TIME DOMAIN ELECTROMAGNETIC SURVEYS FOR ASSISTING IN DETERMINING THE GROUNDWATER RESOURCES ON GREENWELL FARMS PROPERTY ISLAND OF HAWAII

Project Number 5069-1

March 2007

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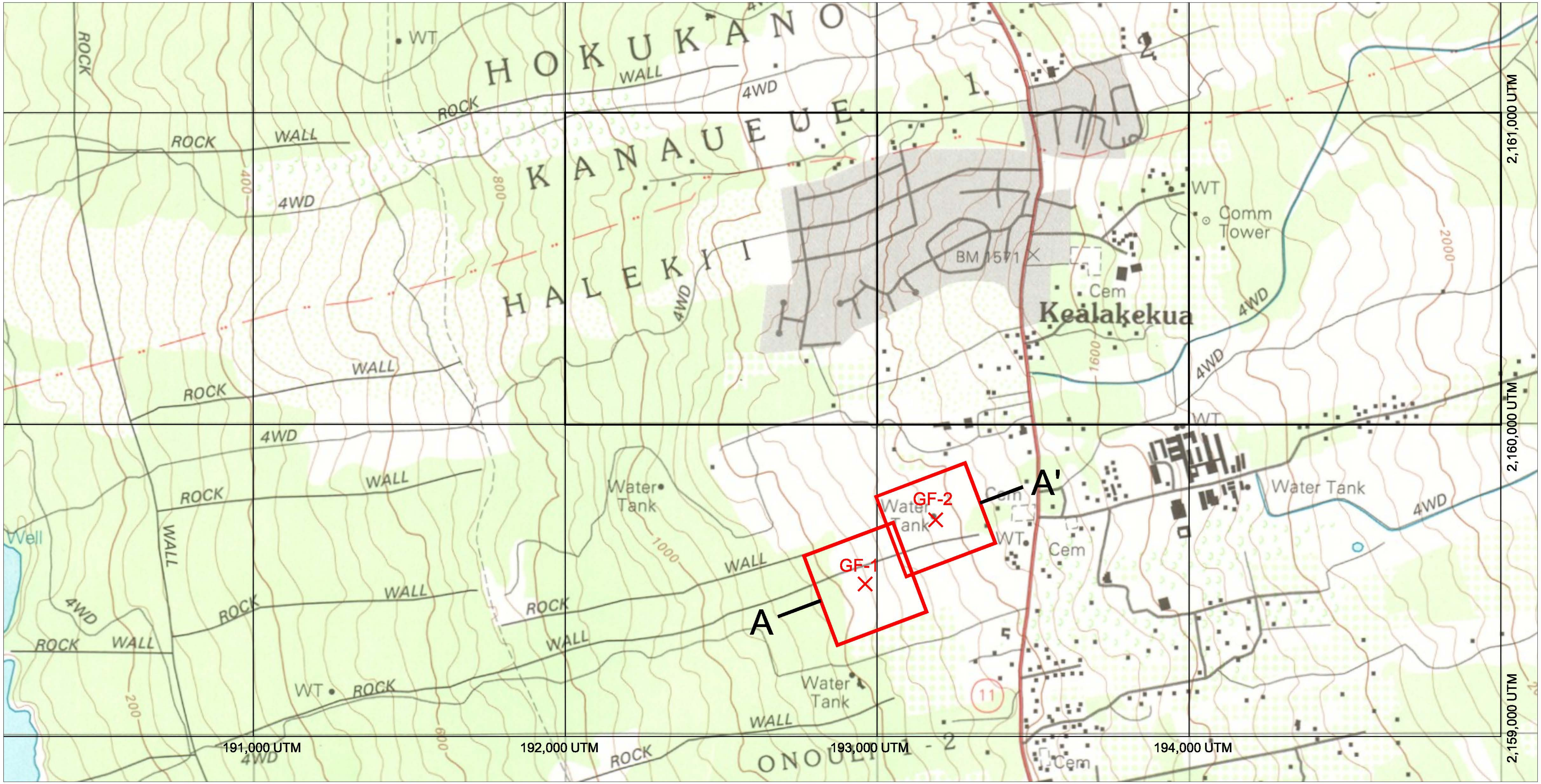
1.0 INTRODUCTION

This report contains the procedures and results of surface Time Domain Electromagnetic (TDEM) geophysical surveys performed for groundwater resource evaluation on Greenwell Farms property located on the Island of Hawaii. ZAPATAENGINEERING Blackhawk Division (Blackhawk) conducted the surveys on February 2, 2007 for Pa'ahana Enterprises LLC (PEL) of Kealakekua, Hawaii and Greenwell Farms (GF) of Kealakekua, Hawaii.

The main objective of the TDEM surveys was to explore for groundwater occurrences located on GF property near the Greenwell Farms Coffee Plantation. The surveys were conducted at two TDEM sites to help determine the optimum location for a future groundwater well below the Mamalahoa Highway in Kealakekua, Hawaii. Figure 1-1 shows the locations of TDEM soundings taken during the surveys on GF property.

TDEM is a geophysical method that determines from the surface the geoelectric section (resistivity layering) of the subsurface. From the geoelectric section, information about geology and water quality can be inferred. This is possible because the electrical resistivity of the earth depends on lithology, porosity, the degree of saturation, and concentration of dissolved solids in the groundwater. Geophysical surveys, combined with other hydrogeologic information, are used to provide optimum locations for well placement and well completion depths.

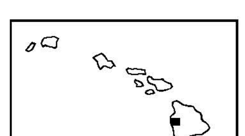


Explanation

A-A' Section Line

GF-1 TDEM Sounding

N



0 1000 2000

Scale in Feet

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Pa'ahana Enterprises LCC
Greenwell Farms Property

Geophysical TDEM Survey
Location Map
Kealakekua, Hawaii

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5069-1	March, 2007	HJV	RJB	1"=1000'	1-1

2.0 GEOLOGY/HYDROGEOLOGY

Groundwater resources occur on the Hawaiian Islands basically in two modes:

- In a basal mode where a lens of fresh water floats on seawater, and
- In a high-level mode where the fresh groundwater occurrence is controlled by damming structures (i.e. intrusives, dikes, etc).

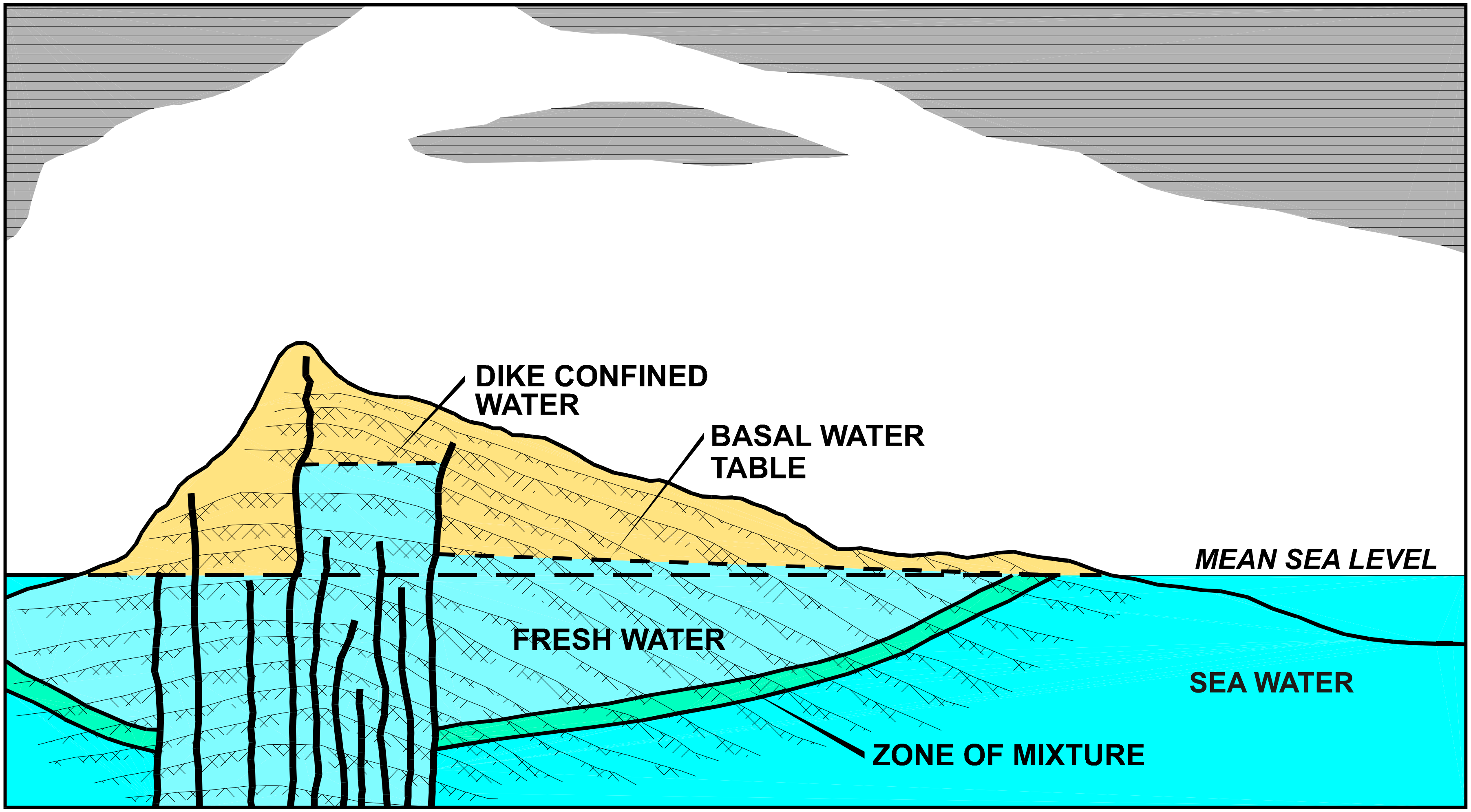
The basic geologic and hydrologic framework of the Island of Hawaii and the two modes of groundwater occurrences are illustrated in Figure 2-1. Fresh groundwater may also occur in areas between these two modes, but production is expected to be highly variable. TDEM surveys previously run on Hawaii have reliably mapped the basal mode groundwater occurrence and the boundary between fresh water in the basal mode and high-level water occurrences.

Basal mode groundwater is resting approximately at sea level near the ocean surrounding the Island of Hawaii. This is generally due to the fact that the volcanic rocks, which comprise the island, allow rainfall to percolate with little impedance directly downward through the rock mass (reference Figure 2-1). The fresh water floats directly on seawater encroaching from the ocean. Fresh water flows laterally toward the ocean causing the fresh water lens to be thinner near the ocean. When groundwater is under conditions of static equilibrium, the Ghyben-Herzberg Principle states that for every one foot of fresh water above sea level, approximately 40 feet of fresh water will exist below sea level as shown in Figure 2-2. The transition from fresh water to seawater at depth may be relatively sharp (i.e. occurring over several tens of feet) or more gradual, depending upon hydrologic flux, horizontal and vertical permeability contrast, and other geologic factors. It is assumed, when resolving TDEM sounding data, that seawater saturated volcanics begin at the midpoint of the transition zone.

TDEM surveys are utilized to map the resistivity stratification of the subsurface. From numerous previous TDEM surveys and calibration at well sites, characteristic ranges of subsurface resistivities have been derived for the geologic/hydrologic units shown in Figure 2-3. Some overlap in resistivity occurs between the units; however, other factors (such as elevation) can be used to help separate the units. Therefore the main geologic/hydrologic units that can be derived from TDEM surveys are:

- Depth to seawater saturated volcanic rocks. This occurs in basal mode situations, and by using the Ghyben-Herzberg Principle, the thickness of the basal fresh water lens can be calculated.
- Weathered volcanic layers (laterite). These lower resistivity units are generally relatively thin layers that occur mainly at or near the ground surface.
- Clay poor and fresh water saturated volcanic rocks. These formations generally exhibit high resistivity values. Note that the extent of fresh water saturation is normally based on geographic and elevation information, and that fresh water cannot be directly detected in the TDEM data.

Groundwater damming structures (i.e. intrusives, dikes) are inferred with TDEM data by uncharacteristic sounding curves (distorted by 2-D structures), and by soundings that transition between detection of seawater at depth (indicating basal mode groundwater) and soundings that map high resistivities to depths below sea level (indicating high-level groundwater).



BLACKHAWK A DIVISION OF ZAPATAENGINEERING	Pa'ahana Enterprises LLC Greenwell Farms Property	Schematic Hydrogeologic Cross Section Island of Hawaii

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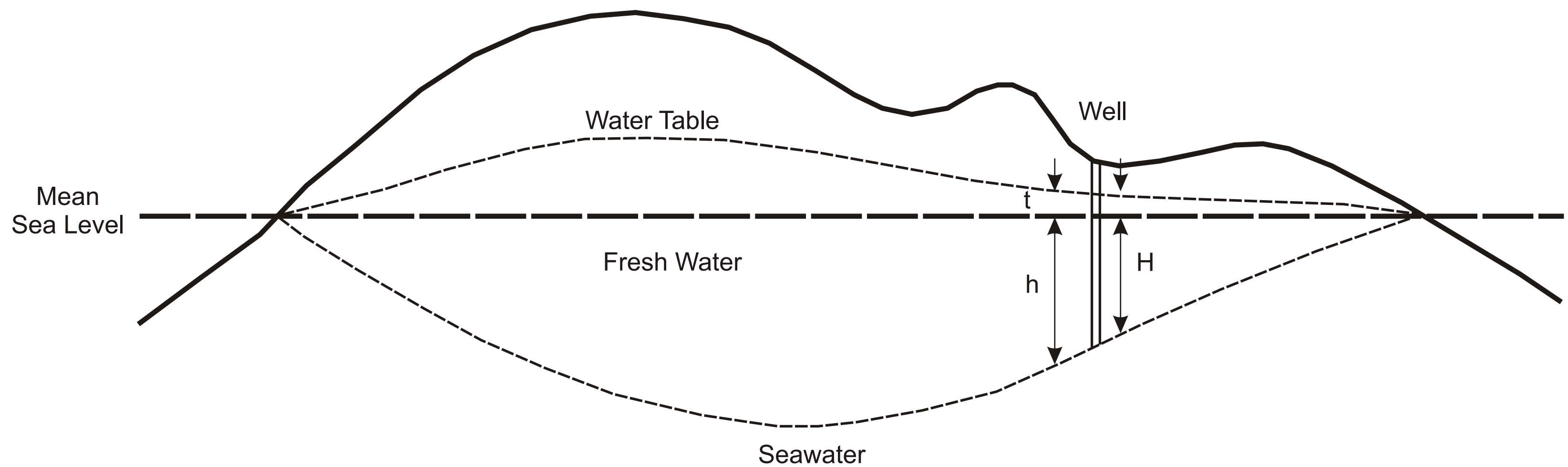

$$t = 1/40\ (h)$$

BLACKHAWK A DIVISION OF ZAPATA ENGINEERING	Pa'ahana Enterprises LLC Greenwell Farms Property			**Illustration of the Ghyben-Herzberg Principle**	
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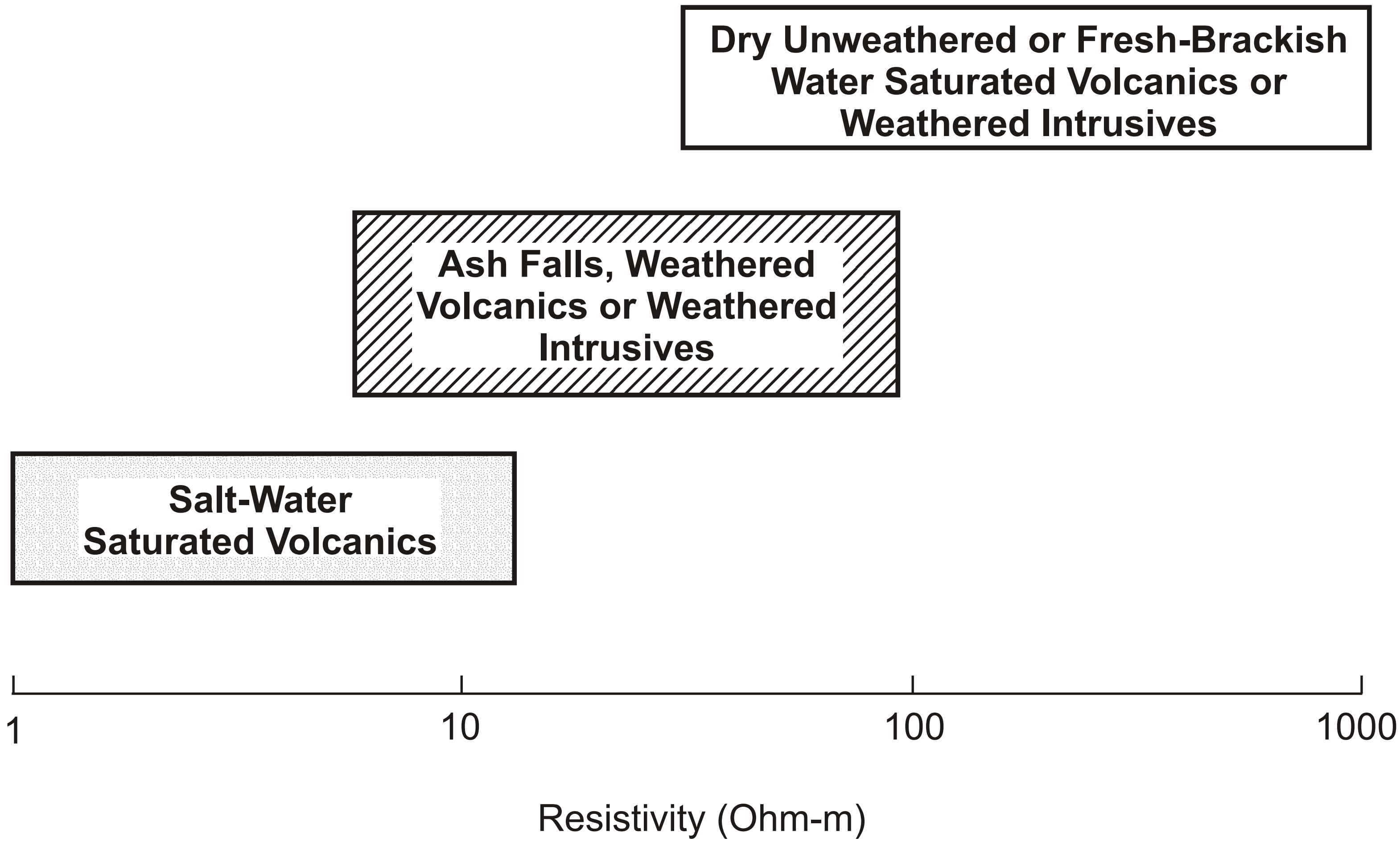

BLACKHAWK A DIVISION OF ZAPATAENGINEERING	Pa'ahana Enterprises LLC Greenwell Farms Property		**Characteristic Resistivity Ranges** *Island of Hawaii*

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3.0 DATA ACQUISITION AND LOGISTICS

Blackhawk mobilized a field crew consisting of a project geophysicist and geophysical technician to perform the geophysical surveys on the GF property. The Blackhawk field personnel and TDEM equipment were mobilized from Golden, Colorado to Kailua-Kona, Hawaii. During the fieldwork PEL personnel provided project direction, maps and site access to the property. A daily log of field activities during the TDEM surveys is presented in Table 3-1.

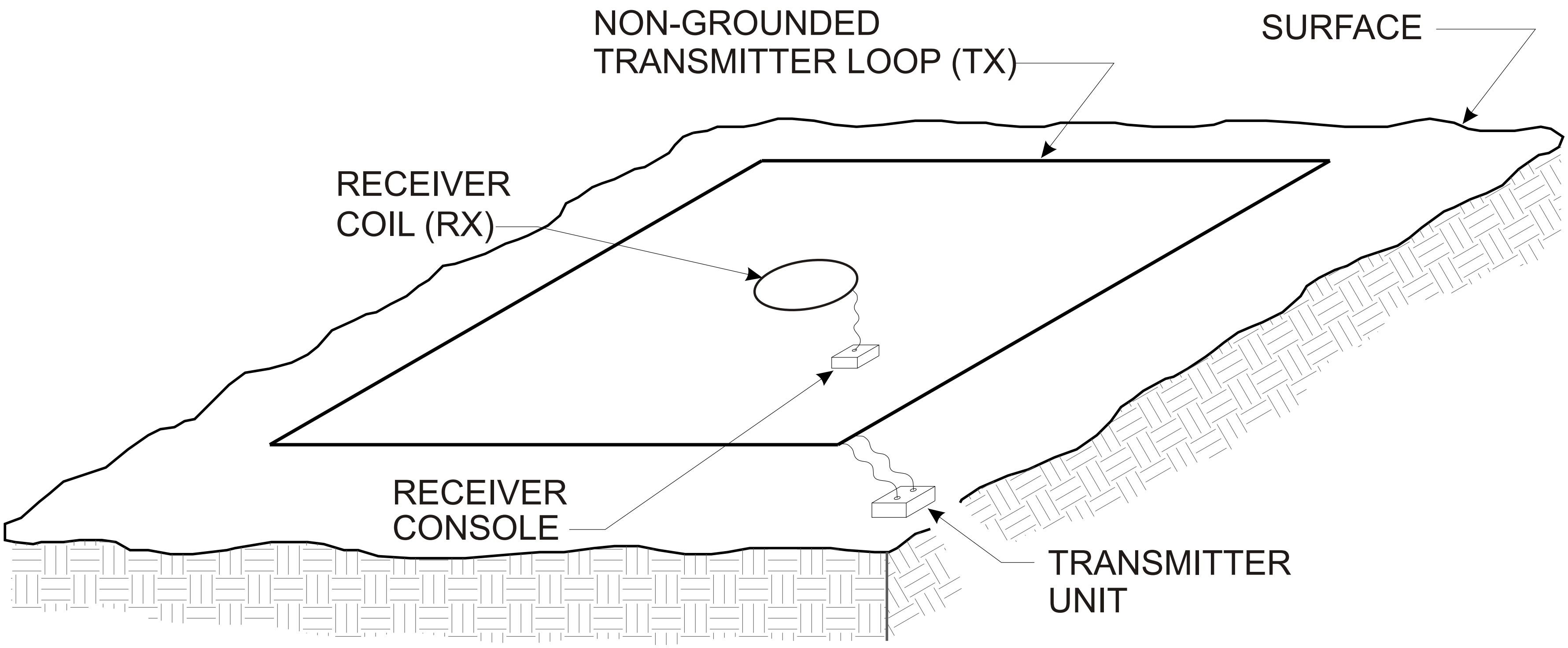
The geophysical equipment utilized for the TDEM surveys was the Geonics EM37 system. The EM37 system consists of both a portable motor-generator powered transmitter and a PROTEM digital receiver. The main purpose of the TDEM measurements is to derive both the vertical and lateral variations in the geoelectric section (resistivity) of the subsurface. To accomplish this, the TDEM measurements were acquired using a central-loop array at each sounding site. The square transmitter loops were constructed using 12-gauge insulated copper wire laid on the ground surface, as illustrated in Figure 3-1. The dimensions of the transmitter wire loops ranged from 900 ft by 1,000 ft to 1,000 ft by 1,000 ft. The motor-generator and transmitter were placed at a corner of the wire-loop and square-wave current pulses were driven through the wire using a current of 15 amperes. The current pulses induce eddy current flow in the subsurface of the ground. A receiver coil (1-meter diameter) attached to the PROTEM receiver was positioned in the center of the wire-loop and used to record the decay of the secondary magnetic field due to the eddy currents induced in the subsurface. The effective exploration depth using a 1,000 ft by 1,000 ft transmitter wire-loop array has been determined to be approximately 2,500 ft. Greater exploration depths are reached with larger wire-loops and several factors that affect the depth of investigation include ground resistivity (ohm-m) and surrounding cultural interference (i.e. 60-cycle powerline, pipelines, etc).

The TDEM data acquired at each sounding consisted of measurements utilizing several receiver gain settings and two transmitter frequencies in order to ensure data quality and to obtain data over the longest possible time interval. The sounding data were recorded at base frequencies of 3 Hz and 30 Hz. For data quality control (QC) purposes, additional offset data sets were collected at designated locations (typically 100 ft) from the center of each sounding, for comparison to the central-loop data. The data from each sounding were stored in a solid-state memory logger in the PROTEM receiver and transferred at the end of each day to a PC for processing. The TDEM data collected at the GF property were of excellent quality with no cultural interferences (i.e. pipelines, powerlines, etc.) noted in the measurements. A technical note describing the principles of TDEM with case histories is given in Appendix A.

The center and corners of each transmitter wire-loop were registered to existing rock walls and fences located on the property. Other known landmark features, such as stock tanks and buildings, were also used to locate the wire-loops on the map with a compass and hip-chain. In addition, a hand-held global positioning system (GPS) was utilized to map both the receiver and transmitter locations of each sounding. The GPS information was used to position each loop center on the geo-referenced topographic map and the elevation was subsequently taken from that position. A total of two soundings were measured on the GF property during the one day of fieldwork. The GPS coordinates and elevations of the TDEM soundings are given in Table 3-2 in Appendix B.

Table 3-1
Daily Log of Field Activities
Greenwell Farms Property TDEM Survey

Date (2007)	Activity
January 16	Ship TDEM geophysical equipment from Golden, CO to Kona, HI.
January 22	Mobilize Blackhawk field personnel from Golden, CO to Kona, HI.
January 23-February 1	Unpack TDEM geophysical equipment at Kona Beach Hotel. Test motor-generator and organize equipment into 4WD vehicle. Work on other TDEM projects in Hawaii.
February 2	Meet with PEL field representative to discuss project. Lay out and collect TDEM data on Soundings GF-1 and GF-2 (pasture land). Download data to PC and perform preliminary data analysis. Discuss results with PEL. Survey complete.
February 3- 12	Fieldwork on other projects in Hawaii. Deliver TDEM equipment to FedEx at Kona Airport. Demobilize Blackhawk personnel from Kona, HI to Golden, CO.



BLACKHAWK A DIVISION OF ZAPATAENGINEERING	Pa'ahana Enterprises LLC Greenwell Farms Property	Schematic layout of TDEM system with locations of TX and RX for Central Loop Array measurements

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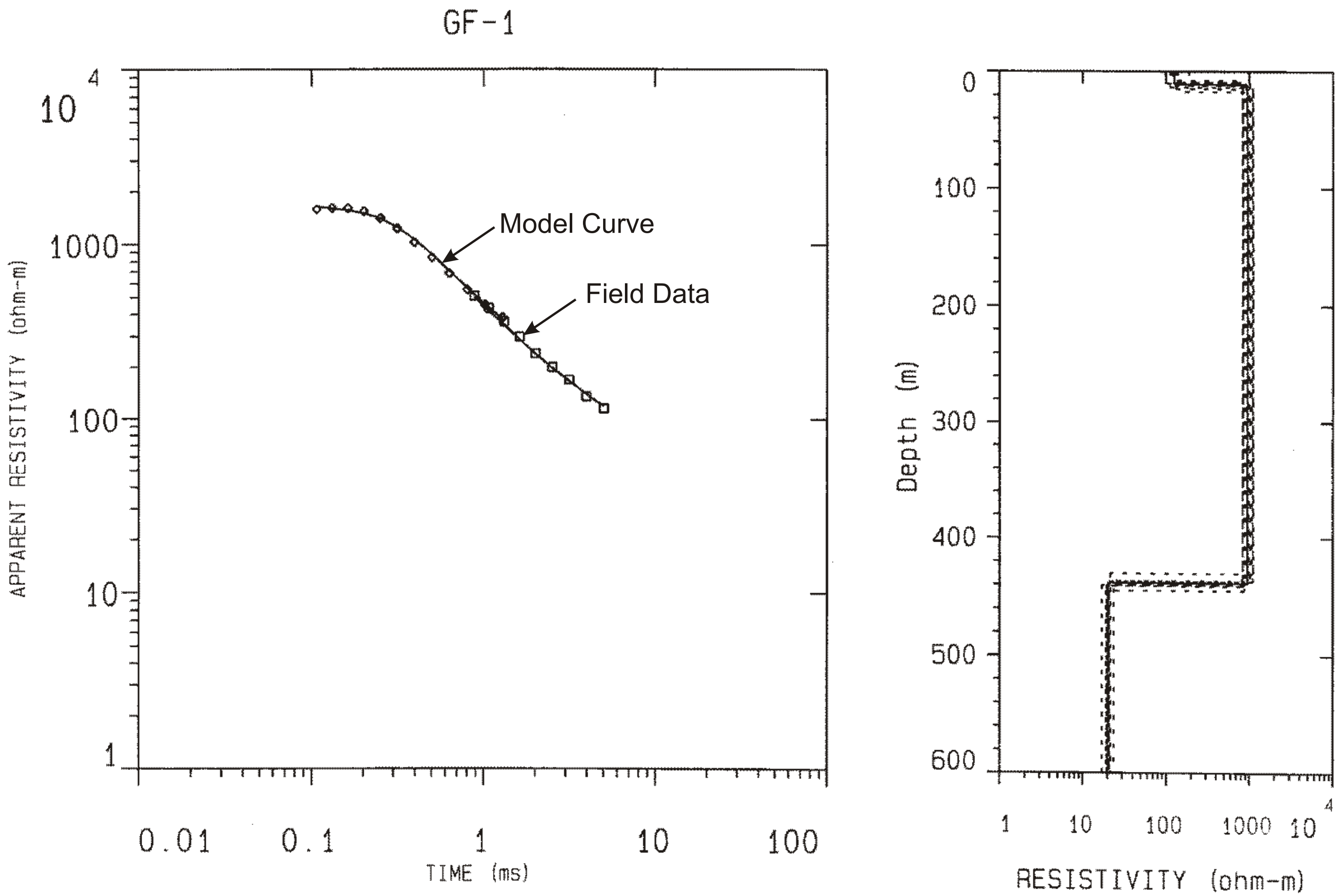
4.0 DATA PROCESSING

The field data collected for each TDEM sounding was transferred from the Geonics PROTEM digital receiver to a PC for editing and processing. Processing of the TDEM data starts with averaging of the electromotive forces recorded at positive and negative receiver polarities. Next, the measurements collected at the two base frequencies (3 and 30 Hz) and different amplifier gains are combined to give one voltage decay curve (transient). The electromotive forces in the various time gates of the decay curves were subsequently entered into the TEMIXXL (Interpex Ltd) inversion program to obtain a one-dimensional (1-D) geoelectric section that best matches the observed decay curve.

The TEMIXXL inversion program requires an initial model of the geoelectric section measured. The initial model includes the number of layers and the resistivities and thickness for each of the layers. This model is usually derived from general knowledge of the geologic section or from data obtained from drill holes or electric logs. The inversion program is then allowed to adjust the layer thickness and the resistivities, so that the model curve converges to best fit the field data. The inversion program does not change the total number of layers within the model curve, but allows all other parameters to change freely or they can optionally be fixed constant. To determine the influence of the number of layers on the solution, separate inversions with a different number of layers are run. Subsequently, the model with the least number of layers that best fits the field data is used.

An example of the output of the inversion program is shown on Figure 4-1 for Sounding GF-1. This figure shows the measured data points (in terms of apparent resistivity) superimposed on a solid line on the left panel. The solid line represents the computed forward model for the geoelectric section on the right panel. This geoelectric section is the best match obtained by the inversion program. Figure 4-2 shows the tabulated inversion parameters consisting of measured data, computed data for best match solutions and an example of the table of inversion statistics. A three-layer inversion model is shown for Sounding GF-1. The model displays a thin (36 ft) upper layer with resistivity of 125 ohm-m, overlying a thick (1,400 ft) second layer with a high resistivity (950 ohm-m). A third lower layer with an intermediate resistivity of 20 ohm-m is interpreted in the section.

The interpreted geoelectric section derived from each TDEM sounding is not unique. The magnitude of each individual layer resistivity and thickness can normally be varied within a limited range with no significant change to the fit of the geoelectric model of the data. This variation is termed equivalence. An equivalence analysis was performed for each TDEM sounding. Figures 4-1 and 4-2 also show the equivalence analysis for Sounding GF-1. This sounding is typical of the TDEM data and shows a +/-5% equivalence in depth determinations and +/-10% in individual layer resistivities. The inversion results for each sounding of this project are given in Appendix B.



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Pa'ahana Enterprises LLC
Greenwell Farms Property

Sounding GF-1
Example Inversion Output
Apparent Resistivity Curve
Kealakekua, Hawaii

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5069	March, 2007	HJV	RJB	No Scale	4-1

DATA SET: GF-1

CLIENT: Paahana Enterprises LLC
LOCATION: Kealakekua
COUNTY: Hawaii
PROJECT: Greenwell Coffee Farms
LOOP SIZE: 305.000 m by 305.000 m
COIL LOC: 0.000 m (X), 0.000 m (Y)
SOUNDING COORDINATES: E: 1.0000 N: 4.0000 SLOPE: 1.00

DATE: 02-02-07
SOUNDING: 1
ELEVATION: 378.00 m
EQUIPMENT: Geonics PROTEM
AZIMUTH:
TIME CONSTANT: NONE

Central Loop Configuration
Geonics PROTEM System

FITTING ERROR: 4.225 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	(ft)	CONDUCTANCE (Siemens)
			378.0	1240.0	
1	125.4	10.97	367.0	1204.1	0.0874
2	949.7	427.4	-60.47	-198.5	0.450
3	20.05				

ALL PARAMETERS ARE FREE

CURRENT: 14.50 AMPS EM-58 COIL AREA: 100.00 sq m.
FREQUENCY: 3.00 Hz GAIN: 3 RAMP TIME: 150.00 muSEC

No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)
1	0.881	80.78	82.98	-2.73
2	1.06	63.37	66.49	-4.92
3	1.31	49.17	52.65	-7.08
4	1.61	39.25	41.62	-6.02
5	2.00	32.02	32.12	-0.318
6	2.50	24.12	24.46	-1.38
7	3.14	17.67	18.09	-2.36
8	3.95	13.97	13.30	4.80
9	4.99	9.88	9.43	4.56

CURRENT: 14.50 AMPS EM-58 COIL AREA: 100.00 sq m.
FREQUENCY: 30.00 Hz GAIN: 3 RAMP TIME: 150.00 muSEC

No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)
10	0.106	2871.1	2719.2	5.28
11	0.131	1672.0	1691.6	-1.17
12	0.161	993.8	1036.3	-4.26
13	0.200	617.7	645.5	-4.49
14	0.250	405.4	407.7	-0.569
15	0.314	282.5	275.4	2.50
16	0.395	208.5	197.6	5.21
17	0.499	157.3	147.5	6.23
18	0.631	119.6	114.1	4.57
19	0.799	90.99	88.09	3.18
20	1.01	67.29	66.55	1.10
21	1.28	47.89	49.86	-4.11

PARAMETER RESOLUTION MATRIX:
"F" INDICATES FIXED PARAMETER

	P 1	P 2	P 3	T 1	T 2
P 1	0.62				
P 2	0.12	0.85			
P 3	-0.01	-0.04	0.84		
T 1	-0.10	-0.21	-0.06	0.41	
T 2	0.00	0.01	0.01	0.02	1.00

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Pa'ahana Enterprises LLC
Greenwell Farms Property

Sounding GF-1
Example of Tabulated Data
From Inversion
Kealakekua, Hawaii

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5.0 INTERPRETATION AND RESULTS

5.1 TDEM SOUNDING DATA

From each TDEM sounding, the geoelectric section of the subsurface is derived. The results of the one-dimensional (1-D) inversion of the individual TDEM soundings can be linked together (layers with similar resistivities) to create a 2-D geoelectric cross-section along a survey line. For this project, two TDEM soundings were collected on the GF property. Figure 1-2 shows the geoelectric cross-section constructed from the TDEM survey data. The correlations established between geoelectric layers and lithologic units (reference Figure 2-3) were used to interpret the geoelectric cross-section.

5.2 GEOELECTRIC CROSS-SECTION – LINE 1 (A-A')

Figure 5-1 shows the layered geoelectric cross-section interpreted from the TDEM data taken along Line 1. The TDEM soundings were located in open pasture land on GF property below the Mamalahoa Highway and are situated in a west to east direction (reference Figure 1-1). The center of Sounding GF-1 was located at elevation of 1,240 ft. Sounding GF-2 (elevation 1,360 ft) was located upslope from Sounding GF-1 and was positioned to avoid known pipelines and buildings in the area.

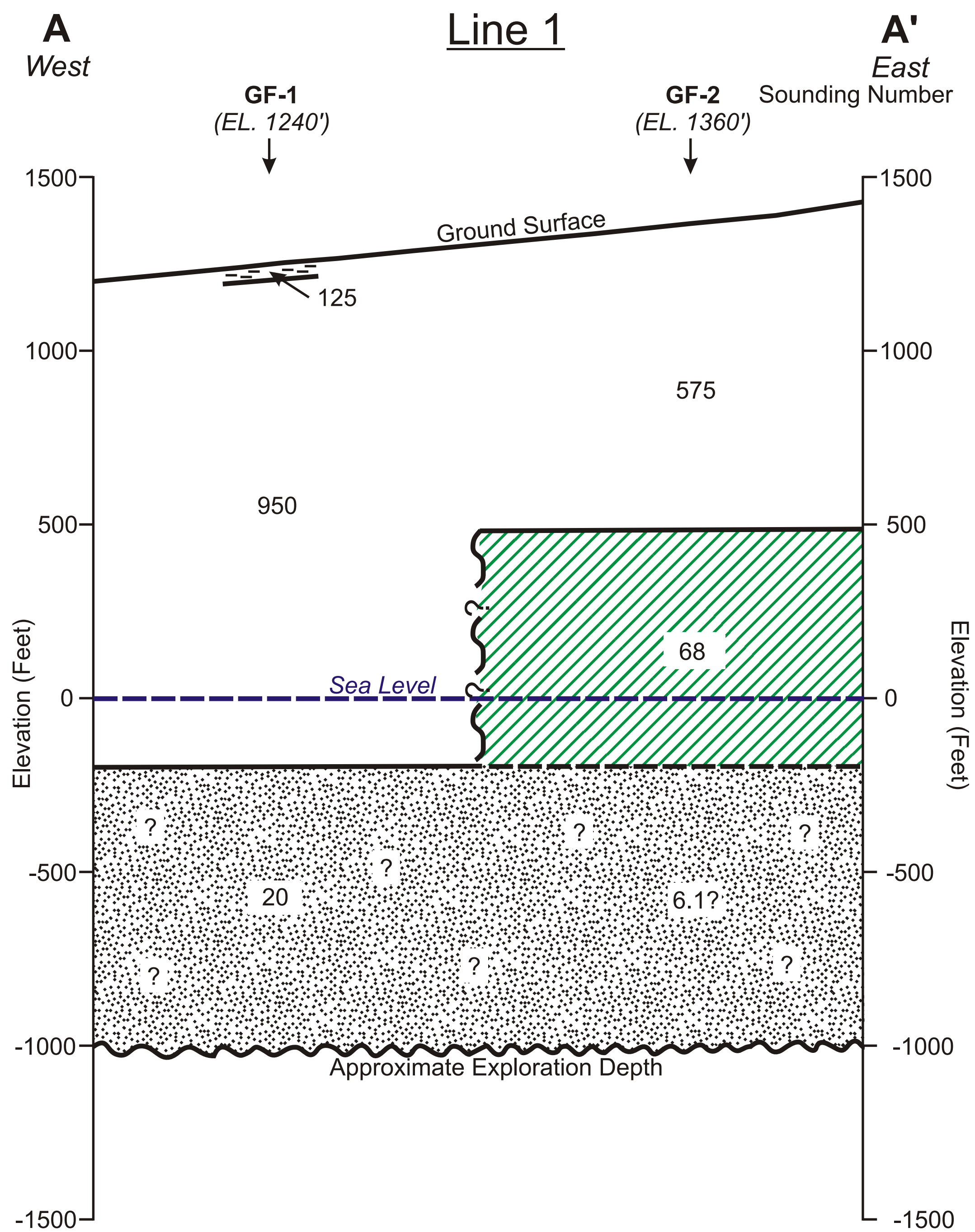
A three-layer cross-section is interpreted for the two soundings along Line 1. The upper layer, beneath Sounding GF-1, exhibits a high resistivity (125 ohm-m) and is interpreted as a thin (36 ft) laterite surface layer. The second layer in the section displays high resistivity of 950 ohm-m and is interpreted as dry, clay poor volcanic formations. Where the second layer occurs below sea level it is expected to be saturated with fresh-brackish basal mode water. The third layer in the section exhibits an intermediate resistivity (20 ohm-m) and is interpreted to represent brackish and/or sea water saturated volcanic layers at depth. This interpreted resistivity is higher than what is normally detected from seawater saturated volcanic layers (3-5 ohm-m). A possible explanation for the higher resistivity is that the porosity of the volcanic layers in this area is less than what is normally encountered. Since the top boundary of the third layer occurs below sea level, the thickness of the fresh-brackish water lens can be calculated beneath this sounding and it is estimated to be 198 ft thick.

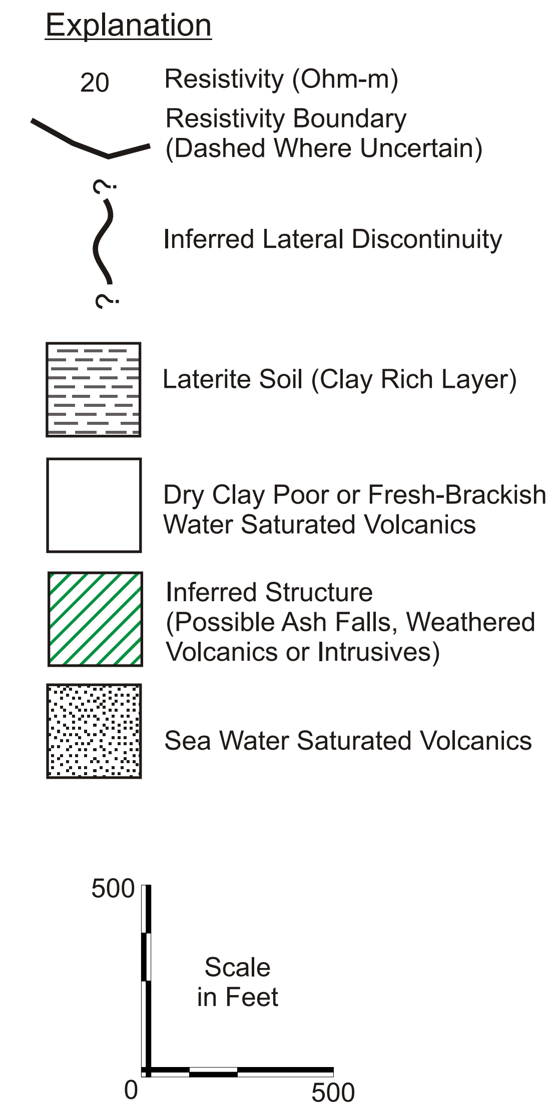
Sounding GF-2 exhibits a high resistivity (575 ohm-m) in the upper layer, which is interpreted as dry, clay poor volcanic formations above sea level. The second layer in the section displays an intermediate resistivity (68 ohm-m) and the top of this layer is interpreted to occur at an elevation of 496 ft above sea level. The second layer has a resistivity that normally indicates volcanic layers containing clays and/or brackish water. The thickness of this layer (730 ft) is significantly greater than expected for weathered clay-bearing layers. At other locations in the Hawaiian Islands the presence of intermediate resistivity layers extending both above and below sea level often indicates a distortion of the TDEM sounding by high angle geologic features. These geologic features often occur in the transition zone between basal groundwater and high-level groundwater. It is expected that high angle 2-dimensional (2-D) geologic features are acting as damming structures to the groundwater. The third layer's interpreted low resistivity

(6.1 ohm-m) may be distorted by these structures. It is possible however; that this represents seawater saturated volcanic layers at depth and that a partial fresh-brackish groundwater lens situation exists in this area. From the limited geophysical and geologic data it cannot be determined if this portion of the sounding curve is distorted.

5.3 HYDROGEOLOGIC INTERPRETATION

The data from the TDEM survey is further summarized on the interpretation map shown in Figure 5-2. On this map Sounding GF-1 (blue) exhibits intermediate resistivity (20 ohm-m) at depth which is interpreted to be seawater saturated volcanics. There is a possibility that this sounding is influenced by 2-D geologic structures (i.e. ash falls, clay layers) resulting in this intermediate resistivity. The interpretation of Sounding GF-2 (shown in green) may be influenced by high angle 2-D geologic features resulting in an abnormally thick intermediate resistivity that extends both above and below sea level. This suggests that this sounding is within the transition zone between basal and high-level groundwater and that there is also a possibility that a basal fresh-brackish water lens is present at depth. Due to the limited TDEM data in this area, the exact position and width of the geologic structure is uncertain in this area of the property.





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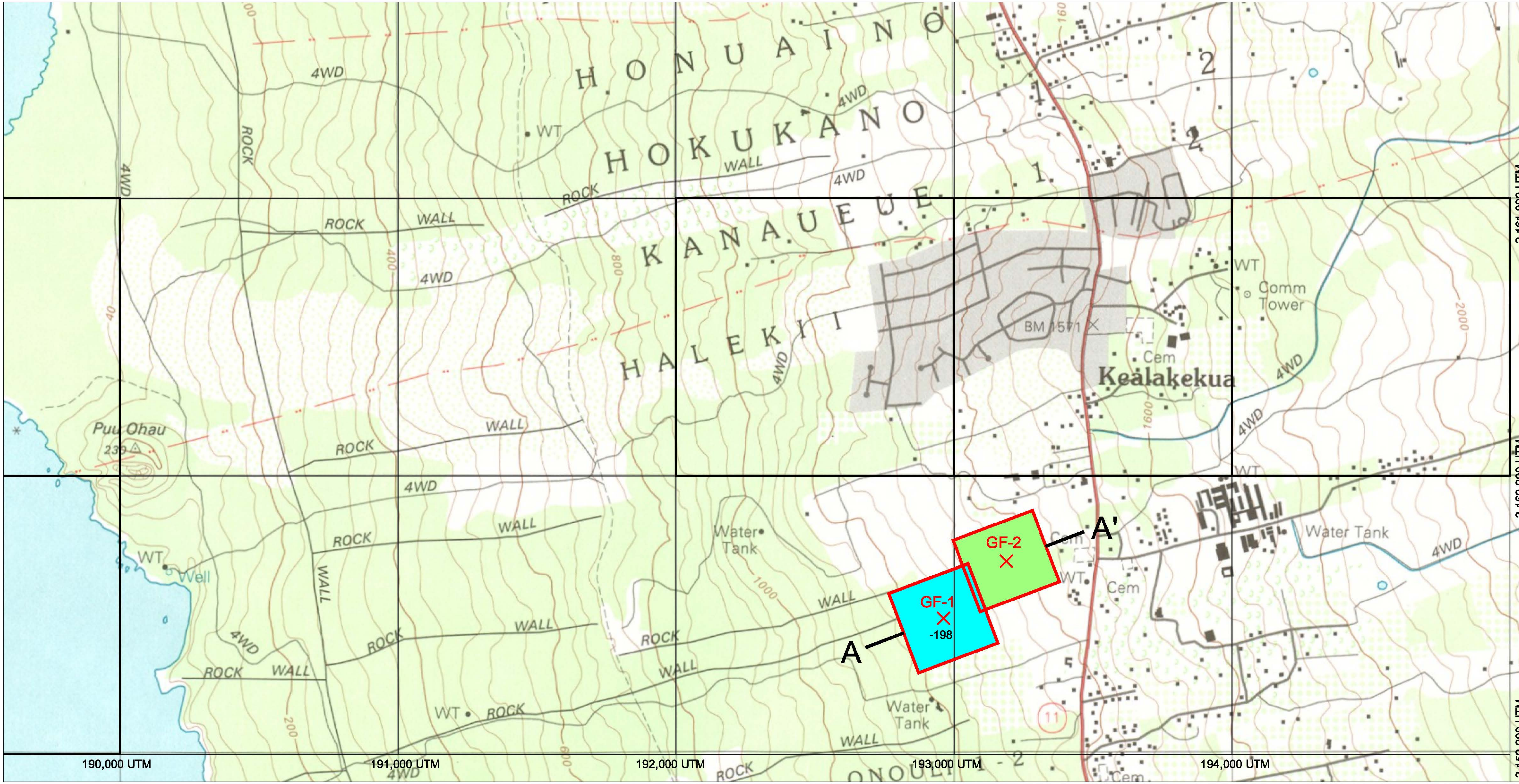
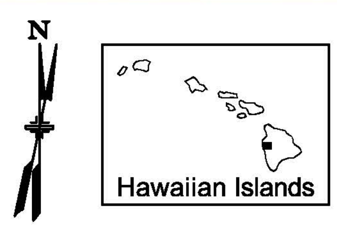


Explanation

-198 Approximate Elevation of Top of Salt-Water Interface in Feet

Sounding in which Groundwater is expected in Basal Mode

Sounding Interpreted to be located within the Groundwater Barrier
Data may be distorted by 2-D Geologic Structures



0 1000 2000
Scale in Feet

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Pa'ahana Enterprises LCC
Greenwell Farms Property

Geophysical TDEM Survey
Summary Interpretation map
Kealakekua, Hawaii

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5069-1	March, 2007	HJV	RJB	1"=1000'	5-2

6.0 CONCLUSIONS AND RECOMMENDATIONS

The main objective of the TDEM surveys on the Greenwell Farms (GF) property on Hawaii was to obtain geophysical data which would aid in the mapping of groundwater resources in the area below the Mamalahoa Highway.

The results from the two TDEM soundings taken on the property are shown on Figures 5-1 and 5-2. A summary of the results are that:

- Neither sounding indicates the presence of high-level groundwater.
- Sounding GF-1 likely represents a basal groundwater resource with an estimated lens thickness of 198 feet.
- Sounding GF-2 may be located within a structurally complicated transition zone between basal and high-level groundwater. The hydrologic regime in this area is complicated and groundwater yield and quality is expected to be highly variable.

Because of the limited TDEM data in this area of the property, the optimum location (lowest elevation) for a high-level groundwater well was not identified. It is expected that high-level groundwater, if present, is located uphill from Sounding GF-2. Therefore, additional TDEM soundings placed above the Mamalahoa Highway will likely help define the extent of the groundwater damming structures and location of potential high-level groundwater in this area.

7.0 CERTIFICATION AND DISCLAIMER

All geophysical data analysis, interpretations, conclusions, and recommendations in this document have been prepared under the supervision of and reviewed by ZAPATA ENGINEERING P.A. Blackhawk Division, Senior Geophysicists and Engineers.

This geophysical investigation was conducted using sound scientific principles and state-of-the-art technology. A high degree of professionalism was maintained during all aspects of the project from the field investigation and data acquisition, through data processing, interpretation, and reporting. All original field data files, field notes and observations, and other pertinent information are maintained in the project files and are available for the client to review.

A geophysicist's certification of interpreted geophysical conditions comprises a declaration of his/her professional judgment. It does not constitute a warranty or guarantee, expressed or implied, nor does it relieve any other party of its responsibility to abide by contract documents, applicable codes, standards, regulations, or ordinances.

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