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# UPDATE OF THE STATEWIDE GEOTHERMAL RESOURCE ASSESSMENT OF HAWAII

*for*

**THE STATE OF HAWAII**

**DEPARTMENT OF BUSINESS, ECONOMIC DEVELOPMENT AND TOURISM**

**Honolulu, Hawaii**

*by*

**GeothermEx, Inc.**
**Richmond, California**

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CONTENTS

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TELEPHONE: (510) 527-9876
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ILLUSTRATIONS

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# EXECUTIVE SUMMARY

The Department of Business, Economic Development and Tourism (DBEDT) has retained GeothermEx, Inc. (GeothermEx) to provide technical assistance to the Department of Land and Natural Resources (DLNR) in the preparation of a county-by-county assessment of areas with geothermal resource potential in the State of Hawaii. DLNR has issued two previous statewide assessments of geothermal resources, in 1984 and 1992. The current report updates the statewide assessment of geothermal resources based on information that has become publicly available since the 1992 assessment.

The State of Hawaii has a policy of increasing the use of renewable and alternative energy resources and of decreasing the State's dependence on imported fossil fuels. The Board of Land and Natural Resources (BLNR) is charged with the responsibility of designating Geothermal Resource Subzones within which geothermal development can take place to help meet the State's energy objectives. The current report is primarily intended to provide information on the potential for geothermal production, which is one of the considerations that the BLNR must take into account in subzone designations. The report also discusses other planning considerations that have changed since 1992, including the State's Hawaii Energy Strategy (HES) program, forecasts of demand for electrical generation capacity, the possibility of direct use of geothermal resources, and the environmental impact of geothermal development.

There has been little exploration for new geothermal resources since the 1992 assessment. The most significant development has been the start-up of the Puna Geothermal Venture (PGV) plant in 1993 and its continued steady operation since then. Some new geophysical and geochemical data have been gathered in geothermal resource areas, but most recent publications have focused on integrating and summarizing earlier

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data. The present assessment leaves unchanged most of the estimated probabilities for occurrence of high- and low-temperature resources, with the following exceptions:

- the probability of a low-temperature resource in the Lihue area of Kauai has been increased from <5% to <15%, based on warm temperatures recently encountered in ground-water monitor wells;
- the probabilities for high- and low-temperature resources in the area of West Molokai have been raised to <10% and <45%, respectively, based on new information about warm ground-water temperatures (these probabilities were previously both <5%);
- the probability of a low-temperature resource in the Palawai area of Lanai has been increased from <5% to <50%, based on new information about ground-water temperatures;
- the probability of a low-temperature resource in the Lahaina area of Maui has been increased from <5% to <15%, for consistency with estimated probabilities with other areas of comparable ground-water temperatures (Lihue and Waianae);
- the probability of a low-temperature resource in the Olowalu area of Maui has been decreased from <75% to <50%, to improve consistency with other areas of comparable ground-water temperatures.

The temperature criterion for low-temperature geothermal resources has been revised slightly, from 50–125°C to 65–125°C. This makes the lower temperature limit consistent with the State's legal definition of geothermal resources, which excludes warm ground waters having a temperature of 150°F (65.6°C) or less.

The present assessment recommends that the BLNR should retain existing Geothermal Resource Subzones in the Haleakala Southwest Rift Zone and in the Kilauea East Rift Zone, including the acreage in existing Geothermal Resource Mining Leases

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R-2, R-3, and S-4602. It is also recommended that future geothermal resource assessments should continue to consider the possibilities for direct use of geothermal resources, such as processing agricultural products, space heating, and providing hot water. DLNR should coordinate with the United States Geological Survey and with county water departments to ensure that temperature measurements and geochemical analyses are performed on any new ground-water well, particularly in the geothermal resource areas identified in this assessment.

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# 1. INTRODUCTION

The Department of Business, Economic Development and Tourism (DBEDT) has retained GeothermEx, Inc. (GeothermEx) to provide technical assistance to the Department of Land and Natural Resources (DLNR) in the preparation of a county-by-county assessment of areas with geothermal resource potential in the State of Hawaii. Section 205-5.2 of the Hawaii Revised Statutes (HRS) requires that such an assessment be updated at least once every five years, starting in 1988. DLNR has issued two previous statewide assessments of geothermal resources (Circular C-103): the first in September 1984 and the second in December 1992.

The current report updates the statewide assessment of geothermal resources based on information that has become publicly available since the 1992 edition of Circular C-103. Section 2 describes the policies and objectives of the State of Hawaii that have guided this update, and Section 3 discusses the criteria that GeothermEx has applied in assessing the potential of geothermal resource areas. Section 4 provides a county-by-county review of newly available data and of currently estimated probabilities for finding geothermal resources. Section 5 discusses the planning considerations and key issues involved in the designation of Geothermal Resource Subzones. Section 6 presents a set of recommendations to DLNR regarding existing subzone designations and actions that should be undertaken in preparation for future subzone updates. Section 7 provides a list of references that have been published since the preparation of the 1992 assessment, including selected earlier references that are cited in the text.

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## 2. STATE POLICIES AND OBJECTIVES

The State of Hawaii has a long-standing commitment to ensuring that the energy needs of its people are met. This commitment found expression in the enabling legislation for the Hawaii State Plan, Hawaii Revised Statutes (HRS), Chapter 226, first enacted in 1978, and amended by Act 96 of the Session Laws of Hawaii (SLH) in 1994. That legislation identifies three major energy objectives (HRS, Section 226-18(a)):

- dependable, efficient, and economical statewide energy systems capable of supporting the needs of the people;
- increased energy self-sufficiency where the ratio of indigenous to imported energy use is increased; and
- greater energy security in the face of threats to Hawaii's energy supplies and systems.

As part of its efforts to meet these objectives, the State enacted legislation relating specifically to geothermal energy. Act 296 (SLH 1983), as amended by Act 151 (SLH 1984), provides for the designation of Geothermal Resource Subzones within which geothermal development activities are allowed. Act 296 assigns to the Board of Land and Natural Resources (BLNR) responsibility for designation and administration of these subzones.

HRS, Section 205-5.1 provides that the BLNR may designate Geothermal Resource Subzones in any of the four land-use districts of the State (urban, rural, agricultural, or conservation). It defines geothermal development activities as "the exploration, development, or production of electrical energy from geothermal resources and direct use applications of geothermal resources." Section 205-5.1 further provides that direct use applications are permitted both inside and outside of Geothermal Resource

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Subzones within urban, rural, and agricultural districts, but within conservation districts direct use applications may only take place in Geothermal Resource Subzones.

HRS, Section 182-1 provides the legal definition of geothermal resources in Hawaii. This definition specifically excludes "naturally heated fluids… found below the surface of the earth, having a temperature of 150 degrees Fahrenheit or less, and not used for electrical power generation." Thus, natural, warm ground waters below 150°F (65.6°C) are not considered geothermal resources in Hawaii, and their use (other than for electrical generation) is not affected by the presence or absence of Geothermal Resource Subzones.

The BLNR has adopted administrative rules regarding the designation and regulation of Geothermal Resource Subzones. Title 13, Chapter 184 of the Hawaii Administrative Rules (HAR 13-184) describes three major objectives of Geothermal Resource Subzones as follows:

1. To allow geothermal development activities to help achieve the State's goal of energy self-sufficiency and to broaden the State's economic base through the development of a natural resource;
2. To allow geothermal development activities in areas where such activities would be of greater benefit to the State than the existing or future use of such areas; and
3. To allow geothermal development activities in areas which best demonstrate an acceptable balance among several criteria, including potential for geothermal production, prospects for geothermal utilization, geologic hazards, environmental and social impacts, compatibility with other land uses, and potential benefits to the counties involved and to the State as a whole.

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# 3. ASSESSMENT APPROACH AND CRITERIA

This assessment has been based on a review of the same types of data that were considered in the two earlier statewide assessments: ground-water temperatures, depth, ground elevation, permeability, geologic age, geochemistry, resistivity, infrared surveys, seismic data, magnetics, gravity, self-potential anomalies, and exploratory drilling. The relationship of each of these types of data to the potential presence of a geothermal resource has been discussed in the 1984 assessment and in a State publication entitled "Geothermal Resource Subzone Designations in Hawaii" (Department of Planning and Economic Development, 1986; subsequently referred to herein as the GRS Designation Report). That discussion is not repeated here. In addition, for the Kilauea East Rift Zone (KERZ), this assessment has taken into account the production performance of the Puna Geothermal Venture (PGV) power plant that has been producing electricity since 1993 (GeothermEx, 1994; Novak, 1995).

The current report continues the practice of the two earlier assessments in estimating probability ranges to describe the likelihood of finding geothermal resources in different areas. For all but two areas, the probability ranges are expressed as a maximum percentage. For example, a well drilled within a certain area of the Haleakala Southwest Rift Zone of Maui has a "25% or less" chance of encountering a geothermal resource. The two exceptions are the east and southwest rift zones of Kilauea, where the probability of encountering a geothermal resource is very high and is expressed as a minimum percentage (for example, greater than 90%). The likelihood of finding geothermal resources has inherent uncertainties due to variable subsurface conditions and limited data. The use of probability ranges does a better job of quantifying this uncertainty than more subjective verbal descriptions.

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The first statewide assessment (1984) assigned two sets of probabilities to the various geothermal resource areas of the State. The first set were probabilities of finding high-temperature resources (suitable for either electrical generation or direct use) that satisfied the following criteria:

- temperature > 125°C (> 257°F)
- depth < 3 kilometers (< 9,843 feet)
- ground elevation < 2,133 meters (7,000 feet)

The second set of probabilities were assigned based on the likelihood of finding low-temperature resources (suitable primarily for direct use) meeting the same criteria as above, except that the temperature range was 50–125°C (122–257°F). The second statewide assessment (1992) did not estimate probabilities of finding low-temperature resources, because "low temperature applications of geothermal heat do not require specialized permits and are not confined to geothermal resource subzones."

The current report reinstates the practice of estimating probabilities for both high- and low-temperature geothermal resources, for several reasons. First, direct uses of geothermal energy are potentially important in their own right and can contribute significantly to State's goal of energy self-sufficiency using indigenous resources. Second, areas with potential for low-temperature resources may also warrant additional investigations for high-temperature resources; the perception of an area as low-temperature may reflect a lack of data rather than the actual characteristics of the resource itself. In addition, as discussed in Section 2, even though HRS, Section 205-5.1 allows direct use irrespective of Geothermal Resource Subzones in urban, rural, and agricultural districts, designation of a Geothermal Resource Subzone is still necessary to allow direct use within conservation districts. Assigning probabilities for both high- and low-temperature resources applies a consistent approach to all four of the land use

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districts in the State, and allows for the possibility that the boundaries of these districts may change.

As discussed earlier, HRS, Section 182-1 has revised the definition of a geothermal resource to exclude naturally heated fluids that are 150°F (65.6°C) or less and that are not used for electrical generation. Therefore, the present assessment revises the temperature range for low-temperature resources from 50–125°C to 65–125°C. Because of the inherent uncertainty of such estimates (especially at the lower end of the temperature range), this revision would have had a negligible impact on the probabilities of low-temperature resources as expressed in the 1984 assessment. The revision makes the temperature criterion consistent with current law, and still allows comparison between the 1984 probabilities and the ones reported here.

The cut-off of 125°C between high- and low-temperature resources was based on an estimate of the lower temperature limit at which binary geothermal plants could generate electricity. This is still a reasonable estimate, and the cut-off of 125°C has been retained in the present assessment. The depth limit of 3 kilometers and the elevation limit of 7,000 feet were based on "limits of current drilling technology." The elevation limit appears to have been related to the depth that a well would need to achieve in order to reach basal ground water (roughly at sea level). Although deeper wells have been drilled in geothermal fields elsewhere in the world, the depth and elevation limits are still reasonable for Hawaii; deeper wells would be prohibitively expensive under current economic conditions.

The 1992 assessment discussed the importance of permeability as an additional factor in estimating the probability of finding high-temperature resources. However, no specific permeability ranges were assigned, and the authors of the 1992 assessment acknowledged that information about reservoir permeability was difficult to obtain. The

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present assessment continues the practice of taking reservoir permeability into account to the extent that such information is available.

For geothermal areas with at least a 25% chance of finding high-temperature resources, maps are presented with specific probability contours. As in earlier assessments, the percentage associated with each contour indicates the probability that any individual well within the contours will encounter temperatures of 125°C or above, at a depth of 3 kilometers or less.

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# 4. STATEWIDE RESOURCE ASSESSMENT

The probabilities of finding high- and low-temperature resources in the various geothermal areas of Hawaii are summarized in Table 1. The table includes the probability estimates from the two earlier assessments for purposes of comparison; changes from the earlier estimates are shown in boldface print. Figure 1 shows the location of geothermal resource areas throughout the State. The following sections discuss the rationale behind the current probability estimates on a county-by-county basis.

## 4.1 Kauai County

### 4.1.1 Lihue

The previous statewide assessments considered the island of Kauai as a whole, rather than focusing on a specific area. Figure 2 shows the inferred caldera boundary and rift axes of Kauai's volcano. Island-building volcanism on Kauai occurred 5.6–3.3 million years ago (mya), and post-erosional activity occurred 1.4–0.6 mya. Because of the relatively advanced geologic age of the island and an absence of significant data from geochemistry, geophysics, and exploratory drilling, both of the previous assessments assigned a low probability (<5%) of finding geothermal resources of any kind on Kauai.

In 1995 and 1996, the United States Geological Survey (USGS) drilled six ground-water monitor wells near the town of Lihue in cooperation with the County of Kauai, Department of Water. These wells ranged in depth from 800 to 1,150 feet. One well (the Northwest Kilohana monitor well) yielded ground water at an initial temperature of 34°C, though this temperature declined to 27°C during the course of a seven-day pump test (Gingerich and Izuka, 1997a). Three kilometers away, the Pukaki

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Reservoir monitor well yielded water that increased in temperature from 25°C to 27°C in the course of a four-day pump test (Izuka and Gingerich, 1997c). Three other wells yielded water with temperatures in the range of 24–26°C (Gingerich and Izuka, 1997b; Izuka and Gingerich, 1997a and 1997b). These temperatures are slightly elevated in comparison with deep ground-water temperatures in non-geothermal areas of the State (typically in the range of 17–22°C).

The ground-water temperatures in the vicinity of Lihue are comparable to ground-water temperatures measured in the Waianae area of Oahu. The 1984 assessment assigned a probability of "15% or less" for finding a low-temperature resource (50–125°C) at Waianae. By analogy, the present assessment assigns a probability of <15% for finding a low-temperature resource (65–125°C) in the Lihue area. No chemical analyses are available for the new ground-water monitor wells, and there are no new geophysical data for the area. The probability of finding a high-temperature resource in the Lihue area is estimated at <5%, the same as the probability estimated for the entire island of Kauai in the two earlier assessments.

## 4.2 City and County of Honolulu

The island of Oahu comprises two principal volcanic centers: Koolau and Waianae. Figure 3 shows the inferred caldera boundaries and the rift axes associated with these volcanoes.

### 4.2.1 Koolau

The 1984 assessment noted that temperatures of 30°C had been measured in two wells in the Koolau area (wells 2043-01 and 2042-05) and that post-erosional volcanism had occurred as recently as 30,000 years ago. However, there has been little indication of

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geothermal potential in the limited geochemical and geophysical data for this area, and no significant new data has become available since the earlier assessments. Therefore, the probabilities for high- and low-temperature resources in the Koolau area remain unchanged at <5% and <10%, respectively.

#### 4.2.2 Waianae

Two water wells on the federal naval reservation near Waianae (wells 2508-02 and 2808-01) have shown temperatures in the range of 27–29°C. Thomas (1986) has delineated three clusters of wells with temperatures of 25°C or above, spanning an area about 10 kilometers across, both inside and outside of the reservation. There is somewhat more encouragement from geochemistry and resistivity surveys than at Koolau, but the data set is still limited, and no significant new data has become available since the previous assessments. The probabilities for high- and low-temperature resources at Waianae remain unchanged at <5% and <15%, respectively.

### 4.3 Maui County

Maui County consists of four principal islands: Maui, Molokai, Lanai, and Kahoolawe. Figure 4 shows the interpreted caldera and rift structures of the county, and it identifies the main geothermal resource areas.

#### 4.3.1 West Molokai

The 1984 assessment noted a reported temperature of 30–33°C in one water well at West Molokai (well 1011-01), but this temperature could not be confirmed because the well had collapsed. Based on the relatively advanced age of volcanism on Molokai (about 1.8 mya for West Molokai, 1.5–1.3 mya for East Molokai) and a general lack of

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significant data, the 1984 assessment estimated a probability of <5% for both high- and low-temperature resources anywhere on the island (West and East Molokai combined). The 1992 assessment deferred making any probability estimate for Molokai pending evaluation of recent water well data and a reported electromagnetic (EM) resistivity survey by Blackhawk.

In 1991, Alpha U.S.A., Inc., drilled five water wells in West Molokai to depths of approximately 400 feet. Three of these (wells 0715-01, 0715-02, and 0815-01) encountered temperatures of 34–36°C over a distance of about 1 kilometer (DLNR completion reports, 1991). The temperatures in these warm wells are comparable to those measured in the Kawaihae area on the island of Hawaii. The salinity of the warm wells at West Molokai was relatively high (8,000–14,300 parts per million based on 24-hour pump tests), but no more detailed analysis of the water chemistry is available. The Blackhawk EM survey for West Molokai was not published and was not available during the preparation of the present assessment. No more recent geochemical, geophysical or drilling data for West Molokai are known. By analogy to Kawaihae, the probabilities of finding high- and low-temperature geothermal resources at West Molokai are estimated at <10% and <45%, respectively. There are insufficient data to make a separate assessment of the probabilities for East Molokai at the present time.

#### 4.3.2 Palawai

Three water wells on the island of Lanai (wells 4854-01, 4555-01, and 4552-01) have encountered temperatures in the range of 35-40°C. The first two of these are in the Palawai Basin and were drilled to about 1,450 feet. The third is south of the basin, near the southern coast of Lanai, and is 621 feet deep. The wells show some chemical evidence of geothermal heating (elevated values of chloride and magnesium in well 4854-01; elevated values of silica and chloride/magnesium ratio in well 4552-01). The wells were originally drilled in 1989 and 1990, and well 4555-01 was deepened in 1993. No new geophysical information is available for the Palawai area.

The 1984 assessment had estimated a low probability (<5%) of finding either high- or low-temperature resources on Lanai. Based on the results of the water wells drilled in 1989 and 1990, the 1992 assessment raised the probability for high-temperature resources in the Palawai Basin to <15%. The prospects for the Palawai area appear more favorable than for West Molokai: measured temperatures are higher, and more geochemical evidence is available. Therefore, the present assessment of the Palawai area retains the probability of <15% for high-temperature resource (versus <10% in West Molokai) and estimates a probability of <50% for low-temperature resource (versus <45% in West Molokai).

#### 4.3.3 Honolua

Although the Honolua area is near the northwest rift of the West Maui volcano, there are no known geochemical or geophysical anomalies, no warm water wells, and no deep exploratory wells. As in the earlier assessments, the probability of finding either high- or low-temperature geothermal resources in the Honolua area is considered to be low (<5%).

#### 4.3.4 Lahaina

One water well (5240-01) has a reported temperature of 27°C. Two other water wells (5340-01 and 5240-03) have reported temperatures of 25°C. The wells span a north-south distance of about 2 kilometers, and all are quite shallow (less than 40 feet deep). The reported temperatures are comparable to those of Lihue and Waianae, and the geologic age is more recent than at these locations. Ground-water chemistry shows no

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evidence of geothermal heating (chloride/magnesium ratios range downward from typical values for seawater), but some anomalies exist in the trace concentrations of mercury and radon in the soil (comparable to the Olowalu area). The present assessment retains the estimated probability of <5% for high-temperature resources at Lahaina, but raises the estimated probability for low-temperature resources to <15%, for consistency with Lihue and Waianae.

#### 4.3.5 Olowalu

The Olowalu area encompasses both Olowalu and Ukumehame Canyons (this report follows the 1992 assessment in referring to the area by the single name). One water well north of Ukumehame Canyon (well 4835-01) has a reported temperature of 35°C at a depth of 44 feet, and ground water in a tunnel at the mouth of Ukumehame Canyon has a reported temperature of 33°C. Another water well north of Olowalu Canyon (well 4937-01) has a reported temperature of 25.6°C at a depth of 300 feet. These temperatures are comparable to those of West Molokai and Kawaihae.

Olowalu and Ukumehame Canyons are located on the southeast flank of the West Maui volcano, in a transitional area between an older southwest rift and a younger southeast rift. The area has numerous dikes, plugs, and vent structures. The 1984 assessment noted a resistivity survey that indicated a low-resistivity layer (possibly ground water at 90°C), located 80–200 meters below sea level. There were also minor anomalies in trace concentrations of mercury and radon in the soil. The high-temperature probability estimate of the 1984 assessment was left unmodified by the 1992 assessment, and there have since been no published geophysical studies or deep well drilling in the Olowalu area.

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The present assessment leaves the probability of a high-temperature resource at <15%, but decreases the probability of a low-temperature resource from <75% to <50%, based on the relatively low ground-water temperatures measured to date. The probability of a low-temperature resource is still considered somewhat higher than at West Molokai or Kawaihae, based on the strength of the resistivity results.

### 4.3.6 Haleakala Northwest Rift Zone

The northwest rift is the oldest of the three Haleakala rift zones on East Maui. The most recent volcanism is estimated to have been about 500,000 years ago. Ground-water temperatures in the area have not exceeded 24°C, and these appear to have been measured in perched water tables rather than in basal ground water. Earlier assessments have noted only a weak resistivity anomaly and some anomalies of radon and mercury as indicators of a possible geothermal resource. No new geothermal exploration work has been done in the Haleakala Northwest Rift area since the earlier assessments. The present assessment leaves unchanged the prior probability estimates for high- and low-temperature resources (<5% and <10%, respectively).

### 4.3.7 Haleakala East Rift Zone

The youngest lava in the east rift zone of Haleakala has been estimated to be between 400 and 10,000 years old. Aside from this evidence of recent volcanism, there is virtually no other information to prove or disprove the existence of geothermal resources in the area. Based solely on considerations of geologic age, the present assessment leaves unchanged the estimated probabilities of 25% or less for a high-temperature resource and 35% or less for a low-temperature resource.

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#### 4.3.8 Haleakala Southwest Rift Zone

The southwest rift zone of Haleakala has erupted within historic times, as recently as 1790. There are no known deep wells inside the rift zone, and wells outside the rift zone have shown no elevated temperatures or chemical evidence of geothermal heating. Controlled-source electromagnetic soundings have indicated regions of moderate to low resistivity (and possible subsurface temperatures in the range of 60–96°C) at depths of about 1 kilometer in the lower portions of the rift (Thomas, 1986). In 1984, the BLNR designated a Geothermal Resource Subzone consisting of 4,108 acres in the Haleakala Southwest Rift Zone (Figure 5).

Earlier assessments estimated the probabilities of finding geothermal resources in the Haleakala Southwest Rift Zone based primarily on the recent age of volcanic activity, and taking into account the results of resistivity surveys. In the absence of any more recent geothermal exploration data, the present assessment retains the probability estimate of 25% or less for a low-temperature resource and 35% or less for a high-temperature resource.

### 4.4 Hawaii County

The island of Hawaii comprises five principal volcanic centers: Kohala, Hualalai, Mauna Kea, Mauna Loa, and Kilauea. Figure 6 shows the interpreted calderas and rift axes on the island, and it identifies the main geothermal resource areas.

#### 4.4.1 Kohala

The Kohala Mountains in the far northwest represent the oldest volcanic center on the island of Hawaii. The principal island-building activity at Kohala was about 300,000

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years ago, and the most recent post-erosional activity was about 60,000 years ago. The 1984 assessment noted that resistivity and magnetic data gave no positive indications of geothermal resource. No other significant geophysical, geochemical, or deep drilling data are known to exist, and there are no known warm wells in the area. The present assessment retains the earlier probability estimates, based principally on geologic age: <5% for a high-temperature resource and <10% for a low-temperature resource.

#### 4.4.2 Kawaihae

The area east of the coastal town of Kawaihae is at the junction of lava flows from the Kohala and Mauna Kea volcanoes. The area is not located on a rift zone. The most recent volcanic activity was a post-erosional cinder cone (Puu Loa), which formed on the southwest flank of Kohala volcano about 80,000 years ago.

Wells in the area have encountered warm ground water within a range of about 8 kilometers from the coast, at ground level elevations up to about 1,200 feet, and depths ranging up to 1,500 feet. The 1984 assessment noted several wells with ground-water temperatures in the range of 26–31°C, including at least one well (6147-01) with an elevated chloride/magnesium ratio. More recent drilling has encountered a temperature of 36°C in one well and temperatures around 32°C in several others (Nance, pers. comm., 1999).

No new geochemical or geophysical data has become available since the 1992 assessment. The water well temperatures in Kawaihae are comparable to those in West Molokai and Olowalu. The probability of finding geothermal resource is considered lower than at Olowalu, because resistivity surveys at Kawaihae have not given positive indications. The present assessment retains the earlier probability estimates for high- and low-temperature resources of <10% and <45%, respectively.

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#### 4.4.3 Mauna Kea East Rift Zone

Mauna Kea formed about 200,000 years ago, with the most recent volcanic activity about 3,600 years ago. The 1984 assessment noted some seismic swarms and deep seismic activity in the East Rift Zone. No other geophysical data is available for the East Rift Zone, and no deep wells have been drilled in the area. Shallow wells at the east coast show no elevated temperatures. The present assessment retains the probability estimates of the earlier assessments, which were based primarily on geologic age: <10% for a high-temperature resource and <30% for a low-temperature resource.

#### 4.4.4 Mauna Kea Northwest Rift Zone

The Northwest Rift Zone includes one deep well at Waikii (well 5239-01) that reached a temperature of 40°C at 4,240 feet. No other deep drilling is known to have taken place in the area, nor are any significant geochemical or geophysical data available. Based on an absence of any new information, the present assessment retains the probability estimates of the earlier assessments, which were again based primarily on geologic age, as well as the temperature of the Waikii well: <20% for a high-temperature resource and <50% for a low-temperature resource.

#### 4.4.5 Mauna Loa Northeast Rift Zone

Mauna Loa is considered currently active in the upper portion of its Northeast Rift Zone. In the middle portion of the rift (between elevations of 4,500 and 6,000 feet), volcanic activity as recent as 800 years old has been documented at a vent near Kulani prison. No volcanic activity has occurred in historic time in the lower portion of the rift (below 4,500 feet).

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In 1995, the USGS drilled a ground-water monitor well in the lower portion of the Mauna Loa Northeast Rift in cooperation with the Hawaii County Department of Water Supply (Ewart, 1998b). The well (8-3207-04) was located near the town of Mountain View at an elevation of 1,687 feet, and it was drilled to a depth of 1,155 feet. It encountered a maximum temperature of 19°C (DLNR completion report, 1996). This is consistent with the temperature range of 19–20°C measured in shallower wells in the lower portion of the rift (Thomas, 1986), and it confirms that the presence of even a low-temperature geothermal resource in the lower rift is unlikely.

The 1984 assessment noted a high concentration of seismic activity in the upper and middle portions of the Mauna Loa Northeast Rift, and there were clear magnetic and self-potential anomalies in the upper rift. Gravity data and ground-water geochemistry showed no significant anomalies. No additional geophysical or geochemical data were available in the preparation of the present assessment. The upper portion of the rift is considered to be above the cut-off elevation of 7,000 feet. The earlier assessments focused on the middle portion of the rift and defined contours of 25% and 35% probability for finding a high-temperature resource (figure 6), based primarily on geologic age and evidence of seismic activity. The present assessment makes no changes in the probability contours for a high-temperature resource, and retains the 1984 estimate of 60% or less for the probability of a low-temperature resource.

### 4.4.6 Mauna Loa Southwest Rift Zone

The upper portion of the southwest rift of Mauna Loa has erupted as recently as 1950, and an 1868 eruption took place in the middle portion of the rift at an elevation of approximately 3000 feet (Thomas, 1986). There is a concentration of seismic activity in the upper rift above 10,000 feet. As noted in the 1984 assessment, resistivity, infrared,

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magnetic, and gravity surveys have all yielded inconclusive results, and self-potential surveys have indicated a negatively polarized anomaly, rather than the positively polarized anomaly that would be expected for a geothermal resource. No geochemical data or drilling results are available above an elevation of about 2,000 feet.

The USGS, in cooperation with the Hawaii County Department of Water Supply, has recently drilled two ground-water monitor wells in the vicinity of the Mauna Loa Southwest Rift Zone: the Waiohinu exploratory well (8-0437-01) in 1994 and the South Point Tank exploratory well (8-0339-01) in 1997 (Ewart, 1998a and 1998c). The Waiohinu well was drilled about 4 kilometers east of the lower rift axis at an elevation of 1,300 feet, and it encountered ground water at a maximum temperature of 17.5°C (DLNR completion report, 1996). The South Point Tank well was drilled close to the axis of the lower rift at an elevation of 1,944 feet. It encountered ground water at a maximum temperature of 24°C (DLNR completion report, 1997). Both wells encountered water tables significantly above basal ground water, though the nature of the impounding structures was not known.

The earlier assessments have postulated an area with at least a 25% probability of a high-temperature resource within the middle portion of the Mauna Loa Southwest Rift Zone, roughly between the elevations of 2,000 and 7,000 feet (figure 6). Because the new USGS wells are both outside this area, they provide no direct evidence about the probabilities for geothermal resource within it. Definitive geothermal exploratory data within the estimated area of 25% probability are still lacking. Based primarily on the recent age of volcanism in the southwest rift, the present assessment leaves unchanged the 25% and 35% probability contours for a high-temperature resource, and it retains the 1984 estimate of 60% or less for the probability of a low-temperature resource.

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#### 4.4.7 Hualalai

Hualalai has erupted as recently as 1801, and twelve to fifteen vents have been identified with eruption dates less than 1,000 years old. The 1984 assessment noted several lines of evidence (geochemistry, resistivity, magnetics, and self-potential surveys) that gave positive indications of geothermal potential on the summit and upper flank areas above 4,000 feet. Seismic activity was also noted near the coast and on the north flank of the volcano. A deep well near Puu Waawaa on the north flank (just below the 4,000-foot elevation) encountered a temperature of 31°C at a depth of 5,555 feet. Water wells near the lower portion of the northwest rift (north of Keahole Airport) have encountered temperatures in the range of 25–26°C (Nance, pers. comm., 1999).

Based primarily on the recent age of volcanic activity and the positive indications from geophysics, the 1984 assessment defined contours of 35% and 25% probability for the occurrence of a high-temperature resource on the northwest rift between the elevations of 3,250 and 7,000 feet (figure 6), and it assigned a probability of 70% or less for a low-temperature resource in this area. Aside from the information about slightly elevated water well temperatures in the vicinity of the lower rift, no new data of interest for geothermal exploration have been available in the preparation of the present assessment. Therefore, no changes are recommended to the earlier probability estimates.

#### 4.4.8 Kilauea Southwest Rift Zone

The summit volcano of Kilauea has been almost continuously active in historical time. The southwest rift has erupted as recently as 1920 at the 3,000-foot level, and an 1823 eruption occurred at elevations of approximately 250–1,700 feet. The southwest rift also has areas of steaming ground, which indicates significant residual heat at shallow depths. Earlier assessments have noted geophysical evidence for the presence of

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geothermal resources (such as seismic activity and anomalies of resistivity and self-potential), as well as more general evidence of the rift structure (such as gravity and magnetic surveys).

Since the 1992 assessment, several authors have published geo-scientific papers about Kilauea (including the southwest rift), covering geology (Moore and Truesdell, 1993), geophysics (Kauahikaua, 1993), geochemistry (Janik et al., 1994; Tilling and Jones, 1995) and hydrogeology (Ingebritsen and Scholl, 1993a; Takasaki, 1994; Scholl et al., 1995 and 1996). The USGS has published annotated bibliographies of literature published on Kilauea through 1993 in the areas of hydrogeology (Ingebritsen and Scholl, 1993b) and seismicity (Klein, 1994). These publications have generally not focused on geothermal potential per se, but they have confirmed that the rift structures can be clearly distinguished from surrounding areas in their geophysical properties and in their impact on the chemistry and flow patterns of ground water.

Ingebritsen and Scholl (1993a) observed that hydrothermal systems exist at depth in both the southwest and east rift zones (as evidenced by thermal springs at the coast in both zones and deep drilling results in the east rift zone). They also note that both rifts appear to host dike-impounded, heated ground water at relatively high elevations. Janik et al. (1994) documented a temperature of 40°C at a coastal spring in the vicinity of the southwest rift (Puu Elemakule spring), significantly higher than the coastal spring temperature of 32°C noted in the 1984 assessment (Wai Welawela spring). Aside from a 4,161-foot research hole drilled with National Science Foundation funding in the early 1970s on the southwest side of Kilauea Crater (Tilling and Jones, 1995), no deep drilling has been performed to date in the southwest rift zone.

The 1984 assessment delineated probability contours of 90% and 25% for the occurrence of a high-temperature resource in the southwest rift (figure 6) and estimated a

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probability of >90% for the occurrence of a low-temperature resource. The 1992 assessment left the probability contours for a high-temperature resource unchanged. The geo-scientific literature since the 1992 assessment has not provided any data that would justify changing these contours or the estimated probability for a low-temperature resource. Therefore, the present assessment retains the earlier probability estimates. As noted in the 1984 assessment, much of the southwest rift is within Hawaii Volcanoes National Park and is thus off-limits to commercial geothermal development.

#### 4.4.9 Kilauea East Rift Zone

The Kilauea East Rift Zone (KERZ) has experienced ongoing eruptions and repeated dike intrusions. It is the site of the only commercial geothermal development currently underway in Hawaii: an electrical generation plant owned by Puna Geothermal Venture (PGV), located in the lower KERZ about 3 miles southeast of Pahoa. The 1992 assessment delineated 90% and 25% contours for the probability of a high-temperature resource (figures 6 and 7). There are currently six Geothermal Resource Subzones in the lower KERZ, including Kilauea Middle East Rift, Kamaili, Kapoho, and three geothermal resource mining leases (GRML R-2, R-3, and S-4602).

Since the 1992 assessment, four main categories of information have become publicly available that are relevant to the geothermal potential of the KERZ:

1. data relating to PGV wells;

2. data relating to other deep wells in the KERZ, including three wells drilled as part of the Scientific Observation Hole (SOH) program, the initial discovery well for the KERZ (HGP-A), and a well drilled by True/Mid-Pacific (KA1-1, also known as TMP-1 or KMERZ A-1).

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3. studies of the geology and geophysics of the KERZ; and

4. studies of the geochemistry and hydrogeology of the KERZ.

PGV Wells

The PGV plant began operation in May 1993 and has maintained an output of approximately 25 megawatts (MW) since then. The characteristics and performance of the PGV wells have been described in several publications (Ingebritsen and Scholl, 1993; GeothermEx, 1994; Novak, 1995), and PGV maintains a web site describing current activities (www.punageothermalventure.com). The plant is supplied by steam from three deep wells (KS-9, KS-10, and KS-11) with total depths greater than 4,500 feet. After being processed by the plant, produced fluids (including unflashed brine, steam condensate, and non-condensible gas) are injected into three wells (KS-1A, KS-3 and KS-4) at depths below 3,900 feet.

In its first six years of operation, the PGV plant utilized just two production wells: KS-9 and KS-10. These wells appear to produce from a discrete, high-pressure, high-capacity fracture zone, dipping steeply to the north and striking generally parallel to the rift zone (Novak, 1995, p.30). Two earlier wells (KS-7 and KS-8) had already intersected the same or a similar fracture zone, and both had to be plugged and abandoned due to mechanical problems associated with the high pressures they had encountered. In the case of KS-8, a blowout and uncontrolled flow on June 12-14, 1991 had resulted in a temporary suspension of PGV's drilling permits (GeothermEx, 1994, p. 4-6; Novak, 1995, p. 28). KS-9 and KS-10 were both drilled in 1993 without incident, to depths of 4,565 feet and 5,083 feet, respectively. KS-11 was also drilled without incident. It was completed in November 1999 at a depth of approximately 6,500 feet, and

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it was put on line to the PGV plant in March 2000. KS-9 and KS-10 encountered fluids at temperatures in the range of 335ºC to 342ºC. Other deep wells in the vicinity of the PGV lease encountered deep temperatures as high as 363°C (GeothermEx, 1994, Table 4.1; Novak, 1995, p.30).

The fracture zone tapped by KS-9 and KS-10 contains a mixture of steam and brine. Both wells initially produced at a high ratio of steam to liquid water. In November 1993, the proportion of liquid produced from KS-10 increased to approximately 75%, apparently in response to a decline of steam pressure with production and a rise of brine levels in the fracture (Novak, 1995, pp. 29-30).

Available data from deep wells indicate steep lateral pressure and temperature gradients perpendicular to the rift axis. The data also indicate relatively low permeabilities in wells that did not intersect the fracture tapped by KS-9 and KS-10. This pattern is consistent with a conceptual model in which the flow of deep geothermal fluids is channeled in steeply dipping tensional fractures associated with dike emplacement (GeothermEx, 1994, section 5.5.3).

Underground Injection Control (UIC) permits for the PGV plant are issued by both the Federal Environmental Protection Agency (EPA) and the State Department of Health (DOH). Pursuant to these permits, the casing integrity of the PGV injection wells has been continuously monitored in the upper 2,000 feet to guard against leaks of deep geothermal fluid into shallow ground water. In June, 1999, the EPA issued a new five-year UIC permit to PGV, allowing continued use of the three existing injection wells and the drilling of up to seven new injection wells (Environmental Protection Agency, 1999). According to the EPA, the conditions of the new federal permit are “consistent or complementary” with those of the existing UIC permit from the State DOH.

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Other Deep Wells

In 1990 and 1991, the State of Hawaii drilled three research wells to help define the distribution of geothermal resources in the KERZ: SOH-1, SOH-2, and SOH-4 (figure 7). Since the preparation of the 1992 assessment, several authors have published technical results from these wells (Olson and Deymonaz, 1993; Hulsebosch, 1993; Kauahikaua, 1993; Evans et al., 1994; GeothermEx, 1994; Bargar et al., 1995), including some comparisons with other deep wells in the KERZ. These studies document that deep temperatures of 300°C or higher exist over a span of 16-kilometers (10 miles) in the middle and lower KERZ, from KA1-1 to SOH-2.

The permeabilities of the SOH holes were generally low, in the range of 1,300–6,100 millidarcy-feet based on injection tests (GeothermEx, 1994, section 4.2.2). The permeability of well KA1-1 also appears to have been limited; no commercial flow from this well has been documented. The HGP-A well, which supplied steam to a pilot geothermal plant from 1982 to 1989, yielded a maximum output of about 3 megawatts (MW), considerably less than the outputs of KS-9 and KS-10 (initially in the range of 20–25 MW apiece). However, all these wells meet the temperature criterion for a high-temperature resource (as defined by earlier assessments), and the results of the PGV wells illustrate that dramatic permeability contrasts can exist over short distances, especially perpendicular to the axis of the rift. The fluid-inclusion study of Bargar et al. (1995) indicates that the minerals in the deeper portions of the SOH holes have increased in temperature since the time of crystallization. This suggests that the formation in the vicinity of these wells has been heated by subsequent dike emplacements and possibly by the convection of geothermal fluids in nearby tensional fractures.

The HGP-A well, which had been shut in since 1989, was plugged and abandoned by the State in the spring of 1999.

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Studies of Geology and Geophysics

Moore and Truesdell (1993) summarized current interpretations of the geology of Kilauea, including the KERZ. Moore and Kauahikaua (1993) presented a discussion of hydrothermal-convection systems and reviewed the history of drilling to investigate these systems in the KERZ. Cooper (1993) described interpretations of seismic and gravity data in the Puna area of the KERZ. Several publications have summarized or re-interpreted results from previous geophysical surveys (Kauahikaua, 1993; Delaney, et al., 1993; Hildenbrand et al., 1993; GeothermEx, 1994). These studies demonstrate that the summit and rift zones of Kilauea are “underlain by dense, magnetic, high P-wave-velocity rocks" at depths of 2 kilometers or less (Kauahikaua, 1993). These dense rocks appear to represent accumulated dikes, which have lower vesicularity than the rocks into which they intrude. Gravity data indicate that the dense rocks in the KERZ extend 4 kilometers to the south and 10 kilometers to the north of rift features at the surface. The emplacement of dikes appears to have moved progressively southward in the KERZ, with older dikes being buried to greater depths by later surface flows. Because of their mode of emplacement, the accumulated dikes have a better probability than the surrounding rocks of preserving near-vertical tensional cracks that can allow the convection of geothermal fluids, even at some distance from the present-day rift axis.

Studies of Geochemistry and Hydrogeology

Several recent publications on the geochemistry and hydrogeology of Kilauea (as listed above in the section on the southwest rift) have included discussions of the KERZ as well. Janik et al (1994) have integrated all previously available geochemical data from springs and wells in the area with data from new samples collected in 1991 and 1992. Sorey and Colvard (1994) and Novak (1995) have distinguished several different

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categories of ground water in the KERZ based on geochemistry, temperature, and depth of occurrence. Thomas (1995) has reported on geochemical monitoring in the KERZ. Gingerich (1995) has presented conceptual and numerical models of the hydrothermal system in the lower KERZ. The consistent picture that emerges from these studies is that the hydrological structure of the KERZ is highly compartmentalized, and that fluids from the deep geothermal reservoir tapped by the PGV wells is chemically distinct from the several types of ground water in shallower formations.

Summary

Since the 1992 assessment, the start-up and sustained operation of the PGV plant have confirmed that a high-temperature geothermal resource exists in the KERZ and that this resource can be commercially developed in an environmentally acceptable manner. Other deep wells have demonstrated that potentially commercial temperatures exist over at least a 16-kilometer length of the KERZ. No published geophysical surveys have been performed since 1992, but available data suggest that past dike emplacements in the KERZ extend several kilometers on either side of the current surface features of the rift. The dense rocks of these dikes can host near-vertical tensional cracks that allow convection of geothermal fluids at depth, even if surface expressions of these geothermal fluids are absent. Geochemical data confirm that the ground waters of the KERZ are highly compartmentalized and that the fluids of the deep reservoir tapped by the PGV wells are chemically distinct.

At the time of the 1992 assessment, productive wells (such as HGP-A) already existed, and the high temperatures observed in other deep wells at that time contributed to a decision to increase the overall estimate of the probability of a high-temperature resource to >95% (from >90% in 1984). The current assessment maintains the probability contours delineated by the 1992 assessment, with the label on the 90%

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contour adjusted to 95% for consistency. Even though commercial production from the KERZ is now confirmed, the limited permeability in several deep wells demonstrates that high temperatures do not necessarily guarantee productivity; thus, it would not be appropriate to raise the estimated probability of a high-temperature resource any further. The 1992 assessment did not address the probability of a low-temperature resource. Logically, this probability should be at least as high as the probability of a high-temperature resource. Therefore, the present assessment retains the 1992 estimate of >95% as the probability of a high-temperature resource and raises the estimated probability for a low-temperature resource to >95% as well (an increase from the 1984 low-temperature estimate of >90%).

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# 5. PLANNING CONSIDERATIONS AND KEY ISSUES

This update of the statewide geothermal resource assessment has focused on geo-scientific evidence to quantify the potential for geothermal production in different areas of the State. In this approach, it has followed the practice of the 1984 and 1992 assessments.

Under State law (HRS, Section 205-5.2), the BLNR is required to strike a balance between a number of factors in the designation of Geothermal Resource Subzones, in addition to the potential for geothermal production. These additional factors include: the prospects for utilization of geothermal energy; geologic hazards; environmental and social impacts; compatibility with other land uses; and potential economic benefits. The BLNR may modify or withdraw existing subzones based on "a preponderance of the evidence that the area is no longer suited for designation." This language gives the BLNR wide discretion, but the factors listed above would still be required for consideration. At the time existing subzones were designated (in 1984 and 1985), all these factors were investigated in detail, and the results of the investigation were summarized in the GRS Designation Report (Department of Planning and Economic Development, 1986). Much of the discussion in the GRS Designation Report remains valid today, and a full reconsideration of these issues is beyond the scope of this assessment. The following discussion focuses on planning considerations that have changed since the 1992 assessment.

The demand for electrical energy is a primary consideration, and it relates directly to the factor of "prospects for utilization" to be considered by the BLNR. Between 1992 and 1995, the Energy Division of DBEDT conducted a series of analyses and public workshops as part of the Hawaii Energy Strategy (HES) program (DBEDT, 1995). This program was implemented to achieve the statutory energy objectives outlined in HRS,

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Section 226-18(a), as amended by Act 96 (SLH 1994). The 1995 report on the HES program noted that Hawaii continues to depend on imported oil for about 90% of its energy requirements and that this dependency has not significantly improved since the first oil crisis in 1973-1974. The HES report described Hawaii's "overdependence upon petroleum" as a "major concern." One of the objectives of the HES was to "displace oil and fossil fuels through alternate and renewable resources." Geothermal resources are one of the alternate energy sources that can help Hawaii overcome its overdependence on fossil fuels and increase the ratio of indigenous to imported energy.

One planning consideration that has changed since 1992 relates to the proposal for constructing an inter-island cable to transmit electricity from geothermal sources on the Big Island to other islands. This concept was actively explored in the late 1980's and early 1990's, but the State is no longer pursuing such a project. Therefore, current projections of demand for electricity from geothermal resources are based exclusively on expected use within the islands where these resources occur. As part of the HES program, DBEDT has made forecasts of electricity needs for each island using a computer model called ENERGY 2020. In the 1995 HES report (the most recent set of forecasts available for electrical generation capacity in Hawaii), the scenarios considered by the ENERGY 2020 model for the Big Island included commissioning an additional 25 MW of geothermal capacity in 2001. Overall, the installed generation capacity of the Big Island was projected to increase by 82 MW between 1999 and 2009 (from 187 MW to 269 MW). For Maui County, the model projected that installed electrical generation capacity would increase by 46 MW between 1999 and 2009 (from 222 MW to 268 MW), though none of this increase was specifically associated with geothermal development (DBEDT, 1995). Thus, for both islands with existing Geothermal Resource Subzones, there appears to be projected demand for electricity that geothermal resources could help to provide.

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Another change in planning considerations is a renewed emphasis on the possibility of direct use applications. As discussed earlier, the 1992 assessment assigned probabilities only for high-temperature resources and focused primarily on potential for electrical generation. In assigning a separate set of probabilities for low-temperature resources, the present assessment is returning to the perspective that direct use applications can have value in their own right. These less intense forms of utilization (such as processing agricultural products) may find greater public acceptance and could broaden the use of the State's geothermal resources. The Federal and State governments could potentially use geothermal energy to provide space heating and hot water for facilities within parks or military reservations, especially if the drilling of wells serves a dual purpose of geological or hydrological research.

An additional planning consideration concerns the environmental effects of geothermal development and the public perception of these effects. At the time of the 1992 assessment, the blowout of KS-8 had undermined public confidence in the possibility of developing geothermal resources in a way that maintained environmental quality. Since the KS-8 blowout, PGV has successfully drilled four wells without incident (production wells KS-9, KS-10, KS-11, and injection well KS-4), and the PGV plant has operated for over seven years without any significant adverse impact on the local environment. Prudent operating procedures must be maintained to prevent another occurrence of uncontrolled flow and to guard against the possibility of ground-water contamination, but PGV operations in the years since 1992 have demonstrated that such procedures can be successful and that environmental quality can be safeguarded.

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# 6. RECOMMENDATIONS

Based on the foregoing review of current State policies, geothermal production potential, and other planning considerations, the present assessment makes the following recommendations:

1. The BLNR should retain existing Geothermal Resource Subzones in the Haleakala Southwest Rift Zone and in the Kilauea East Rift Zone, including the acreage in Geothermal Resource Mining Leases R-2, R-3, and S-4602.

2. In future assessments of the State's geothermal resources, the temperature criterion for low-temperature geothermal resources should be adjusted from 50–125°C to 65–125°C, so that the lower temperature limit corresponds to the legal definition of geothermal resources in HRS Section 182-1; that is, >150°F (>65.6°C). The adjusted temperature criterion has been used in the present assessment.

3. Based on currently available public information, the probabilities of finding high- and low-temperature geothermal resources in different areas of the State should continue to be as shown in Table 1.

4. Possibilities for the use of low-temperature resources should continue to be considered in future geothermal resource assessments (even though subzone designation is not required for direct use applications in urban, rural, or agricultural districts). This will present an integrated view of the spectrum of potential geothermal development activities, rather than focusing exclusively on electrical generation.

5. In reviewing potential future subzone designations in conservation districts, the possibility of geothermal direct use applications (such as providing hot water or space

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heating) should be considered. This could apply to facilities within National or State parks or within Federal military reserves.

6. DLNR should coordinate with the USGS and with County water departments to ensure that temperature measurements and geochemical analyses (including silica concentration and chloride/magnesium ratio) are performed on any new ground-water wells, particularly in the potential geothermal resource areas identified in this assessment.

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TABLE

## Table 1. Probabilities of Finding Geothermal Resources in Hawaii

| County | Island | Resource Area | Probability of High-Temperature Resource: 1984 Assessment (> 125°C ) | Probability of High-Temperature Resource: 1992 Assessment (> 125°C ) | Probability of High-Temperature Resource: Current Assessment (> 125°C ) | Probablility of Low-temperature Resource: 1984 Assessment (50–125°C) | Probablility of Low-temperature Resource: Current Assessment (65–125°C) | New Data Since 1992 | Comments |
|---|---|---|---|---|---|---|---|---|---|
| Kauai | Kauai | Lihue | <5% | <5% | <5% | <5% | **<15%** | Water wells in Lihue Basin up to 34°C. | Earlier assessments did not specify resource area within Kauai Island. |
| Honolulu | Oahu | Koolau | <5% | <5% | <5% | <10% | <10% | None | Two water wells with temperature of 30°C (one unconfirmed). |
| | | Waianae | <5% | <5% | <5% | 15% or less | <15% | None | Water well temperatures of 27-29°C (comparable to Lihue and Lahaina). |
| Maui | Molokai | West Molokai | <5% | Not assessed | **<10%** | <5% | **<45%** | Water wells in West Molokai up to 36°C | 1984 assessment estimated probability for East and West Molokai together. |
| | Lanai | Palawai | <5% | <15% | <15% | <5% | **<50%** | Water wells up to 40°C | Well temperatures comparable to Mauna Kea NE Rift Zone. |
| | Maui | Honolua | <5% | <5% | <5% | <5% | <5% | None | |
| | | Lahaina | <5% | <5% | <5% | <5% | **<15%** | None | Water well temperature of 27°C (comparable to Lihue and Waianae). |
| | | Olowalu | <15% | <15% | <15% | 75% or less | **<50%** | None | Water well temperature of 35°C (comparable to W. Molokai & Kawaihae). |
| | | Haleakala NW Rift Zone | <5% | <5% | <5% | <10% | <10% | None | |

# Table 1. Probabilities of Finding Geothermal Resources in Hawaii

| County | Island | Resource Area | Probability of High-Temperature Resource: 1984 Assessment (> 125°C ) | 1992 Assessment (> 125°C ) | Current Assessment (> 125°C ) | Probablility of Low-temperature Resource: 1984 Assessment (50–125°C) | Current Assessment (65–125°C) | New Data Since 1992 | Comments |
|---|---|---|---|---|---|---|---|---|---|
| Maui (cont.) | Maui (cont.) | Haleakala East Rift Zone | 25% or less | 25% or less | 25% or less | 35% or less | 35% or less | None | |
| | | Haleakala SW Rift Zone | 25% or less | 25% or less | 25% or less | 35% or less | 35% or less | None | |
| Hawaii | Hawaii | Kohala | <5% | <5% | <5% | <10% | <10% | None | |
| | | Kawaihae | <10% | <10% | <10% | 45% or less | <45% | Water wells up to 36°C | Temperature comparable to W. Molokai & Olowalu. |
| | | Mauna Kea East Rift Zone | <10% | <10% | <10% | <30% | <30% | None | |
| | | Mauna Kea NW Rift Zone | <20% | <20% | <20% | <50% | <50% | None | Waikii well temperature 40°C at 4240 ft. |
| | | Mauna Loa NE Rift Zone | 35% or less | 35% or less | 35% or less | 60% or less | 60% or less | New water well in lower rift zone | No new data in middle rift zone, on which probabilities are based. |
| | | Mauna Loa SW Rift Zone | 35% or less | 35% or less | <35% | 60% or less | 60% or less | Two new cool water wells | Wells located southeast of resource area. |
| | | Hualalai | 35% or less | Not assessed | <35% | 70% or less | 70% or less | None | Probabilities are for summit and upper flank. |
| | | Kilauea SW Rift Zone | >90% | >90% | >90% | >90% | >90% | Coastal spring 40°C. | Earlier max. sping temp. was reported as 32°C. |
| | | Kilauea East Rift Zone | >90% | >95% | >95% | >90% | **>95%** | PGV plant operations; geochemistry | Low-temp. probability raised to match high-temp. probability. |

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FIGURES

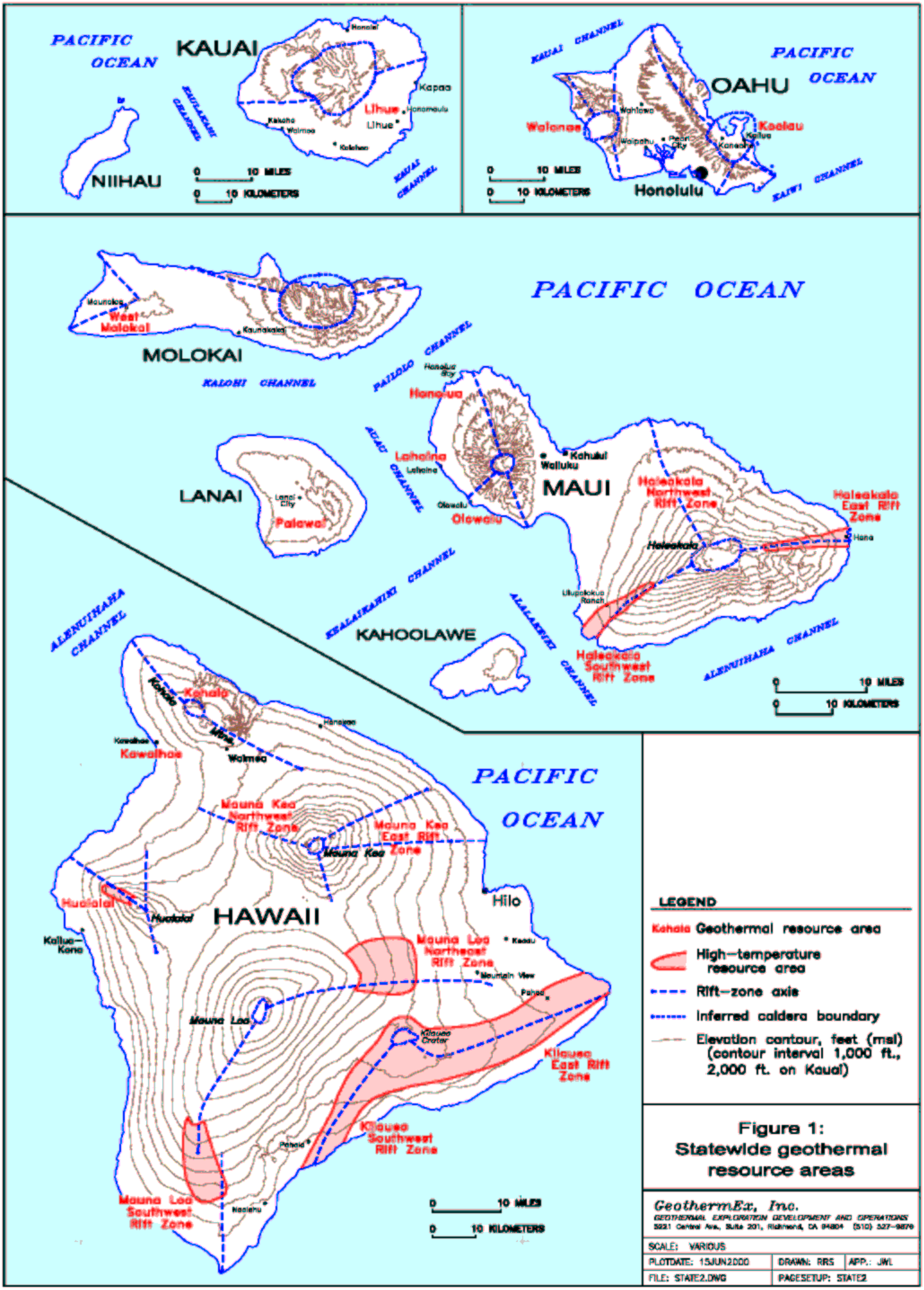
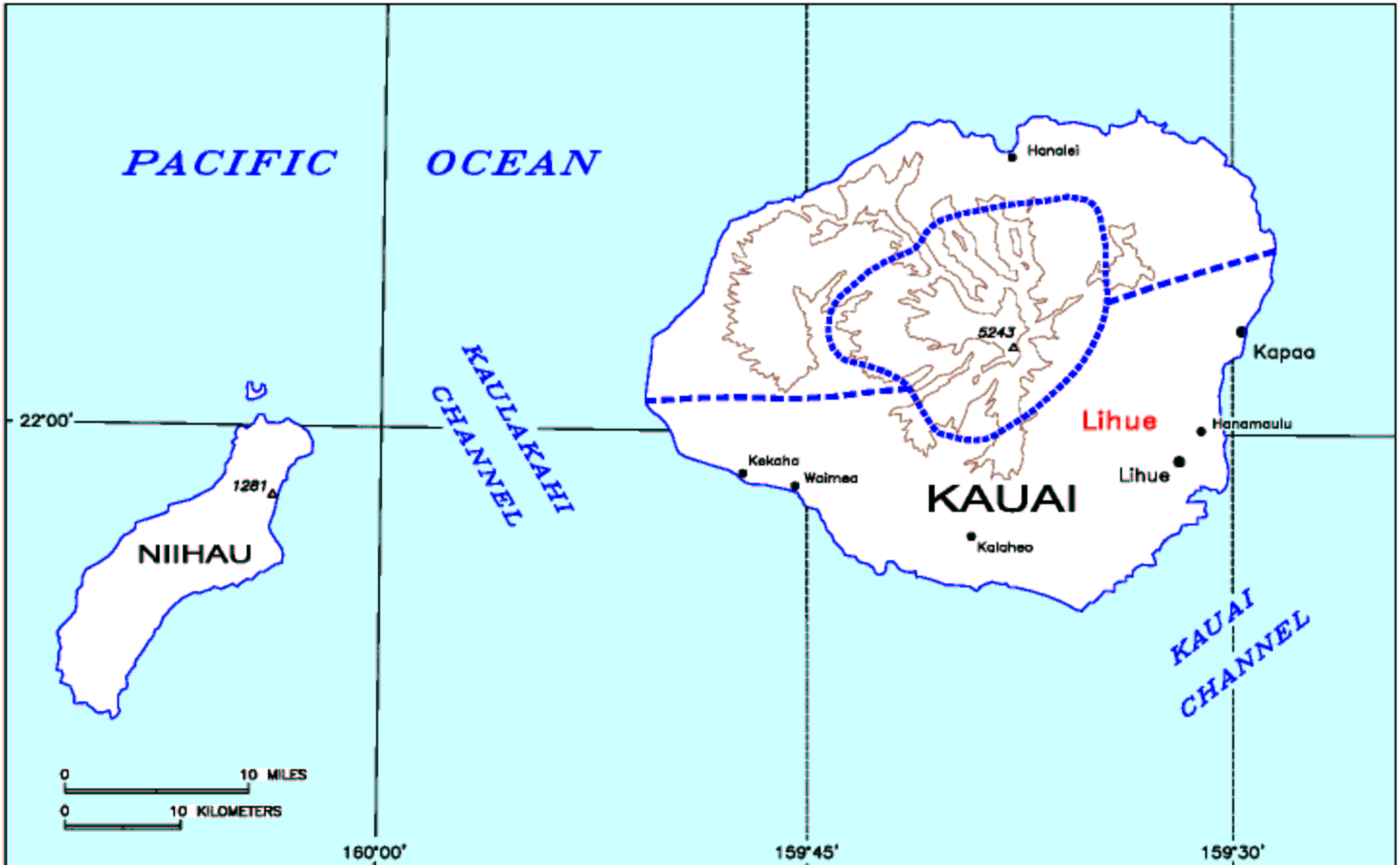



**Figure 1: Statewide geothermal resource areas**

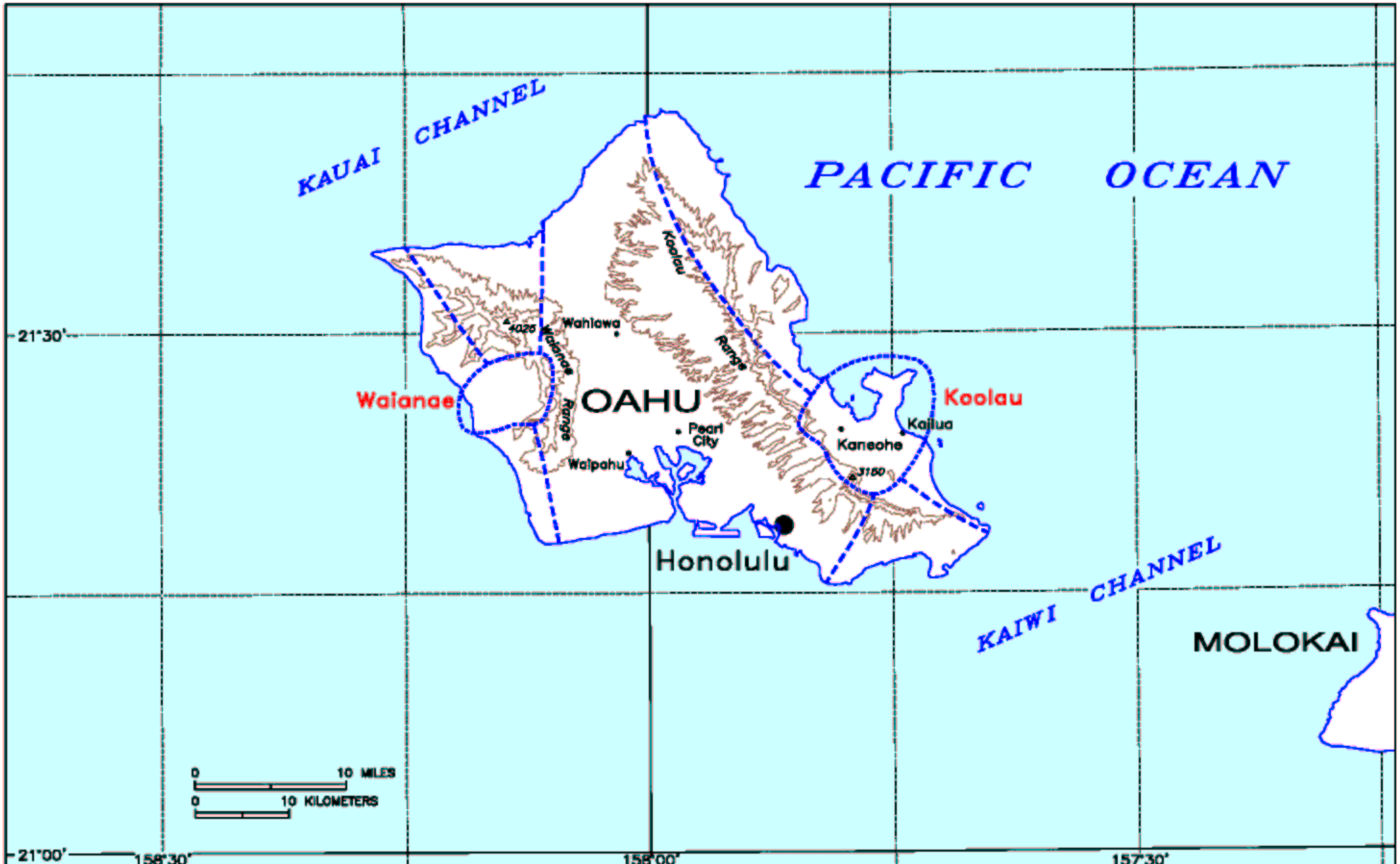



LEGEND

- Town
- Elevation contour, feet (msl) (contour interval 2,000 ft.)
- Rift zone axis
- Inferred caldera boundary

**Figure 2:**
**Geothermal resource areas of Kauai County**

SCALE 1 : 480000




**LEGEND**

- • Town
- Elevation contour, feet (msl) (contour interval 1,000 ft.)
- ▲ Peak
- Rift-zone axis
- Inferred caldera boundary
- Koolau Geothermal resource area

**Figure 3: Geothermal resource areas of Oahu (City and County of Honolulu)**

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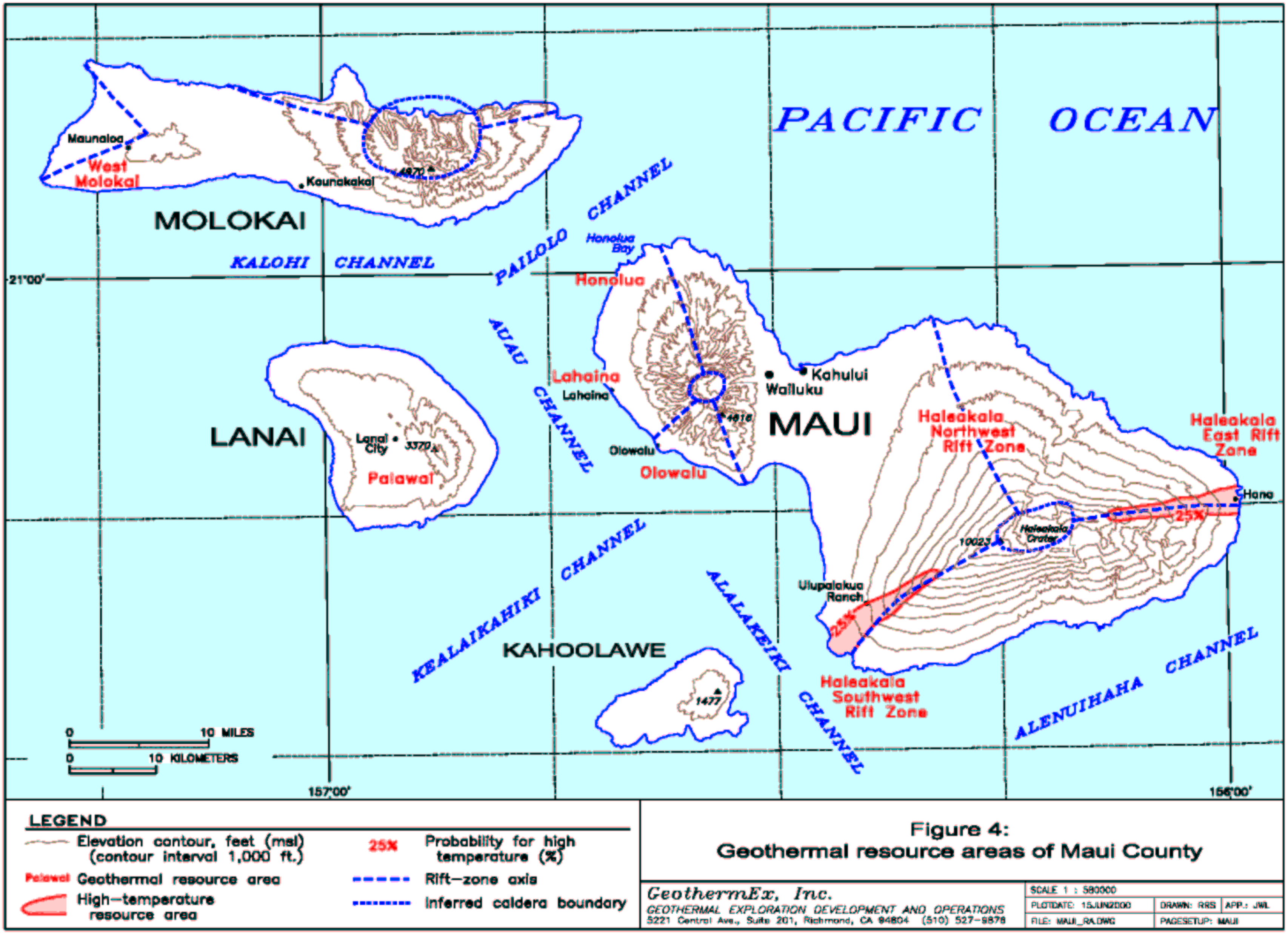


Figure 4:
Geothermal resource areas of Maui County

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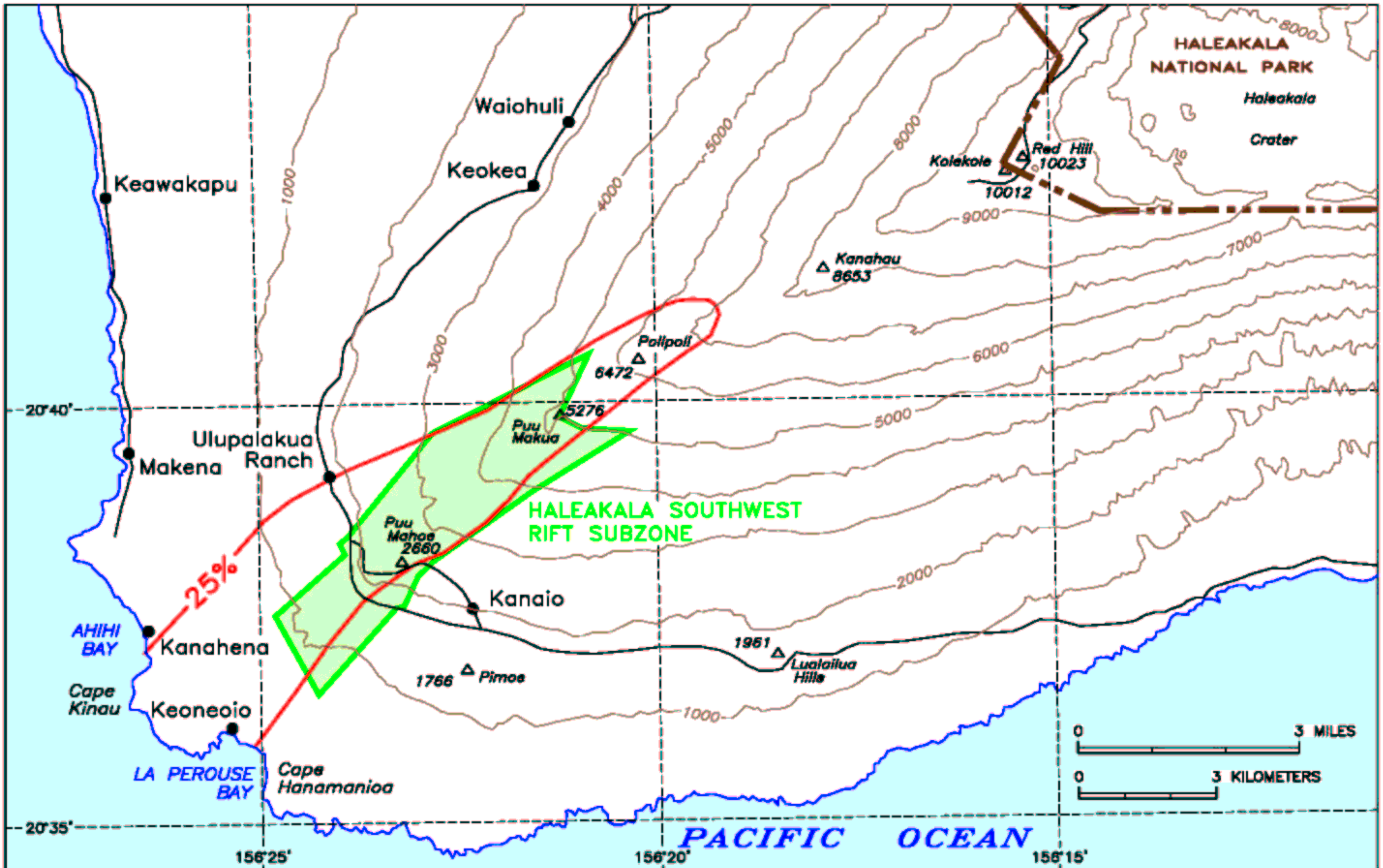


LEGEND

Elevation contour, feet (msl) (contour interval 1,000 ft.)

Δ Peak

Geothermal resource subzone

—25%— Probability of high temperature (%)

Figure 5: Geothermal resource subzone within Haleakala Southwest Rift Zone, Maui County

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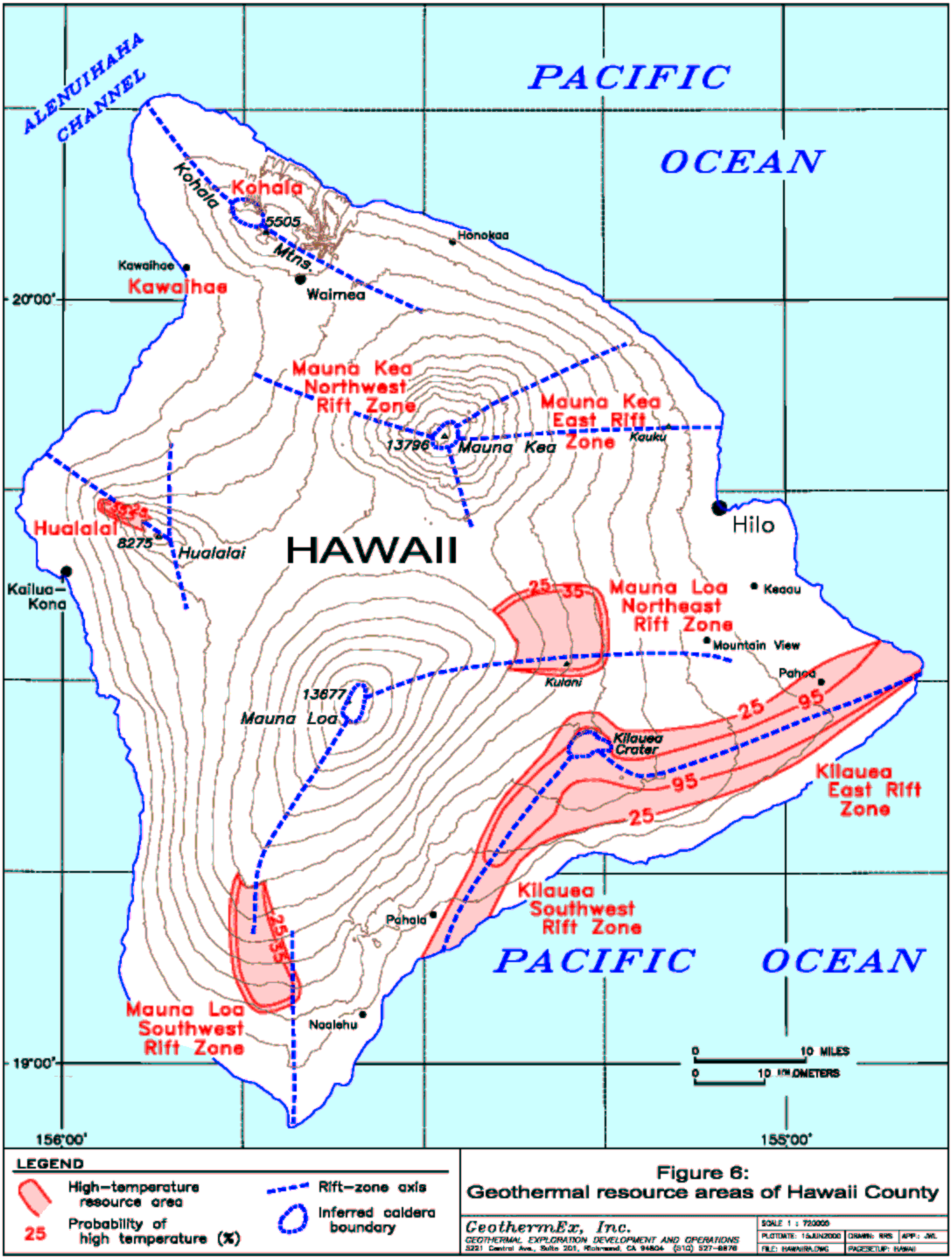
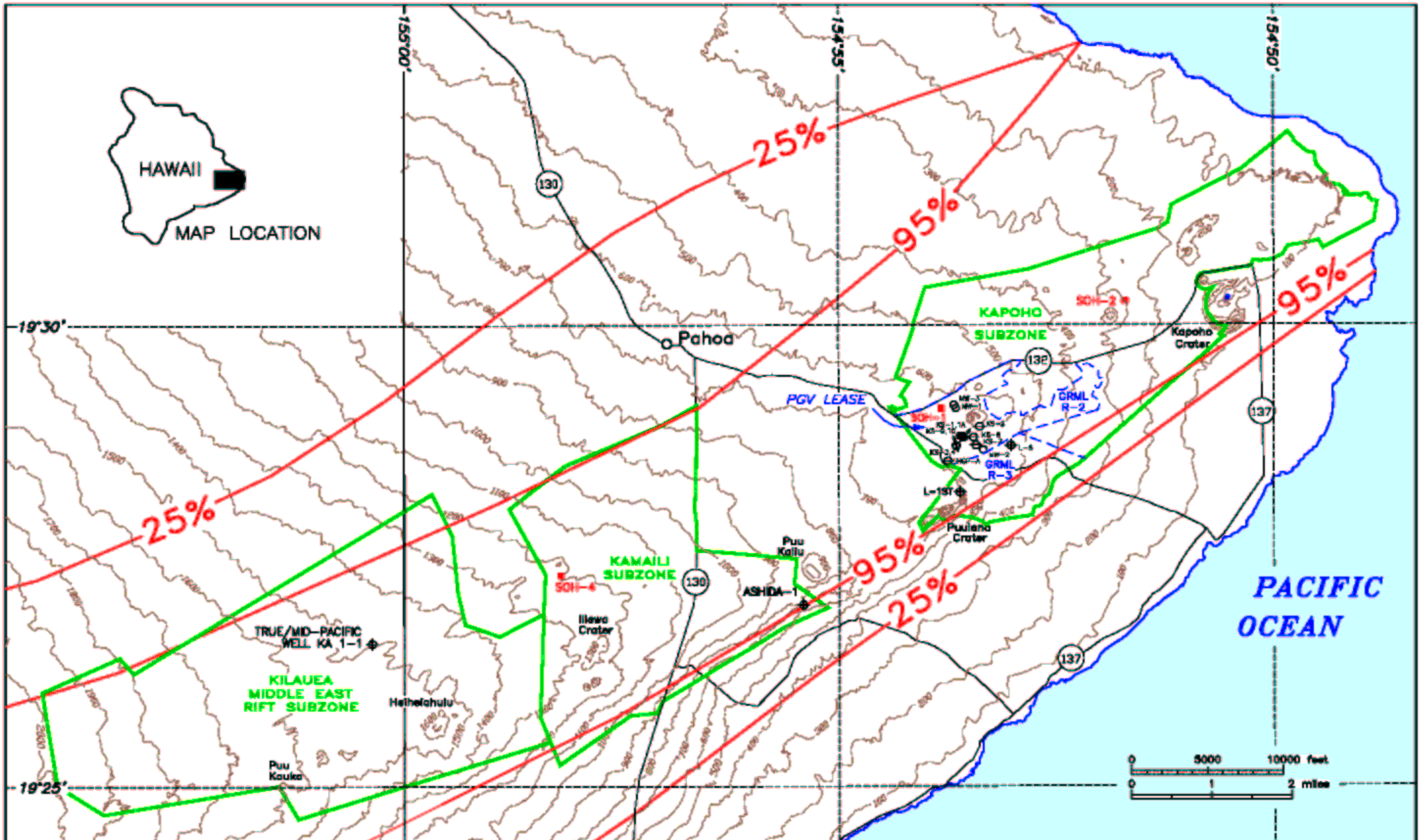



Figure 6:
Geothermal resource areas of Hawaii County




**LEGEND**

- Elevation contour, feet (msl)
- Geothermal resource subzone
- Geothermal lease
- 95% Probability of high temperature (%)
- Scientific observation hole (SOH)
- Deep geothermal wells:
  - Production; injection; dry
  - Plugged; monitor

**Figure 7: Geothermal resource subzones within Kilauea East Rift Zone, Hawaii County**

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