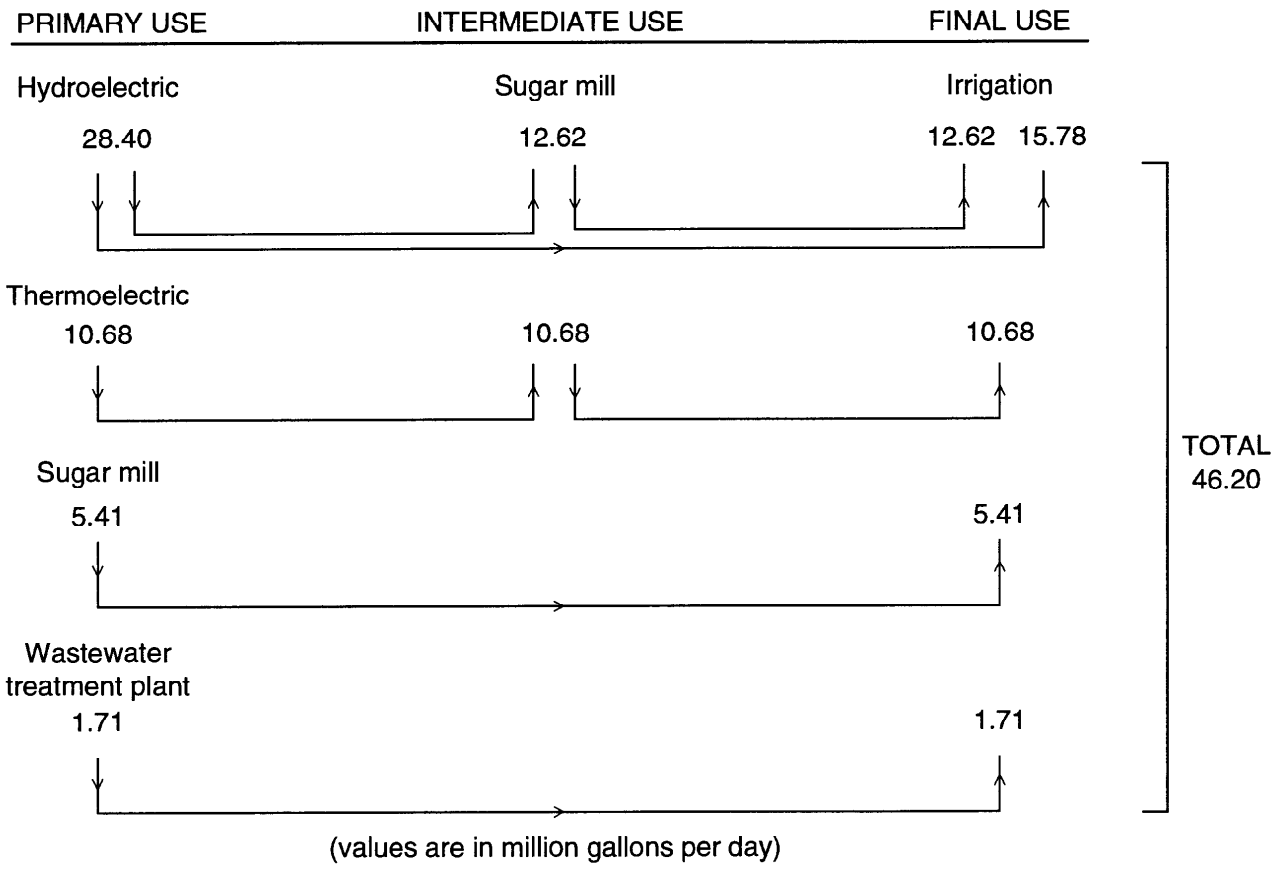


Figure 12. Diagram of recycled water, island of Kauai, 1990.

for the domestic category was estimated to be 50 percent (Ernest Lau, Honolulu Board of Water Supply, oral commun., 1991), which is 4.45 Mgal/d. This consumptive-use estimate was developed from data on deliveries to users and inflows to public sewage-treatment facilities on the island of Oahu. These data are more complete than data available for Kauai, and because the climate is similar and the majority of the populations on both islands are served by a public-supply system, the domestic consumptive-use factor was applied to Kauai's domestic-use data. The domestic consumptive-use factor of 50 percent is comparable to those reported in 1990 for other areas with warm climates such as Arizona (50 percent) and Puerto Rico (44 percent) (Solley and others, 1993, p. 29).

A commercial consumptive-use factor was estimated in two parts and was also estimated from more complete data available on the islands of Oahu and Hawaii. Water use at hotels accounted for 50 percent of the commercial use on Kauai. Few resorts in Hawaii maintain their own water supply and sewage-treatment facilities where data regarding water deliveries to users and inflows to sewage-treatment plants are available. However, at such a resort on the island of Hawaii, a hotel consumptive use was calculated to be 68 percent of the water delivered. This 68-percent factor was applied to the Department of Water hotel deliveries of 2.07 Mgal/d, and the commercial part of the Princeville water, 0.71 Mgal/d. Military installations are another use considered in the commercial category that sometimes maintain their own sewage treatment facilities, although not on Kauai. At a small military installation on Oahu that is publicly supplied and operates its own sewage-treatment plant, the consumptive use was 16 percent. The 16 percent factor was applied to all other Department of Water commercial deliveries on Kauai of 2.10 Mgal/d. The estimated total commercial consumptive use was 2.23 Mgal/d, 46 percent of the total commercial use. This value is similar to the commercial consumptive use reported for Arizona in 1990, 45 percent (Solley and others, 1993, p. 33).

Industrial consumptive use was a small fraction of the total industrial water use of 29.11 Mgal/d. Most of the water in this category, 28.71 Mgal/d, was used to wash sugarcane in the mills. Because harvested sugarcane has a high water content that is discharged in the processing of the cane, the net consumptive use in the mills probably was zero. For the remaining 0.40 Mgal/d used in other industrial activities such as cleaning of facilities, the consumptive use was estimated to be 10 percent, which accounted for about 0.04 Mgal/d, or less than 1 percent of the total industrial water use. The reported statewide industrial consumptive use was 4 percent in 1990 (Solley and others, 1993, p. 45).

The consumptive use of thermoelectric power generation was estimated at the public utility plant and at a single fossil-fuel power plant on a plantation. The public utility plant uses saline water in a "once-through" cooling process where plant personnel estimated that the consumptive use was essentially zero. At the plantation power plant water is used for cooling in a closed system. Consumptive use at this plant is the "makeup water" which is estimated to be 3 percent of the circulating water, 10.98 Mgal/d, (Central Electricity Generating Board, 1971), or 0.33 Mgal/d. The consumptive use for this category, 0.33 Mgal/d, is 1 percent of the total saline and freshwater used, 51.92 Mgal/d, and is comparable to the Statewide consumptive use factor reported for Hawaii and several other states in 1990 (Solley and others, 1993, p. 53).

An estimate of agricultural or irrigation consumptive use was made by using data on mean annual pan evaporation and irrigated acreage. Data given by Chang (1968) show that a reasonable estimate of the actual evapotranspiration rate (consumptive use) of sugarcane is the pan-evaporation rate, and that of coffee is about 50 percent of the pan-evaporation rate (P. Tausend, McBryde Sugar Company, oral commun., 1993). Most of the irrigated acreage was located where the mean annual pan evaporation is more than 60 in/yr (fig. 13). Using the total GIS area of irrigated sugarcane (25,919 acres) and of coffee (5,008 acres) and the appropriate pan-evaporation factor, the total consumptive use was estimated at 186.00 Mgal/d: 169.63 Mgal/d for sugarcane and 16.37 Mgal/d for coffee. If 15 percent of the estimated total ground- and surface-water withdrawals, 243.26 Mgal/d, is subtracted to account for conveyance losses, the remaining 206.77 Mgal/d plus recycled water of 46.20 Mgal/d totals 252.97 Mgal/d applied to the fields. The consumptive use of 186 Mgal/d represents 74 percent of the estimated applied irrigation water. This consumptive use factor is comparable to those reported for the State of Hawaii (83 percent) and other areas where sugarcane is cultivated and that have similar climates such as Alabama (76 percent), Florida (68 percent), and Puerto Rico (74 percent) (Solley and others, 1993, p. 37).

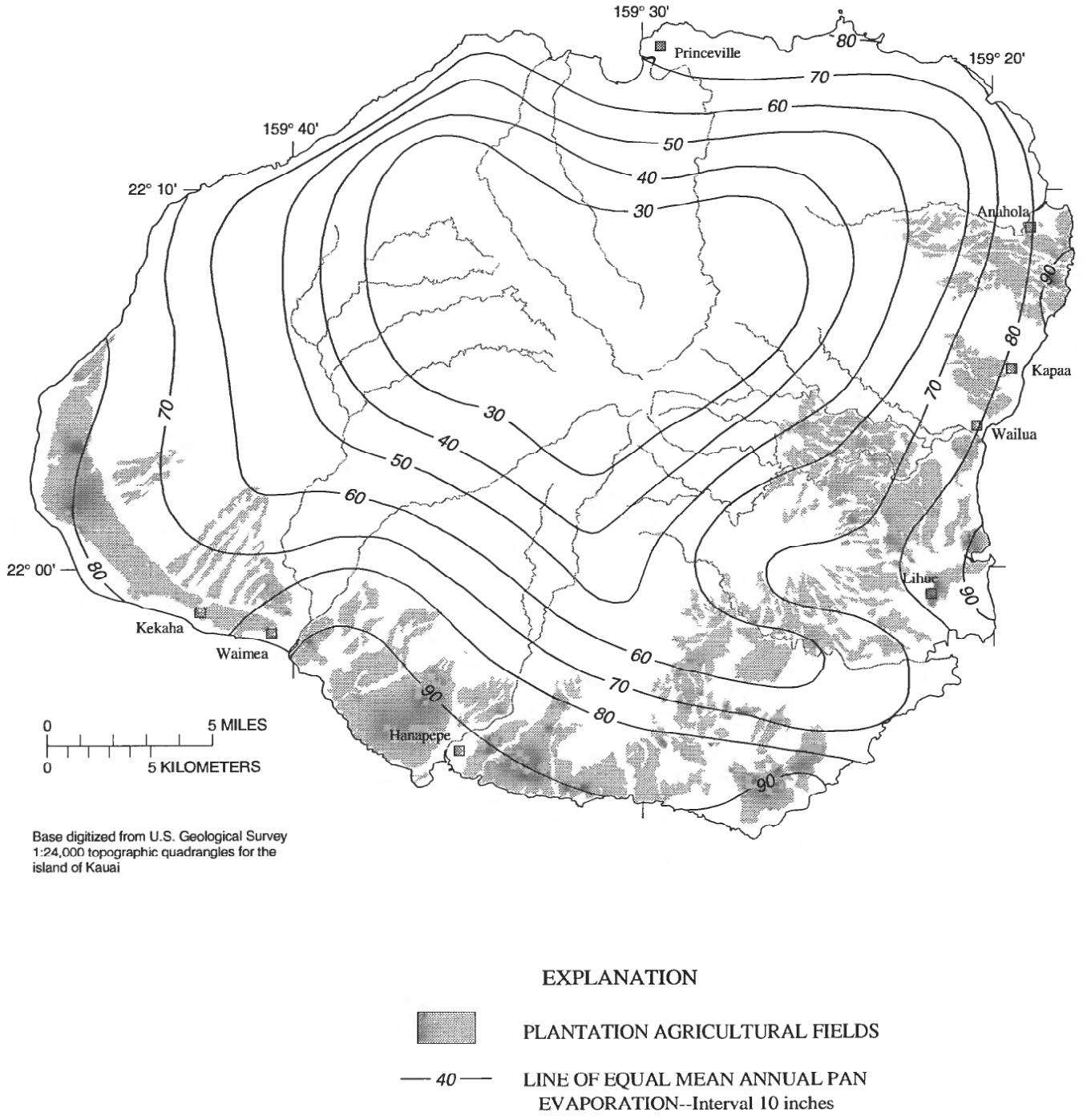
WATER WITHDRAWALS BY AQUIFER-SYSTEM AREA

Aquifer-system areas (fig. 14) were delineated by the State of Hawaii for resource-management purposes (George A.L. Yuen and Assoc., Inc., 1990). The island is divided into 13 aquifer systems numbered 20101–20105, 20201–20204, and 20301–20304. The withdrawals by aquifer systems and the transfer of water between systems (table 3) were estimated from data provided by the plantations, the Kauai County Department of Water, the State of Hawaii, the U.S. Geological Survey, and from data reported by R.M. Towill (1992). The withdrawal by aquifer system is useful information for resource allocation and planning.

Table 3 shows a total estimated ground-water withdrawal of 46.29 Mgal/d and a total estimated surface-water withdrawal of 324.55 Mgal/d for the island. Of the 324.55 Mgal/d withdrawn from surface-water sources, 93.72 Mgal/d was withdrawn for hydroelectric power generation, of which 65.32 Mgal/d was returned to streams (56.59 Mgal/d in 20203, 1.98 Mgal/d in 20103, and 6.75 Mgal/d in 20302).

COMPARISON OF WATER USE, 1980 AND 1990

Changes in water use during the 10 years from 1980 to 1990 reflect the increased resident population, increased tourism, increased demand for electricity, and changes in plantation agriculture, including decreased acreage in cultivated sugarcane and increased use of drip irrigation. Rainfall differences in these years do not appear to be a factor because data from two representative stations on the island indicate that 1980 was a fairly wet year and 1990 was an average year with several months showing only a slight departure from the median rainfall value (State of Hawaii, 1992). Values for the major water-use categories for 1980 (Nakahara, 1984) and 1990 are compared in table 4 and show a total decrease of more than 100 Mgal/d: about 39 Mgal/d of ground-water use and about 69 Mgal/d of surface-water use in 1990. Withdrawals refer to the quantity of water taken either from a stream or pumped from ground-water sources. Use refers to the quantity of water delivered to the point of use; that is, withdrawal minus conveyance losses.



EXPLANATION

PLANTATION AGRICULTURAL FIELDS

— 40 — LINE OF EQUAL MEAN ANNUAL PAN EVAPORATION--Interval 10 inches

Figure 13. Mean annual pan evaporation and plantation agricultural fields, island of Kauai, 1990.

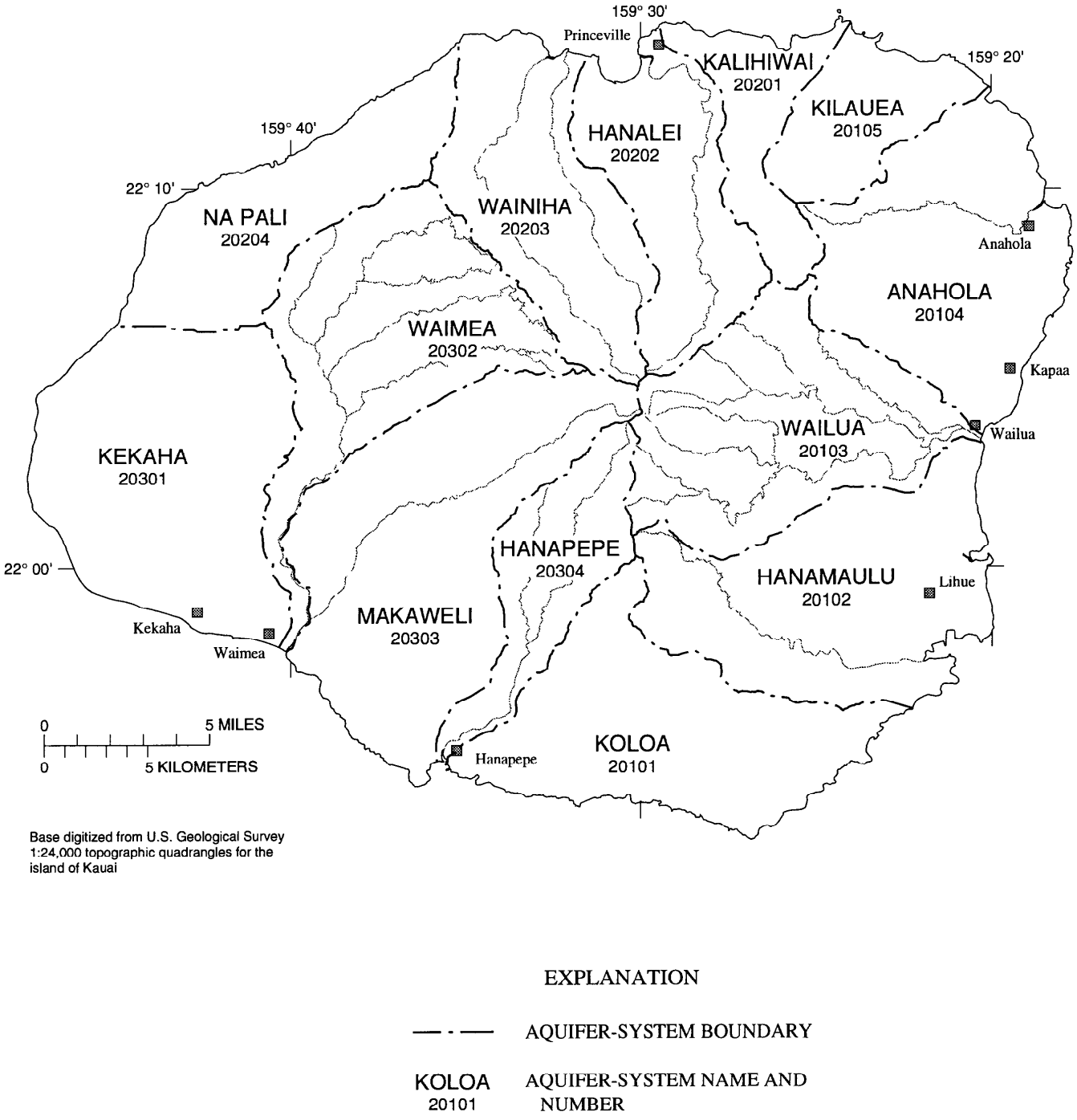


Figure 14. Aquifer-system areas, island of Kauai, 1990 (modified from George A. L. Yuen and Assoc., 1990).

Table 3. Water withdrawals by aquifer system, island of Kauai, 1990.

[Values are in million gallons per day; GW, ground water; SW, surface water; --, none. Aquifer-system names and numbers are from George A.L. Yuen and Associates, Inc., 1990.]

Aquifer-system name	Aquifer-system number	Amount withdrawn and used within area		Amount withdrawn in area for use elsewhere		Amount used in area from withdrawals elsewhere	
		GW	SW	GW	SW	GW	SW
Koloa	20101	9.64	18.70	--	--	--	16.43
Hanamaulu	20102	5.24	21.99	--	6.26	--	--
Wailua	20103	0.75	[a]38.07	--	9.20	0.24	--
Anahola	20104	2.73	19.41	0.24	--	--	9.20
Kilauea	20105	0.30	6.02	0.12	--	--	--
Kalihiwai	20201	1.22	--	--	--	0.12	--
Hanalei	20202	0.12	10.71	--	--	--	--
Wainiha	20203	0.10	[a]64.73	--	--	--	--
Na Pali	20204	--	--	--	--	--	--
Kekaha	20301	22.68	--	--	--	0.53	53.96
Waimea	20302	0.29	0.17	0.53	[a]53.96	--	--
Makaweli	20303	2.16	36.15	--	--	--	--
Hanapepe	20304	0.17	29.01	--	10.17	--	--
TOTAL		45.40	244.96	0.89	79.59	0.89	79.59

[a] Part of surface-water withdrawal was eventually returned to streams

The increase in domestic and commercial water use from 1980 to 1990 reflects the 31-percent increase in the resident population, from 38,856 in 1980 to 50,947 in 1990 (State of Hawaii, 1991a), and an increase in tourism and resort development. Apparent per capita domestic use increased from 152 gal/d in 1980 to 174 gal/d in 1990.

Because irrigation is the largest use of water on the island, changes in agricultural practices cause substantial changes in the water-use data and significantly affect the availability of water for other purposes. Diversifying cultivated crops from high-water-use sugarcane to include lower water-use crops such as coffee and macadamia nuts, and changing from furrow irrigation to drip irrigation caused the decrease in the agricultural water use from 340.22 Mgal/d in 1980 to 252.97 Mgal/d in 1990. Total sugarcane acreage, irrigated and unirrigated, decreased from 46,000 acres in 1980 to 38,100 acres in 1990 (Hawaii Agricultural Statistics Service, 1991). Drip-irrigated acreage increased from 16,077 in 1980 to 19,264 in 1990 and furrow-irrigated acreage decreased from 18,108 in 1980 to 8,837 in 1990.

The decrease of about 5 Mgal/d, or 15 percent, in the industrial use since 1980 is most likely due to a decrease in sugarcane processing, the principal industrial activity on the island. From 1980 to 1990 there was a decrease of almost 300,000 tons of unprocessed sugarcane, about 16 percent (Hawaii Agricultural Reporting Service, 1981 and Hawaii Agricultural Statistics Service, 1991).

The increase in thermoelectric water use reflects the increased demands of a larger resident and tourist population in 1990. Power production by Kauai Electric increased by 37 percent from 1980 to 1990. The decrease in hydroelectric use in 1990 can be explained by a decreasing demand for power on the plantations where the hydroelectric power plants are located because of the decrease in sugar production and processing.

The values shown in table 4 are estimates, and as such, assumptions have been made and in some cases, relationships derived, that are not absolutely accurate. Therefore, although there are reasonable explanations for the differences that are indicated by these data, it is clear that uniform, consistent approaches to compiling and analyzing water-use data are needed for valid analyses and results.

Table 4. Estimated water use, island of Kauai, 1980 and 1990

[Values are in million gallons per day. 1980 use from Nakahara, 1984]

	1980 use	1990 withdrawal	1990 use
DOMESTIC			
ground water	5.44	9.97	8.62
surface water	0.46	0.32	0.27
total	5.90	10.29	8.89
COMMERCIAL			
ground water	4.81	5.63	4.88
INDUSTRIAL			
ground water	17.76	0.49	0.42
surface water	11.48	6.34	5.39
recycled water	5.11	23.30	23.30
total	34.35	30.13	29.11
AGRICULTURE			
ground water	45.49	19.22	16.34
surface water	240.52	224.17	190.54
recycled water	54.21	46.20	46.20
total	340.22	289.59	253.08
THERMOELECTRIC			
ground water	5.16	10.98	9.33
surface water	5.93	0.00	0.00
saline water	10.79	40.94	40.94
total	21.88	51.92	50.27
HYDROELECTRIC	100.38	93.72	93.72
TOTALS			
ground water	78.66	46.29	39.59
surface water	358.77	324.55	289.92
saline water	10.79	40.94	40.94
recycled water	59.32	46.20	46.20

Note: The recycled water listed under industrial and agriculture includes water that was recycled more than once. To avoid double accounting, the total amount of water recycled is 46.20 Mgal/d (million gallons per day), see figure 12. Of the water withdrawn for hydroelectric power generation, 93.72 Mgal/d, 65.32 Mgal/d was returned directly to the streams and ditches available for other uses. The values in the use column, where different from withdrawal values, account for conveyance losses. The industrial category includes mining and the agriculture category includes livestock.

SUMMARY AND CONCLUSIONS

The estimated total freshwater withdrawal for the island of Kauai in 1990 was 370.84 Mgal/d of which 46.29 Mgal/d was from ground-water sources and 324.55 Mgal/d was from surface-water sources. Of this total, 65.32 Mgal/d withdrawn for hydroelectric power generation was released back into the streams for potential use downstream. An additional 40.94 Mgal/d of saline water was withdrawn for cooling purposes at a thermoelectric power plant. An estimated total of 46.20 Mgal/d was recycled to various uses such as for sugarcane processing in the plantation mills, and for agricultural and golf-course irrigation.

The sum of plantation withdrawals for domestic, industrial, irrigation, and hydroelectric power generation uses is about 324 Mgal/d of freshwater in 1990, about 87 percent of the total island withdrawal. Of this 324 Mgal/d, 79 percent, about 257 Mgal/d, was used directly or recycled for irrigation of more than 33,000 acres of sugarcane, coffee, and macadamia nuts. Because the plantations are the dominant users on the island, the changing practices on the plantations, including the diversification of crops from high water-use sugarcane to crops such as coffee and macadamia nuts that have a lower water demand, the reduction in sugarcane acreage, and the change from furrow to drip irrigation significantly affect the availability of water for other purposes.

A comparison of 1980 and 1990 total freshwater uses shows a decrease of more than 100 Mgal/d in 1990. Of this total, agriculture water-use data indicates a reduction of about 87 Mgal/d in 1990 after about 8,000 acres were taken out of sugarcane production, 5,000 acres were converted from sugarcane to coffee, and plantations continued to convert fields from furrow- to drip-irrigation methods. By using uniform methods for water-use accounting, the effects of these kinds of changes can be monitored, and comparisons of water use for the island between years can be analyzed.

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