The Department of Health has received the attached petition and report requesting that a portion of the Kapoho area of Hawaii be reclassified as an exempt aquifer in accordance with the State of Hawaii, Department of Health Administrative Rules, Title 11, Chapter 23, Section 11-23-04, "Underground Injection Control."

The criteria for exempting aquifers from underground source of drinking water (USDW) status is as follows:

1. The aquifer does not currently serve as a source of drinking water; and
2. The aquifer cannot now and will not in the future serve as a source of drinking water because of any of the following criteria:
   a. It is situated at a depth or location which currently makes recovery of water for drinking water purposes economically or technologically impractical; or
   b. It is so contaminated that it would be economically or technologically impractical to render that water fit for human consumption; or
   c. The total dissolved solids (TDS) concentration of the ground water is more than five thousand mg/l, and it is not reasonably expected to supply a public or private drinking water system.

The data presented in the report attached to the petition does indicate some geothermal influences upon the groundwater chemistry in the area which the petitioner wishes to exempt. However, these geothermal influences do not necessarily preclude the use of the water as drinking water. Of the eight wells within the proposed exempted area for which data is shown, five (62%) appear to contain water of less than 5,000 mg/l total dissolved solids and one of them is currently used as a source of drinking water (Well 9-6).
With the exception of the area around Well 9-6, none of the groundwater within the proposed exempted area is currently used as a source of drinking water. However, it is ultimately the decision of the County of Hawaii as to whether or not the area will be developed in the future as a source of drinking water.

The petition, as submitted, does have merit and the establishment of an exempted aquifer in the area would facilitate the development of geothermal resources. However, in view of the points discussed above, the final location of a revised UIC Line in the Kilauea Lower East Rift Zone will be negotiated with the County of Hawaii.

The Department would greatly appreciate any comments and/or technical assistance which you and your staff could provide in this matter. Please direct all comments or inquiries to Mr. Dayton Fraim of the Wastewater Permits Section, Environmental Permits Branch, in writing or by telephone at telephone 548-6410, by September 15, 1986.

Sincerely yours,

LESLEY S. MATSUBARA
Director of Health

Attachment
Hawaii State Department of Health
P. O. Box 3378
Honolulu, Hawaii 96801

Attention: Mr. L. S. Matsubara, Director

Re: Petition to Modify the UIC Line in the Lower East Rift Zone, Puna, Hawaii, Hawaii

Gentlemen:

Thermal Power Company (Thermal), operator for the Puna Geothermal Venture (PGV) which includes Amfac Energy, Inc. and Dillingham Geothermal, Inc., is evolving their geothermal activities from exploration to development of a 25 MW power project. The PGV 25 MW Project Area (PGV-PA) is located in the lower East Rift Zone of Kilauea Volcano, Hawaii (Figure 1).

Injection of geothermal fluid is an integral part of any geothermal electric power generation project. The PGV-PA is presently defined as an "Underground Source of Drinking Water" by Hawaii State Underground Injection Control (UIC) regulations. An internal Thermal Power Company geotechnical report which is attached and summarized below, shows that there exists in the lower East Rift Zone, a broad region where geothermal water is present at the top of the basal water and top of the dike-controlled water (see attached report for definition). Geothermal waters are not considered a viable underground source of drinking water. Consequently, Thermal is herein submitting a petition to modify the existing UIC line on the Big Island of Hawaii to include those areas which can be demonstrated as not containing fresh water (Figures 2 and 3). Modification of the UIC line is requested (1) to facilitate the development of the PGV 25 MW Project and (2) to render State UIC regulations consistent with the new technical analysis results.

Any documents, official notices or requests filed with respect to this petition may be addressed to the following Thermal representatives.

Mr. W. L. D'Olier
Diamond Shamrock Thermal Power Company
3333 Mendocino Avenue, Suite 120
Santa Rosa, California 95401

Mr. M. A. Richard
Diamond Shamrock Thermal Power Company
601 California Street, 17th Floor
San Francisco, California 94108

Thermal Power Company
A subsidiary of Diamond Shamrock, 3333 Mendocino Avenue, Suite 120, Santa Rosa, California 95401
Phone 707-576-7022
The Thermal Power Company review of the geological, hydrological and chemical setting of the lower East Rift Zone has indicated the following important insights to the nature of groundwater in this area.

1. Wells in the lower East Rift Zone can be classified as containing either fresh, geothermal or mixed water with available chemical and temperature data.

2. The PCV-PA is localized at an area of upwelling geothermal fluids. A major structural intersection of the East Rift Zone with a transverse fault (Figure 3) is interpreted to provide the conduit allowing the upward migration of fluids.

3. Geothermal waters are detected in the top of the basal water, south and southeast of the rift zone and the PCV-PA, and in the top of the dike-controlled water within the rift (Figure 3). The presence of this geothermal water is interpreted to be a direct result of upwelling fluids from the geothermal reservoir located at greater depth. Since the tops of these water bodies contain geothermal water, the intermediate depth (1500-3000') interval is also interpreted to contain geothermal fluids with the possible exception of Well A and to a lesser extent, Well 9-9.

4. Geothermal fluid leakage from the reservoir is clearly sufficient to overwhelm the original fresh water character of the area of upwelling.

5. Mixed waters are located within the rift zone near Kapoho Crater. This area of mixed waters lies down gradient from the region of upwelling geothermal fluids (Figure 3).

6. Fresh waters are present north of the rift zone, and south of the rift zone in the region southwest of the PCV-PA (Figure 3).

7. Fresh water areas are physically separated from the intended geothermal development area by the East Rift Zone (Figure 3).

8. The entire East Rift Zone, with its high level of volcanic, magmatic and tectonic activity, is not the typical setting for fresh drinking water in the State of Hawaii.

9. There exists a high likelihood that any well containing a mixed water type (within the rift zone) will entrain an increasing geothermal component under extended flowing conditions.

Thermal believes that those areas shown to contain geothermal and/or mixed water should not be classified as an underground source of drinking water. Accordingly, We petition the Hawaii State Department of Health to modify the existing UIC line on the Big Island of Hawaii to include that area in the lower East Rift Zone demonstrated to contain geothermal or mixed water types as shown in Figures 2 and 3, respectively. The modified UIC line has been
constructed to lie within the Kapoho Geothermal Subzone designated by the Board of Land and Natural Resources under Act. 296 SH 1983 except in the area south-southeast of PGV-PA where Wells 9-9 and A have been included. The observation that the intermediate subsurface in the area of Wells 9-9 and A (Figure 2) may not contain geothermal waters does not impact this petition for the following reason. The UIC line only describes where, in a horizontal dimension, injection can occur. The vertical dimension is regulated by Section 11-23-05 of the HDOH, UIC regulations.

If there are any questions in regard to this petition and/or the technical review, please contact Mr. J. (Joe) Iovenitti at [redacted]

Rappaport, Goff
Vice President
Geothermal Exploration

WLD/JLI/ma
JLI062

cc R. A. Patterson
R. T. Pittenger
M. A. Richard
K. J. Tobias
HA-PU-DB-06
HA-SI-GR-13
Figure 1 PROJECT LOCATION MAP
Green Lake and southeast coast warm and hot springs are not considered. See text for explanation.
Geohydrochemical setting of the lower East Rift Zone with special emphasis on the relationship between geothermal fluid injection and Hawaii Department of Health, Underground Injection Control regulations.

Joe Iovonitti
Senior Geologist
3 July 1986
SUMMARY

Three basic water types: geothermal, fresh and mixed, have been identified in the shallow and intermediate subsurface of the lower East Rift Zone, Puna, Hawaii, Hawaii. Geothermal waters are found proximal to a major structural intersection of the East Rift Zone with a transverse fault. This structural intersection is interpreted to provide the conduit for upward migration of geothermal fluids from the reservoir located in the deep subsurface. The intended PGV 25 MW project lies in this region of upwelling geothermal fluids. Fresh waters are present north of the rift zone and south of the rift in the area southwest of the 25 MW project. Mixed waters are located within the rift near Kapeho Crater which lies down gradient from the region of upwelling geothermal fluids.

The characterization of these water types has been conducted through an integrated geohydrochemical review of the lower East Rift Zone. Utilized in this study were all available geotechnical data, statistical and pattern recognition techniques and set theory.

Thermal Power Company believes that those areas shown to contain geothermal or mixed waters should not be classified as an underground source of drinking water. Current Hawaii State Department of Health Underground Injection Control (UIC) regulations designate a large portion of the lower East Rift Zone region as an underground source of drinking water. Accordingly, Thermal petitions the Department to modify their current UIC line on the Big Island of Hawaii to include those areas demonstrated in this report to contain geothermal and/or mixed waters.

INTRODUCTION

Thermal Power Company, operator of the Puna Geothermal Venture (PGV) which includes Amfac Energy, Inc. and Dillingham Geothermal, Inc., has submitted their description of the PGV 25 MW Project in Puna to State and County agencies. This project is located on the Big Island of Hawaii in the lower East Rift Zone (LERZ) of Kilauea Volcano (Figure 1). Injection of geothermal fluids is an integral part of any geothermal electric power generation project. Concomitant with this requirement is the responsibility of the geothermal developer to protect the quality of underground sources of drinking water (USDW) from pollution by subsurface disposal of fluids.

Protection of USDW in Hawaii is regulated by The Safe Drinking Water Act administered by the Environmental Protection Agency. The State of Hawaii has adopted Chapter 23 of Title 11, Administrative Rules, "Underground Injection Control" (UIC) of Hawaii State Department of Health (HDOH) to receive delegation of Federal authority to administer the UIC program at the State level. A large portion of the lower East Rift Zone is currently defined as an underground source of drinking water by HDOH, UIC regulations. This report reviews the overall geologic, hydrologic and chemical setting of the LERZ. It focuses on the hydrochemical characterization of the shallow (surface to 1500') and intermediate (1500' to 4000') subsurface. Injection of geothermal fluids into the geothermal reservoir from which they originated or into a region surrounding the reservoir at comparable depths is a worldwide practice. Characterization of the deep (greater than 4000') subsurface is not warranted herein because the geothermal system occupies this position. Whatever upward movement of injected fluid takes place would be negligible.
relative to what is naturally occurring. Criteria are developed which allows characterization of waters in the LERZ as either a fresh, geothermal, or mixed type. The latter category refers to waters not clearly of the former two types. The current HDOH, UIC regulations are then evaluated with respect to the geohydrochemical setting. Finally, a recommendation is presented to render the Hawaii State UIC regulations consistent with the new technical findings reported herein.

LERZ GEOHYDROCHEMICAL SETTING

Geohydrology

The East Rift Zone is one of the main conduits for the lateral migration of basaltic magma from the holding chamber beneath Kilauea's summit caldera. It is manifested at the surface as a linear and parallel belt, 1-2 miles wide. The rift zone consists of open fissures, faults, small grabens, pit craters, cones and vents related to numerous volcano-tectonic events. In the LERZ, eruptions have occurred as recently as 1740, 1840, 1955, 1960 and 1961. The East Rift Zone is a constructional ridge standing some 500-1500 feet above the adjoining terrain throughout its length except in its lower portion (LERZ) where the ridge disappears into a series of grabens and splatter deposits (Moore, 1983). This change in topographic expression corresponds to a transverse structural break (Figure 4). It is also the site of the geothermal discovery well HGP-A. Underlying the surface expression of the rift at a depth of generally 7600 feet below the surface, is a much broader (5-15 miles wide) dike complex defined by Furumoto (1978). This dike complex is thought to consist of a dense aggregate of closely spaced, parallel to subparallel, vertical to steeply dipping dikes. The intervening region between the dike complex and surface expression of the rift is considered transitional with respect to dike density (Figure 3). The dikes intrude both Mauna Loa and Kilauea lava flows. The dike complex is reported by Furumoto (1978) to be locally above the Curie Point (1000°F) and in places, may even approach the melting point of basalt (1900°F). Petrologic studies of lavas in the rift indicate the presence of differentiated tholeiite which strongly suggests the existence of secondary magma chambers. The Puna geothermal system overlies such an area (Moore, 1983).

A generalized geohydrological model from the east-trending rift zone of Mauna Kea through the LERZ to the sea and the Ghyben-Herzberg principal, are depicted in Figures 2a and 2b, respectively. Basal water occurs north and south of the rift. Within the rift, however, the Ghyben-Herzberg principal is not thought to apply and the water is considered dike-controlled because of the strong structural constraint on water flow imposed by the rift (e.g., dikes, faults). Dike-impounded (or dike-confined) water occurs within the rift zone typically at high elevations where water levels are encountered hundreds of feet above mean sea level. At lower elevations, water within the rift is approximately at sea level.

1 Utilized in this study are all available geotechnical data, statistical and pattern recognition techniques and set theory. Analytical conservatism is maintained throughout the analysis.

2 The term dike-controlled is credited to Mr. D. Fraim of Hawaii Department of Health whose valuable discussions on the hydrology of the Hawaiian Islands assisted the preparation of this document.
Potential freshwater recharge in the LERZ is thought to be derived from both the area uprift of the PGV-PA, (Figure 1) and local rainfall through infiltration. Annual rainfall in LERZ is about 120 inches. This water immediately infiltrates into the ground as virtually no standing water bodies exist. A secondary source of potential recharge to the LERZ is Mauna Loa to the north and northwest. Flow from this large, volcanic edifice would undoubtedly be ponded against the impermeable, northern boundary of the rift. Water would percolate into and through the rift zone only along relatively discrete high permeability sections (e.g. faults) and/or by physically overflowing the dikes. The East Rift Zone forms an excellent barrier to groundwater flow (Druecker and Fan, 1976; Imada, 1984). Groundwater residence time in the LERZ, reported by Kroopnick et al (1978), is on the order of years. The high annual rainfall and short residence time evidence a vigorous groundwater flow system.

Seven deep exploratory wells have been drilled to date where the east-northeast trending rift zone has been structurally offset by a north-northwest trending transverse fault (Figure 4). The geothermal system is thought to be localized by this major fault intersection. Four of the seven wells have been successful. A conceptual model of the principal elements of the geohydrologic setting of the Puna geothermal system is presented in Figure 3. Briefly, the Puna reservoir is a very high temperature, greater than 600°F, two-phase liquid dominated system containing a varying steam fraction and is rift confined except where broken by faults. The reservoir is maintained in this thermodynamic state by a very high heat flow within the rift and by an effective seal inhibiting significant venting of the reservoir to the surface. In spite of the tremendous heat flux generated by the rift zone environment, no marked geothermal surface manifestations (e.g., Yellowstone type) are present except for several hot springs discharging along the southeastern coast of the Big Island of Hawaii and for isolated steam vents within the rift which appear to be more closely related to recently active fissures. The lack of surface manifestations is attributed to a vigorous, cool groundwater system which "hydraulically masks" the geothermal reservoir and a relatively impermeable seal around the reservoir. This coupling effectively keeps the geothermal reservoir suppressed. Where the seal is locally broken by structure, however, leakage of geothermal fluids does occur. Leakage should diminish over time by mineralogical self-sealing of the permeable structures unless reoccurring fault movement maintains these fluid conduits. While this self-sealing phenomenon does occur in a geologic time frame, it will be shown that currently, geothermal fluid leakage from the reservoir into the shallow and intermediate level ground water system is sufficient to totally alter its original fresh water character.

Hydrochemistry

Cox and Thomas (1979) conducted a chemical review of some 400 groundwater samples in the State of Hawaii and have determined three parameters which identify the presence of geothermal water: temperature in excess of 84°F, chloride to magnesium ratio (Cl/Mg) greater than or equal to 15, and silica content exceeding 30-85 mg/l depending on locality. Their study provides the chemical basis for this review.
The location of all the wells in the LERZ are presented in Figure 4 along with selected, key hydrochemical parameters:

1. Total dissolved solids content.
2. Water level.
3. Temperature.
4. Cl/Mg, and
5. SiO₂ content.

Physical data on these wells and their available water chemistry, are summarized in Tables 1 and 2, respectively. Table 1 indicates that the chemical well data pertains to the top of the basal water north and south of the rift. Within the rift, it applies to the top of the dike-controlled water. The only unequivocal exception is Well HGP-A (Table 2) which corresponds to the intermediate level groundwater system. The location, depth and chemistry of Well 9 suggests that it is producing from a perched aquifer. Although a relatively small number of wells (i.e. only 16 data points) exist, regional geohydrochemical systematics are evident which impart critical insights to the injection regulation issue.

North of the LERZ, groundwater elevations would suggest groundwater flow in a north-south direction towards the ocean. However, given the limited data available, it is inferred that a significant portion of the flow in this area is actually moving to the northeast following the topography of Mauna Loa and the LERZ (Figure 4). Within the LERZ, minor dike impoundment has been reported by Kaahukaua et al (1980) and is also observed most notably in Well KS-1A (Table 1). Water flow is principally parallel to the rift (Takasaki and Mink, 1985). South of the LERZ, groundwater elevations do not show a consistent pattern. Groundwater probably flows in a southerly to southeastern direction following topography towards the ocean.

Maximum water temperature in the LERZ wells indicate that ambient conditions exist to the north. Elevated temperatures are present throughout the rift zone except for Well 9 at Kapoho Crater. This well at the base of the Kapoho Crater taps water from an ash formation (Davis and Yamanaga, 1968). It is believed that much of its flow is derived from Green Lake located up gradient within the crater which is the only standing body of water in the entire LERZ. Its existence is attributed to the ash layer acting as an aquitard. Water flow from Green Lake into Well 9 is interpreted to alter both the well's true temperature and chemical characteristics. Wells south of the LERZ show variable temperatures with significantly greater than ambient temperatures south and southeast of the FGV-FA (Figure 4).

The selected hydrochemical data illustrated in Figure 4 and the detailed water chemistry for these wells presented in Table 2 evidence a variability on both an individual well basis (e.g., Well 9-9a through 9-9e, Table 2) and on an areal basis (e.g., Wells KS-1, KS-1A, KS-2 and GTW-III, Figure 4). These data represent analyses conducted by different State and Federal agencies at different times. The variations can be attributable to:

3 The term well is broadly applied herein to also include shafts, holes, etc.
(1) different sampling procedures,
(2) different analytical methods,
(3) environmental factors affecting the water chemistry of the samples such as a significant rain fall prior to sample collection,
(4) natural variations in water chemistry, and
(5) some combination of the above.

Schoeller diagrams (vertical scale chemical concentration plots) have been used to evaluate the validity of individual well, multiple chemical data (Appendix A). Except for Well 9 which displays at least two distinct waters chemistries, the chemical data are in general, coherent and most likely reflect dilution/concentration effects related to the dynamics of the geohydrochemical setting. Significant sampling and/or analytical errors are not evident. Although variability exists on an areal basis, a consistent geochemical pattern has been detected which distinguishes fresh water from geothermal water.

Figure 5a is a semi-logarithmic frequency distribution diagram of the total dissolved solids (TDS) content for wells from the LERZ. TDS content is utilized as it reflects the gross chemical character of the water. Included in this figure are data from four fresh water drinking wells on the island of Oahu (Table 3) which provide an independent, internal control set. The TDS plot has been coded for the three principal indicators of geothermal waters reported by Cox and Thomas (1979): temperature (Figure 5b), chloride to magnesium ratio (Figure 5c) and silica content (Figure 5d). Conservatively, it is observed that all wells with a TDS content greater than 2000 mg/l, exhibit Cl/Mg ratios in excess of 15 and a temperature greater than or equal to 100°F. An elevated temperature of 100°F and chemical signatures clearly fingerprint a water as geothermally anomalous. The silica content of these waters (Figure 5d) displays a more ambiguous pattern. This is attributed to not only the data variation factors described above but also to some extent, precipitation reactions lowering the silica content of the geothermal waters. This four-parameter analysis provides a basis for discriminating between wells which contain either fresh or geothermal water (Table 4).

An independent validation of water type is made through the utilization of 13 chemical parameters given in Table 2. Consistent relationships observed upon increasing the number of parameters involved in any single analysis is interpreted to reflect a meaningful geologic phenomena. It is postulated that unique geothermal and fresh water Schoeller Diagram patterns exist. To evaluate this, the chemical data for any well which occurred in two out of the three geothermal water categories listed in Table 4 were plotted in Figure 6. In contrast, all three fresh categories for fresh waters in Table 4 had to be satisfied before being plotted (Figure 7) for analytical conservatism. Data for Wells 9a, 9b, 9-6a and 9-6b (Table 4) were not plotted in Figure 7 for the following reasons. Well 9 shows at least two distinct fluids, a Na-Ca-HCO₃ and Na-Cl-SO₄-HCO₃ type. Inada (1984) reports that the high bicarbonate (HCO₃⁻) of the fluids results from volcanic emanations. Perched water in Puna, Hawaii tends to be of either a Na-Ca-HCO₃ or a Na-Mg-HCO₃ type; while basal waters are predominately Na-Cl (Druecker and Fan, 1976). The physical setting of Well 9 is consistent with a perched aquifer origin. Well 9-6 exhibits temperature approximate to 100°F and one of the hotter samples 9-6c also shows a Cl/Mg ratio greater than 15.
Comparison of Figures 6 and 7 illustrates that fresh water can be chemically differentiated from geothermal waters, significantly enhancing the previous conclusions. The geothermal fluid contains markedly higher concentrations than fresh water for most of the ions reviewed. They are also anomalous in Mg, SiO₂, HCO₃ and Cl content, Cl/Mg ratio and pH as shown in Figure 8 which illustrates the chemical relationship between geothermal and fresh waters if the concentration effect in the geothermal waters is reduced by one order of magnitude.

These results allow the characterization of three water types: geothermal, mixed, and fresh for wells in the LERZ (Table 5). To maintain analytical conservatism, geothermal waters were only designated upon clear, overwhelming evidence. The temperature and chemical signatures observed in KS-1, KS-1A, KS-2, and GTW-III within the rift and 9-9 and A south and southeast of the rift (Figure 4) are interpreted to result from relatively direct leakage of geothermal fluid into the dike-controlled and basal waters, respectively. The major fault intersection is considered the principal cause for upwelling of geothermal fluids from the geothermal reservoir located in the deep subsurface. This postulation is corroborated by the spontaneous potential anomalies identified by Zablocki (1977). Well 9-9 is proximal to the transverse fault. Well A is a considerable distance away from this feature and its diluted water chemistry and reduced temperature is consistent with mixing of geothermal fluids with fresh water. Previous studies (Davis and Yamanaga, 1968 and 1974; Druecker and Fan, 1976; McMurtrey et al, 1977; and Imada, 1984) attribute the saline nature of the waters south of the LERZ to be the result at least in part, to a decrease in recharge rate to the basal water. The temperature anomaly clearly identifies the geothermal character of these waters. Wells 9-5 and GTW-IV are a mixed water type because they display a partial geothermal character. These wells occur within the LERZ down the hydrologic gradient from the primary identified area of geothermal fluid upwelling. It is postulated that geothermal fluids migrating down the rift mix and possibly react with fresh water resulting in the modified chemical signature. It is also possible that upward leakage of geothermal fluid is also occurring immediate to 9-5 and GTW-IV but to a much lesser extent than in the primary area. Well 9 is also considered a mixed water type for reasons discussed above. Only Wells 9-5 and 9-7 located north and southwest, respectively of the primary area of geothermal fluid upwelling, unambiguously contain fresh water.

This characterization, while specific to the top of the basal water or dike controlled water in the LERZ (shallow subsurface), is also directly applicable to the intermediate subsurface. However, the paucity of data on the intermediate depth geohydrochemical system limits a detailed review. Figure 9 shows that as expected, the total dissolved solids content of the water in the LERZ and temperature are proportional. Wells HGP-A, KS-1, KS-1A and KS-2 have all been found to increase in temperature with depth. It can be readily expected that with increasing depth and temperature, the geothermal character of the water will be progressively enhanced until the geothermal reservoir itself is intersected. The intermediate subsurface in the area of Well 9-9 and to a greater extent Well A, may not contain geothermal waters. This would depend upon the specific degree and depth location of geothermal fluid upwelling in that portion of the structural intersection outside of the rift (Figure 4).
HDOH, UIC REGULATIONS

Classification of exempted aquifers and Underground Sources of Drinking Water, Section 11-23-04 of the HDOH, UIC regulations is presented in Appendix B. Each criteria listed to classify exempted aquifers, is given below in bold type and reviewed for its applicability to the PGV-PA.

(1) The aquifer does not currently serve as a source of drinking water.

The only wells clearly containing fresh drinking water in the LERZ are 9-5 and 9-7 located to the north and south, respectively of the Rift. Furthermore, Well 9-7 is considerably southwest of the area of primary geothermal fluid leakage and oblique to the hydrologic gradient.

(2) The aquifer cannot now and will not in the future serve as a source of drinking water because of any of the following criteria:

(a) it is situated at a depth or location which currently makes recovery of water for drinking water purposes economically or technologically impractical; or

(b) it is so contaminated that it would be economically or technologically impractical to render that water fit for human consumption; or

(c) the total dissolved solids (TDS) concentration of the groundwater is more than five thousand mg/L, and it is not reasonably expected to supply a public or private drinking water system.

Waters in the PGV-PA and to the south and southeast Wells 9-9 and A are clearly geothermal in character (see Figures 1, 4 and Table 5). Mixed water types exist down the hydrologic gradient from the area of primary geothermal fluid. The East Rift Zone is not the typical geologic setting for drinking water in the State of Hawai‘i. Geothermal waters are considered economically and technologically impractical to render water fit for human consumption. Mixed waters are considered marginal for drinking water. There also exists a high probability that any well containing a mixed fluid type may entrain a greater geothermal component to its fluid under high flow rate conditions.

(3) The UIC maps shall indicate exempted aquifers and USDW, in plan view, by use of a UIC Line, and such maps are an integral part of this chapter. The department's UIC maps shall be the final authority for the identification of the aquifer boundaries on the land surface.

The PGV-PA, as well as, the entire LERZ is mauka (towards the mountain) of the existing HDOH, UIC line. The UIC line should be modified to include that area of the LERZ when geothermal and mixed waters are identified.

(4) Unless expressly exempted, all aquifers are considered to be USDW.

A large region within the LERZ satisfies criteria (1) and (2) in HDOH, UIC rules, Section 11-23-04, given above.
CONCLUSIONS AND RECOMMENDATIONS

The geohydrochemical review of the shallow and intermediate subsurface in the LERZ of Kilauea Volcano, Hawaii, Hawaii indicates:

1. fresh water can be thermochemically differentiated from geothermal waters,
2. wells containing geothermal waters occur in the proximity of a major structural intersection in the LERZ,
3. upwelling geothermal fluids from the geothermal reservoir in the deep subsurface are interpreted to be taking place along the zone of structural intersection,
4. geothermal fluid leakage from the reservoir is sufficiently strong to overwhelm the character of fresh water in the zone of vigorous groundwater flow,
5. mixed water type wells evidence the dynamic nature of the geohydrological setting,
6. the East Rift Zone is not a typical geologic setting for drinking water in the State of Hawaii,
7. the area of primary geothermal fluid leakage both within and outside the rift as well as the area hydrologically downgradient should be withdrawn from the classification of underground sources of drinking water.

It is recommended that the UIC line be modified as shown in Figure 10. The modified line encompasses the Kapoho Geothermal Subzone designated by the Board of Land and Natural Resources under Act 296, SLH 1983, as well as wells 9-9 and A south and southeast of the PGV-PA. Modified UIC line is consistent with the purpose and scope of HDOH, UIC regulations. The observation that the intermediate subsurface in the area of Wells 9-9 and A (Figure 10) may not contain geothermal waters does not impact the petition to modify the UIC line as discussed. The reason for this is that the UIC line only describes where injection can occur in a horizontal dimension. The vertical dimension is regulated by Section 11-23-05 of the HDOH, UIC regulations (Appendix C).

OTHER CONSIDERATIONS

The existence of an GEA defines the exempted aquifer area in a horizontal dimension. The vertical dimension is regulated by Section 11-23-05 of the HDOH, UIC regulations (Appendix C).

Mr. Fraim of HDOH has informed Thermal Power Company (personal communication, May 1986) that the occurrence of water in the LERZ is non-artesian. As a consequence, the entire geologic column in a vertical dimension is treated as an exempted aquifer.
REFERENCES


Iovenitti, J. L., and D'Olier, W. L., 1985, Preliminary results of drilling and testing in the Puna geothermal system, Hawaii: Proceedings of Tenth Workshop on Geothermal Reservoir Engineering, Stanford University.


Figure 2a Schematic cross-section from the rift zone of Mauna Kea through the East Rift Zone of Kilauea (see Figure 1) showing the distribution of fresh water and salt water (modified after Stearns and MacDonald, 1943). Two types of ground water occurrences are illustrated: dike-controlled and basal water (Figure 2b) within and outside the rift zone, respectively. Only two water chemical categories are shown.

Figure 2b The Ghyben-Herzberg Principle showing the lens of fresh (basal) water floating on salt water (modified after Stearns, 1966).

Generalized model of the geohydrologic setting of the East Rift Zone.
ZONE OF INFILTRATION
ZONE OF VIGOROUS GROUNDWATER FLOWS
IMPERMEABLE SEAL
HYDROTHERMAL ALTERATION SEALING FAULT

HIGH DENSITY OF DIKES WITHIN RIFT ZONE INCREASING IN FREQUENCY WITH DEPTH. ONLY A FEW ARE SHOWN FOR CLARITY.

LOW DENSITY OF DIKES ON MARGINS

SUPERCRITICAL FLUID?

HIGH HEAT FLOW

SECONDARY MAGMA CHAMBER (?)

CONCEPTUAL MODEL OF THE PUNA GEOTHERMAL SYSTEM. SECTION IS NORMAL TO THE TREND OF THE RIFT ZONE. THE GEOTHERMAL SYSTEM IS RIFT CONFINED EXCEPT IN AREAS OF CROSS-FAULTING. IMPERMEABLE SEAL IS THOUGHT TO BE DUE TO LITHOLOGY AND HYDROTHERMAL ALTERATIONS.

Figure 3
Figure 4  KEY HYDROCHEMICAL DATA FOR WELLS IN THE LOWER EAST RIFT ZONE OF KILAUEA VOLCANO, HAWAII.
Figure 5a Frequency Distribution of TDS Content for Wells in the LERZ. Also includes four drinking water wells from the Island of Oahu (Tables 2 & 3).
Figure 5b Frequency Distribution of TDS Content (Figure 5e) Coded for Temperature.

**TEMPERATURE (F)**
- N 100
- 85 - 99
- 84

**FREQUENCY**
- 4
- 3
- 2
- 1
- 0

**TOTAL DISSOLVED SOLIDS CONTENT (mg/l)**
- 100,000
- 50,000
- 10,000
- 5,000
- 1,000
- 500
- 100
Figure 5c Frequency Distribution of TDS Content (Figure 5a) Coded for Chloride to Magnesium Ratio (Cl/Mg).

Cl/Mg

- > 15
- < 15

TOTAL DISOLVED SOLIDS CONTENT (mg/l)
Figure 5d Frequency Distribution of TDS Content (Figure 5a) Coded for Silica (SiO₂) Content.

SiO₂ CONTENT (mg/l)

- ≤ 29
- 30 - 84
- > 85

Data not available

TOTAL DISSOLVED SOLIDS CONTENT (mg/l)
Figure 6: Schoeller Diagram, geothermal water pattern for wells in the LENZ (see text for explanation).
Figure 7  Schoeller Diagram, fresh water pattern for wells in the LERZ. Also included are four drinking water wells from the island of Oahu (see text for explanation).
Figure 8  Modified Schoeller Diagram (Figures 6 & 7), geothermal water data (except pH) reduced by factor of ion to correct for concentration effect.

- Fresh Water
- Geothermal Water

Concentration (mg/l)

Na  K  Ca  Fe  Mg  SiO2  HCO3  Cl  SO4  P  pH  TDS  Cl/Mg

Cl/Mg ratio plotted on concentration scale.
Figure 9 Relationship between TDS content and temperature for wells in the Lower East Rift Zone. Also included are four drinking water wells from the Island of Oahu (Table 3).
Figure 10 MODIFIED UIC LINE
Table 1. Physical data on wells in the LERZ. See Figure 4 for location. Data from Epp and Halunen (1979), Weiss Associates (1983) and Thermal Power Company.

<table>
<thead>
<tr>
<th>Well</th>
<th>ELEVATION (ft., amsl)</th>
<th>DEPTH (ft.)</th>
<th>WATER LEVEL (ft., amsl)</th>
<th>MAXIMUM TEMP. (°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9-5 A</td>
<td>705</td>
<td>754.7</td>
<td>17.8</td>
<td>72</td>
</tr>
<tr>
<td>9-5B</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>9-6</td>
<td>287</td>
<td>337.15</td>
<td>3.3</td>
<td>98</td>
</tr>
<tr>
<td>9-7</td>
<td>752</td>
<td>801.9</td>
<td>2.94</td>
<td>73*</td>
</tr>
<tr>
<td>9-9</td>
<td>274</td>
<td>316</td>
<td>0.7</td>
<td>131*</td>
</tr>
<tr>
<td>9-11</td>
<td>402</td>
<td>446</td>
<td>11.6</td>
<td>72</td>
</tr>
<tr>
<td>9</td>
<td>38</td>
<td>41</td>
<td>2.6</td>
<td>77</td>
</tr>
<tr>
<td>A</td>
<td>129</td>
<td>140</td>
<td>4.9</td>
<td>102*</td>
</tr>
<tr>
<td>GTW-III</td>
<td>563</td>
<td>690</td>
<td>4.9</td>
<td>199</td>
</tr>
<tr>
<td>GTW-IV</td>
<td>250</td>
<td>290</td>
<td>NA</td>
<td>109</td>
</tr>
<tr>
<td>KS-1</td>
<td>617</td>
<td>782***</td>
<td>11</td>
<td>113</td>
</tr>
<tr>
<td>KS-1A</td>
<td>617</td>
<td>586***</td>
<td>38**</td>
<td>NA</td>
</tr>
<tr>
<td>KS-2</td>
<td>718</td>
<td>732***</td>
<td>10</td>
<td>NA</td>
</tr>
<tr>
<td>GTW-I</td>
<td>1009</td>
<td>178</td>
<td>NA</td>
<td>156</td>
</tr>
<tr>
<td>GTW-II</td>
<td>1035</td>
<td>556</td>
<td>NA</td>
<td>207</td>
</tr>
</tbody>
</table>

1 The term is loosely applied to also include shafts, holes, etc.

2 Above Mean Sea Level

* Temperatures reported in Table 2 are 69° and 83°F for well 9-7, 126°-128°F for well 9-9, and 100°F for well A.

** The significant differential in water level between KS-1 and KS-1A (Figure 4) is in part, thought to result from a data collection error.

*** Depth of well when formation water was intercepted.
Table 2. Water chemistry for wells in the LERZ. All data is in mg/l unless otherwise indicated. See Figure 4 for locations; no data is available on geothermal wells A-1, L-1, and L-6. The term wells for the purposes of this report also includes shafts. Data source is listed below.

<table>
<thead>
<tr>
<th>WELL</th>
<th>Parameter</th>
<th>9-6a</th>
<th>9-6b</th>
<th>9-6c</th>
<th>GTW-IV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>pH</td>
<td>7.3</td>
<td>6.65</td>
<td>8.5</td>
<td>N.A.</td>
</tr>
<tr>
<td></td>
<td>Na</td>
<td>36.0</td>
<td>19.3</td>
<td>16</td>
<td>921</td>
</tr>
<tr>
<td></td>
<td>K</td>
<td>2.72</td>
<td>2.7</td>
<td>3.3</td>
<td>26.0</td>
</tr>
<tr>
<td></td>
<td>Ca</td>
<td>1.58</td>
<td>1.6</td>
<td>1.9</td>
<td>53.2</td>
</tr>
<tr>
<td></td>
<td>Mg</td>
<td>2.7</td>
<td>1.9</td>
<td>5.1</td>
<td>20.2</td>
</tr>
<tr>
<td></td>
<td>Cl</td>
<td>13.5</td>
<td>9.8</td>
<td>4</td>
<td>1150</td>
</tr>
<tr>
<td></td>
<td>SO4</td>
<td>48</td>
<td>44</td>
<td>11</td>
<td>169</td>
</tr>
<tr>
<td></td>
<td>HCO3</td>
<td>21.1</td>
<td>27.3</td>
<td>71</td>
<td>N.A.</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>0.68</td>
<td>0.13</td>
<td>N.A.</td>
<td>0.06</td>
</tr>
<tr>
<td></td>
<td>Fe</td>
<td>N.A.</td>
<td>N.A.</td>
<td>8.8</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Si</td>
<td>3.0</td>
<td>5.16</td>
<td>0.78</td>
<td>38.08</td>
</tr>
</tbody>
</table>

**Notes:***

a = Total Fe  

b = Not Available

PSa Pahoa Station, 6 Jan. '75 sample from Water Resources Research Center (WRRC), University of Hawaii, Manoa (UH-M).  

Psb Pahoa Station, 21 July '75 sample from WRRC, UH-M.  

PSJF Pahoa Village Fresh Water, October 1985, sample from Thermal Power Company.  

KS-1 Geothermal Well, Kapoho State 1, top of dike impounded water analysis, 1983 from Hawaii Dept. of Land and Natural Resources (DLNR).  

KS-1A Geothermal Well, Kapoho State 1-A, top of dike impounded water analysis, 1985 from DLNR.  

KS-2 Geothermal Well, Kapoho State 2, top of dike impounded water analysis, 1984 from DLNR.  


GTW-IIIa Geothermal hole, 7 Jan. '75 sample from WRRC, UH-M.  

GTW-IIIb Geothermal hole, 21 July '75 sample from WRRC, UH-M.  

GTW-IIIc Geothermal hole, (Thief), 21 July '75 sample from WRRC, UH-M.  

9-6a Kapoho hole, 6 Jan. '75 sample from WRRC, UH-M.  

9-6b Kapoho hole, 22 July '75 sample from WRRC, UH-M.  

9-6c Kapoho hole, analysis from Cox and Thomas (1979).  

GTW-IV Geothermal hole, 21 June '61 sample from Hawaii Department of Health (HDOH).
<table>
<thead>
<tr>
<th>Parameter</th>
<th>9a</th>
<th>9b</th>
<th>9c</th>
<th>9d</th>
<th>9-7a</th>
<th>9-7b</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>7.8</td>
<td>7.1</td>
<td>7.7</td>
<td>7.2</td>
<td>7.35</td>
<td>7.02</td>
</tr>
<tr>
<td>Na</td>
<td>85.8</td>
<td>86.5</td>
<td>97</td>
<td>139</td>
<td>216</td>
<td>2105</td>
</tr>
<tr>
<td>K</td>
<td>6.6</td>
<td>6.2</td>
<td>14</td>
<td>25</td>
<td>10.8</td>
<td>109</td>
</tr>
<tr>
<td>Ca</td>
<td>42.4</td>
<td>23.2</td>
<td>47.7</td>
<td>14</td>
<td>13.4</td>
<td>66.8</td>
</tr>
<tr>
<td>Mg</td>
<td>37</td>
<td>25.7</td>
<td>26.5</td>
<td>17</td>
<td>15</td>
<td>219</td>
</tr>
<tr>
<td>Cl</td>
<td>16.9</td>
<td>95.7</td>
<td>125</td>
<td>331</td>
<td>281</td>
<td>3611</td>
</tr>
<tr>
<td>SO₄</td>
<td>20</td>
<td>22.7</td>
<td>5.9</td>
<td>65.4</td>
<td>69.2</td>
<td>471</td>
</tr>
<tr>
<td>HCO₃</td>
<td>372</td>
<td>328</td>
<td>283</td>
<td>61</td>
<td>132</td>
<td>146</td>
</tr>
<tr>
<td>P</td>
<td>0.233</td>
<td>0.268</td>
<td>N.A.</td>
<td>N.A.</td>
<td>&lt;0.002</td>
<td>0.006</td>
</tr>
<tr>
<td>Fe</td>
<td>N.A.</td>
<td>N.A.</td>
<td>N.A.</td>
<td>0.2</td>
<td>N.A.</td>
<td>N.A.</td>
</tr>
<tr>
<td>9a Kapoho Shaft, 6 Jan. '75 sample from WRRC, UH-M.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9b Kapoho Shaft, 21 July '75 sample from WRRC, UH-M.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9c Kapoho Shaft, 15 March '68 sample from Hawaii Board of Water Supply.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9d Kapoho Shaft, sample from DLNR.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9-7a Kalapana Station, 6 Jan. '75 sample from WRRC, UH-M.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9-7b Kalapana Station, unspecified date for sample from WRRC, UH-M.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

9a = Total Fe  
9b = Not Available

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Kaimuki</th>
<th>Wilder</th>
<th>Beretania</th>
<th>Kalihi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temp (°F)</td>
<td>&lt;85*</td>
<td>&lt;85*</td>
<td>&lt;85*</td>
<td>&lt;85*</td>
</tr>
<tr>
<td>pH</td>
<td>8.2</td>
<td>8.5</td>
<td>8.3</td>
<td>8.15</td>
</tr>
<tr>
<td>Na</td>
<td>55</td>
<td>52</td>
<td>39</td>
<td>42</td>
</tr>
<tr>
<td>K</td>
<td>2.3</td>
<td>5.1</td>
<td>3.7</td>
<td>2.5</td>
</tr>
<tr>
<td>Ca</td>
<td>9.0</td>
<td>4.5</td>
<td>10</td>
<td>14</td>
</tr>
<tr>
<td>Mg</td>
<td>11</td>
<td>6.2</td>
<td>11</td>
<td>14</td>
</tr>
<tr>
<td>Cl</td>
<td>79</td>
<td>56</td>
<td>62</td>
<td>80</td>
</tr>
<tr>
<td>SO₄</td>
<td>14</td>
<td>9.5</td>
<td>9.7</td>
<td>13</td>
</tr>
<tr>
<td>HCO₃</td>
<td>76</td>
<td>79</td>
<td>73</td>
<td>71</td>
</tr>
<tr>
<td>SiO₂</td>
<td>41</td>
<td>34</td>
<td>37</td>
<td>44</td>
</tr>
<tr>
<td>P</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Fe</td>
<td>.02</td>
<td>.02</td>
<td>.02</td>
<td>.02</td>
</tr>
<tr>
<td>TDS</td>
<td>322</td>
<td>249</td>
<td>268</td>
<td>283</td>
</tr>
<tr>
<td>Cl/Mg</td>
<td>7.2</td>
<td>9.0</td>
<td>5.6</td>
<td>5.7</td>
</tr>
</tbody>
</table>

*Parameter not reported by Young (1981). It is assumed given the type of well and location.
Table 4. Listing of wells in the LERZ relative to fresh or geothermal water types, see text for explanation.

### WELLS CONTAINING GEOTHERMAL WATERS

<table>
<thead>
<tr>
<th>TDS &gt; 2000 mg/l</th>
<th>Temperature &gt; 100°F</th>
<th>Cl/Mg &gt; 15</th>
</tr>
</thead>
<tbody>
<tr>
<td>KS-1</td>
<td>KS-1</td>
<td>KS-1</td>
</tr>
<tr>
<td>KS-1A</td>
<td>KS-1A</td>
<td>KS-1A</td>
</tr>
<tr>
<td>KS-2</td>
<td>KS-2</td>
<td>KS-2</td>
</tr>
<tr>
<td>HGP-A</td>
<td>HGP-A</td>
<td>HGP-A</td>
</tr>
<tr>
<td>GTW-IIIa, b, and c</td>
<td>GTW-IIIa, b, and c</td>
<td>GTW-IIIa, b, and c</td>
</tr>
<tr>
<td>9-9a, b, c, d, and e</td>
<td>9-9a, and d</td>
<td>9-9a, and d</td>
</tr>
<tr>
<td>GTW-IV</td>
<td>GTW-IV</td>
<td>GTW-IV</td>
</tr>
<tr>
<td>9a, 9b</td>
<td>9a, 9b</td>
<td>9a, 9b</td>
</tr>
</tbody>
</table>

### WELLS CONTAINING FRESH WATERS

<table>
<thead>
<tr>
<th>TDS &lt; 2000 mg/l</th>
<th>Temperature &lt; 100°F</th>
<th>Cl/Mg &lt; 15</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSA, PSb</td>
<td>PSA, PSb</td>
<td>PSA, PSb</td>
</tr>
<tr>
<td>PVFW</td>
<td>PVFW</td>
<td>PVFW</td>
</tr>
<tr>
<td>9-6a, b, c</td>
<td>9-6a, b, c</td>
<td>9-6a, b, c</td>
</tr>
<tr>
<td>GTW-IV</td>
<td>GTW-IV</td>
<td>GTW-IV</td>
</tr>
<tr>
<td>9a, b, c, and d</td>
<td>9a, b, c, and d</td>
<td>9a, b, c, and d</td>
</tr>
<tr>
<td>A</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>9-7a and b</td>
<td>9-7a and b</td>
<td>9-7a and b</td>
</tr>
<tr>
<td>Kaimuki</td>
<td>Kaimuki</td>
<td>Kaimuki</td>
</tr>
<tr>
<td>Wilder</td>
<td>Wilder</td>
<td>Wilder</td>
</tr>
<tr>
<td>Beretania</td>
<td>Beretania</td>
<td>Beretania</td>
</tr>
<tr>
<td>Kalihi</td>
<td>Kalihi</td>
<td>Kalihi</td>
</tr>
</tbody>
</table>
Table 5. Characterization of fresh, geothermal and mixed waters in the LERZ. See text for explanation.

<table>
<thead>
<tr>
<th>WELL</th>
<th>WATER TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSa, PSb</td>
<td>Fresh</td>
</tr>
<tr>
<td>PVFW</td>
<td>Fresh</td>
</tr>
<tr>
<td>KS-1</td>
<td>Geothermal</td>
</tr>
<tr>
<td>KS-1A</td>
<td>Geothermal</td>
</tr>
<tr>
<td>KS-2</td>
<td>Geothermal</td>
</tr>
<tr>
<td>HGP-A</td>
<td>Geothermal</td>
</tr>
<tr>
<td>GTW-IIIa, b and c</td>
<td>Geothermal</td>
</tr>
<tr>
<td>9-6a, b and c</td>
<td>Mixed</td>
</tr>
<tr>
<td>GTW-IV</td>
<td>Mixed</td>
</tr>
<tr>
<td>9a, b, c, and d</td>
<td>Mixed</td>
</tr>
<tr>
<td>A</td>
<td>Geothermal</td>
</tr>
<tr>
<td>9-9a, b, c, d, and e</td>
<td>Geothermal</td>
</tr>
<tr>
<td>9-7a and b</td>
<td>Fresh</td>
</tr>
<tr>
<td>Kaimuki</td>
<td>Fresh</td>
</tr>
<tr>
<td>Wilder</td>
<td>Fresh</td>
</tr>
<tr>
<td>Beretania</td>
<td>Fresh</td>
</tr>
<tr>
<td>Kalihi</td>
<td>Fresh</td>
</tr>
</tbody>
</table>
Appendix A: Individual Schoeller Diagrams for Wells in the Lower East Rift Zone
LOWER EAST RIFT ZONE

GEOTHERMAL WELLS - TOP OF DIKE CONTROLLED WATER

○ KS-1
□ KO-1A
△ KS-2

CONCENTRATION

(mg/l)

Na  K  Ca  Mg  CO3  HCO3  Cl  SO4  P  pH  TDS  Cu/Mg

GU/kg ratio plotted on concentration scale
LOWER EAST NBT ZONE

WELL: NBP-A (22707)

Kroopnich et al (1978)

Cl/Br ratio plotted on concentration scale
LOWEST EAST NIFT ZONE

WELL: GTW IV

June 21, 1961, IDOH

CONCENTRATION (mg/l)

0.1 1 10 100 1000 10,000

Na K Ca Mg SO4 HCO3 CO3 SO4 pH TDS Cl/Mg

Cl/Mg ratio plotted on concentration scale
LOWER EAST RIFT ZONE

WELL: Q

- Jan. 6, 1975 U. of H.
- July 21, 1975 U. of H.
- March 15, 1985 D.YS
- DLHR

(Cu/Lg ratio plotted on concentration scale)
NATURAL COUNTY
WELL: D-5, PANOQ STATION

- Jan. 6, 1975, U. of Ill.
- July 21, 1975, U. of Ill.

CONCENTRATION (mg/l)

Hg

0.1 1 10 100

Br K Na Fe Mg Ca CO3 HCO3 Cl SO4 P pH TDS CV/Mg

CV/Mg ratio plotted on concentration scale
LOWER EAST RST ZONE

WELL: C-6

O Jan. 0, 1973, U. of M.
□ July 22, 1975, U. of M.
△ Cox & Thomas (1979)

CONCENTRATION
(mg/l)

pH

Na K Ca Fe Mg CaCO3 Cl SO4 P pH TDS Cu/Fe

Cu/Fe ratio plotted on concentration scale
SOUTHEASTERN HAWAII COUNTY

WELL: O-7

Jan. 6, 1975, U. of H.
No data, U. of IL

OH

CONCENTRATION
(mg/l)

Na K Ca Mg Fe Si EDO HCO CH CO P pOH TDS Cl/Cu

CU/Mg ratio plotted on concentration scale
LOWER EAST RIFT ZONE
WELL: Q-Q

- Jan. 7, 1976, U. of H.
- July 22, 1975 U. of H.
- USGS
- Cox & Thomas (1975)
- DLNR

Ca/Mg ratio plotted on concentration scale
LOWE R EAST RIFT ZONE
WELL: ALLISON
[Jan. 7, 1976, U. of M.]

CONCENTRATION

(mg/l)

Na  K  Ca  Fe  Mg  HCO  CO3  Cl  SO  P  pH  TDS Cl/Mg

Cl/Mg ratio plotted on concentration scale
HONOLULU DISTRICT SOURCES FOR DRINKING WATER

Kalowaki
Wilder Well No. 30-c
Deratani
Kooli

All data from Young (1981).

CONCENTRATION (mg/l)

Hd

Na K Ca Fe Mg FNO SO Cl NO P pH TDS Ca/Mg

Ca/Mg ratio plotted on concentration scale
§11-23-04 Classification of exempted aquifers and underground sources of drinking water. (a) Upon request, and with concurrence of the director, the department shall review the aquifer designations. The aquifer designations shall be reviewed at least every three years. In its review, the department may amend the status of an aquifer in accordance with chapter 91, HRS. The criteria for exempting aquifers from underground source of drinking water (USDW) status is as follows:

1. The aquifer does not currently serve as a source of drinking water; and
2. The aquifer cannot now and will not in the future serve as a source of drinking water because of any of the following criteria:
   A. It is situated at a depth or location which currently makes recovery of water for drinking water purposes economically or technologically impractical; or
   B. It is so contaminated that it would be economically or technologically impractical to render that water fit for human consumption; or
   C. The total dissolved solids (TDS) concentration of the ground water is more than five thousand mg/L, and it is not reasonably expected to supply a public or private drinking water system.

(b) The UIC maps shall indicate exempted aquifers and USDW in plan view, by use of a UIC Line, and such maps are an integral part of this chapter. The department's UIC maps shall be the final authority for the identification of the aquifer boundaries on the land surface. Copies of the maps and this chapter are available for examination at an office of the department's environmental protection and health services division, the district health offices and other department offices on each island.

(c) Unless expressly exempted, all aquifers are considered to be USDW.
§11-23-05 Identification of exempted aquifers and USDAW. (a) The department has designated the following formations as exempted portions of aquifers: In the horizontal dimension, lands which are makai of the UIC Line; and in the vertical dimension:

(1) Where the volcanic formation is a non-artesian aquifer, the entire geologic column; or

(2) Where the volcanic formation is an artesian aquifer, from the subaerial ground surface down to fifty feet above the contact between the artesian volcanic aquifer and the overlying confining materials.

(b) Unless an aquifer is expressly exempted, as described above or depicted on the department-issued UIC maps, it is an underground source of drinking water.

(c) In areas where the UIC Line is defined by a roadway, a setback of one lot or one hundred fifty feet, whichever is less, from the mauka property line of that roadway may be considered to be within the exempted area. If the roadway is within a property, the setback shall extend to the mauka property line or to one hundred fifty feet from the mauka edge of said roadway, whichever is less. This interpretation of the UIC line shall be subject to all other conditions of this chapter. The applicant, on the permit application, shall request this interpretation, approval of which shall be based on the proximity and sensitivity of drinking water sources. [Eff. JUL 6, 1984 ]

(Auth: HRS §340E-2) (Imp: HRS §340E-2, 40 CFR §§144.7 and 146.4)
July 10, 1986

Hawaii State Department of Health
P. O. Box 3378
Honolulu, Hawaii 96801

Attention: Mr. L. S. Matsubara, Director

Re: Petition to Modify the UIC Line in the Lower East Rift Zone, Puna, Hawaii, Hawaii

Gentlemen:

Thermal Power Company (Thermal), operator for the Puna Geothermal Venture (PGV) which includes Amfac Energy, Inc. and Billingham Geothermal, Inc., is evolving their geothermal activities from exploration to development of a 25 MW power project. The PGV 25 MW Project Area (PGV-PA) is located in the lower East Rift Zone of Kilauea Volcano, Hawaii (Figure 1).

Injection of geothermal fluid is an integral part of any geothermal electric power generation project. The PGV-PA is presently defined as an "Underground Source of Drinking Water" by Hawaii State Underground Injection Control (UIC) regulations. An internal Thermal Power Company geotechnical report which is attached and summarized below, shows that there exists in the lower East Rift Zone, a broad region where geothermal water is present at the top of the basal water and top of the dike-controlled water (see attached report for definition). Geothermal waters are not considered a viable underground source of drinking water. Consequently, Thermal is herein submitting a petition to modify the existing UIC line on the Big Island of Hawaii to include those areas which can be demonstrated as not containing fresh water (Figures 2 and 3). Modification of the UIC line is requested (1) to facilitate the development of the PGV 25 MW Project and (2) to render State UIC regulations consistent with the new technical analysis results.

Any documents, official notices or requests filed with respect to this petition may be addressed to the following Thermal representatives.

Mr. W. L. D'Olier
Diamond Shamrock Thermal Power Company
3333 Mendocino Avenue, Suite 120
Santa Rosa, California 95401

Mr. M. A. Richard
Diamond Shamrock Thermal Power Company
601 California Street, 17th Floor
San Francisco, California 94108

Thermal Power Company
A subsidiary of Diamond Shamrock, 3333 Mendocino Avenue, Suite 120, Santa Rosa, California 95401
Phone 707-576-7022
The Thermal Power Company review of the geological, hydrological and chemical setting of the lower East Rift Zone has indicated the following important insights to the nature of groundwater in this area.

1. Wells in the lower East Rift Zone can be classified as containing either fresh, geothermal or mixed water with available chemical and temperature data.

2. The PGV-PA is localized at an area of upwelling geothermal fluids. A major structural intersection of the East Rift Zone with a transverse fault (Figure 3) is interpreted to provide the conduit allowing the upward migration of fluids.

3. Geothermal waters are detected in the top of the basal water, south and southeast of the rift zone and the PGV-PA, and in the top of the dike-controlled water within the rift (Figure 3). The presence of this geothermal water is interpreted to be a direct result of upwelling fluids from the geothermal reservoir located at greater depth. Since the tops of these water bodies contain geothermal water, the intermediate depth (1500-3000') interval is also interpreted to contain geothermal fluids with the possible exception of Well A and to a lesser extent, Well 9-9.

4. Geothermal fluid leakage from the reservoir is clearly sufficient to overwhelm the original fresh water character of the area of upwelling.

5. Mixed waters are located within the rift zone near Kapoho Crater. This area of mixed waters lies down gradient from the region of upwelling geothermal fluids (Figure 3).

6. Fresh waters are present north of the rift zone, and south of the rift zone in the region southwest of the PGV-PA (Figure 3).

7. Fresh water areas are physically separated from the intended geothermal development area by the East Rift Zone (Figure 3).

8. The entire East Rift Zone, with its high level of volcanic, magmatic and tectonic activity, is not the typical setting for fresh drinking water in the State of Hawaii.

9. There exists a high likelihood that any well containing a mixed water type (within the rift zone) will entrain an increasing geothermal component under extended flowing conditions.

Thermal believes that those areas shown to contain geothermal and/or mixed water should not be classified as an underground source of drinking water. Accordingly, we petition the Hawaii State Department of Health to modify the existing UIC line on the Big Island of Hawaii to include that area in the lower East Rift Zone demonstrated to contain geothermal or mixed water types as shown in Figures 2 and 3, respectively. The modified UIC line has been
constructed to lie within the Kapoho Geothermal Subzone designated by the Board of Land and Natural Resources under Act. 296 SLH 1983 except in the area south-southeast of PCV-PA where Wells 9-9 and A have been included. The observation that the intermediate subsurface in the area of Wells 9-9 and A (Figure 2) may not contain geothermal waters does not impact this petition for the following reason. The UIC line only describes where, in a horizontal dimension, injection can occur. The vertical dimension is regulated by Section 11-23-05 of the HDOH, UIC regulations.

If there are any questions in regard to this petition and/or the technical review, please contact Mr. J. (Joe) Iovenitti at (707) 576-7232.

Respectfully,

W. L. D'Olier
Vice President
Geothermal Exploration

WLD/JLI/ma
JLI062

cc R. A. Patterson
R. T. Pittenger
M. A. Richard
K. J. Tobias
HA-PU-DB-06
HA-SI-GR-13
Figure 2 MODIFIED UIC LINE
Figure 3 WATER TYPES IN THE LOWER EAST RIFT ZONE

Green Lake and southeast coast warm and hot springs are not considered. See text for explanation.
SUMMARY

Three basic water types: geothermal, fresh and mixed, have been identified in the shallow and intermediate subsurface of the lower East Rift Zone, Puna, Hawaii, Hawaii. Geothermal waters are found proximal to a major structural intersection of the East Rift Zone with a transverse fault. This structural intersection is interpreted to provide the conduit for upward migration of geothermal fluids from the reservoir located in the deep subsurface. The intended PGV 25 MW project lies in this region of upwelling geothermal fluids. Fresh waters are present north of the rift zone and south of the rift in the area southwest of the 25 MW project. Mixed waters are located within the rift near Kapoho Crater which lies down gradient from the region of upwelling geothermal fluids.

The characterization of these water types has been conducted through an integrated geohydrochemical review of the lower East Rift Zone. Utilized in this study were all available geotechnical data, statistical and pattern recognition techniques and set theory.

Thermal Power Company believes that those areas shown to contain geothermal or mixed waters should not be classified as an underground source of drinking water. Current Hawaii State Department of Health Underground Injection Control (UIC) regulations designate a large portion of the lower East Rift Zone region as an underground source of drinking water. Accordingly, Thermal petitions the Department to modify their current UIC line on the Big Island of Hawaii to include those areas demonstrated in this report to contain geothermal and/or mixed waters.

INTRODUCTION

Thermal Power Company, operator of the Puna Geothermal Venture (PGV) which includes Amfac Energy, Inc. and Dillingham Geothermal, Inc., has submitted their description of the PGV 25 MW Project in Puna to State and County agencies. This project is located on the Big Island of Hawaii in the lower East Rift Zone (LERZ) of Kilauea Volcano (Figure 1). Injection of geothermal fluids is an integral part of any geothermal electric power generation project. Concomitant with this requirement is the responsibility of the geothermal developer to protect the quality of underground sources of drinking water (USDW) from pollution by subsurface disposal of fluids.

Protection of USDW in Hawaii is regulated by The Safe Drinking Water Act administered by the Environmental Protection Agency. The State of Hawaii has adopted Chapter 23 of Title 11, Administrative Rules, "Underground Injection Control" (UIC) of Hawaii State Department of Health (HDOH) to receive delegation of Federal authority to administer the UIC program at the State level. A large portion of the lower East Rift Zone is currently defined as an underground source of drinking water by HDOH, UIC regulations. This report reviews the overall geologic, hydrologic and chemical setting of the LERZ. It focuses on the hydrochemical characterization of the shallow (surface to 1500') and intermediate (1500' to 4000') subsurface. Injection of geothermal fluids into the geothermal reservoir from which they originated or into a region surrounding the reservoir at comparable depths is a worldwide practice. Characterization of the deep (greater than 4000') subsurface is not warranted herein because the geothermal system occupies this position. Whatever upward movement of injected fluid takes place would be negligible
relative to what is naturally occurring. Criteria are developed which allows characterization of waters in the LERZ as either a fresh, geothermal, or mixed type. The latter category refers to waters not clearly of the former two types. The current HDOH, UIC regulations are then evaluated with respect to the geohydrochemical setting. Finally, a recommendation is presented to render the Hawaii State UIC regulations consistent with the new technical findings reported herein.

LERZ GEOHYDROCHEMICAL SETTING

Geohydrology

The East Rift Zone is one of the main conduits for the lateral migration of basaltic magma from the holding chamber beneath Kilauea's summit caldera. It is manifested at the surface as a linear and parallel belt, 1-2 miles wide. The rift zone consists of open fissures, faults, small grabens, pit craters, cones and vents related to numerous volcano-tectonic events. In the LERZ, eruptions have occurred as recently as 1740, 1840, 1955, 1960 and 1961. The East Rift Zone is a constructional ridge standing some 500-1500 feet above the adjoining terrain except in its lower portion (LERZ) where the ridge disappears into a series of grabens and splatter deposits (Moore, 1983). This change in topographic expression corresponds to a transverse structural break (Figure 4). It is also the site of the geothermal resource discovery Well HGP-A. Underlying the surface expression of the rift at a depth of generally 7600 feet below the surface, is a much broader (5-15 miles wide) dike complex defined by Furumoto (1978). This dike complex is thought to consist of a dense aggregate of closely spaced, parallel to subparallel, vertical to steeply dipping dikes. The intervening region between the dike complex and surface expression of the rift is considered transitional with respect to dike density (Figure 3). The dikes intrude both Mauna Loa and Kilauea lava flows. The dike complex is reported by Furumoto (1978) to be locally above the Curie Point (1000°F) and in places, may even approach the melting point of basalt (1900°F). Petrologic studies of lavas in the rift indicate the presence of differentiated tholeiite which strongly suggests the existence of secondary magma chambers. The Puna geothermal system overlies such an area (Moore, 1983).

A generalized geohydrological model from the east-trending rift zone of Mauna Kea through the LERZ to the sea and the Chyben-Herzberg principal, are depicted in Figures 2a and 2b, respectively. Basal water occurs north and south of the rift. Within the rift, however, the Chyben-Herzberg principal is not thought to apply and the water is considered dike-controlled (Figure 2a) because of the strong structural constraint on water flow imposed by the rift (e.g., dikes, faults). Dike-impounded (or dike-confined) water occurs within the rift zone typically at high elevations where water levels are encountered hundreds of feet above mean sea level. At lower elevations, water within the rift is approximately at sea level.

1 Utilized in this study are all available geotechnical data, statistical and pattern recognition techniques and set theory. Analytical conservatism is maintained throughout the analysis.

2 The term dike-controlled is credited to Mr. D. Fraim of Hawaii Department of Health whose valuable discussions on the hydrology of the Hawaiian Islands assisted the preparation of this document.
Potential freshwater recharge in the LERZ is thought to be derived from both the area uprift of the PGV-PA, (Figure 1) and local rainfall through infiltration. Annual rainfall in LERZ is about 120 inches. This water immediately infiltrates into the ground as virtually no standing water bodies exist. A secondary source of potential recharge to the LERZ is Mauna Loa to the north and northwest. Flow from this large, volcanic edifice would undoubtedly be ponded against the impermeable, northern boundary of the rift. Water would percolate into and through the rift zone only along relatively discrete high permeability sections (e.g. faults) and/or by physically overflowing the dikes. The East Rift Zone forms an excellent barrier to groundwater flow (Druecker and Fan, 1976; Imada, 1984). Groundwater residence time in the LERZ, reported by Kroopnick et al (1978), is on the order of years. The high annual rainfall and short residence time evidence a vigorous groundwater flow system.

Seven deep exploratory wells have been drilled to date where the east-northeast trending rift zone has been structurally offset by a north-northwest trending transverse fault (Figure 4). The geothermal system is thought to be localized by this major fault intersection. Four of the seven wells have been successful. A conceptual model of the principal elements of the geohydrologic setting of the Puna geothermal system is presented in Figure 3. Briefly, the Puna reservoir is a very high temperature, greater than 600°F, two-phase liquid dominated system containing a varying steam fraction and is rift confined except where broken by faults. The reservoir is maintained in this thermodynamic state by a very high heat flow within the rift and by an effective seal inhibiting significant venting of the reservoir to the surface. In spite of the tremendous heat flux generated by the rift zone environment, no marked geothermal surface manifestations (e.g., Yellowstone type) are present except for several hot springs discharging along the southeastern coast of the Big Island of Hawaii and for isolated steam vents within the rift which appear to be more closely related to recently active fissures. The lack of surface manifestations is attributed to a vigorous, cool groundwater system which "hydraulically masks" the geothermal reservoir and a relatively impermeable seal around the reservoir. This coupling effectively keeps the geothermal reservoir suppressed. Where the seal is locally broken by structure, however, leakage of geothermal fluids does occur. Leakage should diminish over time by mineralogical self-sealing of the permeable structures unless reoccurring fault movement maintains these fluid conduits. While this self-sealing phenomenon does occur in a geologic time frame, it will be shown that currently, geothermal fluid leakage from the reservoir into the shallow and intermediate level ground water system is sufficient to totally alter its original fresh water character.

**Hydrochemistry**

Cox and Thomas (1979) conducted a chemical review of some 400 groundwater samples in the State of Hawaii and have determined three parameters which identify the presence of geothermal water: temperature in excess of 84°F, chloride to magnesium ratio (Cl/Mg) greater than or equal to 15, and silica content exceeding 30-85 mg/l depending on locality. Their study provides the chemical basis for this review.
The location of all the wells\(^3\) in the LERZ are presented in Figure 4 along with selected, key hydrochemical parameters:

1. Total dissolved solids content,
2. Water level,
3. Temperature,
4. Cl/Mg, and
5. SiO\(_2\) content.

Physical data on these wells and their available water chemistry, are summarized in Tables 1 and 2, respectively. Table 1 indicates that the chemical well data pertains to the top of the basal water north and south of the rift. Within the rift, it applies to the top of the dike-controlled water. The only unequivocal exception is Well HGP-A (Table 2) which corresponds to the intermediate level groundwater system. The location, depth and chemistry of Well 9 suggests that it is producing from a perched aquifer. Although a relatively small number of wells (i.e. only 16 data points) exist, regional geohydrochemical systematics are evident which impart critical insights to the injection regulation issue.

North of the LERZ, groundwater elevations would suggest groundwater flow in a north-south direction towards the ocean. However, given the limited data available, it is inferred that a significant portion of the flow in this area is actually moving to the northeast following the topography of Mauna Loa and the LERZ (Figure 4). Within the LERZ, minor dike impoundment has been reported by Kauahikaua et al (1980) and is also observed most notably in Well KS-1A (Table 1). Water flow is principally parallel to the rift (Takasaki and Mink, 1985). South of the LERZ, groundwater elevations do not show a consistent pattern. Groundwater probably flows in a southerly to southeasterly direction following topography towards the ocean.

Maximum water temperature in the LERZ wells indicate that ambient conditions exist to the north. Elevated temperatures are present throughout the rift zone except for Well 9 at Kapoho Crater. This well at the base of the Kapoho Crater taps water from an ash formation (Davis and Yamanaga, 1968). It is believed that much of its flow is derived from Green Lake located up gradient within the crater which is the only standing body of water in the entire LERZ. Its existence is attributed to the ash layer acting as an aquitard. Water flow from Green Lake into Well 9 is interpreted to alter both the well's true temperature and chemical characteristics. Wells south of the LERZ show variable temperatures with significantly greater than ambient temperatures south and southeast of the PGV-PA (Figure 4).

The selected hydrochemical data illustrated in Figure 4 and the detailed water chemistry for these wells presented in Table 2 evidence a variability on both an individual well basis (e.g., Well 9-9a through 9-9e, Table 2) and on an areal basis (e.g., Wells KS-1, KS-1A, KS-2 and CTW-III, Figure 4). These data represent analyses conducted by different State and Federal agencies at different times. The variations can be attributable to:

\(^3\) The term well is broadly applied herein to also include shafts, holes, etc.
(1) different sampling procedures,
(2) different analytical methods,
(3) environmental factors affecting the water chemistry of the samples such as a significant rain fall prior to sample collection,
(4) natural variations in water chemistry, and
(5) some combination of the above.

Schoeller diagrams (vertical scale chemical concentration plots) have been used to evaluate the validity of individual well, multiple chemical data (Appendix A). Except for Well 9 which displays at least two distinct water chemistries, the chemical data are in general, coherent and most likely reflect dilution/concentration effects related to the dynamics of the geohydrochemical setting. Significant sampling and/or analytical errors are not evident. Although variability exists on an areal basis, a consistent geochemical pattern has been detected which distinguishes fresh water from geothermal water.

Figure 5a is a semi-logarithmic frequency distribution diagram of the total dissolved solids (TDS) content for wells from the LERZ. TDS content is utilized as it reflects the gross chemical character of the water. Included in this figure are data from four fresh water drinking wells on the island of Oahu (Table 3) which provide an independent, internal control set. The TDS plot has been coded for the three principal indicators of geothermal waters reported by Cox and Thomas (1979): temperature (Figure 5b), chloride to magnesium ratio (Figure 5c) and silica content (Figure 5d). Conservatively, it is observed that all wells with a TDS content greater than 2000 mg/L, exhibit Cl/Mg ratios in excess of 15 and a temperature greater than or equal to 100°F. An elevated temperature of 100°F and chemical signatures clearly fingerprint a water as geothermally anomalous. The silica content of these waters (Figure 5d) displays a more ambiguous pattern. This is attributed to not only the data variation factors described above but also to some extent, precipitation reactions lowering the silica content of the geothermal waters. This four-parameter analysis provides a basis for discriminating between wells which contain either fresh or geothermal water (Table 4).

An independent validation of water type is made through the utilization of 13 chemical parameters given in Table 2. Consistent relationships observed upon increasing the number of parameters involved in any single analysis is interpreted to reflect a meaningful geologic phenomena. It is postulated that unique geothermal and fresh water Schoeller Diagram patterns exist. To evaluate this, the chemical data for any well which occurred in two out of the three geothermal water categories listed in Table 4 were plotted in Figure 6. In contrast, all three fresh categories for fresh waters in Table 4 had to be satisfied before being plotted (Figure 7) for analytical conservatism. Data for Wells 9a, 9b, 9-6a and 9-6b (Table 4) were not plotted in Figure 7 for the following reasons. Well 9 shows at least two distinct fluids, a Na-Ca-HCO₃ and Na-Cl-SO₄-HCO₃ type. Imada (1984) reports that the high bicarbonate (HCO₃) of the fluids results from volcanic emanations. Perched water in Puna, Hawaii tends to be of either a Na-Ca-HCO₃ or a Na-Mg-HCO₃ type; while basal waters are predominately Na-Cl (Druecker and Fan, 1976). The physical setting of Well 9 is consistent with a perched aquifer origin. Well 9-6 exhibits temperature approximate to 100°F and one of the hotter samples 9-6c also shows a Cl/Mg ratio greater than 15.
Comparison of Figures 6 and 7 illustrates that fresh water can be chemically differentiated from geothermal waters, significantly enhancing the previous conclusions. The geothermal fluid contains markedly higher concentrations than fresh water for most of the ions reviewed. They are also anomalous in Mg, SiO$_2$, HCO$_3$ and Cl content, Cl/Mg ratio and pH as shown in Figure 8 which illustrates the chemical relationship between geothermal and fresh waters if the concentration effect in the geothermal waters is reduced by one order of magnitude.

These results allow the characterization of three water types: geothermal, mixed and fresh for wells in the LERZ (Table 5). To maintain analytical conservatism, geothermal waters were only designated upon clear, overwhelming evidence. The temperature and chemical signatures observed in KS-1, KS-1A, KS-2, and GTW-III within the rift and 9-9 and A south and southeast of the rift (Figure 4) are interpreted to result from relatively direct leakage of geothermal fluid into the dike-controlled and basal waters, respectively. The major fault intersection is considered the principal cause for upwelling of geothermal fluids from the geothermal reservoir located in the deep subsurface. This postulation is corroborated by the spontaneous potential anomalies identified by Zablocki (1977). Well 9-9 is proximal to the transverse fault. Well A is a considerable distance away from this feature and its diluted water chemistry and reduced temperature is consistent with mixing of geothermal fluids with fresh water. Previous studies (Davis and Yamanaga, 1968 and 1974; Druecker and Fan, 1976; McMurtry et al, 1977; and Imada, 1984) attribute the saline nature of the waters south of the LERZ to be the result at least in part, to a decrease in recharge rate to the basal water. The temperature anomaly clearly identifies the geothermal character of these waters. Wells 9-6 and GTW-IV are a mixed water type because they display a partial geothermal character. These wells occur within the LERZ down the hydrologic gradient from the primary identified area of geothermal fluid upwelling. It is postulated that geothermal fluids migrating down the rift mix and possibly react with fresh water resulting in the modified chemical signature. It is also possible that upward leakage of geothermal fluid is also occurring immediate to 9-6 and GTW-IV but to a much lesser extent than in the primary area. Well 9 is also considered a mixed water type for reasons discussed above. Only Wells 9-5 and 9-7 located north and southwest, respectively of the primary area of geothermal fluid upwelling, unambiguously contain fresh water.

This characterization, while specific to the top of the basal water or dike controlled water in the LERZ (shallow subsurface), is also directly applicable to the intermediate subsurface. However, the paucity of data on the intermediate depth geohydrochemical system, limits a detailed review. Figure 9 shows that as expected, the total dissolved solids content of the water in the LERZ and temperature are proportional. Wells HGP-A, KS-1, KS-1A and KS-2 have all been found to increase in temperature with depth. It can be readily expected that with increasing depth and temperature, the geothermal character of the water will be progressively enhanced until the geothermal reservoir itself is intersected. The intermediate subsurface in the area of Well 9-9 and to a greater extent Well A, may not contain geothermal waters. This would depend upon the specific degree and depth location of geothermal fluid upwelling in that portion of the structural intersection outside of the rift (Figure 4).
HDOH, UIC REGULATIONS

Classification of exempted aquifers and Underground Sources of Drinking Water, Section 11-23-04 of the HDOH, UIC regulations is presented in Appendix B. Each criteria listed to classify exempted aquifers, is given below in bold type and reviewed for its applicability to the PGV-PA.

(1) The aquifer does not currently serve as a source of drinking water.

The only wells clearly containing fresh drinking water in the LERZ are 9-5 and 9-7 located to the north and south, respectively of the Rift. Furthermore, Well 9-7 is considerably southwest of the area of primary geothermal fluid leakage and oblique to the hydrologic gradient.

(2) The aquifer cannot now and will not in the future serve as a source of drinking water because of any of the following criteria:

(a) it is situated at a depth or location which currently makes recovery of water for drinking water purposes economically or technologically impractical; or

(b) it is so contaminated that it would be economically or technologically impractical to render that water fit for human consumption; or

(c) the total dissolved solids (TDS) concentration of the groundwater is more than five thousand mg/L, and it is not reasonably expected to supply a public or private drinking water system.

Waters in the PGV-PA and to the south and southeast Wells 9-9 and A are clearly geothermal in character (see Figures 1, 4 and Table 5). Mixed water types exist down the hydrologic gradient from the area of primary geothermal fluid. The East Rift Zone is not the typical geologic setting for drinking water in the State of Hawaii. Geothermal waters are considered economically and technologically impractical to render water fit for human consumption. Mixed waters are considered marginal for drinking water. There also exists a high probability that any well containing a mixed fluid type may entrain a greater geothermal component to its fluid under high flow rate conditions.

(3) The UIC maps shall indicate exempted aquifers and USDW, in plan view, by use of a UIC Line, and such maps are an integral part of this chapter. The department's UIC maps shall be the final authority for the identification of the aquifer boundaries on the land surface.

The PGV-PA, as well as, the entire LERZ is mauka (towards the mountain) of the existing HDOH, UIC line. The UIC line should be modified to include that area of the LERZ when geothermal and mixed waters are identified.

(4) Unless expressly exempted, all aquifers are considered to be USDW.

A large region within the LERZ satisfies criteria (1) and (2) in HDOH, UIC rules, Section 11-23-04, given above.
CONCLUSIONS AND RECOMMENDATIONS

The geohydrochemical review of the shallow and intermediate subsurface in the LERZ of Kilauea Volcano, Hawaii, Hawaii indicates:

1. fresh water can be thermochemically differentiated from geothermal waters,

2. wells containing geothermal waters occur in the proximity of a major structural intersection in the LERZ,

3. upwelling geothermal fluids from the geothermal reservoir in the deep subsurface are interpreted to be taking place along the zone of structural intersection,

4. geothermal fluid leakage from the reservoir is sufficiently strong to overwhelm the character of fresh water in the zone of vigorous groundwater flow,

5. mixed water type wells evidence the dynamic nature of the geohydrological setting,

6. the East Rift Zone is not a typical geologic setting for drinking water in the State of Hawaii,

7. the area of primary geothermal fluid leakage both within and outside the rift as well as the area hydrologically downgradient should be withdrawn from the classification of underground sources of drinking water.

It is recommended that the UIC line be modified as shown in Figure 10. The modified line encompasses the Kapoho Geothermal Subzone designated by the Board of Land and Natural Resources under Act 296, SLH 1983, as well as Wells 9-9 and A south and southeast of the PGV-PA. Modified UIC line is consistent with the purpose and scope of HDOH, UIC regulations. The observation that the intermediate subsurface in the area of Wells 9-9 and A (Figure 10) may not contain geothermal waters does not impact the petition to modify the UIC line as discussed. The reason for this is that the UIC line only describes where injection can occur in a horizontal dimension. The vertical dimension is regulated by Section 11-23-05 of the HDOH, UIC regulations (Appendix C).

OTHER CONSIDERATIONS

The UIC line defines where injection can occur in a horizontal dimension. The vertical dimension is regulated by Section 11-23-05 of the HDOH, UIC regulations (Appendix C).

Mr. Fraim of HDOH has informed Thermal Power Company (personal communication, May 1986) that the occurrence of water in the LERZ is non-arteresian. As a consequence, the entire geologic column in a vertical dimension is treated as an exempted aquifer.
REFERENCES


Figure 1: Location of PGV 25kW Geothermal Project. Line A-A' refers to geohydrologic cross-section in Figure 3c.
Figures 2a and 2b illustrate the hydrological setting of the East Rift Zone of Kilauea. Figure 2a shows a schematic cross-section from the rift zone of Mauna Kea through the East Rift Zone of Kilauea (as in Figure 1), demonstrating the distribution of fresh water and salt water (modified after Stearns and Macdonald, 1946). Two types of ground water occurrences are depicted: dike-controlled and basal water (Figure 2b) within and outside the rift zone, respectively. Only two water chemical categories are shown.

Figure 2b The Ghyben-Herzberg Principle showing the lens of fresh (basal) water floating on salt water (modified after Stearns, 1946).

GENERALIZED MODEL OF THE GEOHYDROLOGIC SETTING OF THE EAST RIFT ZONE.
SURFACE EXPRESSION OF EAST RIFT ZONE

ZONE OF INFILTRATION
ZONE OF VIGOROUS GROUNDWATER FLOWS
IMPERMEABLE SEAL
HYDROTHERMAL ALTERATION SEALING FAULT
HIGH DENSITY OF DIKES WITHIN RIFT ZONE INCREASING IN FREQUENCY WITH DEPTH. ONLY A FEW ARE SHOWN FOR CLARITY.

LOW DENSITY OF DIKES ON MARGINS
DIKE SWARM
SUPERCRITICAL FLUID?
HIGH HEAT FLOW
SECONDARY MAGMA CHAMBER (?)
DIKE COMPLEX

TWO PHASE LIQUID DOMINATED RESERVOIR WITH VARIABLE STEAM FRACTION
SUBOUSED LEAKAGE FROM RESERVOIR

CONCEPTUAL MODEL OF THE PUNA GEOTHERMAL SYSTEM. SECTION IS NORMAL TO THE TREND OF THE RIFT ZONE. THE GEOTHERMAL SYSTEM IS RIFT CONFINED EXCEPT IN AREAS OF CROSS-FAULTING. IMPERMEABLE SEAL IS THOUGHT TO BE DUE TO LITHOLOGY AND HYDROTHERMAL ALTERATIONS.

Figure 3
Figure 4 KEY HYDROCHEMICAL DATA FOR WELLS IN THE LOWER EAST RIFT ZONE OF KILAUEA VOLCANO, HAWAII.
Figure 5a Frequency Distribution of TDS Content for Wells in the LERZ Also Includes Four Drinking Water Wells From the Island of Oahu (Tables 2 & 3).

<table>
<thead>
<tr>
<th>TOT DIS SOLIDS CONTENT (mg/l)</th>
<th>FREQUENCY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>4</td>
</tr>
</tbody>
</table>

Legend:
- Bessie
- Willy
- Kalihi
- Ely
- Kimua
- Pali
- PSB
Figure 5b  Frequency Distribution of TDS Content (Figure 5a) Coded for Temperature.

TEMPERATURE (F)

- ≥ 100
- 85 - 99
- ≤ 84
- Data Not Available

TOTAL SOLIDS CONTENT (mg/l)
Figure 5c Frequency Distribution of TDS Content (Figure 5a) Coded for Chloride to Magnesium Ratio (Cl/Mg).

Cl/Mg
- > 15
- ≤ 15

TOTAL DISOLVED SOLIDS CONTENT (mg/l)
Figure 5d Frequency Distribution of TDS Content (Figure 5a) Coded for Silica (SiO₂) Content.

SiO₂ CONTENT (mg/l)

- ≥ 85
- 30 - 84
- ≤ 29
- Data Not Available

TOTAL DISOLVED SOLIDS CONTENT (mg/l)
Figure 6  Schoeller Diagram, geothermal water pattern for wells in the LERZ (see text for explanation).

Cl/Mg ratio plotted on concentration scale
Figure 7  Schoeller Diagram, fresh water pattern for wells in the LERZ. Also included are four drinking water wells from the Island of Oahu (see text for explanation).
Figure 8 Modified Schoeller Diagram (Figures 6 & 7), geothermal water data (except pH) reduced by factor of ten to correct for concentration effect.

<table>
<thead>
<tr>
<th>Element</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na</td>
<td></td>
</tr>
<tr>
<td>K</td>
<td></td>
</tr>
<tr>
<td>Ca</td>
<td></td>
</tr>
<tr>
<td>Fe</td>
<td></td>
</tr>
<tr>
<td>Mg</td>
<td></td>
</tr>
<tr>
<td>SiO₂</td>
<td></td>
</tr>
<tr>
<td>HCO₃</td>
<td></td>
</tr>
<tr>
<td>Cl</td>
<td></td>
</tr>
<tr>
<td>SO₄</td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td></td>
</tr>
<tr>
<td>TDS</td>
<td></td>
</tr>
<tr>
<td>Cl/Mg</td>
<td></td>
</tr>
</tbody>
</table>

Cl/Mg ratio plotted on concentration scale.
Figure 9  Relationship between TDS content and temperature for wells in the Lower East Rift Zone. Also included are four drinking water wells from the Island of Oahu (Table 3).
Table 1. Physical data on wells\(^1\) in the LERZ. See Figure 4 for location. Data from Epp and Halunen (1979), Weiss Associates (1983) and Thermal Power Company.

<table>
<thead>
<tr>
<th>Well</th>
<th>ELEVATION (ft., amsl(^2))</th>
<th>DEPTH (ft.)</th>
<th>WATER LEVEL (ft., amsl)</th>
<th>MAXIMUM TEMP. ((^\circ)F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9-5 A</td>
<td>705</td>
<td>754.7</td>
<td>17.8</td>
<td>72</td>
</tr>
<tr>
<td>9-5B</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>9-6</td>
<td>287</td>
<td>337.15</td>
<td>3.3</td>
<td>98</td>
</tr>
<tr>
<td>9-7</td>
<td>752</td>
<td>801.9</td>
<td>2.94</td>
<td>73*</td>
</tr>
<tr>
<td>9-9</td>
<td>274</td>
<td>316</td>
<td>0.7</td>
<td>131*</td>
</tr>
<tr>
<td>9-11</td>
<td>402</td>
<td>446</td>
<td>11.6</td>
<td>72</td>
</tr>
<tr>
<td>9</td>
<td>38</td>
<td>41</td>
<td>2.6</td>
<td>77</td>
</tr>
<tr>
<td>A</td>
<td>129</td>
<td>140</td>
<td>4.9</td>
<td>102*</td>
</tr>
<tr>
<td>GTW-III</td>
<td>563</td>
<td>690</td>
<td>4.9</td>
<td>199</td>
</tr>
<tr>
<td>GTW-IV</td>
<td>250</td>
<td>290</td>
<td>NA</td>
<td>109</td>
</tr>
<tr>
<td>KS-1</td>
<td>617</td>
<td>782***</td>
<td>11</td>
<td>113</td>
</tr>
<tr>
<td>KS-1A</td>
<td>617</td>
<td>586***</td>
<td>38**</td>
<td>NA</td>
</tr>
<tr>
<td>KS-2</td>
<td>718</td>
<td>732***</td>
<td>10</td>
<td>NA</td>
</tr>
<tr>
<td>GTW-I</td>
<td>1009</td>
<td>178</td>
<td>NA</td>
<td>156</td>
</tr>
<tr>
<td>GTW-II</td>
<td>1035</td>
<td>556</td>
<td>NA</td>
<td>207</td>
</tr>
</tbody>
</table>

1. The term is loosely applied to also include shafts, holes, etc.

2. Above Mean Sea Level

* Temperatures reported in Table 2 are 69\(^\circ\) and 83\(^\circ\)F for well 9-7, 126\(^\circ\)-128\(^\circ\)F for well 9-9, and 100\(^\circ\)F for well A.

** The significant differential in water level between KS-1 and KS-1A (Figure 4) is in part, thought to result from a data collection error.

*** Depth of well when formation water was intercepted.
Table 2. Water chemistry for wells in the LERZ. All data is in mg/1 unless otherwise indicated. See Figure 4 for locations; no data is available on geothermal wells A-1, L-1, and L-6. The term wells for the purposes of this report also includes shafts. Data source is listed below.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>PSa</th>
<th>PSb</th>
<th>PVFW</th>
<th>KS-1</th>
<th>KS-1A</th>
<th>KS-2</th>
<th>HGP-A</th>
<th>GTW-IIIa</th>
<th>GTW-IIIb</th>
<th>GTW-IIIc</th>
<th>9-6a</th>
<th>9-6b</th>
<th>9-6c</th>
<th>GTW-IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temp(°F)</td>
<td>75</td>
<td>74</td>
<td>75</td>
<td>113</td>
<td>&gt;100</td>
<td>&gt;100</td>
<td>300-350</td>
<td>199</td>
<td>N.A.</td>
<td>165</td>
<td>91</td>
<td>92</td>
<td>96</td>
<td>N.A.b</td>
</tr>
<tr>
<td>pH</td>
<td>7.3</td>
<td>6.65</td>
<td>8.5</td>
<td>N.A.</td>
<td>9.5</td>
<td>9.5</td>
<td>3</td>
<td>6.85</td>
<td>N.A.</td>
<td>1.4</td>
<td>7.42</td>
<td>7.75</td>
<td>7.1</td>
<td>7.9</td>
</tr>
<tr>
<td>Na</td>
<td>31.0</td>
<td>19.3</td>
<td>16</td>
<td>614</td>
<td>921</td>
<td>1000</td>
<td>2008</td>
<td>1740</td>
<td>238</td>
<td>223</td>
<td>2158</td>
<td>2292</td>
<td>3140</td>
<td>49.2</td>
</tr>
<tr>
<td>K</td>
<td>2.72</td>
<td>2.7</td>
<td>3.3</td>
<td>46.1</td>
<td>26.0</td>
<td>94</td>
<td>245</td>
<td>190</td>
<td>195</td>
<td>158</td>
<td>13.6</td>
<td>16.8</td>
<td>15.2</td>
<td></td>
</tr>
<tr>
<td>Ca</td>
<td>1.58</td>
<td>1.6</td>
<td>19</td>
<td>53.2</td>
<td>65.8</td>
<td>65</td>
<td>445</td>
<td>76.8</td>
<td>81</td>
<td>71</td>
<td>23.0</td>
<td>12.5</td>
<td>16.5</td>
<td>16.2</td>
</tr>
<tr>
<td>Mg</td>
<td>2.7</td>
<td>1.9</td>
<td>5.1</td>
<td>30.2</td>
<td>27.1</td>
<td>0.5</td>
<td>14</td>
<td>52</td>
<td>59</td>
<td>62.5</td>
<td>28</td>
<td>27.2</td>
<td>24.1</td>
<td>7.5</td>
</tr>
<tr>
<td>Cl</td>
<td>13.5</td>
<td>9.8</td>
<td>4</td>
<td>1150</td>
<td>1098</td>
<td>1600</td>
<td>4720</td>
<td>3274</td>
<td>3410</td>
<td>2980</td>
<td>310.5</td>
<td>316</td>
<td>450</td>
<td>72</td>
</tr>
<tr>
<td>HCO₃</td>
<td>48</td>
<td>44</td>
<td>11</td>
<td>169</td>
<td>74</td>
<td>210</td>
<td>N.A.</td>
<td>314</td>
<td>335</td>
<td>317</td>
<td>204</td>
<td>211</td>
<td>106</td>
<td>18.4</td>
</tr>
<tr>
<td>SO₄</td>
<td>21.1</td>
<td>27.3</td>
<td>71</td>
<td>N.A.</td>
<td>N.A.</td>
<td>N.A.</td>
<td>N.A.</td>
<td>30</td>
<td>N.A.</td>
<td>20</td>
<td>48</td>
<td>44</td>
<td>46</td>
<td>N.A.</td>
</tr>
<tr>
<td>SiO₂</td>
<td>50.0</td>
<td>0.6</td>
<td>62</td>
<td>80</td>
<td>104.6</td>
<td>93</td>
<td>432</td>
<td>96.6</td>
<td>N.A.</td>
<td>71.3</td>
<td>63</td>
<td>71</td>
<td>44</td>
<td>44</td>
</tr>
<tr>
<td>P</td>
<td>0.09</td>
<td>0.13</td>
<td>N.A.</td>
<td>N.A.</td>
<td>N.A.</td>
<td>N.A.</td>
<td>N.A.</td>
<td>.006</td>
<td>.076</td>
<td>0.053</td>
<td>0.04</td>
<td>0.076</td>
<td>0.076</td>
<td>N.A.</td>
</tr>
<tr>
<td>Fe⁴</td>
<td>N.A.</td>
<td>N.A.</td>
<td>8.8</td>
<td>15</td>
<td>N.A.</td>
<td>70</td>
<td>N.A.</td>
<td>N.A.</td>
<td>N.A.</td>
<td>N.A.</td>
<td>0.2</td>
<td>0.1</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>TDS</td>
<td>176</td>
<td>107</td>
<td>120</td>
<td>2158</td>
<td>2292</td>
<td>3140</td>
<td>7865</td>
<td>6084</td>
<td>6080</td>
<td>5349</td>
<td>929</td>
<td>851</td>
<td>1006</td>
<td>220</td>
</tr>
<tr>
<td>Cl/Mg</td>
<td>5.0</td>
<td>5.16</td>
<td>0.78</td>
<td>38.08</td>
<td>405.17</td>
<td>3200</td>
<td>337.14</td>
<td>62.96</td>
<td>57.8</td>
<td>47.68</td>
<td>14</td>
<td>52</td>
<td>59</td>
<td>9.6</td>
</tr>
</tbody>
</table>

PSa: Pahoa Station, 6 Jan. '75 sample from Water Resources Research Center (WRRC), University of Hawaii, Manoa (UH-M).
PSb: Pahoa Station, 21 July '75 sample from WRRC, UH-M.
KS-1: Geothermal Well, Kapoho State 1, top of dike impounded water analysis, 1983 from Hawaii Dept. of Land and Natural Resources (DLNR).
KS-1A: Geothermal Well, Kapoho State 1-A, top of dike impounded water analysis, 1985 from DLNR.
KS-2: Geothermal Well, Kapoho State 2, top of dike impounded water analysis, 1984 from DLNR.
GTW-IIIa: Geothermal hole, 7 Jan. '75 sample from WRRC, UH-M.
GTW-IIIb: Geothermal hole, 21 July '75 sample from WRRC, UH-M.
GTW-IIIc: Geothermal hole, (Thief), 21 July '75 sample from WRRC, UH-M.
9-6a: Kapoho hole, 6 Jan. '75 sample from WRRC, UH-M.
9-6b: Kapoho hole, 22 July '75 sample from WRRC, UH-M.
9-6c: Kapoho hole, analysis from Cox and Thomas (1979).
GTW-IV: Geothermal hole, 21 June '61 sample from Hawaii Department of Health (HDOH).

a = Total Fe
b = Not Available
Table 2 (Cont'd.)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>9a</th>
<th>9b</th>
<th>9c</th>
<th>9d</th>
<th>A</th>
<th>9-9a</th>
<th>9-9b</th>
<th>9-9c</th>
<th>9-9d</th>
<th>9-9e</th>
<th>9-7a</th>
<th>9-7b</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temp(°F)</td>
<td>77.9</td>
<td>71.8</td>
<td>N.A.</td>
<td>N.A.</td>
<td>99.5</td>
<td>126</td>
<td>N.A.</td>
<td>N.A.</td>
<td>128</td>
<td>N.A.</td>
<td>83.3</td>
<td>69.4</td>
</tr>
<tr>
<td>pH</td>
<td>7.8</td>
<td>7.1</td>
<td>7.7</td>
<td>7.2</td>
<td>7.35</td>
<td>7.02</td>
<td>7.45</td>
<td>6.92</td>
<td>7.1</td>
<td>6.92</td>
<td>7.68</td>
<td>7.05</td>
</tr>
<tr>
<td>Na</td>
<td>85.8</td>
<td>86.5</td>
<td>97</td>
<td>139</td>
<td>216</td>
<td>2105</td>
<td>2890</td>
<td>2935</td>
<td>2695</td>
<td>3090</td>
<td>89.6</td>
<td>78.8</td>
</tr>
<tr>
<td>K</td>
<td>6.6</td>
<td>6.2</td>
<td>14</td>
<td>25</td>
<td>10.8</td>
<td>109</td>
<td>149</td>
<td>155</td>
<td>129</td>
<td>5.3</td>
<td>5.9</td>
<td>5.0</td>
</tr>
<tr>
<td>Ca</td>
<td>42.4</td>
<td>23.2</td>
<td>47.7</td>
<td>14</td>
<td>13.4</td>
<td>66.8</td>
<td>117</td>
<td>182</td>
<td>122</td>
<td>182</td>
<td>5.3</td>
<td>5.9</td>
</tr>
<tr>
<td>Mg</td>
<td>37</td>
<td>25.7</td>
<td>26.5</td>
<td>17</td>
<td>15</td>
<td>210</td>
<td>293</td>
<td>324</td>
<td>267</td>
<td>324</td>
<td>6.6</td>
<td>5.6</td>
</tr>
<tr>
<td>Cl</td>
<td>16.9</td>
<td>95.7</td>
<td>125</td>
<td>331</td>
<td>281</td>
<td>3811</td>
<td>5120</td>
<td>5850</td>
<td>6887</td>
<td>5850</td>
<td>132.2</td>
<td>120</td>
</tr>
<tr>
<td>SO₄</td>
<td>20</td>
<td>22.7</td>
<td>5.5</td>
<td>65.4</td>
<td>69.2</td>
<td>471</td>
<td>598</td>
<td>681</td>
<td>583</td>
<td>681</td>
<td>37.6</td>
<td>38.6</td>
</tr>
<tr>
<td>HCO₃</td>
<td>372</td>
<td>328</td>
<td>283</td>
<td>61</td>
<td>132</td>
<td>144</td>
<td>128</td>
<td>262</td>
<td>173</td>
<td>173</td>
<td>N.A.</td>
<td>N.A.</td>
</tr>
<tr>
<td>SiO₂</td>
<td>53.6</td>
<td>N.A.</td>
<td>44</td>
<td>70.5</td>
<td>24.1</td>
<td>100.7</td>
<td>N.A.</td>
<td>59</td>
<td>83.2</td>
<td>59</td>
<td>44.5</td>
<td>N.A.</td>
</tr>
<tr>
<td>F</td>
<td>0.233</td>
<td>0.268</td>
<td>N.A.</td>
<td>N.A.</td>
<td>&lt;0.002</td>
<td>0.006</td>
<td>0.013</td>
<td>N.A.</td>
<td>N.A.</td>
<td>N.A.</td>
<td>0.056</td>
<td>0.194</td>
</tr>
<tr>
<td>Fe</td>
<td>N.A.</td>
<td>N.A.</td>
<td>N.A.</td>
<td>0.2</td>
<td>N.A.</td>
<td>N.A.</td>
<td>N.A.</td>
<td>N.A.</td>
<td>3.16</td>
<td>3.16</td>
<td>N.A.</td>
<td>N.A.</td>
</tr>
<tr>
<td>TDS</td>
<td>635</td>
<td>588</td>
<td>643</td>
<td>723</td>
<td>762</td>
<td>7018</td>
<td>9295</td>
<td>10450</td>
<td>10949</td>
<td>11700</td>
<td>359</td>
<td>291</td>
</tr>
<tr>
<td>Cl/Mg</td>
<td>0.46</td>
<td>3.72</td>
<td>4.7</td>
<td>19.47</td>
<td>18.73</td>
<td>18.15</td>
<td>17.47</td>
<td>18.06</td>
<td>25.79</td>
<td>18.06</td>
<td>20.0</td>
<td>21.43</td>
</tr>
</tbody>
</table>

9a Kapoho Shaft, 6 Jan. '75 sample from WRRC, UH-M.
9b Kapoho Shaft, 21 July '75 sample from WRRC, UH-M.
9c Kapoho Shaft, 15 March '68 sample from Hawaii Board of Water Supply.
9d Kapoho Shaft, sample from DLNR.
A Well Allison, 7 Jan. '75 sample from WRRC, UH-M.
9-9a Malama-Ki Well, 7 Jan. '75 sample from WRRC, UH-M.
9-9b Malama-Ki Well, 22 July '75 sample from WRRC, UH-M.
9-9c Malama-Ki Well, 6 Sept. '62, sample from USGS.
9-9e Malama-Ki Well, 28 Sept. '62 from DLNR.
9-7a Kalapana Station, 6 Jan. '75 sample from WRRC, UH-M.
9-7b Kalapana Station, unspecified date for sample from WRRC, UH-M.

JLI038

a - Total Fe
b - Not Available

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Kaimuki</th>
<th>Wilder</th>
<th>Beretania</th>
<th>Kalihi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temp (°F)</td>
<td>&lt;85*</td>
<td>&lt;85*</td>
<td>&lt;85*</td>
<td>&lt;85*</td>
</tr>
<tr>
<td>pH</td>
<td>8.2</td>
<td>8.5</td>
<td>8.3</td>
<td>8.15</td>
</tr>
<tr>
<td>Na</td>
<td>55</td>
<td>52</td>
<td>39</td>
<td>42</td>
</tr>
<tr>
<td>K</td>
<td>2.3</td>
<td>5.1</td>
<td>3.7</td>
<td>2.5</td>
</tr>
<tr>
<td>Ca</td>
<td>9.0</td>
<td>4.5</td>
<td>10</td>
<td>14</td>
</tr>
<tr>
<td>Mg</td>
<td>11</td>
<td>6.2</td>
<td>11</td>
<td>14</td>
</tr>
<tr>
<td>Cl</td>
<td>79</td>
<td>56</td>
<td>62</td>
<td>80</td>
</tr>
<tr>
<td>SO₄</td>
<td>14</td>
<td>9.5</td>
<td>9.7</td>
<td>13</td>
</tr>
<tr>
<td>HCO₃</td>
<td>76</td>
<td>79</td>
<td>73</td>
<td>71</td>
</tr>
<tr>
<td>SiO₂</td>
<td>41</td>
<td>34</td>
<td>37</td>
<td>44</td>
</tr>
<tr>
<td>P</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Fe</td>
<td>.02</td>
<td>.02</td>
<td>.02</td>
<td>.02</td>
</tr>
<tr>
<td>TDS</td>
<td>322</td>
<td>249</td>
<td>248</td>
<td>283</td>
</tr>
<tr>
<td>Cl/Mg</td>
<td>7.2</td>
<td>9.0</td>
<td>5.6</td>
<td>5.7</td>
</tr>
</tbody>
</table>

*Parameter not reported by Young (1981). It is assumed given the type of well and location.
Table 4. Listing of wells in the LERZ relative to fresh or geothermal water types, see text for explanation.

### WELLS CONTAINING GEOTHERMAL WATERS

<table>
<thead>
<tr>
<th>TDS &gt; 2000 mg/l</th>
<th>Temperature &gt; 100°F</th>
<th>Cl/Mg &gt; 15</th>
</tr>
</thead>
<tbody>
<tr>
<td>KS-1</td>
<td>KS-1</td>
<td>KS-1</td>
</tr>
<tr>
<td>KS-1A</td>
<td>KS-1A</td>
<td>KS-1A</td>
</tr>
<tr>
<td>KS-2</td>
<td>KS-2</td>
<td>KS-2</td>
</tr>
<tr>
<td>HGP-A</td>
<td>HGP-A</td>
<td>HGP-A</td>
</tr>
<tr>
<td>GTW-IIIa, b, and c</td>
<td>GTW-IIIa, b, and c</td>
<td>GTW-IIIa, b, and c</td>
</tr>
<tr>
<td>9-9a, b, c, d, and e</td>
<td>9-9a, b, c, d, and e</td>
<td>9-9a, b, c, d, and e</td>
</tr>
</tbody>
</table>

### WELLS CONTAINING FRESH WATERS

<table>
<thead>
<tr>
<th>TDS &lt; 2000 mg/l</th>
<th>Temperature &lt; 100°F</th>
<th>Cl/Mg &lt; 15</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSa, PSb</td>
<td>PSa, PSb</td>
<td>PSa, PSb</td>
</tr>
<tr>
<td>PVFW</td>
<td>PVFW</td>
<td>PVFW</td>
</tr>
<tr>
<td>9-6a, b, c</td>
<td>9-6a, b, c</td>
<td>9-6a, b, c</td>
</tr>
<tr>
<td>GTW-IV</td>
<td>GTW-IV</td>
<td>GTW-IV</td>
</tr>
<tr>
<td>9a, b, c, and d</td>
<td>9a, b, c, and d</td>
<td>9a, b, c, and d</td>
</tr>
<tr>
<td>A</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>9-7a and b</td>
<td>9-7a and b</td>
<td>9-7a and b</td>
</tr>
<tr>
<td>Kaimuki</td>
<td>Kaimuki</td>
<td>Kaimuki</td>
</tr>
<tr>
<td>Wilder</td>
<td>Wilder</td>
<td>Wilder</td>
</tr>
<tr>
<td>Beretania</td>
<td>Beretania</td>
<td>Beretania</td>
</tr>
<tr>
<td>Kalihi</td>
<td>Kalihi</td>
<td>Kalihi</td>
</tr>
</tbody>
</table>

---

KS-1A and KS-1A are likely referring to different wells or well configurations within the LERZ that were classified based on their TDS, temperature, and Cl/Mg content.
Table 5. Characterization of fresh, geothermal and mixed waters in the LERZ. See text for explanation.

<table>
<thead>
<tr>
<th>WELL</th>
<th>WATER TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSa, PSb</td>
<td>Fresh</td>
</tr>
<tr>
<td>PVFW</td>
<td>Fresh</td>
</tr>
<tr>
<td>KS-1</td>
<td>Geothermal</td>
</tr>
<tr>
<td>KS-1A</td>
<td>Geothermal</td>
</tr>
<tr>
<td>KS-2</td>
<td>Geothermal</td>
</tr>
<tr>
<td>HGP-A</td>
<td>Geothermal</td>
</tr>
<tr>
<td>GTW-IIIa, b and c</td>
<td>Geothermal</td>
</tr>
<tr>
<td>9-6a, b and c</td>
<td>Mixed</td>
</tr>
<tr>
<td>GTW-IV</td>
<td>Mixed</td>
</tr>
<tr>
<td>9a, b, c, and d</td>
<td>Mixed</td>
</tr>
<tr>
<td>A</td>
<td>Geothermal</td>
</tr>
<tr>
<td>9-9a, b, c, d, and e</td>
<td>Geothermal</td>
</tr>
<tr>
<td>9-7a and b</td>
<td>Fresh</td>
</tr>
<tr>
<td>Kaimuki</td>
<td>Fresh</td>
</tr>
<tr>
<td>Wilder</td>
<td>Fresh</td>
</tr>
<tr>
<td>Beretania</td>
<td>Fresh</td>
</tr>
<tr>
<td>Kalihi</td>
<td>Fresh</td>
</tr>
</tbody>
</table>
Appendix A: Individual Schoeller Diagrams for Wells in the Lower East Rift Zone
LOWER EAST RIFT ZONE
GEOTHERMAL WELLS - TOP OF DIKE CONTROLLED WATER

- KS-1
- KS-1A
- KS-2

CONCENTRATION (mg/l)

Na K Ca Fe Mg SiO₂ HCO₃ Cl SO₄ F pH TDS Cl/Mg

Cl/Mg ratio plotted on concentration scale
LOWER EAST RIFT ZONE

WELL: HGP-A (2270')

Kroopnich et al (1978)

Cl/Mg ratio plotted on concentration scale
LOWER EAST RIFT ZONE

WELL: GTW III

- July 21, 1985, U. of H.
- Jan. 7, 1975, U. of H.
- July 21, 1975, U. of H.

Cl/Mg ratio plotted on concentration scale
LOWER EAST RIFT ZONE

WELL: GTW IV

♦ June 21, 1961, HDOH

Cl/Mg ratio plotted on concentration scale
LOWER EAST RIFT ZONE

WELL: 9

- Jan. 6, 1975 U. of H.
- July 21, 1975, U. of H.
- March 15, 1968 BWS
- DLNR

Cl/Mg ratio plotted on concentration scale
HAWAII COUNTY

WELL: 9-5, PAHOA STATION

- Jan. 6, 1975, U. of H.
- July 21, 1975, U. of H.

CONCENTRATION
(mg/l)

Cl/Mg ratio plotted on concentration scale.
LOWER EAST RIFT ZONE

WELL: 9-5

- Jan. 6, 1975, U. of H.
- July 22, 1975, U. of H.
- Cox & Thomas (1979)

Cl/Mg ratio plotted on concentration scale.
SOUTHEASTERN HAWAII COUNTY

WELL: 9-7

Jan. 6, 1975, U. of H.
No Date, U. of H.

Cl/Mg ratio plotted on concentration scale
LOWER EAST RIFT ZONE WELL: 9-9

Jan. 7, 1975, U. of H.
July 22, 1975, U. of H.

USGS, Cox & Thomas (1978)

Na, K, Ca, Mg, SiO₂, HCO₃, Cl, SO₄, P, pH, TDS, CI/Mg

CI/Mg ratio plotted on concentration scale.
LOWER EAST RIFT ZONE

WELL: ALLISON

Jan. 7, 1975, U. of H.

Cl/Mg ratio plotted on concentration scale
HONOLULU DISTRICT SOURCES FOR DRINKING WATER

Kalmukl
Wilder Well No. 36-c
Beretania
Kalihi

All data from Young (1981).

Cl/Mg ratio plotted on concentration scale
§11-23-04 Classification of exempted aquifers and underground sources of drinking water. (a) Upon request, and with concurrence of the director, the department shall review the aquifer designations. The aquifer designations shall be reviewed at least every three years. In its review, the department may amend the status of an aquifer in accordance with chapter 91, HRS. The criteria for exempting aquifers from underground source of drinking water (USDW) status is as follows:

(1) The aquifer does not currently serve as a source of drinking water; and

(2) The aquifer cannot now and will not in the future serve as a source of drinking water because of any of the following criteria:

   (A) It is situated at a depth or location which currently makes recovery of water for drinking water purposes economically or technologically impractical; or

   (B) It is so contaminated that it would be economically or technologically impractical to render that water fit for human consumption; or

   (C) The total dissolved solids (TDS) concentration of the ground water is more than five thousand mg/L, and it is not reasonably expected to supply a public or private drinking water system.

(b) The UIC maps shall indicate exempted aquifers and USDW, in plan view, by use of a UIC Line, and such maps are an integral part of this chapter. The department's UIC maps shall be the final authority for the identification of the aquifer boundaries on the land surface. Copies of the maps and this chapter are available for examination at an office of the department's environmental protection and health services division, the district health offices and other department offices on each island.

(c) Unless expressly exempted, all aquifers are considered to be USDW.
§11-23-05 Identification of exempted aquifers and USDW. (a) The department has designated the following formations as exempted portions of aquifers: In the horizontal dimension, lands which are makai of the UIC Line; and in the vertical dimension:

(1) Where the volcanic formation is a non-artesian aquifer, the entire geologic column; or

(2) Where the volcanic formation is an artesian aquifer, from the subaerial ground surface down to fifty feet above the contact between the artesian volcanic aquifer and the overlying confining materials.

(b) Unless an aquifer is expressly exempted, as described above or depicted on the department-issued UIC maps, it is an underground source of drinking water.

(c) In areas where the UIC Line is defined by a roadway, a setback of one lot or one hundred fifty feet, whichever is less, from the mauka property line of that roadway may be considered to be within the exempted area. If the roadway is within a property, the setback shall extend to the mauka property line or to one hundred fifty feet from the mauka edge of said roadway, whichever is less. This interpretation of the UIC line shall be subject to all other conditions of this chapter. The applicant, on the permit application, shall request this interpretation, approval of which shall be based on the proximity and sensitivity of drinking water sources. [Eff. JUL 6, 1984 ]

(Auth: HRS §340E-2) (Imp: HRS §340E-2, 40 CFR §§144.7 and 146.4)