INVENTORY OF WELLS IN THE LOWER PUNA DISTRICT

KAPOHO STATE 1, Thermal Power Co.(driller: Water Resources Int'l)

elevation: 619'
well depth: 7290'
casing: 4072' cement; 7216' perforated
drilling days: 9/1/81 - 11/12/81 (65)
temperature: bottom hole 650 F or 343 C
9/11/81: water table at 540'-630', bailed for sample at 608', 113F
2/20/82: casing leaks determined at 900-940' and 1040-1080'
5/12/82: 9-5/8" casing found jammed into the expansion spool
8/4-6/82: flow test, well substantially "dried up" during testing
8/11-28/82: separator test, chemical emission control problem ensued resulting in a temporary shut down; well produces 100% steam at a FWHP of 120 psig with mass flow rate of 72,000 lb/hr
10/2/82: pipe to flange well failed, flowed uncontrolled for 38 hrs
11/2/82: after inspection, wellhead considered to be sound,FBI investigation; as consequence of interzonal flow, a gas cap was forming in the well, bled on 11/29 and 12/14
2/18/83: casing leak found at 670'
4/15/83: Dia-Log caliper logs, parted casing from 226-233', split casing from 362-363', gaps at numerous collars (buttress coupling recess) (found with TV camera recording)
top of cement plug at 1750'

KAPOHO STATE 2, Thermal Power Co.(driller: Water Resources Int'l)

elevation: 718'
well depth: 8005'
casing: 4209' cement, 7891' perforated
drilling days: 1/19/82-4/2/82 (56)
temperature: 659.9F or 348.8C
wellbore deviation: 399.32'
1/2/82: 706' bailed for water sample to DLNR
2/3/82: fluid level noted at 550' in wellbore
3/30/82: flow test
4/20-5/1/82: flow test
7/28-8/2/82: flow test with separator system
5/11/82: wireline, temperature and pressure tools lost in hole due to embrittlement of .092" carbon plow steel
8/24/82: Sanicro-28 stainless steel found embrittled, study indicated that type 310 stainless steel with moderate tensile strength would be most cost effective
7/14/82: casing leak found at 1040-1050'
1/25/83: 4' gap at the 9-5/8" casing tieback between 1093-1097'
3/29/83: with wireline debris still lost in hole, cement plug placed at 3175'

KAPOHO STATE 1A, Thermal Power Co.(driller:Water Resources Int'l)

elevation: ~640'
well depth: 6505'
casing: 4000' cement, 5505 perforated liner
drilling days: 7/8/85-9/3/85
temperature: 654.7F bottomhole; 369F production test
well bore deviation: 619.21'
7/18/85: water table 597"
7/19/85: bailed for sample @618', 75 gal.
1/29/86: chloride from chemical analysis of geo reservoir 21,000 ppm

LANIPUNA 1, Barnwell Indus.(driller:
elevation:
well depth: 8400'(DPED 7/82 Public Sector Geo Dev Program)
casing:
date drilled: 1981
temperature:
well bore deviation:

LANIPUNA 6, Barnwell/GEDCO (driller:
elevation:
well depth: 4000'
casing:
date drilled: 1984 (completion in May)
temperature:
well bore deviation:

2102-01 PULAMA, DOWALD,(driller: Samson Zerbe)
elevation: 230'
well depth: 250' 1979 Prelimary Regional Survey HIG
casing: 250'; 8"
date drilled: 1963
status: unused
location: 192107x1550212
chloride: 110-298 ppm
temperature: 79F or 25.8C

/ 3.3 ft / 278 ppm

2317-01 VOLCANO NATIONAL PARK, Colorado School of Mines(Water Res. Int'l)
elevation: 3606'
well depth: 4127'
casing: 1025'; 14"
date drilled: 1973
status: observation
location: 192344x1551721 (1 km S. Halemaumau)
chloride: 1150 ppm (HIG Chloride/Magnesium Ratio 1979)
temperature: 279F or 137C

1806 ft / ? ppm

2487-01 KEAUOHANA 1, DWS (Ocean View Drilling)
elevation: 752'
well depth: 802'
casing: 800' ; 8"
date drilled: 1961
status: Municipal
location: 192456x1545719
chloride: 72-92ppm
temperature: 72-75F or 23.9C

/ 6.4 ft / 72 ppm

2487-02 KEAUOHANA 2, DWS (Layne Driling)
elevation: 752'
well depth: 803'
casing: 803'; 12"
date drilled: 1970
status: Municipal
location: 192457x1545718
chloride: 124-134ppm
temperature: 23.5C

/ 3.1 ft / 124 ppm

85-01
2685-x ASHIDA 1, Barnwell/GEDCO (driller:
elevation: 244.8m
well depth: 8000'
casing:
date drilled: 1980
status:
location: near Bryson's cinder pit, land owner Harold Ashida
chloride:
temperature:

2686-01 PUNA THERMAL 1,Haw.Thermal Power(driller: Samson Zerbe)
GEOTHERMAL 1
elevation: 1009
well depth:178'
casing: 177'; 14"
date drilled: 1961
status: unused
location: 192634x1545646
chloride:
temperature: 54.5C

2686-02 PUNA THERMAL TH2, Haw.Thermal Power (driller:Samson Zerbe)
GEOTHERMAL 2
elevation: 1035'
well depth: 556'
casing: 107'; 14"
date drilled: 1961
status: unused
location: 192633x1545648 Opihikao off highway
chloride:
temperature: 83C (Preliminary Regional Survey, HIG 1974)
Abandoned at 350' due to loose formation; lost drill piece

2783-01 MALAMA KI, DOWALD (driller: Ocean View Drilling)
elevation: 274'
well depth: 319'
casing: 319'; 8"
date drilled: 1962
status: unused
location: 192728x1545301
chloride: 2200-6600ppm (Preliminary Regional Survey HIG 1974)
temperature: 129F or 53.9C
Chloride/Magnesium Ratio HIG 1979: 9/62 5850ppm
1/74 11000ppm
1/75 3811ppm

✓ (head above sea level) / chloride level (ppm) = 1.9 / 6,600

2881-01 POHOIKI PUNA, Oneloa Co.(driller: Cont. Drilling)
ALLISON (Ralph)
elevation: 132'
well depth: 140'
casing: 138'; 4"
date drilled: 1973
status: irrigation
location: 192819x1545110
chloride: 722-2300ppm
temperature: 39C

✓ 5.0 ft / 722 ppm

ALLISON SPRING
location:
Chloride/Magnesium Ratio, HIG,1979: 1/74 38C 281ppm chloride

1/75 37.8C 1400ppm chloride

2883-01 HGPA, University of Hawaii(driller:UH/GEDCO)
elevation: 184.1m
well depth: 6455'
casing: 2270'; intermediate depth slotted liner rather than cement
date drilled: 11/75-4/76
status: production
location:
chloride: 1040ppm (Chloride/Magnesium Ratio HIG 1979)
temperature: 358F
water table: 5 samplings taken at drill time
4/76: Venting
7/2/76: Unabated 4 hrs, vertical plume 200-300'
7/22/76: Unabated flashing 4 hrs
7/27-28/78: flashing
9/18/81: smell reported as bad
12/11/81: venting through silencers, plume over Lanipuna, 110dba
2/8/82: asthma attack reported
3/4/82: bad smell in Leilani, steam blocking Pohoiki road
3/19/82: smell reported worse than ever
3/30/82: smell & ear infections reported
9/18-20/84: venting, H2S exceeded instrument calibration of 150ppb
9/19/84: odor and noise (brine sparger) complaint filed
8/25/86: odor complaint (plant abatement system out of service for repair)
abated through rock muffler

2982-01 PUNA THERMAL TH3, Hawaii Thermal Power Co (driller: Samson Zerbe)
elevation: 563'
well depth: 690'or 210.3m
casing: 18"
date drilled: 1961
status: unused
location: 192913x1545255, landowner Reginald Ho & Hiroo Sato
temperature: 210m = 48.6C; 175m= 91.6C (USGS)
choloride: 1975 = 3274ppm

2986-01 PAHOA BATTERY 2A, DWS(driller: Maui Drilling)
elevation: 711'
well depth: 755'
casing: 754', 8" ✓ 15.9 ft / 27 ppm
date drilled: 1960
status: municipal
location: 192924x1545647
temperature: 22.2C or 74F
chloride: 2-6ppm

2986-02 PAHOA BATTERY 2B, DWS(driller: Pacific Drilling)
elevation: 705'
well depth:
casing: ✓ 17.8 ft / 6 ppm
date drilled: 1963
status: municipal
location: 192925x1545646
temperature: 23C
chloride: 6-27ppm

ISAAC HALE SPRING at Pohoiki (Chloride/Magnesium Ratio HIG 1979)
temperature: 38.9C; ph:7.28; chloride: 4062ppm

3080-01 KAPOHO CRATER, DWS (driller: Hawaii DWS)
elevation: 38'
well depth: 46'
casing: 46'; 66"
date drilled: 1961
status: municipal
location: 193016x1545021
temperature: 25.3C
chloride: 64-174ppm

/ 3.6 ft / 64 ppm

3081-01 KAPOHO AIRSTRIP, DWS (driller: Ocean View)
elevation: 287'
well depth: 337'
casing: 8"
date drilled: 1961
status: unused
location: 193024x1545159
temperature: 33.9C (1961= 28C)
chloride: 331-345ppm (1972 220ppm USGS)

/ 3.1 ft / 331 ppm

3081-02 PUNA THERMAL TH4,Hawaii Thermal Power Co (driller:Samson Zerbe)
elevation: 250'
well depth: 290'
casing: 14"
date drilled: 1961
status: unused, hole plugged with rocks at 98'
location: 193039x1545119
temperature: 43C
chloride:

3185-01 HAWAIIAN SHORES 1, Miller & Lieb (driller: Ocean View Drilling)
elevation: 402'
well depth: 446'
casing: 446', 8"
date drilled: 1964
status: domestic
location: 193113x1545558
temperature: 21.7C
chloride: 11-16ppm

/ 8.1 ft / 18 ppm

3185-02 HAWAIIAN SHORES 2, Miller & Lieb (driller: Water Resources Int'l)
elevation: 380'
well depth: 430'
casing: 387', 10"
date drilled: 1971
status: domestic
location: 193126x1545544
temperature:
chloride: 23-28ppm

/ ? ft / 23 ppm

3188-01 KEONEPOKO NUI, DWS (Driller: Roscoe Moss)
elevation: 603'
well depth: 650'
casing: 621', 14"
date drilled: 1977
status: municipal
location: 193105x1545803
temperature: 20C
chloride: 4ppm

/ 15.1 ft / 4 ppm

Alpha U.S.A., Inc.

December 13, 1991

Hand-Delivered

Mr. Edwin Sakoda, Geologist
DIV. OF WATER RESOURCE MANAGEMENT
Dept. of Land & Natural Resources
P. O. Box 373
Honolulu, HI 96809

Subject: **Interim Reports - Wells Nos. 0615-01, 0615-02, 0715-01, 0715-02 and 0815-01**

Dear Mr. Sakoda:

Enclosed are Interim Well Completion Reports on the above-referenced wells. A summary is also attached for your convenience.

At this stage of our progress, we have decided to test the water from Well No. 0815-01 (Hole #5) to see if salt-tolerant grasses can grow in water of this salinity. An application for pump installation is attached for this purpose.

Until further testing has been completed, we are reluctant to perform any additional work on any of the other wells because we don't know at this time whether or not they may be of use in the future. Therefore, we would like to do the minimum amount of work necessary to secure the well and provide maximum flexibility for future use. With your approval, we would like to leave the wells with the top 20' cased and a steel cap welded to the top of the casing. Please let me know if this will be acceptable until such time as we have determined how we will use the holes.

Very truly yours,

Bob

Robert G. Diffley
V. P., Development

RGD:jsy

Enclosures

City Financial Tower
201 Merchant Street, Suite 2100
Honolulu, Hawaii 96813
Phone: (808) 532-2121 Fax Phone: (808) 532-2130

ALPHA MOLOKAI
EXPLORATORY DRILLING SUMMARY

December, 1991

Hole No.	Diameter/ Depth	Surface Elevation TOC	Elevation Water Table	Salinity ppm/TDS	Temp. (Farenheit)	24-Hour Pump Test Salinity ppm	Current Status
1	10" / 424'	405.8	1.0'	20,300	Not Available	No Test	Capped - 20' Casing
2	8" / 364'	344.4	0.8' *	22,000	Not Available	No Test	Capped - 20' Casing
3	8" / 401'	381.8	1.6'	8,250	94 F	8,000-8,250	Capped - 20' Casing
4	8" / 387'	367	1.1'	12,500	93 F	10,500-14,300	Capped - 20' Casing
5	8" / 409'	388.5	1.6'	8,600	96 F	8,600-8,700	Capped - 20' Casing

* Estimate

12/12/91

State of Hawaii
COMMISSION ON WATER RESOURCE MANAGEMENT
Department of Land and Natural Resources
Division of Water Resource Management

INTERIM WELL COMPLETION REPORT

INSTRUCTIONS: Please print or type and submit completed report within 30 days of well completion to the Division of Water Resource Management, P. O. Box 373, Honolulu, Hawaii 96809. An as-built drawing of the well and chemical analysis, if available, should also be submitted. If necessary, phone 548-7543, Hydrology, Geology Section for Assistance.

A. STATE WELL NO. 0615-01 WELL NAME Alpha Exploratory Hole #1 ISLAND Molokai

B. LOCATION 4 miles East of La'au Pt., West Molokai TAX MAP KEY 5-1-02-030

C. WELL OWNER Sekihyo Seibaku

D. DRILLING OR PUMP INSTALLATION CONTRACTOR Fred Page Drilling International

E. TYPE OF RIG Cable Tool DRILLER Scott Couch

F. DATE OF WELL COMPLETION N/A DATE OF PUMP INSTALLATION Pump Not Installed

G. GROUND ELEVATION (msl) 405.8 ft.
Top of Drilling Platform (msl) 408.8 ft.
Height of drilling platform above ground surface 3.0 ft.
Bench mark and method used to determine ground elevation Halena Bench Mark (Surveyed by Cummins & Cummins)

H. TOTAL DEPTH OF WELL BELOW GROUND 424 ft.

I. HOLE SIZE: 12 inch dia. from 0 ft. to 20 ft. below ground
10 inch dia. from 20 ft. to 424 ft. below ground
____ inch dia. from ____ ft. to ____ ft. below ground

J. CASING INSTALLED: *
12 in. I.D. x 1/4 in. wall solid section to 20 ft. below ground
____ in. I.D. x ____ in. wall perforated section to ____ ft. below ground
Type of perforation N/A

*Note: See attached sheet for drawing of casing to be installed.

K. ANNULUS: Not Grouted
Grouted from ____ ft. to ____ ft. below ground
Gravel packed from ____ ft. to ____ ft. below ground

L. PERMANENT PUMP INSTALLATION:
Pump type, make, serial No. No Pump to be Installed Capacity ____ gpm
Motor type, H.P., voltage, r.p.m. ____
Depth of pump intake setting ____ ft. below ____ which elevation is ____ ft.
Depth of bottom of airline ____ ft. below ____ which elevation is ____ ft.

M. PROPOSED USE Monitoring Only

N. INITIAL WATER LEVEL 404 ft. below ground. Date and time of measurement 10/3/90 / 10:30 AM

O. INITIAL CHLORIDE 11,000 ppm. Date and time of sampling 10/3/90 /

P. PUMPING TESTS: Reference point (R.P.) used: ____ which elevation is ____ ft.

Date Not Pumped
Start water level ____ ft. below R. P.
End water level ____ ft. below R. P.
Depth of well ____ ft. below R. P.

Elapsed Time (hours)	Rate (gpm)	Draw-down (ft.)	Cl- (ppm)	Temp. °F
... to ...				
... to ...				
... to ...				
... to ...				
... to ...				
... to ...				

Date ____
Start water level ____ ft. below R. P.
End water level ____ ft. below R. P.
Depth of well ____ ft. below R. P.

Elapsed Time (hours)	Rate (gpm)	Draw-down (ft.)	Cl- (ppm)	Temp. °F
... to ...				
... to ...				
... to ...				
... to ...				
... to ...				
... to ...				

Q. DRILLER'S LOG:

Depth, ft.	Rock Description & Remarks	Water Level ft.
... to ...		
... to ...		
... to ...	TO BE FURNISHED WITH FINAL	
... to ...	WELL COMPLETION REPORT	
... to ...		
... to ...		
... to ...		
... to ...		
... to ...		
... to ...		
... to ...		

REMARKS: ____

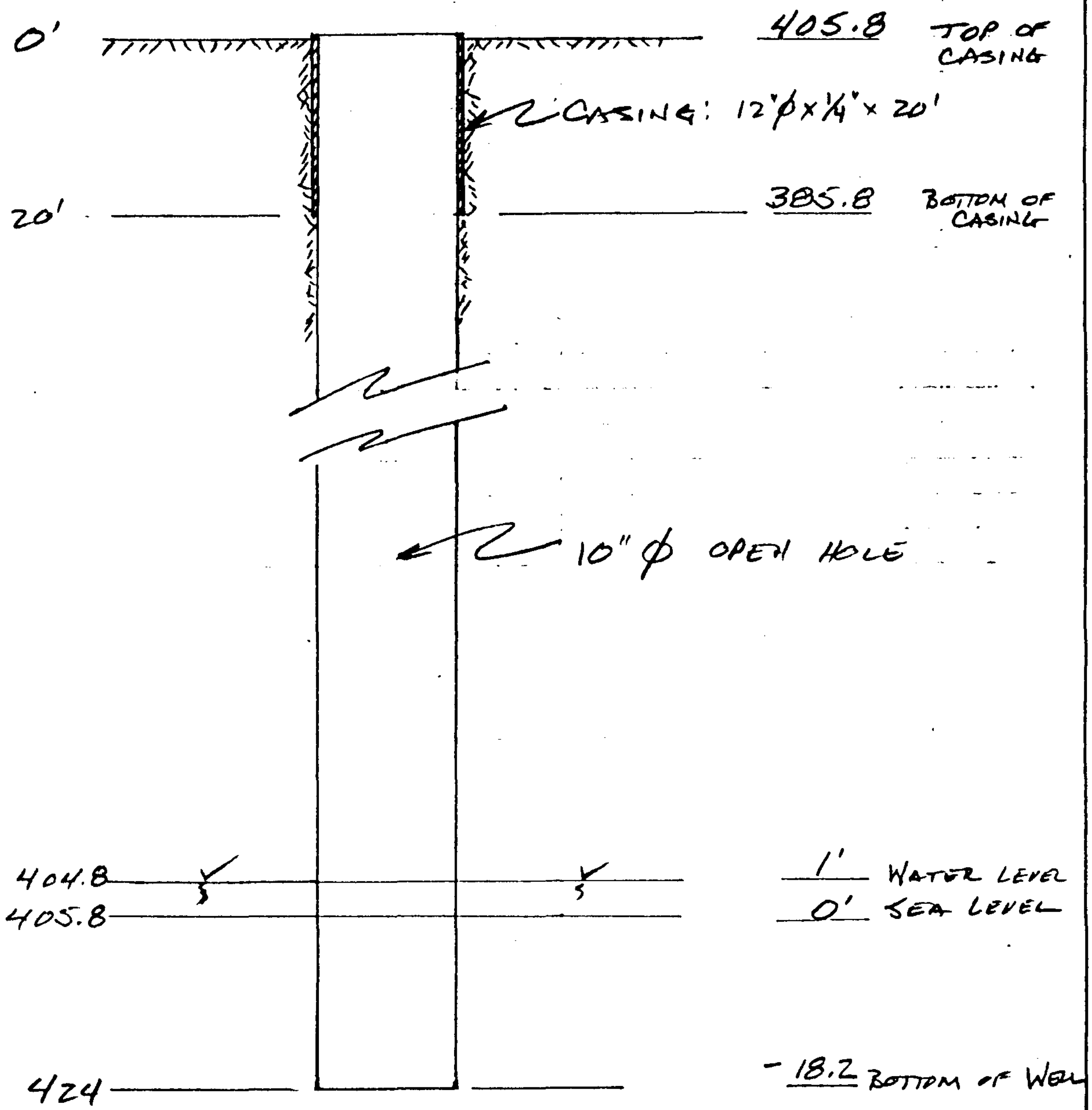
Submitted by (print) Robert G. Diffley Title Exec. Vice President, Dev.

Signature [signature] Date December 13, 1991

FOR DRILLER'S USE
Job Name ____
Job No. ____

FOR OFFICIAL USE
Latitude ____
Longitude ____
Well No. ____

ALPHA U.S.A
WEST MOLOKAI
EXPLORATORY WELL #1
0615-01



State of Hawaii
COMMISSION ON WATER RESOURCE MANAGEMENT
Department of Land and Natural Resources
Division of Water Resource Management

INTERIM WELL COMPLETION REPORT

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A. STATE WELL NO. 0615-02 WELL NAME Alpha Exploratory Hole #2 ISLAND Molokai

B. LOCATION 3.2 miles East of La'au Pt., West Molokai TAX MAP KEY 5-1-02-030

C. WELL OWNER Sekihyo Seibaku

D. DRILLING OR PUMP INSTALLATION CONTRACTOR Fred Page Drilling International

E. TYPE OF RIG Rotary DRILLER Geoffrey Feldman

F. DATE OF WELL COMPLETION N/A DATE OF PUMP INSTALLATION Pump Not Installed

G. GROUND ELEVATION (msl) 344.4 ft.
Top of Drilling Platform (msl) 347.4 ft.
Height of drilling platform above ground surface 3 ft.
Bench mark and method used to determine ground elevation Halena Bench Mark (Surveyed by Cummins & Cummins)

H. TOTAL DEPTH OF WELL BELOW GROUND 364 ft.

I. HOLE SIZE: 10 inch dia. from 0 ft. to 20 ft. below ground
8 inch dia. from 20 ft. to 364 ft. below ground
____ inch dia. from ____ ft. to ____ ft. below ground

J. CASING INSTALLED: *
10 in. I.D. x 1/4 in. wall solid section to 20 ft. below ground
____ in. I.D. x ____ in. wall perforated section to ____ ft. below ground
Type of perforation N/A

*Note: See attached sheet for drawing of casing to be installed.

K. ANNULUS: Not Grouted
Grouted from ____ ft. to ____ ft. below ground
Gravel packed from ____ ft. to ____ ft. below ground

L. PERMANENT PUMP INSTALLATION:
Pump type, make, serial No. No Pump to be Installed Capacity ____ gpm
Motor type, H.P., voltage, r.p.m.
Depth of pump intake setting ____ ft. below ____ which elevation is ____ ft.
Depth of bottom of airline ____ ft. below ____ which elevation is ____ ft.

M. PROPOSED USE Monitoring Only

N. INITIAL WATER LEVEL 345 ft. below ground. Date and time of measurement 7/16/91 / 8:00 AM

O. INITIAL CHLORIDE 11,000 ppm. Date and time of sampling 7/16/91 / 9:00 AM

P. PUMPING TESTS: Reference point (R.P.) used: ____ which elevation is ____ ft.

Date Not Pumped
Start water level ____ ft. below R. P.
End water level ____ ft. below R. P.
Depth of well ____ ft. below R. P.

Elapsed Time (hours)	Rate (gpm)	Draw-down (ft.)	Cl- (ppm)	Temp. °F
to				
to				
to				
to				
to				
to				

Date ____
Start water level ____ ft. below R. P.
End water level ____ ft. below R. P.
Depth of well ____ ft. below R. P.

Elapsed Time (hours)	Rate (gpm)	Draw-down (ft.)	Cl- (ppm)	Temp. °F
to				
to				
to				
to				
to				
to				

Q. DRILLER'S LOG:

Depth, ft.	Rock Description & Remarks	Water Level ft.
to		
to		
to	TO BE FURNISHED WITH FINAL	
to	WELL COMPLETION REPORT.	
to		
to		
to		
to		
to		
to		
to		

Depth, ft.	Rock Description & Remarks	Water Level ft.
to		
to		
to		
to		
to		
to		
to		
to		
to		
to		
to		

REMARKS:

Submitted by (print) Robert G. Diffley Title Exec. Vice President - Dev.

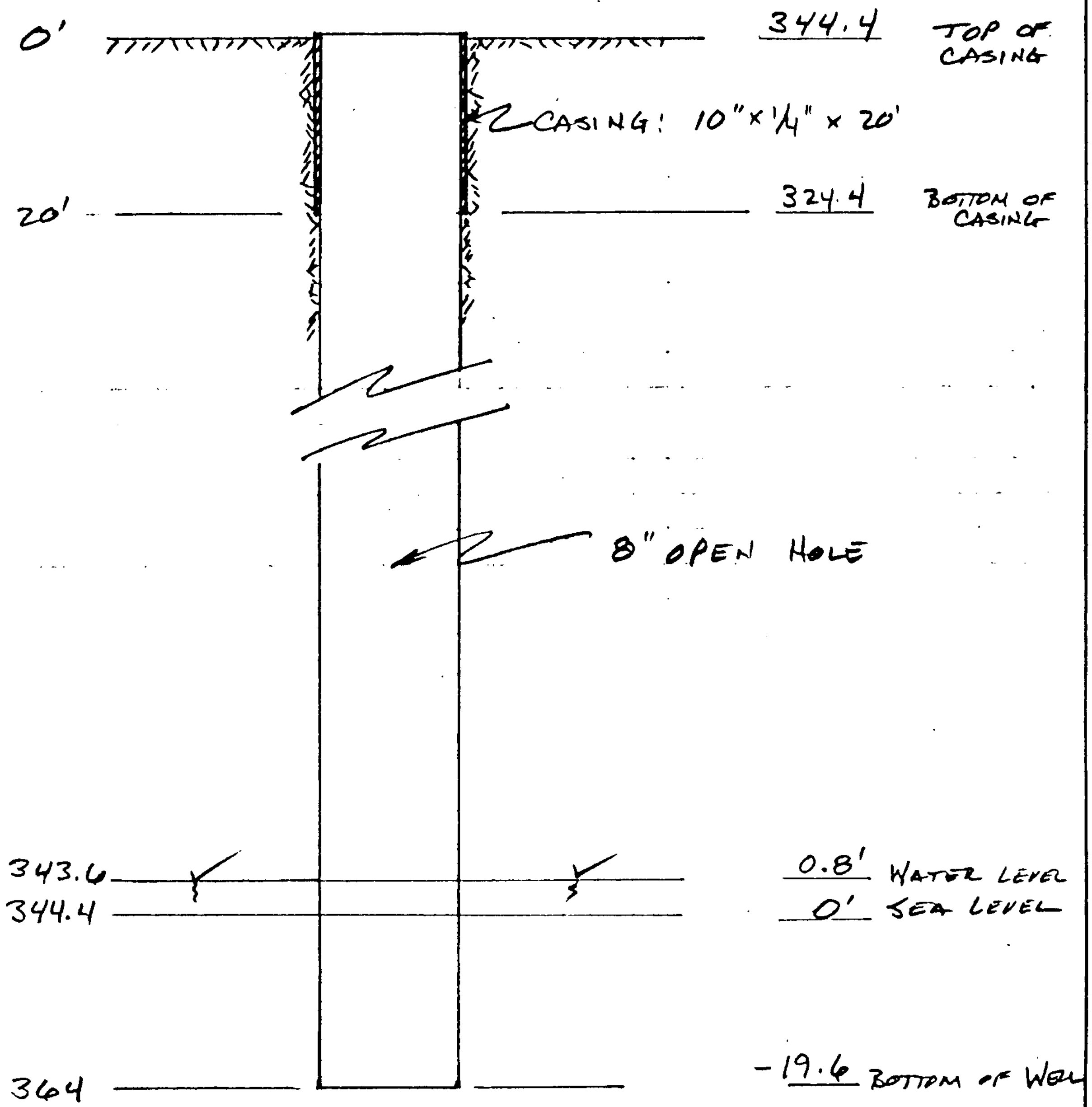
Signature [signature] Date December 13, 1991

FOR DRILLER'S USE
Job Name ____
Job No. ____

FOR OFFICIAL USE
Latitude ____
Longitude ____
Well No. ____

12/91

ALPHA U.S.A
WEST MOLOKAI
EXPLORATORY WELL #2
0615-02



State of Hawaii
COMMISSION ON WATER RESOURCE MANAGEMENT
Department of Land and Natural Resources
Division of Water Resource Management

INTERIM WELL COMPLETION REPORT

INSTRUCTIONS: Please print or type and submit completed report within 30 days of well completion to the Division of Water Resource Management, P. O. Box 373, Honolulu, Hawaii 96809. An as-built drawing of the well and chemical analysis, if available, should also be submitted. If necessary, phone 548-7543, Hydrology, Geology Section for Assistance.

A. STATE WELL NO. 0715-01 WELL NAME Alpha Exploratory Hole #3 ISLAND Molokai

B. LOCATION 4.25 miles NE of La'au Pt., West Molokai TAX MAP KEY 5-1-02-030

C. WELL OWNER Sekihyo Seibaku

D. DRILLING OR PUMP INSTALLATION CONTRACTOR Fred Page Drilling International

E. TYPE OF RIG Rotary DRILLER Geoffrey Feldman

F. DATE OF WELL COMPLETION N/A DATE OF PUMP INSTALLATION Pump Not Installed

G. GROUND ELEVATION (msl) 381.8 ft.
Top of Drilling Platform (msl) 383.8 ft.
Height of drilling platform above ground surface 3 ft.
Bench mark and method used to determine ground elevation Halena Bench Mark (Surveyed by Cummins & Cummins)

H. TOTAL DEPTH OF WELL BELOW GROUND 401 ft.

I. HOLE SIZE:
10 inch dia. from 0 ft. to 20 ft. below ground
8 inch dia. from 20 ft. to 401 ft. below ground
____ inch dia. from ____ ft. to ____ ft. below ground

J. CASING INSTALLED: *
10 in. I.D. x 1/4 in. wall solid section to 20 ft. below ground
____ in. I.D. x ____ in. wall perforated section to ____ ft. below ground
Type of perforation ____

*Note: See attached sheet for drawing of casing to be installed.

K. ANNULUS: Not Grouted
Grouted from ____ ft. to ____ ft. below ground
Gravel packed from ____ ft. to ____ ft. below ground

L. PERMANENT PUMP INSTALLATION:
Pump type, make, serial No. No Pump Installed Capacity ____ gpm
Motor type, H.P., voltage, r.p.m. ____
Depth of pump intake setting / ft. below / which elevation is / ft.
Depth of bottom of airline / ft. below / which elevation is / ft.

M. PROPOSED USE Future Source for Desalination

N. INITIAL WATER LEVEL ____ ft. below ground. Date and time of measurement ____ / ____

O. INITIAL CHLORIDE 4,400 ppm. Date and time of sampling ____ / ____

P. PUMPING TESTS: Reference point (R.P.) used: Static Water Level which elevation is 1.8 ft.

Date ____
Start water level 0 ft. below R. P.
End water level 0 ft. below R. P.
Depth of well 21 ft. below R. P.

Elapsed Time (hours)			Rate (gpm)	Draw-down (ft.)	Cl- (ppm)	Temp. °F
12:00 PM	to	1:00 PM	228	1.2	4,400	
1:00 PM	to	2:00 PM	228	0.2	4,400	
	to		to 20			
2:00 PM	to	12:00 PM	240	0.9	4,400	95.5
	to					
	to					

Date ____
Start water level ____ ft. below R. P.
End water level ____ ft. below R. P.
Depth of well ____ ft. below R. P.

Elapsed Time (hours)			Rate (gpm)	Draw-down (ft.)	Cl- (ppm)	Temp. °F
	to					
	to					
	to					
	to					
	to					
	to					

Q. DRILLER'S LOG:

Depth, ft.			Rock Description & Remarks	Water Level ft.
	to			
	to			
	to		TO BE FURNISHED WITH FINAL	
	to		WELL COMPLETION REPORT.	
	to			
	to			
	to			
	to			
	to			
	to			
	to			

REMARKS: ____

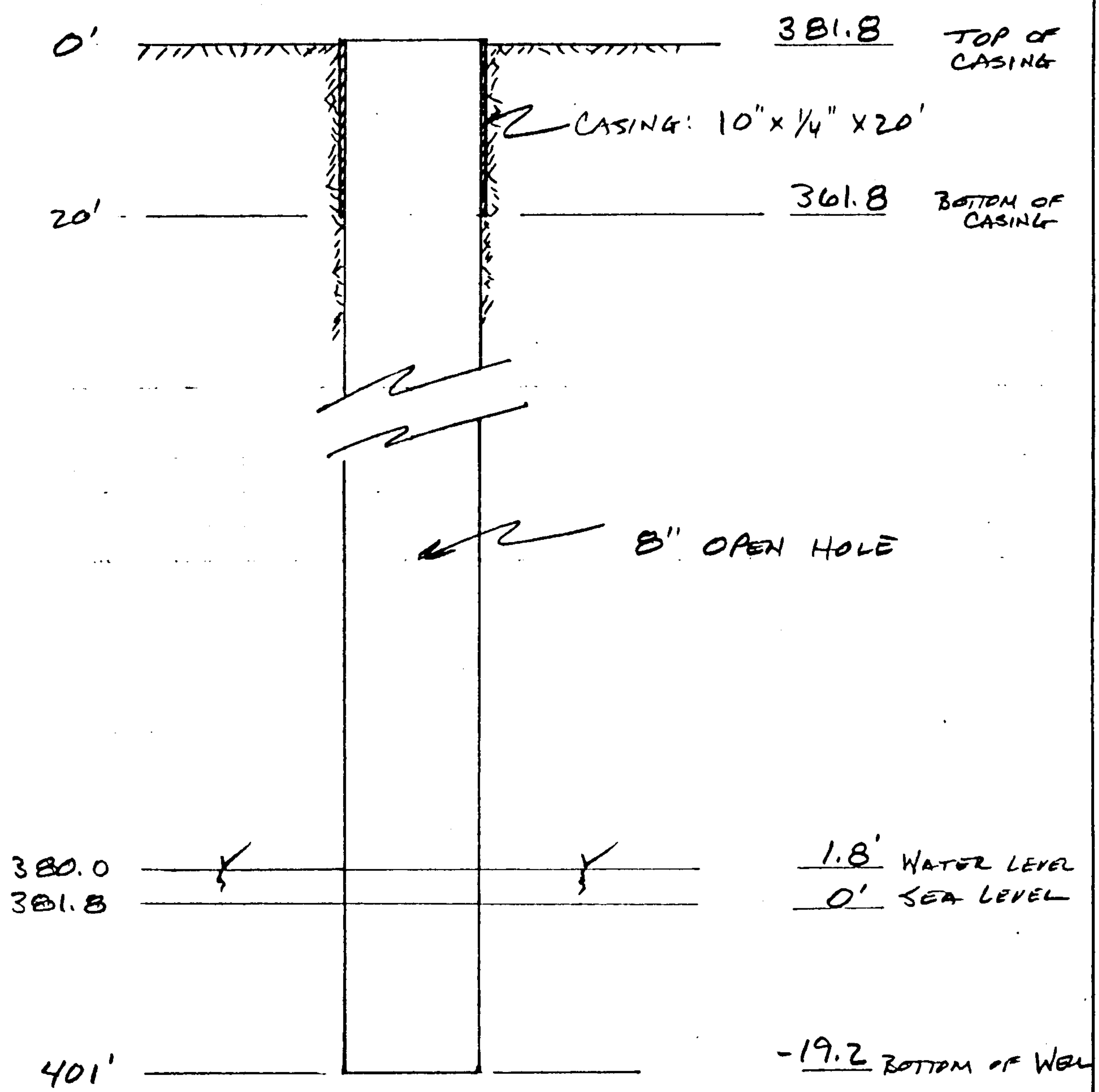
Submitted by (print) Robert G. Diffley
Title Exec. Vice President - Dev.

Signature [signature]
Date December 13, 1991

FOR DRILLER'S USE
Job Name ____
Job No. ____

FOR OFFICIAL USE
Latitude ____
Longitude ____
Well No. ____

ALPHA U.S.A
WEST MOLOKAI
EXPLORATORY WELL #3
0715-01



State of Hawaii
COMMISSION ON WATER RESOURCE MANAGEMENT
Department of Land and Natural Resources
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INTERIM WELL COMPLETION REPORT

INSTRUCTIONS: Please print or type and submit completed report within 30 days of well completion to the Division of Water Resource Management, P. O. Box 373, Honolulu, Hawaii 96809. An as-built drawing of the well and chemical analysis, if available, should also be submitted. If necessary, phone 548-7543, Hydrology, Geology Section for Assistance.

A. STATE WELL NO. 0715-02 WELL NAME Alpha Exploratory Hole #4 ISLAND Molokai

B. LOCATION 3.75 miles NE of La'au Pt., West Molokai TAX MAP KEY 5-1-02-030

C. WELL OWNER Sekihyo Seibaku

D. DRILLING OR PUMP INSTALLATION CONTRACTOR Fred Page Drilling International

E. TYPE OF RIG Rotary DRILLER Geoffrey Feldman

F. DATE OF WELL COMPLETION N/A DATE OF PUMP INSTALLATION No Pump Installed

G. GROUND ELEVATION (msl) 367 ft.
Top of Drilling Platform (msl) 370 ft.
Height of drilling platform above ground surface 3 ft.
Bench mark and method used to determine ground elevation Halena Bench Mark (Surveyed by Cummins & Cummins)

H. TOTAL DEPTH OF WELL BELOW GROUND 387 ft.

I. HOLE SIZE: 10 inch dia. from 0 ft. to 20 ft. below ground
8 inch dia. from 20 ft. to 387 ft. below ground
______ inch dia. from ______ ft. to ______ ft. below ground

J. CASING INSTALLED: *
10 in. I.D. x 1/4 in. wall solid section to 20 ft. below ground
______ in. I.D. x ______ in. wall perforated section to ______ ft. below ground
Type of perforation ______

*Note: See attached sheet for drawing of casing to be installed

K. ANNULUS: Not Grouted
Grouted from ______ ft. to ______ ft. below ground
Gravel packed from ______ ft. to ______ ft. below ground

L. PERMANENT PUMP INSTALLATION:
Pump type, make, serial No. No Pump Installed Capacity ______ gpm
Motor type, H.P., voltage, r.p.m. ______
Depth of pump intake setting / ft. below / which elevation is / ft.
Depth of bottom of airline / ft. below / which elevation is / ft.

M. PROPOSED USE Future Source for Desalination

N. INITIAL WATER LEVEL 365.9 ft. below ground. Date and time of measurement ______ / ______

O. INITIAL CHLORIDE 6,625 ppm. Date and time of sampling ______ / ______

P. PUMPING TESTS: Reference point (R.P.) used: Static Water Level which elevation is 1.1 ft.

Date ......
Start water level 0 ft. below R. P.
End water level 0 ft. below R. P.
Depth of well 21.1 ft. below R. P.

Elapsed Time (hours)	Rate (gpm)	Draw-down (ft.)	Cl- (ppm)	Temp. °F
11:00 AM to 12:00 PM	276	1.4	6,600	–
12:00 PM to 1:00 PM	276	Nil	6,600	–
to	to 50			
1:00 PM to 9:00 AM	260	0.9	7,000	93
to				
to				

Date ......
Start water level ...... ft. below R. P.
End water level ...... ft. below R. P.
Depth of well ...... ft. below R. P.

Elapsed Time (hours)	Rate (gpm)	Draw-down (ft.)	Cl- (ppm)	Temp. °F
to				
to				
to				
to				
to				
to				

Q. DRILLER'S LOG:

Depth, ft.	Rock Description & Remarks	Water Level ft.
to		
to		
to	TO BE FURNISHED WITH FINAL	
to	WELL COMPLETION REPORT.	
to		
to		
to		
to		
to		
to		
to		

REMARKS: ......

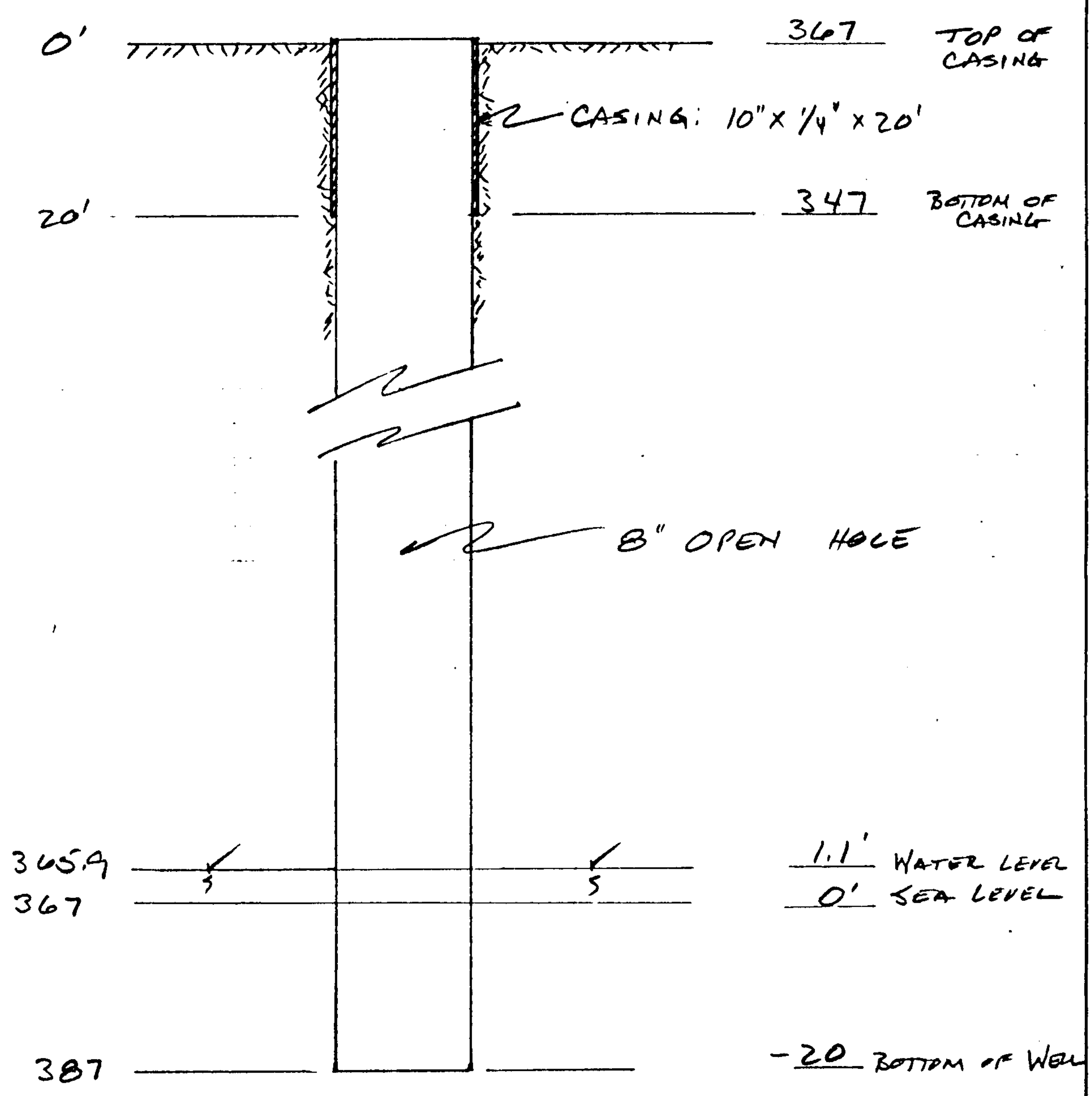
Submitted by (print) Robert G. Diffley Title Exec. Vice President - Dev.

Signature [signature] Date December 13, 1991

FOR DRILLER'S USE
Job Name ......
Job No. ......

FOR OFFICIAL USE
Latitude ......
Longitude ......
Well No. ......

ALPHA U.S.A
WEST MOLOKAI
EXPLORATORY WELL #4
0715-02



State of Hawaii
COMMISSION ON WATER RESOURCE MANAGEMENT
Department of Land and Natural Resources
Division of Water Resource Management

INTERIM WELL COMPLETION REPORT

INSTRUCTIONS: Please print or type and submit completed report within 30 days of well completion to the Division of Water Resource Management, P. O. Box 373, Honolulu, Hawaii 96809. An as-built drawing of the well and chemical analysis, if available, should also be submitted. If necessary, phone 548-7543, Hydrology, Geology Section for Assistance.

A. STATE WELL NO. 0815-01 WELL NAME Alpha Exploratory Hole #5 ISLAND Molokai
B. LOCATION 4.5 miles NE of La'au Pt., West Molokai TAX MAP KEY 5-1-02-030
C. WELL OWNER Sekihyo Seibaku
D. DRILLING OR PUMP INSTALLATION CONTRACTOR Fred Page Drilling International
E. TYPE OF RIG Rotary DRILLER Geoffrey Feldman
F. DATE OF WELL COMPLETION N/A DATE OF PUMP INSTALLATION No Pump Installed
G. GROUND ELEVATION (msl) 388.5 ft.
Top of Drilling Platform (msl) 391.5 ft.
Height of drilling platform above ground surface 3 ft.
Bench mark and method used to determine ground elevation Halena Bench Mark (Surveyed by Cummins & Cummins)
H. TOTAL DEPTH OF WELL BELOW GROUND 409 ft.
I. HOLE SIZE: 10 inch dia. from 0 ft. to 20 ft. below ground
8 inch dia. from 20 ft. to 409 ft. below ground
inch dia. from ____ ft. to ____ ft. below ground
J. CASING INSTALLED: *
10 in. I.D. x 1/4 in. wall solid section to 20 ft. below ground
in. I.D. x ____ in. wall perforated section to ____ ft. below ground
Type of perforation ____

*Note: See attached sheet for drawing of casing to be installed.

K. ANNULUS: Not Grouted
Grouted from ____ ft. to ____ ft. below ground
Gravel packed from ____ ft. to ____ ft. below ground
L. PERMANENT PUMP INSTALLATION: No Pump Installed -
Pump type, make, serial No. Application to Follow Capacity ____ gpm
Motor type, H.P., voltage, r.p.m.
Depth of pump intake setting ____ ft. below ____ which elevation is ____ ft.
Depth of bottom of airline ____ ft. below ____ which elevation is ____ ft.
M. PROPOSED USE Irrigation Test Well - Possible Desalination Feedwater
N. INITIAL WATER LEVEL 390.1 ft. below ground. Date and time of measurement ____/____
O. INITIAL CHLORIDE 4,500 ppm. Date and time of sampling ____/____
P. PUMPING TESTS: Reference point (R.P.) used: Static Water Level which elevation is 390.1 ft.

Date ____
Start water level 0 ft. below R. P.
End water level 0 ft. below R. P.
Depth of well 20 ft. below R. P.

Elapsed Time (hours)	Rate (gpm)	Draw-down (ft.)	Cl- (ppm)	Temp. °F
1:00 PM to 2:00 PM	211	4.2	4,250	96
2:00 PM to 3:00 PM	211	3.9	--	96
to	to 91			
3:00 PM to 3:00 PM	225	2.1	4,400	96
to				
to				

Date ____
Start water level ____ ft. below R. P.
End water level ____ ft. below R. P.
Depth of well ____ ft. below R. P.

Elapsed Time (hours)	Rate (gpm)	Draw-down (ft.)	Cl- (ppm)	Temp. °F
to				
to				
to				
to				
to				
to				

Q. DRILLER'S LOG:

Depth, ft.	Rock Description & Remarks	Water Level ft.
to	TO BE FURNISHED WITH FINAL WELL COMPLETION REPORT.	

REMARKS: ____

Submitted by (print) Robert G. Diffley Title Exec. Vice President - Dev.
Signature [signature] Date December 13, 1991

FOR DRILLER'S USE
Job Name ____
Job No. ____

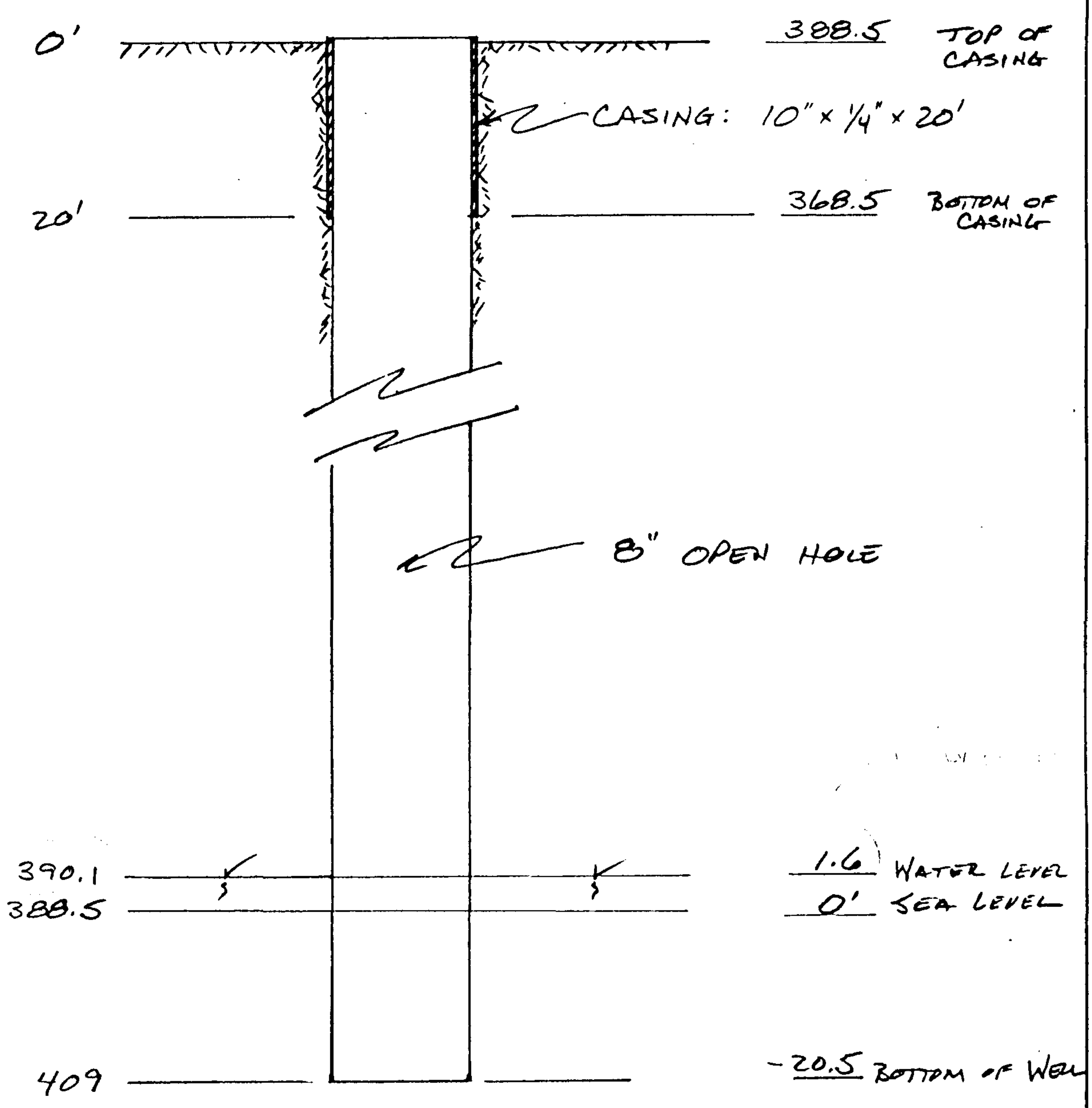
FOR OFFICIAL USE
Latitude ____
Longitude ____
Well No. ____

ALPHA U.S.A

WEST MOLOKAI

EXPLORATORY WELL #5

0815-01



Alpha U.S.A., Inc.

October 3, 1991

RECEIVED
91 OCT 4 A10:33
DIV. OF WATER & LAND DEVELOPMENT

Mr. Edwin Sakoda, Geologist
DIVISION OF WATER RESOURCE MANAGEMENT
Department of Land & Natural Resources
P. O. Box 373
Honolulu, HI 96809 New No. (0815-01)

Subject: Test Hole #5 (Well No. 0717-02)
Laau Point, Molokai

Dear Mr. Sakoda:

After receiving additional water samples from Exploratory Hole #3 (Well No. 0715-01) and Hole #4 (0715-2),we would like to request permission to drill Test Hole #5 closer to Hole #3 in an effort to find usable water. We are enclosing maps showing the originally approved location of Test Hole #5, as well as the new location where we would like to drill.

For your information, also enclosed is interim field information on Test Holes #3 and #4.

We look forward to receiving your approval on the change in location as requested above.

Very truly yours,

Bob

Robert G. Diffley
Executive Vice President
Development

RGD:jsy

Enclosures

City Financial Tower
201 Merchant Street, Suite 2100
Honolulu, Hawaii 96813
Phone: (808) 532-2121 Fax Phone: (808) 532-2130

10/1 c: Tom Nance

ALPHA MOLOKAI

16"-18" HEAD

DRAWDOWN & SALINITY TEST
HOLE # 3 (0715-01)
SEPTEMBER 26, 1991

10/1 ~~FILED~~

TIME	AIRLINE P (STATIC=)	ΔP	DRAWDOWN (FEET)	FLOWMETER READING (	TIME INTERVAL (MIN)	Q (gpm)	S (TDS)	T (°F)
OFF	6.9±	—	0	018869				—
12:00	6.4	0.5	1.15±	886.9		225±	~~9000~~ 8000	—
12:30	6.4	0.5	1.15	907.9	30 min	228.1	~~8000~~ 8000	—
1:00	6.4	0.5	1.15	928.9	30 min	228	~~8800~~ 8000	—
1:25	6.5	0.4	0.9	947	25 M	235.9 (175)	X	X
1:35	6.7	0.2	0.5	953	10 m	195.5 (125)	X	X
1:45	6.7½	0.2	0.35	957.9	10 m	159.7 (50)	X	X
1:55	6.8	0.1	0.2	958.6	10 m	19.5	X	X
2:00	6.5	0.4	0.9 END TEST		—	FULL	X	X
2:04	6.5	0.4	0.9	963.2	—	225±	X	X
3:00	6.6	0.3	0.7	019 003.5	56 m	234 gpm	~~8400~~ 8000	95°
6:00	6.6	0.3	0.7	130	3 Hr	229	8100	95.8°
9:00	6.6	0.3	0.7	264		242	8300	95.8°
12:00	6.6	0.3	0.7	397		241	8300	95.5°
3:00	6.4	0.4	0.9	531		242		95.5
6:00	6.2	0.7	1.61	664		240		95.5
9:00	6.3	0.6	1.4	797		241		95.3
12:00	6.5	0.4	0.9	929	3 Hr	239	8300	95.5°

X X X

9/26/91

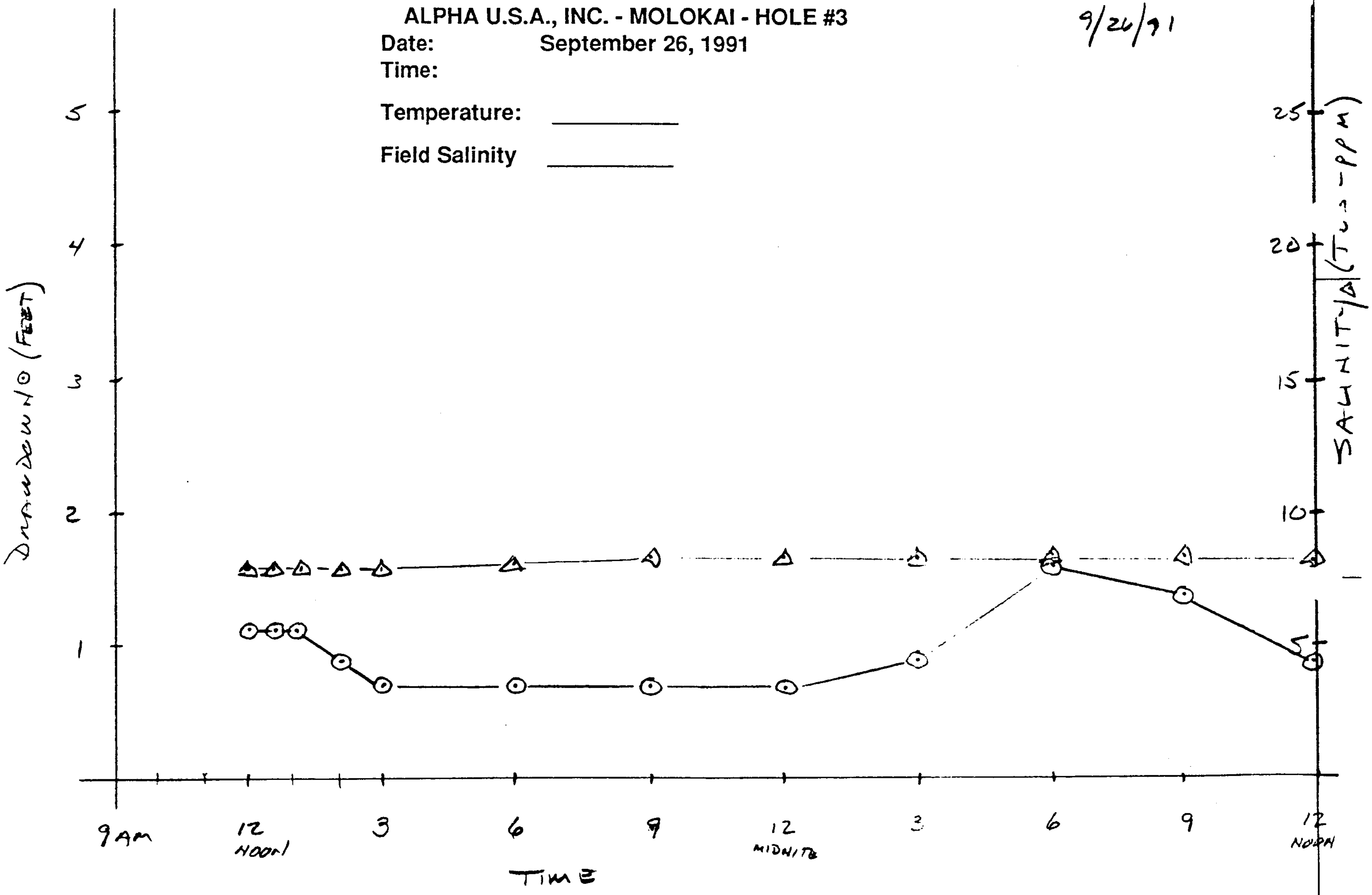
ALPHA U.S.A., INC. - MOLOKAI - HOLE #3

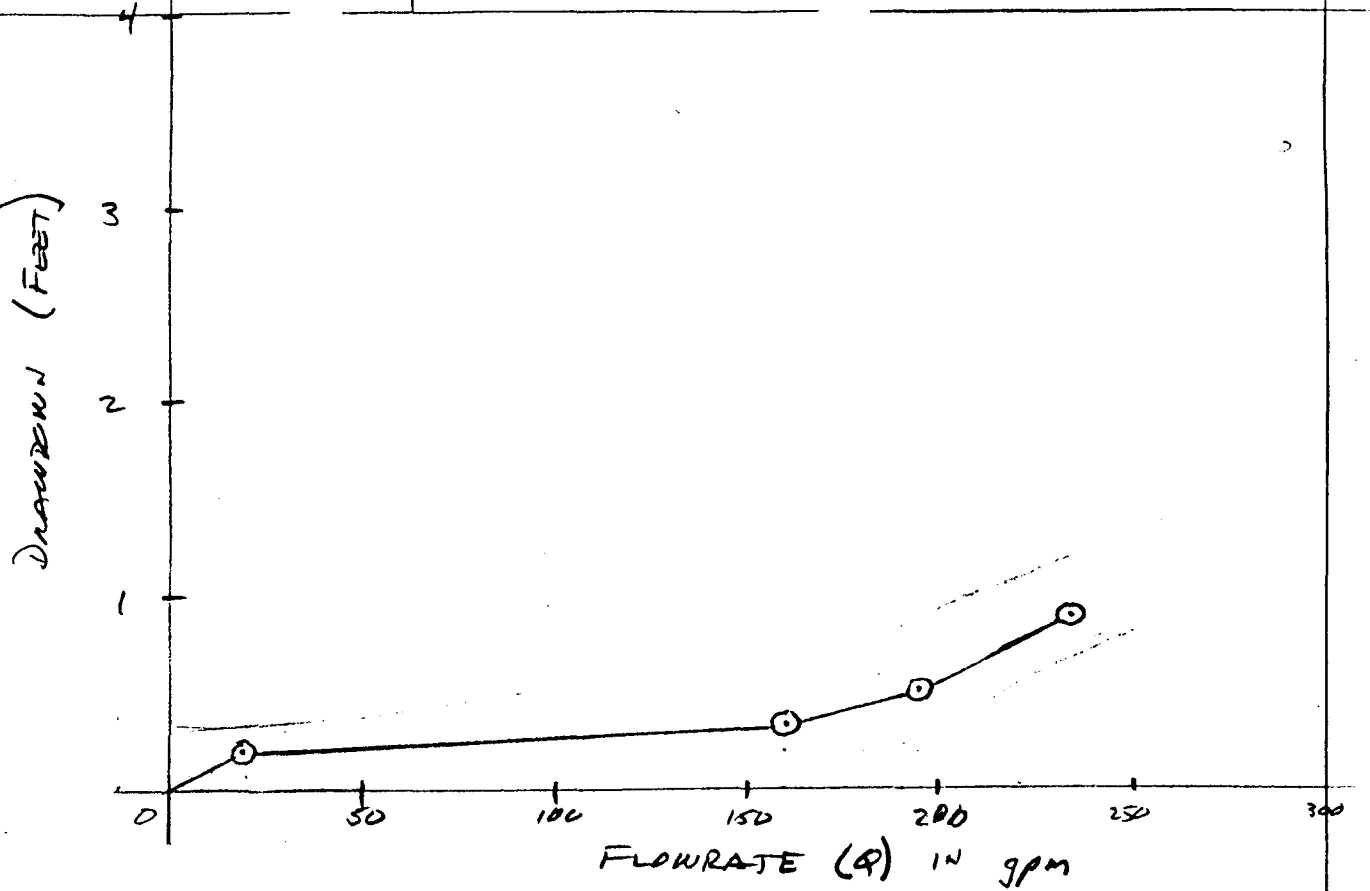
Date: September 26, 1991

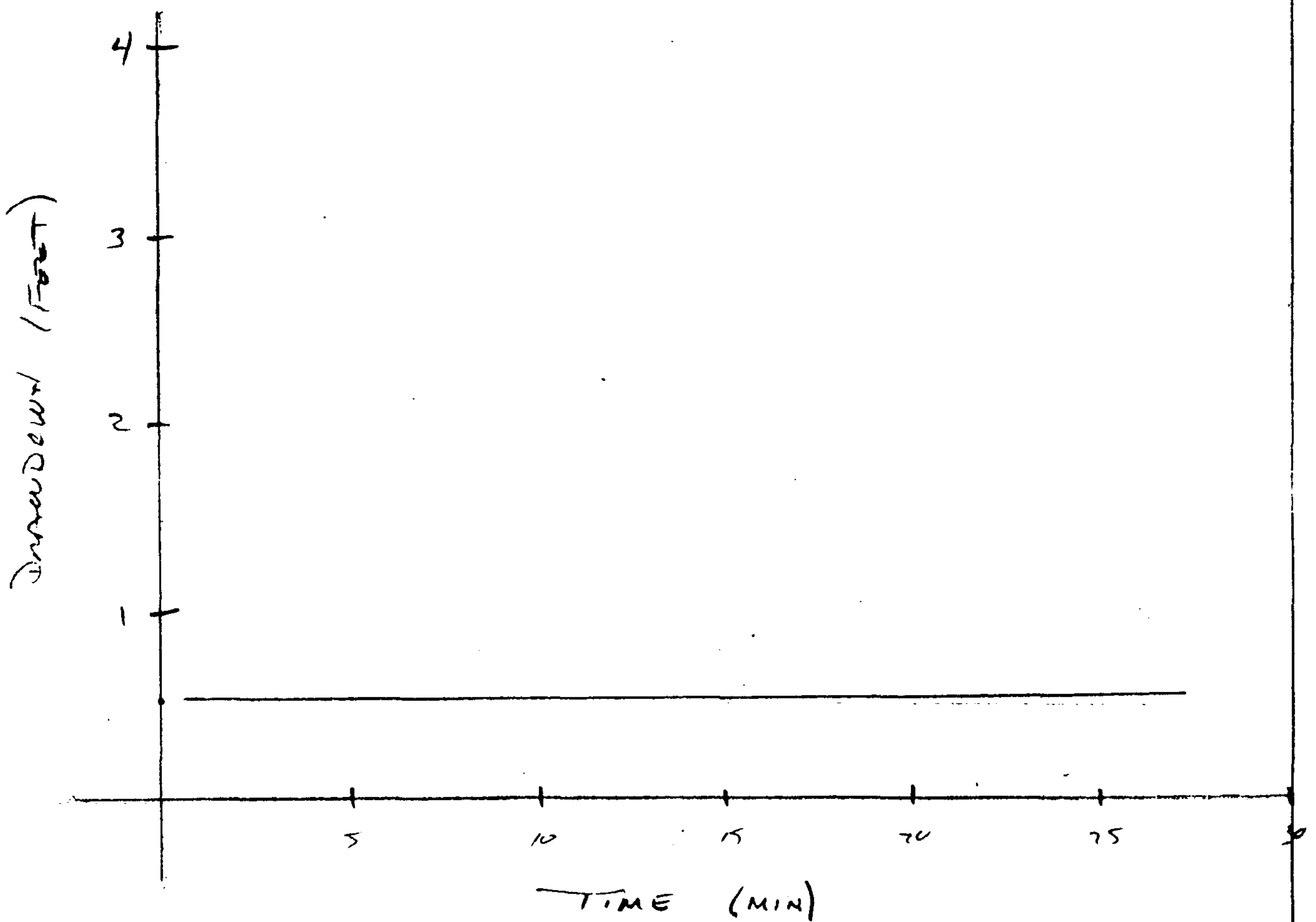
Time:

Temperature: ________

Field Salinity ________







$D = (P_S - P_Q) \times 2.31$

ALPHA MOLOKAI

STEP DRAWDOWN TEST
HOLE #4 (0715-02)
SEPTEMBER 1991

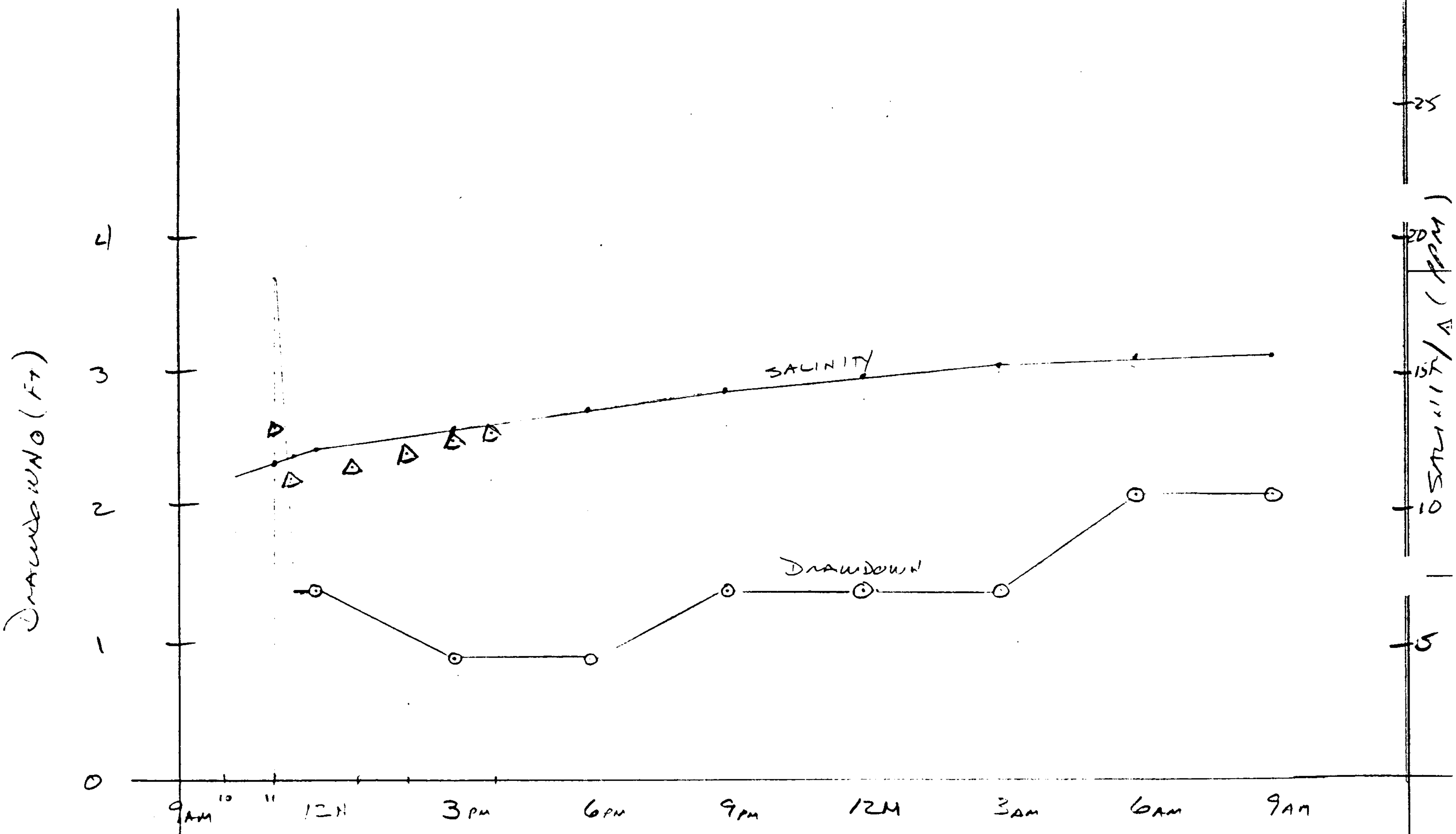
Depth 369.2
FROM TABLE
< 39½" TO TOC
< TAPE ADJST

STATIC PRESSURE : 6.4

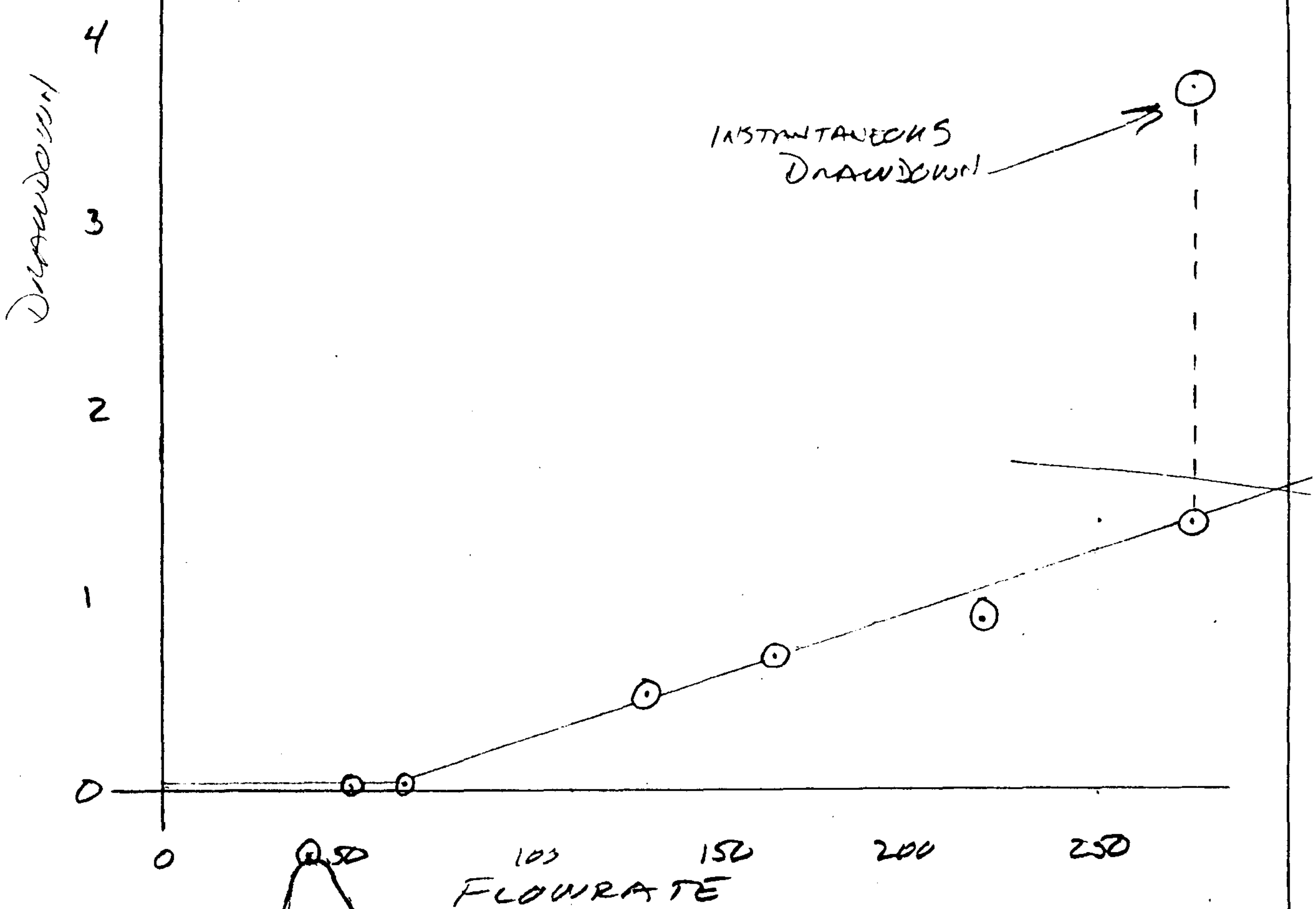
TOC→WL =

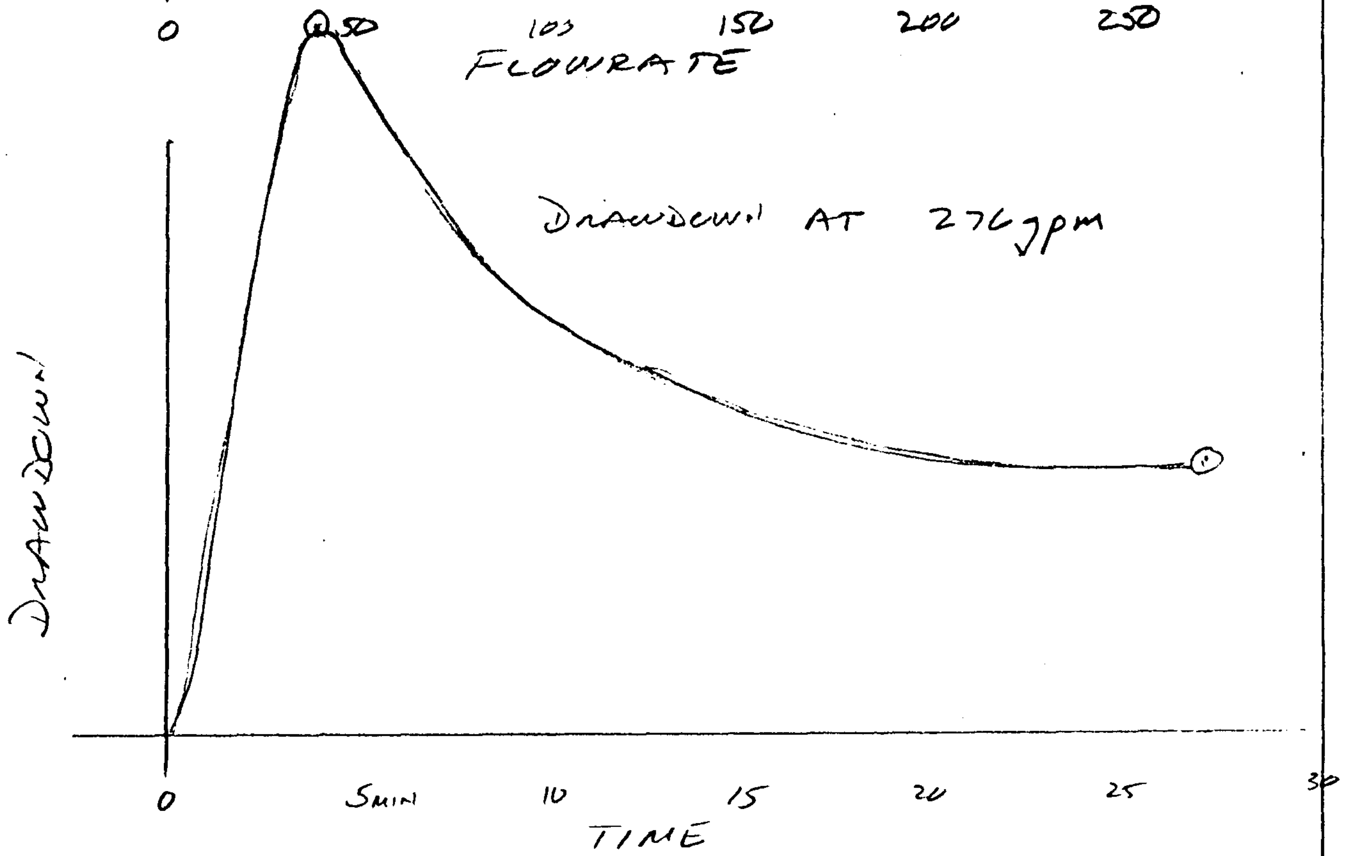
TIME	AIR LINE PRESSURE	ΔP	DRAWDOWN (FEET)	FLOWMETER READING (Ac·ft × .001)	TIME INTERVAL (min.)	Q (gpm)
11:04 AM	6.4 p	–	STATIC	017826	START	
11:08	4.8	1.6	* 3.7			
11:09	?			833		
11:27	5.8	0.6	1.4	847.5		
11:52	5.9	0.5		867		
12:00 N	5.8	0.6	* 1.4	873.5	56	* 276 gpm
12:20	5.9 6.0 p	0.5 0.4	* 0.9	887	20	* 220 gpm
12:25	6.0 6.0 p	0.4	0.9	890.5	5	228 gpm
12:30	6.1 6.2 p	0.3 0.2	* 0.7 0.5	893	5	* 163 gpm
12:35	6.2 6.2 p	0.2	* 0.5	895	5	* 130 gpm
12:40	6.4 6.4 p	0.0	0.0	896	5	65 gpm
12:45	6.4	0.0	0.0	896.8	5	52 gpm
12:45	6.0	0.4	0.9			
1:00 PM	6.0	0.4	0.9	908.5	15	254 gpm
3	6.0	0.4	0.9	004.3	60	
6	6.0	0.4	0.9			
9	5.8	0.6	1.4		250 – 255 260	
12 M	5.8	0.6	1.4			
3 AM	5.8	0.6	1.4			
6 AM	5.5	0.9	2.1			
9 AM	5.5	0.9	2.1	018865		260 gpm

TEMPERATURE CONSTANT 93°F



Alpha Molokai
Drawdown Test
Hole #4 9/91


4
3
2
1
0
DRAWDOWN
INSTANTANEOUS
DRAWDOWN
0
50
100
150
200
250
FLOWRATE


DRAWDOWN AT 276 gpm
DRAWDOWN
0
5 min
10
15
20
25
30
TIME

Job No. 054.16
Date Sent:
Time:

TOM NANCE
WATER RESOURCES ENGINEERING

FACSIMILE HEADER

To: ALPHA (USA)
Fax No. 532-2130
Attention: Bob Diffley
Date: Sept. 10
From: Tom Nance
No. of Pages: 1
(Including Header)
Subject: Well No 4 Water Samples

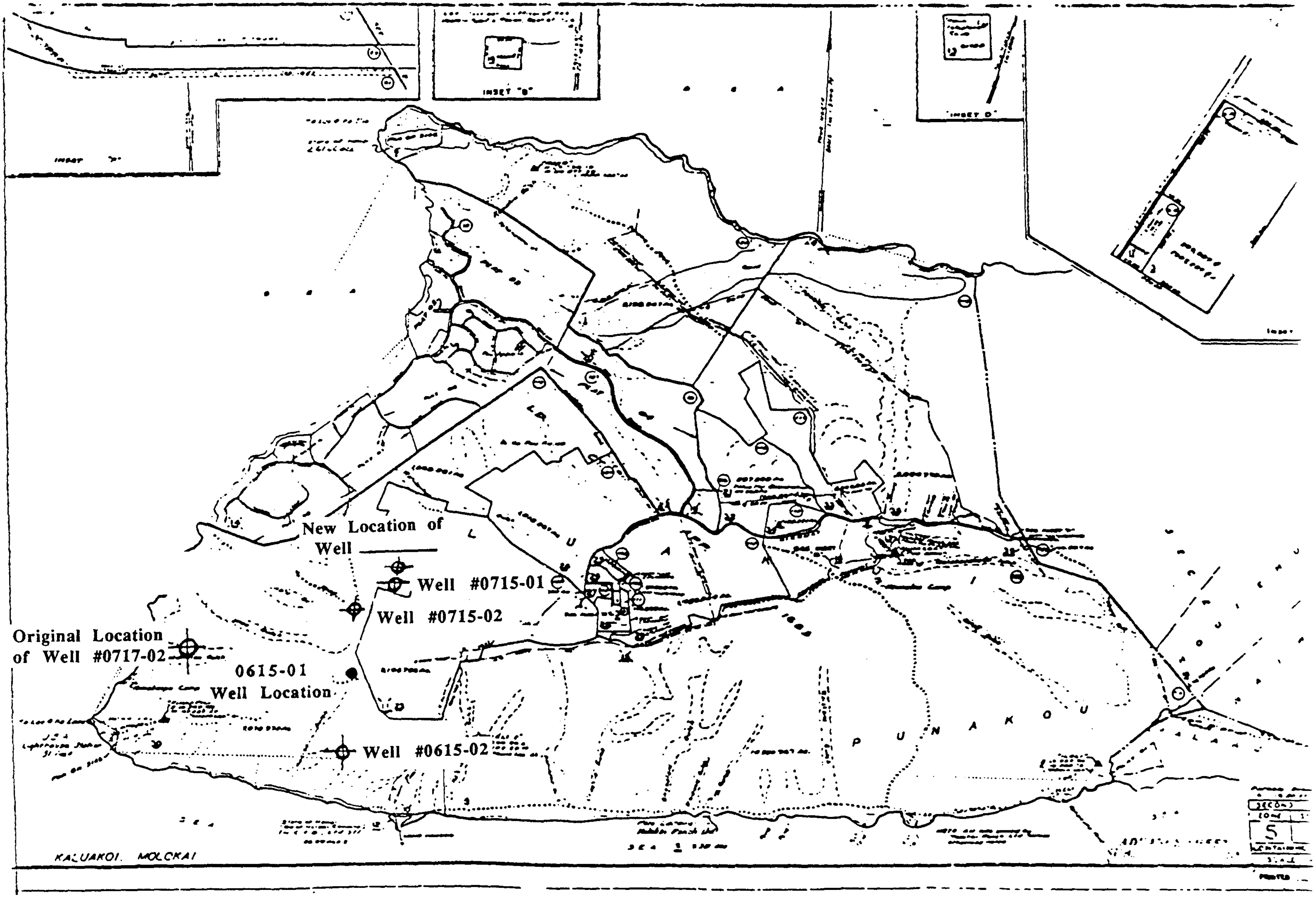
If you do not receive all pages, please telephone immediately.

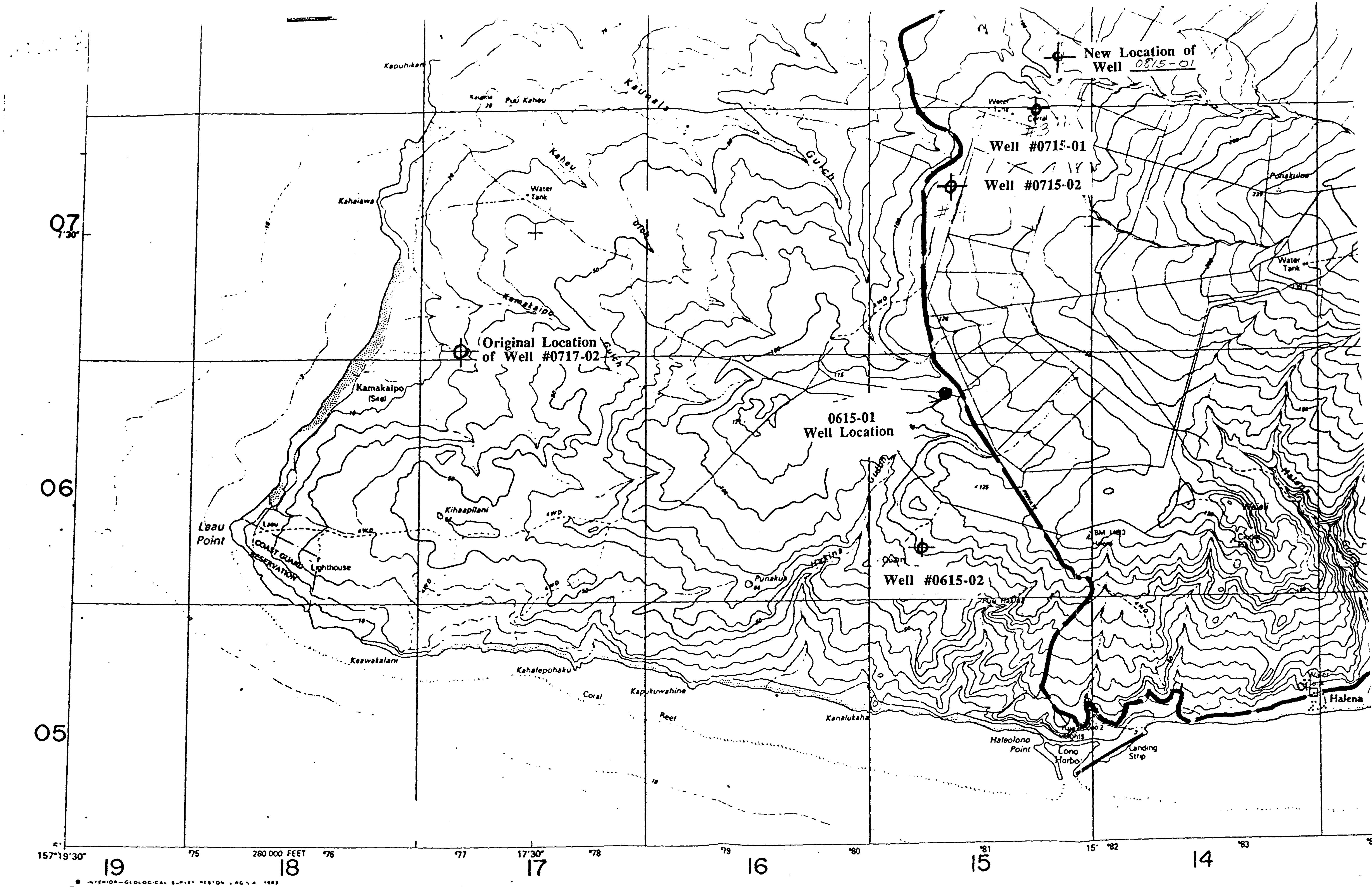
My testing of the Well 4 samples is summarized below....
... a steady increase in salinity, unfortunately

ALPHA USA
PUMP TEST OF WELL No 4
SEPT 11-12, 1991

SAMPLE No	DATE	TIME	SALINITY (‰)	COND. (umhos)
1	9/11	11:00 AM	11.7	17,800
2		11:30 AM	11.9	18,100
3		12:00 PM	12.1	18,360
4		3:00 PM	12.8	19,350
5		6:00 PM	13.6	20,400
6		9:00 PM	14.3	21,460
7	9/12	12:00 AM	14.9	22,250
8		3:00 AM	15.2	22,600
9		6:00 AM	15.6	23,150
10		9:00 AM	15.7	23,460

680 Ala Moana Boulevard, Suite 200 • Honolulu, Hawaii 96813 • Phone: (808) 521-5361 • Fax: (808) 538-7819
A Belt Collins & Associates Company


New Location of Well
Well #0715-01
Well #0715-02
Original Location of Well #0717-02
0615-01 Well Location
Well #0615-02
P U N A K O U
KALUAKOI. MOLOKAI
5


New Location of Well 0815-01
Well #0715-01
Well #0715-02
Original Location of Well #0717-02
0615-01 Well Location
Well #0615-02
Kapuhikani
Puu Kaheu
Kaunala Gulch
Kaheu
Water Tank
Kahaiawa
Kamakaipo Gulch
Kamakaipo (Site)
Laau Point
COAST GUARD RESERVATION
Lighthouse
Kihaapilani
Punakua
Keawakalani
Kahalepohaku
Coral
Kapukuwahine
Reef
Kanalukaha
Haleolono Point
Lono Harbor
Landing Strip
Halena
Pohakuloa
Water Tank
Puu Hakina
07
06
05
157°19'30"
280 000 FEET
17'30"
15'
19
18
17
16
15
14
INTERIOR—GEOLOGICAL SURVEY, RESTON, VIRGINIA—1983

GEOPHYSICAL SURVEY FOR CHARACTERIZING THE HYDROGEOLOGIC REGIME OF THE PUU ANAHULU AREA OF NORTH KONA, ISLAND OF HAWAII

BLACKHAWK GEOSCIENCES, INC.

GEOPHYSICAL SURVEY FOR CHARACTERIZING THE HYDROGEOLOGIC REGIME OF THE PUU ANAHULU AREA OF NORTH KONA ISLAND OF HAWAII

Prepared For:

State of Hawaii
Department of Land and Natural Resources
Division of Water Resource Management
Kalanimoku Bldg., Room 227
1151 Punchbowl Street
Honolulu, HI 96809

Prepared By:

Blackhawk Geosciences, Inc.
17301 West Colfax Ave., Suite 170
Golden, CO 80401

(BGI Project #91052)

December 3, 1991

Table of Contents

1.0 INTRODUCTION

This report contains the results of time domain electromagnetic (TDEM) geophysical surveys for ground water resource evaluation of the Puu Anahulu area of North Kona on the Island of Hawaii. The survey was performed by Blackhawk Geosciences, Inc. (BGI) for the Division of Water Resource Management, State of Hawaii, from October 29 to November 3, 1991.

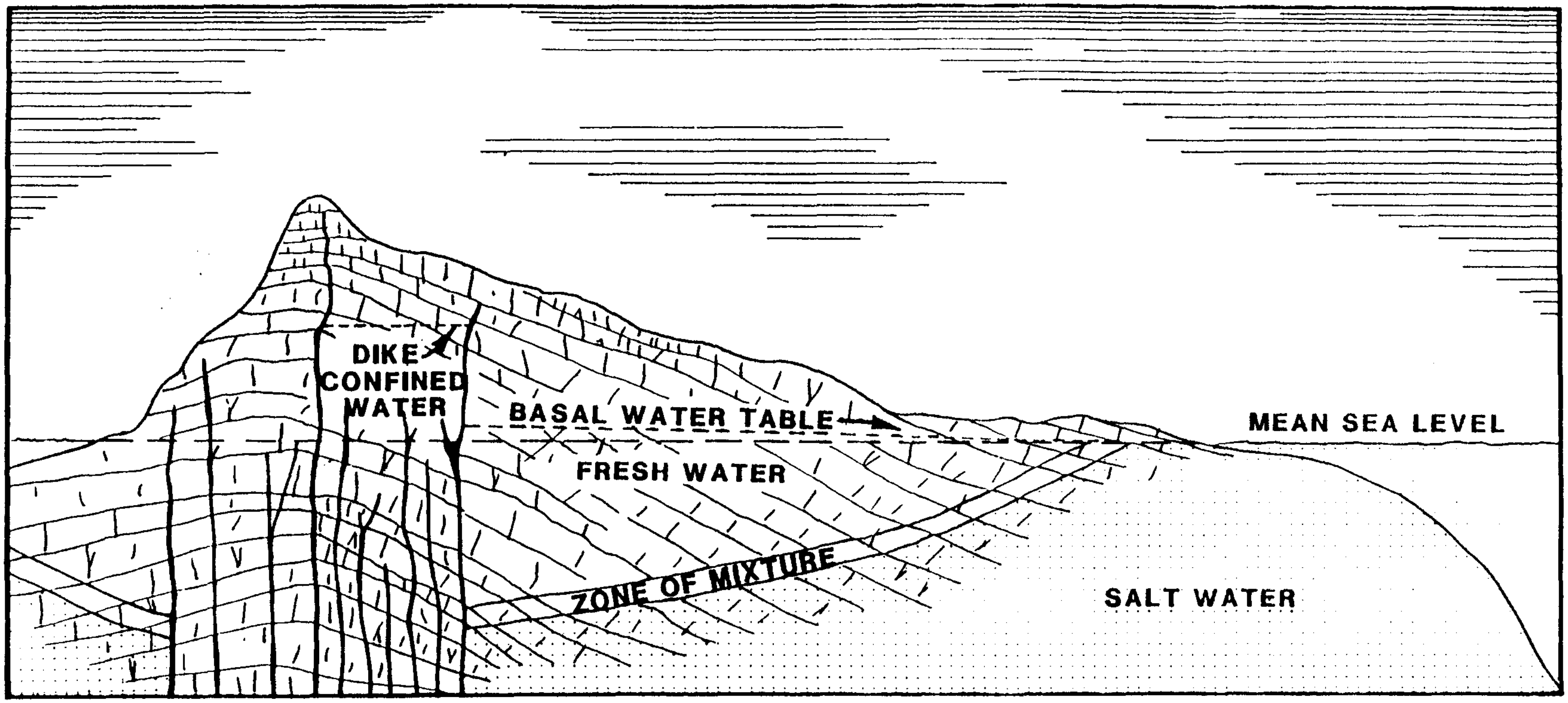
The main objective of the geophysical survey was to characterize the hydrologic regime near Puu Anahulu. The concept for using geophysical surveys for ground water evaluations can be understood using the generalized hydrogeologic cross section shown in Figure 1-1. In the Hawaiian islands, the volcanic rocks are generally highly permeable and rain water rapidly percolates into the ground and migrates downward to the water table. Fresh ground water in island settings is generally found in two environments:

1. Dike-confined waters. Intrusive dikes originating from a magma source below can form ground water dams, and behind these natural dams significant quantities of ground water can be stored.

2. Basal fresh water. The high permeability of the volcanic rocks allows sea water to enter freely under the island, and a delicate balance is reached where a lens of fresh water floats on sea water. In cases where hydrostatic equilibrium exists, the Ghyben-Herzberg relation states that for every foot of fresh water head above sea level there will be 40 ft of fresh water below sea level.

The basal mode water resource was the main focus in the investigations for the State of Hawaii.

Because the electrical resistivity of rock formations is highly dependent upon the salinity of ground water, electrical surface geophysical techniques can map the depth to salt water, and the thickness of the fresh water lens can then be estimated using the Ghyben-Herzberg principle. The impetus for using geophysics is that the cost of a geophysical sounding is about one-thousandth the cost of completing a well at elevations above 1,000 ft. Geophysical surveys, combined with other hydrogeologic information, are used to provide optimum locations for well placement and well completion depths. The specific geophysical method employed was time domain electromagnetic (TDEM) soundings. This method was selected because it has proven effective in prior surveys in similar settings in Hawaii.



BLACKHAWK GEOSCIENCES, INC.

SCHEMATIC HYDRO-GEOLOGIC CROSS SECTION

DIVISION OF WATER RESOURCES MGMT.
STATE OF HAWAII

PROJECT NO: 91054

FIGURE 1-1

2.0 LOGISTICS AND DATA ACQUISITION PROCEDURES

The TDEM survey was performed by a three man crew consisting of two BGI geophysicists and one local field helper. The locations of the sounding sites were determined during consultation with State personnel and their consulting hydrologist. Due to the remoteness of the project area, no jeep roads or trails were available for access. Therefore, helicopter support was supplied by the Client for the duration of the field survey. At the start of the survey a base control point (BCP) was established on the east corner of sounding 1. The BCP was surveyed in by compass and hip-chain on bearing with the road west of Puu Hinai, and to the north edge of the Kaniku lava flow. The survey line numbers and loop locations are shown on Figure 2-1.

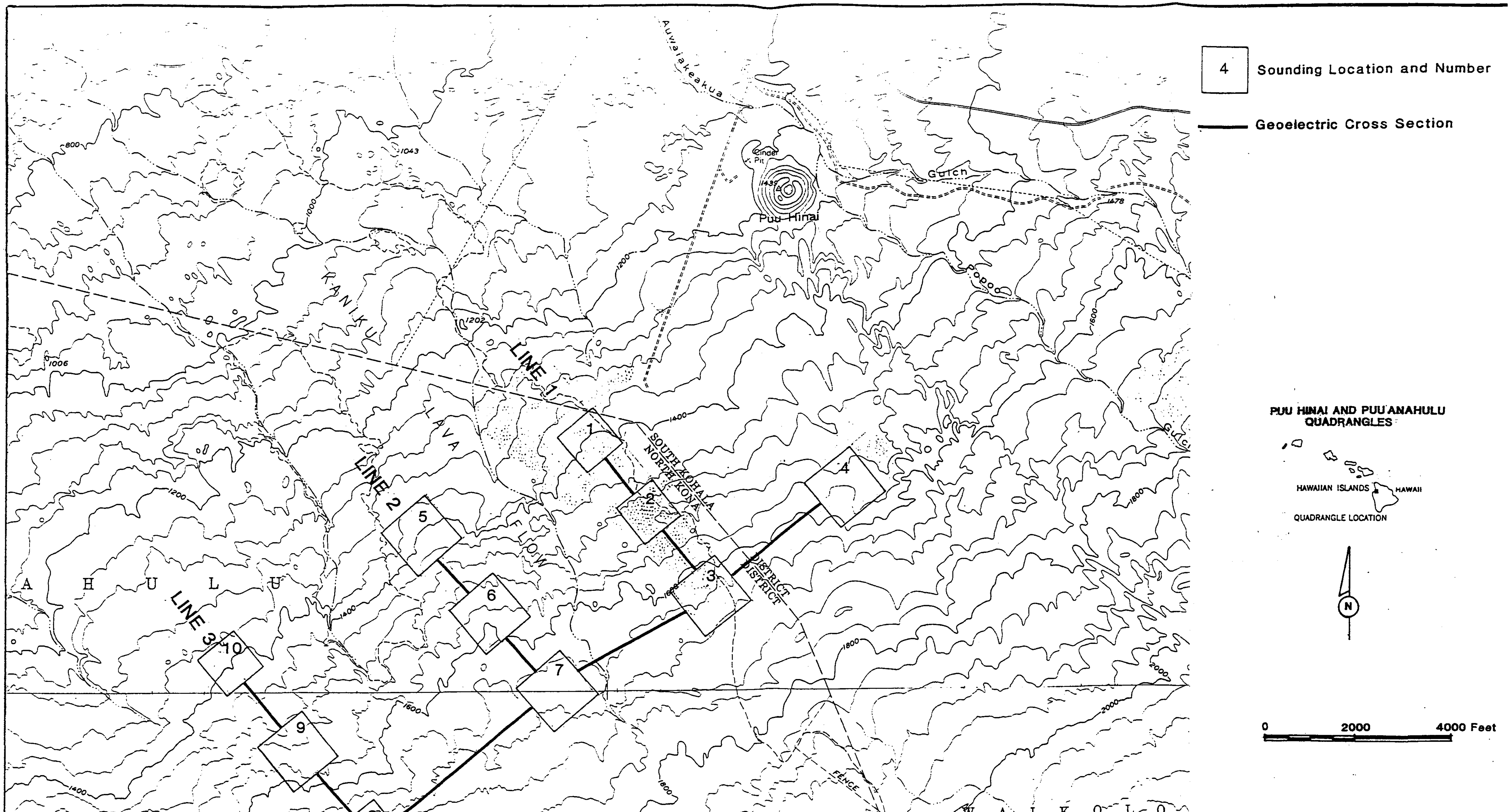
During the five days of field work, a total of 10 sounding measurements were acquired over the area of interest. As the survey progressed the location and number of soundings changed at the request of the consulting hydrologist, to include only measurements between approximately the 1,400 ft and 1,700 ft elevation level. From the BCP, bearings of N40^{0}W and S50^{0}W were used throughout the survey area to layout transmitter loops and when measuring from loop-to-loop and from line-to-line. Elevations of sounding centers were measured with a handheld barometric altimeter in the field and checked periodically against the helicopter altimeter during each day to maintain reliable ($\pm$ 20 ft) elevation readings. A daily log of field activities during the survey is given in Table 2-1. Transmitter loop sizes varied from 1,000 ft by 1,000 ft to 1,200 ft by 1,200 ft in the study area according to depth of investigation needed and the logistics of accomplishing the sounding measurement.

2.1 PROCEDURES

The Geonics EM-37 TDEM system was utilized on this survey. The system basically consists of a transmitter and a receiver. The transmitter loop is constructed of 10 to 12 gauge insulated copper wire. The wire is laid on the ground surface in a square loop varying in size, depending upon the required depth of investigation (larger loop sizes for deeper measurement). A transmitter and motor generator are connected into the non-grounded loop at one corner. A time-varying current is pulsed through the wire at two different base frequencies. The TDEM receiver measures and records the decay of the vertical magnetic field through a receiver coil placed at the center of the non-grounded transmitter loop. Receiver coils with effective areas of 100 m^2 and 1,000 m^2 were utilized at base frequencies of 3 Hz and 30 Hz. During data acquisition numerous transient decays are collected with the receiver for each sounding. Readings were acquired at several receiver gains with opposite receiver polarities for each sounding location. The readings were stored in a DAS-54 solid state data logger, and were nightly transferred to a personal computer for processing. A technical note is given in Appendix A which describes and illustrates the principles of TDEM.

Table 2-1. Daily log of field activities

Date (1991)	Activity
October 27	Demobilize from other Pacific jobs to Kailua-Kona, HI in conjunction with other surveys.
October 28	One-half day of mobilization, clear equipment through customs.
October 29	Perform reconnaissance of sounding site 1, and establish base control point (BCP) on east corner. Transport TDEM equipment and crew by helicopter to east corner of sounding 1. Acquire measurement of soundings 1 and 2.
October 30	Measurement of soundings 3 and 4.
October 31	Measurement of soundings 5 and 6.
November 2	Measurement of soundings 7 and 8.
November 3	Measurement of soundings 9 and 10.
November 4-5	Demobilization of equipment and BGI personnel from Kailua-Kona, HI to Golden, CO.
	(October 28 and November 1 are work at other Hawaii locations)



BLACKHAWK GEOSCIENCES, INC.

TIME DOMAIN EM SURVEY
LOCATION MAP

DIVISION OF WATER RESOURCES MGMT.
STATE OF HAWAII

PROJECT NO: 91054

Figure 2-1

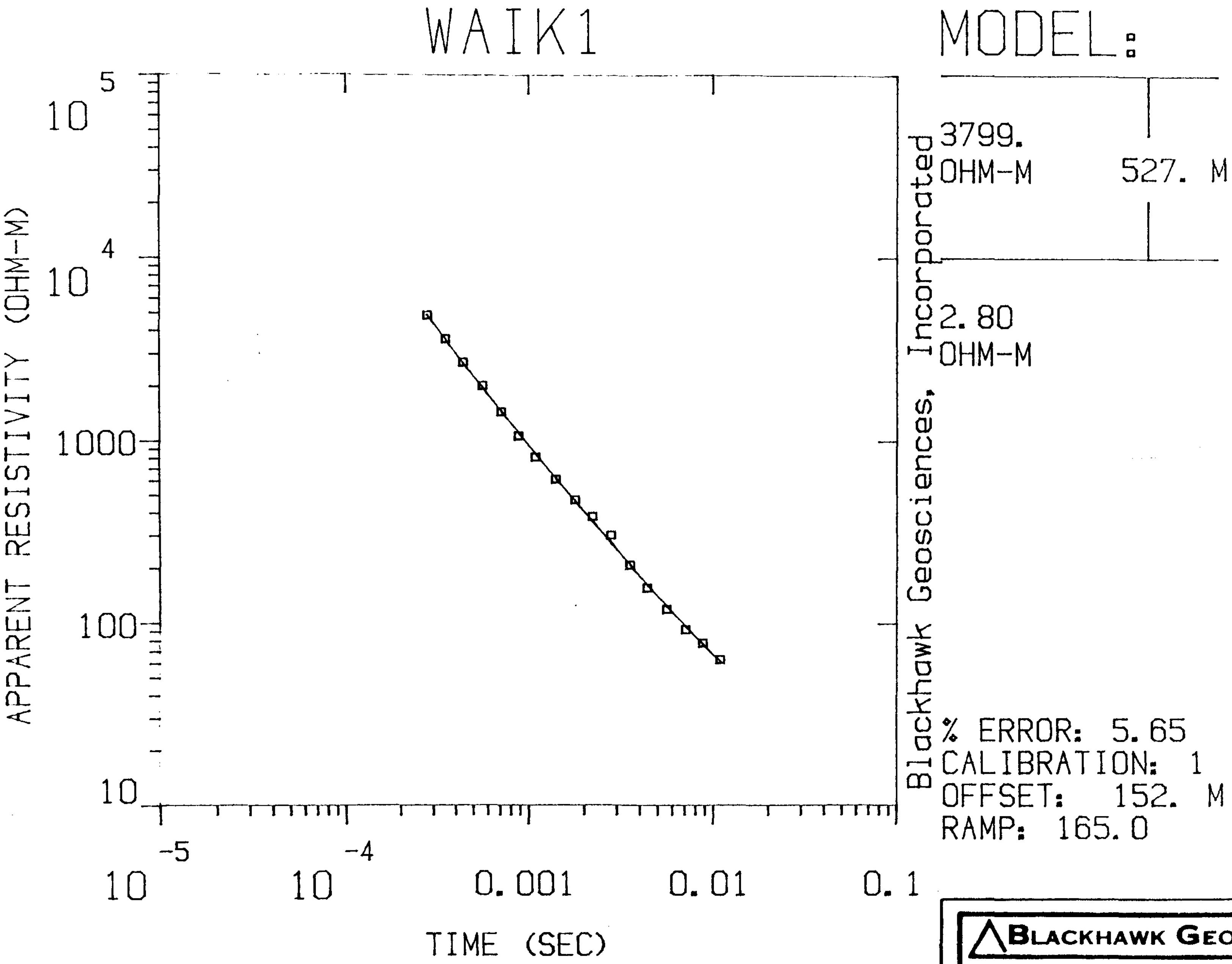
3.0 DATA PROCESSING

The field data acquired each day was transferred from the DAS-54 data logger to a personal computer. The data for each sounding location is edited and combined (both 3 Hz and 30 Hz frequencies) to produce a transient decay curve. This decay curve is transformed into an apparent resistivity curve, which is entered into an Automatic Ridge Regression Transient Inversion Program (ARRTI). From the apparent resistivity curve a one-dimensional model of resistivities and thicknesses is calculated.

The inversion program requires an initial estimate of the geoelectric section, including the number of layers, and the resistivities and thicknesses of each of the layers. The program then adjusts these parameters so that the model curve converges to best fit the curve formed by the field data set. The inversion program does not change the total number of layers within the model, but allows all other parameters to float freely.

An example data set is given in Figures 3-1 and 3-2 for sounding WAIK1 (sounding number 1). Figure 3-1 shows the measured data points (in terms of apparent resistivity) superimposed on a solid line. The solid line represents the computed behavior of the true resistivity layering shown on the right. Thus, the section is interpreted to consist of two layers, - the first layer has a thickness of 527 m (1,729 ft) with a resistivity of 3,799 ohm-m, and the resistivity of the second layer is 2.8 ohm-m. Figure 3-2 lists model and survey parameters, and in column 4 the error between measured and computed data in each time gate.

The apparent resistivity curves and data sheets for all soundings are contained in Appendix B.



BLACKHAWK GEOSCIENCES, INC.

EXAMPLE DATA SET
SOUNDING WAIK1
DIVISION OF WATER RESOURCE MGMT.
STATE OF HAWAII

PROJECT NO: 91054 **Figure 3-1**

MODEL: 2 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		426.7	1400.0		
3799.13	527.1	-100.3	-329.2	0.1	0.1
2.80					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	2.80E-04	4.83E+03	4.86E+03	-0.654	
2	3.55E-04	3.60E+03	3.56E+03	1.050	
3	4.43E-04	2.69E+03	2.67E+03	0.837	
4	5.64E-04	2.00E+03	1.96E+03	2.250	
5	7.13E-04	1.44E+03	1.45E+03	-0.730	
6	8.81E-04	1.06E+03	1.11E+03	-4.274	
7	1.10E-03	8.14E+02	8.49E+02	-4.062	
8	1.41E-03	6.13E+02	6.22E+02	-1.346	
9	1.80E-03	4.72E+02	4.64E+02	1.701	
10	2.22E-03	3.81E+02	3.60E+02	5.959	
11	2.80E-03	3.01E+02	2.74E+02	9.748	
12	3.55E-03	2.08E+02	2.09E+02	-0.474	
13	4.43E-03	1.56E+02	1.62E+02	-3.839	
14	5.64E-03	1.19E+02	1.24E+02	-3.962	
15	7.13E-03	9.24E+01	9.65E+01	-4.237	
16	8.81E-03	7.81E+01	7.70E+01	1.406	
17	1.10E-02	6.32E+01	6.15E+01	2.708	

R: 152. X: 0. Y: 152. DL: 305. REQ: 169. CF: 1.0000
TDHZ ARRAY, 17 DATA POINTS, RAMP: 165.0 MICROSEC, DATA: WAIK1
2910 1111 1111 Z OPR XTL L 6 10+1000
Ch.21 = 0.165 Ch.22 = 0.89 Ch.23 = 15 Ch.24 = 9
RMS LOG ERROR: 2.39E-02, ANTILOG YIELDS 5.6524 %
LATE TIME PARAMETERS

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER

P 1	0.97		
F 2	0.00	0.00	
T 1	0.00	0.00	1.00
	P 1	F 2	T 1

BLACKHAWK GEOSCIENCES, INC.

EXAMPLE DATA SET
SOUNDING WAIK1
DIVISION OF WATER RESOURCES MGMT.
STATE OF HAWAII

PROJECT NO: 91054 Figure 3-2

4.0 INTERPRETATION RESULTS

4.1 GENERAL

The objectives of the geophysical survey for the State of Hawaii were to interpret from the individual TDEM soundings the resistivity layering as a function of depth. Also, to infer from the resistivity information the depth to salt water, and the thickness of the basal fresh water lens. The TDEM soundings were purposely acquired along traverse lines from about the 1,400 ft to 1,700 ft elevation level. The results of the individual soundings were used to construct geoelectric cross sections through several transects. From the 10 soundings taken on the area of interest, four geoelectric cross sections were constructed to display the interpreted data set. Figure 2-1 shows the locations of the soundings and the geoelectric cross sections.

Using available knowledge about the relation between resistivity values and local hydrogeology, geologic and geohydrologic information was inferred from geoelectric cross sections. The characteristic ranges of resistivities expected for local geohydrologic units in the survey area are shown in Figure 4-1. The resistivity range for ash flows, weathered volcanics or intrusives overlaps both the lower range of the dry unweathered or fresh/brackish water saturated volcanics and the upper range for salt water saturated volcanics. In many cases the geohydrologic units can be separated by their relative depth of occurrence in the section.

In the TDEM interpretation, where a very conductive layer (< 5 ohm-m) is detected below sea level, this layer is expected to be caused by salt water saturated volcanics. For this survey a fixed 2.8 ohm-m resistivity value was used to represent the resistivity of the salt water saturated layer. The validity of using this resistivity value for salt water saturated volcanics was confirmed by a previous TDEM survey in the Waikoloa area to the north. Static water levels (heads) can subsequently be calculated from these soundings by using the Ghyben-Herzberg principle. This principle states that under conditions of static equilibrium, for every foot of fresh water above sea level there will be about forty feet of fresh water below sea level. An illustration of the Ghyben-Herzberg principle is given in Figure 4-2. This principle, however, assumes static equilibrium and may not apply to TDEM sounding data in close proximity to ground water damming structures (i.e., dikes, rifts, etc.).

TDEM soundings in areas where ground water has been shown to be dike-confined, typically show high resistivity (greater than 100 ohm-m) layers to the exploration depth of the TDEM system (typically -800 ft below sea level). In other words, no sea water saturated formations are interpreted within the entire section. Within the structure controlled areas which separate the basal mode and dike-confined areas, TDEM data often exhibit intermediate resistivity values (10 to 100 ohm-m) that may occur both above and below sea level. In cases where intermediate resistivities occur well below sea level (-300 to -500 ft) it is generally not possible to determine the exact origin and nature of the subsurface conditions influencing the formation resistivities. The data taken in these areas may be distorted or influenced by the nearby structures and may not be diagnostic of true resistivity layering. This is due to the large subsurface areas that are averaged below a large transmitter loop (1,500 ft by 1,500 ft) and the limitation of present 1-D interpretations for TDEM data.

4.2 GEOELECTRIC CROSS SECTIONS

The results of the 10 TDEM sounding interpretations are presented as four geoelectric cross sections and are shown in Figures 4-3 and 4-4. Layers with similar resistivities have been linked together in the geoelectric sections.

<u>Lines 1 and 2</u>

The geoelectric cross sections for Lines 1 and 2 are both presented as northwest to southeast transects in Figure 4-3. Similar two-layer sequences are interpreted in the geoelectric cross sections for Lines 1 and 2. The upper layer of these two geoelectric cross sections exhibit high resistivities ranging from 2,857 ohm-m at sounding 3 to greater than 9,000 ohm-m at sounding 5 and are interpreted to represent unweathered volcanics. Below sea level, in both cross sections, this resistive layer is expected to be saturated with fresh/brackish water. The lower layer in both lines has been fixed to a 2.8 ohm-m resistivity and is interpreted to represent salt water saturated volcanics. The approximate thickness of the fresh/brackish water lens for these soundings was found to vary between 329 ft at sounding 1 to 430 ft beneath sounding 2.

<u>Lines 3 and 4</u>

In Figure 4-4 the geoelectric cross section for Lines 3 and 4 are displayed. The soundings were interpreted with either a two or three layer geoelectric section. The upper layer in both cross sections exhibits high resistivity values ranging from 1,312 ohm-m to greater than 6,000 ohm-m. This upper layer at soundings 7, 3 and 4 is interpreted to represent dry unweathered volcanics above sea level, and where it occurs below sea level, it is expected to be saturated with fresh/brackish basal mode water. The lower layer of Line 3 (and sounding 8 on Line 4) exhibits intermediate resistivity values ranging from 9.2 ohm-m to 71 ohm-m. This lower layer may be caused by changes in lithology (ash flows, weathered volcanics), changes in water quality or geologic structure.

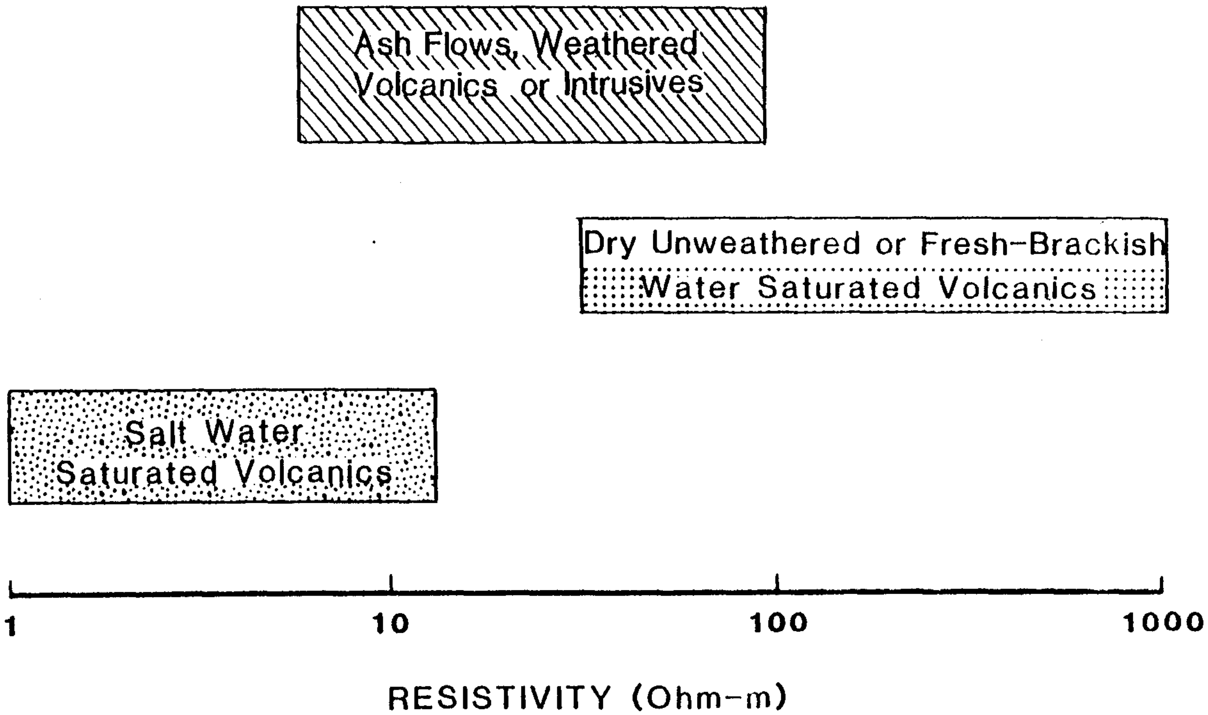
Beneath soundings 3, 4 and 7 of Line 4 where the lower layer is interpreted to represent salt water saturated volcanics, the approximate thickness of the fresh/brackish water lens can be estimated from these soundings and it was found to vary from 344 ft at sounding 4 to 396 ft at sounding 7. Because of the rapid resistivity contrasts between soundings 7 and 8 (2.8 ohm-m to 71 ohm-m) lateral changes are expected to occur between the two soundings and a geologic structure is inferred.

4.3 HYDROGEOLOGIC INTERPRETATIONS

Table 4-2 lists the approximate thickness of the fresh/brackish water lens calculated from the elevation of the salt water interface interpreted from the individual TDEM soundings. The table includes the value of static water level (head) calculated by using the Ghyben-Herzberg principle.

Table 4-1. Hydrogeologic information derived from TDEM soundings (values in ft)

Sounding #	Surface Elevation	Elevation of Salt Water	Calculated Static Water Level (head)	Approximate Thickness of Fresh/ Brackish Water Lens
1	1400	-329	8	337
2	1505	-430	11	441
3	1645	-390	10	400
4	1560	-344	9	353
5	1405	-345	9	354
6	1560	-422	11	433
7	1660	-396	10	406
8	1720	Not Detected	N/A	N/A
9	1525	Not Detected	N/A	N/A
10	1400	Not Detected	N/A	N/A



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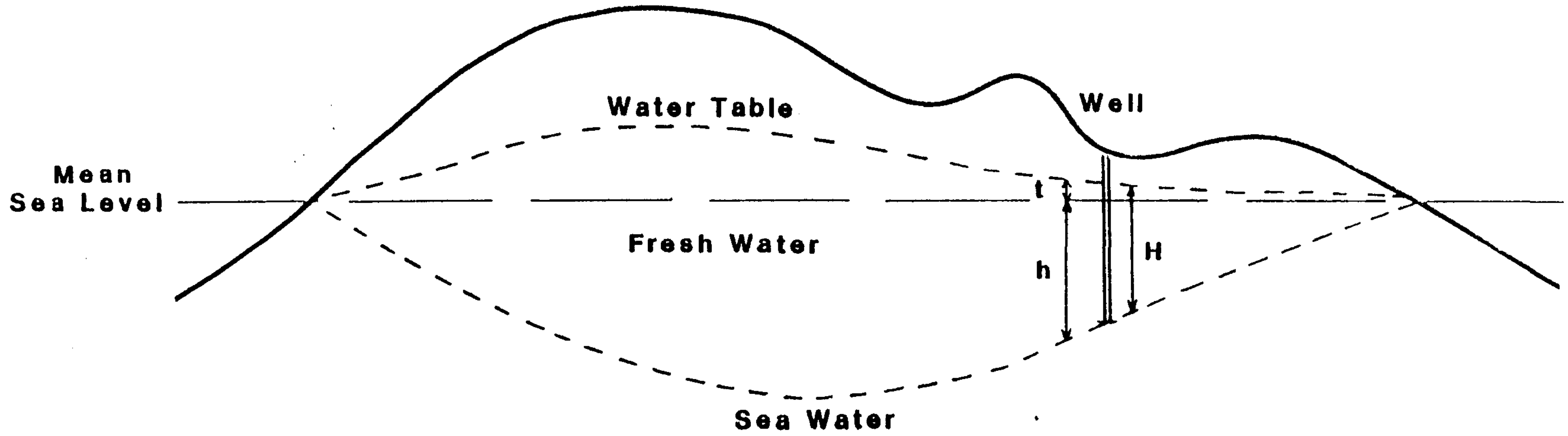
CHARACTERISTIC
RESISTIVITY RANGES

DIVISION OF WATER RESOURCES MGMT.
STATE OF HAWAII

PROJECT NO: 91064 Figure 4-1



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

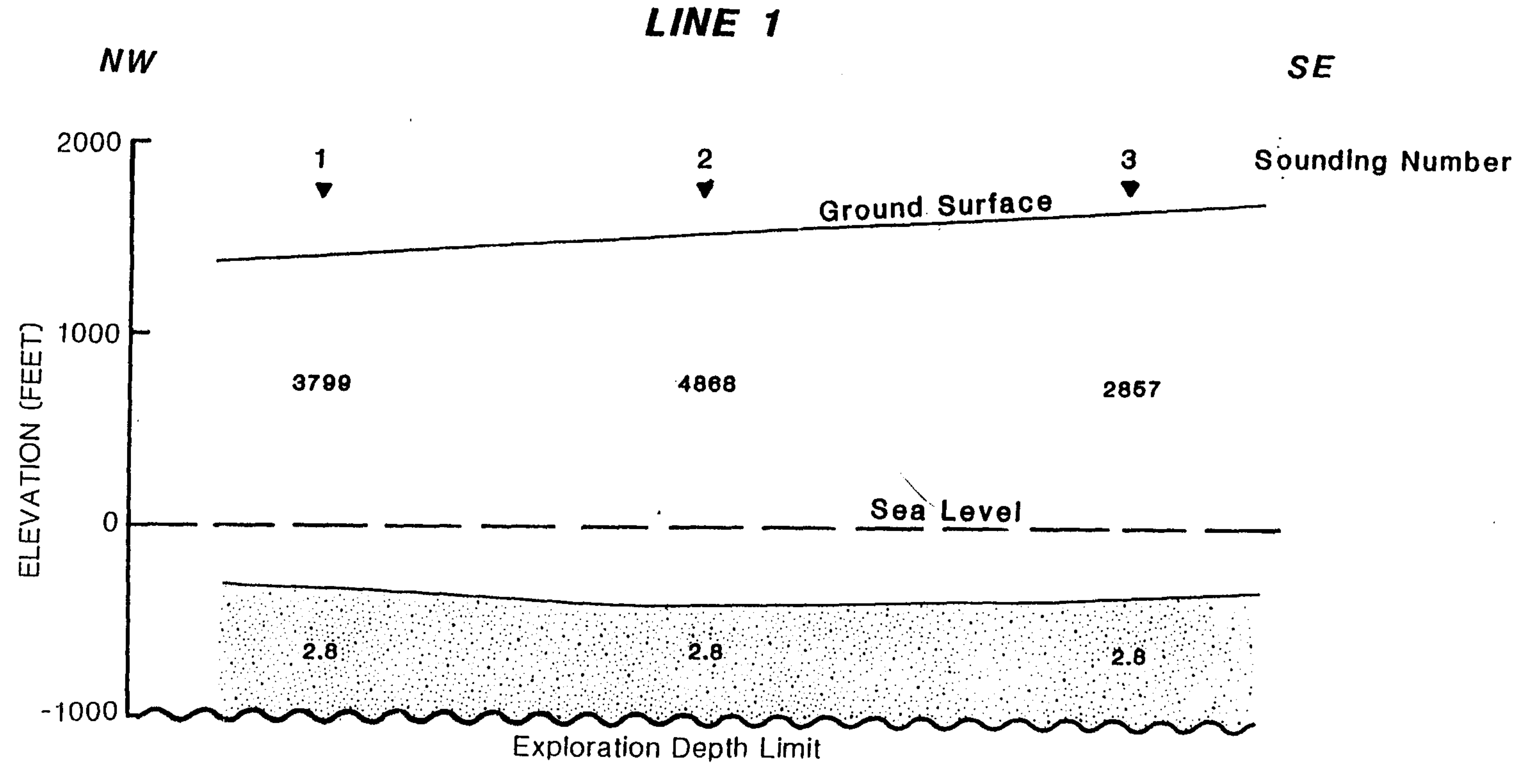
FROM: HERZBERG

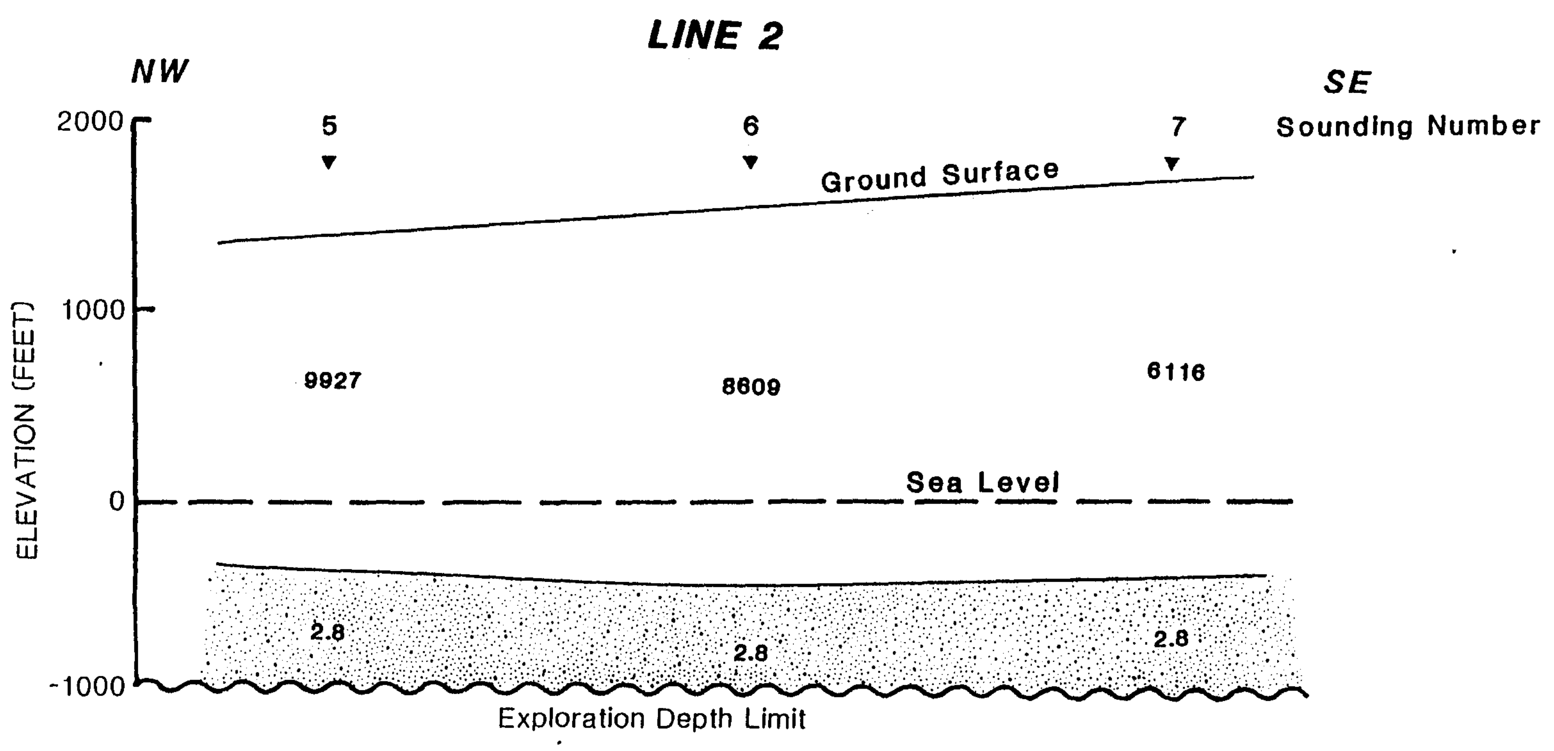
BLACKHAWK GEOSCIENCES, INC.

Illustration of the
Ghyben–Herzberg Principle
DIVISION OF WATER RESOURCES MGMT.
STATE OF HAWAII

PROJECT NO: 91054

Figure 4-2





2.8 Resistivity, Ohm-m

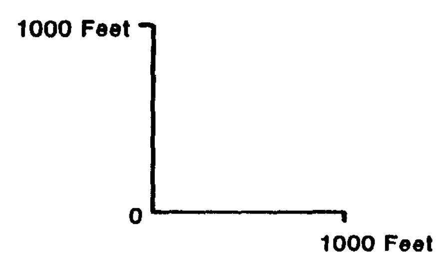
Boundary of Resistivity Values

Inferred Geologic Structure

Unweathered or Fresh/Brackish Water Saturated Volcanics

Ash Flows, Weathered Volcanics or Change in Water Quality

Salt Water Saturated Volcanics



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GEOELECTRIC CROSS SECTION
LINES 1 AND 2
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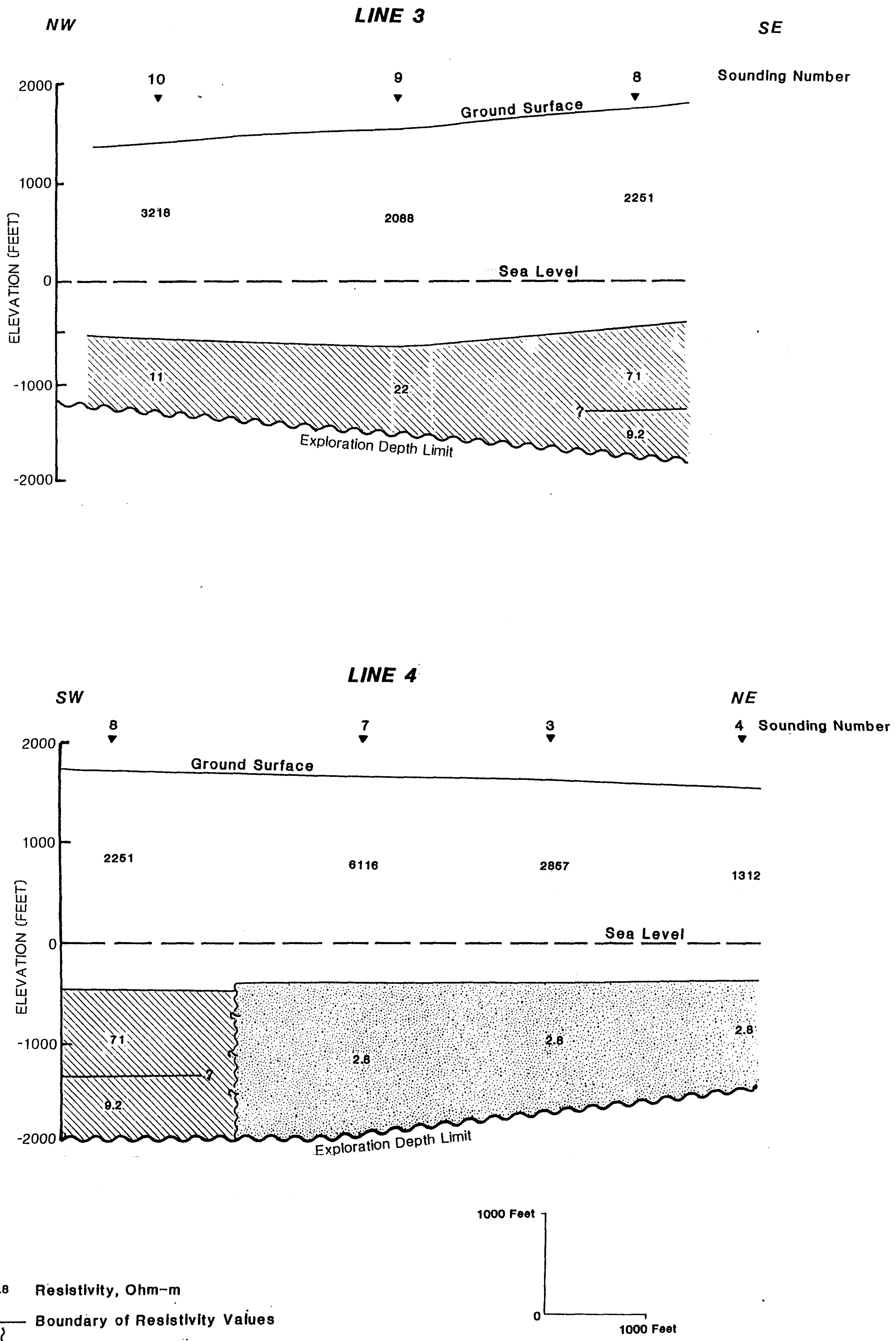

2.8 Resistivity, Ohm–m

Boundary of Resistivity Values

Inferred Geologic Structure

Unweathered or Fresh/Brackish Water Saturated Volcanics

Ash Flows, Weathered Volcanics or Change in Water Quality

Salt Water Saturated Volcanics

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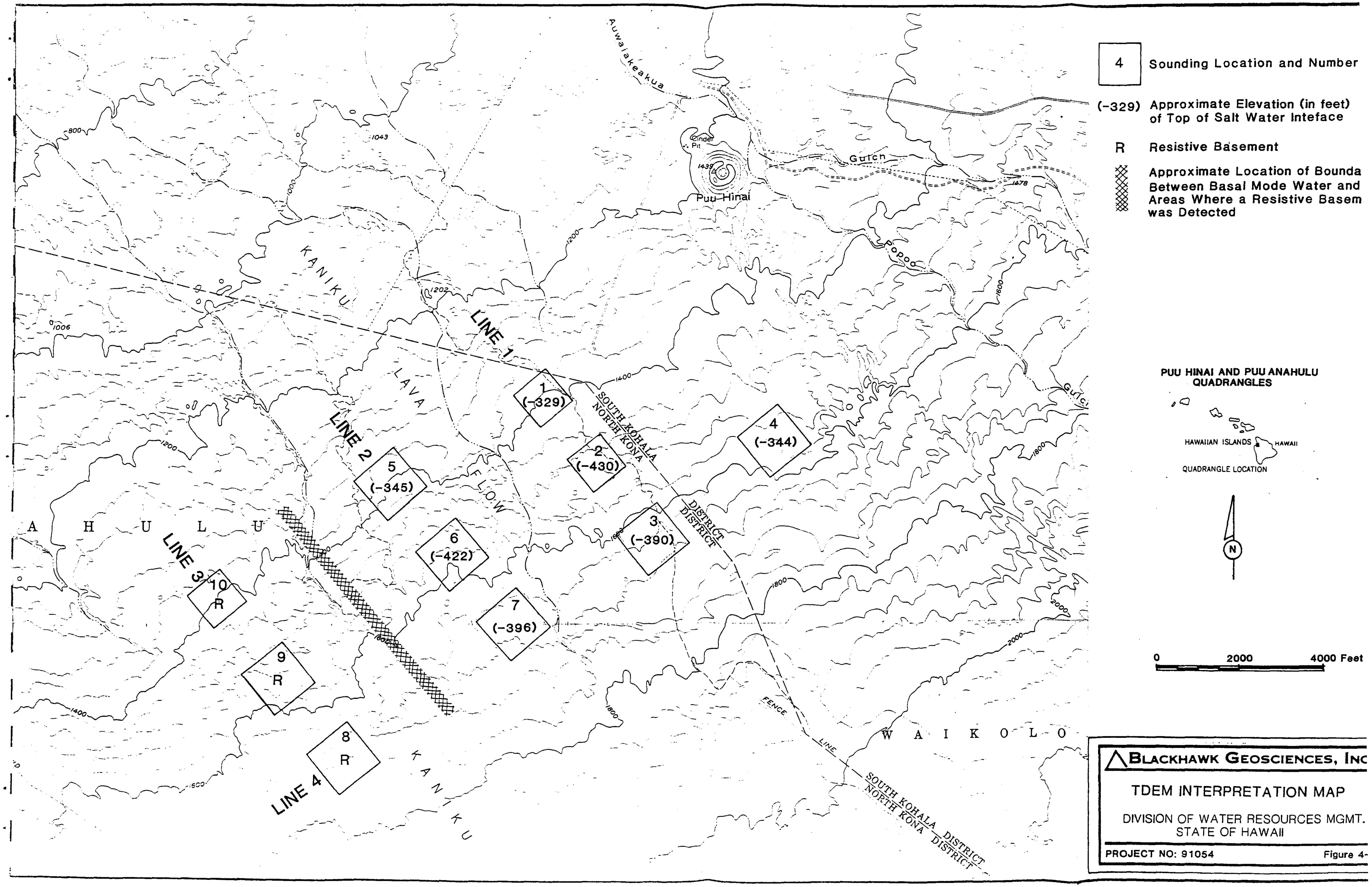
GEOELECTRIC CROSS SECTION
LINES 3 AND 4

DIVISION OF WATER RESOURCES MGMT.



4 Sounding Location and Number
(-329) Approximate Elevation (in feet) of Top of Salt Water Inteface
R Resistive Basement
Approximate Location of Bounda
Between Basal Mode Water and
Areas Where a Resistive Basem
was Detected
PUU HINAI AND PUU ANAHULU QUADRANGLES
HAWAIIAN ISLANDS
HAWAII
QUADRANGLE LOCATION
N
0
2000
4000 Feet
Auwaiakeakua
Cinder Pit
1439
Puu Hinai
Gulch
1678
Popoo
Gulch
KANIKU
LAVA
FLOW
AHULU
WAIKOLO
KANIKU
LINE 1
LINE 2
LINE 3
LINE 4
1 (-329)
2 (-430)
3 (-390)
4 (-344)
5 (-345)
6 (-422)
7 (-396)
8 R
9 R
10 R
SOUTH KOHALA DISTRICT
NORTH KONA DISTRICT
FENCE LINE
800
1000
1043
1006
1200
1202
1400
1600
1800
2000
BLACKHAWK GEOSCIENCES, INC
TDEM INTERPRETATION MAP
DIVISION OF WATER RESOURCES MGMT.
STATE OF HAWAII
PROJECT NO: 91054
Figure 4-

5.0 CONCLUSIONS AND RECOMMENDATIONS

The main objective of the TDEM survey was to assist in the ground water resource evaluation of the Puu Anahulu area of North Kona, Hawaii. The results of the TDEM survey are summarized in Figures 4-3, 4-4 and 4-5. As shown in Figure 4-5 (beneath soundings 1 through 7), salt water saturated volcanics were detected at depth and fresh/brackish ground water resources are expected to be present in the basal mode. The thickness of the basal fresh/brackish water lens is expected to vary from about 329 ft to 430 ft. Beneath soundings along Line 3 (10, 9 and 8) salt water saturated volcanics were not detected. The intermediate to high resistivity layer detected below sea level on these soundings may be caused by lithologic, geologic, or hydrologic variations and thus, estimates of available ground water resources cannot be made for these soundings. The depth and resistivities of the lower layer in these soundings display some similarities to soundings taken on previous surveys near a ground water damming structure. Thus, the potential for significant ground water resources may be present up-gradient of the structure if other favorable subsurface conditions exist, such as high porosity and permeability.

The location of the boundary between areas with basal mode ground water resources and areas where a resistive basement was detected is not accurately determined because of the large distances between lines and soundings in this vicinity of the study area. To better define the boundary location and its relative direction, additional soundings between Line 2 and Line 3 are recommended. To determine if high level ground water resources exist southwest of Line 3, additional soundings are recommended in this area.

The relative accuracy in determining the depth to the salt water saturated interface is expected to be about $\pm$ 5% of the total depth measured.

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Transient Electromagnetic Soundings

GROUNDWATER
STRUCTURAL GEOLOGY
PERMAFROST
MINING
SHALLOW OIL AND GAS

INTRODUCTION

Electromagnetic transient methods for soundings have been used for many years in the U.S. and the U.S.S.R. for mapping structures for hydrocarbon and geothermal exploration. Transient sounding for shallow exploration (< 1 km) was until recently not possible, due to the lack of an instrument with the necessary specifications. The situation has changed since the Geonics EM37 became commercially available. There are several important exploration objectives for shallow exploration using transient methods such as:

1) structural mapping for coal, oil sands and oil shales
2) structural mapping for mineral exploration
3) hydrogeological investigations
4) deep onshore and offshore permafrost mapping for design of well casings, facilities, and for static correction to seismic reflection data

These soundings are being made with separations between transmitter and receiver comparable to the depth of investigation, so that good lateral resolution is obtained.

These methods can be extended with similar equipment for such deeper exploration objectives (3 to 5 km) as:

a) mapping hydrocarbon-water contacts
b) mapping overthrust and thickness of volcanic covers
c) geothermal exploration

Examples of successfully using transient EM for some of these objectives are given in this note.

PHYSICAL PRINCIPLES

A transient system consists of a transmitter and a receiver. The transmitter configuration can be a non-grounded loop or a grounded line. The configuration used in most of our work has been the non-grounded loop. The sensors are multi-turn air coils with effective areas varying from 32 square meters to 1000 square meters. Figure 1 shows the transmitter-receiver arrangements used for transient soundings.

The current generated in the transmitter is shown in Figure 2. There are two periods of time, time-on and time-off. Measurements are made only during time-off. In accordance with Faraday's Law, an electromagnetic induction appears when the current in the transmitter varies with time. When the turn-off ramp is linear the induced electromotive force is a rectangular pulse.

The electromagnetic induction creates eddy currents in the ground. These induced currents are time-variant and cause a time-varying secondary magnetic field, which is measured as an electromotive force in the receiver coil. It has been shown that the induced currents are horizontal closed rings in the absence of lateral inhomogeneities (1). There is no vertical component of current flow. Figure 3 schematically illustrates the distribution of eddy currents as a function of depth at different times. This figure shows that current maxima move down with increasing time. The currents not only move down, but also out. The current expansion can be described by a diffusion type equation.

The electromotive force measured by the receiver coil is the result of the change of current flow with time. It is evident from Figure 3 that a measurement at time, to, will mainly be sensitive to the resistivity of near-surface layers. With increasing time, when the current maxima diffuse down, the electromotive force will progressively become more sensitive to the properties of deeper layers. Therefore, by making measurements as a function of time, information about the geoelectric section is obtained. In transient soundings effective exploration depth is dominantly a function of time rather than distance. This fact results in a high lateral resolution for transient soundings.

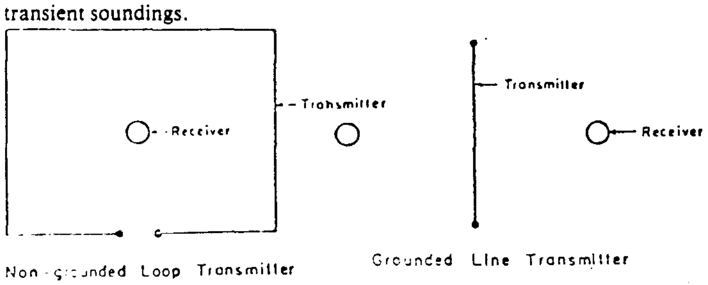


FIGURE 1. Different arrays of transmitter-receiver used in transient soundings.

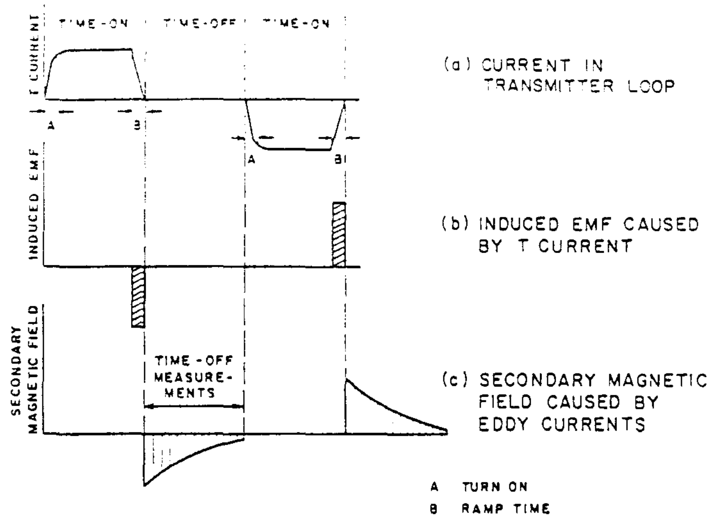


FIGURE 2. System Waveforms

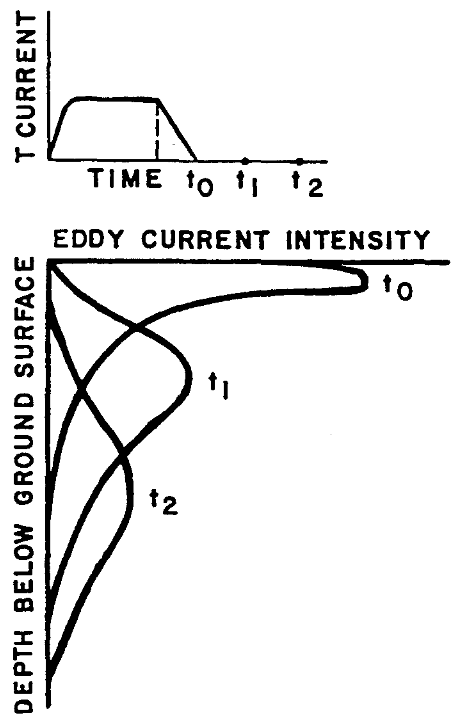


FIGURE 3. Schematic illustration of maximum current distribution intensity in a vertical plane.

Behavior of Field

Over certain ranges of time the transient field also has a higher sensitivity to the geoelectric section than other electrical methods. This fact can be understood from the behavior of the time derivative of the vertical component of the magnetic field over uniform half-space. In Figure 4, $\dot{B}_z$ is given as a function of the dimensionless parameter $\frac{\tau_1}{r}$.

where τ_1 $\tau_1 = \sqrt{2\pi\rho_1 t\, 10^7}$

and t is time after turn-off

ρ_1 is half-space resistivity

Several stages of time can be distinguished in the behavior of the electromotive force. At early time the emf is independent of time; there is an intermediate range of time in which the emf, rapidly decreases with time, and a late range of time in which the emf falls off as $t^{-5/2}$.

At early stage $\frac{\tau_1}{r} < 2$, and at late stage $\frac{\tau_1}{r} > 10$, the behavior of the field can be described by asymptotic expressions (1). The expressions are:

$$\text{early stage } \left(\frac{\tau_1}{r} < 2\right): \dot{B}^z = \frac{3m}{2\pi r^4} \cdot \rho_1 \qquad (1)$$

$$\text{late stage } \left(\frac{\tau_1}{r} > 10\right): \dot{B}^z = \frac{u m r}{40\pi^{3/2} t^{5/2}} \cdot \frac{1}{\rho_1^{3/2}} \qquad (2)$$

It is evident that a measurement at late stage is more sensitive to ground resistivity than a measurement at early stage.

Late stage commences when $\frac{\tau_1}{r} > 10$. Thus, if r (transmitter-receiver separation) is kept small, late stage will commence in earlier time channels. The advantages of small transmitter-receiver separation, therefore, not only is a better lateral resolution, but also a higher sensitivity to the geoelectric section. This often results in a better vertical resolution.

Some of these advantages of transient soundings are lost when large transmitter-receiver separations are used. In the first place increasing separation will decrease lateral resolution. When larger separations are used the geoelectric section measured does not occur directly under the receiver, but will be influenced by the subsurface conditions between transmitter and receiver. Secondly, at large separations the behavior of the field will correspond to early stage, over a large time range, and the sensitivity to the geoelectric section will be less. This will decrease vertical resolution.

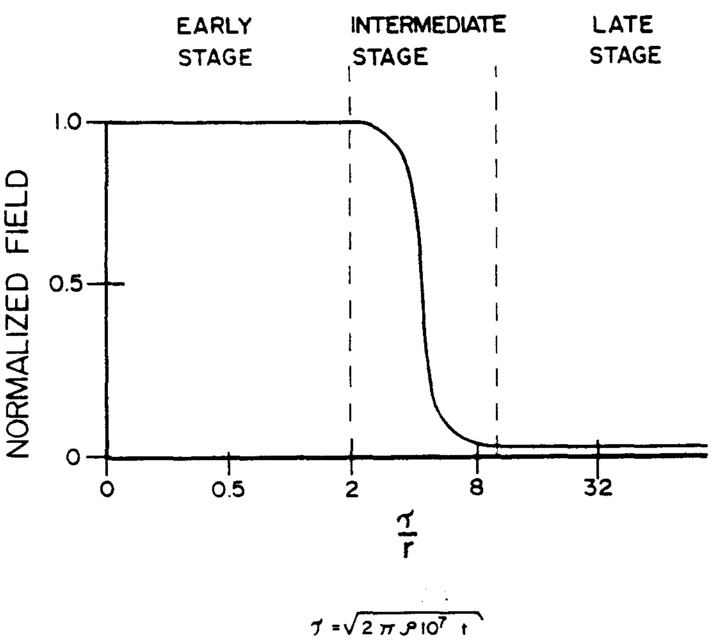


FIGURE 4. Behavior of time derivative of vertical magnetic field as a function of time.

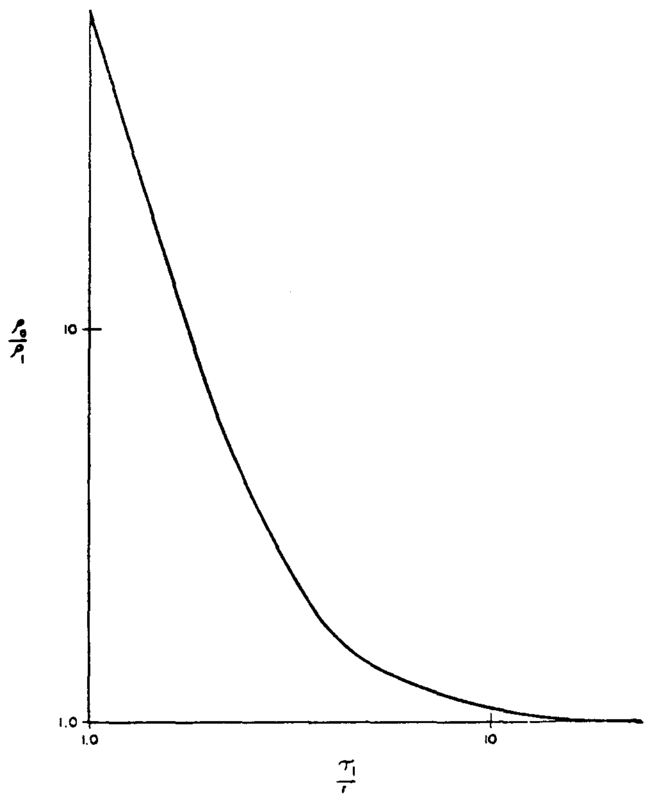


FIGURE 5. Late stage apparent resistivity curve of uniform ground.

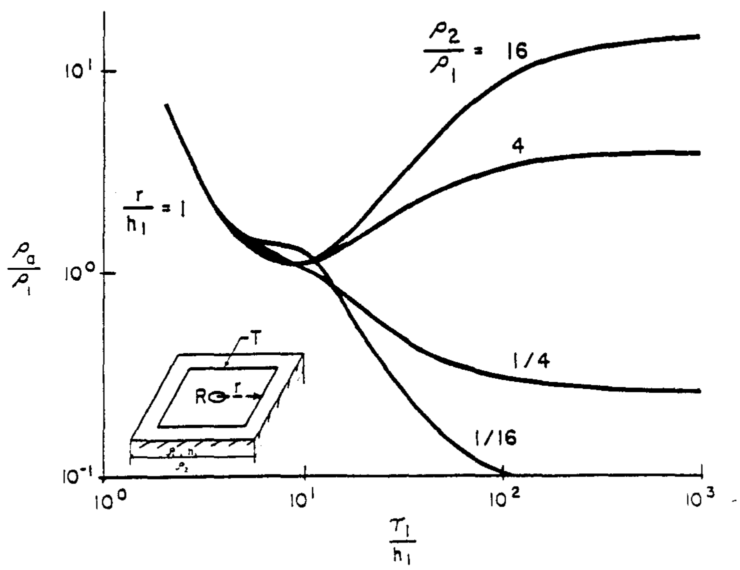


FIGURE 6. Late stage apparent resistivity curves for two-layered sections.

Definition of Apparent Resistivity

It is common in all electrical and electromagnetic methods to transform the fields measured into apparent resistivities. The purpose of that transformation is to obtain a convenient visualization of how the behavior of the field measured, differs from the behavior of the field over uniform half-space. Transient soundings are no exception. In direct current and magnetotelluric soundings the relation between measured signal, and resistivity of uniform half-space, is the same for all electrode spacings (direct current) and over the entire frequency range (magnetotelluric). In transient soundings the relation between resistivity of uniform half-space and measured signal is a function of time of measurement. It is evident from Figure 4 and equation 1 and 2 that there are two ranges of time over which that relation is constant, i.e. early stage and late stage. In these ranges of time the behavior of the field is described by the asymptotic expression in [1] and [2], and these expressions can be used to define the apparent resistivities, given below.

$$\text{Early Stage} \quad \rho = \frac{\dot{\beta}z\,2\pi r^4}{3m} \qquad (3)$$

$$\text{Late Stage} \quad \rho = \left(\frac{u\,r\,m}{40\pi^{1/2}t^{5/2}\,\dot{\beta}z}\right)^{2/3} \qquad (4)$$

The definition used in practice depends on several factors. Generally, when the behavior of the field over the critical range of time corresponds to late stage behavior, the late stage [4] definition is used. This situation generally occurs when small transmitter-receiver separations are used. An early stage definition would be used, if the behavior of the field measured correspond to early stage behavior in the first layer.

Figures 5 and 6 show computed late stage apparent resistivity curves for uniform half-space, and for two-layered sections respectively. The apparent resistivity curves are plotted in terms of the dimensionless parameters,

$$\rho_a/\rho_1 \quad \text{and} \quad \frac{\tau_1}{h_1} \quad \left(\text{or} \quad \frac{\tau_1}{r}\right).$$

In transient EM the parameter τ_1 plays a role similar to skin depth in frequency domain sounding, or electrode spacing in direct current sounding. For a certain section τ_1 is proportional to $t^{1/2}$.

First, consider the apparent resistivity curve for uniform half-space. With increasing time the apparent resistivity gradually approaches the true resistivity of the half-space. For example, when $\tau_1/r > 10$, ρ_a approaches ρ_1. At early time the apparent resistivity exceeds ρ_1 due to the fact that the field behavior has not reached "late stage", while the definition of apparent resistivity is based on "late stage". The early part of the curve, corresponds to the early stage behavior of the field and ρ_1 can be derived from this part of the curve also.

The interpretation of transient soundings is based on the analysis of apparent resistivity curves for 2-, and other multi-layered curves. Along with inversion methods using large sections of curves, many emperical techniques for deriving parameters of the geoelectric section from parts of the curves have been developed and tested by geophysicists in the U.S.S.R.

The behavior of two-layered curves are used for illustration in Figure 6. At early time $\frac{\tau_1}{r} < 2$ all curves merge into one, corresponding to the behavior of the field in the first layer. In this range of time the eddy currents are mainly concentrated in the first layer. From the behavior of the curve at early time information about ρ_1 can be obtained. With increasing time ρ_a/ρ_1 increases, when $\rho_2/\rho_1 > 1$, and decreases when $\rho_2/\rho_1 < 1$. In this range of time currents progressively penetrate the second layer. At later time the apparent resistivity approaches the basement resistivity. In this range of time most currents are concentrated in the basement.

The similarities between the behavior of apparent resistivity used in transient and other electrical soundings should now be evident. The root of time replaces L-spacing or frequency on the horizontal axis.

Case History - Mapping Hydrocarbon-Water Contacts (2)

The formation resistivities of petroleum bearing rocks is dominantly a function of porosity and the resistivities of the fluid (or gas) in the pores. Salt water is commonly found in all oil and gas fields, and the salinity of the water in the pores is invariably high. The formation resistivity of petroleum bearing rocks saturated with water is, therefore, generally low (~2 ohm-m). The resistivity rapidly increases when oil or gas replaces water in the producing formation.

These facts are illustrated in the four induction logs of a shallow gas producing field in Oklahoma in Figure 7. This figure shows that the resistivity in the producing horizon is less than 3 ohm-m when brine saturated, and more than 50 ohm-m when gas saturated. This significant change in resistivity was measured from the surface by transient EM soundings in shallow fields.

To measure the gas-water contact transmitter loops with dimensions of 1500 ft. by 1500 ft. were used and measurements were made in the center of the loops. Figure 8a and b shows apparent resistivity curves obtained over locations with hydrocarbon saturation and brine saturation in the producing horizons, respectively. The difference between these curves at later time is readily observed. The curve obtained over a location with salt water in the producing horizon shows a decrease in apparent resistivity at late time; the curve obtained over a location with gas saturation shows a slight increase in apparent resistivity at late time.

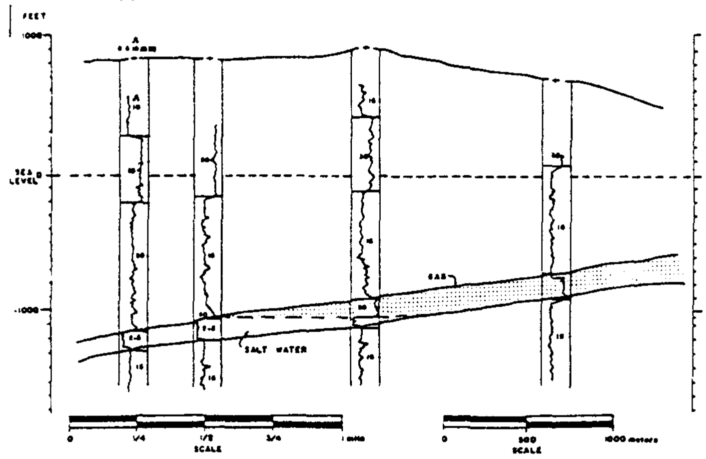


FIGURE 7. Geologic section with four induction logs of a shallow gas field in Oklahoma. The producing horizon occurs at depth of 1500 ft. to 2000 ft.

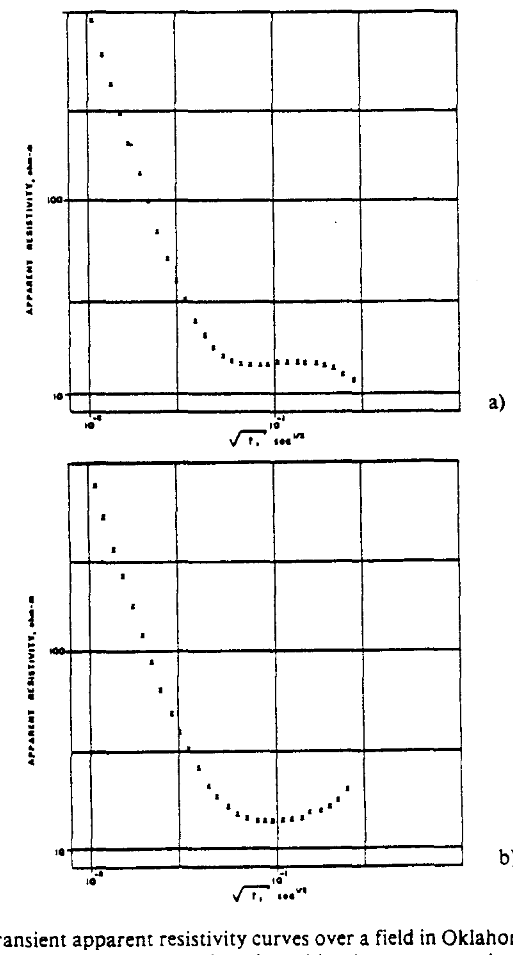


FIGURE 8. Transient apparent resistivity curves over a field in Oklahoma:
a) apparent resistivity curve over a location with salt water saturation
b) apparent resistivity curve over hydrocarbon saturation

From measurements at 11 transmitter loop positions a contour map of the conductance in the producing horizon could be made (Figure 9). Conductance is the product of the thickness of the formation and its conductivity (inverse of resistivity). The contour map derived from the measurements is consistent with the data of the four available induction logs.

Several similiar case histories are also found in the literature from the USSR. On the Siberian platform conductance contour maps of a horizon at depth of about 5000 ft. were constructed from transient soundings over a large area. Changes in conductance of producing horizons can have several causes. These are:

a) change in brine saturation of the pores (hydrocarbon accumulations)
b) change in lithology or porosity
c) disappearance or change in thickness of producing horizon

These conductance maps of producing horizons were used to compliment seismic interpretations to better define drilling targets.

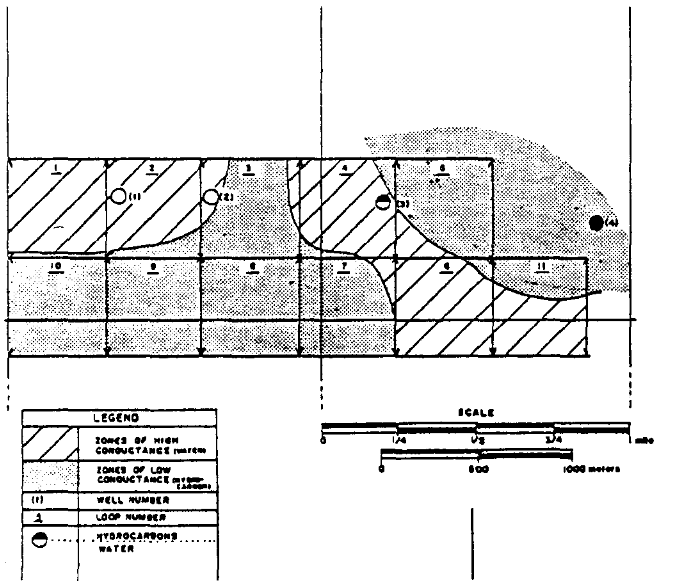
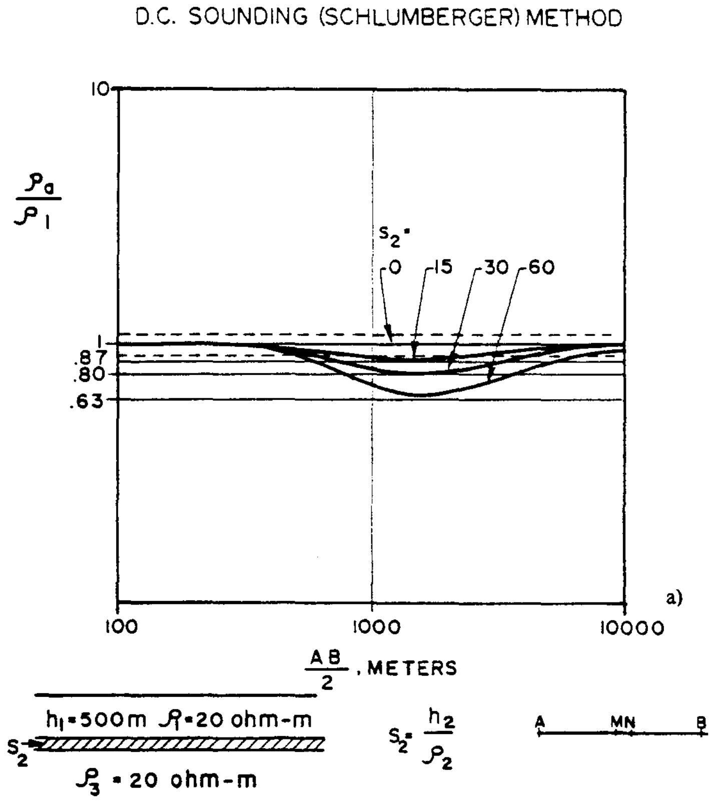
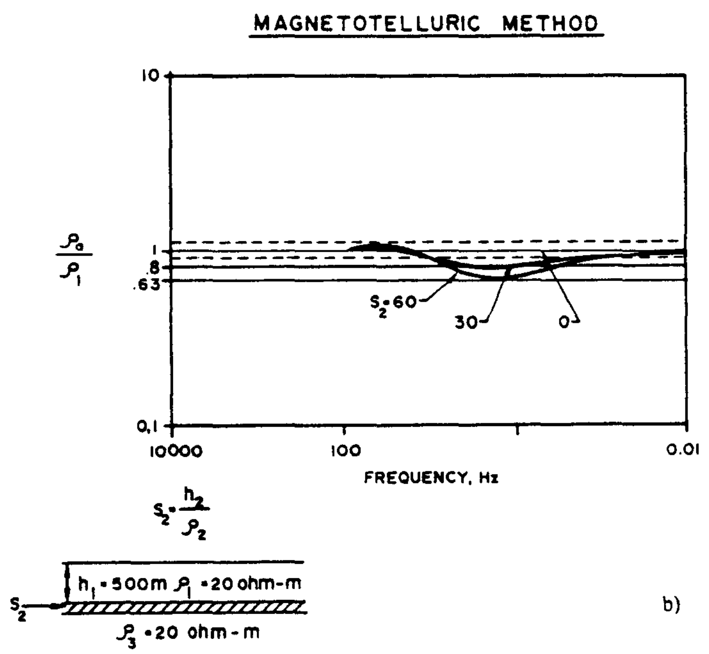


FIGURE 9. Contour conductance map of the producing formation derived from 11 transient soundings.

This case history can be used to illustrate the high sensitivity of transient sounding to the geoelectric section. In Figure 10 a, b, c computed apparent resistivity curves for the same section are shown for direct current, magnetotelluric and transient soundings. In both direct current and magnetotelluric soundings the presence of a conductive layer of 30 mhos would cause approximately 20 percent maximum change in apparent resistivity; for transient soundings the maximum change would be 45 percent. Moreover, it is clear from equation 2 that a 45 percent change in resistivity, will cause a 60 percent change in measured electromotive force. The sensitivity of transient EM to the presence of a conductive layer is approximately three times that of other electrical methods.

It was discussed that lateral resolution in transient soundings to a large extent is a function of transmitter-receiver separation. In the survey in Oklahoma measurements were also made with the receiver outside the transmitter loop, 500m from the center. From curves outside the loop the brine-hydrocarbon contact could not be determined. **It clearly illustrated that the effective geoelectric section is not measured under the receiver, but is affected by the subsurface conditions between transmitter and receiver. Increasing transmitter-receiver separation decreases lateral resolution.**





TRANSIENT METHOD

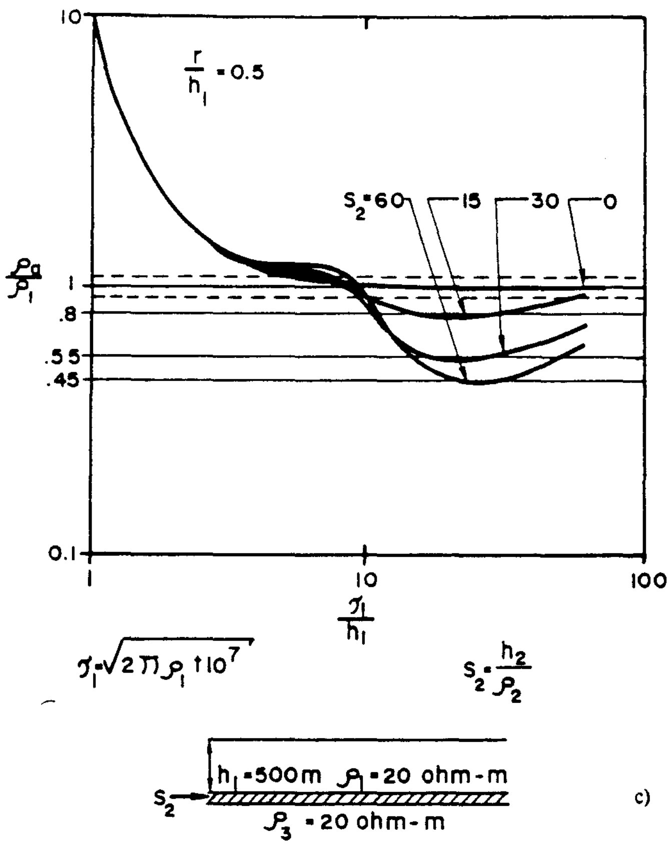


FIGURE 10. Computed apparent resistivity curves for geoelectric section shown:
a) direct current
b) magnetotelluric
c) transient

Case History Onshore and Offshore Permafrost Mapping (3)

The thickness of permafrost along the coast of the Beaufort Sea may reach 2000 ft. The permafrost distribution is variable, particularly near water bodies. Offshore permafrost has been found to exist tens of kilometers from the shore line. The permafrost distribution is required for static correction to seismic reflection data, and for design of well casings and facilities. The increase in resistivity upon freezing is the basis for electrical methods to map permafrost.

Blackhawk Geo has performed hundreds of transient soundings in Alaska and Canada for onshore and offshore permafrost mappings. Figure 11 shows a section of permafrost traversing the coast line passing by the Gull Island well near Prudhoe Bay (4). Above the section the measured apparent resistivity curves are shown.

The section shows that on land permafrost is approximately 2000 ft. thick and has an average resistivity of about 400 ohm-m. The unfrozen ground underneath the permafrost has a resistivity of 2.5 ohm-m. Offshore the top to the permafrost falls off rapidly to 250m about 3 km from the shore line. The unfrozen sediments above the permafrost are saturated with brine and have a resistivity less than 2 ohm-m.

The case history illustrates the ability of transient EM to detect a resistive layer under thick conductive sections. High resolution marine seismic methods sometimes can map top to permafrost, with transient EM both top and bottom could be determined.

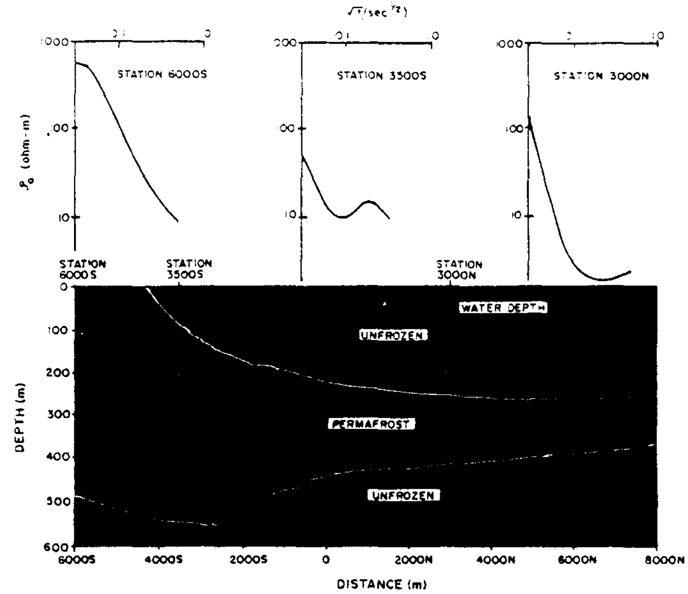


FIGURE 11. Permafrost section with apparent resistivity curves.

Case History - Mapping Depth to Basement

In northern British Columbia a survey was performed in support of a coal exploration program. The objective of transient sounding was to determine the thickness of the sedimentary rock overlaying the crystalline basement, and the contact of sedimentary and volcanic rock.

The geoelectric and geologic section derived from the various soundings is given in Figure 12. In addition to the geologic cross-section the longitudinal resistivity, $\rho \ell$, above the basement is shown. It was computed from the relation:

$$\rho \ell = \frac{H}{\frac{H1}{\rho_1} + \frac{H2}{\rho_2}}$$

where H is total thickness of sedimentary section
and H1, H2 are thicknesses of layer 1 and 2, respectively

The behavior of $\rho \ell$ shows a relatively constant value of about 20 ohm-m from Station 2200m to Station 1200m. From Station 1200m to 200m, $\rho \ell$ increases to a maximum value of about 60 ohm-m. The increase in $\rho \ell$ at Station 1200m was interpreted as the contact of sedimentary and volcanic rock. This interpretation was consistent with the information obtained from two drillholes placed on the cross-section. The drillholes did not penetrate into basement rock.

The section of Figure 12 was largely derived from soundings in the center of 100m by 100m loops.

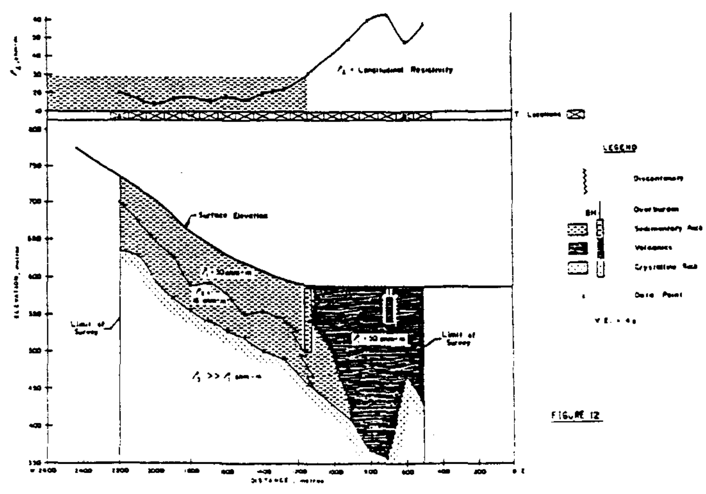


FIGURE 12. Geoelectric section derived from transient soundings.

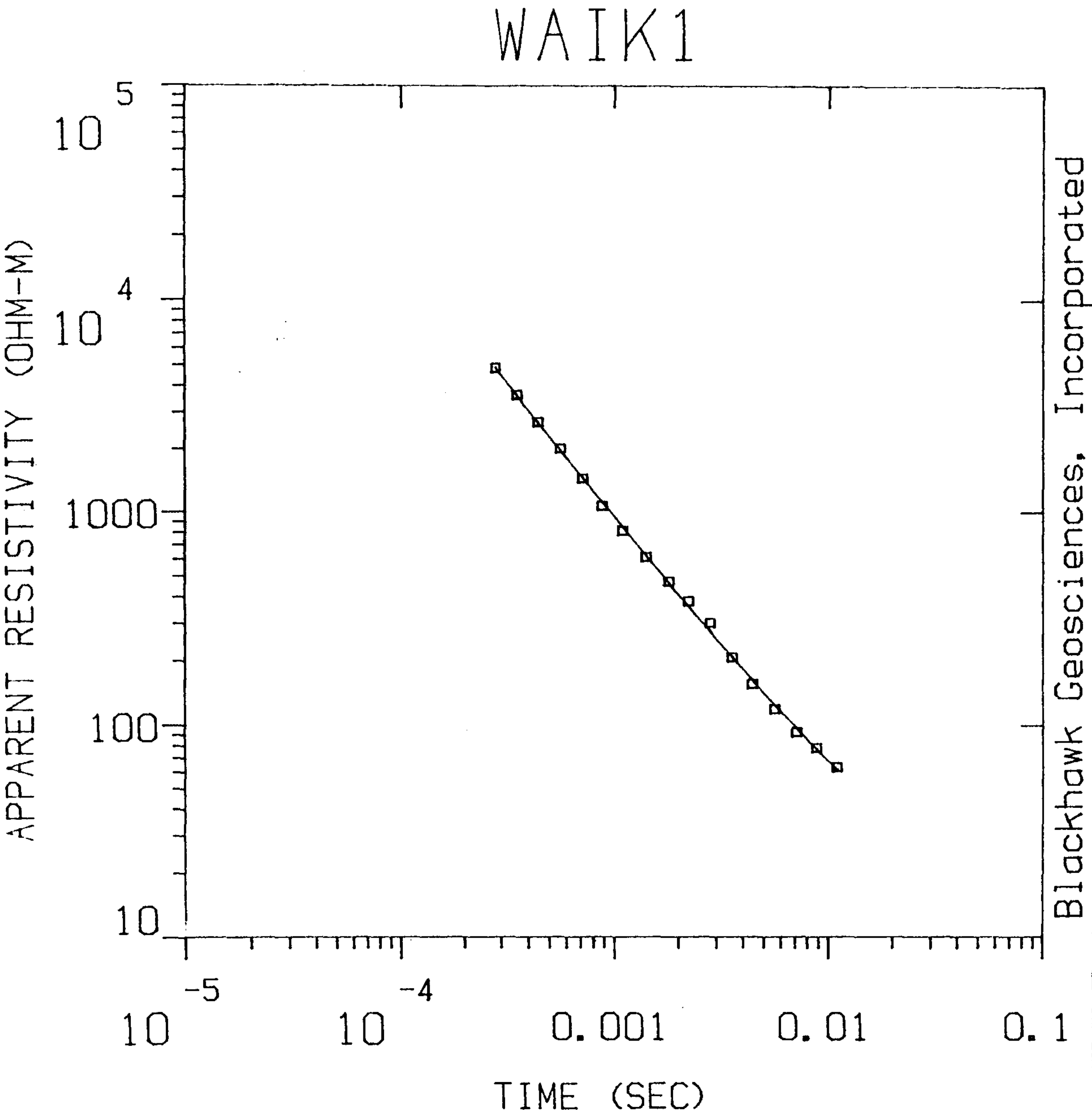
References

1) Kaufman, A.A., and Keller, G.V., **Frequency and Transient Soundings, Elsevier,** (1983).

2) Wightman, W.E., Kaufman, A.A., and Hoekstra, P., Mapping Gas-Water Contacts in Shallow Producing Formations with Transient EM, paper presented to 53rd Annual Meeting SEG, Las Vegas, (1983).

3) Ehrenbard, R.L., Hoekstra, P., and Rozenberg, G., Transient EM for Permafrost Mapping, Proc. 4th Int. Conf. Permafrost, Fairbanks, Ak, (1983).

4) Osterkamp, T.E. and Payne, M.W., Estimates of Permafrost Thickness from Well Logs in Northern Alaska, Cold Regions Sci. and Techn. V. 5 (1981), pp. 13-17.



MODEL:

3799.
OHM-M

527. M

2.80
OHM-M

% ERROR: 5.65
CALIBRATION: 1
OFFSET: 152. M
RAMP: 165.0

MODEL: 2 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		426.7	1400.0		
3799.13	527.1	-100.3	-329.2	0.1	0.1
2.80					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	2.80E-04	4.03E+03	4.06E+03	-0.634	
2	3.55E-04	3.60E+03	3.56E+03	1.050	
3	4.43E-04	2.69E+03	2.67E+03	0.837	
4	5.64E-04	2.00E+03	1.96E+03	2.250	
5	7.13E-04	1.44E+03	1.45E+03	-0.730	
6	8.81E-04	1.06E+03	1.11E+03	-4.274	
7	1.10E-03	8.14E+02	8.49E+02	-4.062	
8	1.41E-03	6.13E+02	6.22E+02	-1.346	
9	1.80E-03	4.72E+02	4.64E+02	1.701	
10	2.22E-03	3.81E+02	3.60E+02	5.959	
11	2.80E-03	3.01E+02	2.74E+02	9.748	
12	3.55E-03	2.08E+02	2.09E+02	-0.474	
13	4.43E-03	1.56E+02	1.62E+02	-3.839	
14	5.64E-03	1.19E+02	1.24E+02	-3.962	
15	7.13E-03	9.24E+01	9.65E+01	-4.237	
16	8.81E-03	7.81E+01	7.70E+01	1.406	
17	1.10E-02	6.32E+01	6.15E+01	2.709	

R: 152. X: 0. Y: 152. DL: 305. REQ: 169. CF: 1.0000
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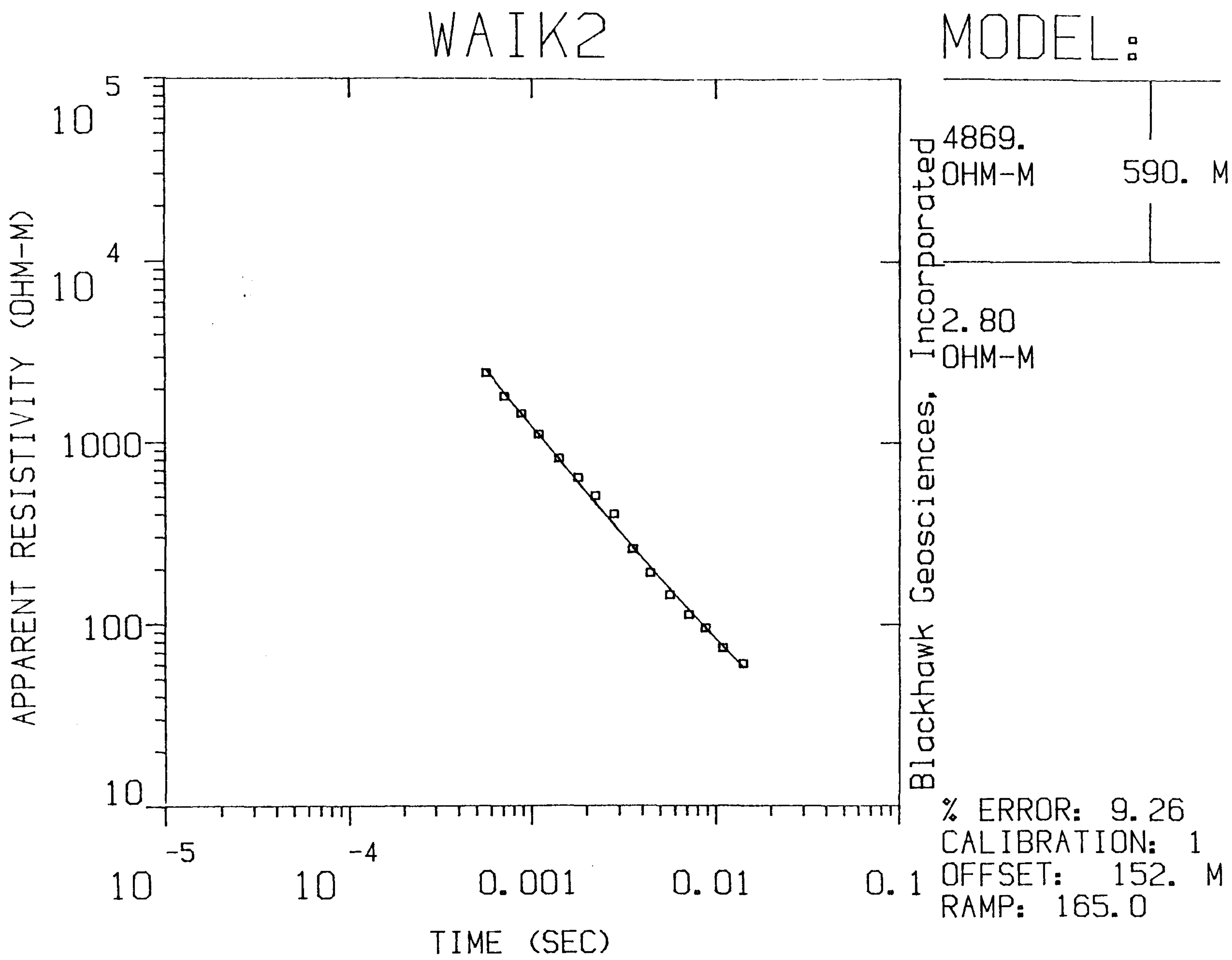
Ch.21 = 0.165 Ch.22 = 0.89 Ch.23 = 15 Ch.24 = 9
RMS LOG ERROR: 2.39E-02, ANTILOG YIELDS 5.6524 %
LATE TIME PARAMETERS

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER

P 1	0.97		
F 2	0.00	0.00	
T 1	0.00	0.00	1.00
	P 1	F 2	T 1


WAIK2
MODEL:
APPARENT RESISTIVITY (OHM-M)
10^5
10^4
1000
100
10
10^-5
10^-4
0.001
0.01
0.1
TIME (SEC)
Blackhawk Geosciences, Incorporated
4869. OHM-M
590. M
2.80 OHM-M
% ERROR: 9.26
CALIBRATION: 1
OFFSET: 152. M
RAMP: 165.0

MODEL: 2 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		458.7	1505.0		
4860.63	589.8	-131.1	-430.2	0.1	0.1
2.80					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	5.64E-04	2.46E+03	2.58E+03	-4.373	
2	7.13E-04	1.82E+03	1.90E+03	-4.246	
3	8.81E-04	1.46E+03	1.46E+03	-0.163	
4	1.10E-03	1.11E+03	1.11E+03	0.603	
5	1.41E-03	8.18E+02	8.08E+02	1.157	
6	1.80E-03	6.39E+02	6.02E+02	6.170	
7	2.22E-03	5.07E+02	4.63E+02	9.435	
8	2.80E-03	4.02E+02	3.52E+02	14.250	
9	3.55E-03	2.59E+02	2.66E+02	-2.594	
10	4.43E-03	1.92E+02	2.06E+02	-6.940	
11	5.64E-03	1.45E+02	1.56E+02	-7.452	
12	7.13E-03	1.13E+02	1.20E+02	-6.319	
13	8.81E-03	9.49E+01	9.53E+01	-0.459	
14	1.10E-02	7.40E+01	7.55E+01	-1.915	
15	1.41E-02	6.07E+01	5.79E+01	4.901	

R: 152. X: 0. Y: 152. DL: 305. REQ: 169. CF: 1.0000
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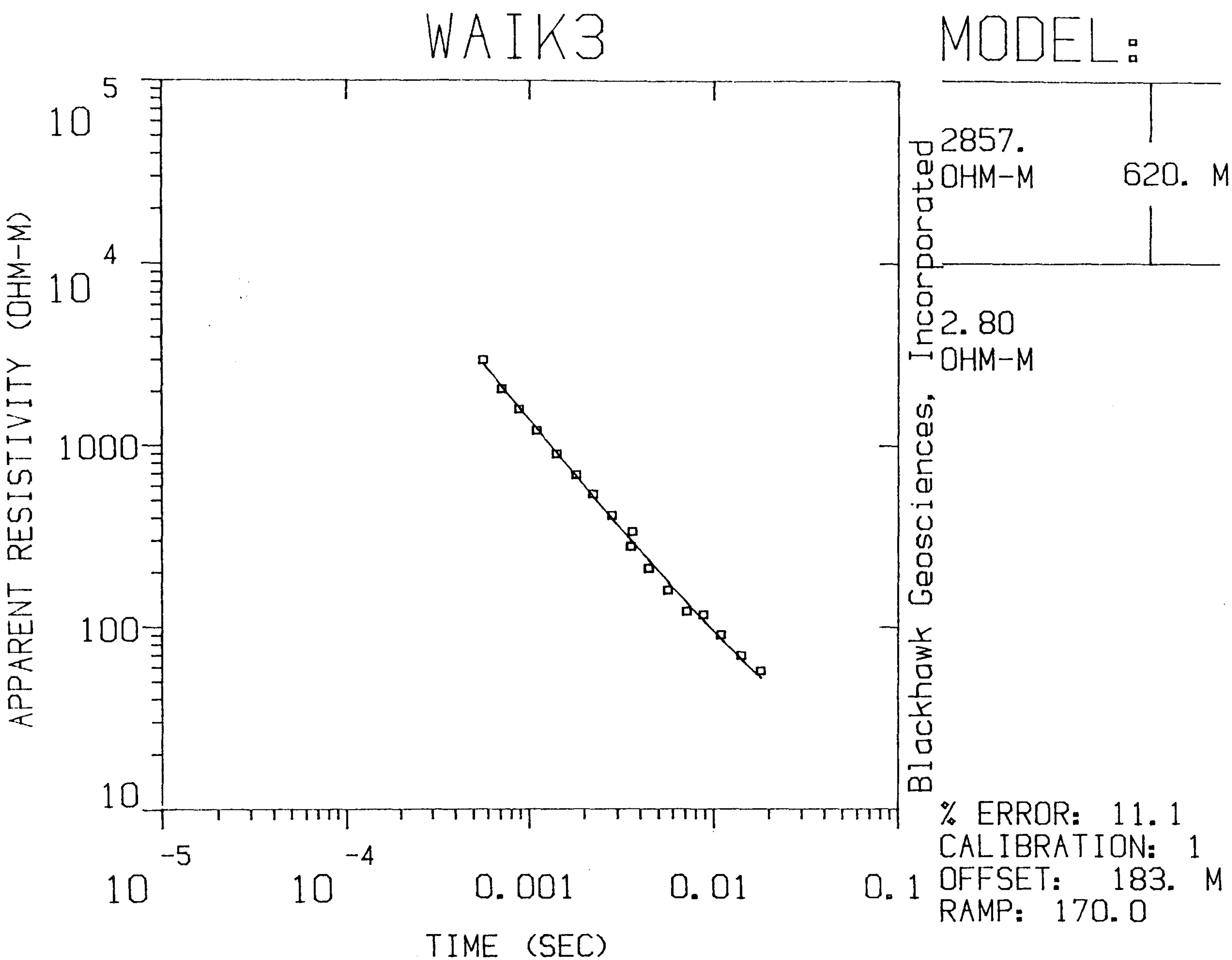
2910 1111 2222 Z OFR XTL 1 6 10+1000
Ch.21 = 0.165 Ch.22 = 0.89 Ch.23 = 15 Ch.24 = 9
RMS LOG ERROR: 3.85E-02, ANTILOG YIELDS 9.2633 %
LATE TIME PARAMETERS

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER
P 1 0.04
F 2 0.00 0.00
T 1 0.00 0.00 1.00
P 1 F 2 T 1


WAIK3
MODEL:
2857.
OHM-M
620. M
2.80
OHM-M
APPARENT RESISTIVITY (OHM-M)
10^5
10^4
1000
100
10
10^-5
10^-4
0.001
0.01
0.1
TIME (SEC)
Blackhawk Geosciences, Incorporated
% ERROR: 11.1
CALIBRATION: 1
OFFSET: 183. M
RAMP: 170.0

MODEL: 2 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		501.4	1645.0		
2857.34	620.1	-118.7	-389.6	0.2	0.2
2.80					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	5.64E-04	2.98E+03	2.86E+03	4.063	
2	7.13E-04	2.06E+03	2.13E+03	-3.195	
3	8.81E-04	1.59E+03	1.63E+03	-2.487	
4	1.10E-03	1.20E+03	1.24E+03	-2.986	
5	1.41E-03	8.95E+02	9.10E+02	-1.372	
6	1.80E-03	6.87E+02	6.76E+02	1.615	
7	2.22E-03	3.40E+02	3.23E+02	5.206	
8	2.80E-03	4.13E+02	3.97E+02	3.961	
9	3.55E-03	2.76E+02	3.00E+02	-8.063	
10	3.60E-03	3.36E+02	2.96E+02	13.669	
11	4.43E-03	2.10E+02	2.33E+02	-9.979	
12	5.64E-03	1.59E+02	1.77E+02	-10.052	
13	7.13E-03	1.22E+02	1.36E+02	-10.851	
14	8.81E-03	1.17E+02	1.08E+02	7.517	
15	1.10E-02	9.02E+01	8.60E+01	4.876	
16	1.41E-02	6.95E+01	6.65E+01	4.584	
17	1.80E-02	5.71E+01	5.22E+01	9.383	

R: 183. X: 0. Y: 183. DL: 366. REG: 203. CF: 1.0000
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3010 1111 0003 Z OPR XTL L 7 10+1000
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RMS LOG ERROR: 4.57E-02, ANTILOG YIELDS 11.1009 %
LATE TIME PARAMETERS

* Blackhawk Geosciences, incorporated *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER

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P 2   0.00   0.00
T 1   0.00   0.00   1.00
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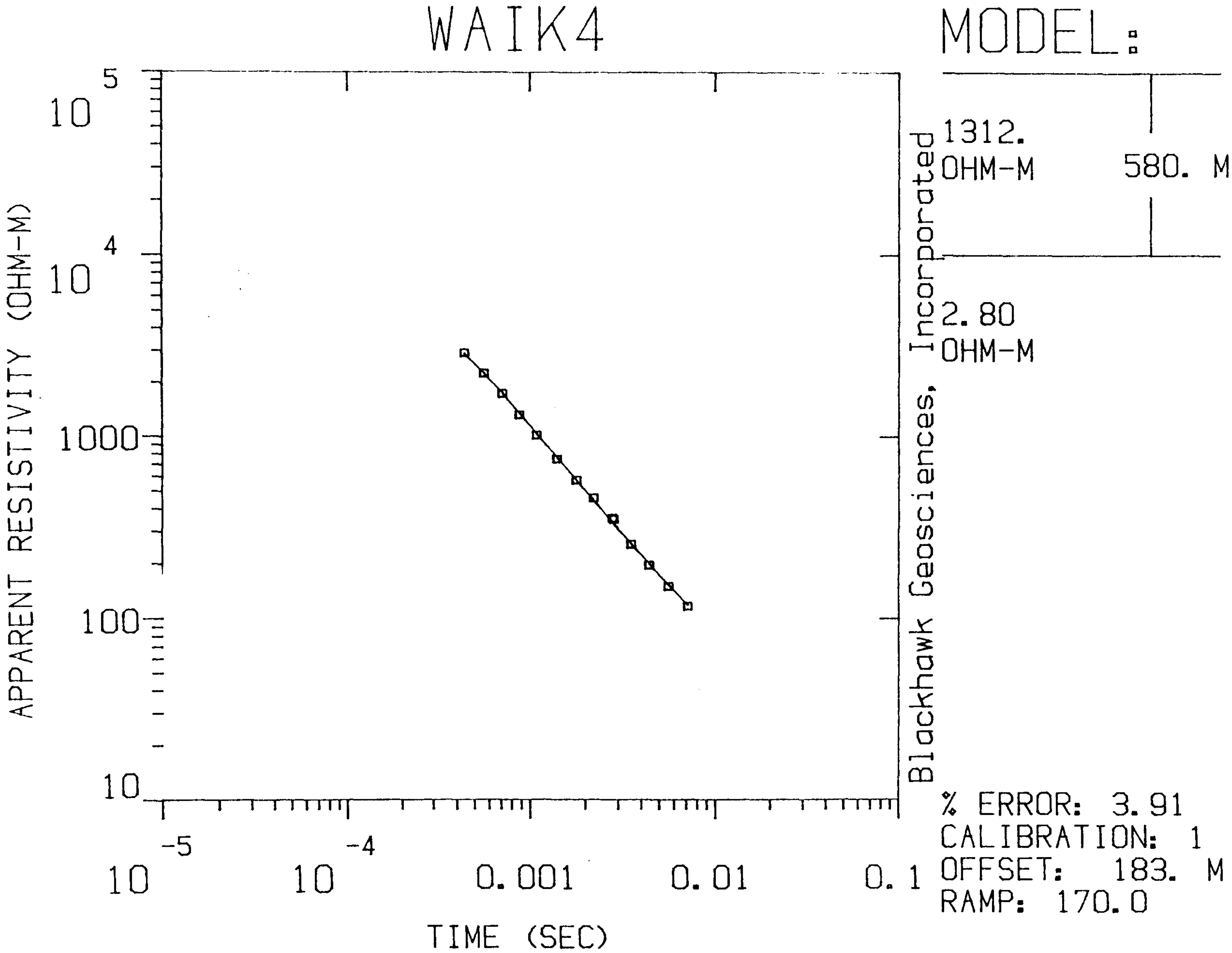
WAIK4
MODEL:
1312.
OHM-M
580. M
2.80
OHM-M
Blackhawk Geosciences, Incorporated
APPARENT RESISTIVITY (OHM-M)
10^5
10^4
1000
100
10
10^-5
10^-4
0.001
0.01
0.1
TIME (SEC)
% ERROR: 3.91
CALIBRATION: 1
OFFSET: 183. M
RAMP: 170.0

WAIK4

MODEL: 2 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		475.5	1560.0		
1312.34	580.3	-104.8	-343.8	0.4	0.4
2.80					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	4.43E-04	2.91E+03	2.88E+03	0.879	
2	5.64E-04	2.24E+03	2.25E+03	-0.463	
3	7.13E-04	1.72E+03	1.75E+03	-1.338	
4	8.81E-04	1.31E+03	1.34E+03	-2.021	
5	1.10E-03	1.01E+03	1.03E+03	-1.556	
6	1.41E-03	7.46E+02	7.61E+02	-1.954	
7	1.80E-03	5.71E+02	5.71E+02	0.002	
8	2.22E-03	4.57E+02	4.42E+02	3.356	
9	2.80E-03	3.56E+02	3.38E+02	5.114	
10	2.85E-03	3.50E+02	3.32E+02	5.489	
11	3.55E-03	2.55E+02	2.57E+02	-0.905	
12	4.43E-03	1.95E+02	2.00E+02	-2.287	
13	5.64E-03	1.50E+02	1.53E+02	-2.154	
14	7.13E-03	1.16E+02	1.19E+02	-1.748	

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3010 0000 0003 Z OPR XTL L 7 10+1000
Ch.21 = 0.17 Ch.22 = 0.89 Ch.23 = 13 Ch.24 = 13
RMS LOG ERROR: 1.67E-02, ANTILOG YIELDS 3.9150 %
LATE TIME PARAMETERS

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER

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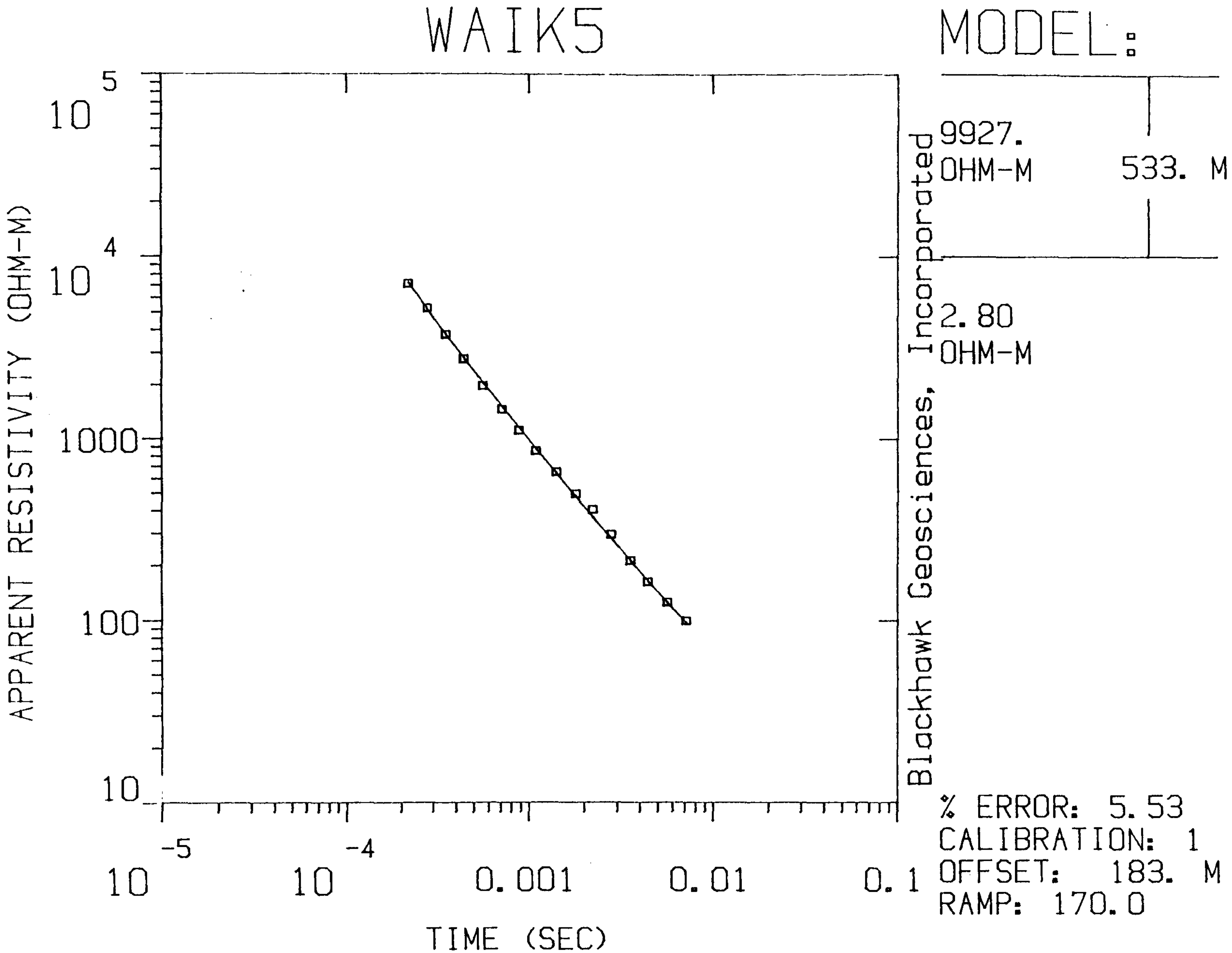
T 1	0.00	0.00	1.00
	P 1	F 2	T 1



WAIK5
MODEL:
9927.
OHM-M
533. M
2.80
OHM-M
APPARENT RESISTIVITY (OHM-M)
10^5
10^4
1000
100
10
10^-5
10^-4
0.001
0.01
0.1
TIME (SEC)
Blackhawk Geosciences, Incorporated
% ERROR: 5.53
CALIBRATION: 1
OFFSET: 183. M
RAMP: 170.0

MODEL: 2 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		428.2	1405.0		
9926.62	533.5	-105.2	-345.2	0.1	0.1
2.80					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	2.20E-04	7.09E+03	7.18E+03	-1.178	
2	2.80E-04	5.22E+03	5.18E+03	0.830	
3	3.55E-04	3.75E+03	3.77E+03	-0.512	
4	4.43E-04	2.76E+03	2.81E+03	-1.835	
5	5.64E-04	1.97E+03	2.05E+03	-4.313	
6	7.13E-04	1.45E+03	1.52E+03	-4.271	
7	8.81E-04	1.11E+03	1.16E+03	-4.325	
8	1.10E-03	8.53E+02	8.81E+02	-3.171	
9	1.41E-03	6.51E+02	6.43E+02	1.373	
10	1.80E-03	4.94E+02	4.78E+02	3.279	
11	2.22E-03	4.05E+02	3.69E+02	9.608	
12	2.80E-03	2.95E+02	2.81E+02	5.313	
13	3.55E-03	2.12E+02	2.13E+02	-0.346	
14	4.43E-03	1.62E+02	1.65E+02	-1.389	
15	5.64E-03	1.25E+02	1.25E+02	0.186	
16	7.13E-03	9.91E+01	9.66E+01	2.611	

R: 183. X: 0. Y: 183. DL: 366. REQ: 203. CF: 1.0000
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1031 2222 0005 Z OPR XTL L 7 10+1000
Ch.21 = 0.17 Ch.22 = 0.89 Ch.23 = 13 Ch.24 = 13
RMS LOG ERROR: 2.34E-02, ANTILOG YIELDS 5.5321 %
LATE TIME PARAMETERS

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER

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P 1   0.00
F 2   0.00   0.00
T 1  -0.01   0.00   0.50
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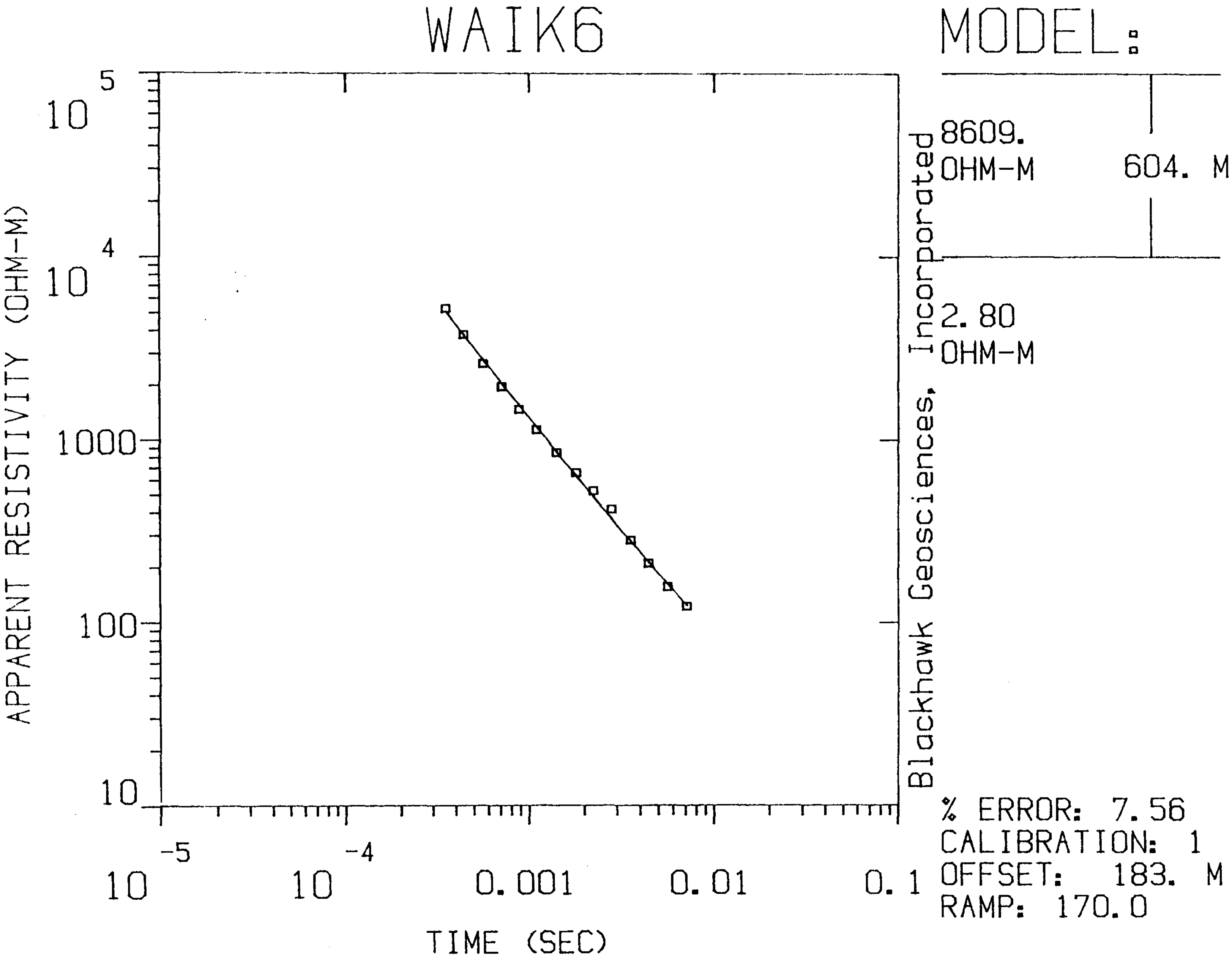


WAIK6
MODEL:
APPARENT RESISTIVITY (OHM-M)
10^5
10^4
1000
100
10
10^-5
10^-4
0.001
0.01
0.1
TIME (SEC)
Blackhawk Geosciences, Incorporated
8609.
OHM-M
604. M
2.80
OHM-M
% ERROR: 7.56
CALIBRATION: 1
OFFSET: 183. M
RAMP: 170.0

WAIK6

MODEL: 2 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		475.5	1560.0		
8609.00	604.3	-128.8	-422.5	0.1	0.1
2.80					

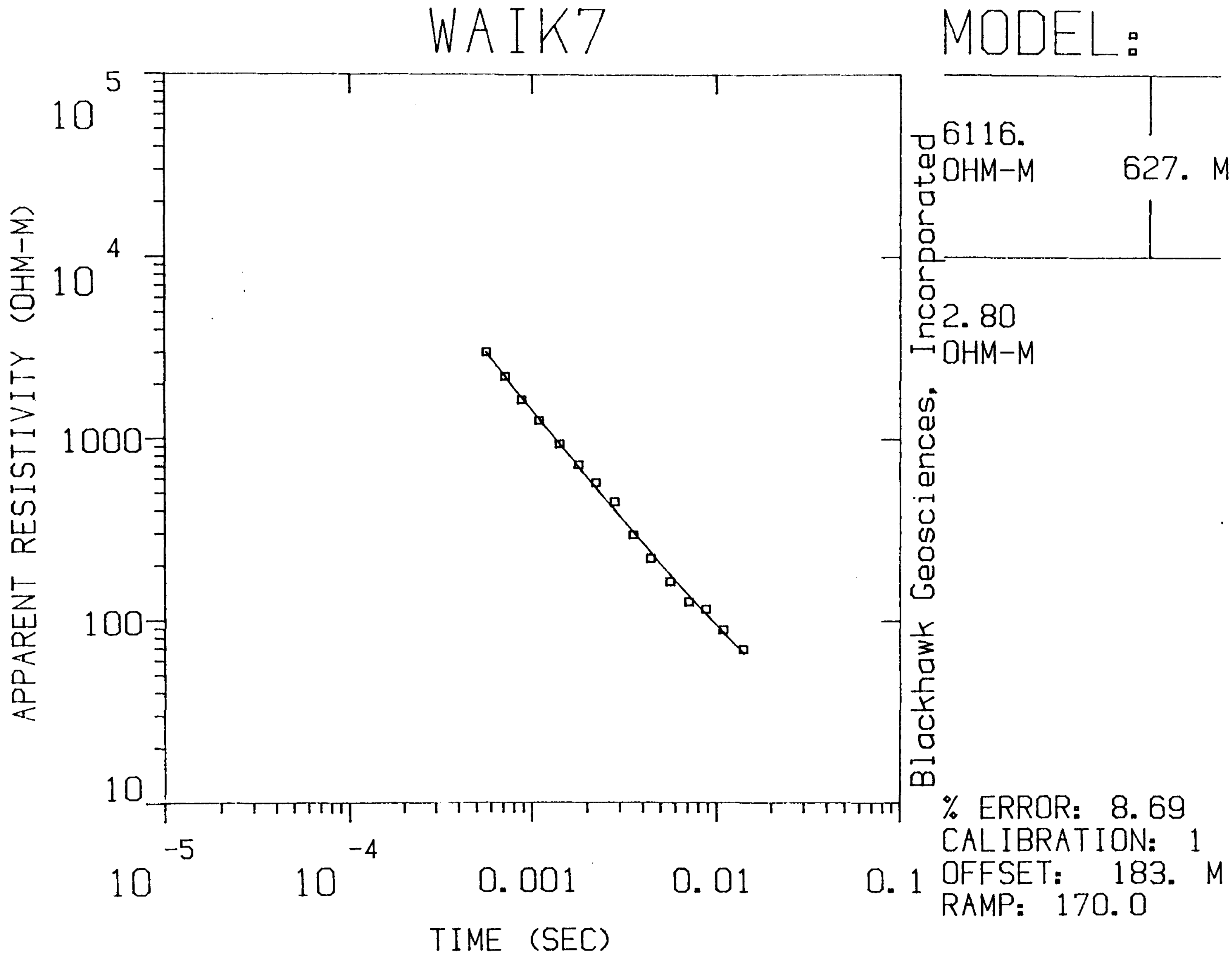
	TIMES	DATA	CALC	% ERROR	STD ERR
1	3.55E-04	3.23E+03	3.07E+03	3.178	
2	4.43E-04	3.77E+03	3.78E+03	-0.290	
3	5.64E-04	2.61E+03	2.75E+03	-5.043	
4	7.13E-04	1.95E+03	2.04E+03	-4.146	
5	8.81E-04	1.46E+03	1.52E+03	-3.663	
6	1.10E-03	1.13E+03	1.17E+03	-3.808	
7	1.41E-03	8.48E+02	8.56E+02	-0.922	
8	1.80E-03	6.58E+02	6.34E+02	3.826	
9	2.22E-03	5.25E+02	4.88E+02	7.605	
10	2.80E-03	4.15E+02	3.69E+02	12.571	
11	3.55E-03	2.81E+02	2.78E+02	1.282	
12	4.43E-03	2.10E+02	2.14E+02	-2.166	
13	5.64E-03	1.56E+02	1.62E+02	-3.240	
14	7.13E-03	1.22E+02	1.24E+02	-1.849	

R: 183. X: 0. Y: 183. DL: 366. REQ: 203. CF: 1.0000
TDHZ ARRAY, 14 DATA POINTS, RAMP: 170.0 MICROSEC, DATA: WAIK6
1031 2222 0006 Z OPR XTL L 7 10+1000
Ch.21 = 0.17 Ch.22 = 0.89 Ch.23 = 13 Ch.24 = 13
RMS LOG ERROR: 3.17E-02, ANTILOG YIELDS 7.5650 %
LATE TIME PARAMETERS

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER

P 1	0.03		
P 2	0.00	0.00	
T 1	0.00	0.00	1.00
	P 1	P 2	T 1



WAIK7
MODEL:
APPARENT RESISTIVITY (OHM-M)
10^5
10^4
1000
100
10
10^{-5}
10^{-4}
0.001
0.01
0.1
TIME (SEC)
Blackhawk Geosciences, Incorporated
6116.
OHM-M
627. M
2.80
OHM-M
% ERROR: 8.69
CALIBRATION: 1
OFFSET: 183. M
RAMP: 170.0

MODEL: 2 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		506.0	1660.0		
6116.43	626.5	-120.5	-395.3	0.1	0.1
2.80					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	5.64E-04	3.01E+03	3.01E+03	0.160	
2	7.13E-04	2.22E+03	2.22E+03	-0.073	
3	8.81E-04	1.64E+03	1.69E+03	-3.030	
4	1.10E-03	1.26E+03	1.29E+03	-2.298	
5	1.41E-03	9.35E+02	9.36E+02	-0.179	
6	1.80E-03	7.16E+02	6.97E+02	2.779	
7	2.22E-03	5.72E+02	5.36E+02	6.605	
8	2.80E-03	4.47E+02	4.05E+02	10.690	
9	3.55E-03	2.95E+02	3.06E+02	-3.713	
10	4.43E-03	2.19E+02	2.36E+02	-7.178	
11	5.64E-03	1.64E+02	1.79E+02	-8.462	
12	7.13E-03	1.27E+02	1.37E+02	-7.552	
13	8.81E-03	1.16E+02	1.09E+02	6.667	
14	1.10E-02	8.89E+01	8.58E+01	3.509	
15	1.41E-02	6.94E+01	6.57E+01	5.692	

R: 183. X: 0. Y: 183. DL: 366. REQ: 203. CF: 1.0000
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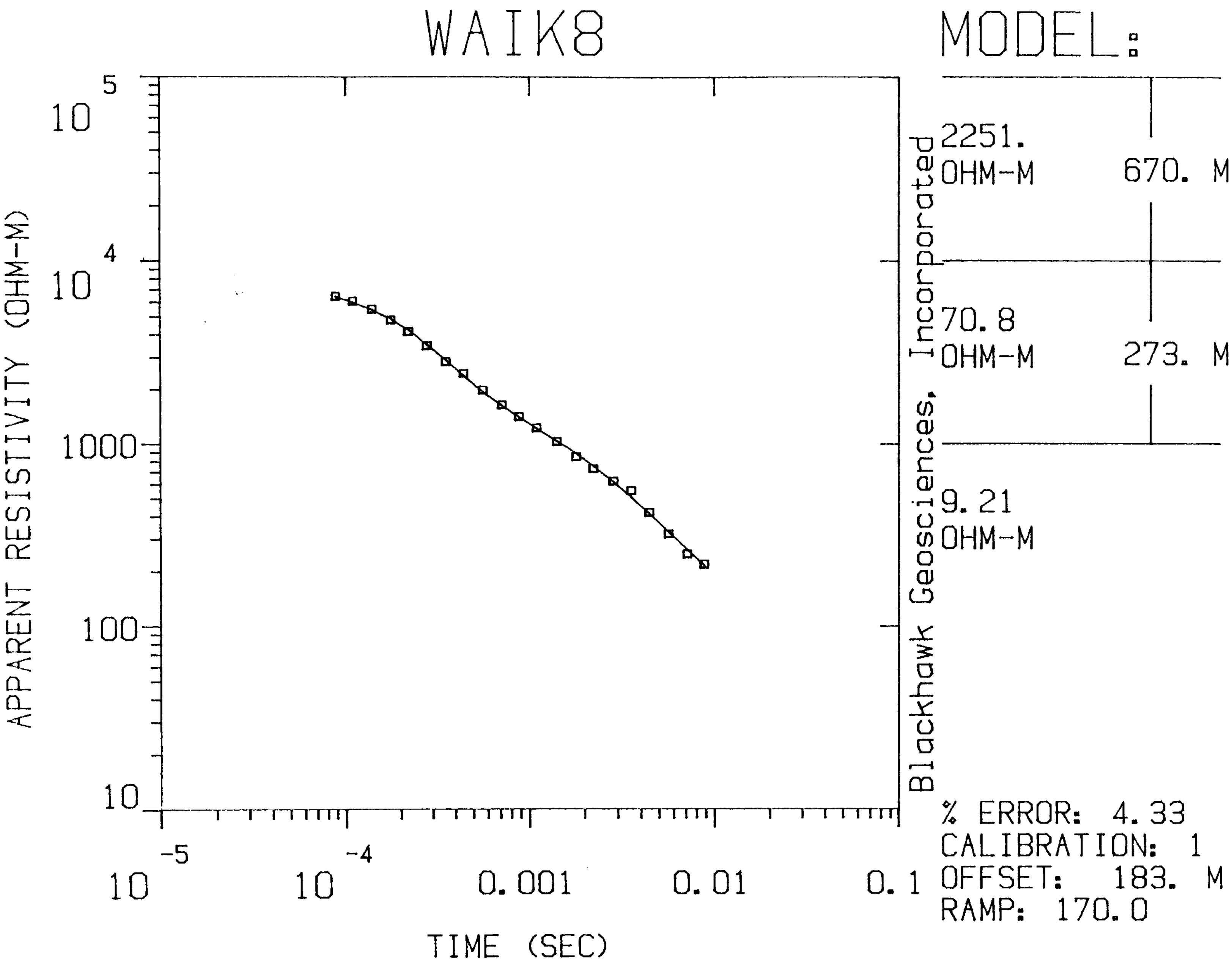
1102 0002 0007 Z OPR XTL L 7 10+1000
Ch.21 = 0.17 Ch.22 = 0.89 Ch.23 = 13 Ch.24 = 13
RMS LOG ERROR: 3.62E-02, ANTILOG YIELDS 8.6887 %
LATE TIME PARAMETERS

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER
P 1 0.03
F 2 0.00 0.00
T 1 -0.03 0.00 0.98
P 1 F 2 T 1


WAIK8
MODEL:
10^5
10^4
1000
100
10
APPARENT RESISTIVITY (OHM-M)
10^-5
10^-4
0.001
0.01
0.1
TIME (SEC)
Blackhawk Geosciences, Incorporated
2251. OHM-M
670. M
70.8 OHM-M
273. M
9.21 OHM-M
% ERROR: 4.33
CALIBRATION: 1
OFFSET: 183. M
RAMP: 170.0

MODEL: 3 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		524.3	1720.0		
2250.81	669.8	-145.5	-477.4	0.3	0.3
70.77	272.7	-418.2	-1371.9	3.9	4.2
9.21					

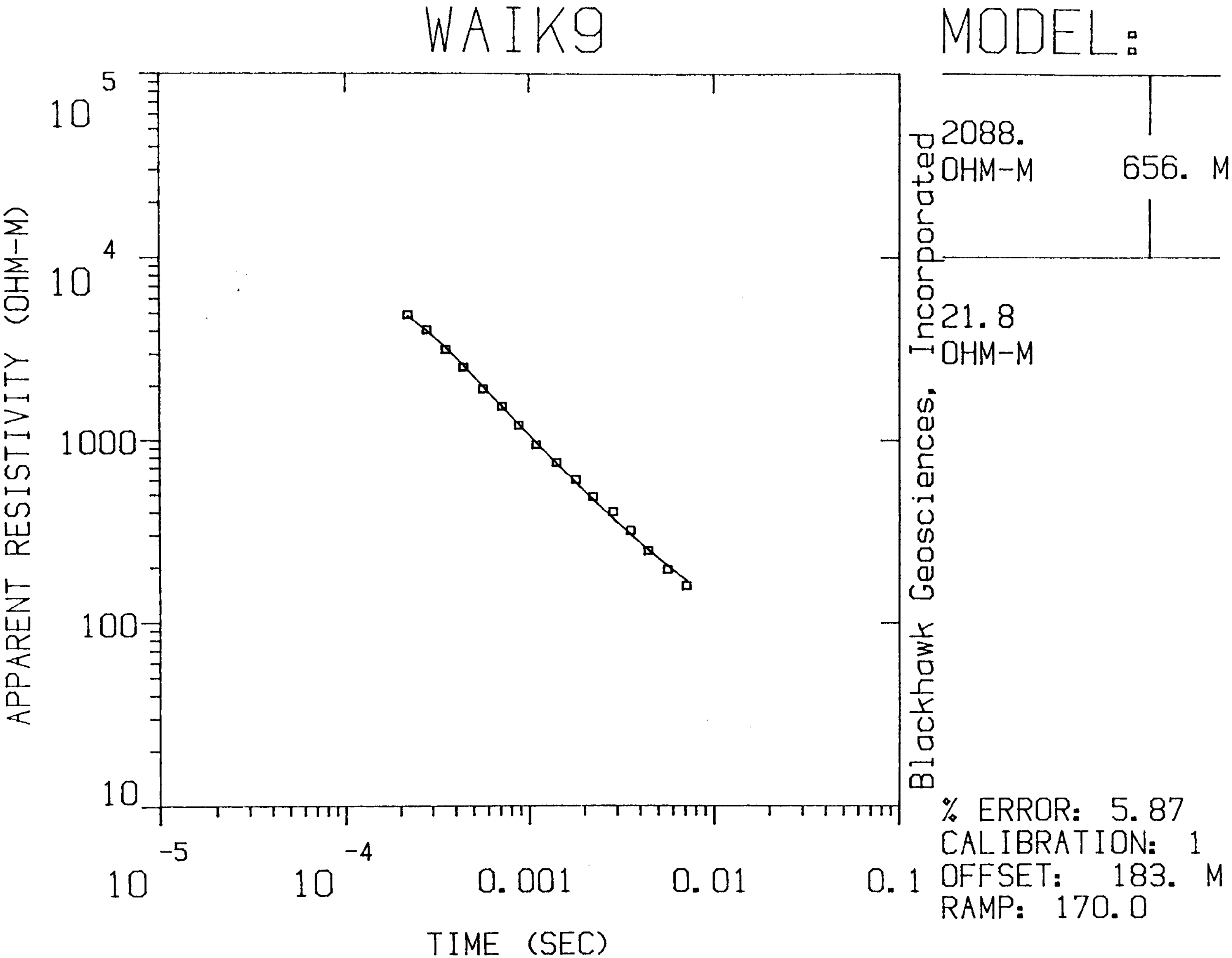
	TIMES	DATA	CALC	% ERROR	STD ERR
1	8.90E-05	6.42E+03	6.41E+03	0.124	
2	1.10E-04	6.04E+03	5.96E+03	1.374	
3	1.40E-04	5.47E+03	5.43E+03	0.790	
4	1.77E-04	4.79E+03	4.85E+03	-1.380	
5	2.20E-04	4.14E+03	4.24E+03	-2.145	
6	2.80E-04	3.47E+03	3.52E+03	-1.532	
7	3.55E-04	2.84E+03	2.89E+03	-1.781	
8	4.43E-04	2.44E+03	2.38E+03	2.717	
9	5.64E-04	1.98E+03	1.93E+03	2.551	
10	7.13E-04	1.64E+03	1.62E+03	0.964	
11	8.81E-04	1.41E+03	1.40E+03	0.589	
12	1.10E-03	1.22E+03	1.21E+03	0.997	
13	1.41E-03	1.03E+03	1.03E+03	-0.409	
14	1.80E-03	8.47E+02	8.86E+02	-4.382	
15	2.22E-03	7.28E+02	7.51E+02	-3.034	
16	2.85E-03	6.21E+02	6.15E+02	0.912	
17	3.55E-03	5.51E+02	5.07E+02	8.563	
18	4.43E-03	4.18E+02	4.12E+02	1.452	
19	5.64E-03	3.20E+02	3.28E+02	-2.459	
20	7.13E-03	2.48E+02	2.62E+02	-5.271	
21	8.81E-03	2.18E+02	2.15E+02	1.677	

R: 183. X: 0. Y: 183. DL: 366. REC: 203. CF: 1.0000
TDHZ ARRAY, 21 DATA POINTS, RAMP: 170.0 MICROSEC, DATA: WAIK8
1102 0003 0008 Z OPR XTL L 7 10+1000
Ch.21 = 0.17 Ch.22 = 0.89 Ch.23 = 13 Ch.24 = 13
RMS LOG ERROR: 1.84E-02, ANTILOG YIELDS 4.3339 %
LATE TIME PARAMETERS

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER
P 1 0.11
P 2 -0.01 0.02
P 3 0.00 -0.01 0.00
T 1 0.03 0.06 -0.03 0.44
T 2 -0.01 -0.01 0.00 -0.02 0.05

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]
THICK	1	660.042	669.764	678.938
	2	253.088	272.656	292.777
DEPTH	1	660.042	669.764	678.938
	2	921.907	942.420	963.446



WAIK9
MODEL:
2088.
OHM-M
656. M
21.8
OHM-M
APPARENT RESISTIVITY (OHM-M)
10^5
10^4
1000
100
10
10^-5
10^-4
0.001
0.01
0.1
TIME (SEC)
Blackhawk Geosciences, Incorporated
% ERROR: 5.87
CALIBRATION: 1
OFFSET: 183. M
RAMP: 170.0

MODEL: 2 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		464.8	1525.0		
2088.39	655.8	-191.0	-626.6	0.3	0.3
21.79					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	2.20E-04	4.87E+03	4.80E+03	1.423	
2	2.80E-04	4.05E+03	4.02E+03	0.665	
3	3.55E-04	3.17E+03	3.26E+03	-2.765	
4	4.43E-04	2.53E+03	2.60E+03	-2.649	
5	5.64E-04	1.92E+03	1.98E+03	-3.157	
6	7.13E-04	1.54E+03	1.54E+03	0.025	
7	8.81E-04	1.20E+03	1.22E+03	-1.617	
8	1.10E-03	9.41E+02	9.67E+02	-2.605	
9	1.41E-03	7.50E+02	7.40E+02	1.341	
10	1.80E-03	6.04E+02	5.81E+02	3.999	
11	2.22E-03	4.87E+02	4.69E+02	3.957	
12	2.85E-03	4.03E+02	3.70E+02	8.923	
13	3.55E-03	3.18E+02	3.03E+02	5.053	
14	4.43E-03	2.46E+02	2.49E+02	-0.926	
15	5.64E-03	1.94E+02	2.04E+02	-4.752	
16	7.13E-03	1.59E+02	1.69E+02	-6.135	

R: 183. X: 0. Y: 183. DL: 366. REQ: 203. CF: 1.0000
TCHZ ARRAY, 16 DATA POINTS, RAMP: 170.0 MICROSEC, DATA: WAIK9
1103 0003 0009 Z OPR XTL L 7 10+1000
Ch.21 = 0.17 Ch.22 = 0.89 Ch.23 = 13 Ch.24 = 13
RMS LOG ERROR: 2.48E-02, ANTILOG YIELDS 5.9733 %
LATE TIME PARAMETERS

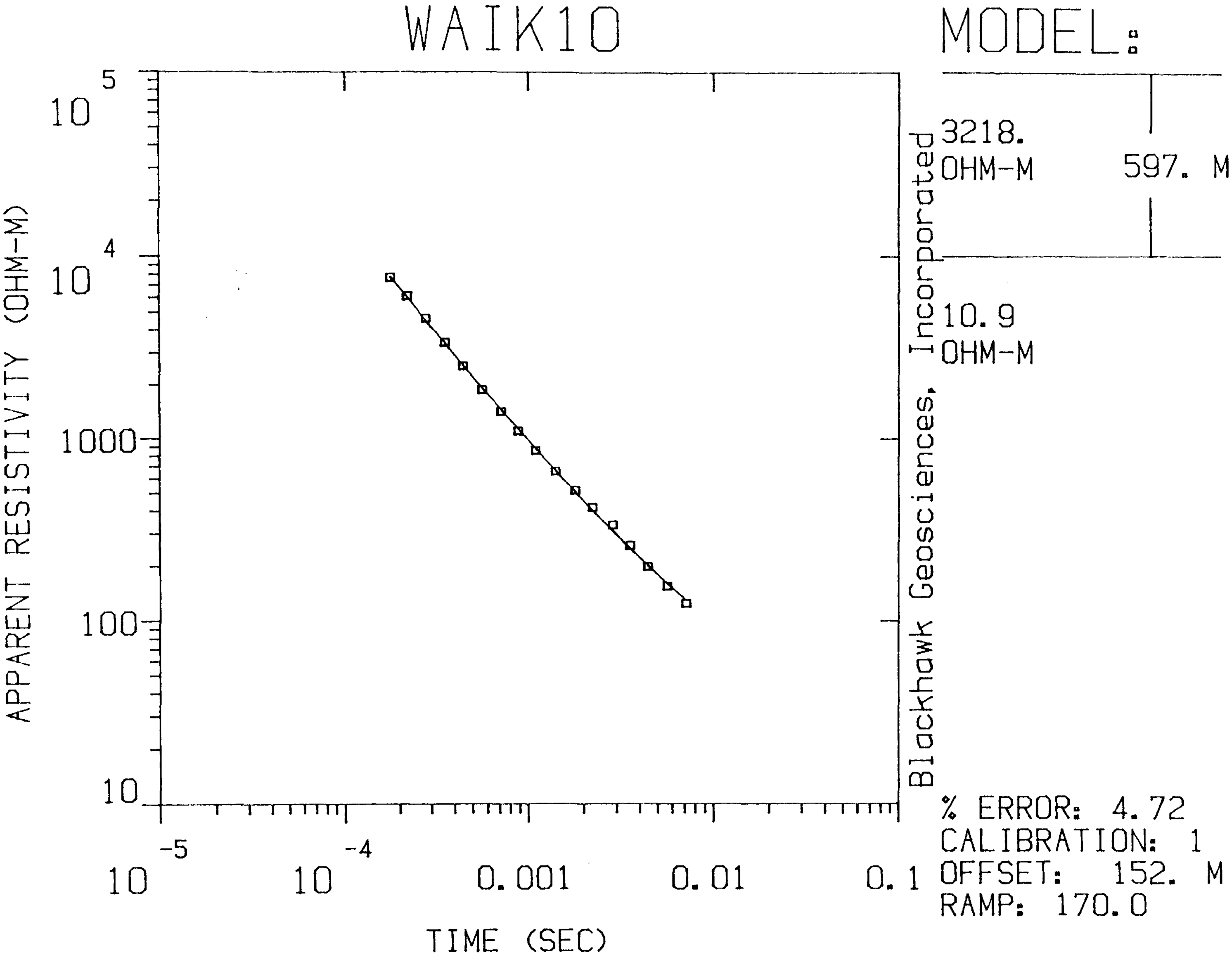
* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER

P 1	1.00		
P 2	0.00	1.00	
T 1	0.00	0.00	1.00
	P 1	P 2	T 1

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

LAYER		MINIMUM	BEST	MAXIMUM
RHO	1	1872.678	2088.394	2419.827
	2	17.213	21.791	27.142
THICK	1	[illegible]	[illegible]	[illegible]
[illegible]		[illegible]	[illegible]	[illegible]



WAIK10
MODEL:
APPARENT RESISTIVITY (OHM-M)
10^5
10^4
1000
100
10
10^-5
10^-4
0.001
0.01
0.1
TIME (SEC)
3218.
OHM-M
597. M
10.9
OHM-M
Blackhawk Geosciences, Incorporated
% ERROR: 4.72
CALIBRATION: 1
OFFSET: 152. M
RAMP: 170.0

[illegible]

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	(FEET)	CONDUCTANCE (S) LAYER	TOTAL
		425.7	1400.0		
1218.38	597.6	-170.1	-558.7	0.2	0.2
10.74					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	1.77E-04	7.67E+03	7.74E+03	-0.953	
2	2.20E-04	6.09E+03	6.02E+03	1.111	
3	2.80E-04	4.63E+03	4.50E+03	2.791	
4	3.55E-04	3.41E+03	3.38E+03	0.832	
5	4.40E-04	2.54E+03	2.57E+03	-1.302	
6	5.64E-04	1.87E+03	1.92E+03	-2.626	
7	7.13E-04	1.41E+03	1.45E+03	-2.771	
8	8.61E-04	1.10E+03	1.13E+03	-2.776	
9	1.10E-03	8.59E+02	8.78E+02	-2.311	
10	1.41E-03	6.59E+02	6.62E+02	-0.474	
11	1.80E-03	5.17E+02	5.07E+02	2.048	
12	2.22E-03	4.19E+02	4.03E+02	4.049	
13	2.85E-03	3.35E+02	3.11E+02	7.665	
14	3.55E-03	2.59E+02	2.49E+02	3.903	
15	4.43E-03	1.98E+02	2.01E+02	-1.470	
16	5.64E-03	1.55E+02	1.60E+02	-3.168	
17	7.13E-03	1.25E+02	1.30E+02	-4.164	

R: 152. X: 0. Y: 152. DL: 305. REC: 169. CF: 1.0000
10HZ ARRAY, 17 DATA POINTS, RAMP: 170.0 MICROSEC, DATA: WAIK10
1103 0003 0010 2 OHR XTL L 7 10+1000
Ch.21 = 0.165 Ch.22 = 0.89 Ch.23 = 15 Ch.24 = 9
RMS LOG ERROR: 2.00E-02, ANTILOG YIELDS 4.71 %
LATE TIME PARAMETERS

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER
P 1 0.99
P 2 0.00 0.99
T 1 0.00 0.00 1.00
P 1 P 2 T 1

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

LAYER	MINIMUM	BEST	MAXIMUM
RHO 1	[illegible]	1218.38	[illegible]
	[illegible]	[illegible]	[illegible]

BLACKHAWK GEOSCIENCES, INC.

GEOPHYSICAL SURVEYS FOR GROUND WATER EVALUATION NEAR THE KAWAIHAE EXPLORATORY WELL NORTHEAST OF KAWAIHAE ISLAND OF HAWAII

GEOPHYSICAL SURVEYS FOR
GROUND WATER EVALUATION
NEAR THE KAWAIHAE EXPLORATORY WELL
NORTHEAST OF KAWAIHAE
ISLAND OF HAWAII

Prepared For:

State of Hawaii
Department of Land & Natural Resources
Division of Water Resource Management
P.O. Box 373
Honolulu, HI 96809

Prepared By:

Blackhawk Geosciences, Inc.
17301 West Colfax Avenue., Suite 170
Golden, CO 80401

October 22, 1990

(Our Project #90041)

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1.0 INTRODUCTION

Time domain electromagnetic (TDEM) geophysical surveys were conducted to assist in ground water resource evaluation near the recently drilled Kawaihae exploratory well northeast of the town of Kawaihae, Island of Hawaii. The surveys were performed by Blackhawk Geosciences, Inc. (BGI) between September 9 and September 15, 1990 for the State of Hawaii (State).

The location of the measurement stations and the interpretations and conclusions derived from this survey were influenced by a prior TDEM survey conducted north of Honokoa Gulch for Kohala Joint Venture (KJV). By agreement from all concerned parties the results of the survey north of Honokoa Gulch are used in this report.

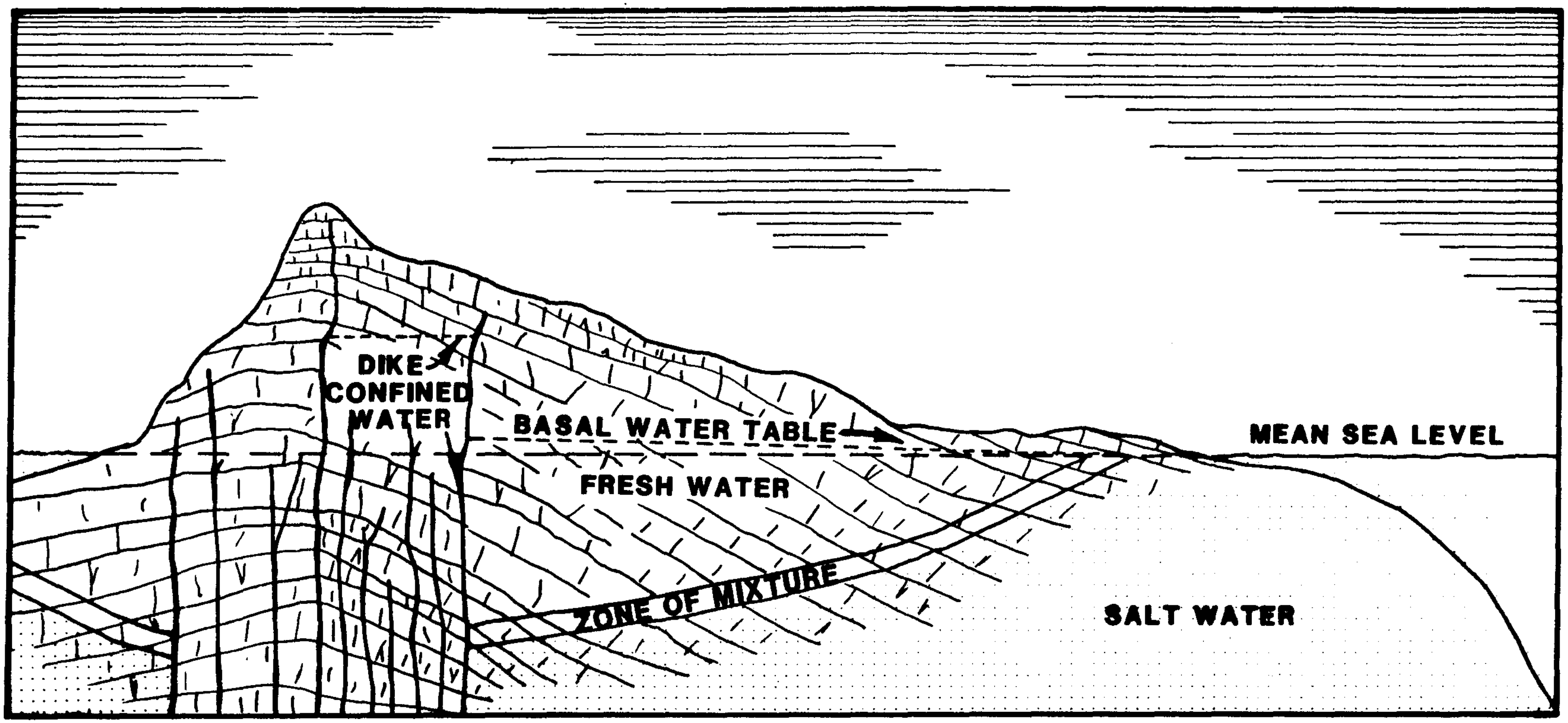
The primary objective of the geophysical survey was to assist in characterizing the hydrologic regime in the vicinity of the Kawaihae well. Drilling results disclosed a low static water level (1.1 ft above msl) in the well. Important reasons for conducting a geophysical survey were (i) to evaluate if such low static water levels are characteristic of a large area, and (ii) if perhaps the potential for better water resources exist elsewhere nearby. The basis for geophysical surveys for ground water evaluations on volcanic islands are illustrated in Figure 1-1. The volcanic rocks are generally highly permeable and this allows rainwater to percolate with little impedance directly downward through the island mass. The fresh water in these island settings is generally found in two environments:

1. Basal fresh water. The high permeability of the volcanic rocks allows sea water to enter freely under the island, and a balance is reached where a lens of fresh water floats on sea water. In cases of hydrostatic equilibrium, the Ghyben-Herzberg principle states that for every foot of fresh water head above sea level there will be 40 ft of fresh water below sea level.

2. Dike-confined waters. Typically, above the rift zone intrusive dikes originating from a magma source below can form ground water dams, and behind these natural dams significant quantities of ground water can be stored.

Because the electrical resistivity of rock formations is highly dependent upon the salinity of ground water, electrical surface geophysical techniques can map the depth to salt water, and the thickness of the fresh water lens can then be estimated using the Ghyben-Herzberg principle. The impetus for using geophysics is that the cost of a geophysical sounding is about one-thousandth the cost of completing a well at elevations above

1,000 ft. Geophysical surveys, combined with other hydrogeologic information, are used to provide optimum locations for well placement and well completion depths. The specific geophysical method employed was time domain electromagnetic (TDEM) soundings. This method was selected because it has proven effective in prior surveys in similar settings in Hawaii.



BLACKHAWK GEOSCIENCES, INC.

SCHEMATIC HYDRO-GEOLOGIC CROSS SECTION

State of Hawaii Division of Water Resources Management

PROJECT NO: 90042

FIGURE 1-1

2.0 LOGISTICS AND DATA ACQUISITION

2.1 GENERAL

The TDEM survey was accomplished by a three man crew consisting of two BGI personnel and one local temporary field helper. The location of the TDEM soundings were determined from consultation with State personnel and were partially based on the results from a prior geophysical survey conducted north of Honokoa Gulch for Kohala Joint Venture (KJV). TDEM measurements were initially made near the Kawaihae Exploratory Well at about the 1,300 ft and 1,600 ft elevation, south of Honokoa Gulch. Several other soundings were also acquired north of Honokoa Gulch on Hawaiian Homelands Property. The TDEM sounding locations for this survey and the March and April 1990 surveys for KJV are shown on Figure 2-1. The report of the KJV survey are contained in Appendix C, and the results are also incorporated in this report.

During the three days of field work a total of 5 soundings were acquired around the well site. A daily log of field activities is given in Table 2-1. Soundings locations were surveyed using a compass and hip chain from known landmarks (i.e., road junctions, rock walls) located on the field map. Elevations of sounding centers were measured with an altimeter in the field and checked with USGS field maps. Transmitter loop sizes of 1,000 ft by 1,000 ft were used on all of the TDEM soundings to detect the salt water interface.

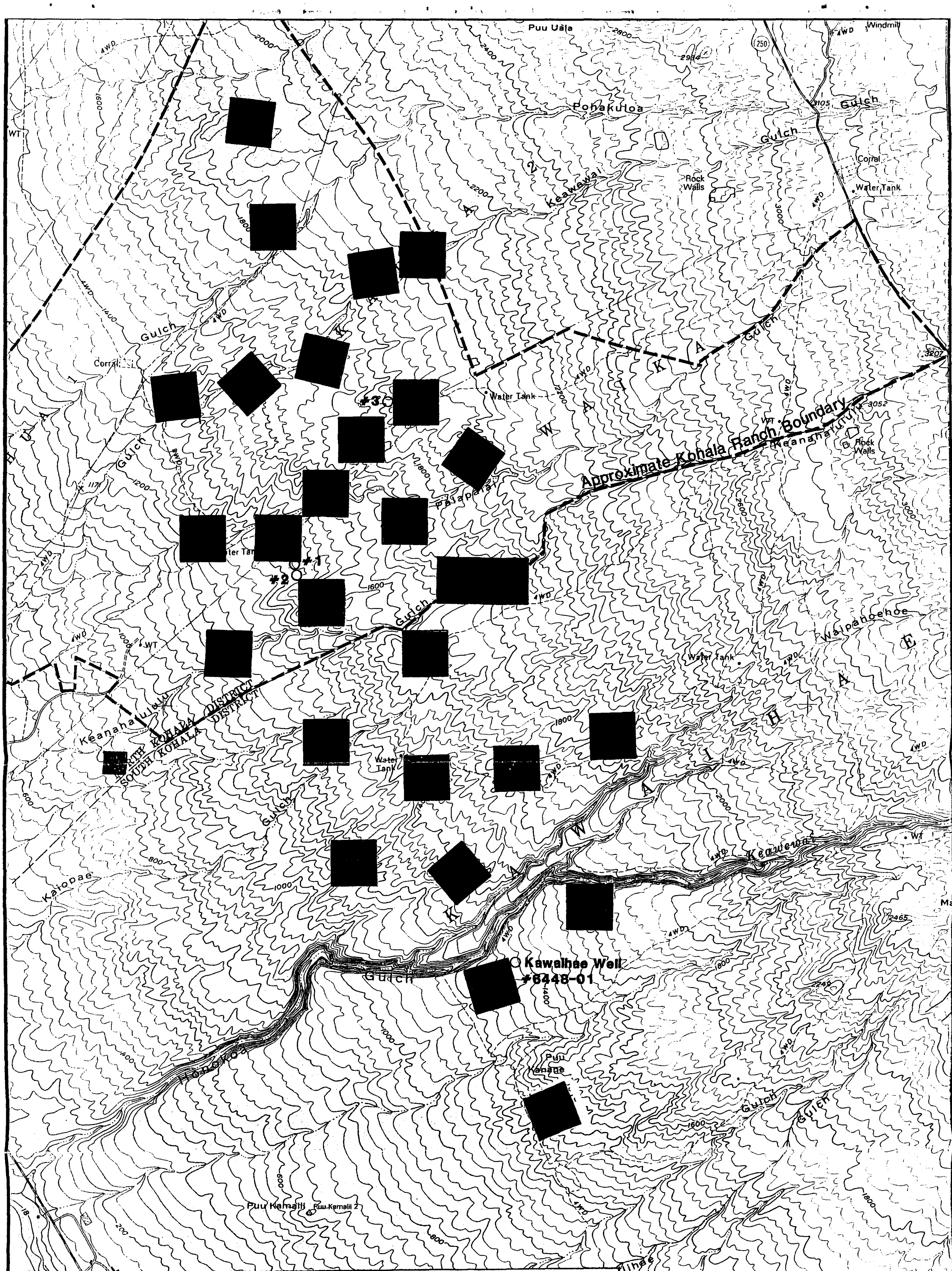
Table 2-1. Daily log of field activities

Date (1990)	Activity
September 6	Mobilization from Denver, CO to Kailua-Kona, HI in conjunction with other geophysical surveys.
September 9	Reconnaissance of Kawaihae Exploratory Well Project Area for sounding sites. Data acquired on soundings 1 and 2.
September 10	Data acquired on sounding 3.
September 15	Reconnaissance for sounding sites on north side of Honokoa Gulch. Data on soundings 4 and 5.
September 19	Demobilize equipment and BGI personnel.

(September 7, 8, 11 through 14, and September 16 through 18 are days of field work at other Hawaii locations)

2.2 PROCEDURES

The Geonics EM-37 TDEM system was utilized on this survey. The system basically consists of a transmitter and a receiver. The transmitter loop is constructed of 10 to 12 gauge insulated copper wire. The wire is laid on the ground surface in a square loop varying in size, depending upon the required depth of investigation (larger loop sizes for deeper measurement). A transmitter and motor generator are connected into the non-grounded loop at one corner. A time-varying current is pulsed through the wire at two different base frequencies. The TDEM receiver measures and records the decay of the vertical magnetic field through a receiver coil placed at the center of the non-grounded transmitter loop. Receiver coils with effective areas of 100 m^2 and 1,000 m^2 were utilized at base frequencies of 3 Hz and 30 Hz. During data acquisition numerous transient decays are collected with the receiver for each sounding. Readings were acquired at several receiver gains with opposite receiver polarities for each sounding location. The readings were stored in a DAS-54 solid state data logger, and were nightly transferred to a personal computer for processing. A technical note is given in Appendix A which describes and illustrates the principles of TDEM.

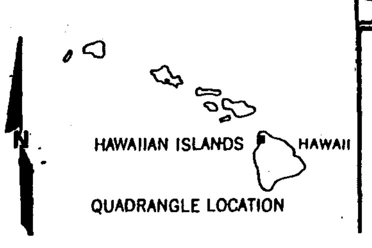


LEGEND

State Sounding Location

Kohala Ranch Location

#01 Well Number and Location



BLACKHAWK GEOSCIENCES, INC.

GEOPHYSICAL SURVEY
LOCATION MAP

State of Hawaii Division of

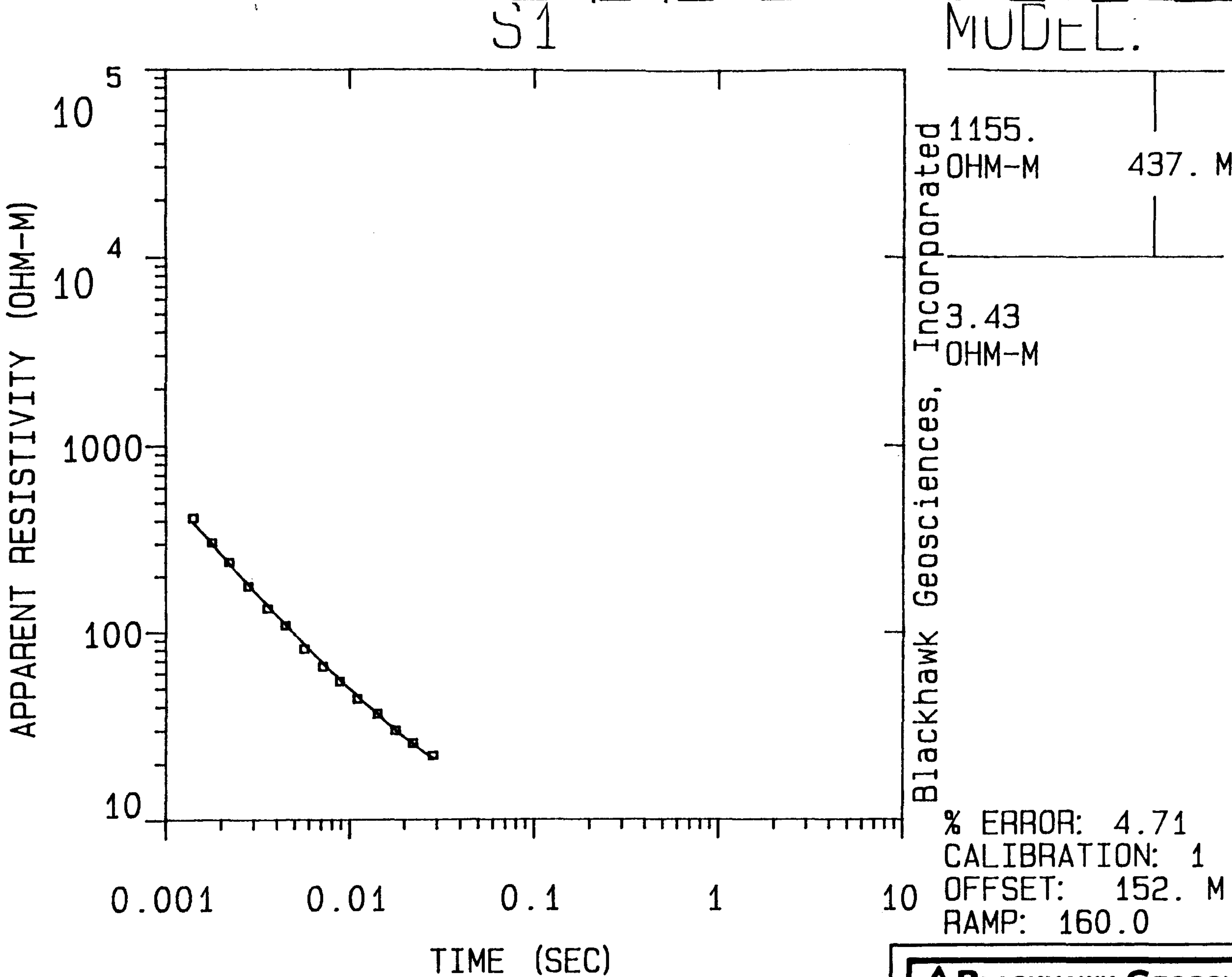
3.0 DATA PROCESSING

The field data acquired each day was transferred from the DAS-54 data logger to a personal computer. The data for each sounding location is edited and combined (both 3 Hz and 30 Hz frequencies) to produce a transient decay curve. This decay curve is transformed into an apparent resistivity curve, which is entered into an Automatic Ridge Regression Transient Inversion Program (ARRTI). From the apparent resistivity curve a one-dimensional model of resistivities and thicknesses is calculated.

The inversion program requires an initial estimate of the geoelectric section, including the number of layers, and the resistivities and thicknesses of each of the layers. The program then adjusts these parameters so that the model curve converges to best fit the curve formed by the field data set. The inversion program does not change the total number of layers within the model, but allows all other parameters to float freely.

An example data set is given in Figures 3-1 and 3-2 for sounding S1. Figure 3-1 shows the measured data points (in terms of apparent resistivity) superimposed on a solid line. The solid line represents the computed behavior of the true resistivity layering shown on the right. Figure 3-2 is the inversion table and it lists in column 4 the error between measured and computed data in each time gate.

The apparent resistivity curves and data sheets for all of the State soundings are contained in Appendix B.



BLACKHAWK GEOSCIENCES, INC.

EXAMPLE DATA SET

State of Hawaii Division of Water Resources Management

PROJECT NO: 90041 **Figure 3-1**

MODEL: 2 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		390.1	1280.0		
1155.34	437.4	-47.3	-155.0	0.4	0.4
3.43					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	1.40E-03	4.13E+02	3.89E+02	6.222	
2	1.77E-03	3.04E+02	2.97E+02	2.472	
3	2.20E-03	2.38E+02	2.32E+02	2.409	
4	2.80E-03	1.76E+02	1.78E+02	-1.003	
5	3.55E-03	1.34E+02	1.38E+02	-2.964	
6	4.43E-03	1.09E+02	1.09E+02	-0.463	
7	5.64E-03	8.09E+01	8.53E+01	-5.152	
8	7.13E-03	6.54E+01	6.77E+01	-3.387	
9	8.81E-03	5.44E+01	5.54E+01	-1.842	
10	1.10E-02	4.42E+01	4.55E+01	-2.809	
11	1.41E-02	3.68E+01	3.65E+01	0.744	
12	1.80E-02	3.01E+01	3.00E+01	0.365	
13	2.22E-02	2.58E+01	2.54E+01	1.838	
14	2.85E-02	2.21E+01	2.12E+01	4.360	

R: 152. X: 0. Y: 152. DL: 305. REQ: 169. CF: 1.0000
CLHZ ARRAY, 14 DATA POINTS, RAMP: 160.0 MICROSEC, DATA: S1
0909 002N 001S Z OPR XTL H 4 8+100
Ch.21 = 0.16 Ch.22 = 0.089 Ch.23 = 15 Ch.24 = 9
RMS LOG ERROR: 2.00E-02, ANTILOG YIELDS 4.7135 %
LATE TIME PARAMETERS

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER

	P 1	P 2	T 1
P 1	0.01		
P 2	-0.04	0.93	
T 1	0.01	0.00	1.00

BLACKHAWK GEOSCIENCES, INC.

EXAMPLE DATA SET

State of Hawaii Division of Water Resources Management

PROJECT NO: 90041 Figure 3-2

4.0 RESULTS AND INTERPRETATION

4.1 CORRELATING GEOELECTRIC SECTIONS WITH HYDROGEOLOGIC INFORMATION

Thus, the results of the interpretations of individual soundings is the resistivity layering (geoelectric section) of the subsurface. The translation of resistivity layering into meaningful hydrogeologic information is generally accomplished in two ways:

(1) Calibrating the geophysical interpretation at a well. The Kawaihae Exploratory Well (#6448-01) was available for comparison, as well as three other wells on the Kohala Ranch property (wells #1, 2 and 3, Fig. 2-1).

The Kawaihae Exploratory Well had a static water level of 1.1 ft above msl. Assuming validity of the Ghyben-Herzberg relation the interface between fresh/brackish water and salt water is expected at about 45 ft below msl. The soundings in the vicinity of the well (soundings S1 through S5 - see Appendix B) show a two-layer resistivity structure - an upper layer with a resistivity greater than 500 ohm-m, and a lower layer with a resistivity less than 3 ohm-m. Comparison of well information with TDEM derived geoelectric sections, therefore, suggest:

(a) resistivities greater than 500 ohm-m are characteristic of (i) unsaturated volcanics above the water table, and (ii) volcanics saturated with fresh/brackish water below the water table and above the interface with salt water; and

(b) resistivities less than 3 ohm-m are characteristic of volcanic rock saturated with salt water.

(2) Using available knowledge about the relation between resistivity values and hydrogeology. In many prior surveys over the volcanic rocks of Hawaii, rocks saturated with salt water also showed resistivities less than 5 ohm-m, and dry and fresh-brackish water saturated volcanic rocks and intrusives displayed very high resistivities (greater than 1,000 ohm-m).

Thus, where a very conductive layer (< 5 ohm-m) is detected below sea level, this layer is expected to represent salt water saturated volcanics. Static water levels (heads) can subsequently be calculated from the geoelectric sections by using the Ghyben-Herzberg principle. This principle states that, under conditions of static equilibrium, for every foot of fresh water above sea level there will be about forty feet of fresh water below sea level. An illustration of the Ghyben-Herzberg principle is given in Figure 4-1. This principle, however, assumes static equilibrium and may not apply in close proximity to ground water damming structures (i.e., dikes, rifts, areas of high hydraulic gradients).

4.2 INTERPRETATION MAP

The results of the 5 State soundings and the 24 Kohala Ranch soundings are summarized on Figure 4-2. The following information is summarized on this figure:

(1) The soundings are classified in two categories:

(i) soundings in which no layer of low resistivity (< 5 ohm-m) was detected within the effective exploration depth of the measurement. In this area ground water is expected to be trapped by ground water damming structures. The interpreted boundary of this area is shown on the map in Figure 4-2. Wells #1, 2 and 3 are located in this area. The head observed at well #3 was 150 ft above msl and is typical of structural controlled ground water; and

(ii) soundings in which a layer of low resistivity (< 5 ohm-m) was detected. This layer is interpreted to represent the interface between fresh/brackish and salt water. Ground water in this area is expected to occur in a basal mode with a lens of fresh water floating on salt water.

(2) For soundings which detected the interface between fresh/brackish water and salt water the elevation in ft of the interface is listed.

(3) The elevation of the salt water interface is contoured.

Several features stand out on the interpretation map:

(1) The contours are approximately perpendicular to the interpreted boundary between basal and structurally controlled water. It suggests a dominant ground water flow direction in a westerly direction near parallel to the boundary of the mapped structure.

(2) The area where ground water is expected to be controlled by structures is wedged shaped and extends from about 1,000 ft elevation near sounding 4 (on the Kohala Ranch property) and widens with increasing elevation toward the northeast.

(3) The gradients of the contours are highest in an area just north of the Honokoa Gulch. The results of the TDEM survey suggest a complex ground water regime near the Honokoa Gulch. This can be further illustrated by constructing a hydrogeologic cross-section perpendicular to the coast consistent with the TDEM derived data. Such a cross section is shown on Figure 4-3. Since no local recharge or discharge is known to occur along the cross section, the flow rate along the cross section must be expected to be basically the same. If this is true a large hydraulic transmissivity contrast must occur where the gradient is steep. A nominal hydraulic gradient and high permeabilities are expected from about the Kawaihae Exploratory Well to the ocean, and high hydraulic gradients with low transmissivities east of the well.

Such large contrasts in transmissivity would be unusual. Possible causes for such a contrast could be:

(1) A trachyte flow several hundred feet thick. Trachytes are volcanic flows of fine grained intrusives and they can be of low permeability.

(2) A series of north-south oriented leaky ground water damming structures. The origin of these structures could be from the same source as the inferred ground water damming structures on the Kohala Ranch.

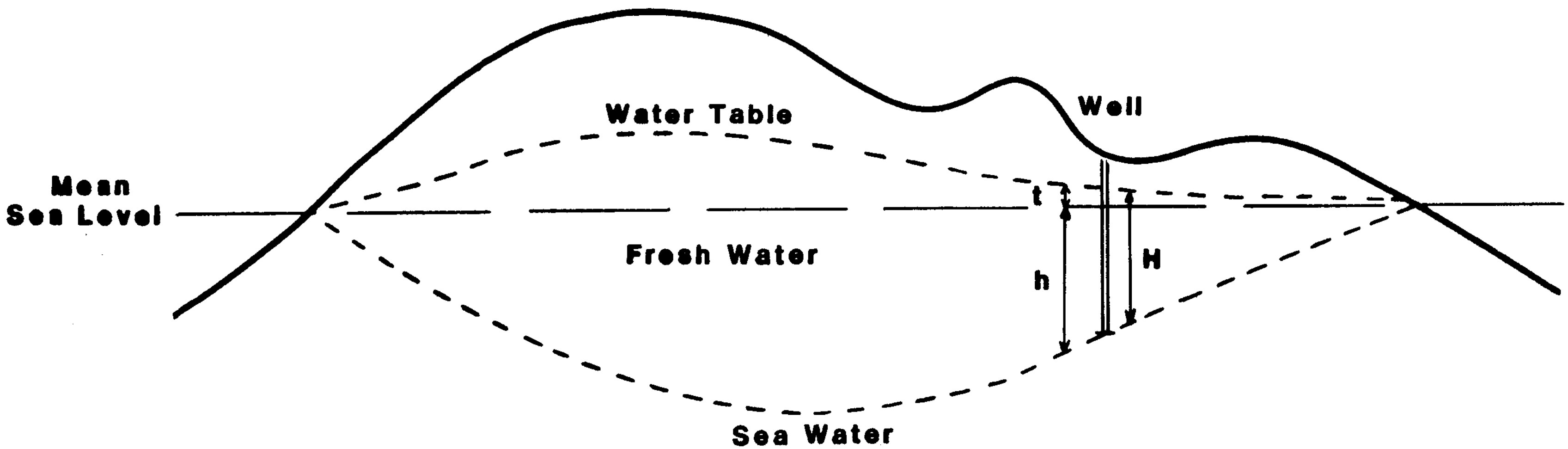
If indeed lower permeabilities are the cause of the change in gradient, than the higher heads observed north of the Kawaihae Exploratory Well may not directly convert to a successful well. Lower permeabilities of the rock could result in low yield.

Table 4-1 lists the approximate thicknesses of the fresh-brackish water lens computed from the elevations of the salt water interface derived from TDEM soundings. The list includes the five State soundings and the six soundings taken south of the interpreted boundary between basal and structure controlled water on the Hawaiian Homelands Property for the KJV.

Table 4-1. Hydrogeologic information derived from TDEM soundings

Sounding #	Surface Elevation (ft)	Approximate Thickness of Fresh/Brackish Water Lens (ft)
S1	1280	155
S2	1350	239
S3	1600	291
S4	1320	236
S5	1200	75
1W	830	98
4W	1665	771
5W	1340	484
6W	1450	778
7W	1680	905
8W	1885	1000?

When the surface elevations are plotted versus the approximate thicknesses of fresh water lenses (Fig. 4-4), it provides further evidence of the existence of two regions with different hydrogeologic characteristics. The head observed in the Kawaihae Exploratory Well is consistent with the results from TDEM soundings S1 through S5.



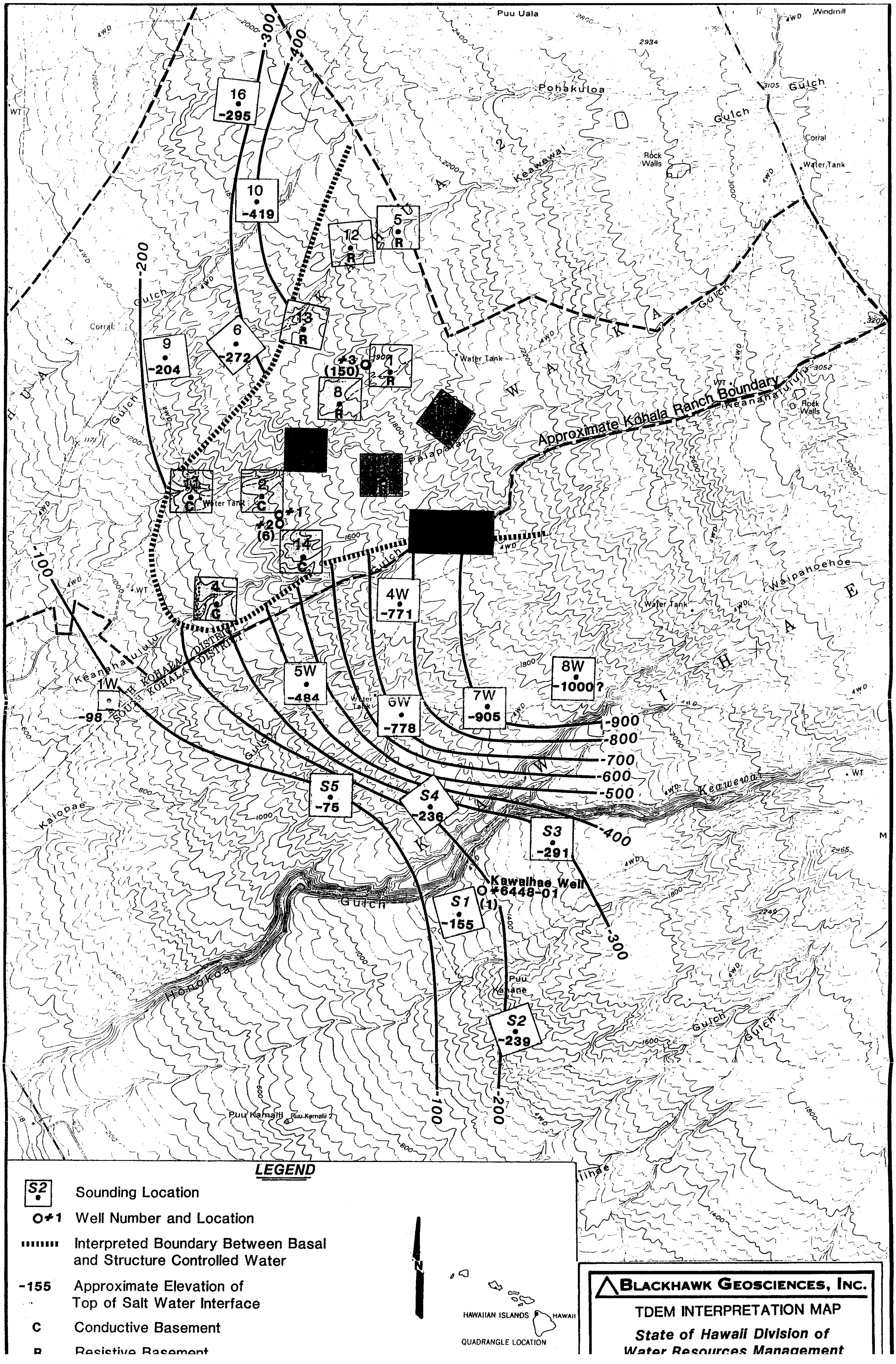
$t = 1/40\ (h)$

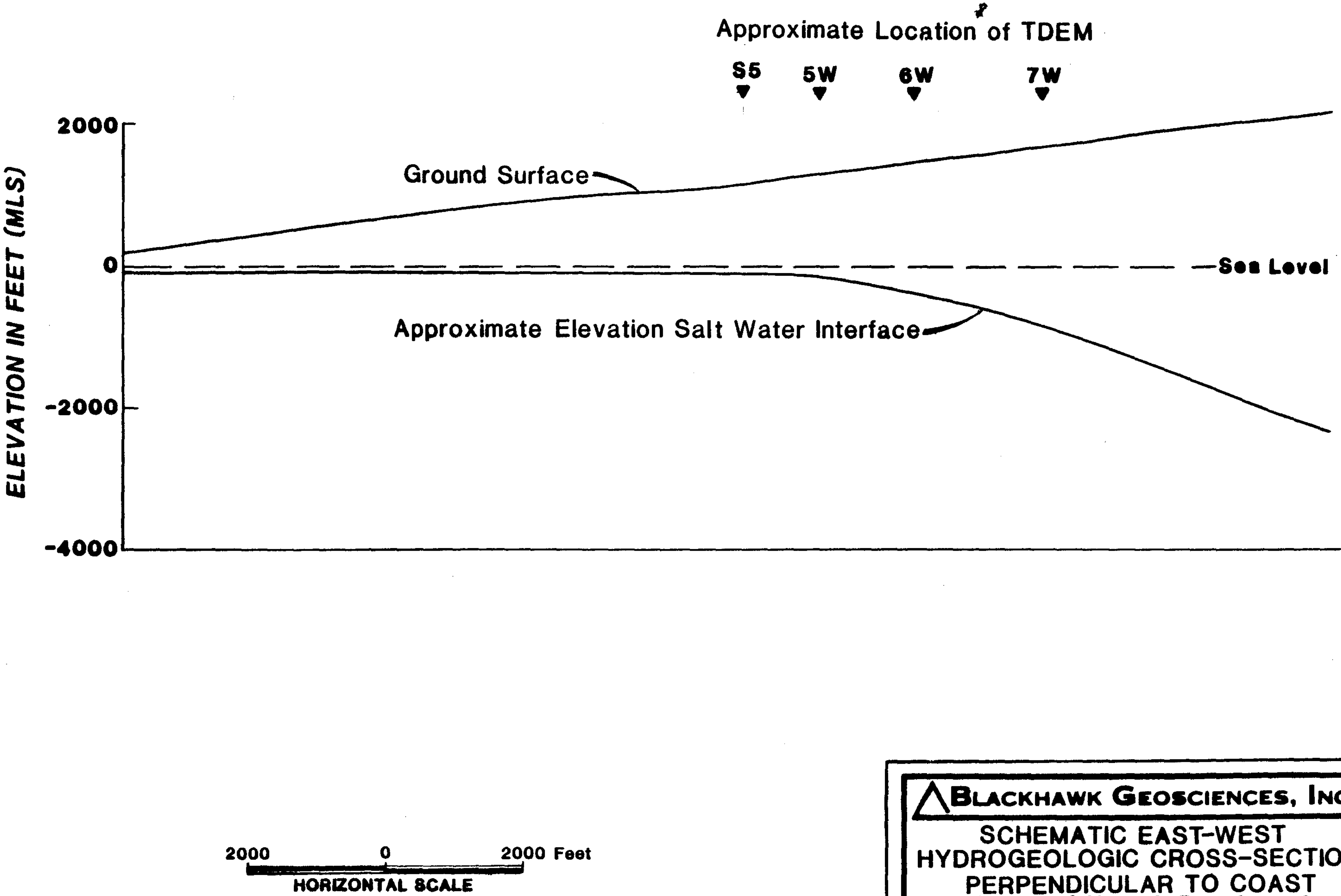
FROM: HERZBERG

BLACKHAWK GEOSCIENCES, INC.

Illustration of the
Ghyben–Herzberg Principle
State of Hawaii Division of
Water Resources Management

PROJECT NO: 90042 Figure 4-1


Puu Uala
Windmill
2934
Pohakuloa
Gulch
Gulch
Corral
Water Tank
Rock Walls
Keawewai
Corral
Water Tank
Approximate Kohala Ranch Boundary
Keanahaluulu
Rock Walls
Palapalai
Waipahoehoe
Water Tank
NORTH KOHALA DISTRICT
SOUTH KOHALA DISTRICT
Keawewai
Kalopae
Kawaihae Well
O#6448-01
(1)
Gulch
Honokoa
Puu Kanane
Gulch
Gulch
Puu Kamalii
16 -295
10 -419
12 R
5 R
13 R
6 -272
9 -204
#3 (150)
1 R
8 R
11 C
2 C
O#1
#2 O
(6)
14 C
4 C
4W -771
5W -484
6W -778
7W -905
8W -1000?
1W -98
S5 -75
S4 -236
S3 -291
S1 -155
S2 -239
-100
-200
-300
-400
-500
-600
-700
-800
-900
LEGEND
S2 Sounding Location
O#1 Well Number and Location
Interpreted Boundary Between Basal and Structure Controlled Water
-155 Approximate Elevation of Top of Salt Water Interface
C Conductive Basement
R Resistive Basement
N
HAWAIIAN ISLANDS
HAWAII
QUADRANGLE LOCATION
BLACKHAWK GEOSCIENCES, INC.
TDEM INTERPRETATION MAP
State of Hawaii Division of Water Resources Management

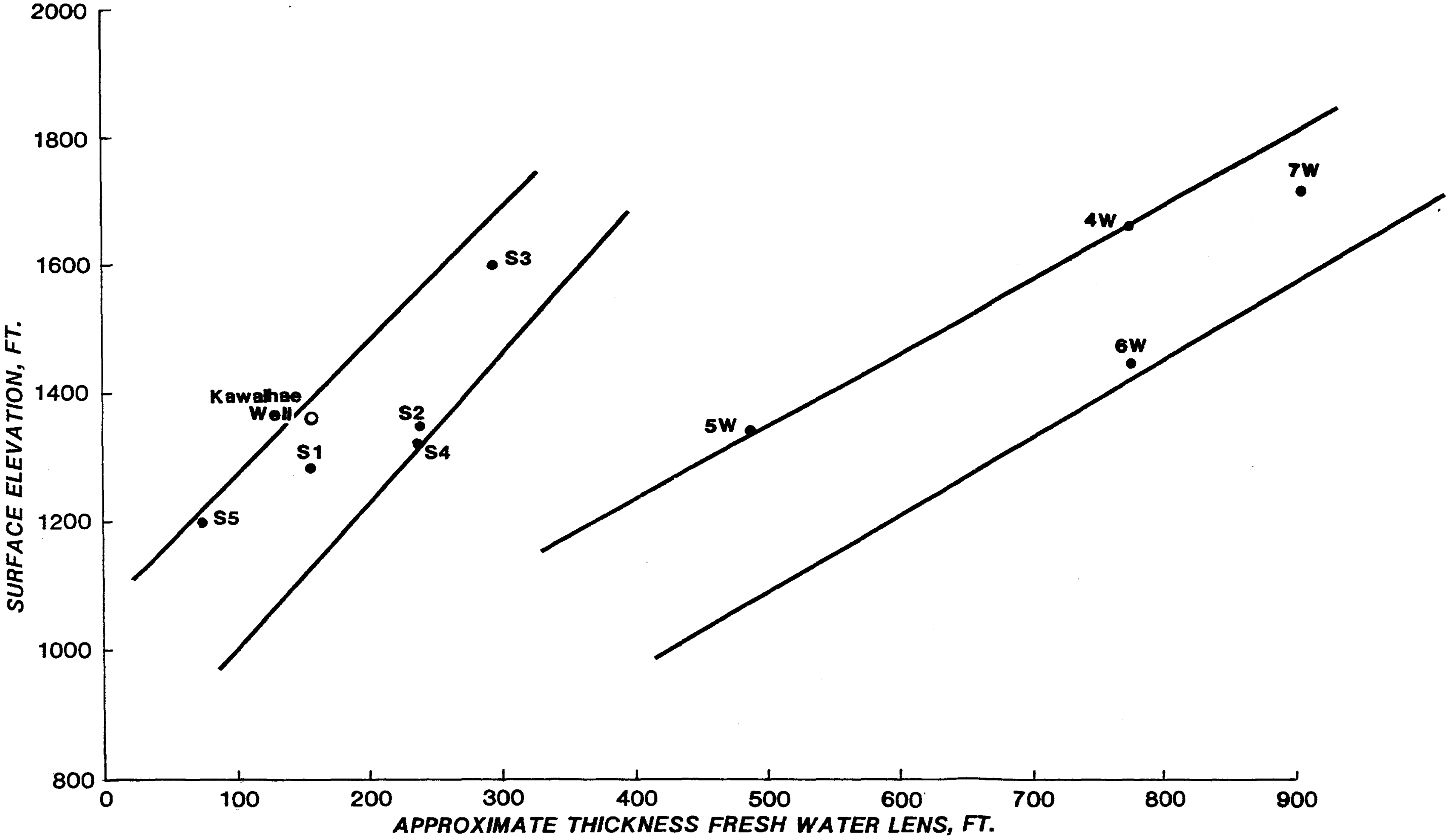


BLACKHAWK GEOSCIENCES, INC.

SCHEMATIC EAST-WEST HYDROGEOLOGIC CROSS-SECTION PERPENDICULAR TO COAST

State of Hawaii Division of Water Resources Management

PROJECT NO: 90041 Figure 4-3



BLACKHAWK GEOSCIENCES,

SURFACE ELEVATION VS
THICKNESS FRESH WATER LEN

State of Hawaii Division of
Water Resources Management

PROJECT NO: 90041 Figu

5.0 CONCLUSIONS AND RECOMMENDATIONS

The main objective of the TDEM survey was to assist in characterizing the hydrologic regime near the recently drilled Kawaihae Exploratory Well. Five soundings were made in an area around the well. The data collected for the State was combined with a data set of 24 soundings in an area mainly north of the Honokoa Gulch. The combined interpretation show several distinct zones of hydrogeologic behavior. These are:

1. Two distinct areas where ground water occurs in the basal mode. One area north of the Honokoa Gulch, and one area around the Kawaihae well.

2. A zone of structural controlled ground water. The contours suggest minor ground water flow from north to south across the boundary between areas of structurally controlled and basal ground water.

It is not possible from the TDEM survey to determine the origin and nature of the subsurface structures causing the apparent complex ground water flow regime. The main information derived from the TDEM survey is

- delineation of boundaries between areas (i) where ground water is trapped by structures, and (ii) where it occurs as a lens of fresh/brackish water floating on sea water (basal mode)

- determining approximate thickness of fresh/brackish water lens where it occurs in the basal mode.

It is likely that in this complex area TDEM surveys can further assist in resolving the ground water regime by stations east and south of the Kawaihae Exploratory Well.

PRINCIPLES OF TIME DOMAIN EM

BLACKHAWK GEOSCIENCES, INC.

Question.-- What is TDEM?

Answer.-- TDEM is a surface geophysical method for determining the lateral and vertical resistivity variation (geoelectric section) in the subsurface.

Question.-- What useful information can be derived from the geoelectric section?

Answer.-- Electrical resistivity can be used as an indicator for mapping several important objectives in the subsurface, such as:

1. Presence of contaminants. Dissolved solids in ground water decrease formation resistivities, so that industrial contaminant plumes and differences in salinity (e.g., salt water intrusion) can often be delineated from geoelectric sections.

2. Soil and rock types. Clays and clay shales, and formations of low hydraulic permeability, have lower resistivities than formations of high hydraulic permeability, such as sands and gravels, sandstones, basalts, and high porosity limestones. The geoelectric section can, therefore, be used to map continuity of clay and clay shale lenses.

3. Fractures and shear zones. Such zones are conduits for ground water flow and contaminant migration, and they are often characterized by zones of low resistivity. The reasons for the lower resistivities of these zones are infilling of the fracture zones by clay gouge, alteration of wall rock, and higher water contents.

Question.-- What advantages does TDEM have over other electrical and electromagnetic methods, such as resistivity (direct current) and electromagnetic conductivity profiling with the Geonics EM-31 and EM-34?

Answer.-- The advantages of TDEM over other electrical and electromagnetic methods are

- better vertical and lateral resolution
- lower sensitivity to geologic noise (see page 5)
- the ability to explore below highly conductive layers (e.g., brine saturated layers and clay lenses).

Some of the most frequently asked questions about TDEM and their answers are given below.

Question.-- Are the principles of TDEM similar to electromagnetic induction profiling, such as used in the Geonics EM-31 and EM-34?

Answer.-- Yes, the principles of electromagnetic induction profiling in the frequency domain (FDEM), used in the Geonics EM-31 and EM-34, are in many ways similar to the principles of TDEM.

An important difference between FDEM and TDEM is the current waveform driven through the transmitter loops. It is a continuous, harmonic-varying current in FDEM, and a half-duty cycle waveform in TDEM.

Question.-- Why does the current waveform of the transmitter make a large difference?

Answer.-- The large difference results from the fact that in FDEM the secondary magnetic field due to ground currents is measured when the transmitter current is on, and in TDEM when the transmitter current is off. In both cases the time-variant current driven through the transmitter causes a time-variant primary magnetic field. Associated with this primary magnetic field is an induced electromotive force (emf) that causes eddy current flow in the subsurface. The intensity of these currents is used to determine subsurface conductivities. The induced emf is a harmonic-varying function in FDEM and consists of narrow pulses in TDEM.

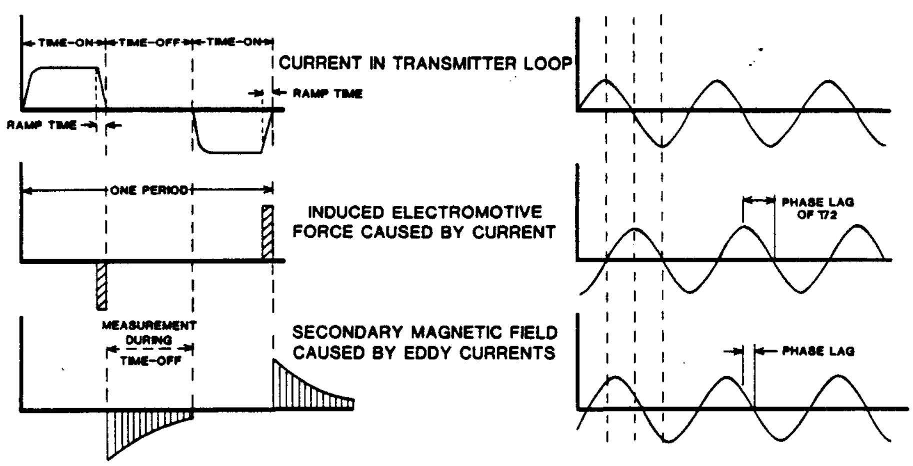


Fig. 1. System waveforms in time domain EM (TDEM) and frequency domain EM (FDEM).

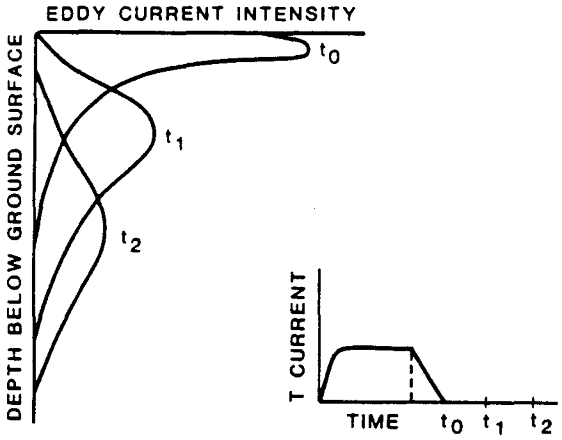


Fig. 4. Schematic illustration of eddy current distribution at different times after turn-off.

Another useful presentation of distribution of current intensity as a function of time is given in Figure 4. At early time, t_0, all currents are concentrated near the surface. At later times (e.g., t_3) the current maxima occur at increasingly greater depth. Thus, from measurements of the decay of emf at one location, the geoelectric section to a substantial depth is obtained.

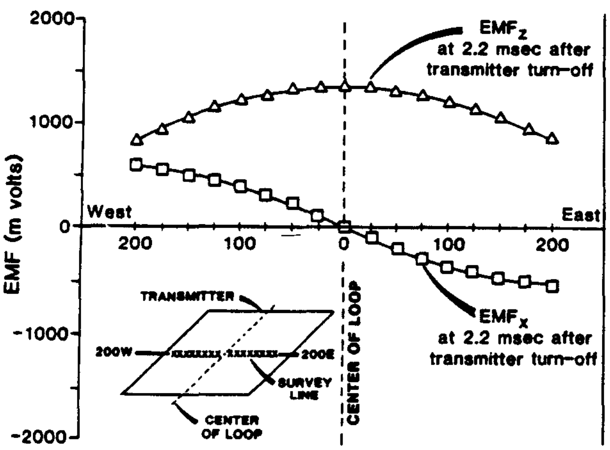


Fig. 5. Spatial behavior of emfs due to vertical (emf_z) and horizontal (emf_x) magnetic field on a profile through the center of square transmitter loop at one time (2.2 millisec) after turn-off.

The emfs caused by square transmitter loops vary with time and distance from the center. Figure 5 shows a typical measured behavior of emfs at a certain time (2.2 milliseconds) after turn-off. At other times the amplitudes will be different, but the spatial behavior is similar. The spatial behavior of the emf_z is relatively flat about the center so that measurements of emf, due to the vertical magnetic field, are relatively insensitive to errors in surveying the center of the loop, or to deviations from a square loop. This is clearly of practical value because it (1. reduces the cost of land surveys and measurement errors, and (2) allows for some flexibility in the field in positioning the measurement stations.

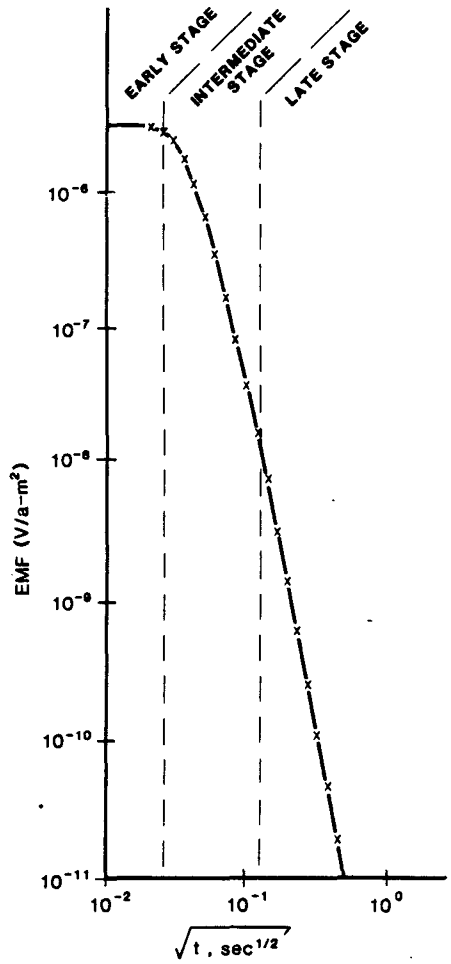


Fig. 6. Typical transient behavior of emf_z in center of square transmitter loop.

Thus, in TDEM soundings, the geoelectric section is derived from measurement of the emf due to the vertical magnetic field (emf_z) as a function of time during the period the transmitter is off. Figure 6 shows a typical behavior of emf_z as a function of time. Emf_z can be seen to decay rapidly with increasing time. One transient decay recorded over a few tens of milliseconds contains information about resistivity layering over a significant depth range.

The emfs, due to the decay of the ground eddy currents, must be measured in the presence of ambient noise sources, such as geomagnetic storms, lightning, 60 hertz powerlines, and other man-made sources. It is common to stack several hundred transient decays to improve signal to noise. Stacking of several hundred transient decays requires only a few seconds, and multiple data sets can be quickly obtained.

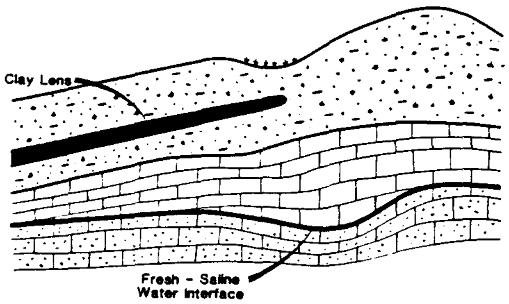


Fig. 9. Schematic geologic section of Floridan aquifer.

Question.-- How does TDEM reduce geologic noise?

Answer.-- This fact can be conceptually explained from Figure 10 where the intensity of eddy current distribution is schematically illustrated as a function of time for the FDEM and TDEM method. At early time (t_0) in TDEM all currents are concentrated near the surface, and near surface formations will largely determine the emf measured. At later time, for example, t_3, currents have largely decayed in near surface layers, and currents dominantly flow at greater depth. The emf measured at time t_3 is near transparent to near surface layers, so that their influence is greatly reduced at time t_3 and later times.

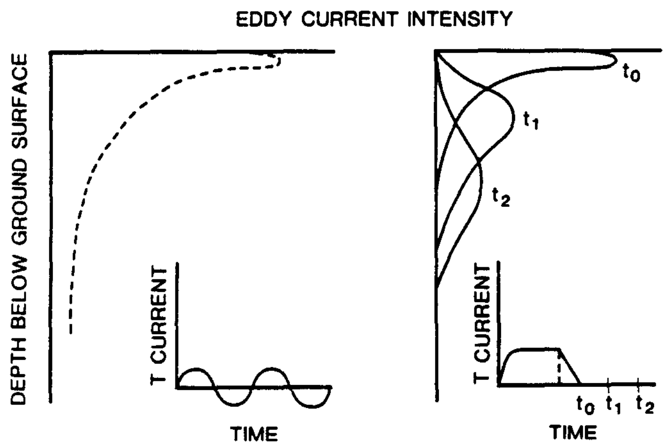


Fig. 10. Eddy current intensity in FDEM and TDEM.

In the FDEM method current intensity is always highest near the surface amplifying the influence of near surface layers.

In summary, geologic noise due to lateral and vertical resistivity variation in TDEM is reduced because:

(a) Exploration depth is mainly a function of time rather than transmitter-receiver separation. The transmitter-receiver separation need not be altered to change exploration depth as is the case in FDEM (EM-31 and EM-34), and direct current resistivity methods.

(b) Relatively small transmitter-receiver separations compared to effective exploration depth are employed.

(c) Measurements at later times are nearly transparent to near surface layers, because eddy currents at later times dominantly flow at greater depth.

Question.-- Can TDEM surveys be effective in mapping fractures and shear zones?

Answer.-- Yes, TDEM can detect contacts, fractures, and shear zones below considerable overburden thickness. The physical concepts of fracture and shear zone mapping are briefly explained.

Electrical and electromagnetic methods are often effective in mapping fractures and shear zones, because fractures and shear zones often are zones of low resistivity in more resistive host rocks. These lower resistivities are generally caused by clay gouge, higher water contents, and alteration in wall rocks. The mapping of fractures and shear zones becomes increasingly more difficult with increasing overburden thickness where outcrops are limited. It is in these situations that geophysical surveys can play an important role.

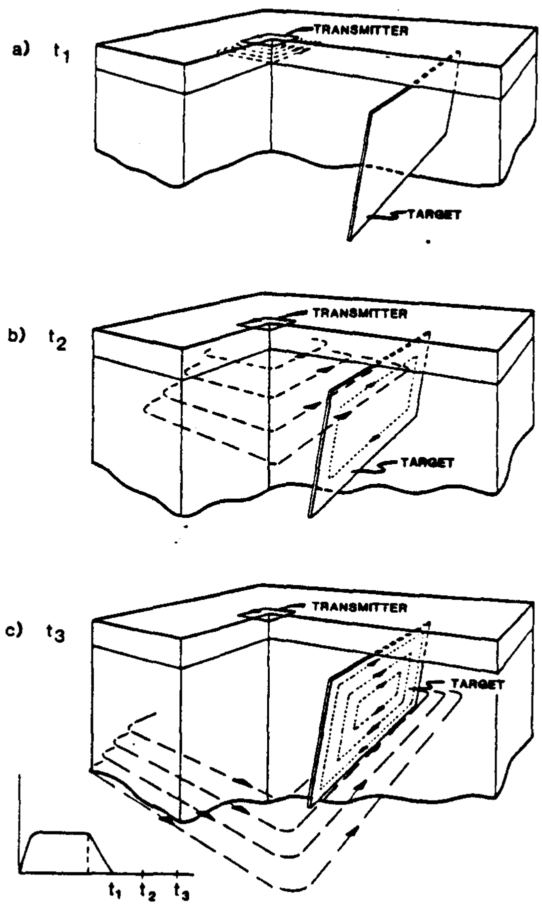


Fig. 11. Illustration of eddy current flow induced in overburden, host rock, and fracture or shear zones at different times.

Measurements at the same location were made with TDEM in 200 m by 200 m transmitter loops, and the results of central-loop TDEM soundings are shown in Figure 14. Again, the measured apparent resistivity curves are superimposed on three forward model curves, and the geoelectric sections of the three model curves are shown on the right. Depth to bedrock in the models is varied by 20 m. It is evident that vertical resolution of determining depth to bedrock is now ± 10 m.

Thus, not only was the physical effort required to sound to a depth of 168 m greatly reduced - only 800 m (4 x 200 m) of wire needed to be laid out, - but the vertical resolution was greatly improved.

Question.-- Summarize for me the potential of TDEM in environmental and ground water geophysics.

Answer.--Electrical surface geophysical methods are an important tool because (1) electrical resistivity is the only readily measureable physical property highly dependent of concentration of dissolved solids (water quality), and (2) electrical resistivity often closely relates to clay content and hydraulic permeability. In the past the vertical and lateral resolution of electrical methods was poor. TDEM techniques are changing that reputation.

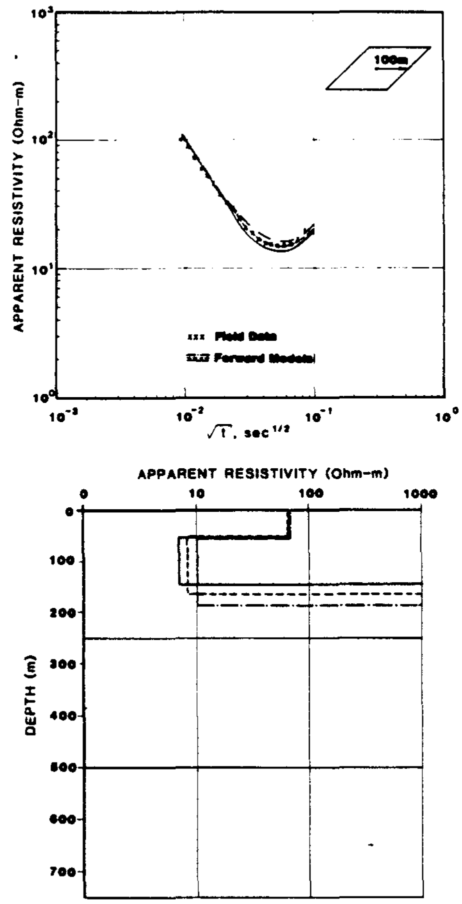
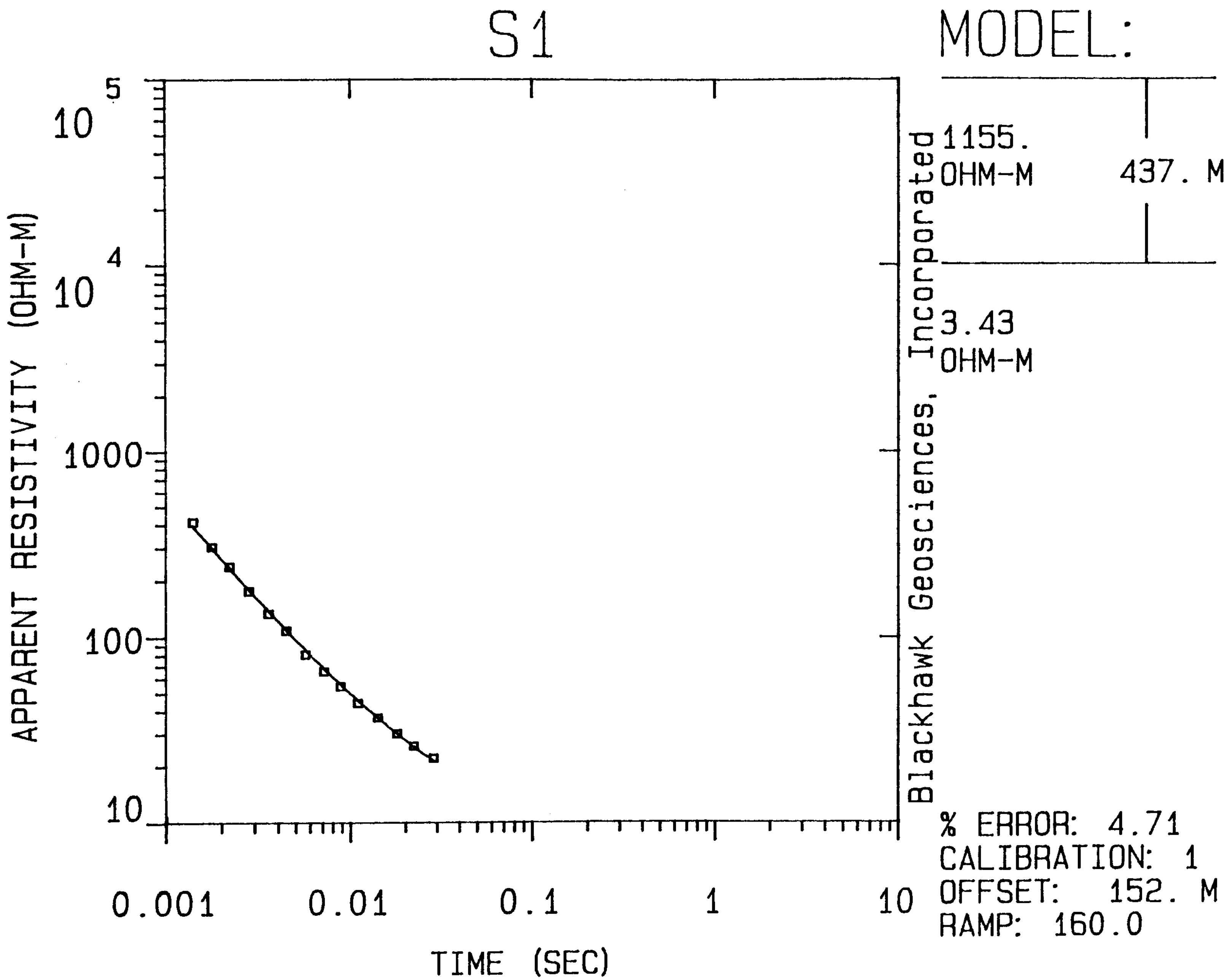


Fig. 14. TDEM measured apparent resistivities (a) superimposed on three one-dimensional geoelectric sections.


S1
MODEL:
APPARENT RESISTIVITY (OHM-M)
10^5
10^4
1000
100
10
0.001
0.01
0.1
1
10
TIME (SEC)
Blackhawk Geosciences, Incorporated
1155. OHM-M
437. M
3.43 OHM-M
% ERROR: 4.71
CALIBRATION: 1
OFFSET: 152. M
RAMP: 160.0

MODEL: 2 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		390.1	1280.0		
1155.34	437.4	-47.3	-155.0	0.4	0.4
3.43					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	1.40E-03	4.13E+02	3.89E+02	6.222	
2	1.77E-03	3.04E+02	2.97E+02	2.472	
3	2.20E-03	2.38E+02	2.32E+02	2.409	
4	2.80E-03	1.76E+02	1.78E+02	-1.003	
5	3.55E-03	1.34E+02	1.38E+02	-2.964	
6	4.43E-03	1.09E+02	1.09E+02	-0.463	
7	5.64E-03	8.09E+01	8.53E+01	-5.152	
8	7.13E-03	6.54E+01	6.77E+01	-3.387	
9	8.81E-03	5.44E+01	5.54E+01	-1.842	
10	1.10E-02	4.42E+01	4.55E+01	-2.809	
11	1.41E-02	3.68E+01	3.65E+01	0.744	
12	1.80E-02	3.01E+01	3.00E+01	0.365	
13	2.22E-02	2.58E+01	2.54E+01	1.838	
14	2.85E-02	2.21E+01	2.12E+01	4.360	

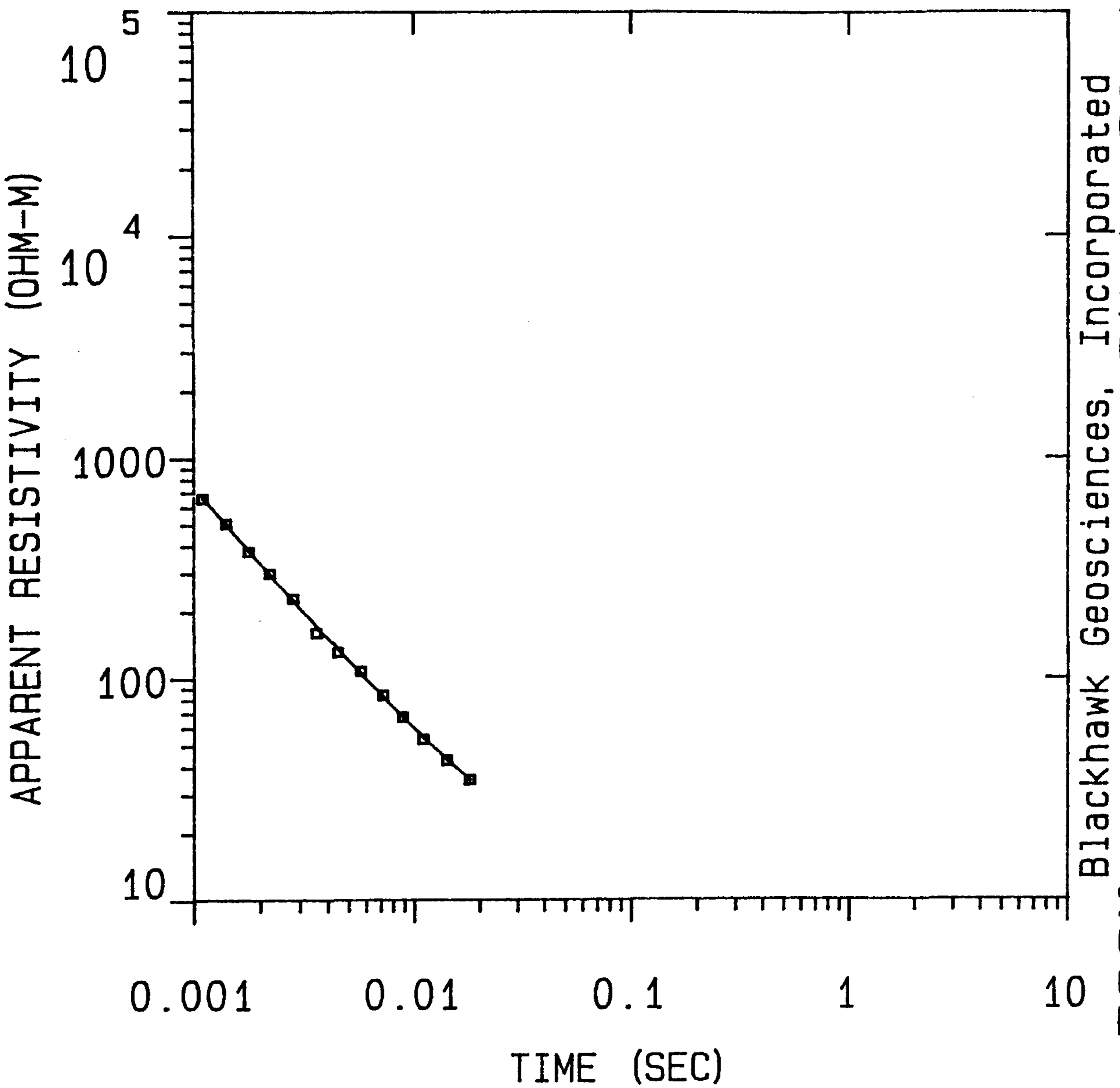
R: 152. X: 0. Y: 152. DL: 305. REQ: 169. CF: 1.0000
CLHZ ARRAY, 14 DATA POINTS, RAMP: 160.0 MICROSEC, DATA: S1
0909 002N 001S Z OPR XTL H 4 8+100
Ch.21 = 0.16 Ch.22 = 0.089 Ch.23 = 15 Ch.24 = 9
RMS LOG ERROR: 2.00E-02, ANTILOG YIELDS 4.7135 %
LATE TIME PARAMETERS

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER

P 1	0.01		
P 2	-0.04	0.93	
T 1	0.01	0.00	1.00
	P 1	P 2	T 1

S2



MODEL:

2001.
OHM-M
484. M

3.23
OHM-M

% ERROR: 3.85
CALIBRATION: 1
OFFSET: 152. M
RAMP: 140.0

MODEL: 2 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		411.5	1350.0		
2001.20	484.3	-72.8	-238.9	0.2	0.2
3.23					

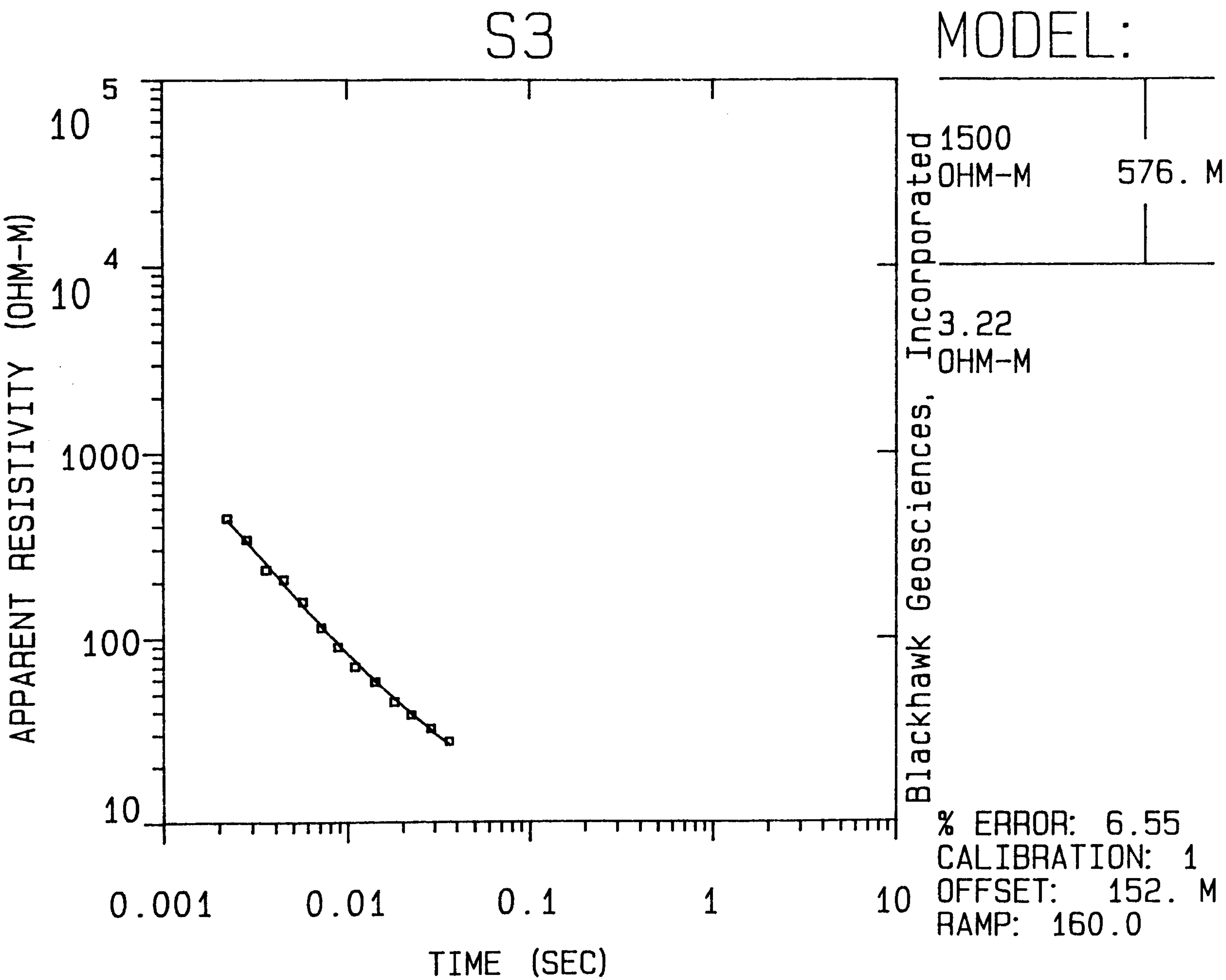
	TIMES	DATA	CALC	% ERROR	STD ERR
1	1.10E-03	6.58E+02	6.65E+02	-1.107	
2	1.40E-03	5.06E+02	4.98E+02	1.581	
3	1.77E-03	3.78E+02	3.78E+02	-0.148	
4	2.20E-03	2.99E+02	2.94E+02	1.654	
5	2.80E-03	2.30E+02	2.24E+02	3.057	
6	3.55E-03	1.61E+02	1.72E+02	-6.366	
7	4.43E-03	1.31E+02	1.35E+02	-2.689	
8	5.64E-03	1.08E+02	1.05E+02	3.004	
9	7.13E-03	8.40E+01	8.24E+01	1.847	
10	8.81E-03	6.72E+01	6.69E+01	0.450	
11	1.10E-02	5.33E+01	5.43E+01	-1.895	
12	1.41E-02	4.31E+01	4.31E+01	-0.152	
13	1.80E-02	3.52E+01	3.50E+01	0.511	

R: 152. X: 0. Y: 152. DL: 305. REQ: 169. CF: 1.0000
CLHZ ARRAY, 13 DATA POINTS, RAMP: 140.0 MICROSEC, DATA: S2
0909 002N 002S Z OPR XTL L 6 10+1000
Ch.21 = 0.14 Ch.22 = 0.89 Ch.23 = 14 Ch.24 = 92
RMS LOG ERROR: 1.64E-02, ANTILOG YIELDS 3.8493 %
LATE TIME PARAMETERS

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER

P 1	0.23		
P 2	-0.04	0.99	
T 1	0.00	0.00	1.00
	P 1	P 2	T 1


S3
MODEL:
1500
OHM-M
576. M
3.22
OHM-M
Blackhawk Geosciences, Incorporated
APPARENT RESISTIVITY (OHM-M)
10^5
10^4
1000
100
10
0.001
0.01
0.1
1
10
TIME (SEC)
% ERROR: 6.55
CALIBRATION: 1
OFFSET: 152. M
RAMP: 160.0

MODEL: 2 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		487.7	1600.0		
1500.00	576.3	-88.7	-290.9	0.4	0.4
3.22					

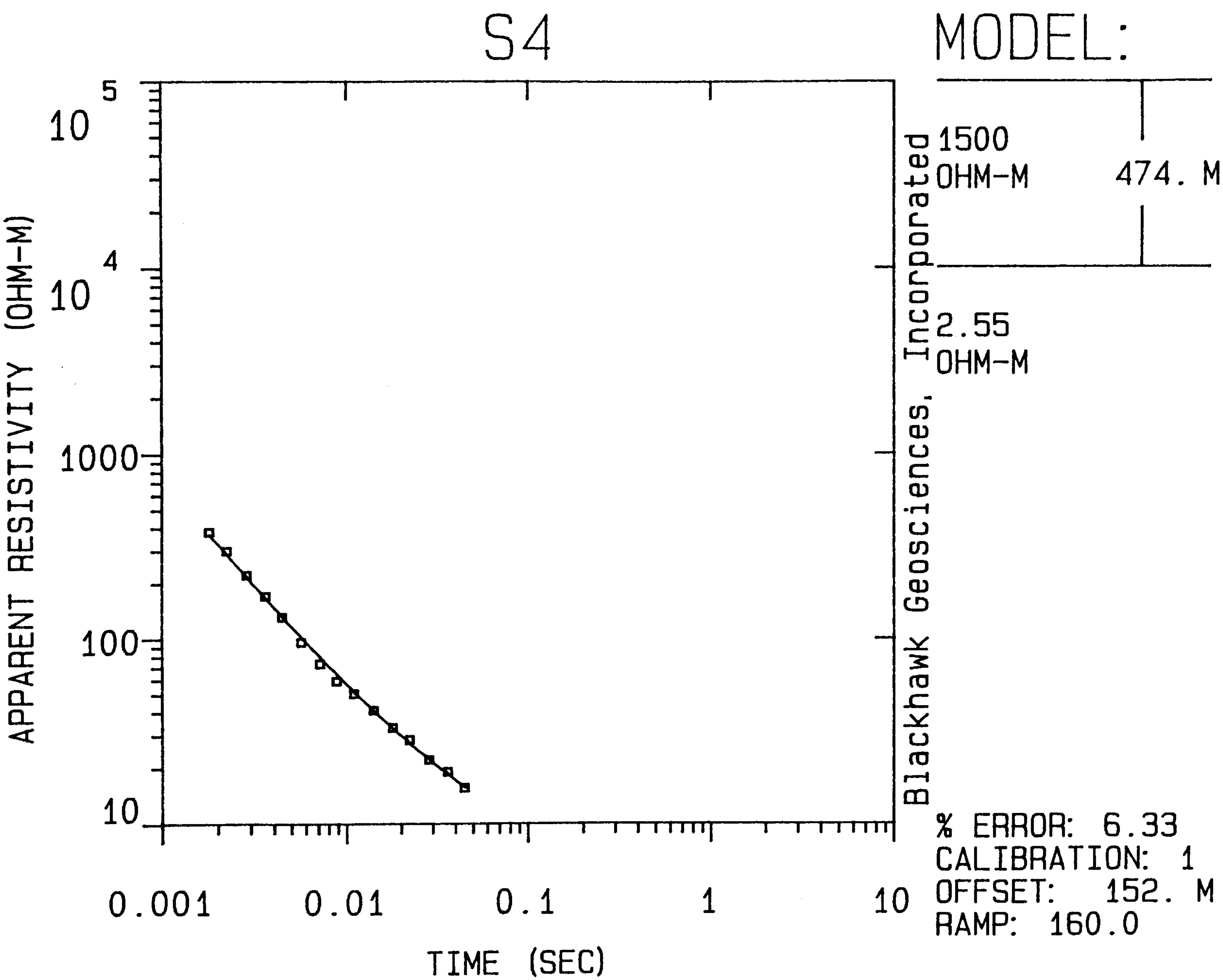
	TIMES	DATA	CALC	% ERROR	STD ERR
1	2.20E-03	4.42E+02	4.31E+02	2.549	
2	2.80E-03	3.37E+02	3.26E+02	3.432	
3	3.55E-03	2.32E+02	2.49E+02	-6.734	
4	4.43E-03	2.06E+02	1.94E+02	6.216	
5	5.64E-03	1.57E+02	1.49E+02	5.211	
6	7.13E-03	1.14E+02	1.16E+02	-1.648	
7	8.81E-03	9.00E+01	9.35E+01	-3.746	
8	1.10E-02	7.05E+01	7.51E+01	-6.105	
9	1.41E-02	5.84E+01	5.88E+01	-0.732	
10	1.80E-02	4.53E+01	4.71E+01	-3.685	
11	2.22E-02	3.85E+01	3.89E+01	-1.144	
12	2.85E-02	3.24E+01	3.16E+01	2.638	
13	3.60E-02	2.75E+01	2.62E+01	5.035	

R: 152. X: 0. Y: 152. DL: 305. REQ: 169. CF: 1.0000
TDHZ ARRAY, 13 DATA POINTS, RAMP: 160.0 MICROSEC, DATA: S3
1009 002N 003S Z OPR XTL L 6 10+1000
Ch.21 = 0.16 Ch.22 = 0.89 Ch.23 = 15 Ch.24 = 92
RMS LOG ERROR: 2.75E-02, ANTILOG YIELDS 6.5473 %
LATE TIME PARAMETERS

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER

F 1	0.00		
P 2	0.00	1.00	
T 1	0.00	0.00	1.00
	F 1	P 2	T 1


S4
MODEL:
APPARENT RESISTIVITY (OHM-M)
10^5
10^4
1000
100
10
0.001
0.01
0.1
1
10
TIME (SEC)
Blackhawk Geosciences, Incorporated
1500
OHM-M
474. M
2.55
OHM-M
% ERROR: 6.33
CALIBRATION: 1
OFFSET: 152. M
RAMP: 160.0

MODEL: 2 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		402.3	1320.0		
1500.00	474.2	-71.9	-235.8	0.3	0.3
2.55					

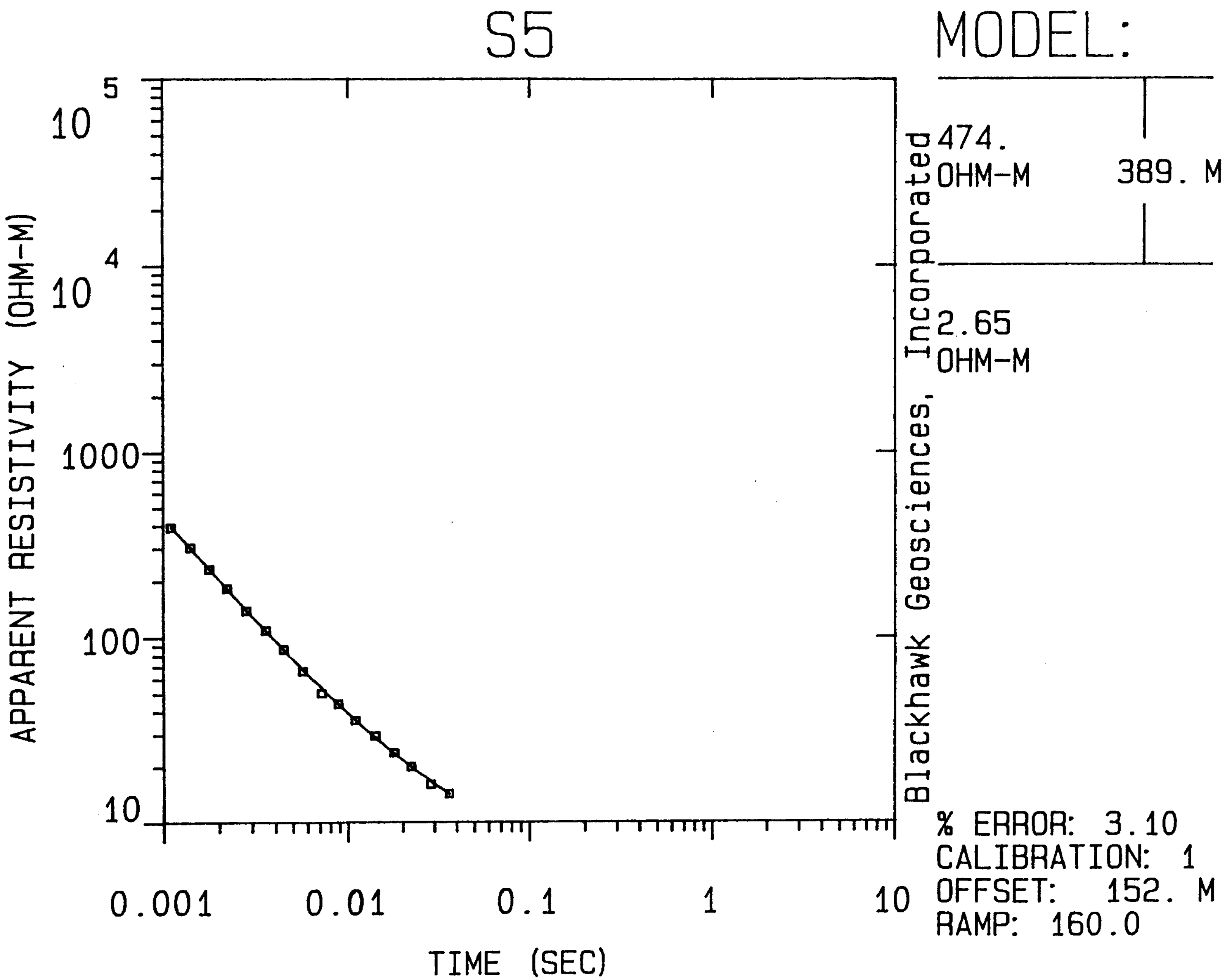
	TIMES	DATA	CALC	% ERROR	STD ERR
1	1.80E-03	3.81E+02	3.69E+02	3.446	
2	2.22E-03	3.01E+02	2.87E+02	4.878	
3	2.85E-03	2.22E+02	2.16E+02	3.099	
4	3.60E-03	1.71E+02	1.66E+02	3.250	
5	4.43E-03	1.31E+02	1.32E+02	-0.107	
6	5.64E-03	9.58E+01	1.01E+02	-5.604	
7	7.13E-03	7.32E+01	7.94E+01	-7.711	
8	8.81E-03	5.91E+01	6.40E+01	-7.597	
9	1.10E-02	5.05E+01	5.16E+01	-2.205	
10	1.41E-02	4.11E+01	4.06E+01	1.139	
11	1.80E-02	3.30E+01	3.27E+01	1.036	
12	2.22E-02	2.84E+01	2.72E+01	4.652	
13	2.85E-02	2.23E+01	2.22E+01	0.414	
14	3.60E-02	1.91E+01	1.85E+01	3.080	
15	4.49E-02	1.57E+01	1.58E+01	-0.486	

R: 152. X: 0. Y: 152. DL: 305. REQ: 169. CF: 1.0000
CLHZ ARRAY, 15 DATA POINTS, RAMP: 160.0 MICROSEC, DATA: S4
1509 002N 004S Z OPR XTL H 3 8+100
Ch.21 = 0.16 Ch.22 = 0.089 Ch.23 = 14 Ch.24 = 9
RMS LOG ERROR: 2.67E-02, ANTILOG YIELDS 6.3333 %
LATE TIME PARAMETERS

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER

F 1	0.00		
P 2	0.00	1.00	
T 1	0.00	0.00	1.00
	F 1	P 2	T 1


S5
MODEL:
474.
OHM-M
389. M
2.65
OHM-M
APPARENT RESISTIVITY (OHM-M)
TIME (SEC)
0.001
0.01
0.1
1
10
10
100
1000
Blackhawk Geosciences, Incorporated
% ERROR: 3.10
CALIBRATION: 1
OFFSET: 152. M
RAMP: 160.0

MODEL: 2 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		365.8	1200.0		
474.49	388.5	-22.8	-74.7	0.8	0.8
2.65					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	1.10E-03	3.91E+02	3.96E+02	-1.242	
2	1.40E-03	3.04E+02	3.01E+02	0.984	
3	1.77E-03	2.33E+02	2.31E+02	0.662	
4	2.20E-03	1.83E+02	1.81E+02	1.006	
5	2.80E-03	1.39E+02	1.39E+02	-0.107	
6	3.55E-03	1.10E+02	1.08E+02	1.472	
7	4.43E-03	8.65E+01	8.57E+01	0.900	
8	5.64E-03	6.61E+01	6.71E+01	-1.527	
9	7.13E-03	5.03E+01	5.33E+01	-5.602	
10	8.81E-03	4.41E+01	4.36E+01	1.081	
11	1.10E-02	3.58E+01	3.58E+01	0.197	
12	1.41E-02	2.95E+01	2.87E+01	2.789	
13	1.80E-02	2.39E+01	2.35E+01	1.423	
14	2.22E-02	2.01E+01	1.99E+01	0.897	
15	2.85E-02	1.61E+01	1.66E+01	-3.248	
16	3.60E-02	1.43E+01	1.41E+01	1.099	

R: 152. X: 0. Y: 152. DL: 305. REQ: 169. CF: 1.0000
CLHZ ARRAY, 16 DATA POINTS, RAMP: 160.0 MICROSEC, DATA: S5
1509 002N 005S Z OPR XTL H 3 8+100
Ch.21 = 0.16 Ch.22 = 0.089 Ch.23 = 14 Ch.24 = 9
RMS LOG ERROR: 1.32E-02, ANTILOG YIELDS 3.0974 %
LATE TIME PARAMETERS

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER

P 1	0.79		
P 2	-0.02	1.00	
T 1	0.00	0.00	1.00
	P 1	P 2	T 1

GEOPHYSICAL SURVEY
GROUND WATER EVALUATION
KOHALA RANCH
ISLAND OF HAWAII

GEOPHYSICAL SURVEY
GROUND WATER EVALUATION
KOHALA RANCH, ISLAND OF HAWAII

Prepared For:

Kohala Joint Venture
737 Bishop Street, Suite 2775
Honolulu, HI 96813

Prepared By:

Blackhawk Geosciences, Inc.
17301 West Colfax Avenue, Suite 170
Golden, CO 80401

May 18, 1990

(Our Project #90016)

Table of Contents

EXECUTIVE SUMMARY

A surface geophysical survey was conducted at the Kohala Ranch Development between March 26 and April 25, 1990 for the purpose of assisting in mapping ground water resources.

Ground water resources in geologic settings, such as that found on the Kohala Ranch Development, are of two types:

(1) Basal fresh water where a lens of fresh water floats on sea water, and the elevation of the interface can be described by the Ghyben-Herzberg equation. This equation states that for every foot of fresh water head above mean sea level, 40 ft of fresh water is expected below sea level.

(2) Dike-confined water where geological structures such as intrusive rock bodies and dikes control the ground water regime. Fresh water heads in these areas are controlled by many factors, and can be highly variable.

At the Kohala Ranch both types of water resources occur and the geophysical surveys outlined boundaries between these types of hydrological provinces. In areas of basal fresh water occurrences the thickness of lenses of fresh water were computed. In areas of dike-confined water, areas of similarity in geophysical responses and expected hydrology were outlined.

1.0 INTRODUCTION

This report contains the results of a geophysical survey for ground water resource evaluation at the Kohala Ranch Development (KRD) on the Island of Hawaii. The work was performed by Blackhawk Geosciences, Inc. (BGI) for Kohala Joint Venture during March 26 to April 26, 1990.

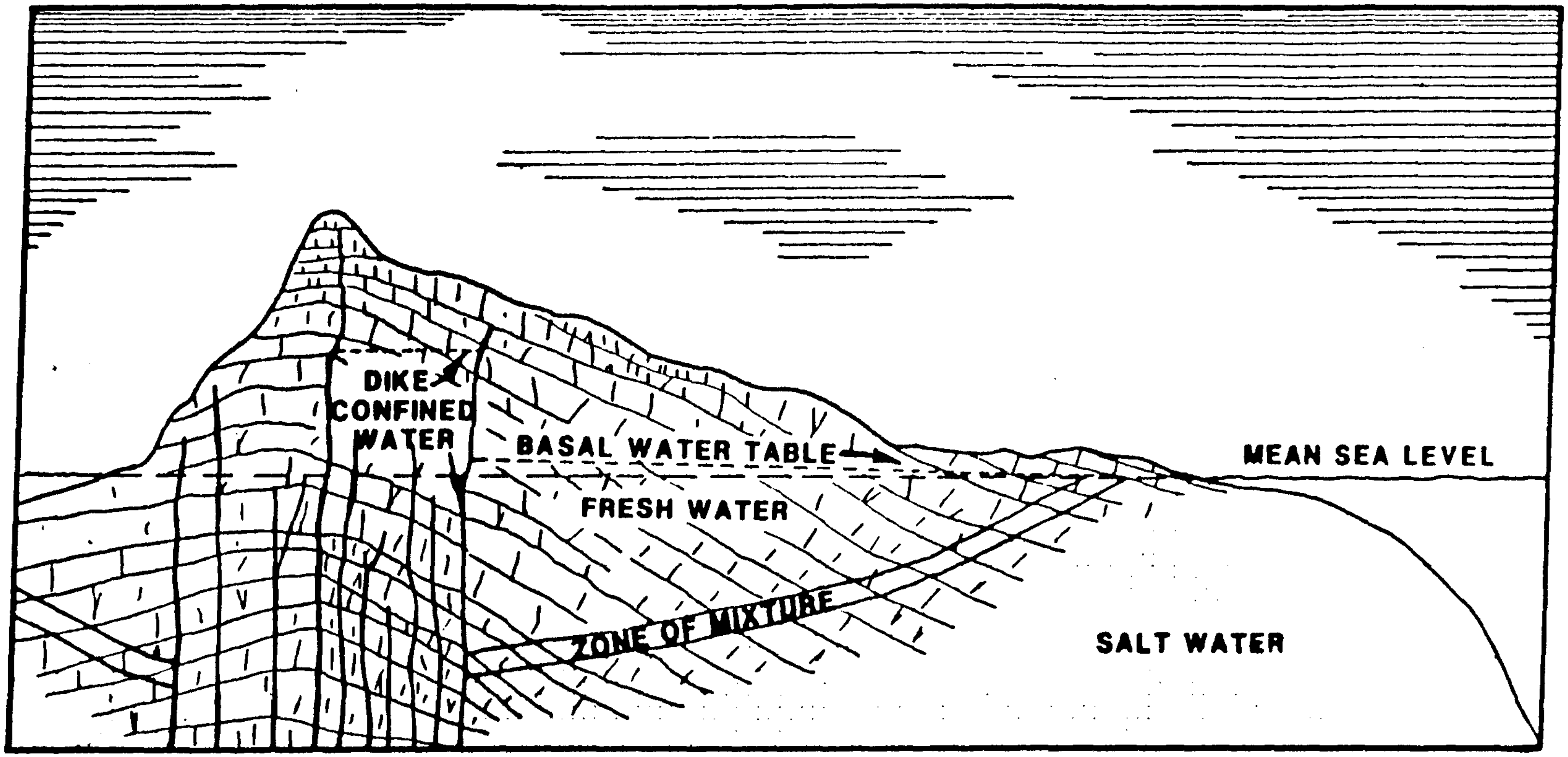
The general objective of the geophysical survey at KRD was to assist in characterizing the hydrologic regime in the study area. Recent drilling results revealed abnormally high static water levels in a well on the property, and the geophysical survey was performed to attempt to map the extent and cause of this anomaly. The generalized objectives for geophysical surveys for ground water evaluations on volcanic islands are illustrated in Figure 1-1. The volcanic rocks are generally highly permeable and this allows rainwater to percolate with little impedance directly downward through the island mass. The fresh water in these island settings is generally found in two environments:

1. Dike-confined waters. Typically, above the rift zone, intrusive dikes originating from a magma source below can form ground water dams, and behind these natural dams significant quantities of ground water can be stored.

2. Basal fresh water. The high permeability of the volcanic rocks allows sea water to enter freely under the island, and a delicate balance is reached where a lens of fresh water floats on sea water. In cases of hydrostatic equilibrium, the Ghyben-Herzberg relation states that for every foot of fresh water head above sea level there will be 40 ft of fresh water below sea level.

At KRD both dike-confined and basal fresh water resources were indicated due to the large variation in static water levels at the various wells within the development (well #3 ≈ 150 ft, wells #1 and #2 ≈ 6 ft). The impetus for using geophysics is that the cost of a geophysical station is about one-thousandth the cost of completing a well at elevations above 1,000 ft. Geophysical surveys, combined with other hydrogeologic information, are used to provide optimum locations for well placement and well completion depths.

The geophysical method employed was time domain electromagnetic (TDEM) soundings. This method was selected because it has proven effective in prior surveys in similar settings in Hawaii.



BLACKHAWK GEOSCIENCES, INC.

SCHEMATIC HYDRO-GEOLOGIC CROSS SECTION

KOHALA RANCH PROJECT

NORTH KOHALA, HAWAII

PROJECT NO.: 90016

FIGURE 1-1

2.0 LOGISTICS AND DATA ACQUISITION

A brief description of the fundamentals of TDEM are given in Appendix A. Briefly, the logistics of a TDEM measurement consist of:

1. Laying out a square loop of insulated wire. A generator placed in the loop is used to drive current pulses through this closed loop. The dimensions of the square loops employed depend on the exploration depth requirements. The dimensions of the loops used for KRD were 1,000 ft by 1,000 ft on each side for all loops, with the exception of loop 1W where a 500 ft by 500 ft transmitter loop was used.

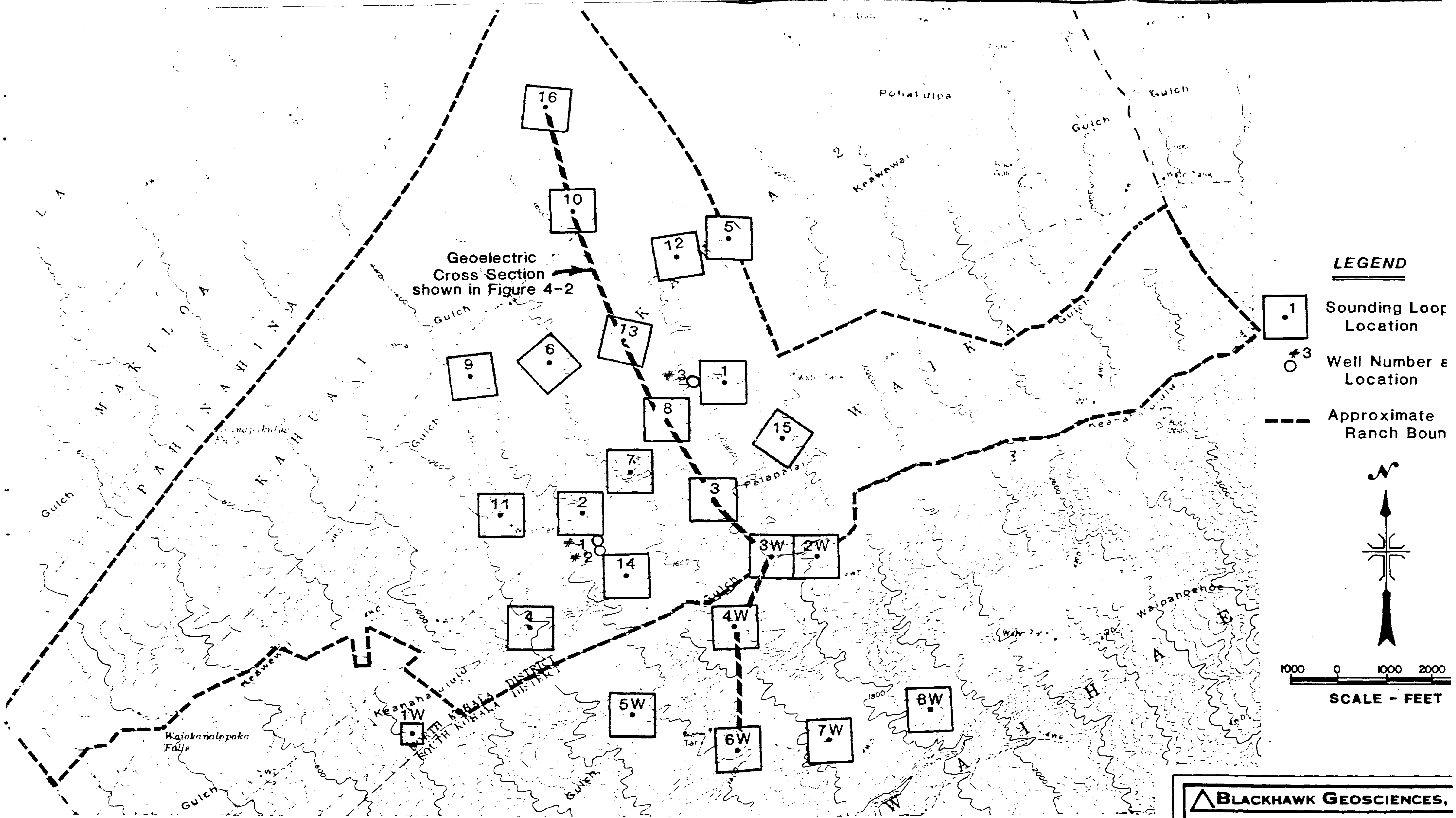
   Transmitter loop wires were positioned so as not to cross utility lines. Soundings 1, 2 and 1W were positioned near wells.

2. Making a measurement with a receiver in the center of the loop. The data acquired at each station was stored in the field on a solid state data logger and subsequently dumped to a computer at the end of each field day. The data acquired at each station usually consisted of measurements at several receiver gain settings and transmitter frequencies in order to assure data quality and to obtain data over the largest time range possible. Data quality was generally very good.

During the 8 days of field work 24 stations (soundings) were completed. A daily log of field activity is given in Table 2-1. Figure 2-1 shows the location of the soundings conducted for KRD.

Table 2-1. Daily log of field activities

Date (1990)	Activity
March 26	BGI personnel mobilize from Golden, CO to Kailua-Kona, Hawaii in conjunction with the other surveys.
April 5	Meet with KRD personnel and check survey areas.
April 6	Soundings 1, 2 and 3.
April 7	Soundings 4, 5 and 6.
April 8	Soundings 7, 8, 9 and 10.
April 9	Soundings 11, 12 and 13.
April 10	Soundings 14, 15 and 16.
April 11-12	Demobilize to Golden, CO and perform preliminary analysis of data.
April 18	Mobilize to Kailua-Kona, Hawaii.
April 23	Soundings 1W, 2W and 3W.
April 24	Soundings 4W, 5W and 6W.
April 25	Soundings 7W and 8W.
April 26	Demobilize to other Hawaii geophysical surveys.



BLACKHAWK GEOSCIENCES,

TDEM SURVEY LOCATION M

KOHALA RANCH PROJECT
NORTH KOHALA, HAWAII

PROJECT NO.: 90016 FIGUR

3.0 DATA PROCESSING

The field data acquired each day was transferred from the DAS-54 data logger to a Compaq computer. The data for each sounding location is edited and combined (both 3 Hz and 30 Hz frequencies) to produce a transient decay curve. This decay curve is transformed into an apparent resistivity curve, which is entered into an Automatic Ridge Regression Transient Inversion Program (ARRTI). From the apparent resistivity curve a one-dimensional model of resistivities and thicknesses is calculated.

The inversion program requires an initial estimate of the geoelectric section, including the number of layers, and the resistivities and thicknesses of each of the layers. The program then adjusts these parameters so that the model curve converges to best fit the curve formed by the field data set. The inversion program does not change the total number of layers within the model, but allows all other parameters to float freely.

An example data set is given in Figures 3-1 and 3-2 for sounding KR1. Figure 3-1 shows the measured data points (in terms of apparent resistivity) superimposed on a solid line. The solid line represents the computed behavior of the true resistivity layering shown on the right. Figure 3-2 lists in column 4 the error between measured and computed data in each time gate.

The apparent resistivity curves and data sheets for all soundings are contained in Attachment A.

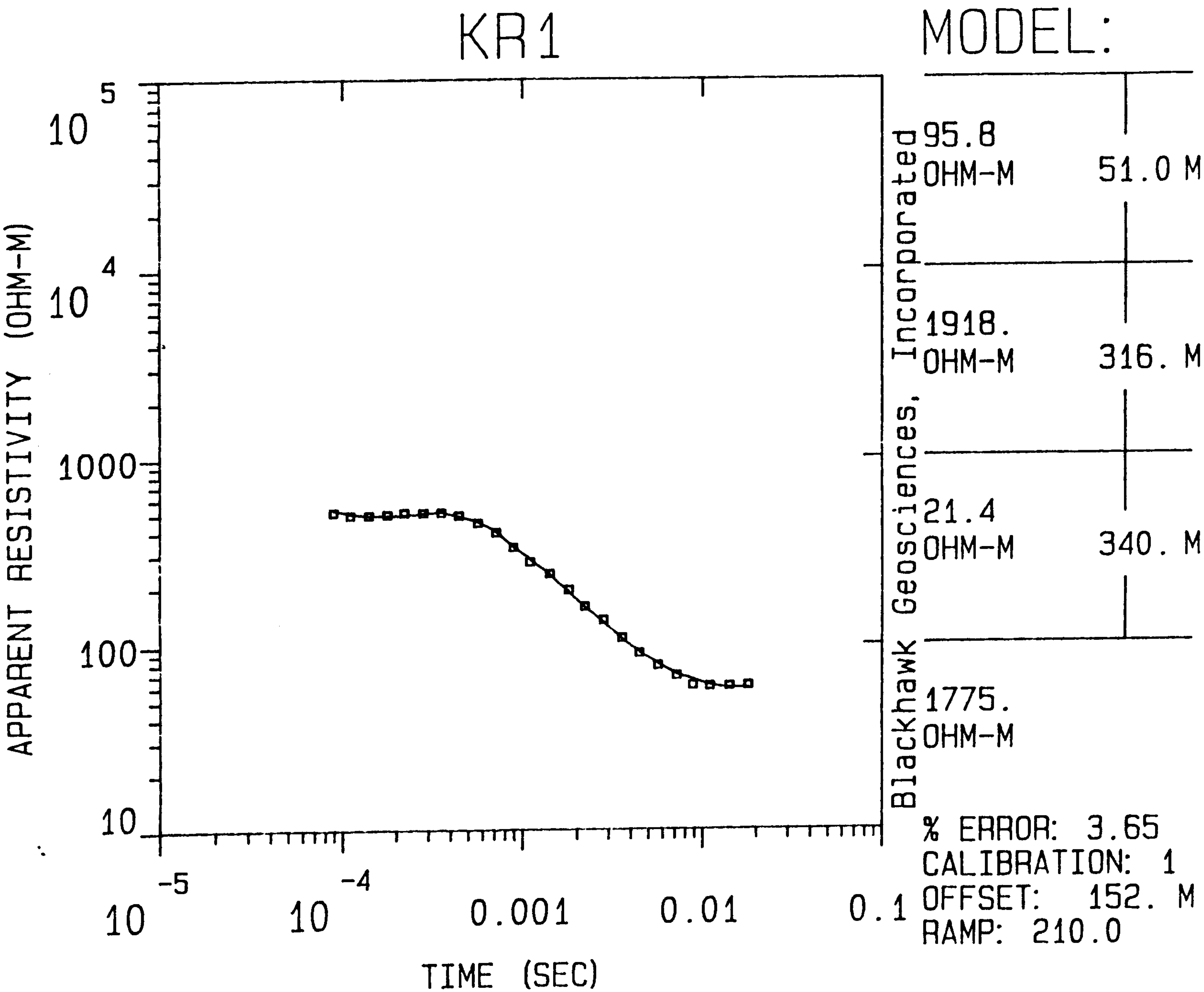

KR1
MODEL:
APPARENT RESISTIVITY (OHM-M)
10^5
10^4
1000
100
10
10^-5
10^-4
0.001
0.01
0.1
TIME (SEC)
Blackhawk Geosciences, Incorporated
95.8 OHM-M
51.0 M
1918. OHM-M
316. M
21.4 OHM-M
340. M
1775. OHM-M
% ERROR: 3.65
CALIBRATION: 1
OFFSET: 152. M
RAMP: 210.0

FIGURE 3-1

FIGURE 3-2

KR1

MODEL: 4 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		579.1	1900.0		
95.78	51.0	528.1	1732.6	0.5	0.5
1918.02	316.3	211.8	694.8	0.2	0.7
21.40	339.5	-127.7	-419.1	15.9	16.6
1774.88					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	8.90E-05	5.09E+02	5.26E+02	-3.141	
2	1.10E-04	4.90E+02	4.99E+02	-1.693	
3	1.40E-04	4.91E+02	4.86E+02	1.058	
4	1.77E-04	4.96E+02	4.88E+02	1.606	
5	2.20E-04	5.06E+02	4.94E+02	2.547	
6	2.80E-04	5.05E+02	5.04E+02	0.196	
7	3.55E-04	5.07E+02	5.13E+02	-1.261	
8	4.43E-04	4.88E+02	4.80E+02	1.563	
9	5.64E-04	4.45E+02	4.52E+02	-1.521	
10	7.13E-04	3.95E+02	3.99E+02	-1.130	
11	8.90E-04	3.27E+02	3.29E+02	-0.409	
12	1.10E-03	2.73E+02	2.81E+02	-2.843	
13	1.41E-03	2.35E+02	2.32E+02	1.523	
14	1.80E-03	1.94E+02	1.87E+02	3.585	
15	2.20E-03	1.59E+02	1.56E+02	1.501	
16	2.80E-03	1.34E+02	1.30E+02	3.090	
17	3.55E-03	1.08E+02	1.07E+02	1.757	
18	4.43E-03	9.06E+01	9.13E+01	-0.692	
19	5.64E-03	7.79E+01	7.90E+01	-1.382	
20	7.13E-03	6.86E+01	6.96E+01	-1.438	
21	8.81E-03	6.07E+01	6.49E+01	-6.573	
22	1.10E-02	6.00E+01	6.06E+01	-0.967	
23	1.41E-02	5.99E+01	5.83E+01	2.780	
24	1.80E-02	6.03E+01	5.85E+01	3.120	

R: 152. X: 0. Y: 153. DL: 305. REQ: 170. CF: 1.0000
TDHZ ARRAY, 24 DATA POINTS, RAMP: 210.0 MICROSEC, DATA: KR1
0604 0001 0001 Z OPR XTL H 4 10+100
Ch.21 = 0.21 Ch.22 = 0.089 Ch.23 = 20 Ch.24 = 9
RMS LOG ERROR: 1.56E-02, ANTILOG YIELDS 3.6503 %
LATE TIME PARAMETERS

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER
P 1 0.94
P 2 -0.03 0.05
P 3 0.01 -0.02 0.97

4.0 INTERPRETATION RESULTS

4.1 GENERAL

The main objective of the geophysical survey is not to obtain the resistivity layering of the subsurface, but to infer from the resistivity layering information about the elevation and thickness of the fresh water resource. The translation of resistivity layering into meaningful hydrogeologic information is generally accomplished in two ways:

1. Using available knowledge about the relation between resistivity values and hydrogeology. For example, in the volcanic rocks of Hawaii, rocks saturated with salt water will generally have resistivities less than 5 ohm-m. On the other hand, dry and fresh water/brackish water saturated volcanic rocks and intrusives can have very high resistivities (greater than 1,000 ohm-m).

2. Calibrating the geophysical interpretation at a well. In this case several wells were available for comparison. The approximate location of these wells are shown in Figure 2-1. The two wells (#1 and 2) located at lower elevation (1,460 ft) had static water levels (heads) of 6 ft above sea level. The well #3 located at higher elevation (1,835 ft) had a head of approximately 150 ft above sea level. This large difference in heads over the approximate 4,000 ft distance can best be explained by major geologic structures (rifts, dikes, etc.) which act to dam ground water flow.

In the case where a very conductive layer is detected below sea level in the TDEM interpretation, then the layer is expected to be caused by saline saturated volcanics. Static water levels (heads) can be calculated from these soundings by using the Ghyben-Herzberg relation. This relation, however, assumes hydrostatic equilibrium and is not expected to apply to soundings in close proximity to ground water damming structures.

The soundings acquired in a large area around wells #1, 2 and 3 did not detect salt water saturated volcanics below sea level. The behavior of the ground water in these areas is, therefore, expected to be dike or structure controlled. Other TDEM soundings in the survey area were able to detect salt water saturated volcanics below sea level, and for these soundings ground water levels may behave according to the Ghyben-Herzberg relationship.

4.2 GEOELECTRIC CROSS-SECTION

The results of some the TDEM interpretations are presented as a south to north geoelectric cross section in Figure 4-1. In the geoelectric section layers with similar resistivities have been linked together. In the geoelectric section soundings 6W and 4W (on the south) and soundings 10 and 16 (to the north) show similar three-layer sequences. The upper surface layer (44 to 220 ohm-m) is interpreted to represent soils or weathered volcanics. The intermediate layer of very high resistivities (> 5000 ohm-m) is interpreted as unweathered volcanics. The portions of this layer below sea level are expected to contain fresh or brackish water. The deepest layer in the section with resistivities of 4.2 to 9.6 ohm-m is interpreted to represent salt water saturated volcanics.

In the geoelectric section beneath soundings 3W, 3, 8 and 13 a more complex layering sequence is interpreted. A third layer which exhibits resistivities from 2 to 22 ohm-m is interpreted as volcanic ash flows or altered volcanic occurring above and below sea level. The lowest layer beneath soundings 3, 8 and 13, with resistivities of 1030 to 1672 ohm-m, probably represents unaltered volcanics or intrusives to the maximum search depth (≈ 3,000 ft). Generally, it is difficult to discriminate between unaltered volcanics which are dry or which contain fresh or brackish water (less than 250 ppm chloride). The reason is that, in addition to salinity, changes in porosity and lithology also influence formation resistivity.

Within the geoelectric section several vertical structures are interpreted. These structures are likely caused by vertical dikes of impermeable rocks resulting in a barrier to ground water flow which may explain the high level ground water head (150 ft) at well #3.

4.3 INTERPRETATION MAP

In order to incorporate all the soundings into one data set, an interpretation map of the TDEM results for the Kohala Ranch area was constructed (Fig. 4-2). In this figure the soundings which detected saline saturated volcanics below sea level are separated from the soundings which have a resistive basement (or conductive basement which occurs above sea level). In other words, soundings which are expected to represent basal saline water are separated from soundings which are influenced by dike impoundment or other geologic structures.

In this figure the elevation of the top of the salt water interface derived from the TDEM measurements is contoured. These values will be approximately equal to the thickness of the fresh-brackish water lens if the basal water is in equilibrium. In addition to the TDEM data, static water level (heads) from three wells drilled on the ranch property are shown on the contour map (information furnished by Nance, 1990, personal communication).

The main features evident in the interpretation map are:

(1) Areas outside the boundary between impounded and basal water generally show the salt water interface to deepen towards the northeast. On the south side of the boundary the depth to basal saline water increases rapidly with increasing elevation. On the north side of the boundary the depth to saline water increases gradually with increasing elevation.

(2) The area interpreted to be effected by confining structures extends in a narrow zone from about 1,000 ft above sea level near sounding 4 and widens with increasing elevation towards the northeast. Wells #1 and #2 also lie within the interpreted dike confined water zone.

Within the boundary the TDEM data can be grouped according to comparable model results. Soundings 2, 4, 11 and 14 (near wells #1 and #2) have similar two-layer model results. These soundings show a thick resistive (280 to 497 ohm-m) layer above a conductive layer (3 to 5 ohm-m) both occurring above sea level. This lower conductive layer is most likely interpreted as volcanic ash flows or altered volcanics.

Soundings 1, 8 and 13 in the vicinity of well #3 have comparable model results. Each sounding shows a four-layer sequence (Fig. 4-1) with the deep resistive layer (1049 to 1775 ohm-m) interpreted as unaltered volcanics or intrusives. Sounding 7, which does not fit in either of these two grouped areas exhibits a three-layer sequence with a lower resistive (181 ohm-m) layer occurring approximately 748 ft below sea level. This lower layer may also be best interpreted as unaltered volcanics or intrusives.

Soundings 3 and 15 have similar four-layer model results with a resistive lower layer (1030 to 1688 ohm-m) occurring above sea level. This layer is most likely interpreted as unaltered volcanics or intrusives.

Models for soundings 2W and 3W are similar to each other, but are quite different from surrounding soundings (Fig. 4-1). These soundings are located close to the interpreted boundary between basal and dike-confined water. This closeness to the boundary may be the reason for differences seen between these sounding sets.

Soundings 5 and 12 have similar three layer model results. Both soundings show a resistive (79 to 360 ohm-m) layer at depth occurring below sea level. This lower layer can best be interpreted as unaltered volcanics or intrusives.

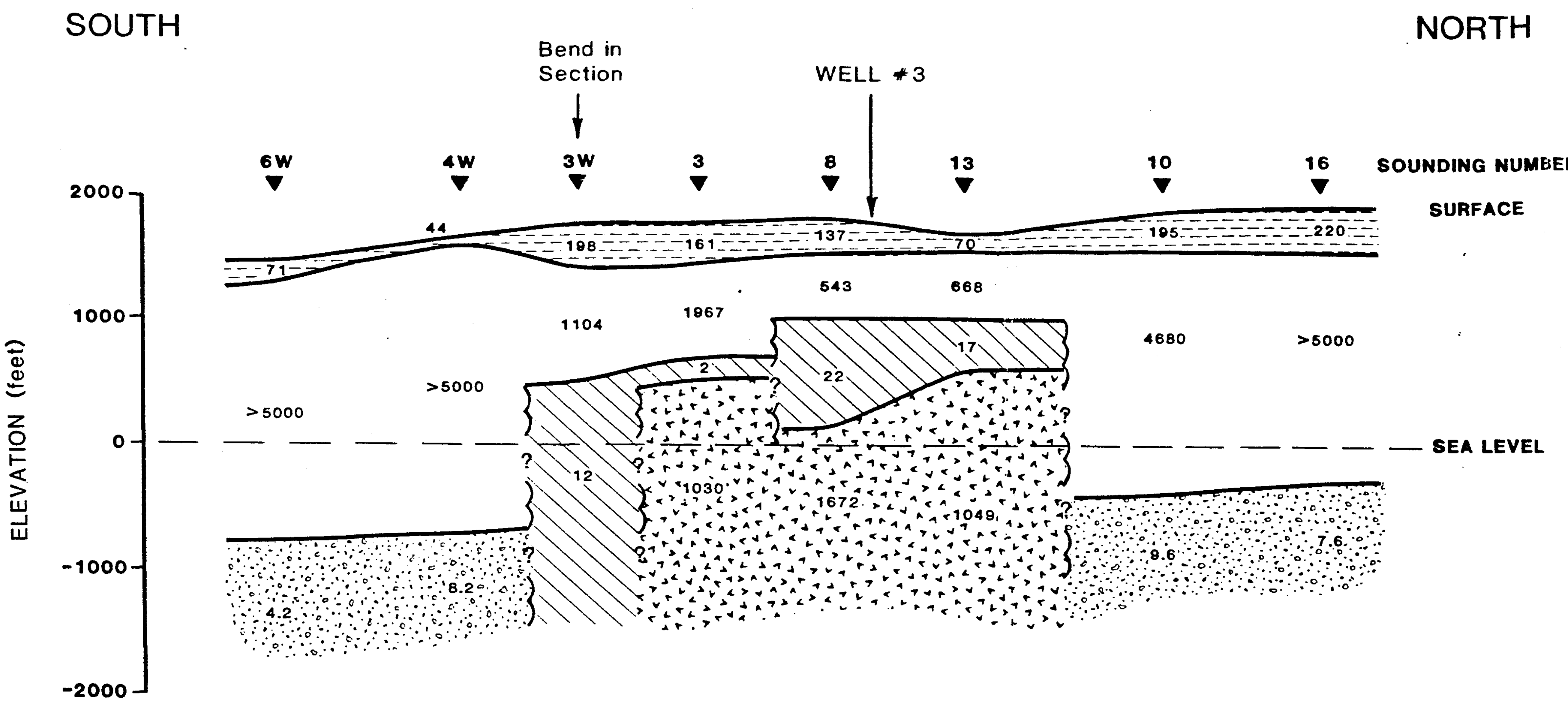
4.4 HYDROGEOLOGIC INTERPRETATION

The geophysical interpretation (Fig. 4-2) outlined two areas of different hydrogeologic parameters, i.e., an area in which the ground water is expected to be controlled by geologic structures (dikes, intrusives, etc.) and an area in which the ground water is expected to occur mainly in the basal mode. Within the area interpreted to be controlled by geologic structures, the hydrologic parameters such as static head and volume of the ground water resource, cannot be inferred from the geophysical data. This is due to the fact that the presence or absence of fresh water has little effect upon the electrical resistivity measured by the TDEM method. In areas with comparable TDEM results (see Section 4.3) it can be assumed that similar hydrologic parameters may exist. For example, soundings 1, 8 and 13 near well #3 all display similar results, and therefore likely outline the extent of the structure which creates the anomalous head at well #3. Similarly, the soundings around wells #1 and #2 (11, 2, 14, and 4) all display similar results and could be expected to define the boundary of the lower heads seen in these wells. Geologic structures are inferred between separate groups of soundings with similar results (reference Figs. 4-1 and 4-2).

In the area interpreted to be represented by basal water resources, the fresh water resource can be estimated by the volume between sea level and the elevation of the interpreted saline water. If this water can be assumed to be hydrostatic equilibrium, then the static water level (head) can be calculated using the Ghyben-Herzberg relation. Table 4-1 shows the thickness of the fresh/brackish water lens obtained directly from the model results for each sounding.

Table 4-1. Hydrogeologic information derived from TDEM soundings

Sounding #	Surface Elevation (ft)	Approximate Thickness of Fresh/Brackish Water Lens (ft)
6	1550	272
9	1420	204
10	1850	419
16	1890	295
1W	830	98
4W	1665	771
5W	1340	484
6W	1450	778
7W	1680	905
8W	1885	1000?



LEGEND

- Soils or Weathered Volcanics
- Unweathered Volcanics
- Volcanic Ash Flows or Altered Volcanics
- Unaltered Volcanics or Intrusives
- Salt Water Saturated Volcanics
-) ?) Inferred Geologic Structure

4.2 Values in Ohm-m

HORIZONTAL EXAGERATION 2 TO 1

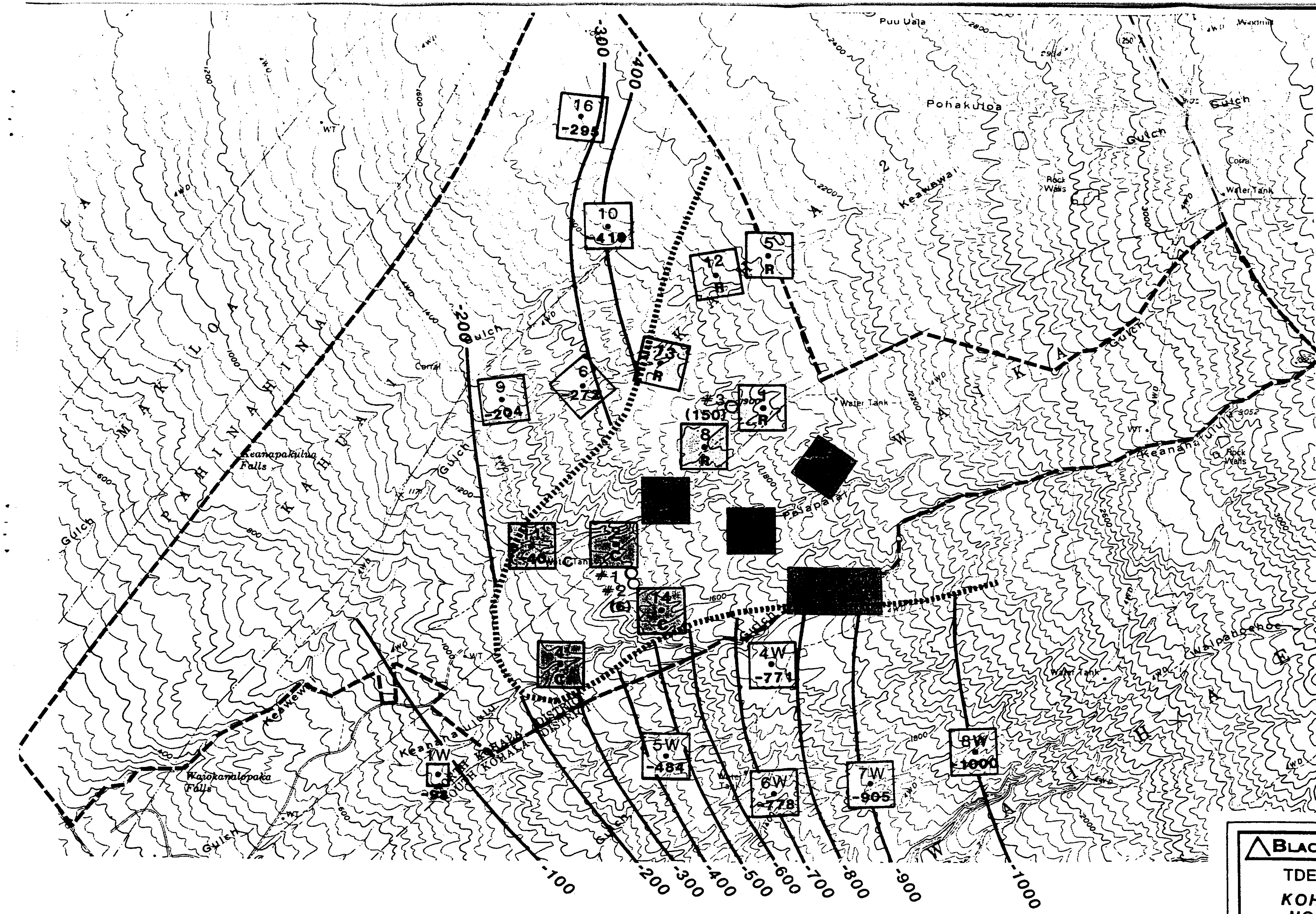
1000 0 1000 2000 3000 4000

SCALE - FEET

BLACKHAWK GEOSCIENCES, I

TDEM SURVEY
GEOLOGIC CROSS SECTION
KOHALA RANCH PROJECT
NORTH KOHALA, HAWAII

PROJECT NO.: 90016 FIGURE



LEGEND

▪▪▪▪▪▪	Interpreted Boun[…] between Bas[…] Dike confined […]
-295	Approximate loc[…] of top-of inter[…] Salt Water Int[…] (feet)
C	Conductive Base[…]
R	Resistive Basem[…]
(140)	Static Water Le[…] at Well (feet)
[square with •1]	Sounding Loop Location
○ #3	Well Number a[…] Location
— — —	Approximate Ranch Bound[…]

N

1000 0 1000 2000

SCALE - FEET

BLACKHAWK GEOSCIENCES, […]

TDEM INTERPRETATION MA[…]

KOHALA RANCH PROJECT
NORTH KOHALA, HAWAII

PROJECT NO.: 90016 FIGUR[…]

5.0 CONCLUSIONS AND RECOMMENDATIONS

The results of the TDEM survey at KRD are summarized in Figure 4-2. In this figure areas of the development in which ground water is expected to be controlled by geologic structures (dikes, intrusives, etc.) are separated from the area in which the ground water is expected to exist in the basal mode. The ground water resources within the area controlled by geologic structures cannot be determined directly from the TDEM data, however, sub-zones in which the hydrologic parameters are expected to be the same have been identified. For example, soundings 1, 8 and 13 near well #3 all exhibit similar behavior, and therefore can be expected to define the limits of the structure in which well #3 was positioned. Structures are inferred to exist between groups of soundings with similar results.

In the area interpreted to be represented by basal water resources, the fresh water resource is expected to be the volume between sea level and the elevation of the interpreted salt water. If the area can be assumed to be in hydrostatic equilibrium then the static water level (head) can be calculated using the Ghyben-Herzberg relation. The applicability of the Ghyben-Herzberg relationship in the area is expected to be marginal due to the existence of ground water damming structures.

Rev. 11/90

DIVISION OF WATER RESOURCE MANAGEMENT

FROM: ______ DATE: ______ FILE IN: ______

TO:	INITIAL:		PLEASE:	REMARKS:
___	___	G. AKITA	___ See Me	
___	___	L. Nanbu	___ Take Action By___	
			___ Route to Your Branch	
___	___	E. Sakoda	✓ Review & Comment	
___	___	G. Matsumoto	___ Draft Reply___	
___	___	E. Lau	___ Acknowledge Receipt	
___	___	L. Chang	___ Xerox ___copies	
___	___	~~Y. Shiroma~~	___ File	
___	___	___	___ Mail	
✓	___	___		
___	___	___	FOR YOUR:	
✓	___	___	___ Approval	
___	___	___	___ Signature	
___	___	___	___ Information	
___	___	M. TAGOMORI		
___	___	S. Kokubun		

Assessment of Well Data from Recently Drilled Wells

Lanai Island

4954-02	Lanai 8	Temperature shows slight increase near bottom to a maximum of $76.8^{\circ}C$. Chemical composition indicates low Cl/Mg ratios, possibly indicative of residual heat. Would be worth resampling.
4854-01	Lanai 9	Temperature is elevated; chloride and magnesium are elevated for a water source as distant from the coast as this one is. Resampling is in order for this well.
	Lanai 12	Temperature, silica, and Cl/Mg are elevated; well should be resampled.

Molokai Island

0801-03	Kualapuu Mauka	All characteristics of this well appear normal for a groundwater source; no geothermal evidence is apparent. In the absence of other indications, no further sampling recommended.

Maui Island

5539-01	Kaanapali	Chloride slightly elevated; no temp or other chemistry data available. For completeness, should sample for chem and temperature when convenient.
5539-02	Kaanapali	As for 5539-01 above.
5332-04	Kepaniwai	Temperature and salinity appear normal for location. No further sampling is recommended.
4300-02	Hamoa	Temperature and chloride appear normal for location. No further sampling is recommended.

Hawaii Island

6340-05	Kohala Mtn. 1	Temperature appears normal; no chemistry data. In the absence of other indications, no further sampling is recommended. (Note: This well appears to have been cored throughout.)
6649-01	Kohala Ranch 3	Temperature appears to be normal; chemistry data indicate a slight elevation of silica but Cl and Mg data are not available. Given the proximity to other wells having thermal and chemical anomalies, it might be useful to obtain full chemistry for this well.

5339-01	Waikii 1	Temperature is elevated with a higher rate of increase at depth. Cl/Mg appear normal to low. Further sampling should be done when wells come into production.
5339-02	Waikii 2	No data. Should be sampled and logged (if possible).
6451-01	Kohala Estates	High chlorides, no other data. Sample only if convenient.
6451-02	Kohala Estates	High chlorides, no other data. Sample only if convenient.
6451-03	Kohala Estates	High chlorides, no other data. Sample only if convenient.
6046-02	Ouli 2	Temperatures are slightly elevated; chloride is low but no other chemistry is available. Proximity to thermal wells suggests further sampling would be useful.
4650-01	Puuwaawaa Ranch	Temperatures and salinities are low. No geothermal indicators found.
4658-02	Kaupulehu	Temperature and chloride appear normal; no other chemical data available. Sample only if convenient.
4558-01	Huehue Ranch 1	No data available. Close to Hualalai rift zone so sampling would be useful.
4558-01	Huehue Ranch 2	No data available. Close to Hualalai rift zone so sampling would be useful.
4459-01	Huehue Ranch 3	No data available. Close to Hualalai rift zone so sampling would be useful.
4160-01	Kaloko	No temperature data. Cl/Mg data appear normal. Additional sampling not recommended.
4160-02	Kaloko	No temperature data. Cl/Mg data appear normal. Additional sampling not recommended.
3457-02	Keauohou 2	Temperatures and salinity appear normal. No additional sampling appears warrented.
3603-01	Olaa 3	Temperatures are normal, chlorides are low. No evidence of thermal effects. Additional sampling not recommended.

Quarterly Progress Report

Brine Silica Control Project

Project efforts were initiated in April, 1991 with the completion of a data search for reports on silica control and recovery efforts that have been conducted at geothermal facilities within the continental U.S. and North America. The results of this effort indicated that very few projects have encountered silica deposition problems as severe as those present in Hawaii. The areas chiefly experiencing difficulties were Salton Sea and Cerro Prieto. At present, there are no commercial efforts to recover silica from the geothermal brines.

The second area of effort has been the relocation of a laboratory trailer from Keahole to the Puna Research Center. The laboratory trailer will enable us to conduct analyses of geothermal brines from well tests performed in the Kilauea East Rift Zone and to perform extensive experimentation on recovered silica immediately after acquisition. The laboratory has been moved and we are now in the process of testing out the equipment and bringing it into operation.

The third area of effort has been the analysis of alteration minerals from the SOH core. Samples of material have been taken from the core, x-ray analysis are currently being conducted, and samples are being prepared for electron microscopy and elemental analysis.