# "ENVIRONMENTAL RESOURCES OF SELECTED AREAS OF HAWAII: GROUNDWATER IN THE PUNA DISTRICT OF THE ISLAND OF HAWAII"
**(William Staub)**

**EE-12 COMMENTS**

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## I. GENERAL COMMENTS

DOE's cooperating agency agreements required that DOE give early draft EIS sections for review to those cooperators who have "relevant technical expertise" and/or "legal jurisdiction". Even though this is not to become an EIS, we are of the opinion that the report would be enhanced if reviewed by:

| | |
|---|---|
| USGS: | Water Resources Division |
| State of Hawaii: | Dept. Business, Economic Development and Tourism |
| | Dept. Land and Natural Resources |
| County of Hawaii: | Geothermal Coordinator |

At the same time, as Dr. San Martin has requested, costs must continue to be carefully controlled.

## II. SPECIFIC COMMENTS

Note: Specific comments are keyed to page/paragraph/line numbers in the Staub report.

1. Section 5, "Relationship of Shallow Groundwater to Hydrothermal Systems, Seawater, and Meteoric Water," depicts a series of complex watertable interactions involving fresh water, seawater, steam condensate, and mixed meteoric water. (18/4). This discussion is based on data from "shallow wells in the Puna District." (21/2). Given the limited data base, this interpretation should be referenced. If it is only the author's speculation, it should be deleted.

2. Some of this report contains factual information that is not referenced: 2/all; 9/2,3,4; 12/2/8-13; 18/2,3,4; and 24/2,3,4. If appropriate references cannot be obtained, deletion of the corresponding statement is recommended.

3. A mark-up of the report is attached and identifies statements in need of reference.

# DISCLAIMER

Mark-up

"★" indicates need for reference

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# ENVIRONMENTAL RESOURCES OF SELECTED AREAS OF HAWAII: GROUNDWATER IN THE PUNA DISTRICT OF THE ISLAND OF HAWAII


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Energy Division


June 1994

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**CAUTION**

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## ACRONYMS

| | |
|---|---|
| B | boron |
| Br | bromine |
| Cl/Mg | chlorine/magnesium |
| Cl/B | chlorine/boron |
| Cl/Br | chlorine/bromine |
| DOE | U.S. Department of Energy |
| DWS | Hawaii County Department of Water Supply |
| EIS | environmental impact statement |
| gpm | gallons per minute |
| GTW | geothermal test well |
| h | hour |
| HGP | Hawaii Geothermal Project |
| HSCA | Hawaiian Shores Community Association |
| KERZ | Kilauea's east rift zone |
| kg | kilogram |
| L | liter |
| lb | pound |
| LERZ | lower east rift zone |
| MERZ | middle east rift zone |
| mg | milligram |
| mg/L | milligram per liter |
| MLWC | Miller and Lieb Water Company |
| MW | monitor well |
| Pa | pascal(s) |
| PGV | Puna Geothermal Venture |
| psig | pounds per square inch, gage |
| TDS | total dissolved solids |
| USDW | underground source of drinking water |

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# 1. INTRODUCTION

This report has been prepared to make available and archive the background scientific data and related information collected on groundwater during the preparation of the environmental impact statement (EIS) for Phases 3 and 4 of the Hawaii Geothermal Project (HGP) as defined by the state of Hawaii in its April 1989 proposal to Congress. The U.S. Department of Energy (DOE) published a notice in the *Federal Register* on May 17, 1994 (Fed. Regis. 59:25638), withdrawing its notice of intent (Fed. Regis. 57:5433) of February 14, 1992, to prepare the HGP-EIS. Since the state of Hawii is no longer pursuing or planning to pursue the HGP, DOE considers the project to be terminated.

The background scientific data and related information presented in this report were collected for the geothermal resource subzones in the Puna District on the island of Hawaii. The scientific background data and related information is being made available for use by others in conducting future scientific research in these areas. This report describes the environmental resources present in the areas studied (i.e., the affected environment) and does not represent an assessment of environmental impacts.

This paper summarizes the current state of knowledge with respect to groundwater in the Puna District of the island of Hawaii (hereinafter referred to as Hawaii). Groundwater quality inside and outside the lower east rift zone (LERZ) of Kilauea is compared with that of meteoric water, seawater, and geothermal fluid. The degree of mixing between meteoric water, sea water, and geothermal water in and adjacent to the LERZ also is discussed. Finally, groundwater pathways and use in the Puna District are discussed. Most of the information contained herein is compiled from recent U.S. Geological Survey publications and open-file reports.

# 2. CHEMICAL AND THERMAL CHARACTERISTICS OF SHALLOW GROUNDWATER IN THE PUNA DISTRICT

Shallow groundwater has highly variable chemical and thermal characteristics depending on its location in or adjacent to the LERZ. Table 1 lists six groundwater types (Sorey and Colvard 1993) based on temperature and chloride concentration.

Groundwater in the Pahoa region north of the LERZ (Fig. 1 and Table 2) is cold and dilute (Type I). An excellent underground source of drinking water (USDW) exists in this region. Six municipal and privately-owned wells are located in the Pahoa region. Chemical and thermal characteristics of water from five of these wells were compiled from Janik, Nathenson and Scholl (1994). No data are currently available for the Orchidland well. Water in these wells is remarkably consistent in quality. The temperature ranges from 20°C (68°F) to 24°C (75°F), total dissolved solids (TDS) ranges from 106 to 143 mg/L, and the only trace element reported is zinc (0.07 mg/L). Such consistently high quality groundwater is not found further to the south in the Puna District.

**Table 1. Groundwater types in the lower east rift zone**

| Groundwater type | Temperature (°C) | Chloride concentration (mg/L) |
|---|---|---|
| I (cold & dilute) | | |
| II (cold & brackish) | | 75 to 300 |
| III (warm & dilute) | | |
| IV (warm & brackish) | | 100 to 800 |
| V (hot & saline) | 50 to 100 | |
| VI (warm & saline) | 30 to 40 | |

*Source:* Sorey and Colvard (1993).

Groundwater in the LERZ (Fig. 2 and Table 3) ranges between warm and dilute (Type III) and hot and saline (Type V). Most of the wells shown in Fig. 2 are shallow, geothermal test wells (GTW) from various geothermal exploration activities or monitor wells (MW) associated with Puna Geothermal Venture's (PGV) operating power plant. Most of these wells are in or near the area leased by PGV. Two wells (Kapoho Airstrip and Kapoho Shaft) are privately owned and (along with GTW-4) are several km northeast of the area leased by PGV. Water from the Kapoho Shaft well is unique in that it is perched rather than basal lens groundwater. The perched water is cold and slightly brackish (Type II). Although some groundwater in the LERZ may be potable without chemical treatment, it does not have the same consistent quality as groundwater in the Pahoa region. Most of these wells contain trace amounts of either boron (B) or bromine (Br), or both, ranging up to 3 mg/L. However, most well water in this area would be considered by the Environmental Protection Agency as a potential USDW, having a TDS ≤ 10,000 mg/L). Water from one shallow well (GTW-3) exceeds 10,000 mg/L TDS and has a bromine concentration of 21 mg/L. ★

Groundwater is hot and saline (Type V) immediately south of Kapoho near the eastern end of the LERZ (Fig. 3 and Table 4). In contrast, groundwater is cold and slightly brackish (Type II) on the south sides of the middle east rift zone (MERZ) and near the western end of the LERZ. The very limited data available suggests that the easternmost region (south of Kapoho) has a very marginal USDW. Water from the Malama Ki well is very hot [53°C (127°F)], very saline (TDS is nearly 9000 mg/L) and contain s measurable concentrations of several trace elements (As, 0.08 mg/L; B, 2.3 mg/L; and Br, 17.4 mg/L). In contrast, the westernmost region (south of the MERZ and the Kamaili region to the south of the LERZ) has a fairly good USDW. ★

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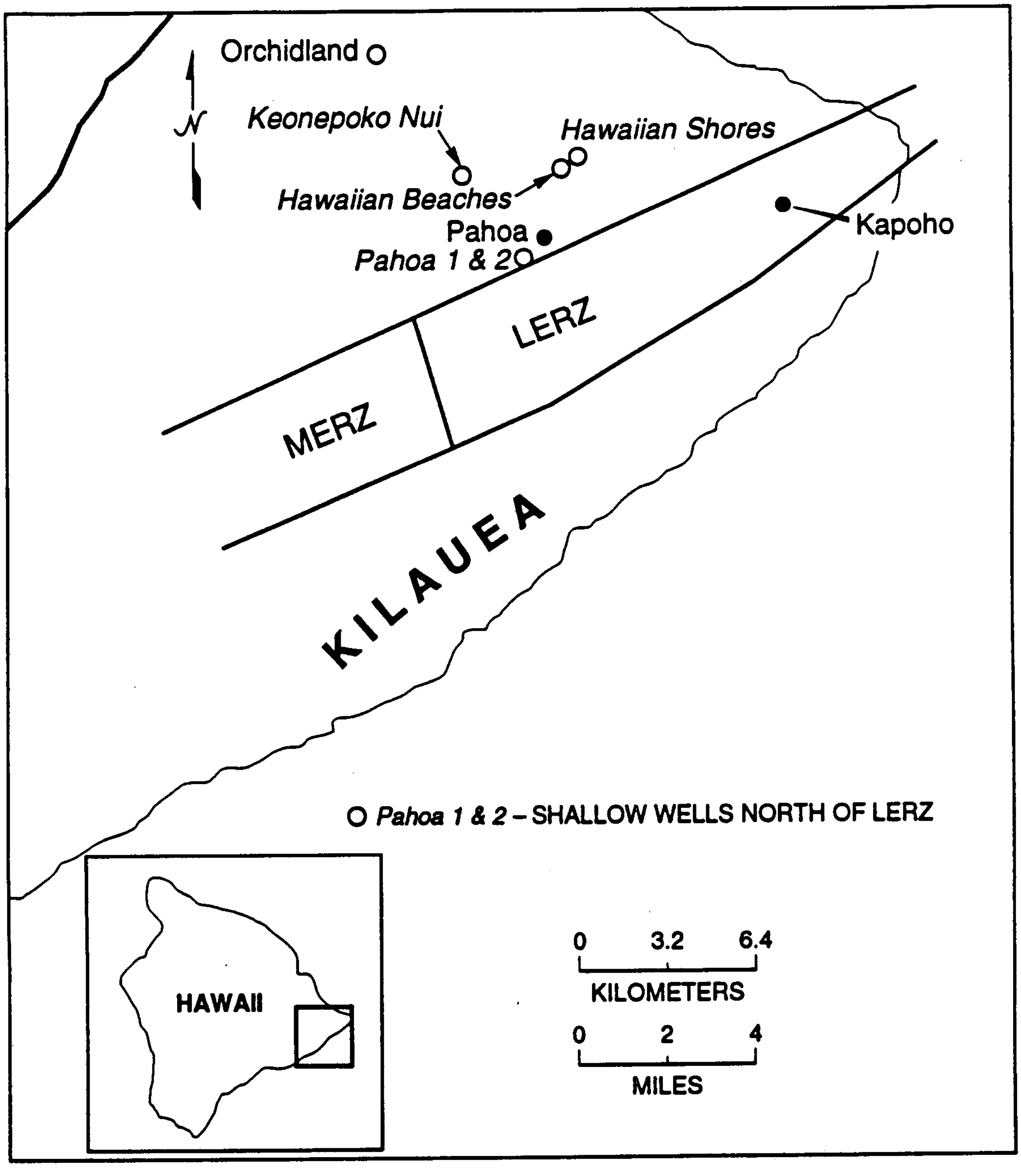


**Fig. 1. Shallow wells north of the lower east rift zone.** *Source:* Sorey and Colvard 1993.

**Table 2. Chemical and thermal characteristics of water in shallow municipal and private wells north of the lower east rift zone**
(See Fig. 1 for well locations)

| Well | Date sampled | Depth (m) | Water type[a] | Temp (°C) | pH | TDS | Cl | $HCO_3$ | $SO_4$ | $SiO_2$ | F | $NO_3$ | Trace elements[b] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pahoa 1 | 9/92 | 230 | I | 24 | 6.8 | 124 | 4 | 46 | 14 | 57 | 0.3 | BDL | BDL |
| Pahoa 2 | 3/72 | NP[c] | I | 23 | 7.4 | 121 | 6 | 50 | 13 | 50 | 0.8 | 0.2 | BDL |
| Hawaiian Beaches | 9/92 | 136 | I | 23 | 7.6 | 123 | 14 | 56 | 5 | 52 | 0.3 | 0.2 | 0.06 (Zn) |
| Hawaiian Shores | -/74 | 131 | I | NP | 7.6 | 143 | 28 | 56 | 7 | 49 | 0.6 | 0.1 | 0.07 (Zn) |
| Keonepoko Nui | 9/92 | 198 | I | 20 | 76 | 106 | 4 | 52 | 4 | 50 | 0.2 | 1.0 | BDL |
| **Range** | | | | | | | | | | | | | |
| High | | 230 | I | 24 | 7.6 | 143 | 28 | 56 | 14 | 57 | 0.8 | 1.0 | 0.07 (Zn) |
| Low | | 131 | I | 20 | 6.8 | 106 | 4 | 46 | 4 | 49 | 0.2 | BDL | BDL |

Note: Chemical concentrations in milligrams per liter, except as noted.
[a]Water types are defined in Table 1.
[b]Generally below detection limits (BDL) for elements tested (Li, B, Br, Ag, Al, As, Ba, Cd, Co, Cr, Cs, Cu, Mo, Ni, Pb, Rb, Sb, Se, Sr, Zn), except as noted.
[c]NP - not provided.

*Source:* Janik, Matherson and Scholl 1994.

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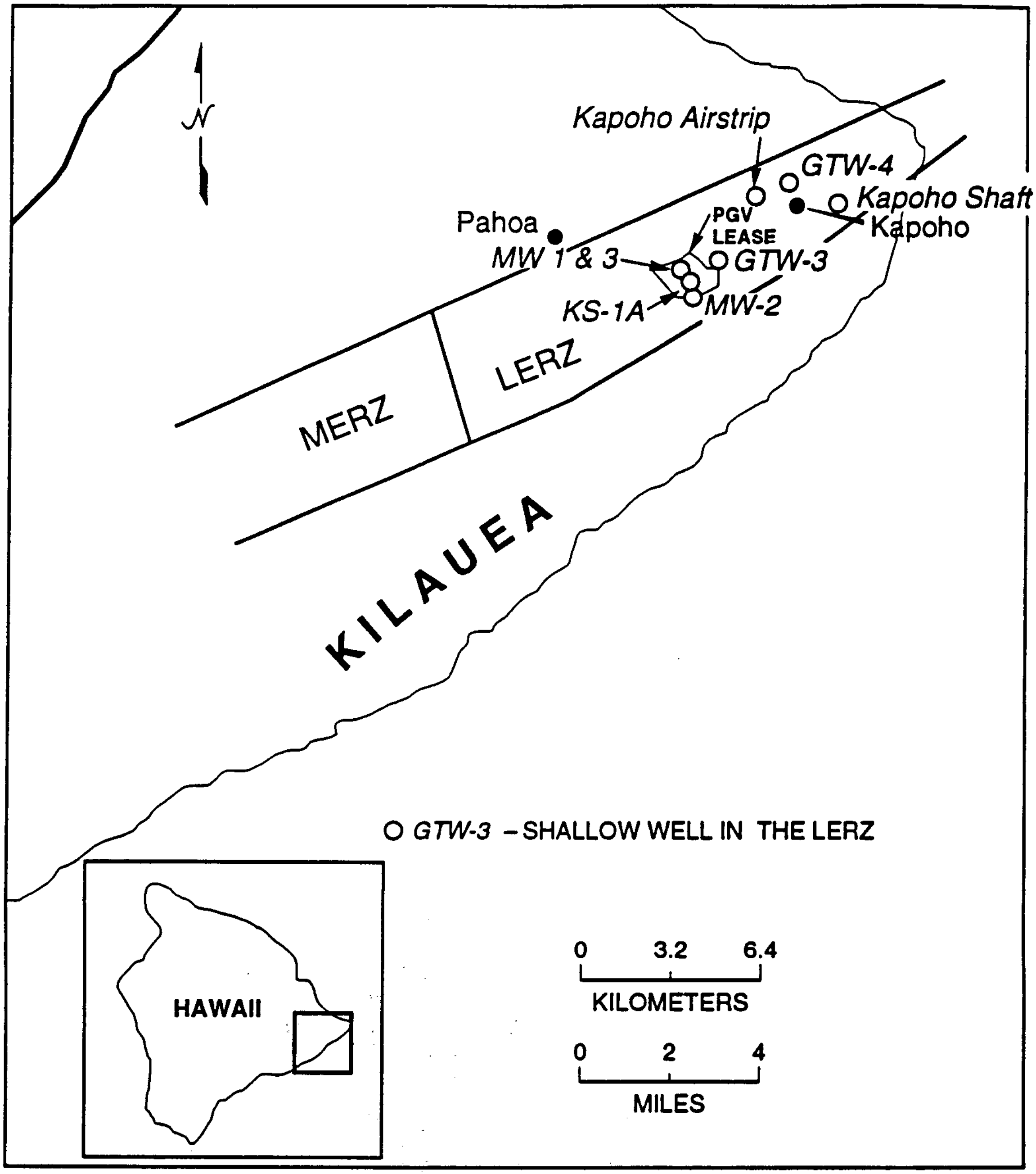


**Fig. 2. Shallow wells in Kilauea's lower east rift zone.** *Source:* Sorey and Colvard 1993.

**Table 3. Chemical and thermal characteristics of water in shallow wells in the lower east rift zone[a]**
(See Fig. 2 for well locations)

| Well | Date sampled | Depth (m) | Water type[a] | Temp (°C) | pH | TDS | Cl | $HCO_3$ | $SO_4$ | $SiO_2$ | F | $NO_3$ | Trace elements[b] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GTW-3[c] | 9/92 | 210 | V | 89 | 7.2 | 11,000 | 6040 | 28 | 565 | 220 | 0.3 | BDL | 20.8(Br)[d] |
| GTW-4 | 6/61 | 88 | IV | 43 | 7.9 | 220 | 72 | NP[e] | 18 | 44 | NP | NP | NP |
| Kapoho airstrip | 11/82 | 103 | IV | 35 | 7.2 | 905 | 390 | NP | 65 | 70 | NP | NP | NP |
| Kapoho shaft | 9/92 | 14 | II | 26 | 8.0 | 603 | 143 | 352 | 18 | 57 | 0.1 | 10.1 | 0.44(Br) |
| MW-1[f] | 9/92 | 220 | III | 44 | 7.1 | 449 | 20 | 36 | 195 | 104 | 0.3 | BDL | 0.3(B) |
| MW-2 | 4/93 | 195 | V | 67 | 7.8 | 1700 | 838 | 75 | 121 | 80 | 0.4 | BDL | 3.0(Br)[g] |
| MW-3 | 9/92 | 220 | III | 44 | 7.1 | 459 | 20 | 37 | 203 | 106 | 0.3 | BDL | 0.3(B) |
| KS-1A[h] | -/85 | NP | V | 38 | 8.5 | NP | 1100 | NP | 74 | 105 | NP | NP | NP |
| Range[i] | | | | | | | | | | | | | |
| High | | 220 | V | 89 | 7.9 | 11,000 | 6040 | 75 | 565 | 220 | 0.4 | | 20.8(Br) |
| Low | | 88 | III | 35 | 7.1 | 220 | 20 | 28 | 18 | 44 | 0.1 | BDL | BDL |

Note: Chemical concentrations in milligrams per liter, except as noted.

[a]Water types are defined in Table 1.

[b]Generally near or below detection limits (BDL) for trace elements tested (Li, B, Br, Ag, Al, As, Ba, Cd, Co, Cr, Cs, Cu, Mo, Ni, Pb, Rb, Sb, Se, Sr, Zn), except as noted.

[c]GTW - shallow geothermal test wells.

[c]Concentrations near or below detection limits (BDL) for elements tested (Li, B, Br, Ag, Al, As, Ba, Cd, Co, Cr, Cs, Cu, I, Mo, Pb, Rb, Sb, Se, Sr, Zn), except as noted.

[d]Other trace elements are: B - 2.0, As - 0.05, Ba - 0.25.

[e]NP - not provided.

[f]MW - monitor wells at Puna Geothermal Venture Power Plant.

[g]Other trace element is: B - 0.3.

[h]KS-1A, shallow groundwater in Kapoho state geothermal well.

[i]Range for wells completed in the basal groundwater lens. Groundwater in Kapoho shaft is perched.

*Source:* Sorey and Colvard 1993; Jink, Matherson and Scholl 1994.

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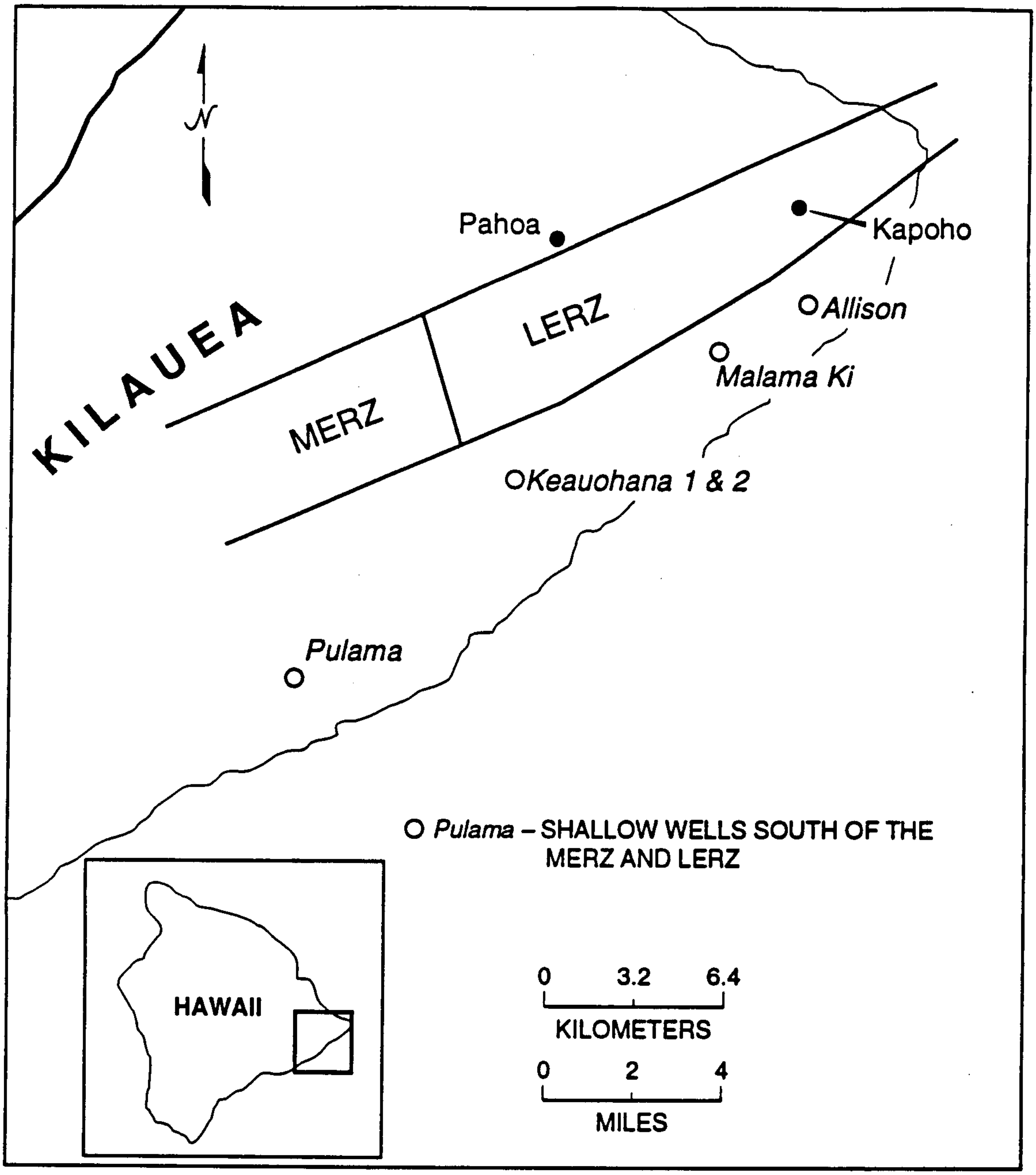


**Fig. 3. Shallow wells south of the middle east rift zone and the lower east rift zone.** *Source:* Sorey and Colvard 1993.

**Table 4. Chemical and thermal characteristics of water in shallow wells south of the middle east rift zone and the lower east rift zone[a]**
(See Fig. 3 for well locations)

| Well | Date sampled | Depth (m) | Water type[a] | Temp (°C) | pH | TDS | Cl | $HCO_3$ | $SO_4$ | $SiO_2$ | F | $NO_3$ | Trace elements[b] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Allison | 7/82 | 43 | V | 38 | 7.3 | 3709 | 2042 | 132 | 69 | 24 | NP[c] | NP | NP |
| Keauohana 1 | 9/92 | 244 | II | 25 | 7.0 | 225 | 76 | 34 | 16 | 51 | 0.2 | BDL | 0.2 (Br) |
| Keauohana 2 | - /74 | 245 | II | 24 | 7.0 | 304 | 160 | 42 | 25 | 45 | 0.3 | 0.2 | BDL |
| Malama Ki | 4/93 | 97 | V | 53 | 7.3 | 8980 | 5850 | 178 | 589 | 144 | 0.3 | 1.4 | 17.4(Br)[d] |
| Pulama | 12/63 | 76 | II | 28 | 7.5 | 838 | 345 | 54 | 65 | 72 | 0.1 | 0.3 | 0.1 (Cu, Zn) |
| **Range[c]** | | | | | | | | | | | | | |
| High | | 245 | V | 53 | 7.5 | 8980 | 5850 | 178 | 589 | 144 | 0.3 | 1.4 | 17.4 (Br) |
| Low | | 43 | II | 24 | 7.0 | 225 | 76 | 34 | 16 | 24 | 0.1 | BDL | BDL |

Note: Chemical concentrations in milligrams per liter, except as noted.
[a]Water types are defined in Table 1.
[b]Generally near or below detection limits (BDL) for elements tested (Li, B, Br, Ag, Al, As, Ba, Cd, Co, Cr, Cs, Cu, Mo, Ni, Pb, Rb, Sb, Se, Sr, Zn), except as noted.
[c]NP - not provided.
[d]Other trace elements B - 2.3, As - 0.08

*Source:* Janik, Matherson, and Scholl 1994.

Water from springs that feed anchialine ponds (coastal ponds which are hydraulically connected to the sea by subsurface conduits) is warm and saline (Type VI). Figure 4 provides the locations of anchialine springs on the southeastern coast of Hawaii. Table 5 lists the chemical and thermal characteristics of these springs as provided by Janik, Nathenson, and Scholl (1994). The locations of uncharacterized anchialine ponds are not shown. Lighthouse Spring (near Cape Kumukahi) and Opihikao Spring are the easternmost and westernmost springs for which chemical and thermal data are available. Data for these springs are arranged with the easternmost spring displayed at the top of Table 5 and the westernmost spring at the bottom. As seen in the table, temperatures and TDS concentrations increase in an orderly manner from east to west [28°C (82°F) to 38°C (100°F) and 3490 mg/L TDS to 8110 mg/L TDS, respectively]. Selected trace element (B and Br) concentrations also increase in an orderly manner from 0.6 to 1.2 mg/L for B and from 6.0 to 14.3 mg/L for Br.

There are two inland springs in Kilauea's LERZ. One (Blue Grotto) is now covered by lava that erupted between 1955 and 1961. It contained Type VI water, based on its temperature and chloride content in 1941 [32°C (90°F) and 1017 mg/L, respectively]. Water in Kapoho Crater Lake is Type I, based on temperature [26°C (79°F)] and chloride concentration (31 mg/L). This lake water also is perched and not in hydraulic connection with either basal lens water or seawater.★

The generalized chemical and thermal characteristics of shallow groundwater in the Puna District suggest that groundwater flows south to the coast from the Kapoho region of the LERZ. The three westernmost springs (Wayne's, Pohoiki, and Opihikao) have water chemistries which are very similar to that of water from the nearby Malama Ki well. The three easternmost springs (Lighthouse, Vacationland, and Kapoho Beachlots) have water chemistries that are more similar to that of the Allison well. Water temperatures in these two wells are 10–20°C (50–68°F) higher than those of the springs. Water from GTW-3 has water chemistry which is very similar to both the Malama Ki well and Pohoiki Spring. Water from the GTW-3 well is about 36°C (97°F) hotter than that of the Malama Ki well. Water in all of these wells and springs contains small concentrations of B and Br (elements commonly found in seawater). In contrast to water in shallow wells and springs on the south side of the KERZ, water in shallow wells on the north side is uniformly cold and low in TDS, and its B and Br concentration are below detection limits.★

There is no evidence to suggest that basal-lens groundwater or anchialine springs on the south side of the KERZ is significantly connected with the KERZ's hydrothermal system. Water in the two Keauohana wells (south of Kamaili) and in the Pulama well (south of the MERZ) is cold and only slightly brackish (Type II). Both of these wells are located near the coast where slightly brackish water would be expected. Boron concentrations are below detection limits in all three wells, and only one well contains a measurable concentration of Br (0.2 mg/L in Keauohana 1).★

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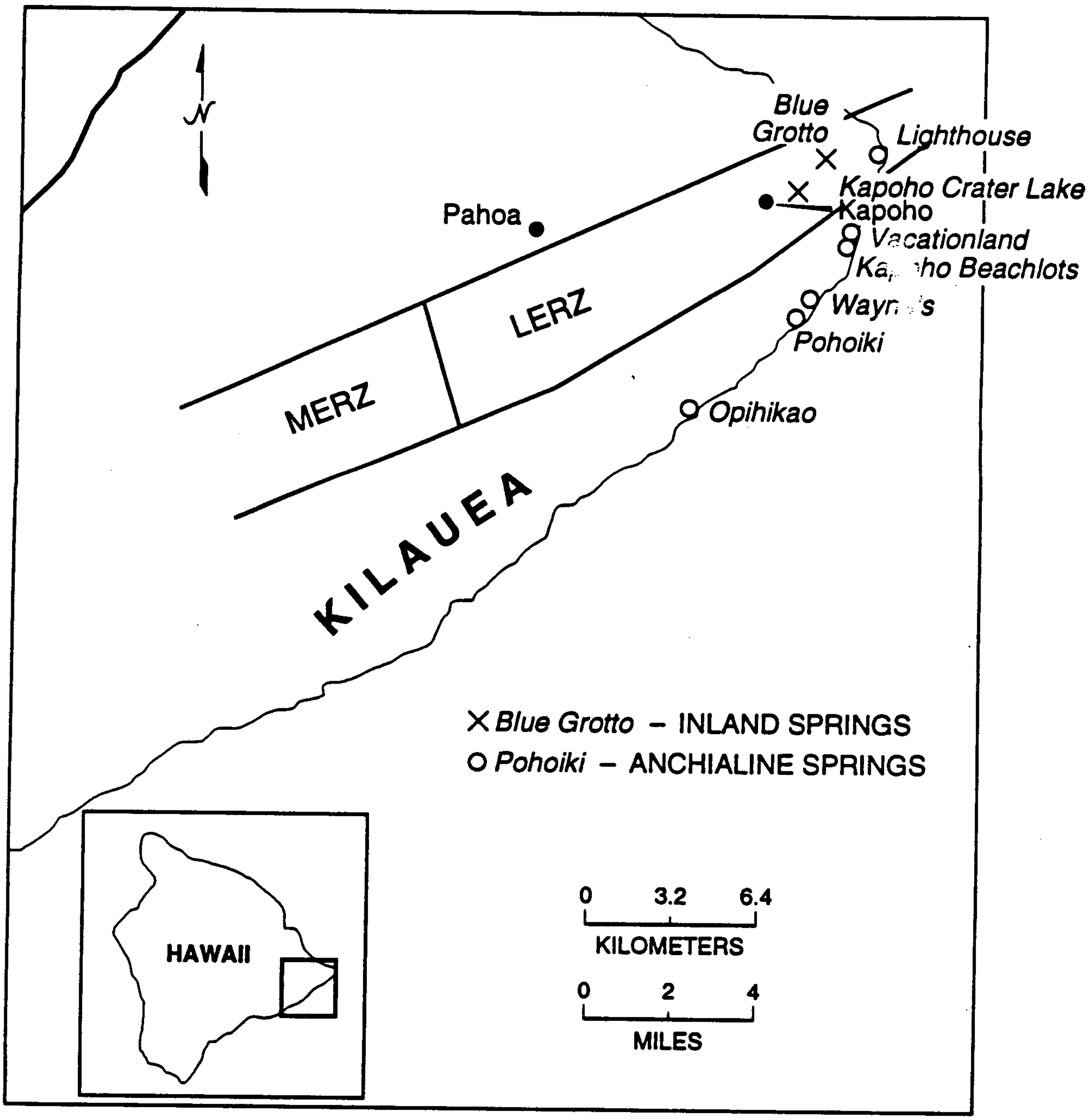


**Fig. 4. Anchialine and inland springs that have been characterized for water chemistry on the southeast coast of Hawaii.** *Source:* Sorey and Colvard 1993.

Table 5. Chemical and thermal characteristics of water in springs and anchialine ponds in the Puna District of Hawaii (See Fig. 4 for well locations)

| Ponds and springs on the coast (NE-SW) | Date sampled | Water type[a] | Temp (°C) | pH | TDS | Cl | $HCO_3$ | $SO_4$ | $SiO_2$ | F | $NO_3$ | Trace elements[b] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lighthouse | 9/92 | VI | 28 | 6.9 | 3490 | 1815 | 46 | 304 | 64 | 0.2 | BDL | B(0.6), Br (6.0) |
| Vacationland | 8/91 | VI | 32 | 7.3 | 4270 | 2168 | 51 | 365 | 76 | 0.5 | 2.2 | B(0.6), Br(8.3 |
| Kapoho beachlots | 9/92 | VI | 33 | 7.1 | 5130 | 2729 | 51 | 457 | 72 | 0.5 | 0.5 | B(0.9), Br(8.5) |
| Wayne's | 8/91 | VI | 37 | 7.1 | 6590 | 3505 | 52 | 509 | 93 | 0.1 | 1.0 | B(0.9), Br(12.4) |
| Pohoiki | 9/15 | VI | 34 | 7.0 | 8110 | 4441 | 60 | 640 | 86 | BDL | 4.7 | B(1.2), Br(14.3) |
| Opihikao | 8/61 | VI | 38 | NP[c] | NP | 4800 | NP[c] | NP | NP | NP | NP | NP |
| **Range** | | | | | | | | | | | | |
| High | | VI | 38 | 7.3 | 8110 | 4800 | 60 | 640 | 93 | 0.5 | 4.7 | B(1.2), Br(14.3) |
| Low | | VI | 28 | 6.9 | 3490 | 1815 | 46 | 304 | 64 | BDL | BDL | B(0.6), Br(6.0) |

Note: Chemical concentrations in milligrams per liter, except as noted.
[a]Water types are defined in Table 1.
[b]Concentrations near or below detection limits (BDL) for elements tested (Li, B, Br, Ag, Al, As, Ba, Cd, Co Cr, Cs, Cu, I, Mo, Pb, Rb, Sb, Se, Sr, Zn), except as noted.
[c]NP - not provided.

*Sources:* Sorey and Colvard 1993; Janik, Nathenson, and Scholl 1994.

## 3. CHEMICAL AND THERMAL CHARACTERISTICS OF GEOTHERMAL FLUID

Figure 5 shows the locations of deep wells in the KERZ. Most of these wells are near Pahoa in the LERZ. Geothermal fluid characteristics are known for only a few wells in and adjacent to the PGV lease. Currently PGV is the only active private developer of geothermal energy in Hawaii. Geothermal fluid characteristics are summarized in this section.

Tables 6 and 7 provide concentrations of common and selected trace elements, respectively, in several Kapoho State PGV wells, two Lanipuna wells, and the HGP-A well.[1] Two distinct groups of wells are represented in these tables. One set of wells characterizes geothermal fluids which consist of a combination of brine and steam. These wells are relatively deep, varying in depth from 1900 to 2560 m (6200 to 8400 ft), have well-head pressures $>10^7$ Pa (a few hundred psig), and are capable of producing mixed brine and steam at rates ranging between 22,700 and 45,350 kg/h (50,000 and 100,000 lb/h) (Janik, Nathenson, and Scholl 1994). A second set of wells characterizes geothermal fluids which consist of steam and steam condensate. These wells (KS-8 and KS-9) are relatively shallow (1070 m, 3500 ft), have well-head pressures from $7 \times 10^6$ to $1.4 \times 10^6$ Pa (1000 to 2000 psig), and are capable of producing predominantly steam at rates between 136,000 and 227,000 kg/h (300,000 and 500,000 lb/h). The chemical characteristics of fluids from these two sets of wells also are remarkably different.★

Table 6 provides chemical characteristics for the HGP-A well both before production began (February 1977) and about midway through the production period (November 1984). A liquid sample taken in 1977 was collected after considerable steam had separated out at atmospheric pressure (0 psig) and at a temperature of 100°C (212°F). Although chemicals become more concentrated in the remaining liquid, this sample had relatively low TDS (2500 mg/L). Eight years later a sample was taken from separated liquid at a pressure of $1 \times 10^6$ Pa (158 psia) and a temperature of 184°C (363°F). Although proportionately less steam probably separated out of the more recent sample, the TDS was relatively high (17,000 mg/L). Geothermal fluid was not reinjected during production. The nature of the reservoir fluid changed over time, perhaps because more saline water was drawn into the well from more distant sources within the reservoir or from separate reservoirs (Sorey and Colvard 1993).

Table 6 also provides chemical characteristics for other combination brine and steam wells. Like the HGP-A well, the liquid phase was sampled after steam-separation occurred. The data represent chemical characteristics of the liquid phase of shut-in wells at their most recent sampling dates. Although these data do not provide information about the nature of unseparated reservoir fluid, they provide an indication of chemical characteristics of the liquid phase in the borehole as steam is released at various temperatures and pressures. The TDS in the liquid phase ranges from 17,000 mg/L to 86,000 mg/L. The pH ranges from 3.6 (strongly acidic) to 8.3 (moderately alkaline). Most of the geothermal liquids are mildly to strongly acidic.

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[1]Most of these geothermal wells were drilled since 1981. The HGP-A well was completed as a production well in 1977 to provide steam for the Hawaii Geothermal Projects 3 MW(e) pilot plant.

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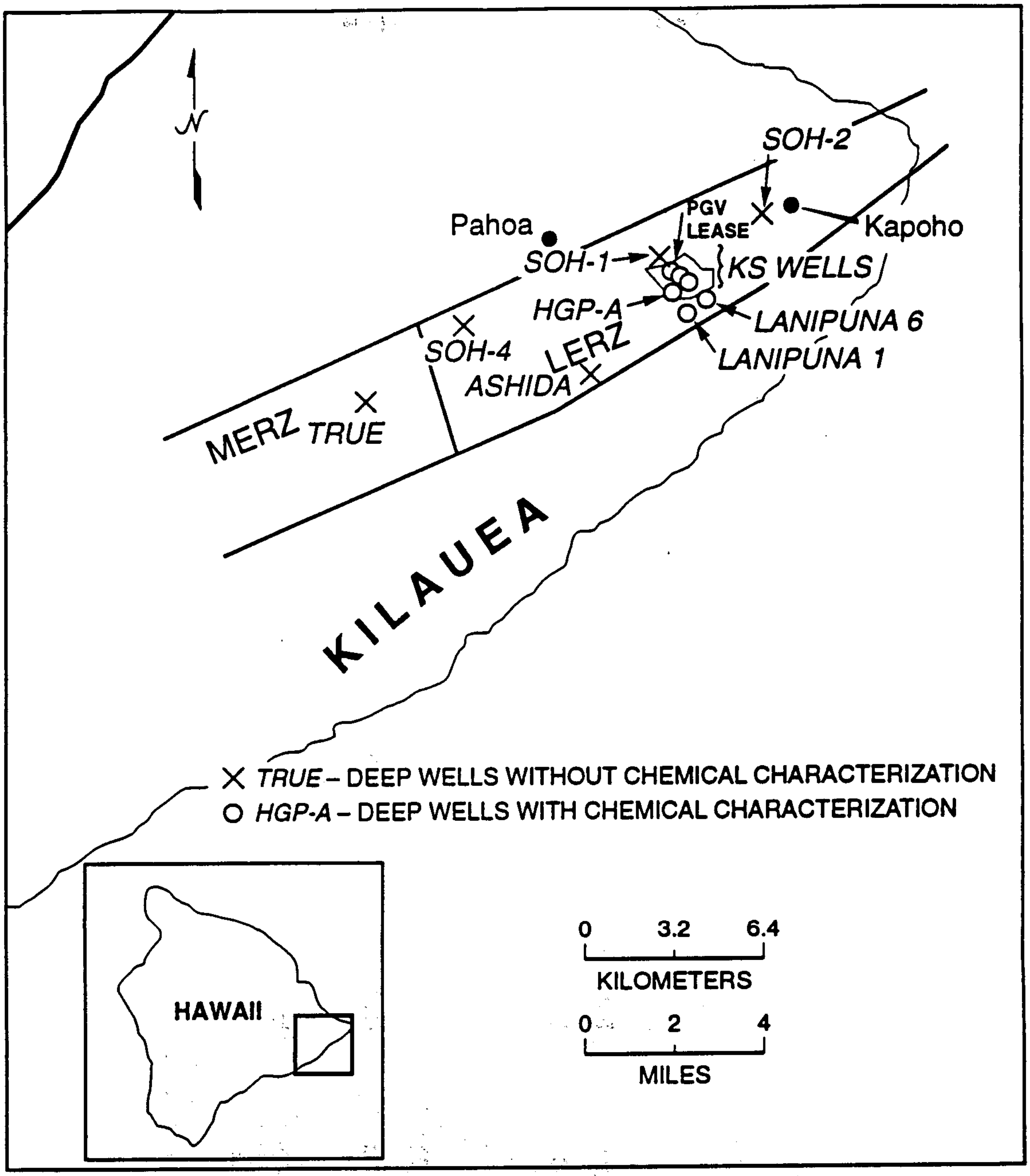


**Fig. 5. Deep wells in the Kilauea east rift zone.** *Source:* GeothermEx, Inc. 1992.

## Table 6. Chemical and thermal characteristics of geothermal fluids in deep wells
(See Fig. 5 for well locations)

| Well | Date sampled | Pressure Pa × $10^5$ | Temp (°C) | pH | TDS | Cl | $HCO_3$ | $SO_4$ | $SiO_2$ | F | $NO_3$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Brine/steam wells**[a] | | | | | | | | | | | |
| HGP- A[b] | 2/77 | 1.0 | 100 | NP[c] | 2500 | 1600 | NP | NP | 740 | NP | NP |
| HGP-A | 11/84 | 10.3 | 184 | 6.6 | 17,000 | 9500 | NP | 5 | 913 | NP | NP |
| HGP-A[e] | 11/84 | 10.3 | 184 | 6.6 | 12,400 | 6920 | NP | NP | 664 | NP | NP |
| KS[e]-1A | 10/85 | 11.6 | 185 | 4.5 | 36,700 | 21,000 | 0 | 12 | 2000 | 0.9 | NP |
| KS-1A[d] | 10/85 | 11.6 | 185 | 4.5 | 16,300 | 9340 | | 5 | 683 | 0.7 | |
| KS-2 | 6/82 | NP | NP | NP | 22,200 | NP | NP | NP | 1100 | 0.8 | NP |
| KS-3 | -/91 | NP | NP | 3.6 | 86,300 | 50,100 | 0 | 6 | 1400 | 2.0 | NP |
| Lanipuna 1 | 7/81 | NP | NP | 6.6 | 26,500 | 16,400 | 9 | 71 | 284 | 0.1 | |
| Lanipuna 6 | 8/84 | NP | 168 | 8.3 | 26,500 | 15,600 | 34 | 403 | 135 | NP | NP |
| **Predominantly steam wells** | | | | | | | | | | | |
| KS-8 | | | | | | | | | | | |
| Liquid | 8/92 | 15.8 | 198 | 4.2 | 241 | 17 | 0 | 3 | 203 | 0.3 | BDL |
| Vapor | 8/92 | 15.8 | 198 | 3.8 | 6 | BDL | 0 | 6 | 0.1 | BDL | BDL |
| KS-9 | | | | | | | | | | | |
| Liquid | 4/93 | 16.0 | 200 | 5.9 | 262 | 11 | 0 | 2 | 231 | 0.5 | 0.03 |
| Vapor | 4/93 | 16.0 | 200 | 4.0 | NP | BDL | NP | 12 | 0.2 | BDL | BDL |
| KS-9I[f] | 4/93 | NP | 72 | 4.7 | 47 | 2 | 0 | 16 | 24 | 0.1 | 0.03 |

Note: Chemical concentrations in milligrams per liter, except where noted; to convert from Pascals (Pa) to pounds per square inch (psi) divide by $6.9 \times 10^3$.

[a]Liquid phase only; uncorrected for steam loss, except as noted.
[b]HGP–Hawaii Geothermal Project.
[c]NP–not provided.
[d]Reservoir fluid characterization corrected for steam loss;TDS not provided but estimated by ORNL staff from chloride concentration.
[e]KS–Kapoho State.
[f]Recombined KS9 liquid and vapor injected into KS-1A.

*Sources:* GeothermEx, Inc. 1992; Janik, Nathenson, and Scholl 1994.

**Table 7. Trace element and metals concentration in geothermal fluids of deep wells in the Kilauea east rift zone**

| Well | Date | Li | B | Br | Fe | Mn | Other[b] |
|---|---|---|---|---|---|---|---|
| **Brine/steam wells[b]** | | | | | | | |
| HGP-A | 01/84 | NP[c] | 4.3 | 44.0 | NP | 0.2 | As(0.09) |
| KS-1A | 10/85 | 8.7 | 11.0 | 80.0 | 8.4 | 8.5 | As(0.4), Fe(3.4), Mn(5.8) |
| KS-3 | 11/90 | NP | 2.8 | NP | NP | NP | Cr(0.05), Ni(0.06), Pb(0.06), V(0.7) |
| Lanipuna 1 | 7/81 | NP | 16.4 | NP | NP | NP | NP |
| Lanipuna 6 | 8/84 | NP | 3.4 | NP | NP | NP | NP |
| **Predominantly steam wells** | | | | | | | |
| KS-8 | | | | | | | |
| Liquid | 8/92 | BDL | 6.1 | BDL | 0.31 | 0.11 | Al(0.008), As(0.17), Ba(0.17), Rb(0.004), Sr(0.1) |
| Vapor | 8/92 | BDL | 0.3 | BDL | 0.28 | BDL | NP |
| KS-9 | | | | | | | |
| Liquid | 4/93 | BDL | 8.2 | 0.03 | 0.15 | 0.11 | Al(0.001), As(0.22), Ba(0.57) Rb(0.005) |
| Vapor | 4/93 | BDL | 0.2 | BDL | 0.09 | BDL | NP |
| KS-9I[d] | 4/93 | BDL | 1.2 | BDL | 0.54 | 0.06 | Rb(0.002) |

Note: Concentrations in milligrams per liter.
[a]Very few trace elements tested in brine/steam wells. The following elements were below detection limits (BDL) in KS-8 and KS-9 geothermal fluids: Ag, Cd, Co, Cr, Cs, Cu, I, Mo, Ni, Pb, Sr, and Zn.
[b]Liquid phase only, uncorrected for steam loss.
[c]NP—not provided.
[d]Recombined KS-9 liquid and vapor injected into KS-1A.
*Source:* Janik, Nathenson, and Scholl 1994.

GeothermEx (1992) provides data on reservoir fluid chemical characteristics corrected for steam loss for the HGP-A and KS-1A wells. These values are more representative of reservoir conditions after long-term production in the case of the HGP-A well and prior to commencement of production in the case of the KS-1A well. The TDS in HGP-A and KS-1A reservoir fluids are 12,400 mg/L and 16,300 mg/L, respectively, prior to steam-separation. The TDS concentration after long-term production from the HGP-A well was lower than that of the KS-1A well, which has never been used as a production well. These results suggest that the chemical composition of reservoir fluids may be highly variable over short distances as well as over time.

Chemical characteristics of the predominantly steam wells (steam and steam condensate) also are shown in Table 6. The steam condensate (liquid) in these wells has a very low TDS (241 mg/L to 262 mg/L) and is strongly to moderately acidic (pH from 4.2 to 5.9). The steam (vapor) phase has an even lower concentration of TDS (6 mg/L) and also is more strongly acidic (pH from 3.8 to 4.2). Separation pressures and temperatures range from (214 to 218) psig and 198° C (388° F) to 200° C (392° F), respectively. The KS-9 well's recombined liquid and vapor (KS-9I, injectate to injection well KS-1A) has a very low TDS (47 mg/L) and is strongly acidic (pH = 4.7) at a temperature of 72° C (162° F). These data represent reservoir chemistry prior to initiation of steam production. Data are not currently available for reservoir chemistry during steam production from the KS-9 well.

Table 7 presents data on trace elements and metals concentrations in both brine/steam wells and steam wells. Arsenic (As), boron (B), bromine (Br), iron (Fe), and manganese (Mn) are common constituents of brine/steam wells, but only As and B significantly carry over into the steam wells.

## 4. SUMMARY OF CHEMICAL AND THERMAL CHARACTERISTICS OF GROUNDWATER IN THE PUNA DISTRICT.

Table 8 presents a summary of chemical and thermal characteristics of groundwater in the Puna District. Water in shallow wells north of the KERZ is uniformly cold, low in TDS, and low in chemical species normally found in seawater. Water in shallow wells in the KERZ is uniformly warm and most of it is high in TDS and chemical species normally found in seawater. Water in shallow wells south of the KERZ is variable. Water in wells south of the east end of the LERZ is warm and high in TDS, whereas water south of the MERZ and the west end of the LERZ is cold and dilute. Water in anchialine ponds south of the Kapoho Section of the KERZ is warm, high in TDS, and high in chemical species normally associated with seawater. Geothermal brine in the KERZ is hot, high in TDS, and high in chemical species normally associated with seawater. Geothermal steam from steam wells is hot, low in TDS, and low in chemical species normally associated with seawater.

Table 8. Summary of groundwater resource characteristics in the Puna District of Hawaii

| Groundwater resource | Water type[a] | Temp (°C) | pH | TDS | Cl | B | Br |
|---|---|---|---|---|---|---|---|
| **Shallow groundwater** | | | | | | | |
| North of the KERZ | I | 20-24 | 6.8-7.6 | 106-143 | 4-28 | BDL[b] | BDL |
| In the KERZ | III-V | 35-89 | 7.1-7.9 | 220-11,000 | 20-6,040 | BDL-0.3 | BDL-21 |
| South of the KERZ | II & V | 24-53 | 7.0-7.5 | 225-8,980 | 76-5,850 | BDL | BDL-17 |
| **Anchialine ponds** | VI | 28-38 | 6.9-7.3 | 3,490-8,110 | 1,815-4,800 | 0.6-1.2 | 6-14 |
| **Geothermal fluid** | | | | | | | |
| Brine/steam wells | V | 185[c] | 4.5-6.6 | 12,000-16,000 | 6,920-9,340 | 4.3-11 | 44-80 |
| Predominantly steam wells | | | | | | | |
| Liquid | *[d] | 198-200[e] | 4.2-5.7 | 241-262 | 11-17 | 6.1-9.2 | BDL-0.03 |
| Steam condensate | * | 198-200[e] | 3.8-4.0 | NP - 6[f] | BDL | 0.2-0.3 | BDL |
| Recombined | * | 72[g] | 4.7 | 47 | 2 | 1.2 | BDL |

Note: Milligrams per liter, except as noted.
[a]Water types are defined in Table 3.2-4.
[b]BDL (below detection limits), NP (not provided).
[c]Well-head pressures between 144 and 153 psig.
[d]Hot-fresh water, a previously undefined water type.
[e]Well-head pressures between 214 and 218 psig.
[f]NP—not provided.
[g]Well-head pressure of 0 psig.
*Sources*: Janik, Nathenson, and Scholl 1994; Sorey and Colvard (1993); GeothermEx, Inc. 1992.

## 5. RELATIONSHIP OF SHALLOW GROUNDWATER TO HYDROTHERMAL SYSTEMS, SEAWATER, AND METEORIC WATER

The degree of mixing between meteoric and seawater in groundwater can be determined by comparing chloride concentrations, chlorine-magnesium (Cl/Mg), chlorine-boron (Cl/B), and chlorine-bromine (Cl/Br) ratios in groundwater with those in seawater (Sorey and Colvard 1993). Similarities in these ratios suggest that a seawater component is present in groundwater. Assuming steam has not been distilled off, the percentage of seawater may be approximated by the ratio of chloride in seawater versus groundwater. Mixed meteoric and seawater that has been heated by volcanic activity to form hydrothermal water has a much higher ratio of Cl/Mg than unheated seawater but similar Cl/B and Cl/Br ratios. Meteoric water without a seawater component has much smaller Cl/Mg and Cl/B ratios. The temperature of the groundwater provides an indication of influence by the hydrothermal system. Table 9 compares water chemistry in various wells and springs with that of seawater, hydrothermal brine, and hydrothermal steam condensate.

Data from Table 9 are interpreted as follows. Water in shallow wells north of the LERZ is meteoric. This water is mixed with neither seawater nor hydrothermal fluid, and its temperature is low. Hot brine in deep wells in the LERZ is hydrothermally altered seawater. Water in shallow wells in the LERZ is believed to be a mixture of meteoric water, seawater, and steam condensate (Cl–Mg ratios are too low for a significant contribution from geothermal brine) with higher than normal temperatures. Water in shallow wells (Malama Ki and Allison) and all anchialine ponds south and southeast of the east end of the LERZ is a mixture of meteoric and seawater, without hydrothermal fluid; however, higher than normal temperatures suggest that geothermal heating has occurred. Water in shallow wells south of the west end of the LERZ and the MERZ (Keauohana 1, and Pulama, respectively) is meteoric with a slight mix of seawater, normal temperatures, and no hydrothermal fluids.

The presence of seawater in shallow wells in the LERZ (in contrast to similar wells north of the LERZ) may be explained in terms of either convective heating of seawater or heating by commingling seawater with escaping steam and steam condensate. Seawater underlies the fresh water basal lens throughout Hawaii. At the same temperature, seawater is denser than fresh water and remains below the freshwater lens. However, seawater's density decreases when it is heated and/or diluted with steam or steam condensate. This characteristic may allow mixing of heated seawater, steam condensate, and cool fresh water through convective circulation.

It is further suggested (based on this limited data) that the water table must slope south and southeast toward the coast. Fresh water from the north would flush through the LERZ and displace mixed meteoric water, seawater, and steam condensate toward the southeast coast. Convective circulation of heated seawater and steam condensate would replace the displaced groundwater in dynamic equilibrium with fresh water that flushes through the system from the north. The displaced, mixed water eventually would reach the anchialine ponds along the southeast coast. Apparently, this flushing action does not occur south of the west end of the LERZ or the MERZ where the Keauohana and Pulama wells are located. Apparently,

**Table 9. Chloride concentrations and ionic ratios for samples from wells, warm pools, and seawater**

| Feature | Date | Water type[a] | T °C | Cl | Cl/Mg | Cl/B | Cl/Br |
|---|---|---|---|---|---|---|---|
| Sea water | | — | — | 19,000 | 14.1 | 4,200 | 284 |
| Deep wells in the LERZ[b] Geothermal brine wells | | | | | | | |
| KS-1A[c] | 10/29/85 | HB | (360) | 14,280 | 15,870 | 1,721 | 263 |
| KS-3 | 6/9/85 | HB | (360) | (50,100) | (860) | (2,150) | nd |
| HGP-A[d] | 11/28/84 | HB | (330) | 6,924 | 46,160 | 2,086 | 204 |
| Geothermal steam well | | | | | | | |
| KS-8 | 8/92 | SC | (360) | (17) | (425) | (3) | nd |
| Shallow wells north of the LERZ | | | | | | | |
| Hawaiian beaches | 9/16/92 | I | 23 | 16 | 5.7 | 129 | 775 |
| Keonepoko Nui | 9/15/92 | I | 20 | 4 | 0.9 | >175 | >175 |
| Orchidland | | I | 23 | 6–12 | | | |
| Pahoa 2 | 9/15/92 | I | 24 | 4.5 | 1.8 | >450 | >225 |
| Shallow wells in the LERZ | | | | | | | |
| GTW-4[e] | 6/21/61 | IV | 43 | 72 | 9.6 | nd | nd |
| Kapoho Airstrip | 1/11/82 | IV | 35 | 390 | 17.4 | nd | nd |
| Kapoho Shaft | 8/14/92 | II | 25 | 128 | 3.8 | >6,400 | 298 |
| GTW-3 | 9/16/92 | V | 89 | 6,042 | 29.5 | 2,863 | 290 |
| HGP-A (shallow) | 1976 | V | (150) | 4,720 | 337 | nd | nd |
| KS-1 (shallow) | 1985 | V | (45) | 1,150 | 38 | nd | nd |
| KS-1A (shallow) | 1985 | V | (50) | 1,098 | 405 | nd | nd |
| MW-2 | 8/6/91 | V | 58 | 533 | 27.3 | 2,960 | 303 |

Table 9. (Continued)

| Feature | Date | Water type[a] | T °C | Cl | Cl/Mg | Cl/B | Cl/Br |
|---|---|---|---|---|---|---|---|
| MW-2[f] | 9/16/92 | V | 57 | 1,060 | 83.5 | 2,360 | 328 |
| MW-1 | 9/16/92 | III | 44 | 19.6 | 1.5 | 73 | 392 |
| MW-3 | 9/16/92 | III | 44 | 19.9 | 1.5 | 71 | 498 |
| Spring in the LERZ | | | | | | | |
| Blue Grotto | 1941 | VI | 29–32 | 1,017 | nd | nd | nd |
| Lake in the LERZ | | | | | | | |
| Kapoho Crater | 8/14/91 | P | 26 | 31 | 2.8 | >1,550 | 443 |
| Shallow wells south of the east side of the LERZ | | | | | | | |
| Allison | 1/7/75 | IV | 38 | 281 | 18.7 | nd | nd |
| Malama Ki | 9/6/62 | V | (53) | 5,850 | 18.1 | nd | nd |
| Anchialine ponds south of the east side of the LERZ | | | | | | | |
| Kapoho Beachlots | 9/17/92 | VI | 33 | 2,729 | 16.5 | 3,100 | 321 |
| Lighthouse | 8/14/91 | VI | 29 | 1,821 | 16.3 | 4,140 | 276 |
| Opihikao | 8/1/61 | VI | 38 | 4,800 | nd | nd | nd |
| Pohoiki | 8/4/91 | VI | 35 | 3,011 | 15.8 | 4,125 | 280 |
| Pohoiki | 9/15/92 | VI | 34 | 4,441 | 16.7 | 3,800 | 311 |
| Vacationland | 8/14/91 | VI | 32 | 2,168 | 15.4 | 3,740 | 261 |
| Wayne's | 8/3/91 | VI | 37 | 3,505 | 17.2 | 4,800 | 280 |
| Shallow well south of the west side of the LERZ | | | | | | | |
| Keauohana | 9/15/92 | II | 25 | 76 | 23 | >7,600 | 362 |
| Shallow well south of the MERZ[g] | | | | | | | |
| Pulama | 12/6/63 | II | 26 | 345 | 11.1 | nd | nd |

Note: Concentrations in milligrams per liter, except were noted.
[a]Water types are defined in Table 1.
[b]LERZ—lower east rift zone
[c]KS—Kapoho State (well)
[d]HGP—Hawaii Geothermal Project
[e]GTW—geothermal test well
[f]MW—monitor well
[g]MERZ—middle east rift zone.

*Source:* Sorey and Colvard 1993.

groundwater in the MERZ is dike-impounded so that it flows down the axis of the KERZ (east-northeast) rather than across it (south-southeast). ★

The above interpretations are based on the limited number of shallow wells in the Puna District. These interpretations may be confirmed or changed as new groundwater data become available. Groundwater data are especially limited in and adjacent to the MERZ and the west end of the LERZ.

## 6. DIRECTION AND RATE OF GROUNDWATER FLOW IN THE LERZ

Sorey and Colvard (1993) state that a quantitative interpretation of groundwater flow in the LERZ and adjacent regions is complicated by (1) differences in temperature, chemistry, and water source; (2) large differences in permeability related to dikes and other intrusive bodies; (3) influences of fresh water/salt water interfaces; and (4) faults and fracture zones oriented along and transverse to the LERZ. Faults and fracture zones cannot be properly characterized by available drill hole and geophysical data.

Figure 6 is a map of the shallow water table in the LERZ and adjacent areas. Sorey and Colvard (1993) identify two shallow groundwater zones in this region. One is the basal lens, where the water table ranges from about 5.2 m (17 ft) to a meter or so above sea level (from the HGP-A well to the east and south coasts). The other is dike-impounded groundwater, where the water table exceeds 30 m (100 ft) above sea level (the True and SOH-4 wells).[2] Based on the reasonable assumption that there are no barriers to groundwater flow in the basal lens throughout this region, the groundwater flow direction is directly down the slope of the water table to the sea. In contrast, the dike-impounded groundwater may be separated by one or more dikes that are barriers to groundwater flow. Sorey and Colvard (1993) make no predictions with regard to flow directions in dike-impounded groundwater.

Figure 6 provides enough water-table data for Sorey and Colvard (1993) to develop tentative conclusions in regard to shallow groundwater movement east and south of the HGP-A well. These conclusions are based on statistically uncertain data. The uncertainty arises from the fact that variations in water levels from repeated measurements within a given well are similar to the small differences in water levels between wells spaced kilometers apart. North of the LERZ, groundwater flows generally to the northeast; south of the LERZ, the groundwater flows generally to the southeast. Within the LERZ, groundwater generally flows downrift to the northeast. A groundwater flow component also is directed to the east and southeast toward the region of the anchialine ponds.

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[2]The True and SOH-4 wells are the only geothermal test holes drilled in the MERZ. The True well was drilled by a private developer. The SOH-4 well was a scientific observation hole that was drilled by the Hawaii Natural Energy Institute at the University of Hawaii at Monoa.

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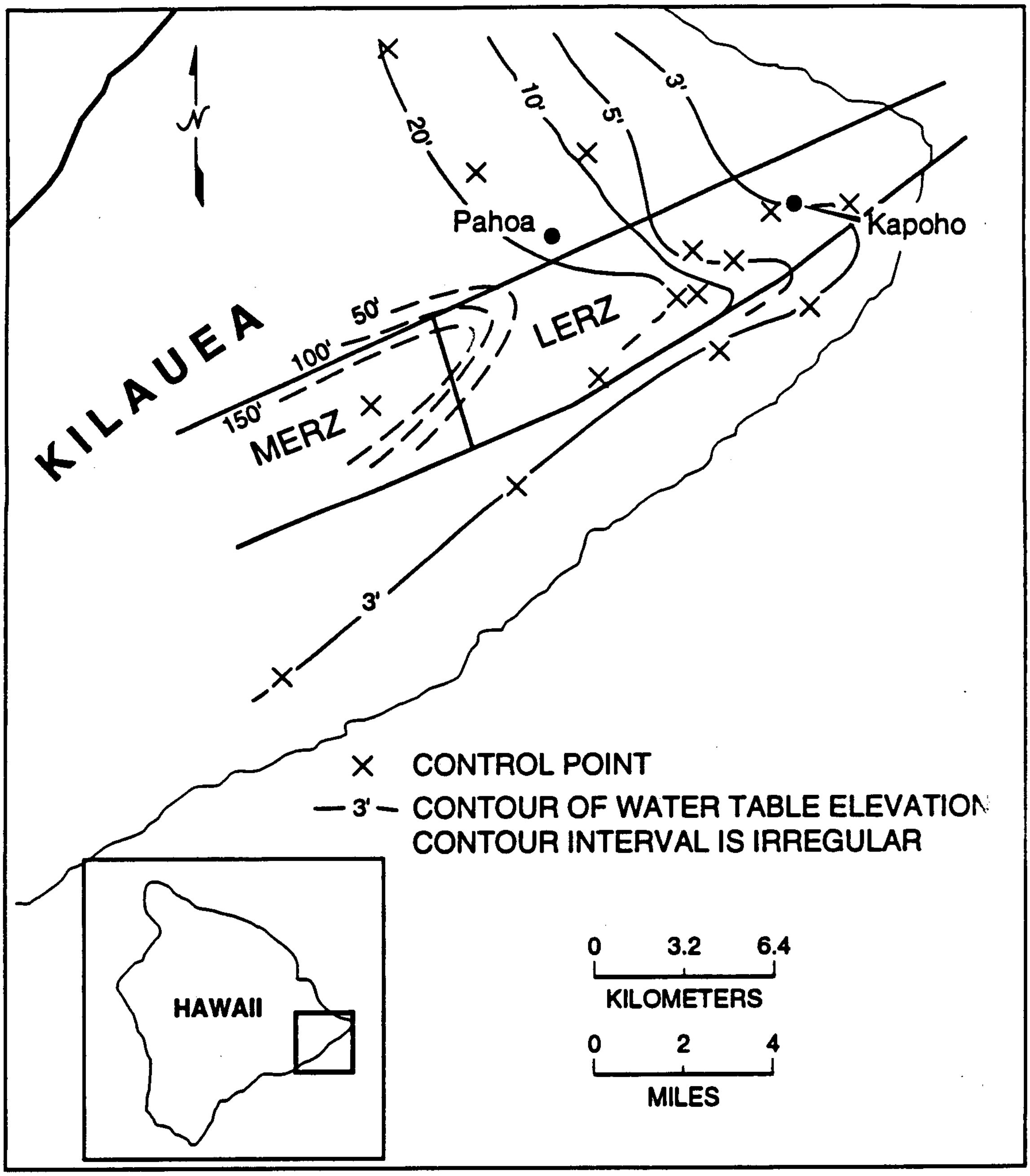


**Fig. 6. Water table elevations in the Puna District.** *Sourc* ey and Colvard, 1993.

The hydraulic gradient (defined as the change in water table elevation per unit of horizontal distance) varies depending on location with respect to the LERZ. Sorey and Colvard (1993) provide estimates of hydraulic gradients from the HGP-A well to the south and east coasts of Hawaii. North of the LERZ the gradient is 0.2–0.8 m/km (1–4 ft/mile with flow northeast toward the coast; south of the LERZ the gradient is about 0.3 m/km (1.5 ft/mile) with flow to the east or southeast toward the coast; within the LERZ the gradient is 0.2–2.8 m/km (1–15 ft/mile) with flow to the northeast as well as east and southeast toward the coast and the anchialine ponds. The average hydraulic gradient in the apparent zone of southeasterly flow is about 0.6 m/km (3 ft/mile). Sorey and Colvard assume that these hydraulic gradients apply to the shallow, unconfined, basal-lens groundwater system where volcanic dike barriers have little or no effect.

The near surface between the HGP-A well site and the south coast is a region of low electrical resistivity as revealed by various geophysical surveys (Kauahikaua 1993; Jackson and Kauahikaua 1987; Flanigan and Long 1987). The low resistivity zone has been interpreted as representing hot, saline (Type V) groundwater moving toward the coast from the LERZ. These natural flows feed the warm anchialine ponds along the southeast coast. Hot and saline (Type V) groundwater has been found in several wells (Malama-ki, GTW-3, and MW-2) within the zone of low electrical resistivity, thus confirming the geophysical interpretation.

Shallow groundwater velocities in the region of the LERZ are uncertain because hydraulic conductivities have been measured in only a few places. Direct measurements from well tests and analyses of tidal fluctuations indicate that hydraulic conductivities range between approximately 900 and 4000 m/day (3000 and 13,000 ft/day) outside the LERZ and about one-tenth that inside the LERZ (M&E Pacific, Inc. 1987). Imada (1984) modeled groundwater flow in the Puna District using assumed hydraulic conductivities of about 4600, 900, and 10 m/day (15,000, 3000, and 30 ft/day) in nonrift, eastern, and western halves of the LERZ, respectively. Water table elevations predicted from the model (using various hydraulic conductivities) were compared with measured water table elevations at a few locations. The best match between predicted and observed water table elevations were obtained using the above hydraulic conductivities. In a similar study, hydraulic conductivities calculated by Takasaki (1993) range from approximately 900–2700 m/day (3000–9000 ft/day) in dike-free lavas of the LERZ, 1800 m/day (6000 ft/day) north of the LERZ, 900 m/day (3000 ft/day) south of the LERZ., and 1.5–9 m/day (5–30 ft/day) in the dike-impounded MERZ.

Sorey and Colvard (1993) used these hydraulic conductivity (k) estimates, water table gradients (i) from Fig. 6, and an assumed porosity (n) of 10% to calculate shallow groundwater velocities (v) in the LERZ. The groundwater velocity is determined using Darcy's law:

$$v = ki/n, \qquad (1)$$

Order of magnitude groundwater velocity estimates range from about 3–30 m/day (10–100–ft/day) in dike-free regions to less than 0.3–3 m/day (1–10 ft/day) where there is dike-impounded shallow groundwater. Imada (1984) obtained groundwater velocities of about

0.03–3.3 m/day (0.1 to 11 ft/day) for the LERZ, the higher values being applicable to the region east of HGP-A where there is no dike-impounded shallow groundwater.

## 7. GROUNDWATER USE IN THE PUNA DISTRICT

Groundwater is currently being withdrawn for domestic use from eight large-capacity wells in the Pahoa, Kapoho, and Kalapana regions. Locations and production data are provided for these wells in Fig. 1 and Table 10, respectively. Production data for Hawaii County Department of Water Supply (DWS) wells were obtained for the years 1988 through 1991. The production data for Miller and Lieb Water Company's (MLWC) and Hawaiian Shores Community Association's (HSCA) wells are more recent (1992). Information concerning these wells was provided to Sorey and Colvard by DWS and Hawaii State Department of Land and Natural Resources (DLNR). The overall average groundwater withdrawal rate for these wells (without regard to groundwater withdrawal records representing different time intervals) is 815 gpm.

Most of the 1989 to 1992 groundwater withdrawals listed in Table 10 were from wells in the Pahoa region north of the LERZ. Together, these five wells accounted for 722 of the 815 gpm average withdrawal rate. The DWS's Pahoa system supplies approximately 2400 people through 787 service hookups. MLWC and HSCA connect to another 1100 service hookups in the Pahoa region. Water from these wells has a relatively low temperature and low chloride concentration compared to other wells in the Puna District (Table 10).★

Smaller groundwater withdrawals occur from wells in and south of the LERZ. One well (Kapoho Shaft) is in the LERZ and two others (Keauohana 1 and 2) are south of the LERZ. The combined groundwater systems in and south of the LERZ (Kapoho and Kalapana systems) connect to only 91 service hookups. Water from these wells has a relatively high temperature and high chloride concentration compared to wells supplying the Pahoa system. Other high yield ($\geq$300 gpm) wells which have been drilled in the LERZ also exhibit high water temperatures and/or chloride concentrations. ★

Future water requirements on the Pahoa system include a proposed golf course and housing development near Pohoiki (south of the LERZ). Although Pohoiki is currently served by the Kapoho Shaft well (in the LERZ), future requirements at Pohoiki may be provided by wells in the Pahoa system.★

Rain catchment systems are used for water supply in areas not serviced by county or water company wells. Catchment systems also are used as backup sources of supply in the event of well supply system failures. To date, contacts with various agencies in Hawaii have failed to provide maps or inventories of water catchment systems in the Puna District.

Historical water requirements for the existing PGV geothermal development have been low. Although two wells were drilled for water supply (MW-1 and MW-3), most of the water consumption for drilling and plant operations has been provided by the DWS well system because of its higher quality (compare Tables 2 and 3). Under normal operations, water is needed for

**Table 10. Average pumping rates and water quality for shallow groundwater wells in and adjacent to the Kilauea lower east rift zone**

| Well (number) | Owner | Location with respect to LERZ | Long-term average pumping rate (L/m) | | Water quality: Temperature (°C) | Water quality: Chloride concentration (mg/L) |
|---|---|---|---|---|---|---|
| Pahoa 1,2 (2986-01, 02) | DWS | North | 795 | (210) | 24[a] | 5[a] |
| Keonepoko Nui (3188-01) | DWS | North | 375 | (99) | 20 | 4 |
| Hawaiian Beaches (3185-01) | MLWC | North | 1438 | (380) | 23 | 16 |
| Hawaiian Shores (3185-02) | HSCA | North | 125 | (33) | | |
| Kapoho Shaft (3080-01) | DWS | In | 155 | (41) | 25 | 128 |
| Keauohana 1,2 (2487-01, 02) | DWS | South | 197 | (52) | 25[c] | 76[c] |
| | | Subtotal: | | | | |
| | | North | 2733 | (722) | | |
| | | In | 155 | (41) | | |
| | | South | 197 | (52) | | |
| | | Total: | 3085 | (815) | | |

Note: DWS—Hawaii County Department of Water Supply; LERZ—Kilauea Volcano's lower east rift zone; MLWC—Miller and Lieb Water Company; HSCA - Hawaiian Shores Community Association.

[a]Pahoa 2.

[b]Keauohana 1.

*Source*: Open-file pumping rate data from the Hawaii County Department of Water Supply and the Hawaii State Department of Land and Natural Resources.

drilling in the upper 600 m (2000 ft) lost water used in drilling does not return to the surface (i.e., lost circulation) for reuse. Flow rates of about 60 gpm per well are required for a period of about two weeks. A significant amount of water also was used to quench uncontrolled venting of geothermal fluid from PGV's KS-8 well during an accidental blowout in June 1991. The existing PGV plant is air-cooled (forced draft), and does not require cooling water.

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