Special Publication SJ93-SP1

TIME DOMAIN ELECTROMAGNETIC SOUNDINGS
ST. JOHNS RIVER WATER MANAGEMENT DISTRICT
IN NORTHEAST FLORIDA
JULY 1992

Performed For:

St. Johns River Water Management District
P.O. Box 1429
Palatka, Florida 32178-1429

(Contract No. 92G201)

Performed By:

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(CRC Project #9001-001)

December 2, 1992

Contract No. 92G201
December 2, 1992

This is to certify that I, James Hild, have reviewed the figures, tables, and text of the following report, and have retained one copy for my files.

By:

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Professional Geologist
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EXECUTIVE SUMMARY

Time domain electromagnetic (TDEM) measurements were made in the St. Johns River Water Management District (SJRWMD) in northeast and east-central Florida and southeast Georgia during July 1992. TDEM is a geophysical method that measures from the surface the resistivity layering (geoelectric section) of the subsurface. The impetus for using surface geophysics for obtaining water quality is its low cost per station compared to drilling, so that a higher density of measurements can be afforded. Surface TDEM measurements does not provide information about water quality at the same level of detail (e.g., chemical composition) or accuracy as can be derived from wells. The confidence in the water quality information inferred from TDEM measurements is enhanced when it is calibrated against well data. The objective of this TDEM survey was to infer from the geoelectric sections measured information about water quality in the Floridan aquifer, such as the first depth of occurrence of ground water with a chloride concentration greater than 5,000 mg/l and the depth at which chloride content of the ground water equals 250 mg/l (250 mg/l isochlor).

The objective of determining the first depth of occurrence of chloride concentration greater than 5,000 mg/l was most readily accomplished. At the 18 sites surveyed the depth varied from about 220 ft below surface to in excess of 3,000 ft below surface which is below the base of the Floridan aquifer. TDEM measurements are an indirect method for determining water quality, and validity of interpretations are best tested against salinity measurements in wells. At one site (site 5, Ponte Vedra), a well penetrated the interface with highly saline water, and the depth to ground water of high salinity inferred from TDEM measurements was within 8% of the depth observed in the well.

The objective of determining the depth to the 250 mg/l isochlor is a difficult one to accomplish. At the 18 sites surveyed, depth varied from 246 ft below surface to 1,504 ft below surface. At several of the sites the 250 mg/l isochlor was not present within the Floridan aquifer or its location could not be determined. This objective is more sensitive to assumptions that necessarily need to be made about chemical composition of ground water and porosity. Also, in present day methods of analysis, the geoelectric section is approximated by distinct boundaries. In real aquifers, ground water quality generally changes gradually. Nevertheless, at the majority of sites meaningful information about water quality in the Floridan aquifer was obtained that corresponded well with available regional water quality data.

1.0 INTRODUCTION

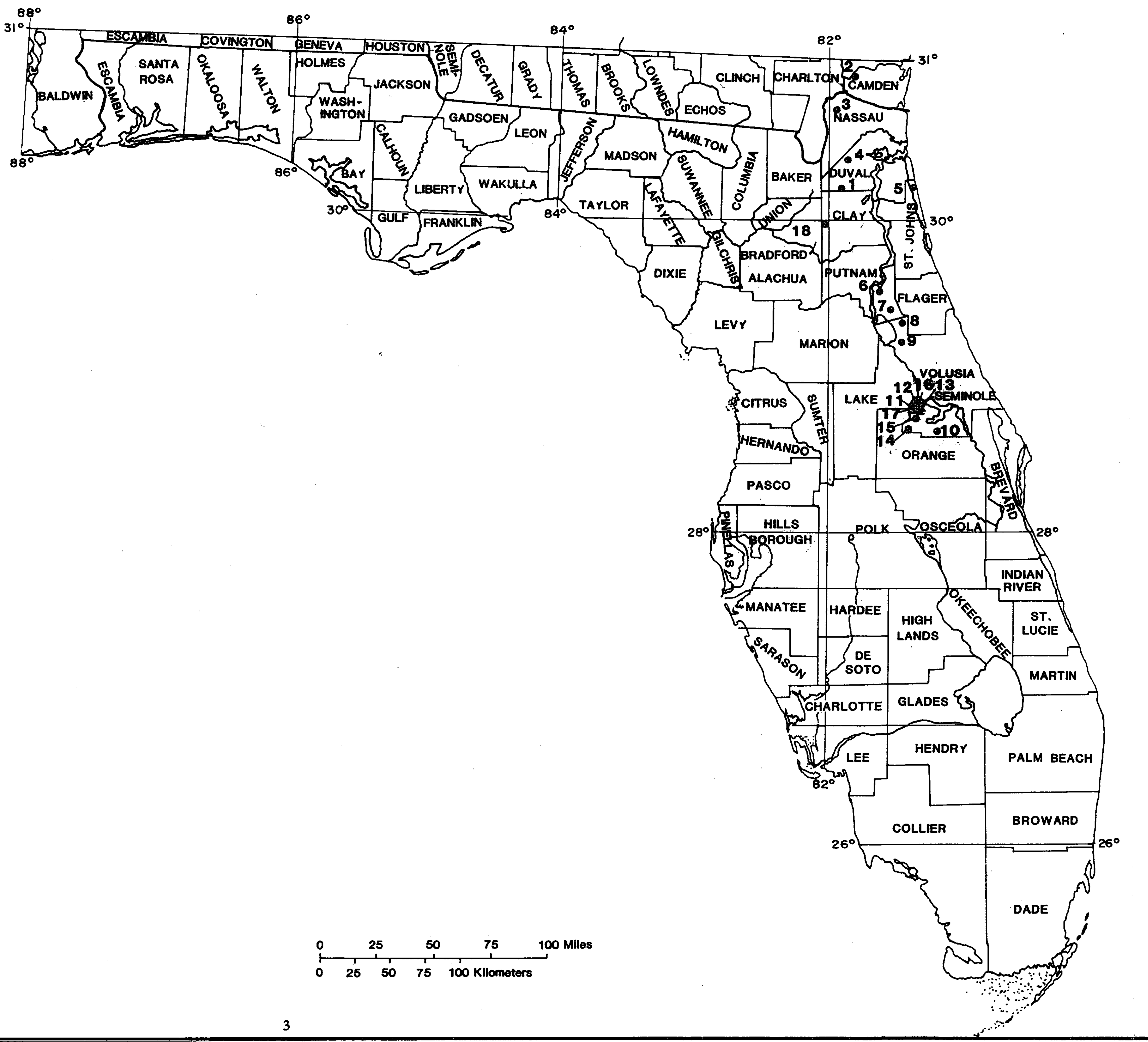
This report covers the data acquisition, processing, interpretation, and results of a time domain electromagnetic (TDEM) survey performed at 17 sites in the St. Johns River Water Management District (SJRWMD) in northeast and east-central Florida, and one site in southeast Georgia. TDEM is a geophysical method that determines from the surface the geoelectric section (resistivity layering) in the subsurface. From the geoelectric section information about geology and water quality can be inferred, because the electrical resistivity of the earth depends on lithology, porosity, and concentration of dissolved solids in the ground water.

The objectives of the measurements at the 18 sites were to

- map the interface within the Floridan aquifer between fresh water and saline water, defined here as ground water with a chloride concentration greater than 5,000 mg/l,
- infer the position of the 250 mg/l isochlor relative to the fresh water/saline water interface,
- estimate the chloride content of the saline water layer assuming a range of porosities for the Floridan aquifer.

The selection of the locations for the 18 sites for TDEM measurements were made by personnel of SJRWMD, and the overview map of Figure 1-1 shows their location.

Two separate TDEM systems were utilized in data acquisition for this survey. For sites 1 through 5, and site 18, which required a depth of exploration in excess of 2,000 ft, the EM42 TDEM system was utilized. At all other sites, the required depth of exploration was less than 2,000 ft and the EM37 TDEM system was employed.



BLACKHAWK GEOSCIENCES, INC.

TIME DOMAIN ELECTROMAGNETIC SITE LOCATION MAP

ST. JOHNS RIVER WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) Figure 1-1

2.0 HYDROGEOLOGIC SETTING

The hydrogeologic setting for the study area is summarized in Figure 2-1. The position of the saline water interface for all the EM37 sites and for the EM42 site at Ponte Vedra (Site 5) is within the Floridan aquifer system. EM42 soundings, other than Ponte Vedra, detect a low resistivity zone beneath the Floridan aquifer. This zone may represent saline brines within Upper Cretaceous carbonates or shales. The Floridan aquifer system is defined by Miller (1990) on the basis of permeability. In general, the system is at least 10 times more permeable than its bounding upper and lower confining units. The aquifer system is thick and widespread, and the rocks within it generally vary in permeability. It is divided into an Upper Floridan aquifer and a Lower Floridan aquifer, separated by a less permeable unit in most places, and bounded above and below by confining units that may be less permeable.

The differences in geology across the survey area consists primarily of changes in thickness of the various units. In the area around Jacksonville, the thickness of the lithologic units overlying the Floridan aquifer is from 300 ft to 500 ft, while in Volusia and Seminole counties, these units range from 50 ft to 150 ft thick. Another major difference is the occurrence of the Fernandia permeable zone at the base of the Floridan aquifer in the area around Jacksonville. This unit occurs in the lower Oldsmar and upper Cedar Keys Formations, and consists of limestone and dolomite that has extremely high permeability, and it is locally cavernous. There is little direct information on the characteristics of the Fernandia zone but porosities are likely to be significantly higher than elsewhere in the Floridan aquifer system.

GEOLOGIC UNITS
(ADAPTED FROM FAULKNER, 1973, FIG. 2)

Era	System	Series	Stratigraphic unit	Thickness (feet)	Lithology	Aquifer
CENOZOIC	QUATERNARY	Holocene	Unnamed alluvial, lake, and windblown deposits	0-75	Alluvium, freshwater marl, peats and muds in stream and lake bottoms. Also, some dunes and other windblown sand.	SURFICIAL AQUIFER
					unconformity	
		Pleistocene	Pamlico Formation and marine and estuarine terrace deposits	0-75	Mostly marine quartz sand, unconsolidated and generally well graded. Also, some fluviatile and lacustrine sand, clay, marl, and peat deposits.	
					unconformity	
	TERTIARY, UPPER	Pliocene	Jackson Bluff Formation	0-75±	Marine sands, argillaceous, carbonaceous; and sandy shell marl. Some phosphatic limestone.	
			Alachua Formation	0-100±	Nonmarine interbedded deposits of clay, sand, and sandy clay; much of unit is phosphatic, base characterized by rubble of phosphate rock and silicified limestone residuum in a gray and green phosphatic clay matrix.	
		Miocene	Fort Preston Formation	0-100±	Nonmarine fluviatile sand, white to gray, variegated orange, purple and red in upper part, fine- to coarse-grained to pebbly, clayey, crossbedded.	
			Hawthorn Formation	0-300±	Marine interbedded sand, cream, white, and gray, phosphatic, often clayey; clay, green to gray and white, phosphatic, often sandy; dolomite, cream to white and gray, phosphatic, sandy, clayey; and some limestone, hard, dense, in part sandy and phosphatic. Tends to be sandy in upper part and dolomitic and limy in lower part.	
					unconformity	
	TERTIARY, LOWER	Oligocene	Suwannee Limestone	0-150	Marine limestone, very pale orange, finely crystalline, small amounts of silt and clay.	FLORIDAN AQUIFER SYSTEM
					unconformity	
		Eocene, UPPER	Ocala Limestone, Upper member	0-325	Marine limestone, cream to white, soft, granular, highly porous, coquinal; often consists almost entirely of tests of foraminifers; cherty in places.	
			Ocala Limestone, Lower member		Marine limestone, cream to tan and brown, granular, soft to firm, porous, highly fossiliferous; lower part at places is dolomite, gray and brown, crystalline, saccharoidal, porous.	
					unconformity	
		Eocene, MIDDLE	Avon Park Formation	600-1600	Marine limestone, light brown to brown, finely fragmental, poor to good porosity, highly fossiliferous (mostly foraminifers); and dolomite, brown to dark brown, slightly porous to good porosity, crystalline, saccharoidal; both limestone and dolomite are carbonaceous or peaty; gypsum is present in small amounts. Marine limestone, light brown to brown, fragmental, highly fossiliferous, slightly carbonaceous or peaty and cherty; and dolomite, brown to dark brown with very minor amounts of gypsum and anhydrite. Unit is slightly porous to porous.	
		Eocene, LOWER	Oldsmar Formation	300-1350	Marine limestone, light brown to chalky, white, porous, fossiliferous, with interbedded brown, porous, crystalline dolomite; minor amounts of anhydrite and gypsum.	
		Paleocene	Cedar Keys Formation	500-2200	Marine dolomite, light gray, hard, slightly porous to porous, crystalline, in part fossiliferous, with considerable anhydrite and gypsum, some limestone.	
					unconformity	
MESOZOIC	CRETACEOUS		Upper and Lower Cretaceous	1500-?	Mostly marine Upper Cretaceous carbonate and evaporite rocks, sands and shales; thin Lower Cretaceous clastic section in some of area.	
					Coastal Plain Bedrock	
PALEOZOIC and PRE-CAMBRIAN			DEVONIAN to PRECAMBRIAN (?)	Basement rocks	Marine Devonian, Silurian, and Ordovician quartzose sandstone and dark shale; lower Paleozoic (?) or Precambrian (?) rhyolite, tuff, and agglomerate.	

PRINCIPAL HYDROGEOLOGIC UNITS (CONCEPTUAL MODEL)

- SURFICIAL AQUIFER
- UPPER CONFINING UNIT
- UPPER FLORIDAN AQUIFER
- MIDDLE SEMICONFINING UNIT
- LOWER FLORIDAN AQUIFER
  - FERNANDIA ZONE
- LOWER CONFINING UNIT (EXTREMELY LOW PERMEABILITY)
- BASEMENT ROCKS

BLACKHAWK GEOSCIENCES, INC.

GENERALIZED HYDROGEOLOGIC SECTION FOR STUDY AREA
ST. JOHNS RIVER WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) Figure 2-1

3.0 LOGISTICS, EQUIPMENT AND DATA PROCESSING

3.1 LOGISTICS

The general locations for time domain electromagnetic (TDEM) measurements were determined by SJRWMD. Using the general locations, Blackhawk Geosciences Inc. (BGI) personnel positioned the transmitter loops and receiver station with compass and measuring string. The transmitter loop locations were selected to mitigate, to the maximum extent possible, against interferences caused by buried pipelines, other utility lines, fences, power lines, and buildings. The transmitter loops were formed of 12-gauge insulated wire laid out in either a square or rectangle on the surface. Dimensions of the loops were determined by the depth of exploration required and availability of open land. At sites 1 through 5, and site 18, loop sizes of 1,500 ft by 1,500 ft were employed, and at the remaining sites the transmitter loop sizes were 1,000 ft by 1,000 ft. Most of the transmitter loops were square in shape, but at site 5 access required that a five-sided loop be used. The actual dimensions of the transmitter loops at each sounding location are shown on the location maps in Section 5.0. The locations of the loops were plotted on maps by SJRWMD personnel.

The field crew consisted of three persons, a geophysicist and two geophysical technicians. A representative of SJRWMD was also present during the field work. Table 3-1 summarizes the daily field activities.

3.2 EQUIPMENT

The Geonics EM37 and EM42 TDEM systems were used in acquiring the data for this survey. Both sets of equipment use the current waveform illustrated in Figure 3-1, consisting of equal periods of time-on and time-off. Figure 3-2 illustrates the difference in data acquisition between the EM37 and EM42. In the EM37 an analog stack is performed, and after completion of the stacking and analog to digital conversion, the data are stored in solid state memory. Normally, at the completion of a survey day, the data are transferred to a computer for data processing, plotting and interpretation. During field operations no real-time processing is available. Minimum detectable signal in typical, urban, ambient-noise environments is 10^{-9} Voltage/Amps-meter^2 (normalized by current in transmitter loop, and effective area of receiver coil).

In the EM42 the transient is sampled at 400 μs intervals, and these samples are digitally stored on high density floppy disks. "Smart stacking" is applied to the data in real time. The minimum detectable signal with the EM42 in typical ambient noise environments is 10^{-12} V/A-m^2.

3.3 DATA PROCESSING

3.3.1 EM37 System

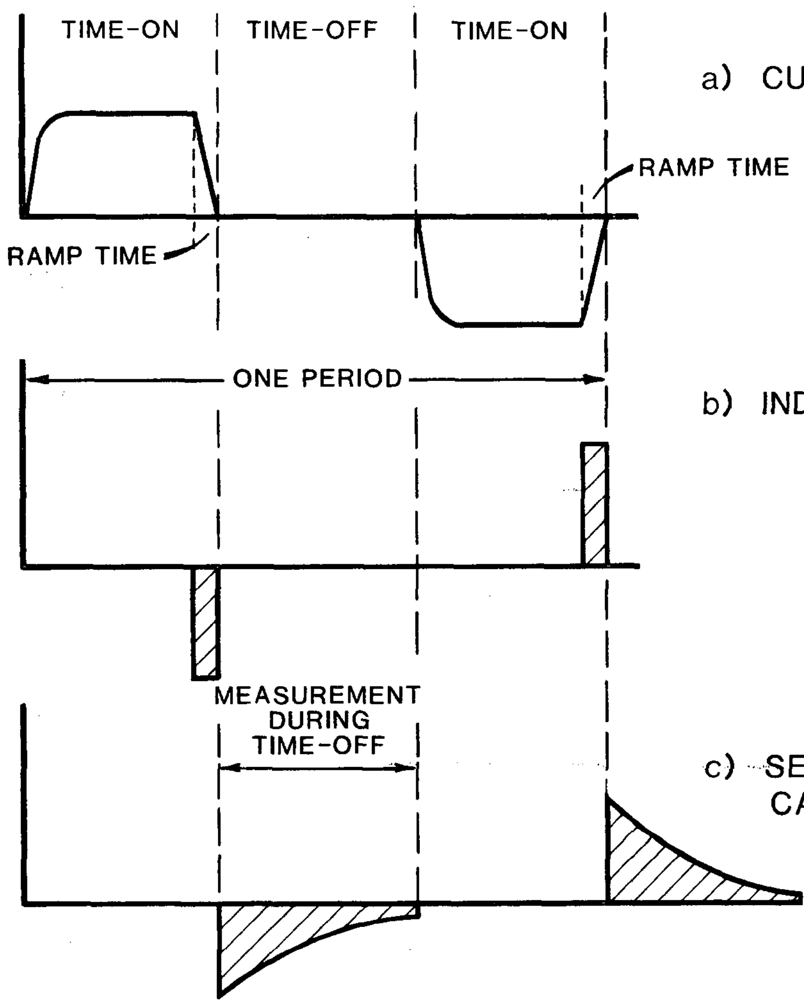
The data acquired with the EM37 system was stored in a DAS-54 solid memory logger and was transferred each day to floppy disks on a computer. The first step in data processing was to average the emf's recorded at opposite receiver polarities. Next, the recordings at different amplifier gains and frequencies are combined to produce one transient decay. The emf's in the various time gates of this decay curve are subsequently entered into a ridge regression inversion program to obtain a one-dimensional geoelectric section that matches the observed decay curve.

3.3.2 EM42 System

The data acquired with the EM42 system is digitally recorded directly into a microcomputer. With this system post acquisition processing is possible. Normally the data is processed to remove individual data sets that statistically are inconsistent, and to remove noise from 60-cycle electric power lines which tend to be the major source of noise for TDEM surveys in urban areas. This processed data is then entered into a ridge regression program to obtain a one-dimensional geoelectric section.

Table 3-1. Daily log of field activities

Date (1992)	Activity
July 11-14	Mobilize equipment and personnel from Denver, CO to Jacksonville, FL.
July 15	Read Cecil Field (Site 1) EM42 TDEM sounding.
July 16	Read Silco Tract (Site 2) EM42 TDEM sounding.
July 17	Read Hilliard (Site 3) EM42 TDEM sounding.
July 18	Read Garden Street (Site 4) EM42 TDEM sounding.
July 19	Read Ponte Vedra (Site 5) EM42 TDEM sounding. Mobilize to Palatka, FL.
July 20	Read Satsuma (Site 6) and Crescent City (Site 7) EM37 soundings.
July 21	Read Seville (Site 8) and Pierson (Site 9) EM37 soundings. Mobilize to Longwood, FL.
July 22	Read Mitchell-Hammock (Site 10) and Yankee Lake (Site 11) EM37 soundings.
July 23	Read Astor Farms (Site 12) and Sanford (Site 13) EM37 soundings.
July 24	Read Altamonte Springs (Site 14) and Lake Emma (Site 15) EM37 soundings.
July 25	Read Lower Wekiva 1 (Site 16) EM37 sounding.
July 26	Read Lower Wekiva 2 (Site 17) EM37 sounding. Mobilize to Palatka, FL.
July 27	Read Camp Blanding (Site 18) EM42 sounding.
July 28-31	Demobilize equipment and personnel from Palatka, FL to Denver, CO.



a) CURRENT IN TRANSMITTER LOOP

b) INDUCED ELECTROMOTIVE FORCE

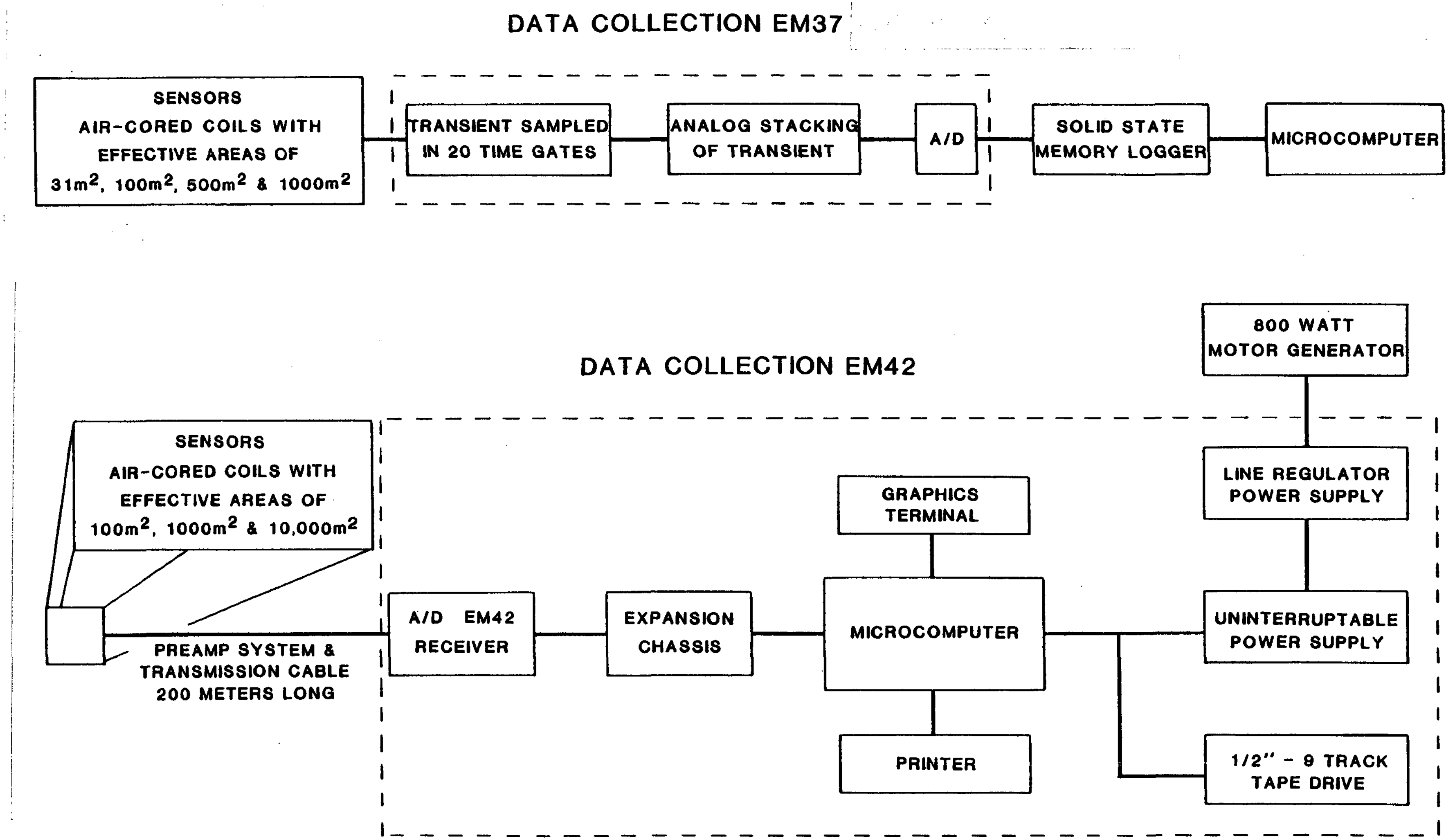
c) SECONDARY MAGNETIC FIELD CAUSED BY EDDY CURRENTS

BLACKHAWK GEOSCIENCES, INC.

SYSTEM WAVEFORMS EMPLOYED IN GEONICS EM-37 & EM-42

ST. JOHNS RIVER WATER MANAGEMENT DISTRICT

PROJECT NO:9001-000 (92022) | Figure 3-1



BLACKHAWK GEOSCIENCES, INC.

BLOCK DIAGRAMS OF
TDEM SYSTEMS

ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT

PROJECT NO:9001-000 (92022) Figure 3-2

4.0 TECHNICAL APPROACH

4.1 GENERAL

The interpretation of the time domain electromagnetic (TDEM) data from this survey consisted of several tasks. These are:

- Inversion of apparent resistivity curves into geoelectric profiles and evaluation of equivalence
- Distinguishing reliable soundings from soundings distorted by interference
- Correlation of geoelectric profiles derived from inversions to chloride concentration
- Determination of depth of occurrence of 250 mg/l isochlor and depth to salt water (defined by 5,000 mg/l isochlor).

This section of the report discusses the technical approach to accomplish these tasks.

4.2 INVERSION OF APPARENT RESISTIVITY CURVES INTO GEOELECTRIC PROFILES, EVALUATION OF EQUIVALENCE (TASK 1)

4.2.1 Definition and Function of Apparent Resistivity

The definition of apparent resistivity, the computation of apparent resistivity curves, and the inversion process in which a geoelectric section is modeled to the apparent resistivity data, are important steps in the interpretation of TDEM data. Apparent resistivity is defined as the resistivity of a homogeneous isotropic ground giving the same voltage-time relationship as measured over a multi-layered section. Because of their importance, they are briefly reviewed here.

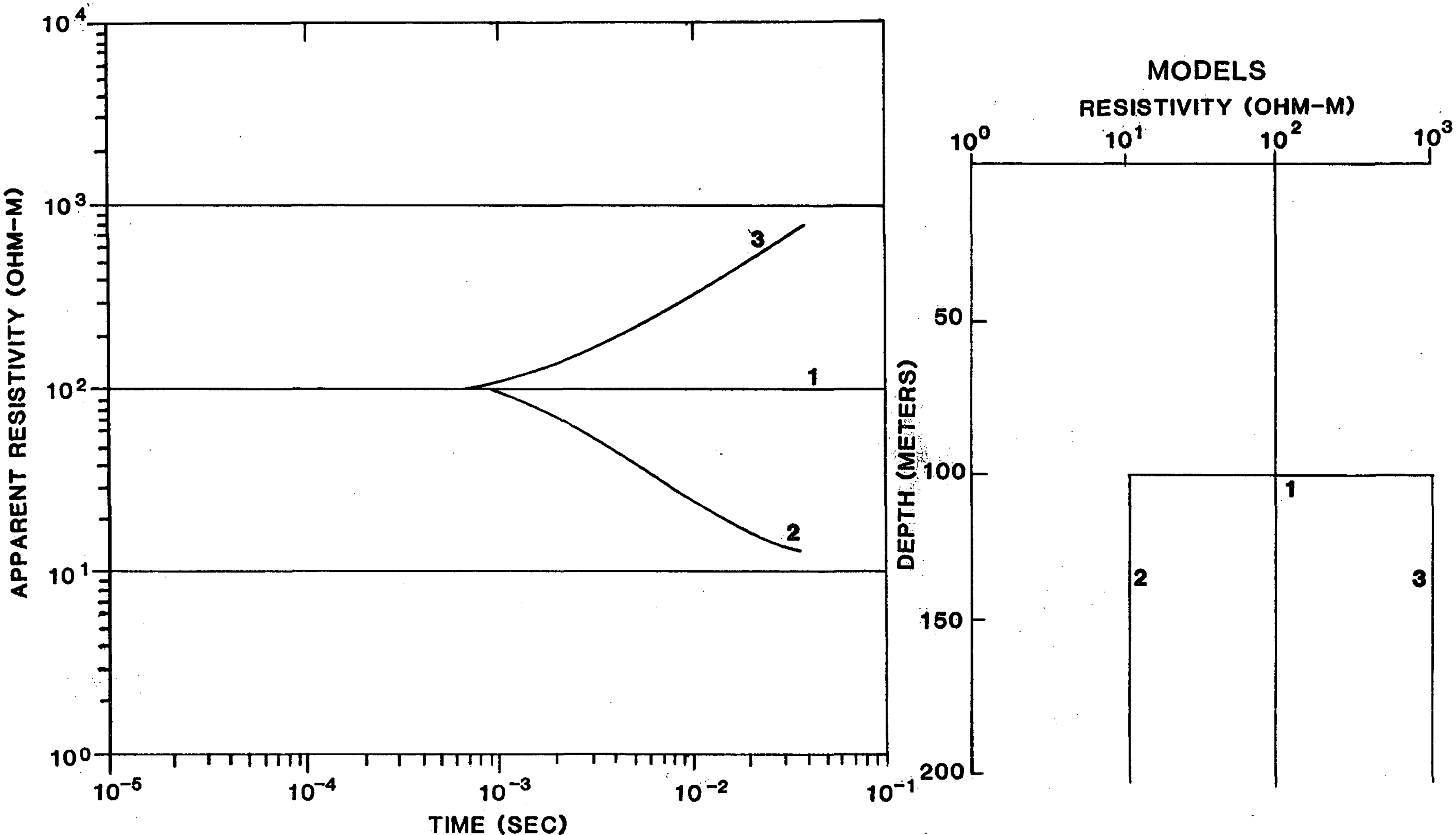
The field data from a TDEM geophysical survey consists of voltages (electromotive forces) which decay with time. These voltages are transformed into apparent resistivities to better visualize how the geoelectric profile, over which a measurement is made, differs from a geoelectric profile with a uniform resistivity.

Figure 4-1 shows three computed apparent resistivity curves for three different idealized geoelectric sections. In TDEM, effective exploration depth increases with time of measurement after turn-off. The principals of TDEM soundings are discussed in a technical note in Appendix A located at the back of this volume. In model 1 the resistivity is uniform with depth and the apparent resistivity is constant over the entire time interval. In model 2 true resistivities decrease with depth, and the apparent resistivity curves reflect that, i.e., the apparent resistivities can be seen to decrease with increasing time. In model 3 the resistivity increases with depth and at later time the apparent resistivity curve also shows an increase. Thus, qualitative information about the geoelectric section can be visualized from displaying the data as apparent resistivities.

The function of an apparent resistivity curve can be further explained by the example shown in Figure 4-2. The apparent resistivity values can be seen to continuously decrease with increasing time, and to asymptotically approach a value between 10 ohm-m and 20 ohm-m. Thus, from merely viewing the behavior of the apparent resistivity curve, the conclusions can be drawn that (i) the resistivities decrease with depth, and (ii) the resistivity of the lowest layer within the effective exploration depth of the measurement is between 10 ohm-m and 20 ohm-m.

To derive more quantitative information the experimental data points are submitted to an automatic ridge regression transient inversion (ARRTI) program developed by Interpex Limited of Golden, Colorado. This inversion program finds the geoelectric section of the subsurface that best matches the observed data. The inversion program requires an initial model for the geoelectric section. A model consists of the number of layers within the effective exploration depth, and the resistivities and thicknesses for each layer. Such an initial model can be obtained in a number of ways, such as

- approximate matching of apparent resistivity curves with model curves from albums of model curves,
- from knowledge of the geoelectric section based on resistivity logs run in drill holes,
- from conceptual models formed on the basis of known geology and water quality.



1- Geoelectric section is uniform and equals 100 ohm-m.

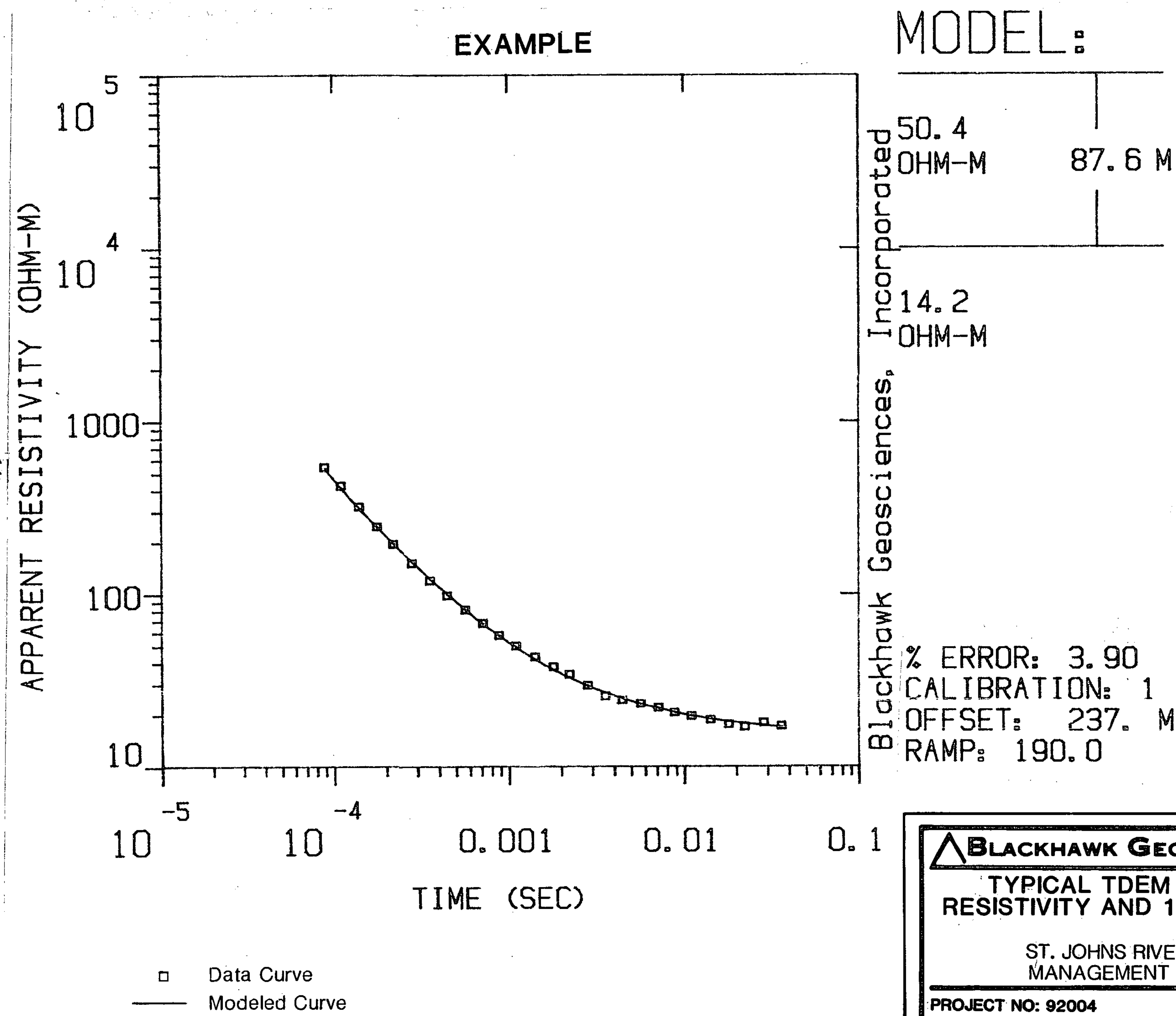
2- Two layer Geoelectric section with layer 1 resistivity 100 ohm-m and thickness of 100 meters. Layer 2 with infinite thickness and resistivity of 10 ohm-m.

3- Two layer Geoelectric section with layer 1 resistivity 100 ohm-m and thickness 100 meters. Layer 2 has infinite thickness and resistivity of 1000 ohm-m.

BLACKHAWK GEOSCIENCES, INC.

MODELED APPARENT RESISTIVITY CURVES
ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) **Figure 4-1**



BLACKHAWK GEOSCIENCES, INC.

TYPICAL TDEM APPARENT RESISTIVITY AND 1-D INVERSION

ST. JOHNS RIVER WATER MANAGEMENT DISTRICT

PROJECT NO: 92004 **Figure 4-2**

The inversion program is then allowed to adjust the model to improve the fit. This involves the adjustment of resistivities and thicknesses of the layers within the geoelectric model. The inversion program does not change the total number of layers submitted for the model, but all other parameters float freely or optionally can be held constant. To determine the influence of number of layers on the solution, separate inversions with a different number of layers may be run.

The geoelectric section obtained from the inversion routine that best matches the experimental data is shown on the right side of Figure 4-2. It consists of a two-layer geoelectric section consisting of an upper layer 87.6 m thick with a resistivity of 50.4 ohm-m. The second layer has a resistivity of 14.2 ohm-m and its thickness extends beyond the effective exploration depth of the measurement. The solid line on Figure 4-2 represents the computed behavior for the two-layer geoelectric section shown on the right, and the experimental data are superimposed on the solid line.

To evaluate the error between the geoelectric section derived from the inversion routine and the experimental data, a tabulation of the inversion and experimental data is also given for each site. The parameters listed on these tables are identified in Table 4-1 for the generalized sounding. Thus, this table lists the error (column 4) between experimental measurements (data, column 2) and calculated data (column 3) for each time gate of measurement (column 1). Also listed on the table is the root mean square (RMS) averaged over all time gates.

4.2.2 Analysis of Equivalence

The parameters derived for the geoelectric section by the ridge regression inversion are not unique, but generally a range of values will equally fit the observed data within the overall RMS error. This phenomena is called equivalence, and the range of equivalence differs for each parameter of a geoelectric section. It is a measure of how well each parameter is resolved, and for each sounding the equivalence was evaluated.

The equivalence analysis for the example sounding is shown on Figure 4-3, and the upper and lower bound for each parameter of the geoelectric section is also shown on Table 4-1. Thus, at this site the largest range of equivalence is in determining the depth to the second layer. It may vary from 80 m to 94 m and still result in the same RMS error. The ranges of equivalence for the resistivities of the first and second layer are relatively small.

EXAMPLE

MODEL: 2 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		12.2	40.0		
50.36	87.6	-75.4	-247.3	1.7	1.7
14.19					

Solution Geoelectric Section

Inversion Table

	TIMES	DATA	CALC	% ERROR	STD ERR
1	8.90E-05	5.46E+02	5.36E+02	1.955	
2	1.10E-04	4.24E+02	4.14E+02	2.399	
3	1.40E-04	3.21E+02	3.15E+02	1.981	
4	1.77E-04	2.46E+02	2.46E+02	0.182	
5	2.20E-04	1.94E+02	1.97E+02	-1.253	
6	2.80E-04	1.51E+02	1.55E+02	-2.519	
7	3.55E-04	1.20E+02	1.23E+02	-3.069	
8	4.43E-04	9.80E+01	1.01E+02	-2.880	
9	5.64E-04	8.08E+01	8.16E+01	-0.902	
10	7.13E-04	6.75E+01	6.70E+01	0.826	
11	8.81E-04	5.75E+01	5.72E+01	0.541	
12	1.10E-03	4.99E+01	4.91E+01	1.570	
13	1.41E-03	4.32E+01	4.17E+01	3.603	
14	1.80E-03	3.78E+01	3.64E+01	4.045	
15	2.22E-03	3.42E+01	3.28E+01	4.404	
16	2.83E-03	2.94E+01	2.93E+01	0.574	
17	3.55E-03	2.56E+01	2.68E+01	-4.320	
18	4.43E-03	2.43E+01	2.49E+01	-2.452	
19	5.64E-03	2.32E+01	2.30E+01	0.983	
20	7.13E-03	2.20E+01	2.18E+01	1.075	
21	8.81E-03	2.06E+01	2.07E+01	-0.497	
22	1.10E-02	1.96E+01	1.97E+01	-0.497	
23	1.41E-02	1.86E+01	1.89E+01	-1.604	
24	1.80E-02	1.76E+01	1.82E+01	-3.485	
25	2.22E-02	1.70E+01	1.77E+01	-4.029	
26	2.85E-02	1.80E+01	1.72E+01	4.460	
27	3.60E-02	1.72E+01	1.68E+01	2.225	

R: 237. X: 0. Y: 237. DL: 475. REQ: 264. CF: 1.0000

TDHZ ARRAY, 27 DATA POINTS, RAMP: 190.0 MICROSEC, DATA: 03-01

BLACKHAWK GEOSCIENCES, INC.

EXAMPLE INVERSION TABLE

ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT

PROJECT NO:9001-000 (92022) Table 4-1

RMS Error

RMS LOG ERROR: 1.66E-02, ANTILOG YIELDS 3.8953 %

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

Result of Computation of Equivalence

LAYER		MINIMUM	BEST	MAXIMUM
RHO	1	46.620	50.357	54.730
	2	13.612	14.189	14.831
THICK	1	79.931	87.560	94.326
DEPTH	1	79.931	87.560	94.326

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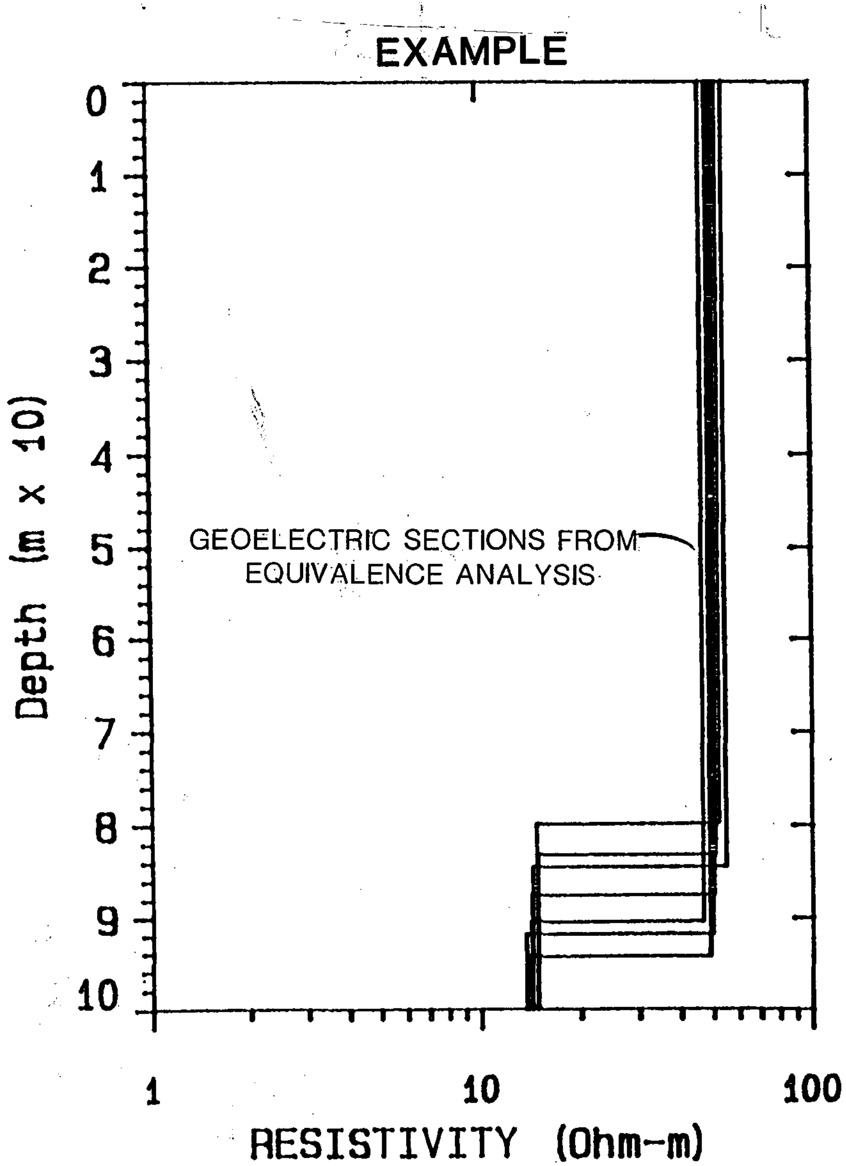
EXAMPLE INVERSION TABLE (CONTINUED)

ST. JOHNS RIVER WATER MANAGEMENT DISTRICT

PROJECT NO:9001-000 (92022) Table 4-1



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EQUIVALENCE IN 1-D INVERSION

ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT

PROJECT NO:9001-000 (92022) **Figure 4-3**

Examination of the equivalence was performed for all 18 sites. The ranges of equivalence are dependent on the particular geoelectric section encountered. Also when the number of layers increases, the range of equivalence of some parameters in the section may be quite large.

4.3 DISTINGUISHING RELIABLE SOUNDINGS FROM SOUNDINGS DISTORTED BY INTERFERENCE (TASK 2)

Parts of the survey area, particularly Seminole County, are heavily urbanized and TDEM station locations in such areas are subject to noise. In TDEM two types of noise must be considered:

1) Ambient electrical noise due to power lines, radio stations and spherics. This noise can to a large extent be mitigated by stacking, which is the averaging of multiple sets of data taken at a sounding location. The duration of on-and-off pulses is a few milliseconds, and many pulses of positive and negative polarities are stacked in a short period of time and averaged to remove noise. That process can be very effective in dealing with ambient electrical noise, and successful surveys have been performed in athletic fields and parks in urban areas in the presence of strong ambient noise.

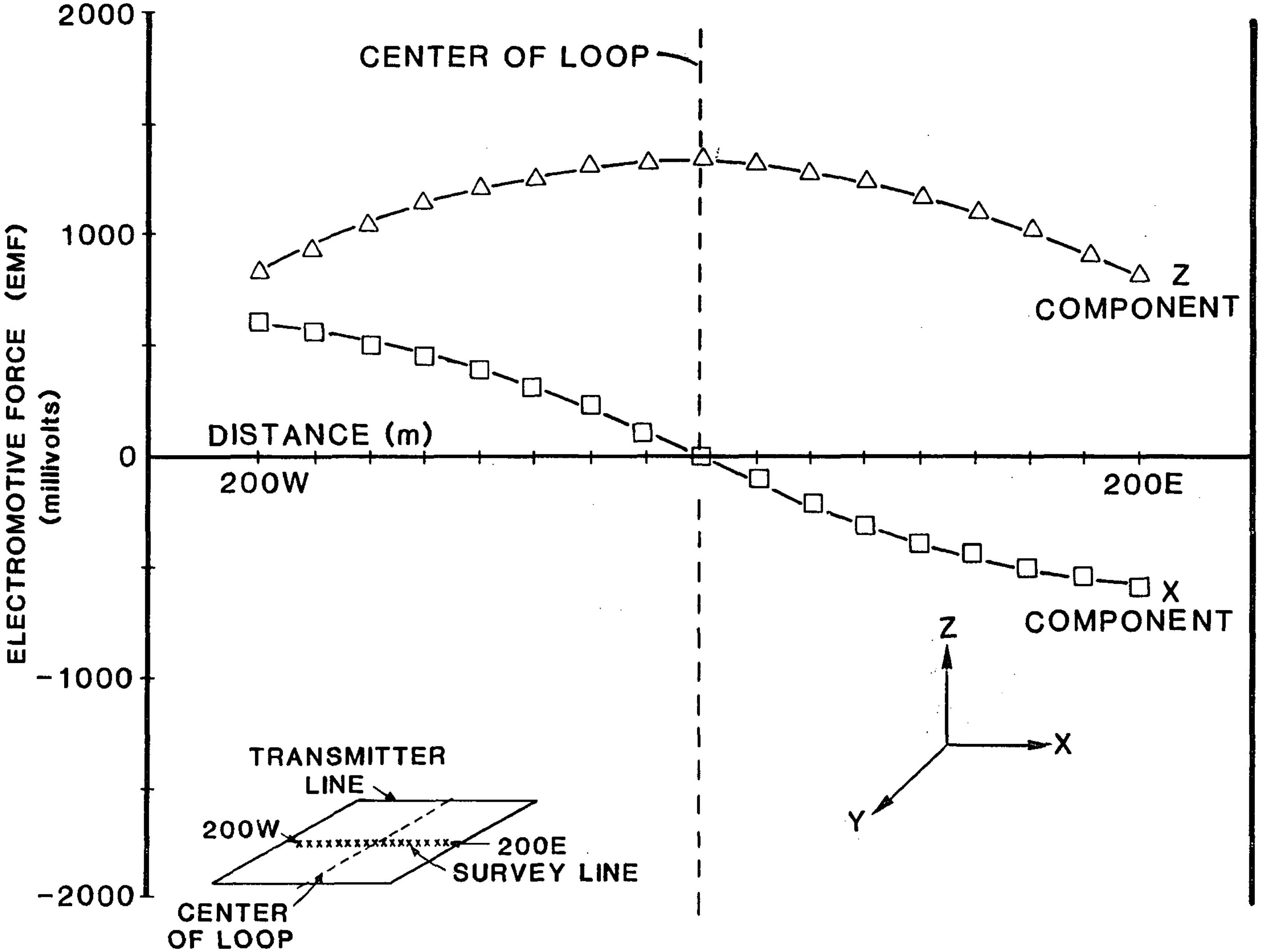
2) Inductive noise due to coupling in metallic structures, such as buried utilities, fences, grounded power lines and buildings. The primary magnetic field of the transmitter will not only induce eddy current flow in the subsurface, but also in metallic structures. These structures in turn will radiate a secondary magnetic field that is measured at the receiver together with the field caused by eddy currents in the ground. This source of noise cannot be removed by stacking, because it is coherent with the transmitter waveform. It can only be minimized by selecting locations away from the influence of inductive noise sources. The distance required between TDEM receiver stations and inductive noise sources depends on a number of factors, such as required exploration depth, transmitter loop dimension, geoelectric section, and the type of inductive noise source. It can range from 100 ft over conductive geoelectric sections and for small inductive noise sources (e.g., a building), to a thousand feet for resistive geoelectric sections for deep exploration depth requirements, and for elongated structures such as pipelines. Lack of availability of good measurement locations in urban and industrial areas is a major limitation of TDEM surveys.

The procedures adopted for recognizing the influence of inductive noise is based on the information conveyed by Figure 4-4. Figure 4-4 shows a typical measured behavior of the electromotive forces (emf's) due to the horizontal and vertical magnetic fields on a profile through the center of the loop over horizontally stratified ground at 2.2 millisec after current turn-off. At other times the behavior would be similar, but of different amplitude. The behavior of emf_z (vertical) is relatively flat about the center, so that measurements made at different locations inside the loop should be nearly identical. On the other hand, measurements in the presence of interference by metallic structures depend on distance of the receiver from such structures. Figure 4-5a shows four apparent resistivity data curves measured at different locations inside a transmitter loop. From the coincidence of the four curves of Figure 4-5a no inductive noise is expected. Figure 4-5b shows apparent resistivity curves from measurements at five stations inside a loop, and substantial deviation between the curves is observed, indicating the presence of inductive noise. This measurement would be rejected because at present no reliable procedures to accurately remove this inductive noise are available.

The procedures outlined above are routinely performed for TDEM soundings in urban settings. To determine which soundings are distorted, the criteria is employed:

1) Noisy data. The apparent resistivity curve data points show a large amount of scatter along the entire curve and a large total RMS error. An example of this type of curve is shown in Figure 4-6. In addition, noisy data can be localized in some portion of the curve with only a limited amount of scatter along the rest of the curve. If this scatter occurs along the latter portion of the curve, these data points are deleted and an interpretation is made on the remaining data. The validity of this interpretation is checked based on other soundings in the vicinity or available ground truth. In urban settings data with this type of noise may still be usable if it is not too severe. It does, however, often result in a total RMS error of the fit of model curve to greater than 5%. Because of this the total RMS error may not be sufficient to determine if TDEM is distorted.

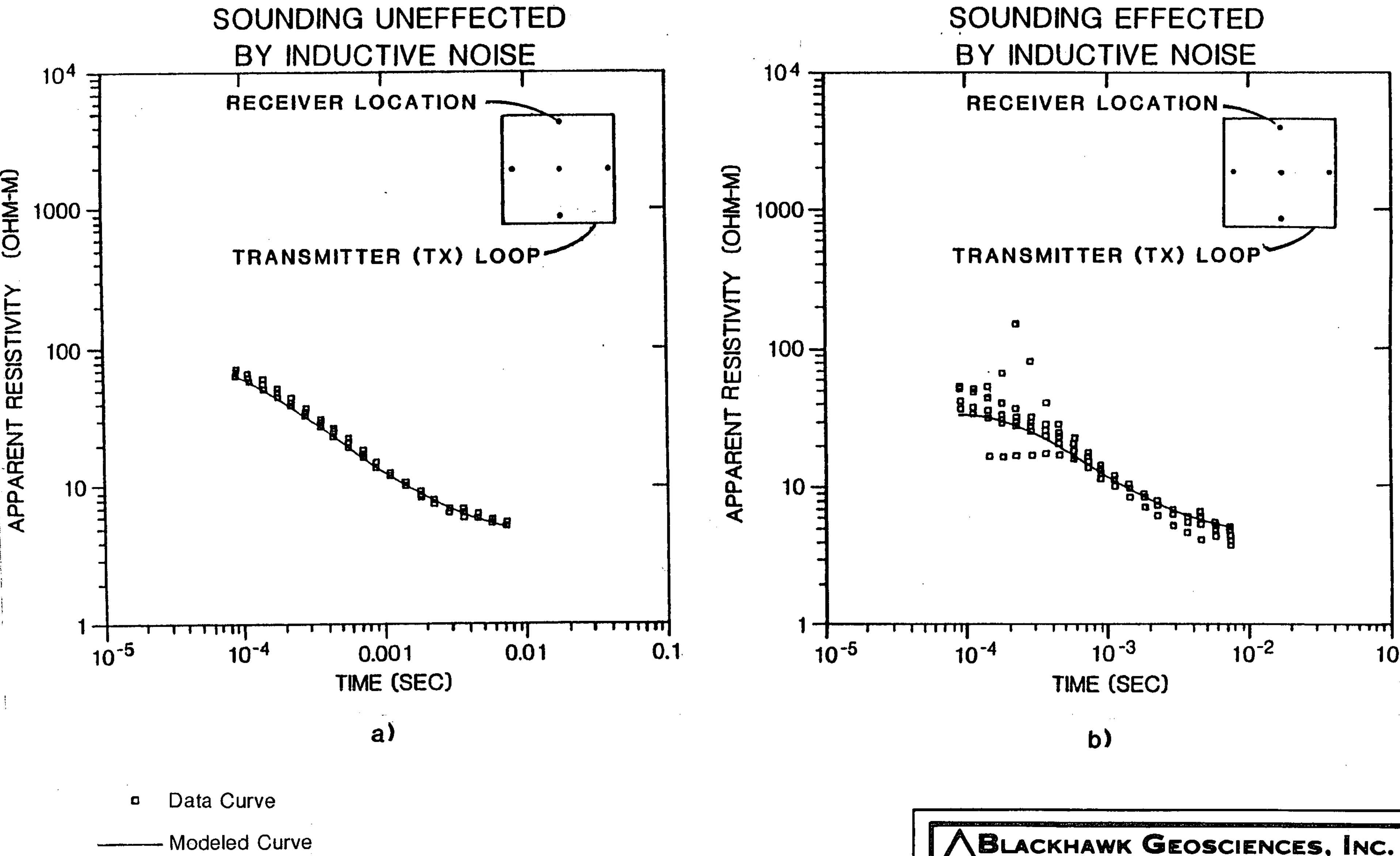
2) Modeling of an unrealistic geoelectric section to the data. For the "typical" Floridan aquifer it is assumed that average porosities over wide areas average between 25 and 35%. At these porosities, it is unlikely that ground water salinities would be high enough to result in bulk resistivities less than 2 ohm-m. For example, a $<$ 2 ohm-m layer with a porosity of 25% would require a salinity of greater than 30,000 mg/l which would be



BLACKHAWK GEOSCIENCES, INC.

SPATIAL BEHAVIOR OF
EMF_Z AND EMF_X ON PROFILE
THROUGH CENTER OF LOOP
ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT

PROJECT NO:9001-000 (92022) Figure 4-4

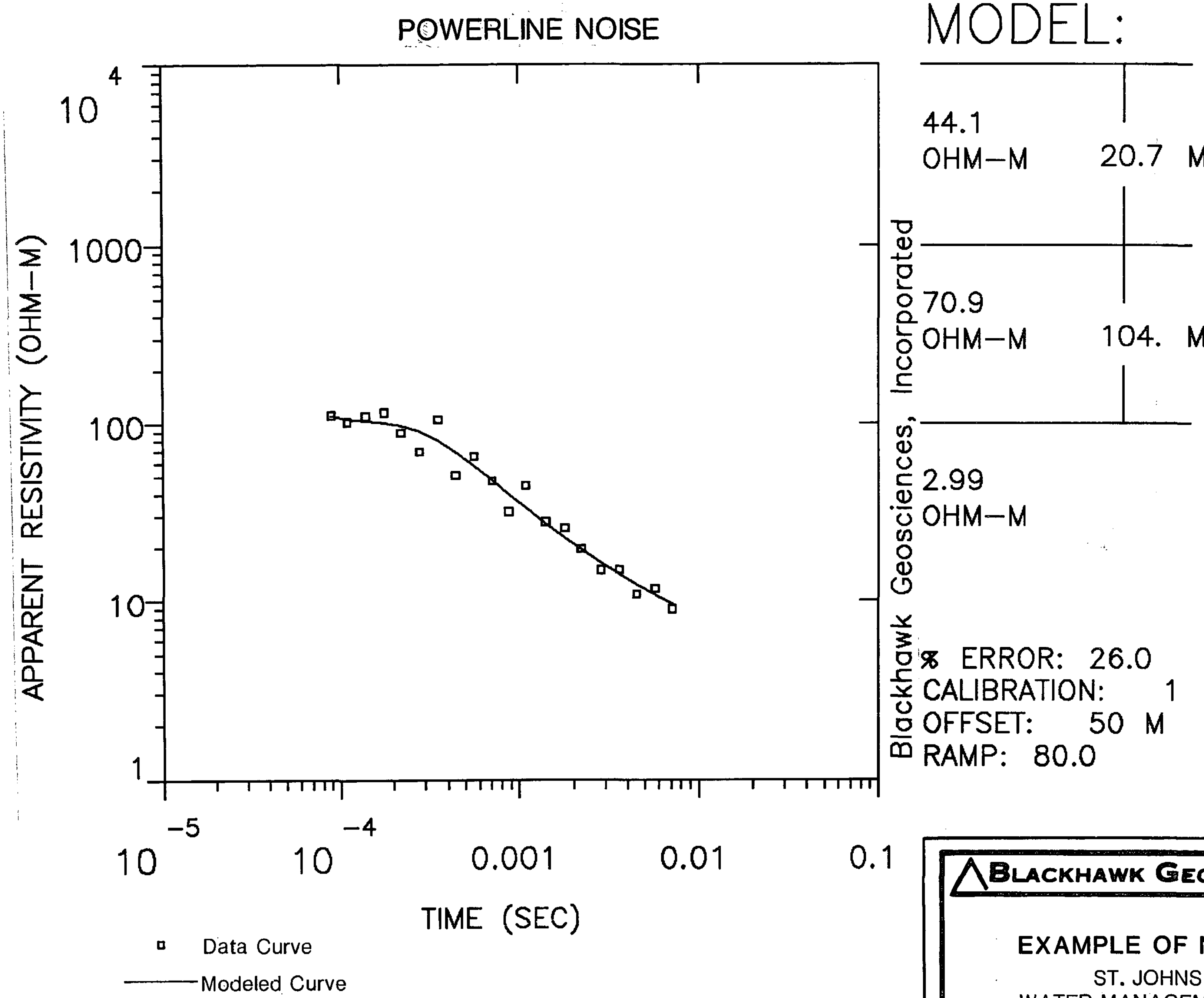


BLACKHAWK GEOSCIENCES, INC.

APPARENT RESISTIVITY CURVES AT POSITIONS INSIDE TX LOOP

ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT

PROJECT NO:9001-000 (92022) **Figure 4-5**



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BLACKHAWK GEOSCIENCES, INC.

EXAMPLE OF NOISY DATA

ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT

PROJECT NO:9001-000 (92022) **Figure 4-6**

unrealistic for most of the Floridan aquifer. The soundings in Seminole County would be considered distorted if they required modeling layers less than 2 ohm-m to fit the data. Figure 4-7 shows an example of this type of sounding.

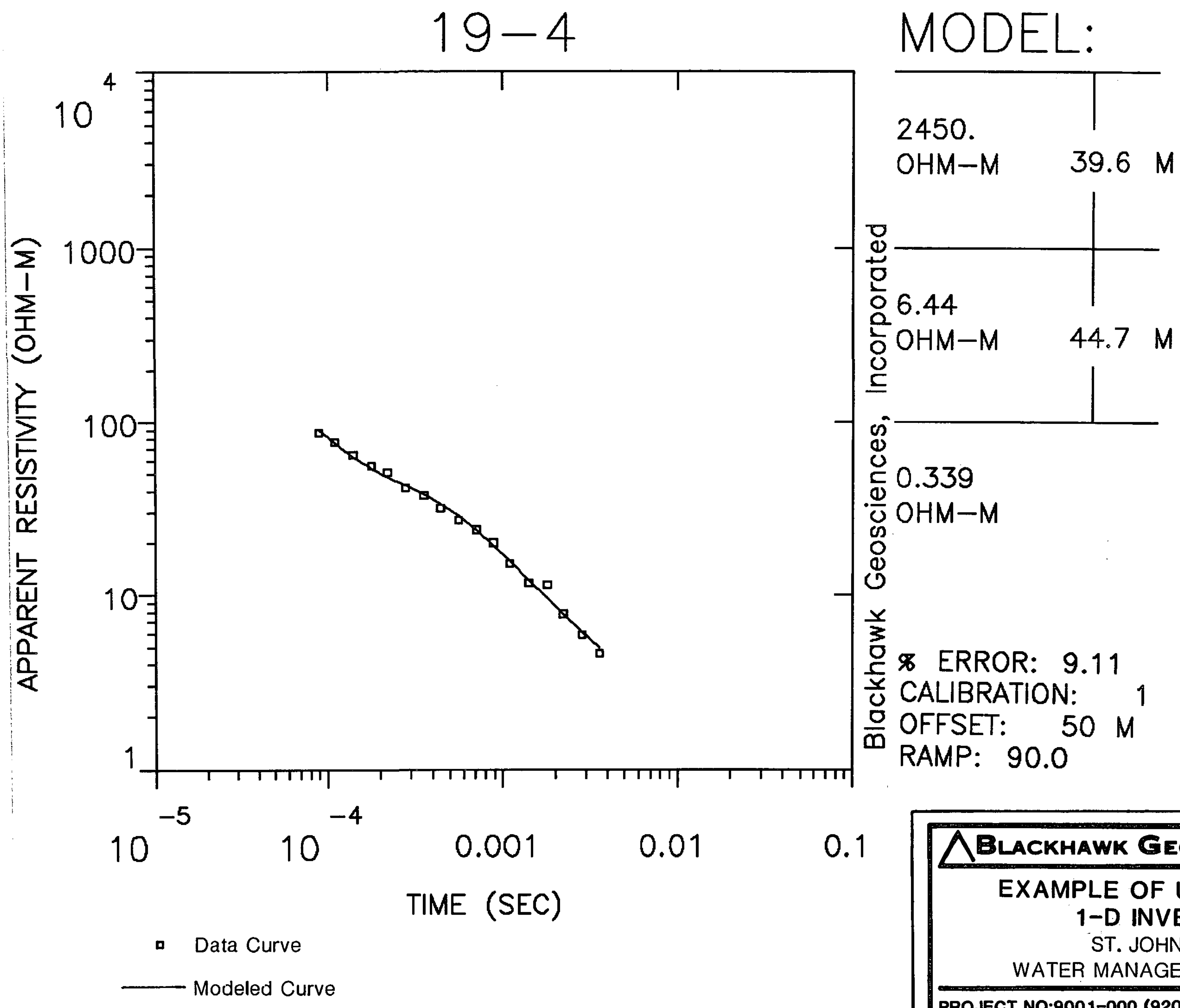
This criteria, however, must be considered with care. The EM42 soundings made around the City of Jacksonville, except for Ponte Vedra (Site 5) are likely detecting a real low resistivity layer below the base of the Floridan aquifer because this zone occurs at depth substantially greater than the thickness of the Floridan aquifer system reported by Krause and Randolph (1989). These low resistivity zones may occur within evaporite sequences underlying the Floridan or within upper Cretaceous shales. The salinity of pore fluids within these units can be significantly greater than sea water, and as a result formation resistivities can be significantly lower than those encountered within the Floridan aquifer. Most of the EM42 soundings interpret resistivities at depths less than 1.0 ohm-m. Such low resistivities likely indicate brines of high total dissolved solids in formations below the Floridan aquifer, and not distorted data.

3) Modeled geoelectric section from a sounding is not consistent with other soundings or well data within the general area. This criteria is based on the assumption that large isolated fluctuations in the depth to either the 250 mg/l or 5,000 mg/l isochlor are unlikely. Rapid changes in the depths to the isochlors are assumed to occur only along regional trends. This criteria eliminates the "bullseye" type anomalies which are determined by one or two soundings. This clearly is the most subjective criteria, because it presupposes a certain behavior, albeit a reasonable one, on the isochlors. It may, however, result in the rejection of valid soundings in areas where isolated pockets of poor quality water (> 250 mg/l Cl) occur.

4.4 CORRELATION OF GEOELECTRIC PROFILES DERIVED FROM INVERSIONS TO CHLORIDE CONCENTRATION (TASK 3)

From the soundings determined to be reliable, geoelectric sections were derived by 1-D inversions. In this section the procedures used in correlating the geoelectric sections to water quality in the Floridan aquifer are discussed.

The hydrogeologic section across the survey area can be separated into two regions:



BLACKHAWK GEOSCIENCES, INC.

EXAMPLE OF UNREALISTIC 1-D INVERSION

ST. JOHNS RIVER WATER MANAGEMENT DISTRICT

PROJECT NO:9001-000 (92022) **Figure 4-7**

(1) The EM42 soundings made in the area around the city of Jacksonville required a depth of exploration of greater than 2,000 ft. The depth to saline ground water inferred from the soundings is (except for Ponte Vedra) likely located beneath the Floridan aquifer. Due to the anomalous characteristics of the formations underlying the Floridan aquifer, i.e., extremely high ground water salinities and unknown permeability, the correlation between formation resistivity and chloride concentration derived for the Floridan aquifer cannot be used to infer chloride concentrations for the low resistivity layers for the soundings at sites 1 through 4, and at site 18. A chloride content for the low resistivity layers interpreted at these sites is greater than 5,000 mg/l.

(2) The EM37 soundings acquired were mainly located in Seminole County, but included sites 6 through 9 in Putnam and Volusia Counties. The saline ground water interface for these soundings are inferred to occur within the Floridan aquifer system. In addition, depth to the top of the Floridan aquifer generally was less than 200 ft. The approach used to correlate interpreted resistivities from TDEM data to ground water chloride content is discussed below.

The resistivity of a water bearing rock is mainly a function of lithology, dissolved solids in ground water, and porosity. Most rock forming minerals are essentially insulators and nearly all electrical current is carried either by free ions in pore water or by exchangeable ions associated with clay particles. To separate the causes of vertical and lateral variation in a geoelectric section requires careful correlation with lithology, and often assumptions about the dominant cause of resistivity variation locally must be made. Within the survey area variation in lithology is mainly expected in the Hawthorn Group and younger surficial units. The composition of these formations can vary from coarse-grained sands and gravels to clays. Thus, in the Hawthorn Group and younger sediments three factors potentially can influence resistivity, - lithology (clay content), porosity, and water quality. Without other independent information the causes of lateral and vertical resistivity variation cannot be separated, and no attempt has been made to infer information about water quality from resistivity measurements for the formations above the Floridan aquifer.

On the other hand, the lithology of the carbonate rocks comprising the Floridan aquifer system in this area are expected to be uniform. The resistivity of the rocks of the Floridan aquifer will be mainly determined by porosity and dissolved solids concentrations of the pore fluids. Archie's Law is used to express the relationship between formation resistivity, Ro; fluid resistivity, Rw; and porosity, ϕ:

$$F = Ro/Rw = a\ \phi^{-m} \qquad [1]$$

where F = formation factor and a,m are empirically derived constants dependent on lithology and pore type distribution. Kwader (1982) found a value of m = 1.6 and a = 1 to best fit his many observations from wells completed in the Upper Floridan aquifer in Seminole County.

Fluid resistivity is a function of concentration of dissolved solids and ionic composition. The most common cations in water in the Upper Floridan aquifer are calcium, magnesium and sodium; the most common anions are bicarbonate, chloride and sulfate. Water quality is often expressed in terms of equivalent chloride concentrations. Kwader (1982) established on the basis of many measurements on water samples throughout Seminole County the relation between chloride concentration and fluid resistivity, Rw, given by

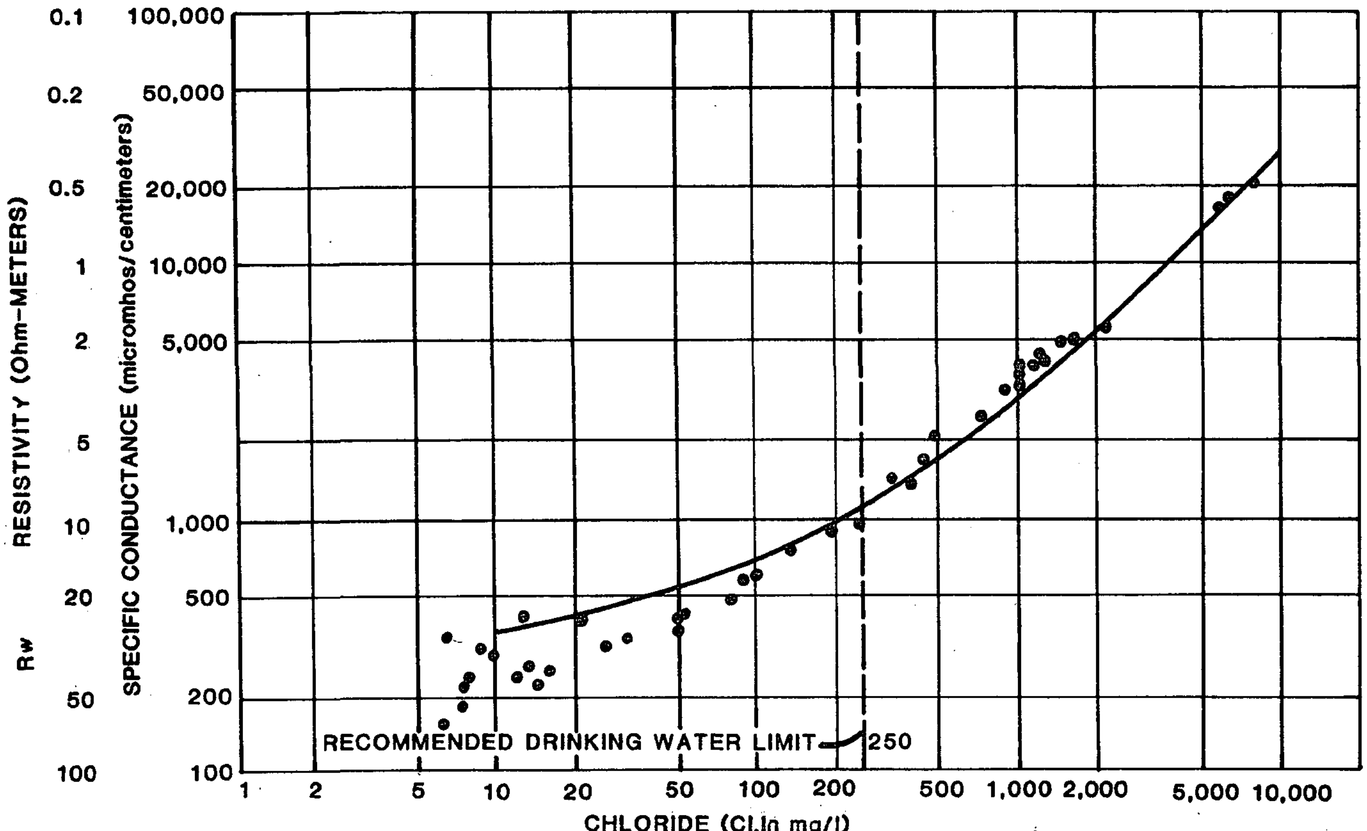
$$CL = 3500/Rw - 153 \qquad [2]$$

where CL is chloride concentration in mg/l, and Rw is fluid resistivity in ohm-meter.

Equation [2] assumes that the ratio between chloride content and other ions within the ground water is approximately constant. The sulfate anion is the most likely species whose content will vary relative to chloride depending primarily on the amount of gypsum and anhydride within the geologic section. In Seminole County the chloride/sulfate ratio is approximately 5:1 (Sprinkle, 1989). When equation [2] is utilized in areas other than Seminole County it is assumed that the chloride/sulfate ratio for ground water within the Floridan aquifer is approximately 5:1. If this ratio varies significantly from 5:1 Kwader's equation [2] may not be valid.

A graphic presentation of equation [2] is given in Figure 4-8, and it also shows the data points from which relation [2] was derived. The maximum chloride concentrations for which data points were available to Kwader (1982) was about 10,000 mg/l, and the relation is untested at higher chloride concentrations.

By combining equations [1] and [2] chloride concentration can be related to formation resistivity as a function of porosity, and this relation is displayed in Figure 4-9. Thus, for the Upper Floridan aquifer with an average porosity of 25%, chloride concentrations less than 250 mg/l are expected when its formation resistivity is greater than 80 ohm-m. Chloride concentrations greater than 5,000 mg/l would be indicated by formation resistivity values less than about 6.2 ohm-m.



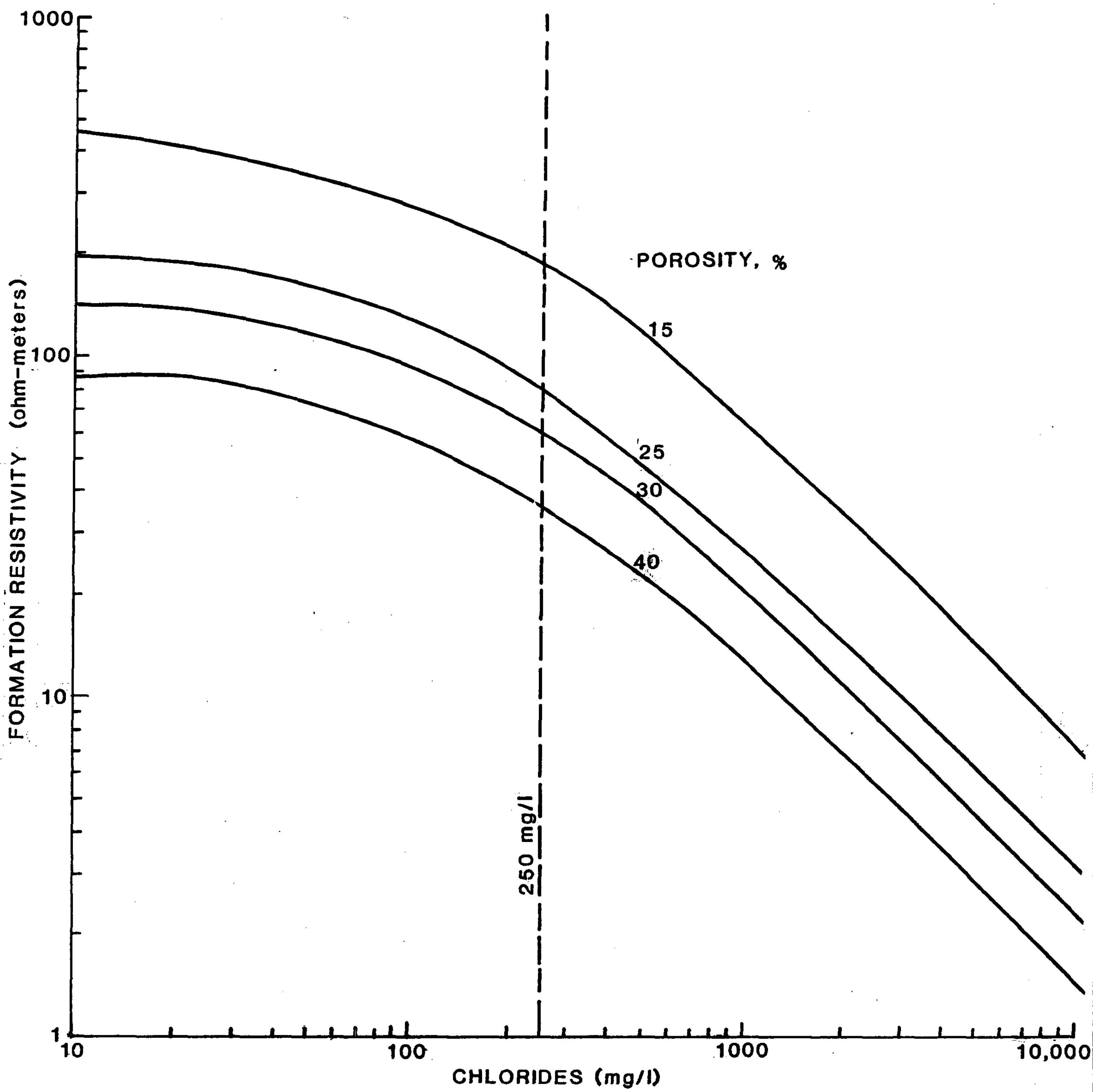
(After: Kwader, 1982

BLACKHAWK GEOSCIENCES, INC.

FLUID RESISTIVITY (Rw) VERSUS CHLORIDE CONCENTRATION

ST. JOHNS RIVER WATER MANAGEMENT DISTRICT

PROJECT NO:9001-000 (92022) **Figure 4-8**



BLACKHAWK GEOSCIENCES, INC.

FORMATION RESISTIVITY VERSUS CHLORIDE CONCENTRATION

ST. JOHNS RIVER WATER MANAGEMENT DISTRICT

PROJECT NO:9001-000 (92022) **Figure 4-9**

It is evident from the above discussion that to derive chloride concentration from a measured value of formation resistivity certain assumptions must be made. The assumptions consistently made for all the TDEM soundings are:

a) The relation (Fig. 4-8) between fluid resistivity and chloride concentration established by Kwader (1982) for Seminole County is valid. This implies a chloride to sulfate ratio of 5:1 for ground water within the Floridan aquifer.

b) In deriving chloride content within the Floridan aquifer from formation resistivity, an average porosity of 25% was used for all sites. Information about porosity of the Floridan aquifer is limited. In one published data set, porosities were computed from geophysical logs over the depth interval between 338 ft and 458 ft. Porosities over this depth range varied between 12% to 32% (NW Florida Water Management District, 1983). Since site specific information about porosities was not available, a porosity value of 25% has been used at all TDEM sites. The reference listed above is the only independent information about porosity available. Moreover, comparison between well information and TDEM derived geoelectric sections at several sites throughout the St. Johns River Water Management District indicate 25% porosity to result in reasonable agreement (Blackhawk Geosciences, Inc., 1992).

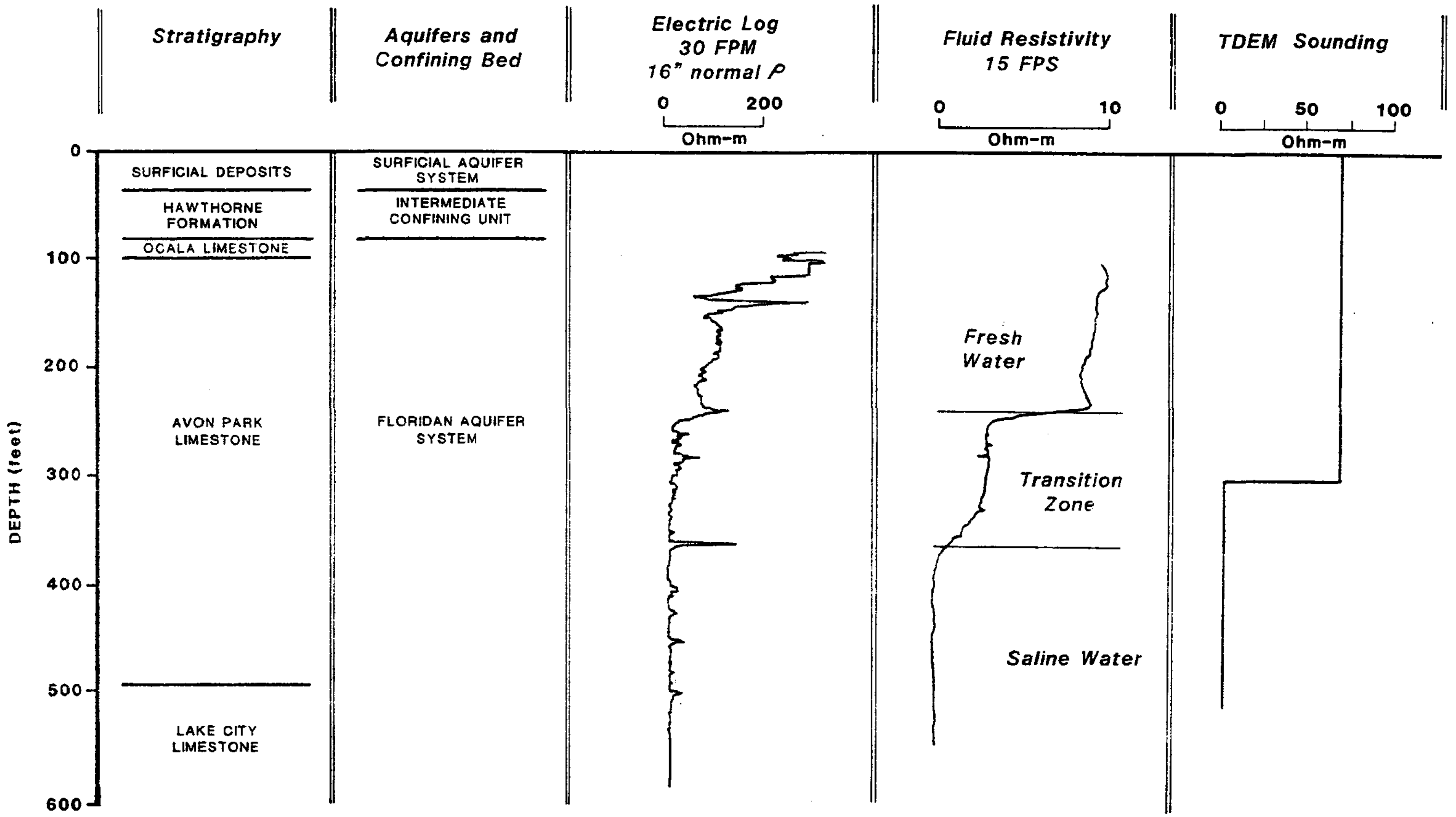
c) In the Hawthorn Group and more recent formations, resistivity values are influenced by changes in lithology, porosity, and chloride concentration. This precluded inferring meaningful interpretations about chloride concentrations in the Hawthorn Group and the formations overlying it. Inferences about water quality are, therefore, ideally drawn only for the carbonate rocks below the Hawthorn Group, and for each site an evaluation must be made of the extent clay stringers in the Hawthorn Group may have influenced the average resistivity value measured. Therefore, the total thickness of the upper one or two layers resolved in the geoelectric section are compared with published information on the thickness of the Hawthorn and younger sediments overlying the Floridan aquifer in the area of the sounding. If the thicknesses are comparable, it is assumed that a resistivity contrast occurs between the Floridan and overlying sediments and the TDEM sounding is mapping this interface. If the thicknesses are not comparable, it is assumed that there is insufficient contrast in resistivity between the Floridan and overlying sediments. In this case, the total thickness of the upper one or two layers is fixed in the inversion at the expected total thickness for the sediments overlying the Floridan aquifer. Those soundings in which the thicknesses of surficial layers are fixed, are noted in the discussion of sounding results. The fixed value is based on published information.

In Seminole County good information about the thickness of the surficial sediments and the Hawthorn Group is available from Tibbals (1977), while for sites outside of Seminole County, information from Krause and Randolph (1989) and Ross and Munch (1980) was utilized. No information about equivalent chloride concentration can be inferred for layers above the Floridan.

4.5 DETERMINATION OF DEPTH OF OCCURRENCE OF 250 MG/L AND 5,000 MG/L ISOCHLOR (TASK 4)

As discussed in the preceding section, a resistivity of 80 ohm-m within the Floridan aquifer corresponds to a chloride content of 250 mg/l, and a resistivity of 6.2 ohm-m corresponds to chloride content of 5,000 mg/l, assuming 25% porosity. In nearly all the inverted geoelectric sections these exact resistivities are not derived from 1-D inversions. Therefore, to determine the depth of occurrence of resistivities corresponding to chloride concentrations of 250 mg/l and 5,000 mg/l certain manipulations and assumptions need to be made.

The contact between brackish to saline water (> 250 mg/l Cl) and fresh water (< 250 mg/l Cl) in an aquifer is not abrupt. Normally, a transition zone exists, in which salinities gradually change from fresh water to saline water. Figure 4-10 shows a salinity profile encountered in a well drilled in northeast Seminole County. The transition zone from saline to fresh water in this example is approximately 100 ft thick. The TDEM method usually does not measure the transition zone as a separate layer unless its thickness is large, relative to its depth. The resistivity boundary determined by TDEM is normally positioned near the center of the transition zone. Thicknesses of transition zones are variable depending mainly on salinity contrasts and ground water mixing. Significant mixing is most prevalent in areas of high ground water flow. In the procedures adapted to compute depth to the 250 mg/l and 5,000 mg/l isochlor thicknesses of transition zones are varied based on probable assumptions derived from the geoelectric section. The geoelectric sections derived in the survey were placed in classes as shown in Figure 4-11. A summary of the criteria utilized in positioning the 250 mg/l isochlor is contained in Table 4-2.

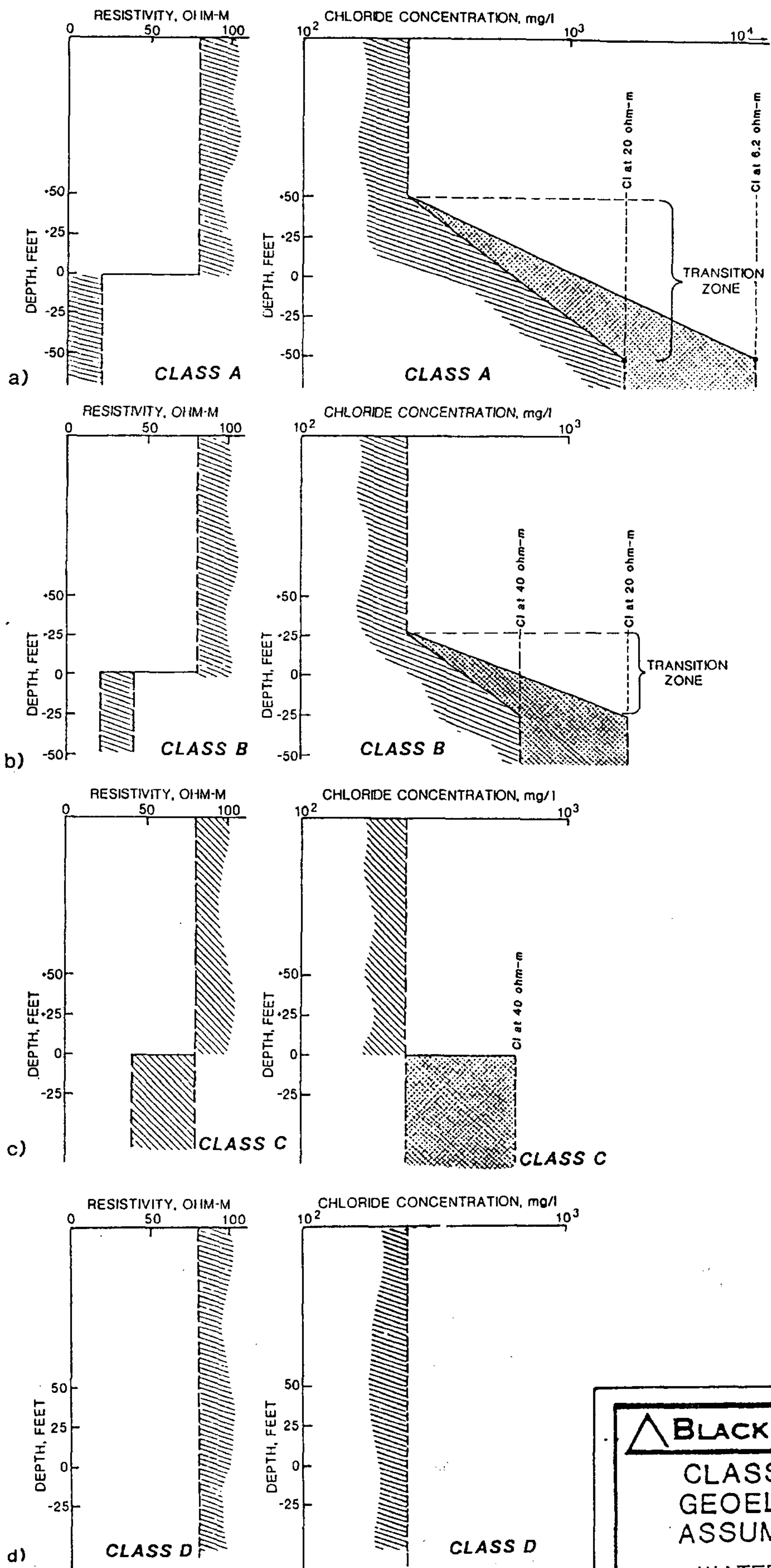


BLACKHAWK GEOSCIENCES, INC.

SALINITY PROFILE OF WELL IN SEMINOLE COUNTY

ST. JOHNS RIVER WATER MANAGEMENT DISTRICT

PROJECT NO:9001-000 (92022) **Figure 4-10**



BLACKHAWK GEOSCIENCES, INC.

CLASSIFICATION OF TYPICAL GEOELECTRIC PROFILES AND ASSUMED SALNITY PROFILES

ST. JOHNS RIVER WATER MANAGEMENT DISTRICT.

PROJECT NO:9001-000 (92022)

Figure 4-11

Table 4-2. Summary of Criteria for Positioning the 250 mg/l Isochlor

Class	Lowest Resistivity Encountered in Geoelectric Section	Chloride Values Corresponding to Lowest Resistivity in Geoelectric Section	Position of Isochlor Relative to Modeled Geoelectric Boundary
A	< 20 ohm-m	> 1,450 mg/l	50 ft higher
B	> 20 ohm-m, < 40 ohm-m	> 650 mg/l, < 1,450 mg/l	25 ft higher
C	> 40 ohm-m, < 80 ohm-m	> 250 mg/l, < 650 mg/l	Same position
D	> 80 ohm-m	< 250 mg/l	Requires modeling

4.5.1 Class A

In the geoelectric section (Fig. 4-11a) layers with resistivities greater than 80 ohm-m overlay layers with resistivities less than 20 ohm-m. The corresponding model for equivalent chloride concentrations used is also shown in Figure 4-11a. An example of a sounding over a geoelectric section in this class is Site 8. The assumptions made in relating the geoelectric sections to equivalent chloride concentration profiles are:

1) The transition zone is assumed to be 100 ft thick. The 250 mg/l isochlor occurs at the top of the interface, and 50 ft above the resistivity boundary measured with TDEM. In the transition zone chloride concentration varies exponentially with depth. Hence, Cl (mg/l) = A exp $(\text{depth})^B$, where A and B are constants.

2) The chloride concentration at the bottom of the transition zone depends on the resistivity determined in the geoelectric section immediately below the layer with a resistivity greater than 80 ohm-m.

4.5.2 Class B

In the geoelectric section layers with resistivities greater than 80 ohm-m overlay layers with resistivities greater than 20 ohm-m and less than 40 ohm-m. The corresponding model for equivalent chloride concentrations used is also shown on Figure 4-11b. This survey does not have an example of this type transition zone. The assumptions made in relating the geoelectric section to equivalent chloride concentration profiles are:

1) The transition zone is assumed to be 50 ft thick. The 250 mg/l isochlor occurs at the top of the interface and 25 ft above the resistivity boundary measured with TDEM. Again, in the transition zone chloride concentrations are assumed to increase exponentially with depth.

2) The chloride concentration at the bottom of the transition zone depends on the resistivity of the geoelectric section immediately below the layer with a resistivity greater than 80 ohm-m.

4.5.3 Class C

In the geoelectric section layers with resistivities greater than 80 ohm-m overlay layers with resistivities greater than 40 ohm-m and less than 80 ohm-m. The corresponding model for equivalent chloride concentrations used is also shown on Figure 4-11c. An example of a sounding over a geoelectric section in this class is Site 16. The assumptions made in relating the geoelectric section to equivalent chloride concentration profiles are:

1) The transition zone is assumed to be thin and the top of the 250 mg/l isochlor is assumed to be at the same depth as the resistivity boundary.

2) The chloride concentration at the bottom of the transition zone depends on the resistivity of the geoelectric section immediately below the layer with a resistivity greater than 80 ohm-m.

4.5.4 Class D

In the geoelectric section (Fig. 4-11d) no layers with a resistivity less than 80 ohm-m are encountered within the effective exploration depth of the measurement, and the 250 mg/l isochlor also is assumed to occur at a depth greater than the effective exploration depth of the measurement. No soundings of this type were encountered in the present survey.

The grouping of the geoelectric sections in four classes yielded an approach for calculating the depth to the 250 mg/l isochlor. Next, an approach for determining the depth to the 5,000 mg/l isochlor is discussed.

Using a porosity of 25% for the Upper Floridan aquifer and the relation shown in Figure 4-9, a resistivity of 6.2 ohm-m corresponds to an equivalent chloride concentration of 5,000 mg/l. The criteria utilized in determining the depth of the 5,000 mg/l isochlor is dependent on the type of geoelectric section encountered and is explained below:

1) When the contrast in resistivities in the modeled geoelectric section is between a layer with a resistivity greater than 80 ohm-m (corresponding to chlorides less than 250 mg/l) and a layer with a resistivity of less than 20 ohm-m (corresponding to chlorides greater than 1,450 mg/l) the transition zone between these waters is assumed to be approximately 100 ft thick, as shown in Figure 4-11 and as previously explained for class A. The position of the 5,000 mg/l isochlor is assumed to be 50 ft below the position of the mapped resistivity contrast which normally occurs near the center of the transition zone (Fig. 4-10). It is likely that chloride concentrations rapidly increase with depth at high salinities and the 5,000 mg/l isochlor occurs only a small distance below the 1,450 mg/l isochlor.

2) When the contrast in resistivities in the modeled geoelectric section is between a layer with resistivities from 20 ohm-m to 80 ohm-m (corresponding to chlorides of between 1,450 and 250 mg/l) and a layer with a resistivity of less than 20 ohm-m (corresponding to chlorides greater than 1,450 mg/l) it is assumed that the transition zone between the two ground waters is thin since the chloride concentration gradient is expected to be steep at higher salinities. For this type of geoelectric section, the position of the 5,000 mg/l isochlor is placed at the top of the layer with a resistivity of less than 20 ohm-m.

4.5.5 Layers Mapped Beneath the Floridan Aquifer

The assumptions utilized in developing a scheme to correlate bulk formational resistivities with chloride content are not valid for formations underlying the Floridan aquifer. The reasons for this are:

1) The porosities of these formations may be significantly less than the Floridan aquifer, although relatively thin (≈ 100 ft) horizons of higher porosity may exist.

2) The salinity of the pore fluids are likely to be significantly greater than sea water due to the presence of evaporites and shales in the sequence. Kwader's correlation of fluid resistivity and chloride content (Fig. 4-8) does not hold at these high salinities.

For those soundings mapping a low resistivity zone below the Floridan aquifer, an estimate of the chloride content for this layer cannot be made, although it is likely that the ground water is highly saline. The position of the 5,000 mg/l and 250 mg/l isochlors also cannot be determined for these soundings. The position of the low resistivity zone below the Floridan aquifer indicates that these isochlors do not occur within the Floridan aquifer. It is likely that most ground water in formations below the Floridan aquifer has a chloride content in excess of 5,000 mg/l. The low porosity within these formations, however, may cause formation resistivities to be high even though interstitial ground waters may be saline. The reason for this is illustrated in Archie's Law (Equation 1). As the porosity of a lithologic unit decreases, the ratio between the formation resistivity (Ro) and the fluid resistivity (Rw) increases. For example, a formational porosity of 10% results in a Ro/Rw ratio of 40, while for a porosity of 5% this ratio increases to 120.

For a strata below the Floridan aquifer to have a formation resistivity less than 1 ohm-m, a porosity in excess of 10% is required. The extremely high salinities of ground water that are expected below the Floridan aquifer result in low bulk formational resistivities even for relatively low porosity zones (10% to 20%). These zones can be detected by TDEM soundings even though they may be thin.

5.0 RESULTS AND DISCUSSION

5.1 SUMMARY OF RESULTS

In this section, the results of all 18 sites are summarized. In Sections 5.2 through 5.19, the results of the time domain electromagnetic (TDEM) measurements at the 18 sites are given. In these sections, the geoelectric section is shown, and information about first depth of occurrence of highly saline water (5,000 mg/l isochlor) and depth of occurrence of the 250 mg/l isochlor are inferred from the geoelectric section.

Table 5-1.1 lists the sites, equipment utilized at each site, the dimensions of the transmitter loops employed, the county in which the site is located, and the longitude and latitude of the center of the loop.

In Table 5-1.2, the geoelectric section measured at each site is summarized. It first lists the number of layers of different resistivities used in the inversion. This number corresponds to the number of distinct resistivity boundaries resolved with surface TDEM within the effective exploration depth of the measurement. For each parameter of the geoelectric section (resistivities and thicknesses), the range of equivalences are given in terms of the minimum and maximum value this parameter can assume, and the "best" value.

Table 5-1.3 summarizes the first depth of occurrence of ground water with a chloride concentration greater than 1,450 mg/l at 25% porosity. As explained under Task 3 of Section 4, it is assumed that the 5,000 mg/l isochlor is nearly coincident with the position of any isochlor greater than 1,450 mg/l. Since information about chloride concentration is derived from resistivity values, the correlation of resistivities to chloride concentrations require assuming a value of porosity. In Table 5-1.3, chloride concentrations are derived for three porosity values - 25%, 30% and 35%. The depth to saline water listed on Table 5-1.3 is expected to represent the top of the boundary between ground water of chloride concentrations less than 5,000 mg/l and ground water with chloride concentrations greater than 5,000 mg/l. Likely chloride concentrations gradually increase below this interface, and gradually decrease above it. The inversion of TDEM data can, at present, only resolve distinct boundaries, and transition zones are not mapped. The depth listed is based on the criteria outlined under Task 3, which is described in Section 4. For soundings in which saline water is detected below the Floridan aquifer, the relationship between formation resistivity and chloride concentration is unknown and the depth to the 5,000 and 250 mg/l isochlor cannot be determined. This is because the ground water composition and formational porosities are significantly different from the Floridan aquifer and consequently the assumptions utilized in deriving Figure 4-9 are not valid. For sites 1 through 4 and site 18 the low resistivity zones which are detected below the Floridan aquifer likely represent saline water within shales or carbonates and evaporites in which porosities are greater than 10%. Saline water may exist in formations above the low resistivity layers but the bulk porosities of these formations would be less than 10%.

Table 5-1.4 lists the depths of the 5,000 mg/l and 250 mg/l isochlor for each sounding.

Table 5-1.1 - **Geographic Information About Measurement Sites**

Site Name	Equipment Utilized	Site #	County	Loop Size (ft)	Latitude	Longitude
Cecil Field	EM-42	1	Duval	1,500 x 1,500	30°11'34"	81°53'06"
Silco Tract	EM-42	2	Camden, GA	1,500 x 1,500	30°55'05"	81°46'45"
Hilliard	EM-42	3	Nassau	1,500 x 1,500	30°43'52"	81°56'28"
Garden Street	EM-42	4	Duval	1,500 x 1,500	30°23'50"	81°51'25"
Ponte Vedra	EM-42	5	St. Johns	1,600 x 1,600	30°11'33"	81°23'09"
Satsuma	EM-37	6	Putnam	1,000 x 1,000	29°32'12"	81°38'32"
Crescent City	EM-37	7	Putnam	1,000 x 1,000	29°28'27"	81°32'32"
Seville	EM-37	8	Volusia	1,000 x 1,000	29°19'15"	81°28'50"
Pierson	EM-37	9	Volusia	1,000 x 1,000	29°13'22"	81°28'26"
Mitchell-Hammock	EM-37	10	Seminole	1,000 x 1,000	28°39'02"	81°13'18"
Yankee Lake	EM-37	11	Seminole	1,000 x 1,000	28°49'04"	81°23'53"
Astor Farms	EM-37	12	Seminole	1,000 x 1,000	28°49'55"	81°21'52"
Sanford	EM-37	13	Seminole	1,000 x 1,000	28°47'02"	81°19'37"
Altamonte Springs	EM-37	14	Seminole	1,000 x 1,000	28°39'36"	81°25'03"
Lake Emma	EM-37	15	Seminole	1,000 x 1,000	28°43'51"	81°21'39"
Lower Wekiva I	EM-37	16	Seminole	1,000 x 1,000	28°49'10"	81°24'24"
Lower Wekiva II	EM-37	17	Seminole	1,000 x 1,000	28°50'10"	81°23'50"
Camp Blanding	EM-42	18	Clay	1,500 x 1,500	29°55'55"	82°00'33"

Table 5-1.2
Summary of Geoelectric Sections with Range of Equivalence

Site Name	Number of Modeled Layers in Geoelectric Section	Layer 1 Resistivity ρ_1 (ohm-m) Min	Best	Max	Layer 1 Thickness h_1 (meters)* Min	Best	Max	Layer 2 Resistivity ρ_2 (ohm-m) Min	Best	Max	Layer 2 Thickness h_2 (meters)* Min	Best	Max	Layer 3 Resistivity ρ_3 (ohm-m) Min	Best	Max	Layer 3 Thickness h_3 (meters)* Min	Best	Max	Layer 4 Resistivity ρ_4 (ohm-m) Min	Best	Max	Total Depth To Deepest Conductor which is Interpreted as Saline Water (meters)* Min	Best	Max
1 Cecil Field	4	69	104	135	67	84	94	2.3	3.4	13.1	8.7	13	51	600	900	1300	860	900	980	0.9	0.9	0.9	960	1000	1080
2 Silco Tract	3	38	42	46	120	120	120	56	65	75	630	680	720	1.6	2.4	3.6							750	800	840
3 Hilliard	4	72	106	169	30	40	48	19	21	26	66	82	125	55	66	83	569	640	705	0.7	1.4	2.7	706	762	818
4 Garden Street	3	43	46	49	145	145	145	79	100	129	690	800	940	0.2	0.7	2.5							830	950	1080
5 Ponte Vedra	4	53	89	234	23	33	44	10	13	17	40	60	91	47	54	70	420	470	510	4.2	5.5	7.0	530	560	590
6 Satsuma	3	25	27	30	11	13	14	84	104	134	7.6	24	36	139	152	168	225	234	244	10.6	13.6	17.3	260	270	280
7 Crescent City	3	34	44	50	20	45	63	71	78	86	240	250	280	1.8	2.2	2.7							300	300	300
8 Seville	3	17	24	32	16	30	52	89	120	160	200	220	250	4.8	6.6	8.9							250	250	260
9 Pierson	4	47	89	150	25	25	25	9.8	20	47	8.9	17	47	180	260	560	280	310	320	1.9	2.9	4.3	350	350	360
10 Mitchell-Hammoc	3	22	38	50	12	26	40	190	220	250	430	450	470	6.7	10	15							470	470	490
11 Yankee Lake	3	91	130	240	30	30	30	95	110	130	240	260	270	5.1	7.1	9.7							270	290	300
12 Astor Farms	3	38	48	72	4.9	21	56	45	49	54	250	290	320	6.3	8.4	11.							280	310	330
13 Sanford	Distorted																								
14 Altamonte Springs	Distorted																								
15 Lake Emma	3	53	110	390	20	20	20	140	170	280	300	340	370	8.3	15	25							320	360	390
16 Lower Wekiva I	4	101	236	1292	20	20	20	337	745	2357	43	55	79	48	57	63	229	251	264	5.2	6.0	6.9	316	325	335
17 Lower Wekiva II	3	30	64	94	15	15	15	29	35	54	44	52	57	10	11	12							59	67	73
18 Camp Blanding	3	55	60	65	125	125	125	110	120	150	660	710	740	0.5	1.1	2.1							790	830	867

*1 meter equals 3.28 ft

Table 5-1.3

Interpreted Depths to Saline Water and Estimated Chloride Concentrations at Three Porosities

	Site	Formation Resistivity (ohm-m)	Interpreted Depth of Saline Water Occurrence (ft below surface)	Estimated Chloride Concentration (Mg/l) at 3 Porosities — Porosity 25%	30%	35%
1*	Cecil Field	0.9	3,264	Cannot	Be	Determined
2*	Silco Tract	2.4	2,618	Cannot	Be	Determined
3*	Hilliard	1.4	2,500	Cannot	Be	Determined
4*	Garden Street	0.7	3,102	Cannot	Be	Determined
5	Ponte Vedra	5.5	1,845	5,700	4,220	3,260
6	Satsuma	14.0	939	2,200	1,600	1,230
7	Crescent City	2.2	975	>10,000	>10,000	8,370
8	Seville	6.6	881	4,700	3,490	2,690
9	Pierson	2.9	1,204	>10,000	8,130	6,320
10	Mitchell-Hammock	10.0	1,604	3,060	2,250	1,720
11	Yankee Lake	7.1	993	4,400	3,230	2,490
12	Astor Farms	8.4	1,007	3,680	2,710	2,080
13	Sanford	Distorted Sounding				
14	Altamonte Springs	Distorted Sounding				
15	Lake Emma	15	1,232	1,990	1,450	1,100
16	Lower Wekiva I	6.0	1,068	5,200	3,850	2,975
17	Lower Wekiva II	11.0	219	2,770	2,030	1,550
18*	Camp Blanding	1.2	2,727	Cannot	Be	Determined

*Position of saline water interface is below Floridan aquifer.

Table 5-1.4

Depth to 5,000 mg/l and 250 mg/l Isochlor as Determined by Time Domain Electromagnetics

	Site	Interpreted Depth of 5,000 mg/l Isochlor (ft below surface)	Interpreted Depth of 250 mg/l Isochlor
1	Cecil Field	Not present in Floridan aquifer	Not present in Floridan aquifer
2	Silco Tract	Not present in Floridan aquifer	Cannot be determined
3	Hilliard	Not present in Floridan aquifer	Cannot be determined
4	Garden Street	Not present in Floridan aquifer	Not present in Floridan aquifer
5	Ponte Vedra	1,845	Cannot be determined
6	Satsuma	939	839
7	Crescent City	975	Cannot be determined
8	Seville	881	781
9	Pierson	1,204	1,104
10	Mitchell-Hammock	1,604	1,504
11	Yankee Lake	993	893
12	Astor Farms	1,007	Not present in Floridan aquifer
13	Sanford	Sounding Distorted	
14	Altamonte Springs	Distorted Sounding	
15	Lake Emma	1,232	1,132
16	Lower Wekiva I	1,068	246
17	Lower Wekiva II	219	Not present in Floridan aquifer
18	Camp Blanding	Not present in Floridan aquifer	Not present in Floridan aquifer

5.2 CECIL FIELD (SITE 1)

5.2.1 Location and Geoelectric Section

The detailed location map of the Cecil Field sounding is shown in Figure 5-2.1. The interpreted geoelectric section is shown in Figure 5-2.2 and Table 5-2.1 and consists of four layers. The equivalence plot of the geoelectric section is shown in Figure 5-2.3.

5.2.2 Geologic Interpretation of Geoelectric Section

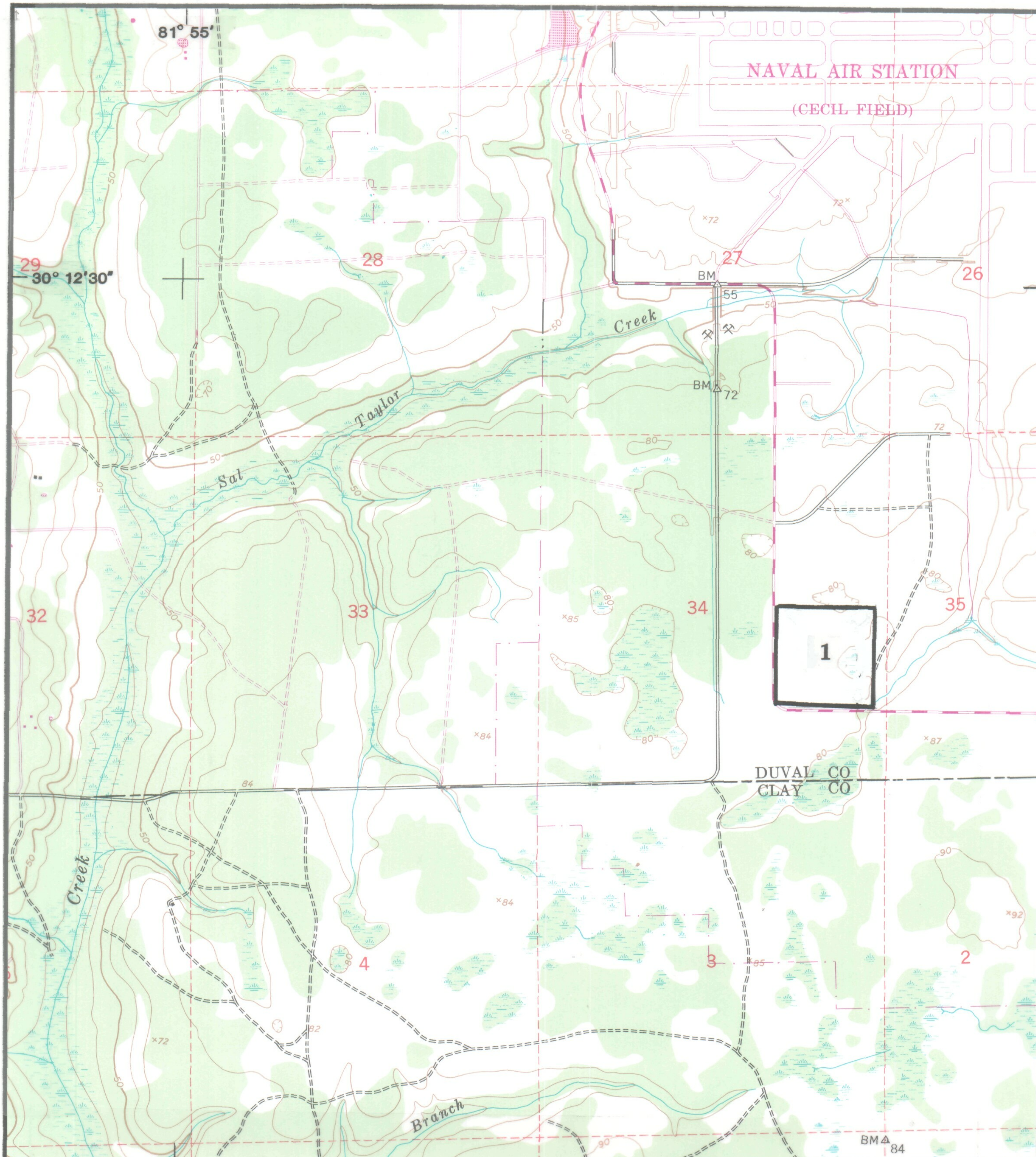
The upper two layers have resistivities of 104.0 and 3.4 ohm-m, and a combined thickness of 320 ft. These two layers likely represent material overlying the Floridan aquifer consisting of the Hawthorn Group and younger sediments. The total thickness is consistent with the estimated depth below surface to the Floridan in this area (≈ 350 ft, Miller, 1986). The 3.4 ohm-m layer likely represents a clay-rich portion of the Hawthorn Group which may be an upper confining unit for the Floridan aquifer.

The third layer, with a resistivity of 912 ohm-m, is interpreted to represent both fresh water within the Floridan aquifer and low porosity formations beneath the Floridan aquifer system. Since formations underlying the Floridan aquifer generally are confining units, their porosities are lower resulting in increased formation resistivities and resistivity values comparable to those of fresh water saturated sections of higher porosities, even though the ground water within these formations may be saline (> 5,000 mg/l chloride).

The lower layer of the geoelectric section, with a resistivity of 0.9 ohm-m, likely represents saline water either in evaporite sequences beneath the Floridan aquifer or within Upper Cretaceous shales and sands (Fig. 2-1). The salinities within these formations are expected to greatly exceed 5,000 mg/l. This would account for the low resistivity (0.9 ohm-m) of this layer.

5.2.3 Depth of Occurrence of Saline Water

The lowest resistivity encountered in the geoelectric section is 0.9 ohm-m (layer 4) and the top of this layer occurs at a depth of 3,264 ft (3,185 ft below mean sea level). This depth is 1,300 ft below the base of the Floridan aquifer in this area (Fig. 5-2.4). Since the low resistivity zone is not within the Floridan aquifer, the criteria developed for positioning the 5,000 mg/l isochlor and estimating chloride content for saline water in the Floridan aquifer could not be applied. Based on the TDEM sounding, the



FLORIDA

QUADRANGLE LOCATION

N

0 2000 4000 Feet

BLACKHAWK GEOSCIENCES, INC.

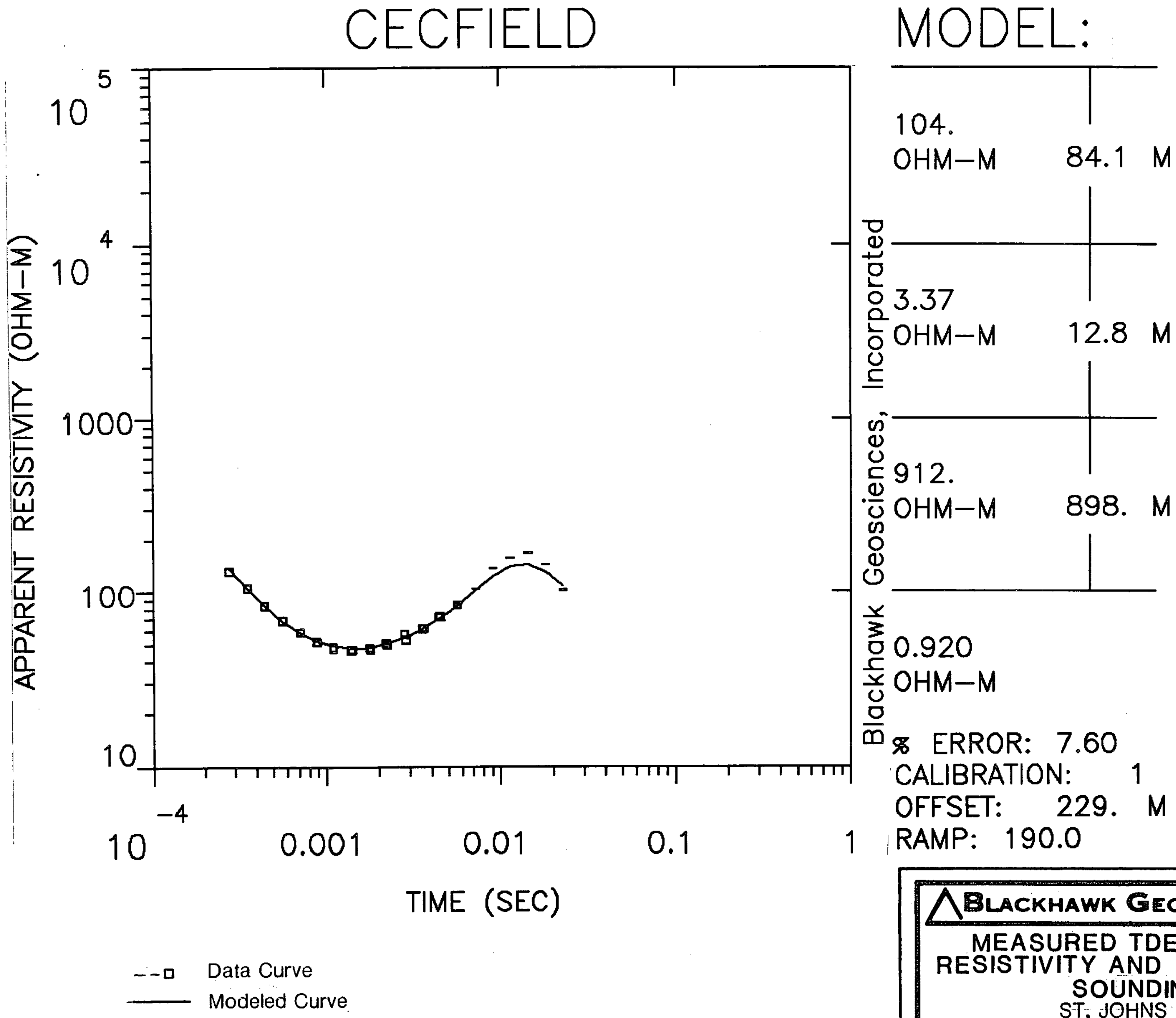
TDEM SURVEY LOCATION MAP

SOUNDING 1

ST. JOHNS RIVER
WATER MANAGEMENT DISTRCT

PROJECT NO 9001-000

Figure 5-2.1



BLACKHAWK GEOSCIENCES, INC.

MEASURED TDEM APPARENT RESISTIVITY AND 1-D INVERSION SOUNDING 1

ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) **Figure 5-2.2**

CECFIELD

MODEL: 4 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		24.1	79.0		
104.43	84.1	-60.1	-197.1	0.8	0.8
3.37	12.8	-72.8	-238.9	3.8	4.6
911.88	898.0	-970.9	-3185.2	1.0	5.6
0.92					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	2.80E-04	1.32E+02	1.36E+02	-3.314	
2	3.55E-04	1.06E+02	1.04E+02	1.955	
3	4.43E-04	8.36E+01	8.32E+01	0.550	
4	5.64E-04	6.85E+01	6.79E+01	0.951	
5	7.13E-04	5.88E+01	5.82E+01	1.117	
6	8.81E-04	5.19E+01	5.26E+01	-1.264	
7	8.90E-04	5.15E+01	5.24E+01	-1.667	
8	1.10E-03	4.81E+01	4.92E+01	-2.146	
9	1.10E-03	4.74E+01	4.91E+01	-3.572	
10	1.40E-03	4.65E+01	4.77E+01	-2.544	
11	1.41E-03	4.65E+01	4.77E+01	-2.412	
12	1.77E-03	4.77E+01	4.82E+01	-1.117	
13	1.80E-03	4.70E+01	4.83E+01	-2.675	
14	2.20E-03	5.07E+01	5.04E+01	0.542	
15	2.22E-03	4.96E+01	5.06E+01	-1.910	
16	2.80E-03	5.71E+01	5.48E+01	4.164	
17	2.85E-03	5.30E+01	5.52E+01	-4.010	
18	3.55E-03	6.14E+01	6.14E+01	-0.018	
19	3.60E-03	6.19E+01	6.19E+01	-0.072	
20	4.43E-03	7.16E+01	7.03E+01	1.885	
21	4.49E-03	7.27E+01	7.10E+01	2.427	
22	4.54E-03	6.84E+01	7.15E+01	-4.243	
23	5.64E-03	8.43E+01	8.37E+01	0.613	
24	5.71E-03	8.58E+01	8.46E+01	1.453	
25	7.20E-03	1.05E+02	1.02E+02	2.702	
26	9.07E-03	1.36E+02	1.22E+02	11.168	
27	1.14E-02	1.57E+02	1.40E+02	11.930	
28	1.44E-02	1.67E+02	1.44E+02	16.197	

BLACKHAWK GEOSCIENCES, INC.

INVERSION TABLE
SOUNDING 1
ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) Table 5-2.1

29	1.81E-02	1.43E+02	1.31E+02	9.633
30	2.29E-02	1.02E+02	1.08E+02	-5.381

R: 229. X: 0. Y: 229. DL: 457. REQ: 254. CF: 1.0000
CLHZ ARRAY, 30 DATA POINTS, RAMP: 190.0 MICROSEC, DATA: CECFIELD
1507 0001 0000 Z OPR XTL H 2 8+100
Ch.21 = 0.24 Ch.22 = 0.089 Ch.23 = 30 Ch.24 = 2
RMS LOG ERROR: 3.18E-02, ANTILOG YIELDS 7.6020 %
LATE TIME PARAMETERS

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER

P 1	0.20						
P 2	0.06	0.63					
P 3	0.16	-0.11	0.28				
F 4	0.00	0.00	0.00	0.00			
T 1	0.16	0.06	-0.06	0.00	0.94		
T 2	-0.13	-0.38	-0.14	0.00	0.10	0.56	
T 3	-0.01	-0.02	0.01	0.00	0.01	-0.02	0.99
	P 1	P 2	P 3	F 4	T 1	T 2	T 3

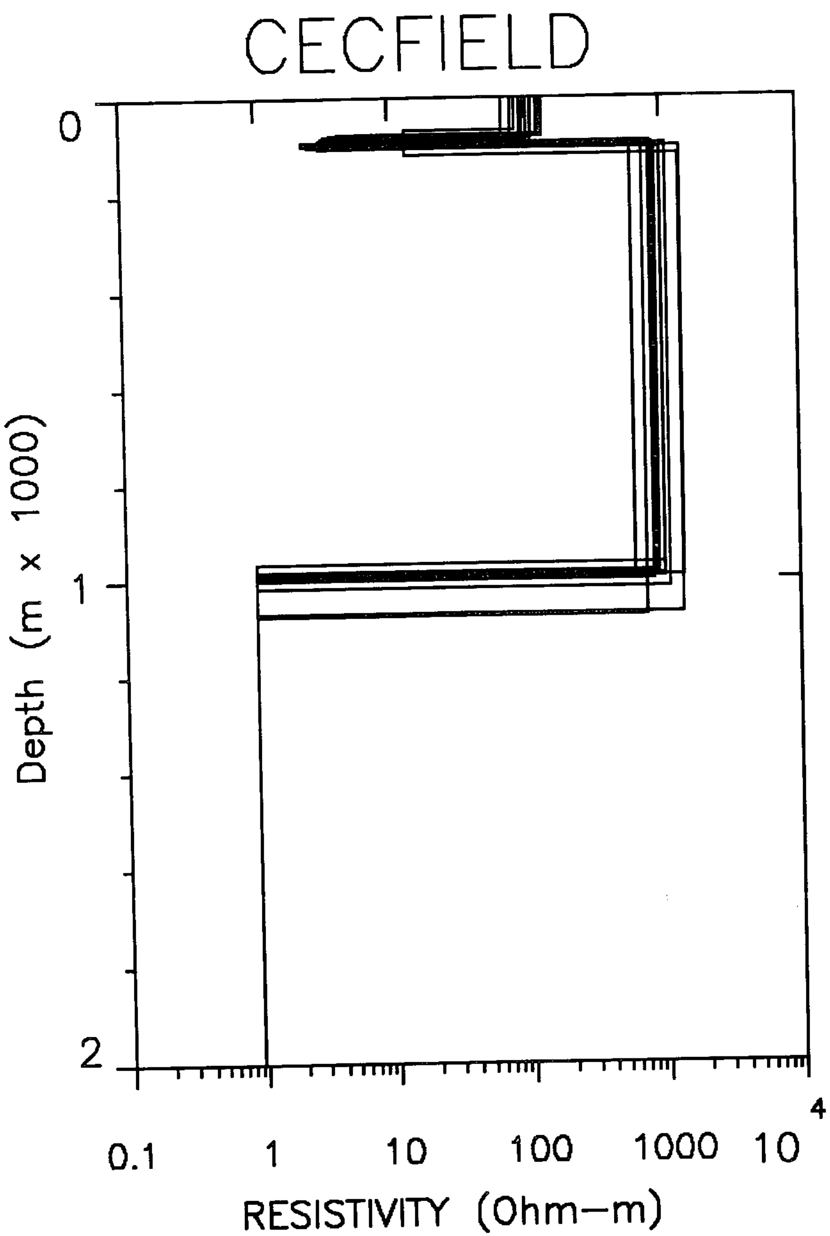
PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

LAYER		MINIMUM	BEST	MAXIMUM
RHO	1	68.718	104.426	135.463
	2	2.295	3.367	13.124
	3	603.937	911.876	1376.827
	4	0.920	0.920	0.920
THICK	1	66.526	84.143	93.705
	2	8.650	12.756	50.628
	3	864.963	898.039	983.777
DEPTH	1	66.526	84.143	93.705
	2	91.281	96.898	117.154
	3	964.616	994.938	1075.429

BLACKHAWK GEOSCIENCES, INC.

INVERSION TABLE CONTINUED
SOUNDING 1
ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) Table 5-2.1



BLACKHAWK GEOSCIENCES, INC.

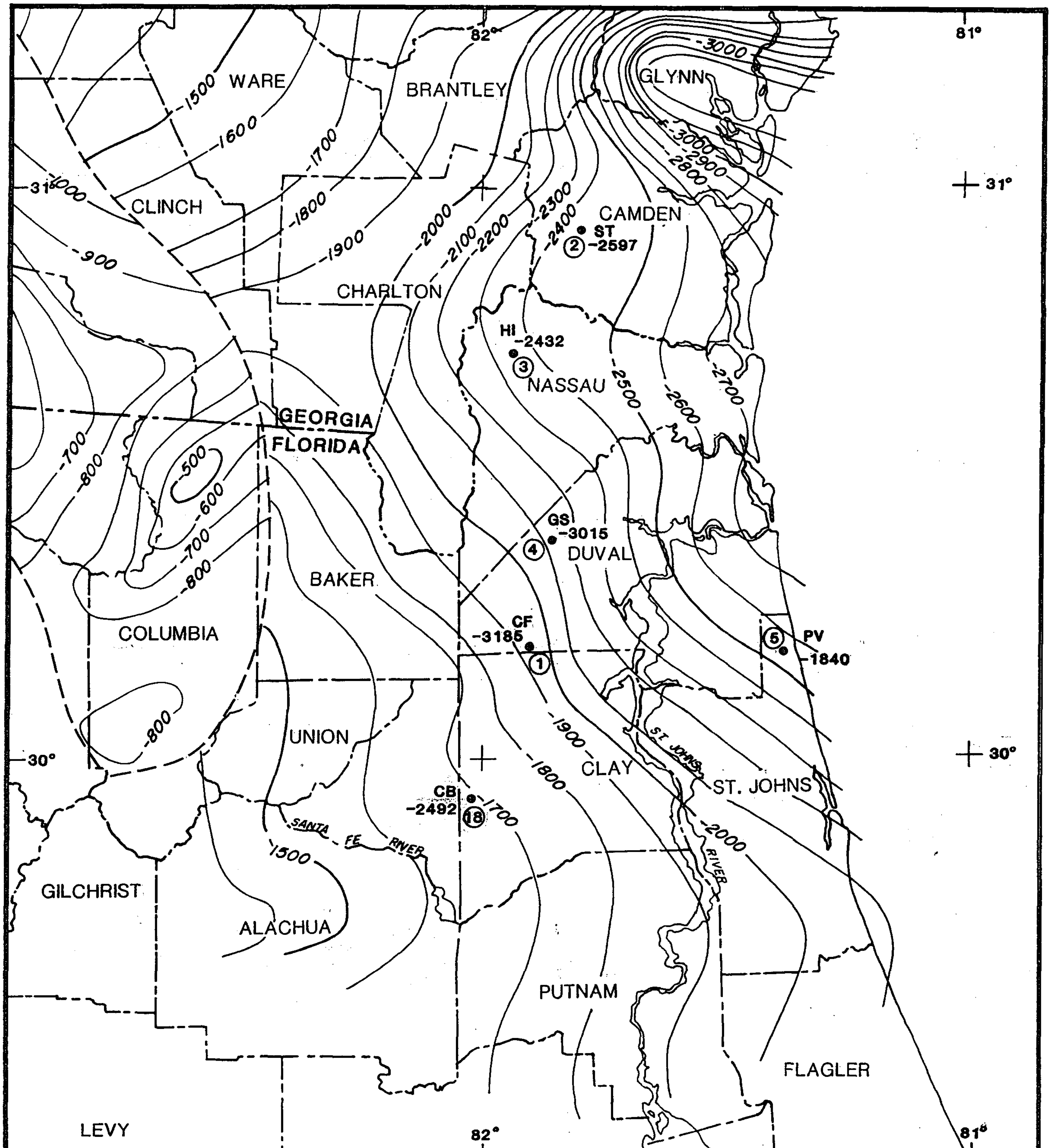
EQUIVALENCE IN 1-D INVERSION

SOUNDING 1

ST. JOHNS RIVER

WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) Figure 5-2.3



Contours show altitude of base of the Floridan aquifer system. Contour interval 100 feet. From Krause and Randolf, (1989). Datum is Sea Level.

CB ⑱ -2492 Time Domain Electromagnetic (TDEM) Site with elevation of top of saline water as determained by TDEM

BLACKHAWK GEOSCIENCES, INC.

MAP OF THE CONFIGURATION OF THE BASE OF THE FLORIDAN AQUIFER

ST. JOHNS RIVER WATER MANAGEMENT DISTRICT

PROJECT NO:9001-000 (92022) Figure 5-2.4

5,000 mg/l isochlor does not occur within the Floridan aquifer at this site. Ground water with a chloride content greater than 5,000 mg/l likely occurs within the low resistivity layer mapped by the TDEM sounding. In addition, saline water may occur between the base of the Floridan aquifer and the top of the low resistivity layer, and not significantly decrease resistivity if formational porosities within this zone are low (< 10%).

5.2.4 Depth of Occurrence of the 250 mg/l Isochlor

The 912 ohm-m resistivity interpreted between a depth of 320 ft and 3,185 ft corresponds to a chloride content of less than 100 mg/l, assuming an average porosity of 25% and the validity of Figure 4-9. Since the base of the Floridan occurs at a depth of approximately 2,000 ft (-1,900 ft msl), the TDEM sounding indicates that the entire Floridan aquifer contains ground water with a chloride content less than 100 mg/l. The chloride to sulfate ratio in this area is approximately 5:1 (Sprinkle, 1989) and should not affect the interpreted chloride content.

5.2.5 Accuracy of Measurement and Interpretation

Figure 5-2.3 shows the evaluation of equivalence for the TDEM sounding at this site, and the inversion table shown in Table 5-2.1 lists the upper and lower bounds of the parameters of the geoelectric section.

The range of equivalence in determining the depth to the layer of lower resistivity (layer 4) is about $\pm$ 245 ft (75 m) which is 8% of the total depth. The resistivity range of this layer indicates a very high chloride content, although specific values cannot be calculated since this layer is below the Floridan aquifer. The resistivity equivalence of the third layer is from 604 ohm-m to 1,376 ohm-m, and corresponds to a chloride content of less than 100 mg/l.

The depth to the saline layer, as determined by the TDEM sounding, is significantly below (1,300 ft) the base of the Floridan aquifer as determined by Krause and Randolph (1989) (-1,900 ft msl) and shown in Figure 5-2.4. Therefore, the position of the 250 mg/l and 5,000 mg/l isochlors are not expected to occur within the Floridan aquifer.

5.2.6 <u>Summary of Results of TDEM Measurements at Cecil Field (Site 1)</u>

From the TDEM measurements the following information about aquifer characteristics and water quality was derived:

1) The 5,000 mg/l isochlor does not occur within the Floridan aquifer. The low resistivity zone mapped at depth by the TDEM sounding likely represents high salinity brines within evaporite or shale formations below the Floridan.

2) The 250 mg/l isochlor does not occur within the Floridan aquifer since the aquifer's interpreted chloride content is less than 100 mg/l. The chloride to sulfate ratio of 5:1 should not affect this interpretation.

5.3 SILCO TRACT (SITE 2)

5.3.1 Location and Geoelectric Section

The location of the Silco Tract sounding is shown in Figure 5-3.1. The interpreted geoelectric section is shown in Figure 5-3.2 and consists of a three layer section.

5.3.2 Geologic Interpretation of Geoelectric Section

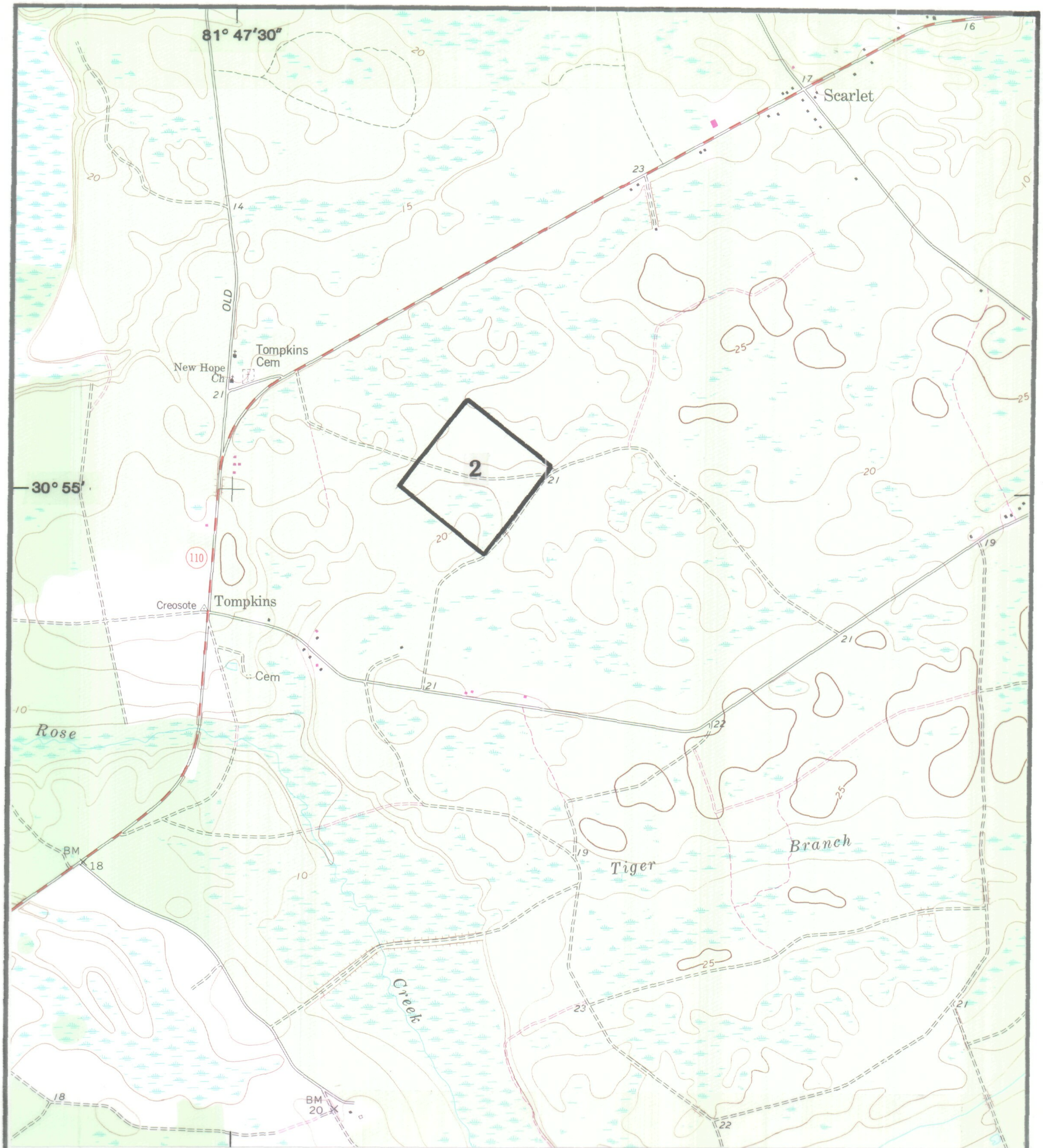
The upper layer of 42 ohm-m represents the Hawthorn Group and younger sediments overlying the Floridan aquifer. The thickness of this layer was fixed in the inversion at 394 ft based on information from Miller (1986). The resistivity of 65 ohm-m is expected to represent the Floridan aquifer. The 2.4 ohm-m layer occurs below the Floridan based on information contained in Figure 5-2.4. It likely represents a saline water zone beneath the Floridan aquifer system which may occur within shale or carbonate and/or evaporitic formations with porosities greater than 10%.

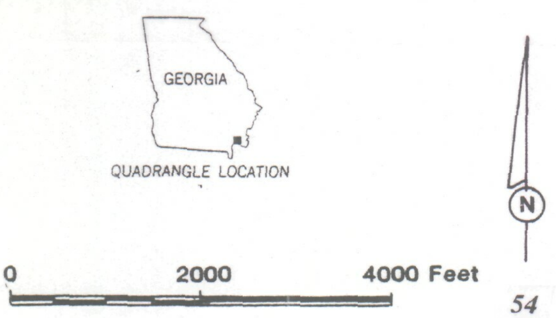
5.3.3 Depth of Occurrence of Saline Water

Since the TDEM sounding does not detect a low resistivity zone within the Floridan aquifer, the 5,000 mg/l isochlor is not present within the Floridan. The low resistivity zone located at a depth of 2,618 ft (-2,597 msl) likely represents saline water (> 5,000 mg/l chloride).

5.3.4 Depth of Occurrence of 250 mg/l Isochlor

The second layer in the geoelectric section, which represents the Floridan aquifer, has a resistivity of 65 ohm-m. At 25% porosity, and using Figure 4-9, this corresponds to a chloride content of 342 mg/l. Data from Sprinkle (1989) however indicates a chloride content for the upper Floridan in this area of less than 250 mg/l. The most likely cause of this difference is the sulfate content of the ground water. Sprinkle (1989) reports sulfate concentrations between 101 mg/l to 250 mg/l; sulfate levels approximately equal the chloride content. In developing a correlation between resistivity and chloride concentrations, Kwader (1982) assumed that sulfate content of the ground water was approximately 20% that of chloride. The increased sulfate content likely is decreasing the resistivity of the ground water resulting in interpreted chloride concentrations that are too high.





BLACKHAWK GEOSCIENCES, INC.

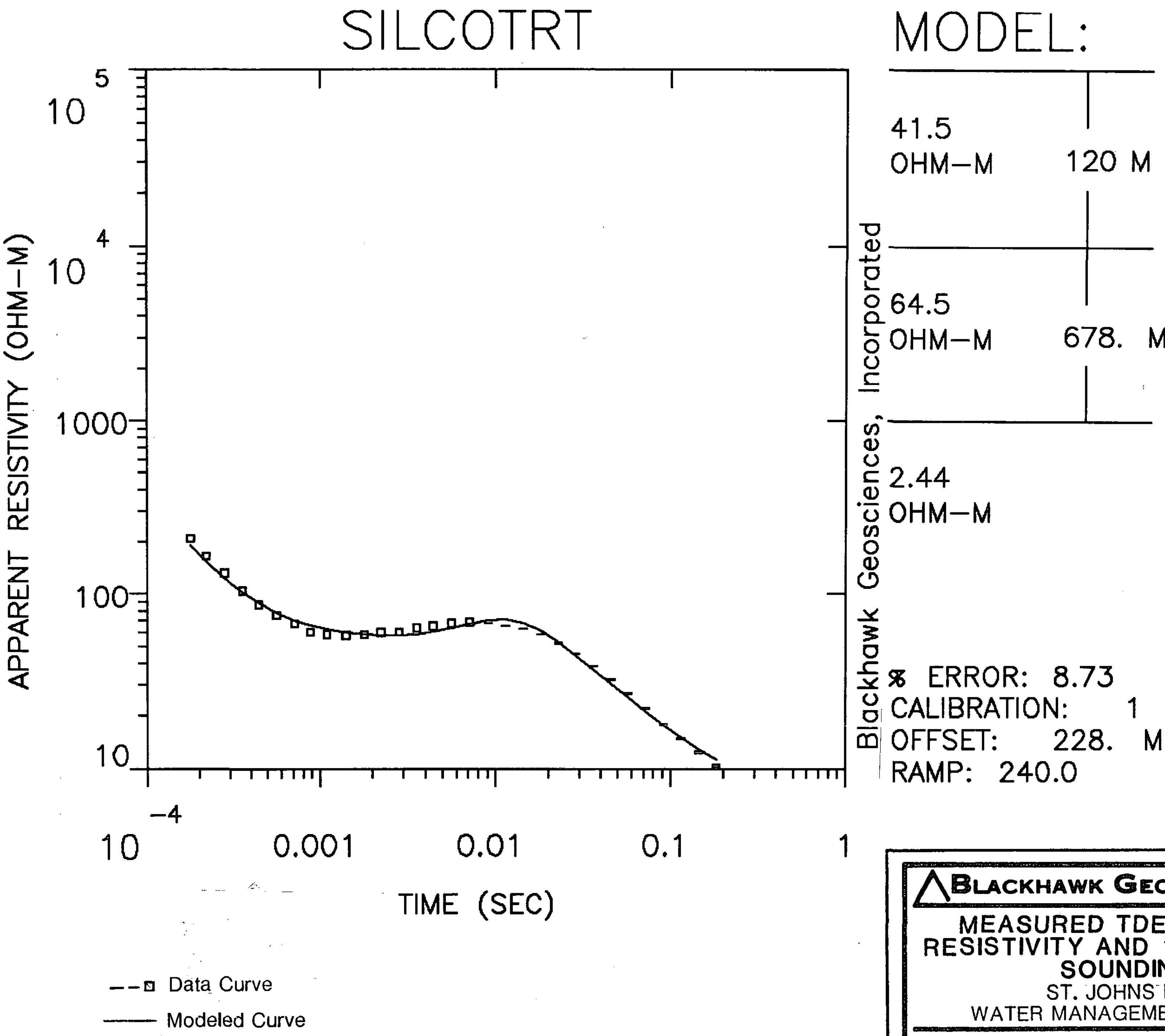
TDEM SURVEY LOCATION MAP

SOUNDING 2

ST. JOHNS RIVER
WATER MANAGEMENT DISTRCT

PROJECT NO 9001-000

Figure 5-3.1



BLACKHAWK GEOSCIENCES, INC.

MEASURED TDEM APPARENT RESISTIVITY AND 1-D INVERSION
SOUNDING 2
ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) Figure 5-3.2

5.3.5 <u>Accuracy of Measurement and Interpretation</u>

Figure 5-3.3 shows the evaluation of equivalence of the TDEM sounding at this site, and the inversion table (Table 5-3.1) lists the upper and lower bounds of the parameter of the geoelectric section. The range of equivalence in determining the depth to the layer of low resistivity (layer 3) is shown in Figure 5-3.3 to be about $\pm$ 130 ft (40 m) which is 5% of the total depth. The resistivity range for this layer is from 1.6 ohm-m to 3.5 ohm-m, and although a quantitative estimate of chloride cannot be made, chloride contents likely are in excess of 5,000 mg/l.

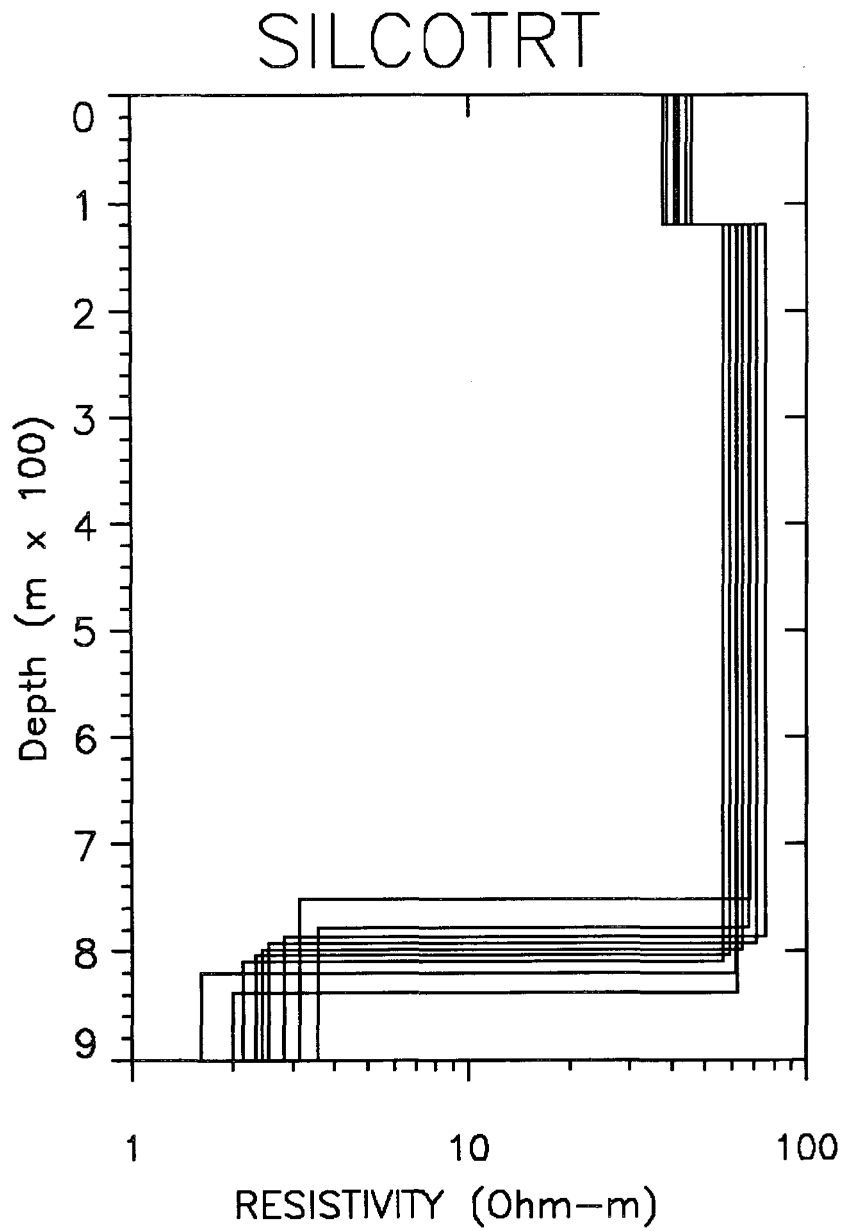
The resistivity of layer 2 has an equivalence of from 56 ohm-m to 75 ohm-m. This corresponds to a chloride content greater than 250 mg/l. The difference between sampled and inferred chloride content is likely the result of high sulfate concentrations.

5.3.6 <u>Summary of Results of TDEM Measurements at Silco Tract (Site 2)</u>

From the TDEM measurements, the following information about water quality was derived:

(1) The first depth of occurrence of a low resistivity zone interpreted to be saline water in a formation whose porosity is greater than 10% is 2,618 ft (-2,597 ft msl), and this zone is below the Floridan aquifer. Since a low resistivity zone was not mapped within the Floridan aquifer, the 5,000 mg/l isochlor does not occur within the Floridan.

2) The interpreted chloride concentration of the Floridan aquifer (342 mg/l) is higher than published data (less than 250 mg/l) for this area. This is likely the result of a higher chloride to sulfate ratio (1:1) in the ground water than what was assumed in developing Figure 4-9.



SILCOTRT
0
1
2
3
4
5
6
7
8
9
Depth (m x 100)
1
10
100
RESISTIVITY (Ohm–m)

BLACKHAWK GEOSCIENCES, INC.
EQUIVALENCE IN 1-D INVERSION
SOUNDING 2
ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT
PROJECT NO: 9001-000 (92022)
Figure 5-3.3

SILCOTRT

MODEL: 3 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		6.4	21.0		
41.53	120.0	-113.6	-372.7	2.9	2.9
64.55	678.0	-791.6	-2597.1	10.5	13.4
2.44					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	1.77E-04	2.09E+02	1.90E+02	9.801	
2	2.20E-04	1.65E+02	1.52E+02	8.767	
3	2.80E-04	1.32E+02	1.22E+02	7.732	
4	3.55E-04	1.04E+02	1.02E+02	2.167	
5	4.43E-04	8.68E+01	8.84E+01	-1.850	
6	5.64E-04	7.53E+01	7.79E+01	-3.419	
7	7.13E-04	6.72E+01	7.08E+01	-5.064	
8	8.81E-04	6.04E+01	6.61E+01	-8.597	
9	1.10E-03	5.86E+01	6.27E+01	-6.529	
10	1.41E-03	5.76E+01	6.00E+01	-3.936	
11	1.80E-03	5.80E+01	5.84E+01	-0.617	
12	2.22E-03	5.99E+01	5.77E+01	3.794	
13	2.83E-03	6.04E+01	5.77E+01	4.785	
14	3.57E-03	6.38E+01	5.86E+01	8.829	
15	4.43E-03	6.55E+01	6.04E+01	8.445	
16	5.64E-03	6.80E+01	6.34E+01	7.169	
17	7.13E-03	6.87E+01	6.71E+01	2.273	
18	7.20E-03	6.59E+01	6.73E+01	-2.043	
19	9.07E-03	6.79E+01	7.04E+01	-3.632	
20	1.14E-02	6.51E+01	7.12E+01	-8.551	
21	1.44E-02	6.30E+01	6.81E+01	-7.561	
22	1.81E-02	5.82E+01	6.14E+01	-5.169	
23	2.29E-02	5.20E+01	5.28E+01	-1.598	
24	2.88E-02	4.51E+01	4.43E+01	1.783	
25	3.63E-02	3.84E+01	3.68E+01	4.488	
26	4.57E-02	3.22E+01	3.05E+01	5.779	
27	5.76E-02	2.68E+01	2.53E+01	5.965	
28	7.26E-02	2.20E+01	2.12E+01	4.159	
29	9.14E-02	1.78E+01	1.78E+01	0.025	

BLACKHAWK GEOSCIENCES, INC.

INVERSION TABLE
SOUNDING 2
ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) Table 5-3.1

30	1.15E-01	1.48E+01	1.51E+01	-1.816
31	1.45E-01	1.25E+01	1.30E+01	-3.724
32	1.83E-01	1.04E+01	1.12E+01	-7.061

R: 228. X: 0. Y: 229. DL: 457. REQ: 254. CF: 1.0000

TDHZ ARRAY, 32 DATA POINTS, RAMP: 240.0 MICROSEC, DATA: SILCOTRT

EM37 SITE 2

RMS LOG ERROR: 3.63E-02, ANTILOG YIELDS 8.7266 %

LATE TIME PARAMETERS

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:

"F" MEANS FIXED PARAMETER

P 1	1.00				
P 2	0.00	0.99			
P 3	0.00	-0.01	0.95		
F 1	0.00	0.00	0.00	0.00	
T 2	0.00	0.00	0.00	0.00	1.00
	P 1	P 2	P 3	F 1	T 2

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

LAYER		MINIMUM	BEST	MAXIMUM
RHO	1	37.657	41.527	45.780
	2	56.321	64.549	75.478
	3	1.605	2.438	3.558
THICK	1	120.000	120.000	120.000
	2	631.079	678.001	717.643
DEPTH	1	120.000	120.000	120.000
	2	751.079	798.001	837.643

BLACKHAWK GEOSCIENCES, INC.

INVERSION TABLE CONTINUED
SOUNDING 2
ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) Table 5-3.1

5.4 HILLIARD (SITE 3)

5.4.1 Location and Geoelectric Section

The detailed location map of this sounding is shown in Figure 5-4.1. The TDEM data and the inverted geoelectric section is shown in Figure 5-4.2 and consists of a four-layer section.

5.4.2 Geologic Interpretation of Geoelectric Section

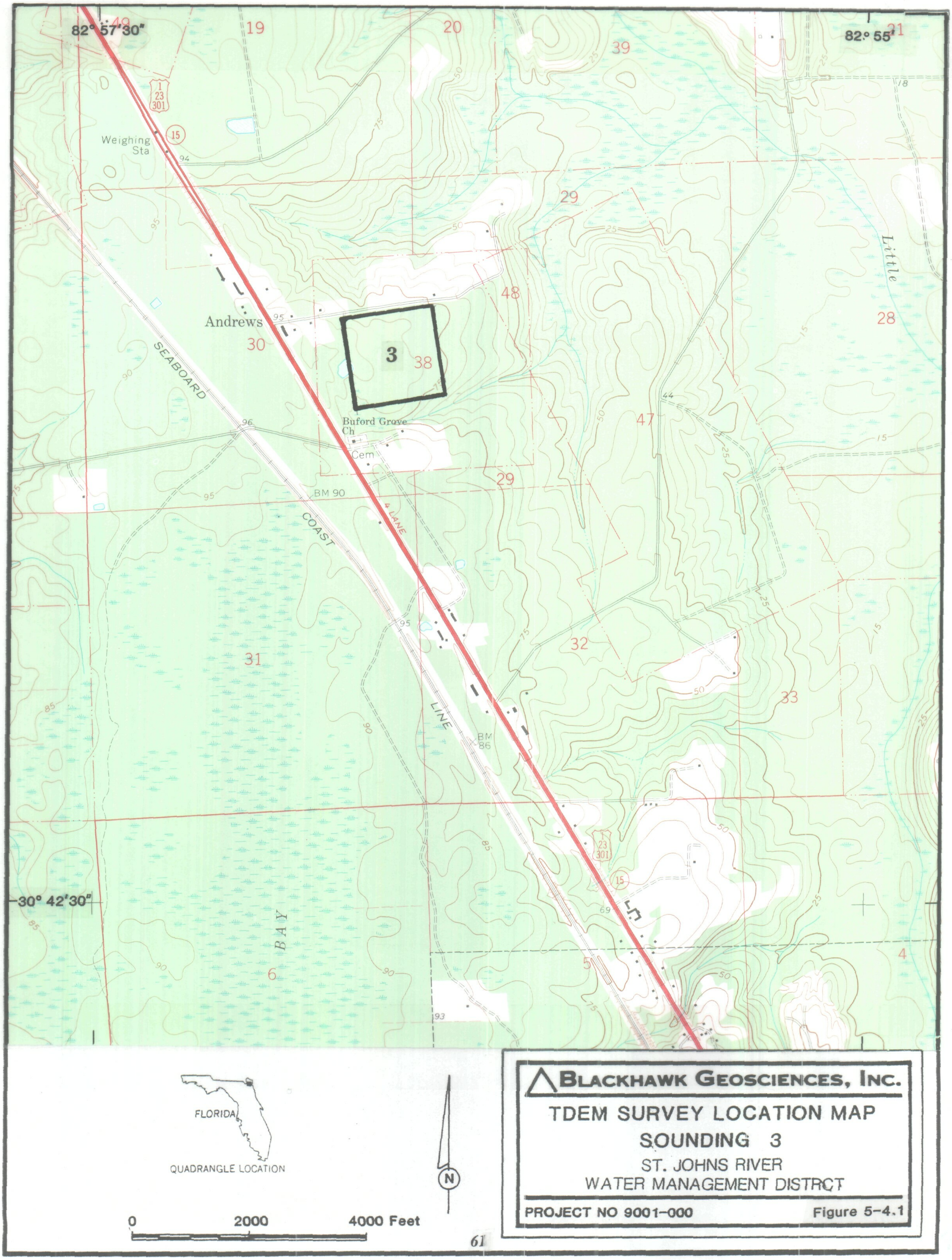
The first two layers in the geoelectric section have resistivities of 160 and 21 ohm-m, and a combined thickness of 400 ft. These layers likely correspond to the material overlying the Floridan aquifer, including the Hawthorn Group and younger formations, and is consistent with the approximately 400 ft depth from surface to the top of the Floridan aquifer shown in Miller (1986). The third layer with a resistivity of 66 ohm-m and a thickness of 2,099 ft represents the Floridan aquifer. The fourth layer in the geoelectric section, with a resistivity of 1.4 ohm-m, is probably caused by saline water below the Floridan aquifer occurring within shales or carbonate and/or evaporitic formations with porosities greater than 10%.

5.4.3 Depth of Occurrence of Saline Water

The fourth layer geoelectric section, with a resistivity of 1.4 ohm-m, has been interpreted as saline water below the Floridan aquifer. Cole (1944) reports that a drill hole located approximately one mile north of the TDEM sounding intersected saline water with chlorides in excess of 30,000 mg/l at a depth of from 2,205 ft to 2,230 ft. This is approximately 270 ft (12% of total depth) less than the depth to the zone mapped by the TDEM sounding. It is unclear whether this zone represents a continuous saline layer in the lower portion of the Floridan aquifer or is an isolated pocket. Its salinity in excess of sea water may indicate that it is not hydrologically connected to the main Floridan aquifer. The depth to the low resistivity layer from the TDEM sounding is below the Floridan aquifer, so that the 5,000 mg/l isochlor does not occur within the Floridan.

5.4.4 Depth of Occurrence of 250 mg/l Isochlor

The Floridan aquifer (layer 3) has a resistivity of 66 ohm-m. At a porosity of 25%, and utilizing Figure 4-9, this corresponds to a chloride content of 334 mg/l. This is not consistent with Sprinkle (1989) which indicates a chloride content of less than 250 mg/l for the upper Floridan in this area. The reason



BLACKHAWK GEOSCIENCES, INC.

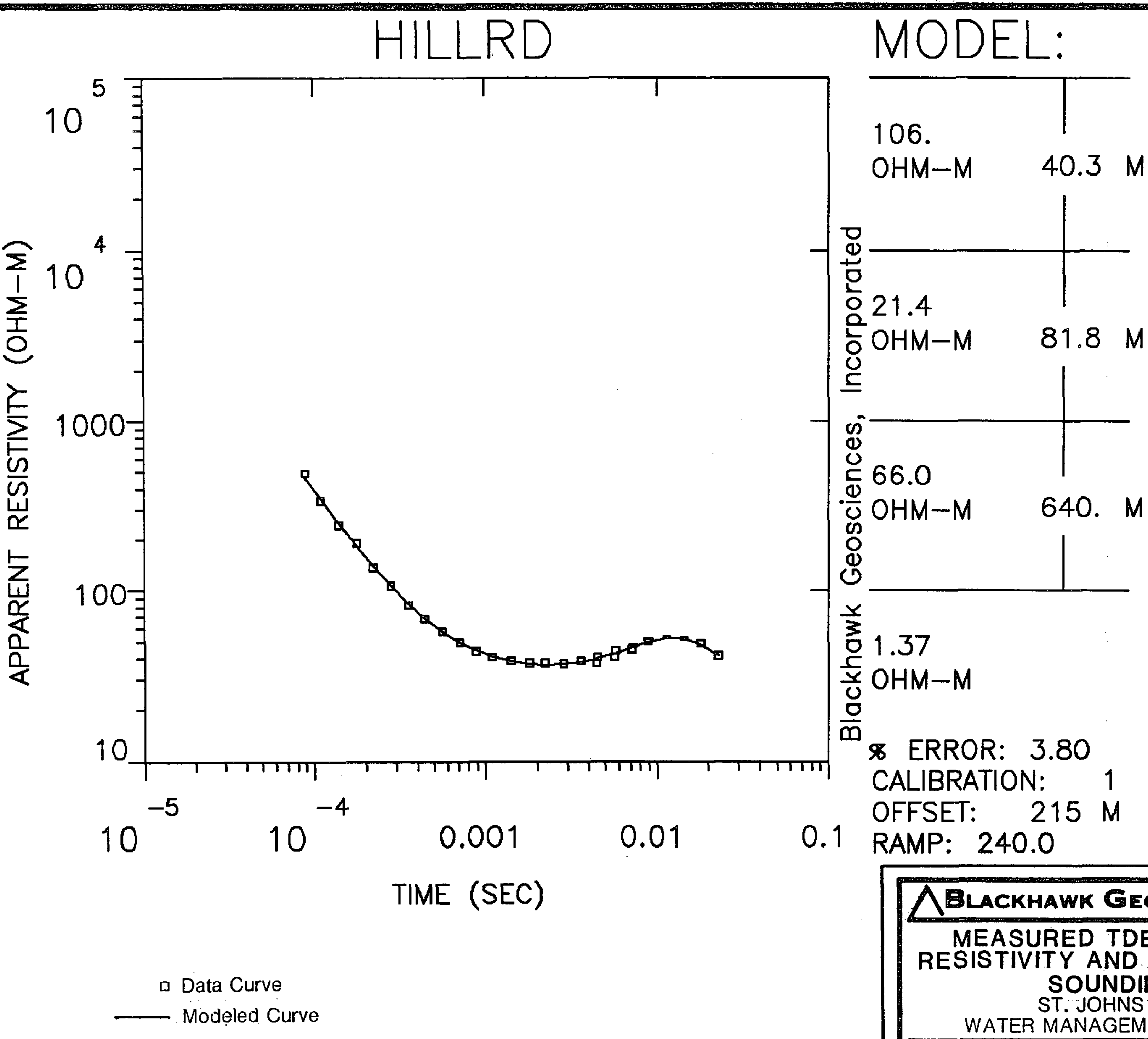
TDEM SURVEY LOCATION MAP

SOUNDING 3

ST. JOHNS RIVER
WATER MANAGEMENT DISTRCT

PROJECT NO 9001-000

Figure 5-4.1



BLACKHAWK GEOSCIENCES, INC.

MEASURED TDEM APPARENT RESISTIVITY AND 1-D INVERSION SOUNDING 3

ST. JOHNS RIVER WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) **Figure 5-4.2**

for this difference is likely the sulfate concentration of the ground water. Sprinkle (1989) reports sulfates in the upper Floridan aquifer between 101 mg/l to 250 mg/l and approximately equal to the chloride concentration. The chloride to sulfate ratio in ground waters used by Kwader (1982) in developing Figure 4-8 was 5:1. The high concentration of sulfates in the ground water decrease the expected formational resistivity and invalidate one of the assumptions utilized in developing Figure 4-9. Because of this the 250 mg/l isochlor cannot be mapped.

5.4.5 Accuracy of Measurement and Interpretation

Figure 5-4.3 shows the evaluation of equivalence for the TDEM sounding at this site, and the inversion table (Table 5-4.1) lists the upper and lower boundary of the parameters of the geoelectric section.

The range of equivalence in determining the depth to the layer of low resistivity (1.4 ohm-m) can be seen on Figure 5-4.3 to be about $\pm$ 148 ft (45 m) or about 6% of total depth. The shallowest depth (2,315 ft) in the equivalence range is still 100 ft below the saline water reported in a drill hole located within one mile. The upper and lower bound in the resistivity of this layer is between 0.7 ohm-m and 2.7 ohm-m and does not negate the conclusion that this layer represents saline water.

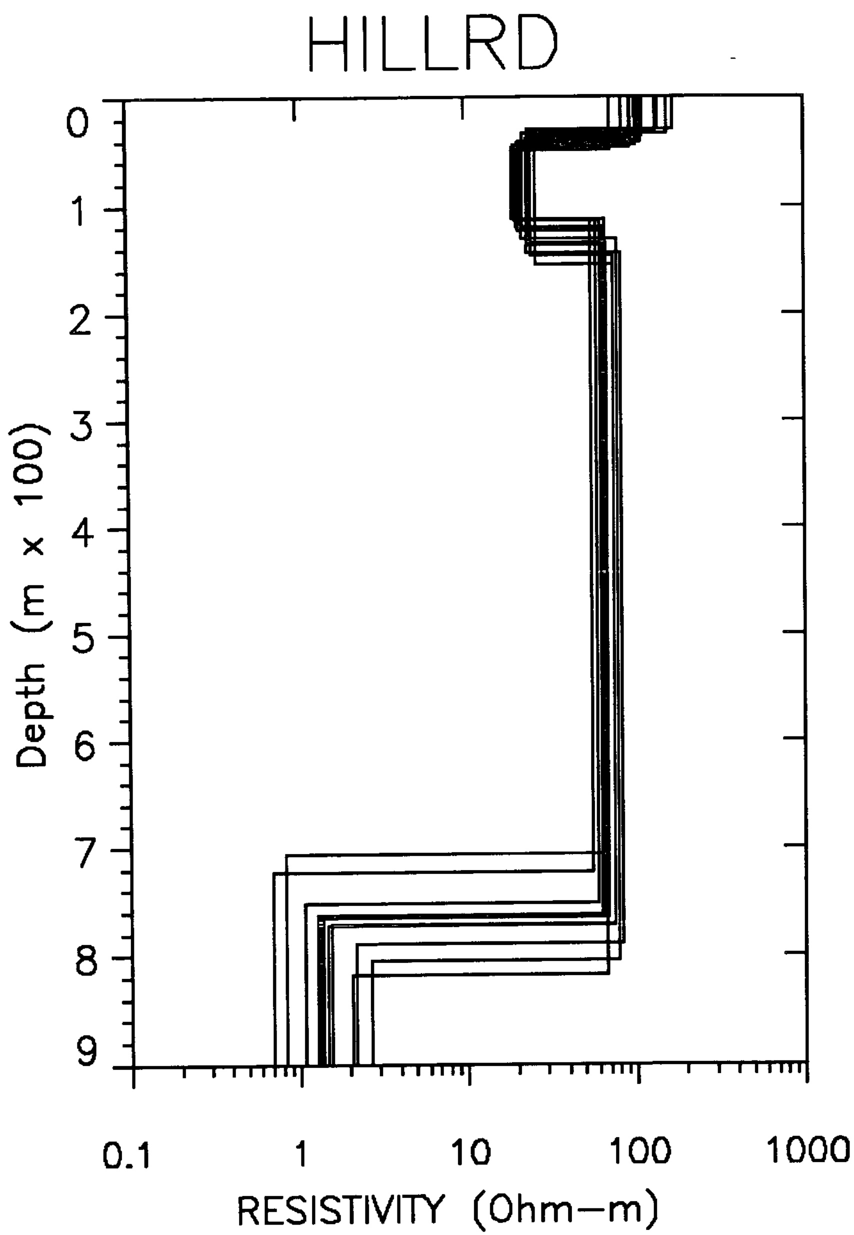
The equivalence in the resistivity of the second layer, representing the Floridan aquifer, is between 55 ohm-m and 82 ohm-m. Since the increased sulfates of the ground water in this area invalidate Figure 4-9, an estimate of chloride content from formational resistivity cannot be made.

5.4.6 Summary of Results of TDEM Measurements at Hilliard (Site 3)

From the TDEM measurements, the following information about water quality was derived:

(1) The depth of occurrence of saline water was interpreted at a depth of 2,500 ft (-2,432 ft msl). This depth is below the Floridan aquifer. This inferred depth is 12% greater than the depth of saline water reported in a drill hole approximately one mile away.

(2) The chloride to sulfate ratio (1:1) of the upper Floridan in this area is significantly higher than that assumed in developing Figure 4-9. Consequently, an estimate of the position of the 250 mg/l isochlor cannot be made at this site.



BLACKHAWK GEOSCIENCES, INC.

EQUIVALENCE IN 1-D INVERSION
SOUNDING 3

ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) **Figure 5-4.3**

HILLRD

MODEL: 4 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	(FEET)	CONDUCTANCE (S) LAYER	TOTAL
		20.7	68.0		
106.08	40.3	-19.5	-64.1	0.4	0.4
21.35	81.8	-101.3	-332.5	3.8	4.2
66.02	640.0	-741.3	-2432.1	9.7	13.9
1.37					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	8.90E-05	4.94E+02	4.70E+02	5.272	
2	1.10E-04	3.40E+02	3.49E+02	-2.441	
3	1.40E-04	2.43E+02	2.51E+02	-2.895	
4	1.77E-04	1.91E+02	1.84E+02	3.525	
5	2.20E-04	1.37E+02	1.40E+02	-2.640	
6	2.80E-04	1.07E+02	1.06E+02	0.511	
7	3.55E-04	8.21E+01	8.33E+01	-1.427	
8	4.43E-04	6.81E+01	6.83E+01	-0.225	
9	5.64E-04	5.74E+01	5.69E+01	0.946	
10	7.13E-04	4.95E+01	4.93E+01	0.429	
11	8.81E-04	4.40E+01	4.45E+01	-1.212	
12	1.10E-03	4.07E+01	4.11E+01	-0.972	
13	1.41E-03	3.87E+01	3.86E+01	0.129	
14	1.80E-03	3.76E+01	3.73E+01	0.947	
15	2.22E-03	3.76E+01	3.68E+01	2.082	
16	2.85E-03	3.71E+01	3.71E+01	0.160	
17	3.60E-03	3.88E+01	3.81E+01	1.784	
18	4.43E-03	3.74E+01	3.97E+01	-5.758	
19	4.49E-03	4.06E+01	3.98E+01	2.057	
20	5.64E-03	4.08E+01	4.25E+01	-3.979	
21	5.70E-03	4.43E+01	4.27E+01	3.774	
22	7.13E-03	4.49E+01	4.61E+01	-2.713	
23	7.20E-03	4.77E+01	4.63E+01	3.112	
24	8.81E-03	5.00E+01	4.96E+01	0.875	
25	9.07E-03	5.19E+01	5.00E+01	3.720	
26	1.14E-02	5.32E+01	5.27E+01	0.956	
27	1.44E-02	5.22E+01	5.23E+01	-0.180	
28	1.81E-02	4.90E+01	4.82E+01	1.602	

BLACKHAWK GEOSCIENCES, INC.

INVERSION TABLE
SOUNDING 3
ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) Table 5-4.1

29   2.29E-02   4.14E+01   4.17E+01   -0.732

R: 215. X: 0. Y: 228. DL: 457. REQ: 254. CF: 1.0000

CLHZ ARRAY, 29 DATA POINTS, RAMP: 240.0 MICROSEC, DATA: HILLRD

HILLIARD LINE FILTER

SET 2

RMS LOG ERROR: 1.62E-02, ANTILOG YIELDS 3.7976 %

LATE TIME PARAMETERS

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:

"F" MEANS FIXED PARAMETER

	P 1	P 2	P 3	P 4	T 1	T 2	T 3
P 1	0.31						
P 2	-0.07	0.95					
P 3	0.01	-0.03	0.92				
P 4	0.03	-0.02	-0.17	0.37			
T 1	0.33	0.08	0.02	0.00	0.78		
T 2	-0.17	-0.11	-0.09	-0.10	0.17	0.74	
T 3	0.00	0.01	0.00	-0.05	-0.01	0.02	0.99

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

	LAYER	MINIMUM	BEST	MAXIMUM
RHO	1	72.118	106.078	168.656
	2	19.218	21.352	26.356
	3	55.213	66.023	82.603
	4	0.691	1.368	2.707
THICK	1	29.614	40.251	48.452
	2	66.092	81.811	125.353
	3	568.645	639.954	704.826
DEPTH	1	29.614	40.251	48.452
	2	112.843	122.062	154.967
	3	705.776	762.016	817.669

BLACKHAWK GEOSCIENCES, INC.

INVERSION TABLE CONTINUED
SOUNDING 3

ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022)   Table 5-4.1

5.5 GARDEN STREET (SITE 4)

5.5.1 Location and Geoelectric Section

The detailed location map for this sounding is shown in Figure 5-5.1. The sounding data and the inverted geoelectric section is shown in Figure 5-5.2, it consists of a three layer section. In 1990 an EM37 sounding was made at this location, but its depth of exploration was insufficient to detect saline water. From the results of the 1990 sounding it was estimated that saline ground water likely occurred at a depth in excess of 2,600 ft below the surface.

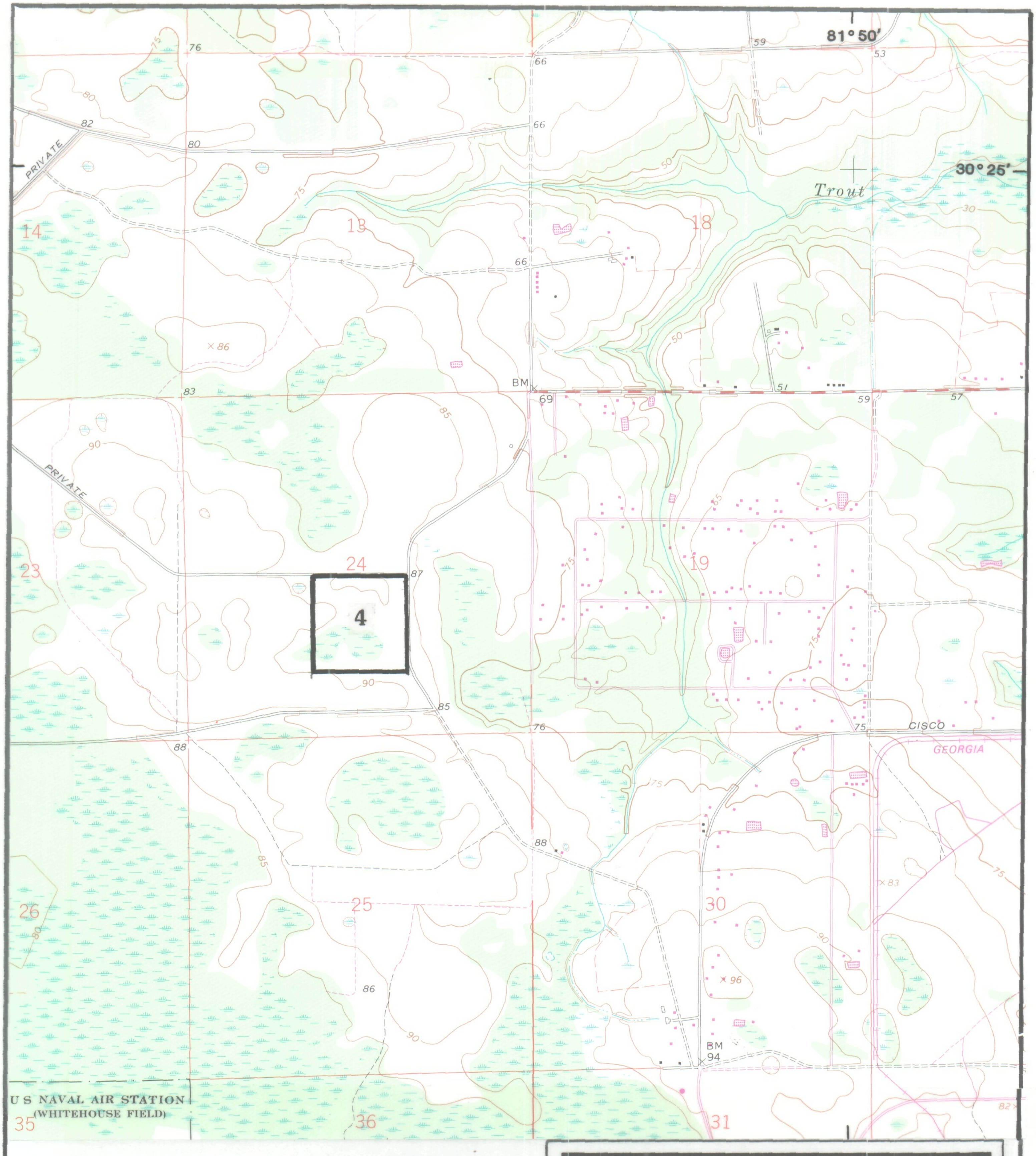
5.5.2 Geologic Interpretation of Geoelectric Section

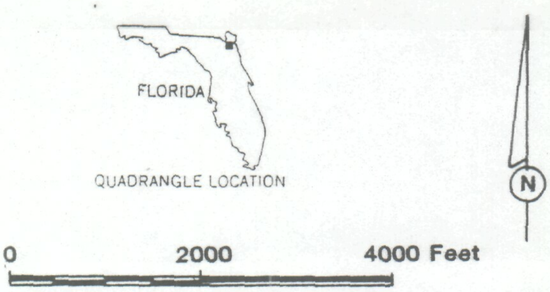
The first layer in the geoelectric section is 476 ft thick and has a resistivity of 46 ohm-m. This layer likely includes the Hawthorn Group and younger formations which overlie the Floridan. This is consistent with Miller (1986) which indicates a depth from surface of 450 to 500 ft to the top of the Floridan aquifer. In the 1990 sounding, two layers were interpreted for the sediments overlying the Floridan. In the present sounding, the second layer is not sufficiently resolved, and it was included in the first layer. The main differences in the upper portion of the interpreted sections from the two soundings are largely a result of using different number of layers in the inversion.

The second layer in the interpreted geoelectric section is 2,626 ft thick, and has a resistivity of 100 ohm-m. It has been interpreted to include the Floridan aquifer saturated with fresh water and a portion of the confining formations below the Floridan. The third layer, with a resistivity of 0.7 ohm-m, likely represents saline water within formations below the Floridan aquifer whose porosities are greater than 10%. At this location Chen (1965) maps a marker horizon of low resistivity (Taylor Kick) in the Upper Cretaceous at a depth corresponding to the top of layer 3. The Taylor Kick corresponds to a thin shale layer which likely contains saline water.

5.5.3 Depth of Occurrence of Saline Water

The third layer in the geoelectric section, with a resistivity of 0.7 ohm-m, has been interpreted as saline water below the Floridan aquifer. Figure 5-2.4 shows the base of the Floridan aquifer to occur at a depth of around 2,190 ft (-2,100 ft msl). Thus, the 5,000 mg/l isochlor is not expected within the Floridan aquifer. This conclusion is supported by a resistivity log from an oil well nearby. In the log a low resistivity zone is indicated at a depth of 2,930 ft, within 5% of the depth (3,100 ft) of the low resistivity



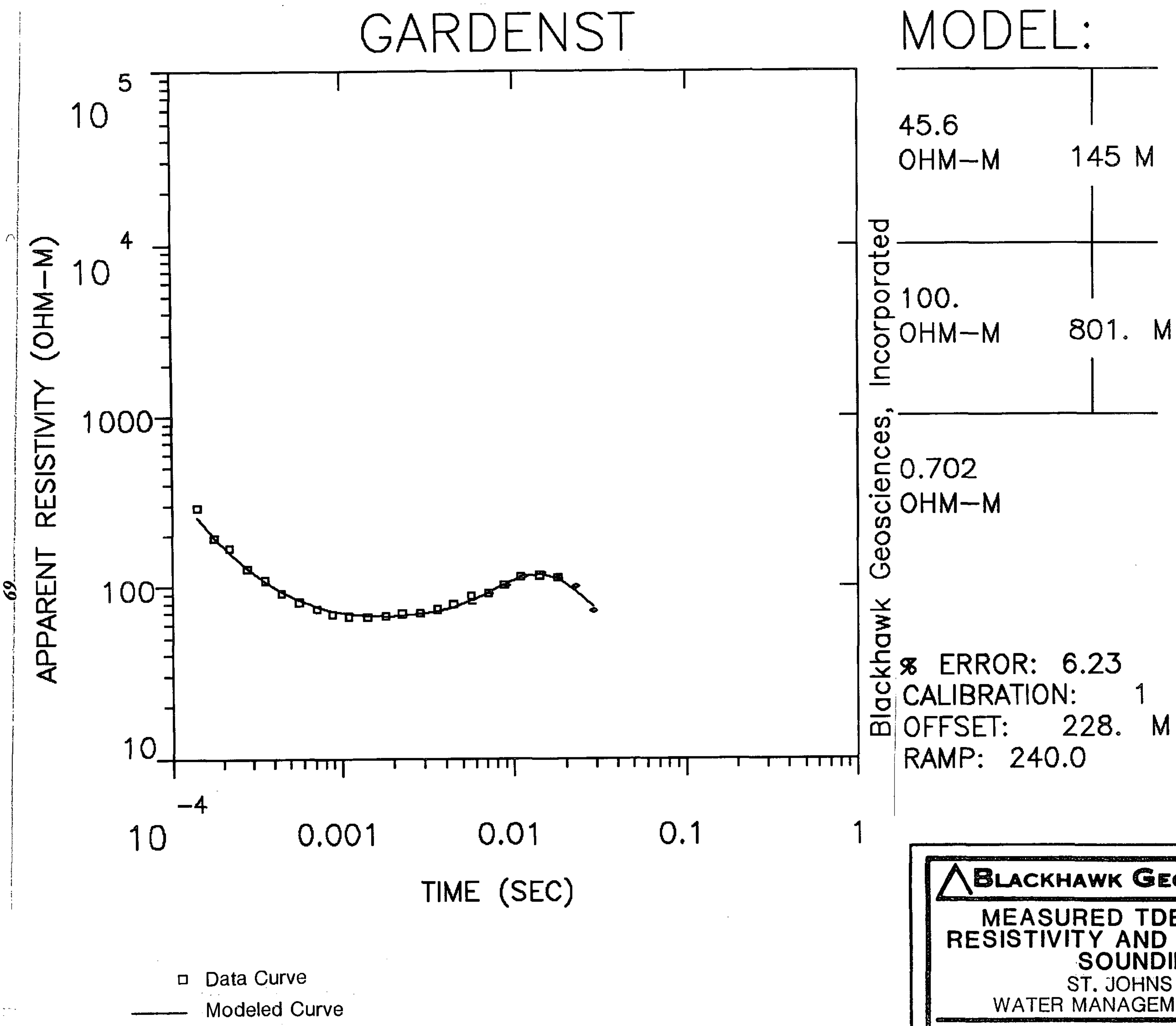


BLACKHAWK GEOSCIENCES, INC.

TDEM SURVEY LOCATION MAP
SOUNDING 4

ST. JOHNS RIVER
WATER MANAGEMENT DISTRCT

PROJECT NO 9001-000 **Figure 5-5.1**



BLACKHAWK GEOSCIENCES, INC.

MEASURED TDEM APPARENT RESISTIVITY AND 1–D INVERSION SOUNDING 4

ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT

PROJECT NO: 9001–000 (92022) **Figure 5–5.2**

zone mapped by the TDEM sounding. Also, the resistivity log indicates no zones of low resistivity within the depth interval of the Floridan aquifer. Saline water may exist in the formations between the base of the Floridan aquifer and above the low resistivity zone if porosities are less than 10%.

5.5.4 Depth of Occurrence of 250 mg/l Isochlor

Since the resistivity of the depth interval corresponding to the Floridan aquifer is inferred to be in excess of 100 ohm-m, the interpreted chloride content for the Floridan is expected to be less than 250 mg/l. Therefore, the 250 mg/l isochlor does not occur within the Floridan aquifer. The chloride to sulfate ratio for ground water within the Floridan aquifer in this area is approximately 5:1 (Sprinkle, 1989) which should not affect the interpreted chloride salinity.

5.5.5 Accuracy of Measurement and Interpretation

Figure 5-5.3 shows the evaluation of equivalence for the TDEM sounding, and the inversion table (Table 5-5.1) lists the upper and lower boundaries of the parameters of the geoelectric section.

The range of equivalence in determining the depth of the interpreted saline water (layer 3) is about ± 373 ft (114 m) or about ± 12% of total depth. The resistivity of the third layer ranges from 0.22 to 2.5 ohm-m.

The equivalence in resistivity of the second layer which represents the Floridan aquifer, ranges from 79 ohm-m to 129 ohm-m. Assuming a 25% porosity, this corresponds to a chloride content between 96 mg/l to 254 mg/l.

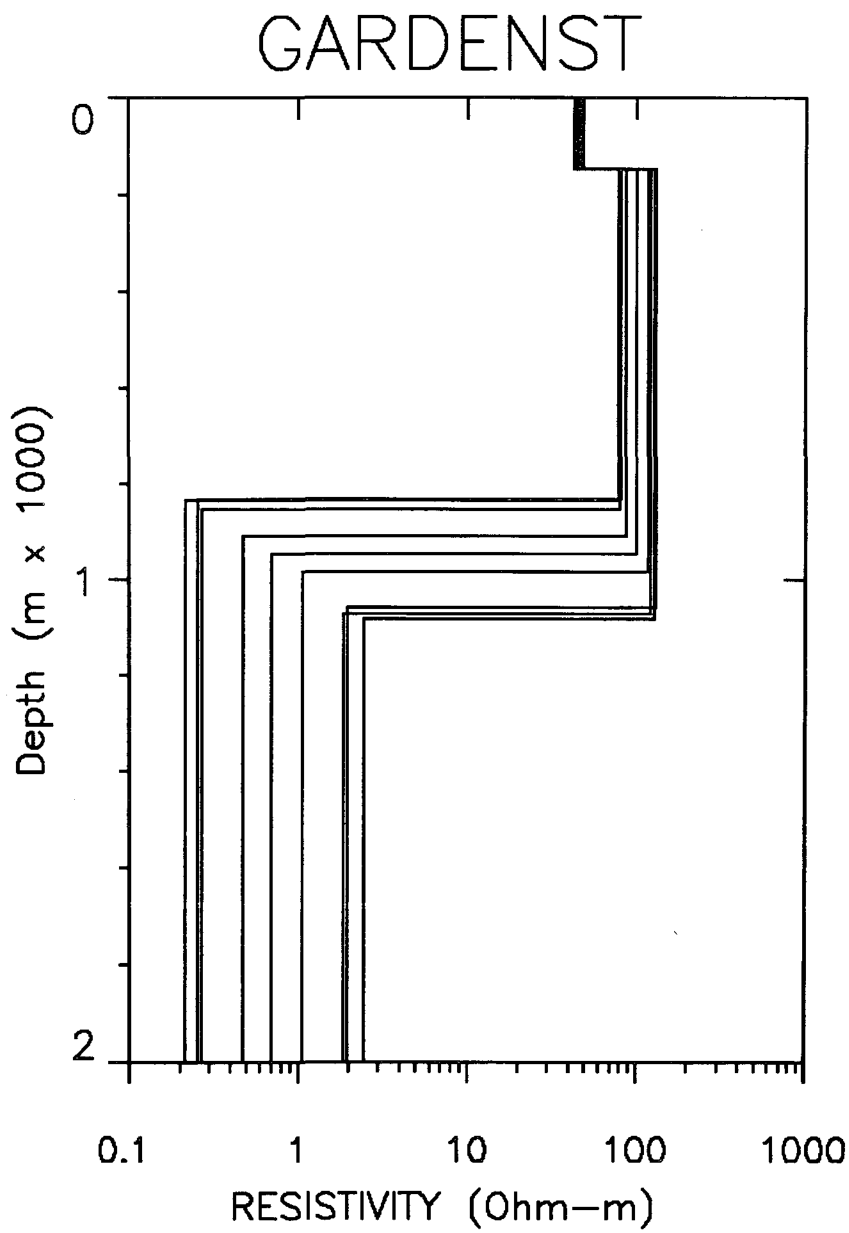
The depth to saline water, as determined by the TDEM sounding, is below the base of the Floridan aquifer as determined by Krause and Randolph (1989) and shown in Figure 5-2.4. Since the mapped zone of saline water is below the Floridan aquifer, Figure 4-9 is not valid and a quantitative estimate of chloride content cannot be made.

5.5.6 Summary of Results of TDEM Measurements at Garden Street (Site 4)

From the TDEM measurements, the following information about water quality was derived:

(1) The depth of occurrence of saline water within formations with porosities greater than 10% was interpreted at a depth of 3,100 ft (-3,015 ft msl) which is below the Floridan aquifer. Therefore, the 5,000 mg/l isochlor does not occur within the Floridan aquifer.

(2) The 250 mg/l isochlor does not occur within the Floridan aquifer. Also, the chloride concentration in ground water within the Floridan aquifer is interpreted to be less than 170 mg/l, assuming 25% porosity and the validity of Figure 4-9. The chloride to sulfate ratio for the Floridan aquifer in this area is approximately 5:1 and does not affect the interpreted chloride concentration.



BLACKHAWK GEOSCIENCES, INC.

EQUIVALENCE IN 1-D INVERSION

SOUNDING 4

ST. JOHNS RIVER

WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) Figure 5-5.3

GARDENST

MODEL: 3 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		26.5	87.0		
45.64	145.0	-118.5	-388.7	3.2	3.2
100.12	800.6	-919.1	-3015.3	8.0	11.2
0.70					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	1.40E-04	2.91E+02	2.55E+02	14.032	
2	1.77E-04	1.94E+02	1.96E+02	-1.243	
3	2.20E-04	1.70E+02	1.58E+02	7.573	
4	2.80E-04	1.28E+02	1.28E+02	0.117	
5	3.55E-04	1.10E+02	1.07E+02	2.342	
6	4.43E-04	9.17E+01	9.36E+01	-2.064	
7	5.64E-04	8.14E+01	8.32E+01	-2.183	
8	7.13E-04	7.44E+01	7.63E+01	-2.437	
9	8.81E-04	6.92E+01	7.21E+01	-4.004	
10	1.10E-03	6.71E+01	6.93E+01	-3.235	
11	1.41E-03	6.67E+01	6.76E+01	-1.255	
12	1.80E-03	6.76E+01	6.71E+01	0.722	
13	2.22E-03	6.96E+01	6.76E+01	3.064	
14	2.83E-03	6.99E+01	6.91E+01	1.103	
15	3.57E-03	7.38E+01	7.20E+01	2.454	
16	4.43E-03	7.93E+01	7.62E+01	4.120	
17	5.64E-03	8.81E+01	8.32E+01	5.986	
18	5.71E-03	-7.94E+01	8.36E+01	-194.982	
19	7.13E-03	9.18E+01	9.26E+01	-0.894	
20	7.20E-03	-9.09E+01	9.31E+01	-197.676	
21	8.81E-03	1.02E+02	1.03E+02	-0.479	
22	9.07E-03	-1.01E+02	1.04E+02	-197.088	
23	1.10E-02	1.14E+02	1.13E+02	1.092	
24	1.14E-02	-1.15E+02	1.15E+02	-200.423	
25	1.41E-02	1.16E+02	1.18E+02	-1.699	
26	1.44E-02	-1.20E+02	1.18E+02	-201.776	
27	1.80E-02	1.13E+02	1.11E+02	1.689	
28	1.81E-02	-1.14E+02	1.11E+02	-202.684	
29	2.29E-02	-1.01E+02	9.47E+01	-206.377	

BLACKHAWK GEOSCIENCES, INC.

INVERSION TABLE
SOUNDING 4
ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) Table 5-5.1

```
30   2.88E-02  -7.18E+01   7.68E+01  -193.459

R:  228. X:     0. Y:  228. DL: 457. REQ:  254. CF: 1.0000
CLHZ ARRAY,  30 DATA POINTS, RAMP:   240.0 MICROSEC, DATA: GARDENST
GARDEN STREET  LINE FILTER
SET 1
RMS LOG ERROR:    2.62E-02, ANTILOG YIELDS     6.2290 %
LATE TIME PARAMETERS


      * Blackhawk Geosciences, Incorporated  *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER
P 1  1.00
P 2  0.00  1.00
P 3  0.00  0.00  0.99
F 1  0.00  0.00  0.00  0.00
T 2  0.00  0.00  0.00  0.00  1.00
      P 1   P 2   P 3   F 1   T 2

  PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

  LAYER     MINIMUM       BEST     MAXIMUM

RHO     1      42.834     45.639     48.555
        2      78.957    100.118    129.426
        3       0.216      0.702      2.479

THICK   1     145.000    145.000    145.000
        2     685.921    800.596    937.840

DEPTH   1     145.000    145.000    145.000
        2     830.921    945.596   1082.840
```

BLACKHAWK GEOSCIENCES, INC.

INVERSION TABLE CONTINUED
SOUNDING 4
ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022)   Table 5-5.1

5.6 PONTE VEDRA (SITE 5)

5.6.1 Location and Geoelectric Section

The detailed location map of this sounding is shown in Figure 5-6.1. The sounding data and the inverted geoelectric section is shown in Figure 5-6.2 and consists of a four layer geoelectric section. In 1990 an EM37 sounding was made at this location, but its depth of exploration was insufficient to detect saline water because of interference from power lines.

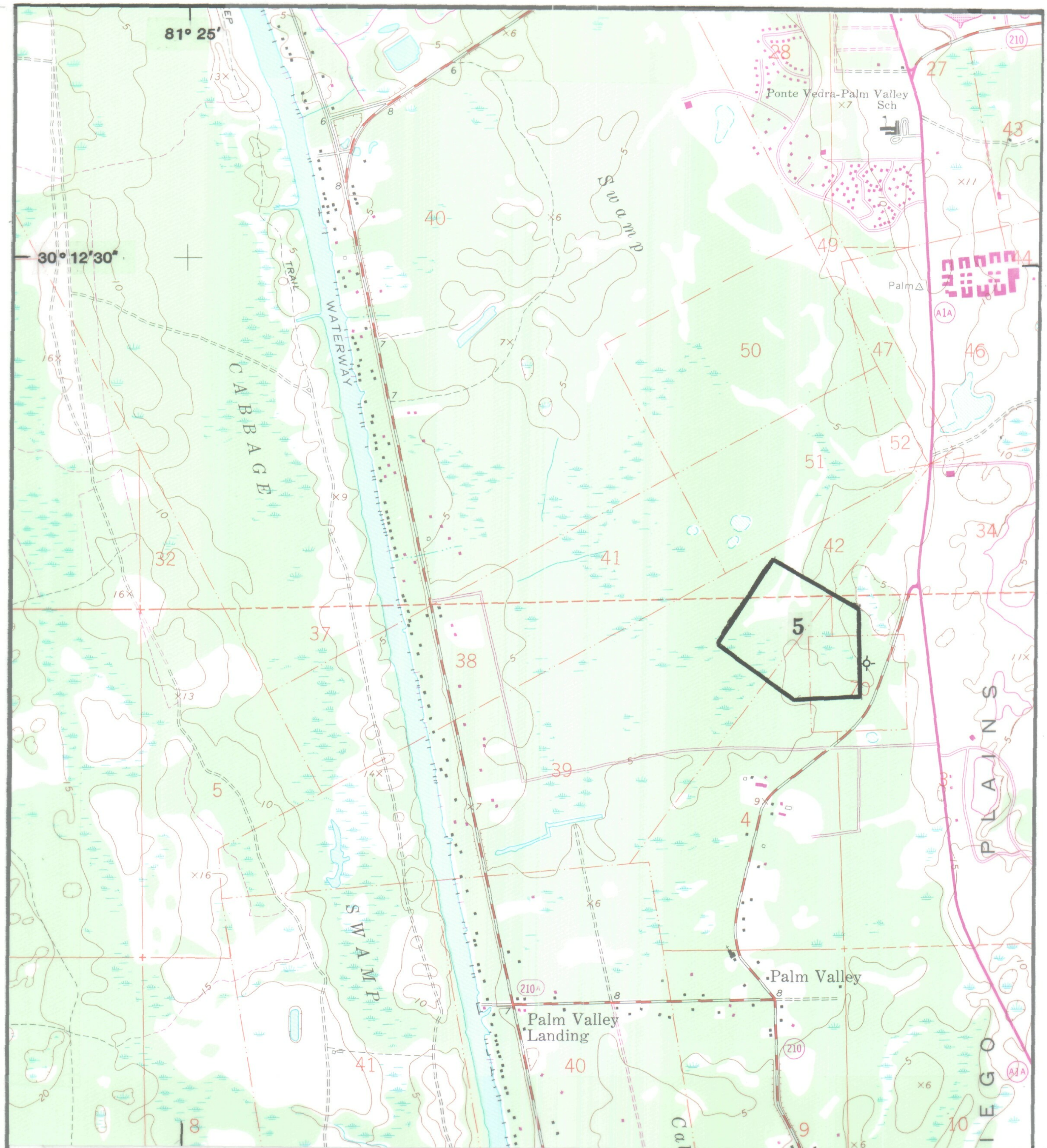
5.6.2 Geologic Interpretation of Geoelectric Section

The first two layers of the interpreted geoelectric section have resistivities of 89 ohm-m and 13 ohm-m, and a combined thickness of 303 ft (92 m). These two layers likely corresponds to the Hawthorn Group and younger formations overlying the Floridan aquifer. The 1990 sounding shows a similar combined thickness for these layers. This is consistent with Miller (1986) who maps the top of the Floridan aquifer at a depth of 300 ft below surface.

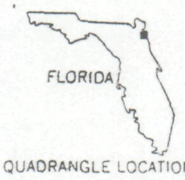
The third layer in the interpreted geoelectric section, with a resistivity of 54 ohm-m and a thickness of 1,542 ft, corresponds to the upper portion of the Floridan aquifer. The 1990 sounding, which did not fully resolve the resistivity of this layer, shows a resistivity of 76 ohm-m. The fourth layer, with a resistivity of 5.5 ohm-m, corresponds to a saline water saturated portion of the Floridan aquifer.

5.6.3 Depth of Occurrence of Saline Water

Layer 4 of the geoelectric section, with a resistivity of 5.5 ohm-m, is interpreted to represent saline water and occurs at a depth of 1,845 ft (-1,840 ft msl). Since the resistivity of layer 3 (54 ohm-m) is less than 80 ohm-m, the water quality in the entire section of the Floridan aquifer is expected to exceed 250 mg/l. Assuming a porosity of 25% and the validity of Figure 4-9, the 5.5 ohm-m resistivity of layer 4 corresponds to a chloride content of 5,695 mg/l. Figure 5-6.3 shows a comparison between the geoelectric section and data from a test well drilled adjacent to the east side of the transmitter loop (Fig. 5-6.1). Saline water was encountered within the drillhole at a depth of 2,000 ft, and its chloride content was greater than 10,000 mg/l. Thus, the depth of the saline water within the drillhole was approximately 8% greater than the TDEM interpreted depth. The difference in salinities observed in the well, and inferred from TDEM-derived resistivities, is likely due to (i) the porosity of the formation being less than 25%, or (ii) errors in resolving the resistivity of this layer in a high electromagnetic noise environment.



Test Well



N

0 2000 4000 Feet

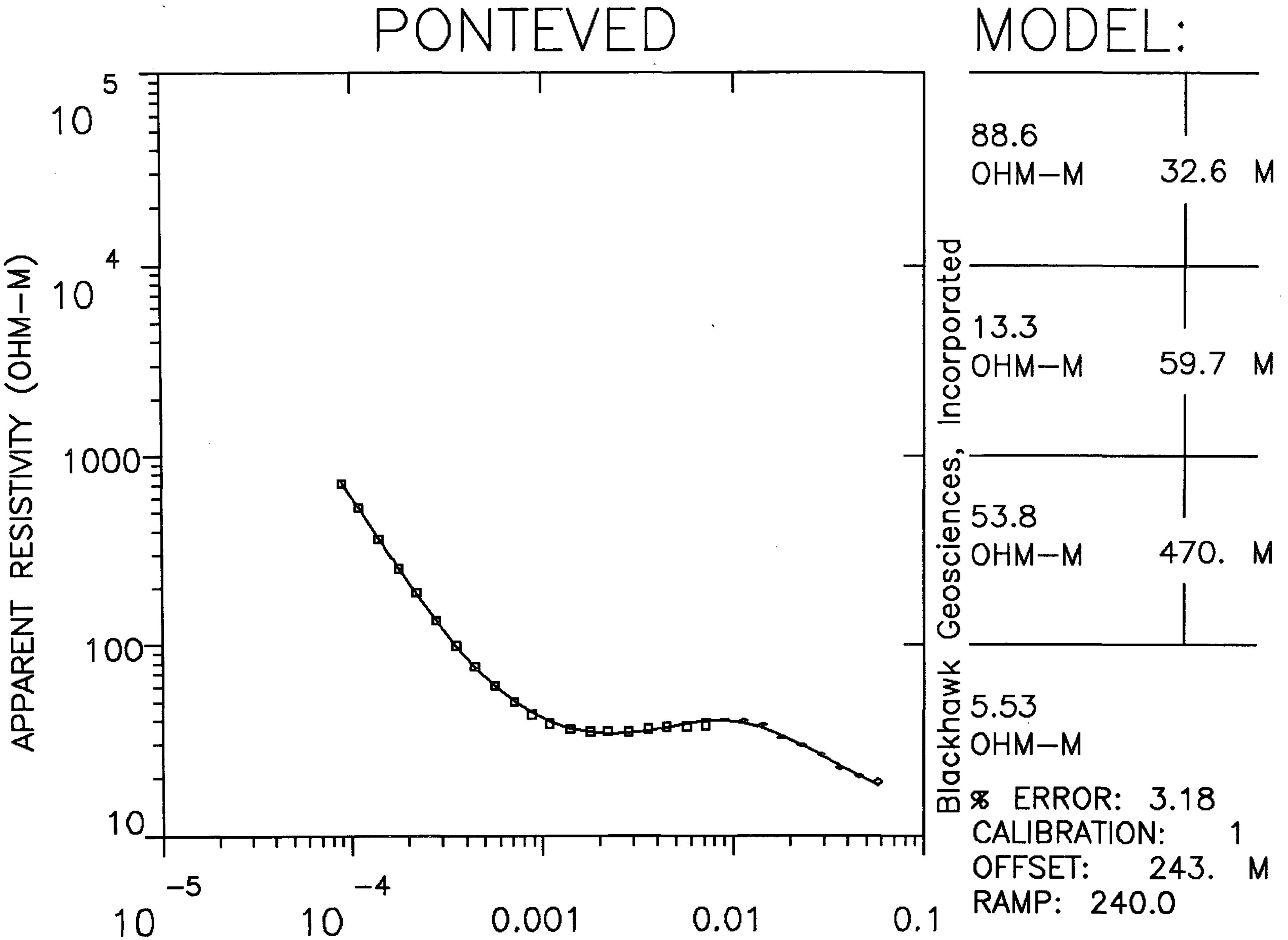
BLACKHAWK GEOSCIENCES, INC.

TDEM SURVEY LOCATION MAP
SOUNDING 5

ST. JOHNS RIVER
WATER MANAGEMENT DISTRCT

PROJECT NO 9001-000

Figure 5-6.1



Data Curve

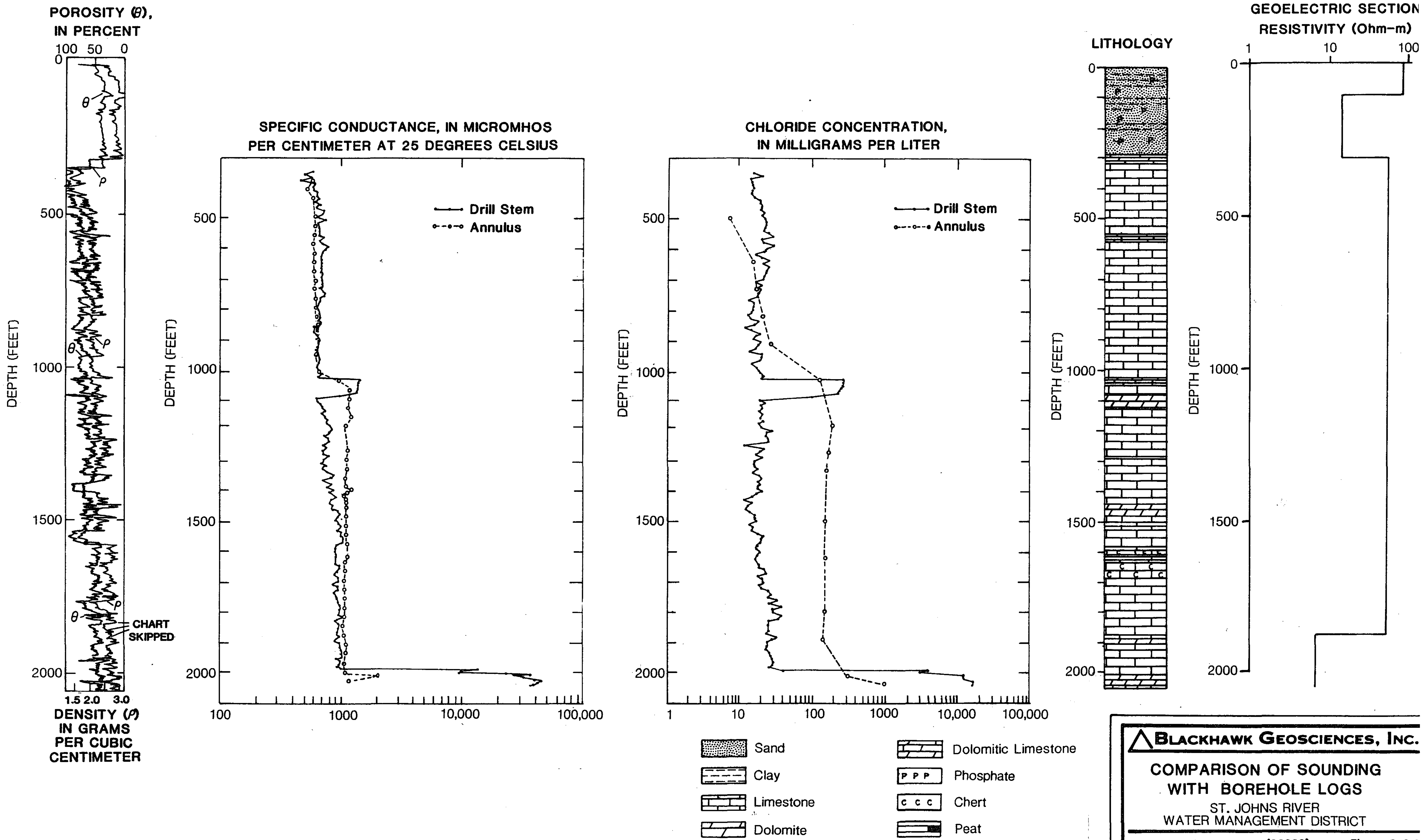
Modeled Curve

BLACKHAWK GEOSCIENCES, INC.

MEASURED TDEM APPARENT RESISTIVITY AND 1-D INVERSION SOUNDING 5

ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) **Figure 5-6.2**



BLACKHAWK GEOSCIENCES, INC.

COMPARISON OF SOUNDING WITH BOREHOLE LOGS

ST. JOHNS RIVER WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) Figure 5-6.3

Figure 5-6.3 shows a porosity log for the test hole, and although the absolute values of porosity appear to be too high, it is apparent that there is a decrease in porosity in the lower portion of the drillhole.

5.6.4 Depth of Occurrence of the 250 mg/l Isochlor

Layer 3 of the geoelectric section, which is interpreted to represent the Floridan aquifer, has a resistivity of 54 ohm-m. Utilizing a porosity of 25% and Figure 4-9, this corresponds to a chloride content of 442 mg/l. Figure 5-6.3, however, shows the chloride content for the depths corresponding to this layer within the adjacent drillhole to be approximately 20 mg/l. This difference is likely due to a combination of higher formational porosities and the presence of higher than normal concentrations of anions other than chloride in the water. This is supported by (1) the porosity log shown in Figure 5-6.3 which indicates high porosities for the upper portion of the Floridan aquifer, and (2) the log of specific conductance, also shown in Figure 5-6.3. This log shows a specific conductance for formational water between 600 micromhos and 1000 micromhos per centimeter for the Floridan aquifer. These conductances are equivalent to a ground water resistivity of 10 ohm-m to 16 ohm-m and would correspond to formational resistivities between from 43 ohm-m and 69 ohm-m, consistent with the value interpreted by the TDEM sounding. In addition, Sprinkle (1989) indicates sulfate concentrations between 101 mg/l and 250 mg/l in this area. This results in a chloride to sulfate ratio less than 1, and is considerably greater than the ratio of 5:1 for ground water used by Kwader (1982) in formulating Figure 4-8.

5.6.5 Accuracy of Measurement and Interpretation

Figure 5-6.4 shows the evaluation of equivalence for the TDEM sounding at this site and the inversion table (Table 5-6.1) lists the upper and lower boundary of the parameters of the geoelectric section.

The range of equivalence in determining the depth to the interpreted saline water (layer 4) is shown in Figure 5-6.4 to be about $\pm$ 98 ft (30 m) or about 5% of the total depth. At the high end of the range (1,944 ft) the difference between the drillhole determined depth is approximately 3%. The resistivity of this layer ranges from 4.2 to 6.9 ohm-m.

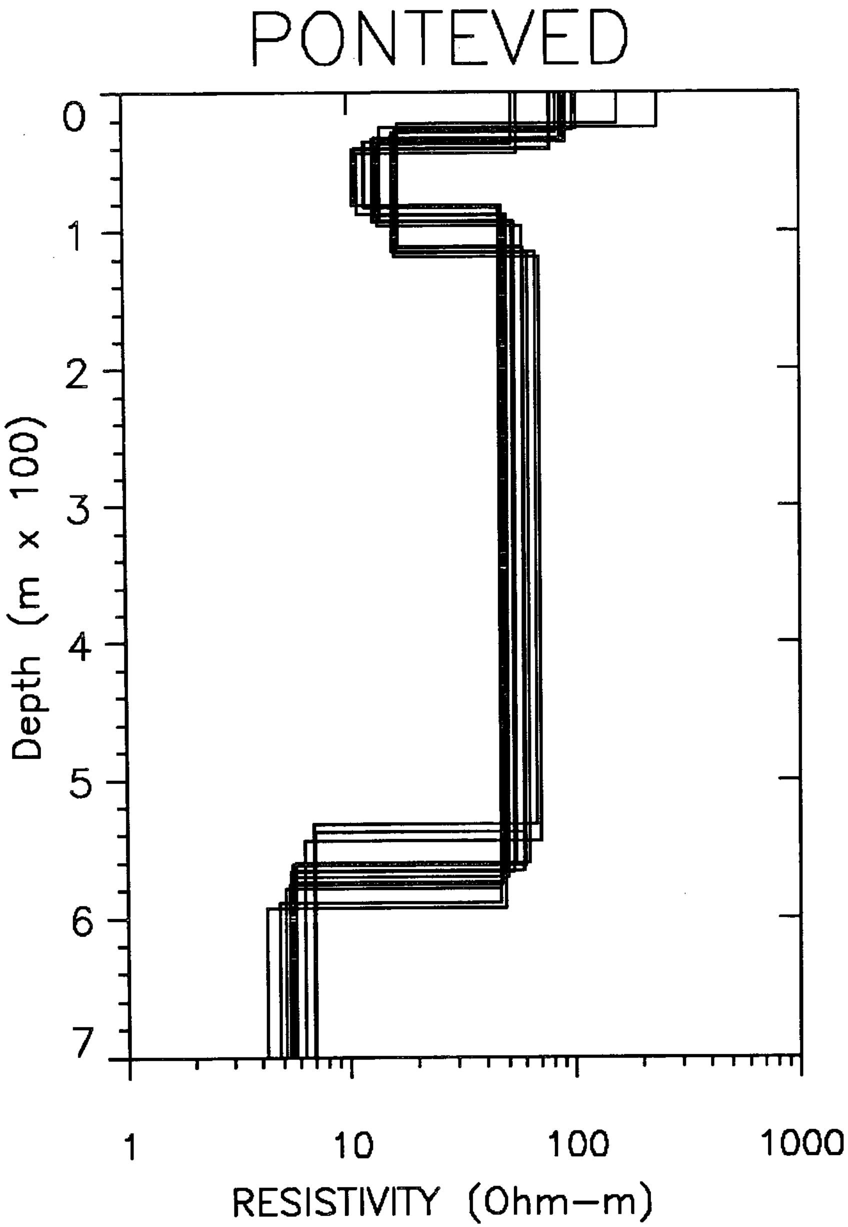
The equivalence of the third layer's resistivity is between 47 ohm-m and 70 ohm-m. The 70 ohm-m corresponds to a chloride content of 300 mg/l assuming 25% porosity and utilizing Figure 4-9. This is significantly higher than the (20 to 30 mg/l) inferred from the chloride concentration log measured in the drill hole. Likely reasons for this discrepancy are discussed in the previous section.

5.6.6 Summary of Results of TDEM Measurements at Ponte Vedra (Site 5)

From the TDEM measurements, the following information about water quality was derived:

(1) The depth of occurrence of saline water was interpreted to be 1,840 ft (-1,835 ft msl) which is within 8% of that determined by a test hole at the site. The salinity of ground water in this layer was interpreted to be 5,695 mg/l chloride, assuming 25% porosity and utilizing Figure 4-9. This is lower than the 10,000 mg/l chloride content indicated in the drillhole, but a porosity log run in the drillhole indicates lower porosities in this zone of saline water.

(2) From the TDEM data, ground water within the Floridan aquifer has a chloride concentration corresponding to 442 mg/l, assuming 25% porosity and utilizing Figure 4-9. Drillhole data shows chloride concentrations to be around 20 to 30 mg/l. Porosity logs, however, indicate that the Upper Floridan is of higher porosity than 25%. Also, specific conductance logs indicate a TDS greater than 20 mg/l, and Sprinkle (1989) indicates a low chloride to sulfate ratio of less than 1 so that other dissolved ionic species may account for the differences.



18

BLACKHAWK GEOSCIENCES, INC.

EQUIVALENCE IN 1-D INVERSION
SOUNDING 5

ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) **Figure 5-6.4**

PONTEVED

MODEL: 4 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		1.5	5.0		
88.61	32.6	-31.1	-101.9	0.4	0.4
13.29	59.7	-90.7	-297.7	4.5	4.9
53.75	470.1	-560.9	-1840.1	8.7	13.6
5.53					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	8.90E-05	7.15E+02	7.29E+02	-1.817	
2	1.10E-04	5.30E+02	5.26E+02	0.822	
3	1.40E-04	3.64E+02	3.64E+02	0.018	
4	1.77E-04	2.53E+02	2.56E+02	-1.113	
5	2.20E-04	1.89E+02	1.86E+02	1.708	
6	2.80E-04	1.34E+02	1.33E+02	0.665	
7	3.55E-04	9.95E+01	9.86E+01	0.885	
8	4.43E-04	7.69E+01	7.67E+01	0.340	
9	5.64E-04	6.09E+01	6.06E+01	0.472	
10	7.13E-04	5.01E+01	5.03E+01	-0.380	
11	8.81E-04	4.31E+01	4.40E+01	-1.889	
12	1.10E-03	3.86E+01	3.95E+01	-2.361	
13	1.41E-03	3.60E+01	3.63E+01	-1.050	
14	1.80E-03	3.49E+01	3.47E+01	0.437	
15	2.22E-03	3.51E+01	3.41E+01	2.708	
16	2.85E-03	3.49E+01	3.44E+01	1.518	
17	3.60E-03	3.63E+01	3.53E+01	2.797	
18	4.49E-03	3.70E+01	3.67E+01	0.979	
19	5.70E-03	3.72E+01	3.84E+01	-3.160	
20	7.19E-03	3.75E+01	3.98E+01	-5.577	
21	7.20E-03	-4.02E+01	3.98E+01	-201.194	
22	9.07E-03	-4.03E+01	4.02E+01	-200.268	
23	1.14E-02	-4.02E+01	3.91E+01	-202.788	
24	1.44E-02	-3.81E+01	3.67E+01	-203.945	
25	1.81E-02	-3.26E+01	3.34E+01	-197.789	
26	2.29E-02	-2.96E+01	2.98E+01	-199.423	
27	2.88E-02	-2.65E+01	2.64E+01	-200.510	
28	3.63E-02	-2.26E+01	2.33E+01	-196.930	

BLACKHAWK GEOSCIENCES, INC.

INVERSION TABLE
SOUNDING 5
ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) Table 5-6.1

29	4.57E-02	-2.05E+01	2.07E+01	-198.797
30	5.76E-02	-1.90E+01	1.85E+01	-202.871

R: 243. X: 0. Y: 243. DL: 487. REQ: 270. CF: 1.0000

CLHZ ARRAY, 30 DATA POINTS, RAMP: 240.0 MICROSEC, DATA: PONTEVED

PONTE VEDRE LINE FILTER

SET 1

RMS LOG ERROR: 1.36E-02, ANTILOG YIELDS 3.1782 %

LATE TIME PARAMETERS

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:

"F" MEANS FIXED PARAMETER

P 1	0.13						
P 2	-0.05	0.90					
P 3	0.02	-0.05	0.93				
P 4	0.01	-0.01	-0.03	0.91			
T 1	0.24	0.10	0.04	0.00	0.85		
T 2	-0.11	-0.17	-0.11	-0.03	0.17	0.70	
T 3	-0.01	0.02	0.03	0.03	-0.01	0.04	0.99
	P 1	P 2	P 3	P 4	T 1	T 2	T 3

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

LAYER		MINIMUM	BEST	MAXIMUM
RHO	1	53.170	88.606	234.305
	2	10.499	13.292	16.776
	3	46.610	53.754	69.959
	4	4.242	5.526	6.969
THICK	1	22.502	32.582	43.899
	2	40.208	59.673	90.573
	3	417.743	470.129	507.191
DEPTH	1	22.502	32.582	43.899
	2	81.063	92.255	118.826
	3	532.530	562.383	592.959

BLACKHAWK GEOSCIENCES, INC.

INVERSION TABLE CONTINUED
SOUNDING 5
ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) Table 5-6.1

5.7 SATSUMA (SITE 6)

5.7.1 Location and Geoelectric Section

The detailed location map for this sounding is shown in Figure 5-7.1. The sounding data and the inverted geoelectric section is shown in Figure 5-7.2 and consists of a four layer section.

5.7.2 Geologic Interpretation of Geoelectric Section

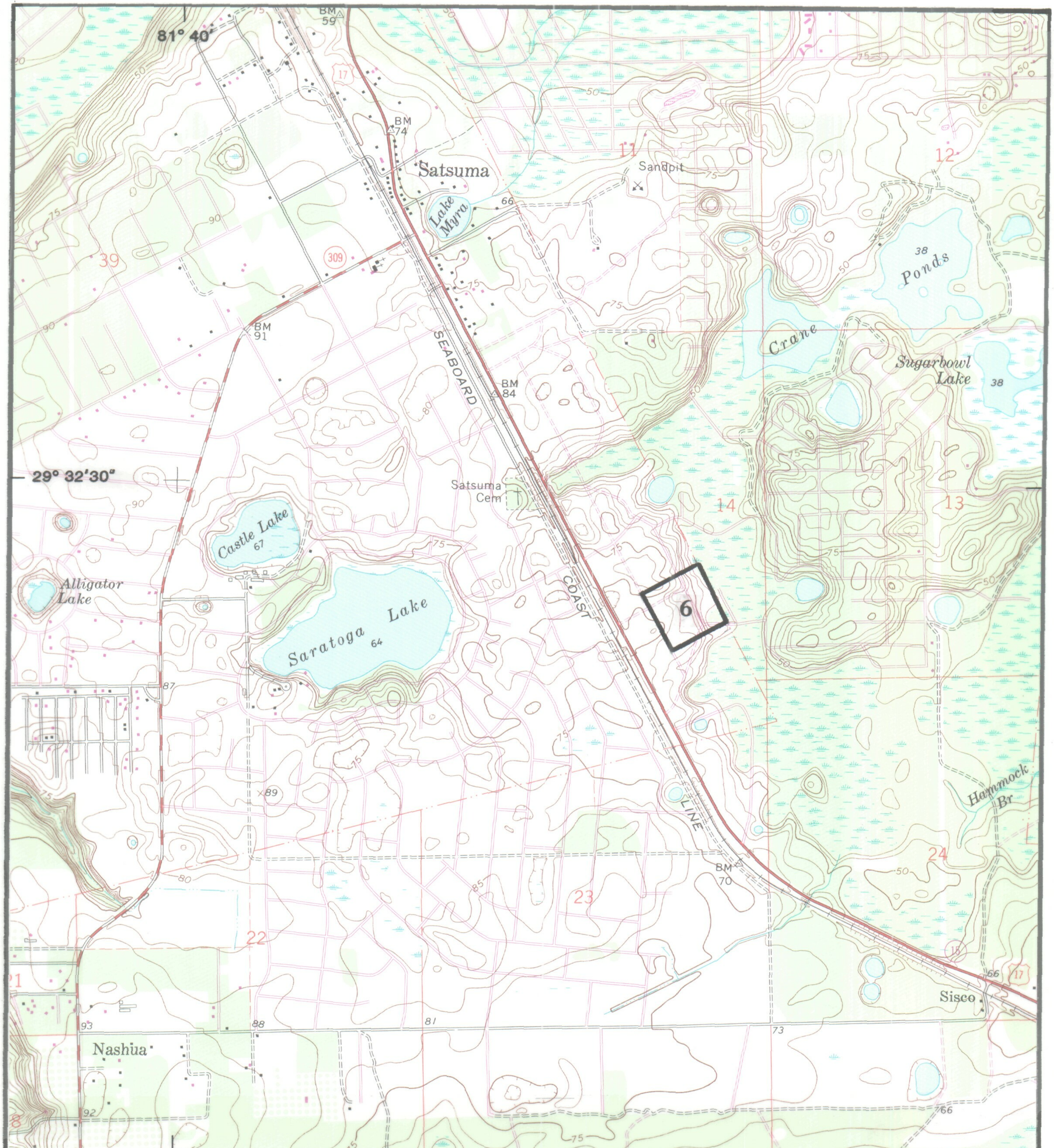
The first two layers of the geoelectric section, with resistivities of 27 ohm-m and 104 ohm-m, and a combined thickness of 120 ft, correspond to the Hawthorn Group and younger formations overlying the Floridan aquifer. This agrees with Ross and Munch (1980) who map the top of the Floridan aquifer at a depth of surface of between 90 ft and 110 ft in the area of the sounding. The third layer, with a resistivity of 152 ohm-m and a thickness of 769 ft, corresponds to the upper portion of the Floridan aquifer saturated with fresh ground water. The fourth layer, with a resistivity of 13.6 ohm-m, corresponds to the lower portion of the Floridan aquifer containing brackish to saline water.

5.7.3 Depth of Occurrence of Saline Water

The position of the top of layer 4, which represents saline water, occurs at a depth of 889 ft (-829 ft msl). Since the resistivity of layer 3 (152 ohm-m) is greater than 80 ohm-m, the saline water interface is interpreted to occur 50 ft below this position at a depth of 939 ft (-879 ft msl). This positioning is based on criteria outlined under Task 3, Section 4. The interpreted resistivity of layer 4, 13.6 ohm-m, corresponds to a salinity of 2,212 mg/l chloride. The 5,000 mg/l isochlor which, for this study, marks the interface with saline water should occur slightly below the 2,212 mg/l isochlor mapped by the TDEM sounding. As explained under Task 3 of Section 4, the position of the two isochlors is assumed to be coincident.

5.7.4 Depth of Occurrence of the 250 mg/l Isochlor

The resistivity of layer 3 of the geoelectric section, 152 ohm-m, corresponds to a chloride concentration of less than 100 mg/l, assuming a porosity of 25% and the validity of Figure 4-9. Based on the criteria in Task 3 of Section 4, and illustrated in Figure 4-11, this constitutes a class A type of transition zone and the 250 mg/l isochlor is located 50 ft higher than the top of layer 4 of the interpreted geoelectric section. This places the 250 mg/l isochlor at a depth of 839 ft (-779 ft msl). The chloride to



QUADRANGLE LOCATION

0 2000 4000 Feet

BLACKHAWK GEOSCIENCES, INC.

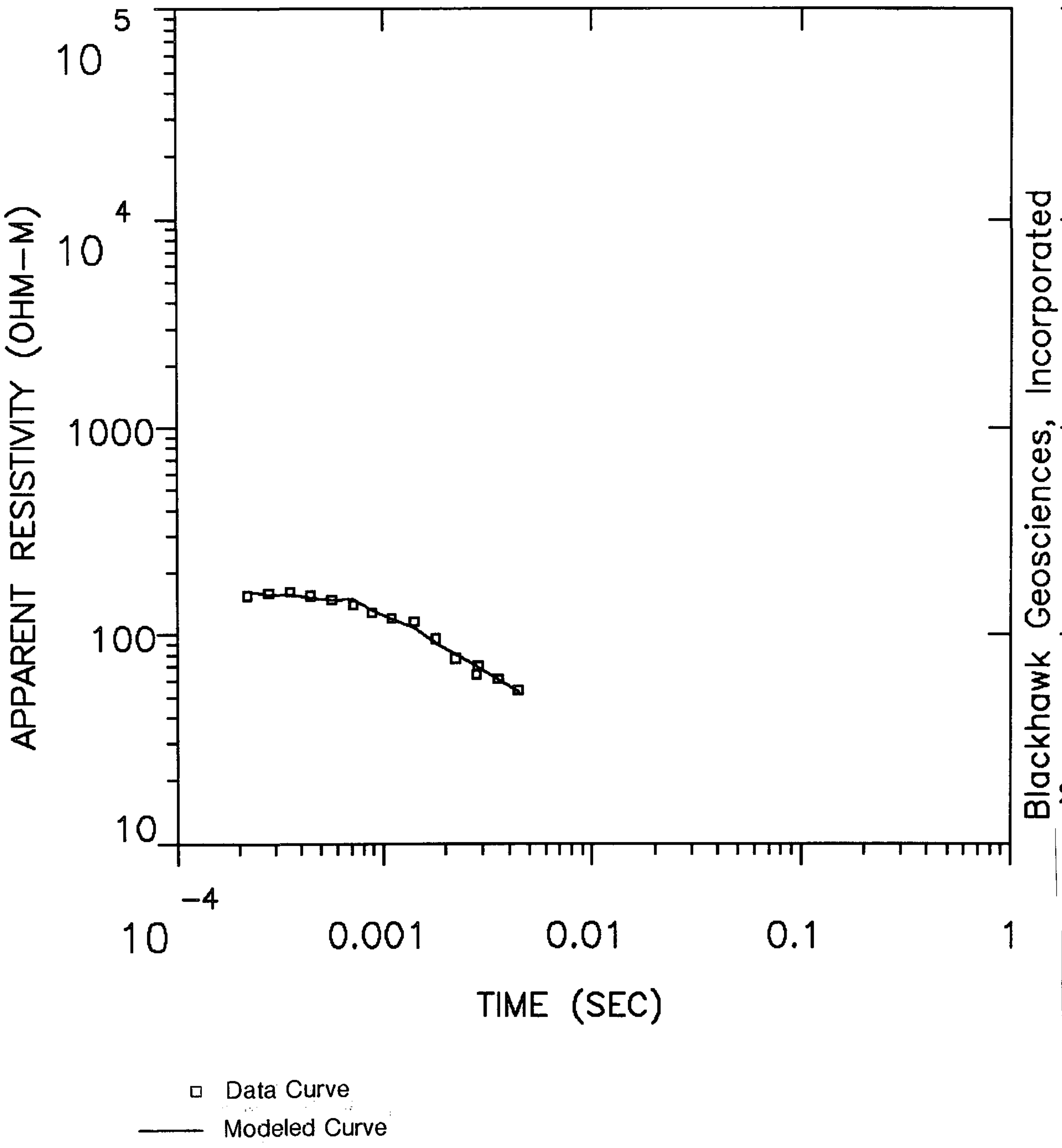
TDEM SURVEY LOCATION MAP

SOUNDING 6

ST. JOHNS RIVER
WATER MANAGEMENT DISTRCT

PROJECT NO 9001-000 **Figure 5-7.1**

SATSUMA



MODEL:

27.2 OHM–M	12.7 M
104. OHM–M	23.9 M
152. OHM–M	234. M
13.6 OHM–M	

% ERROR: 6.44
CALIBRATION: 1
OFFSET: 150 M
RAMP: 170.0

BLACKHAWK GEOSCIENCES, INC.

MEASURED TDEM APPARENT RESISTIVITY AND 1-D INVERSION SOUNDING 6

ST. JOHNS RIVER WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) **Figure 5-7.2**

sulfate ratio in the Floridan aquifer is generally less than 5:1, based on data from wells in the area (Ross and Munch, 1980).

5.7.5 Accuracy of Measurement and Interpretation

Figure 5-7.3 shows the evaluation of equivalence for the TDEM sounding at this site, and the inversion table (Table 5-7.1) lists the upper and lower boundary of the parameters of the geoelectric section.

The range of equivalence in determining the depth to the layer of low resistivity (layer 4) is shown on Figure 5-7.3 to be $\pm$ 33 ft (10 m), about 4% of the total depth. The upper and lower boundary in the resistivity of this layer is between 10.5 ohm-m and 17.3 ohm-m. At the higher resistivity of 17.3 ohm-m this layer corresponds to a salinity of 1,706 mg/l chloride.

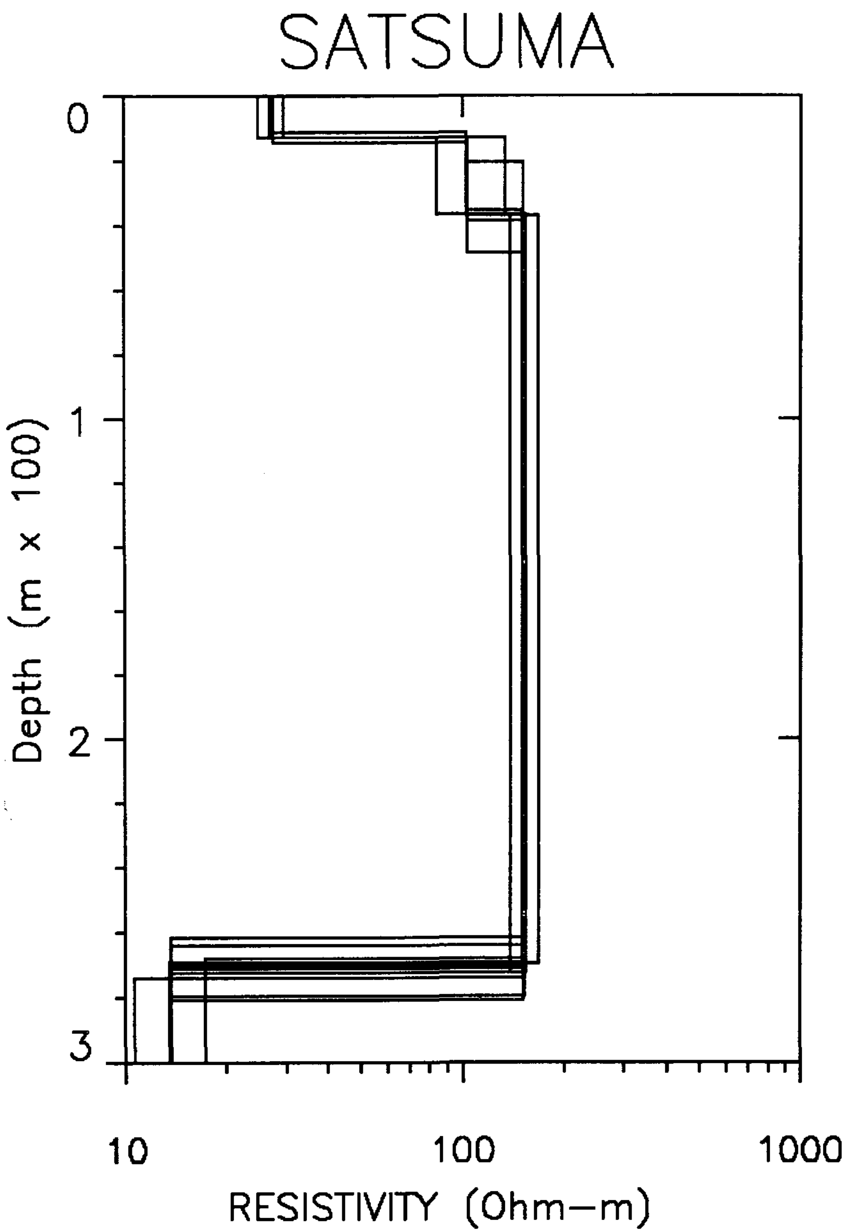
The equivalence in the resistivity of the third layer, which represents the upper portion of the Floridan aquifer, is between 139 ohm-m and 168 ohm-m. Over this range of resistivities the calculated chloride concentrations are less than 100 mg/l and the above conclusions are not altered.

5.7.6 Summary of Results of TDEM Measurements at Satsuma (Site 6)

From the TDEM measurements, the following information about water quality was derived:

(1) The depth of occurrence of saline water was interpreted to be 939 ft (-879 ft msl), and the salinity at this interface was calculated to be 2,212 mg/l chloride. The location of the 5,000 mg/l isochlor is assumed to be coincident with this depth.

(2) The position of the 250 mg/l isochlor was interpreted to occur at a depth of 839 ft (-779 ft msl). The calculated chloride content of the fresh water saturated portion of the Floridan aquifer above the 250 mg/l isochlor was inferred to be less than 100 mg/l. A chloride to sulfate ratio of less than 5:1 for the Floridan aquifer is consistent with the interpretation.



BLACKHAWK GEOSCIENCES, INC.

EQUIVALENCE IN 1-D INVERSION
SOUNDING 6
ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022)

Figure 5-7.3

SATSUMA

MODEL: 4 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		18.3	60.0		
27.25	12.7	5.6	18.3	0.5	0.5
103.60	23.9	-18.3	-60.2	0.2	0.7
152.19	234.4	-252.7	-829.2	1.5	2.2
13.59					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	2.20E-04	1.55E+02	1.62E+02	-4.198	
2	2.80E-04	1.60E+02	1.57E+02	1.587	
3	3.55E-04	1.61E+02	1.56E+02	3.146	
4	4.43E-04	1.54E+02	1.50E+02	2.662	
5	5.64E-04	1.48E+02	1.47E+02	0.801	
6	7.13E-04	1.39E+02	1.49E+02	-6.386	
7	8.81E-04	1.28E+02	1.31E+02	-2.280	
8	1.10E-03	1.20E+02	1.20E+02	-0.121	
9	1.41E-03	1.16E+02	1.08E+02	6.661	
10	1.80E-03	9.54E+01	9.07E+01	5.181	
11	2.22E-03	7.67E+01	8.00E+01	-4.130	
12	2.80E-03	6.43E+01	7.02E+01	-8.393	
13	2.85E-03	7.09E+01	6.95E+01	1.969	
14	3.55E-03	6.12E+01	6.04E+01	1.416	
15	4.43E-03	5.41E+01	5.29E+01	2.259	

R: 150. X: 0. Y: 150. DL: 300. REQ: 167. CF: 1.0000

CLHZ ARRAY, 15 DATA POINTS, RAMP: 170.0 MICROSEC, DATA: SATSUMA

2007 0006 0000 Z OPR XTL H 2 8+100

Ch.21 = 0.17 Ch.22 = 0.089 Ch.23 = 30 Ch.24 = 9

RMS LOG ERROR: 2.71E-02, ANTILOG YIELDS 6.4363 %

LATE TIME PARAMETERS

* Blackhawk Geosciences, Incorporated *

BLACKHAWK GEOSCIENCES, INC.

INVERSION TABLE
SOUNDING 6
ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) Table 5-7.1

PARAMETER RESOLUTION MATRIX:

"F" MEANS FIXED PARAMETER

P 1	0.11						
P 2	0.04	0.02					
P 3	0.08	0.04	0.10				
P 4	-0.01	0.00	-0.01	0.02			
T 1	-0.07	-0.03	-0.07	0.01	0.06		
T 2	-0.01	0.00	-0.01	0.01	0.01	0.00	
T 3	0.02	0.01	0.06	0.05	0.00	0.03	0.36
	P 1	P 2	P 3	P 4	T 1	T 2	T 3

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

LAYER		MINIMUM	BEST	MAXIMUM
RHO	1	24.898	27.248	29.671
	2	83.901	103.603	134.202
	3	139.271	152.190	168.229
	4	10.566	13.589	17.306
THICK	1	11.082	12.696	14.447
	2	7.567	23.929	35.739
	3	225.223	234.390	244.220
DEPTH	1	11.082	12.696	14.447
	2	20.417	36.625	48.382
	3	261.901	271.015	280.791

BLACKHAWK GEOSCIENCES, INC.

INVERSION TABLE CONTINUED
SOUNDING 6
ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) Table 5-7.1

5.8 CRESCENT CITY (SITE 7)

5.8.1 Location and Geoelectric Section

The detailed location map for this sounding is shown in Figure 5-8.1. The sounding data and inverted geoelectric section is shown in Figure 5-8.2 and consists of 3 layers.

5.8.2 Geologic Interpretation of Geoelectric Section

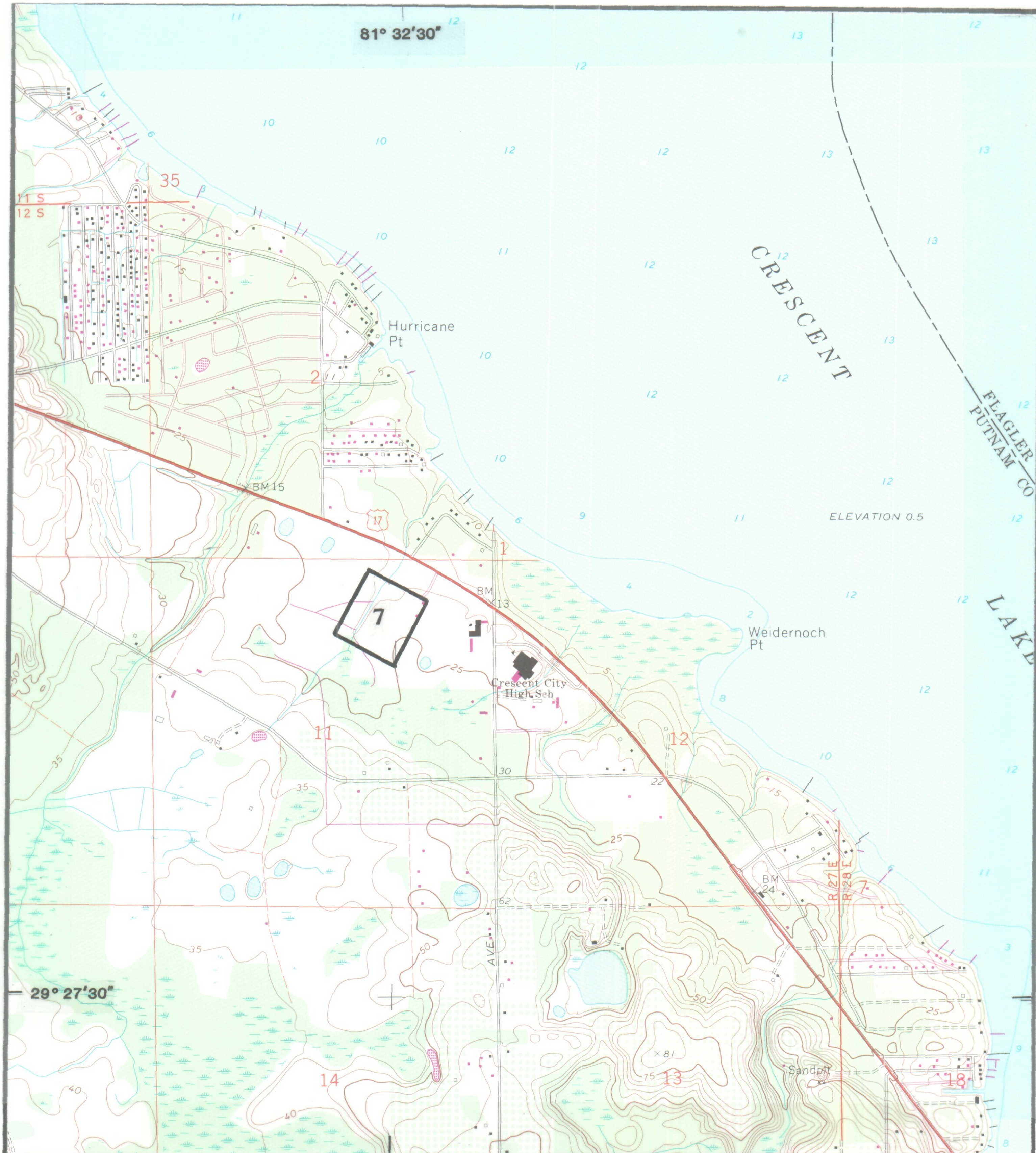
The first layer of the geoelectric section, with a resistivity of 44 ohm-m and a thickness of 148 ft, corresponds to the Hawthorn Group and younger formations overlying the Floridan aquifer. Ross and Munch (1980) map the top of the Floridan aquifer at a depth greater than 115 ft below the surface. The second layer in the section with a resistivity of 78 ohm-m and a thickness of 827 ft represents the Floridan aquifer saturated with ground water with an inferred chloride concentration just in excess of 250 mg/l. Layer 3 of the section, with a resistivity of 2.2 ohm-m, corresponds to the saline water saturated portion of the Floridan aquifer.

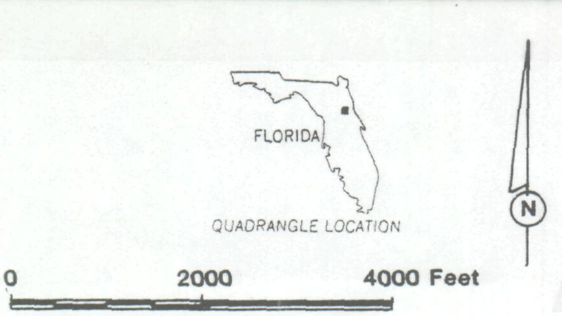
5.8.3 Depth to Saline Water

Layer 3 of the geoelectric section, with a resistivity of 2.2 ohm-m, occurs at a depth of 975 ft (-953 ft msl). Since the resistivity of layer 2 (78 ohm-m) is below 80 ohm-m, the position of the saline water interface is at the same depth. This is based on the criteria outlined under Task 3 of Section 4. The resistivity of layer 3 is 2.2 ohm-m which corresponds to a chloride content greater than 10,000 mg/l, assuming a porosity of 25% and the validity of Figure 4-9.

5.8.4 Depth of Occurrence of the 250 mg/l Isochlor

The resistivity of layer 2 of the geoelectric section, 78 ohm-m, corresponds to a chloride content of 259 mg/l, assuming a porosity of 25% and the validity of Figure 4-9. Wells in the immediate vicinity of the sounding indicate chloride concentrations within the upper Floridan aquifer to be less than 50 mg/l and to have chloride to sulfate ratios of less than 5:1 (Ross and Munch, 1980). This discrepancy may be the result of the average bulk porosity of the Floridan aquifer to be higher than normal. As shown in Figure 4-9 a formation with a chloride content of 30 mg/l and a bulk porosity of 40% would result in a formational resistivity of approximately 80 ohm-m, which is in the range of sounding interpretation.



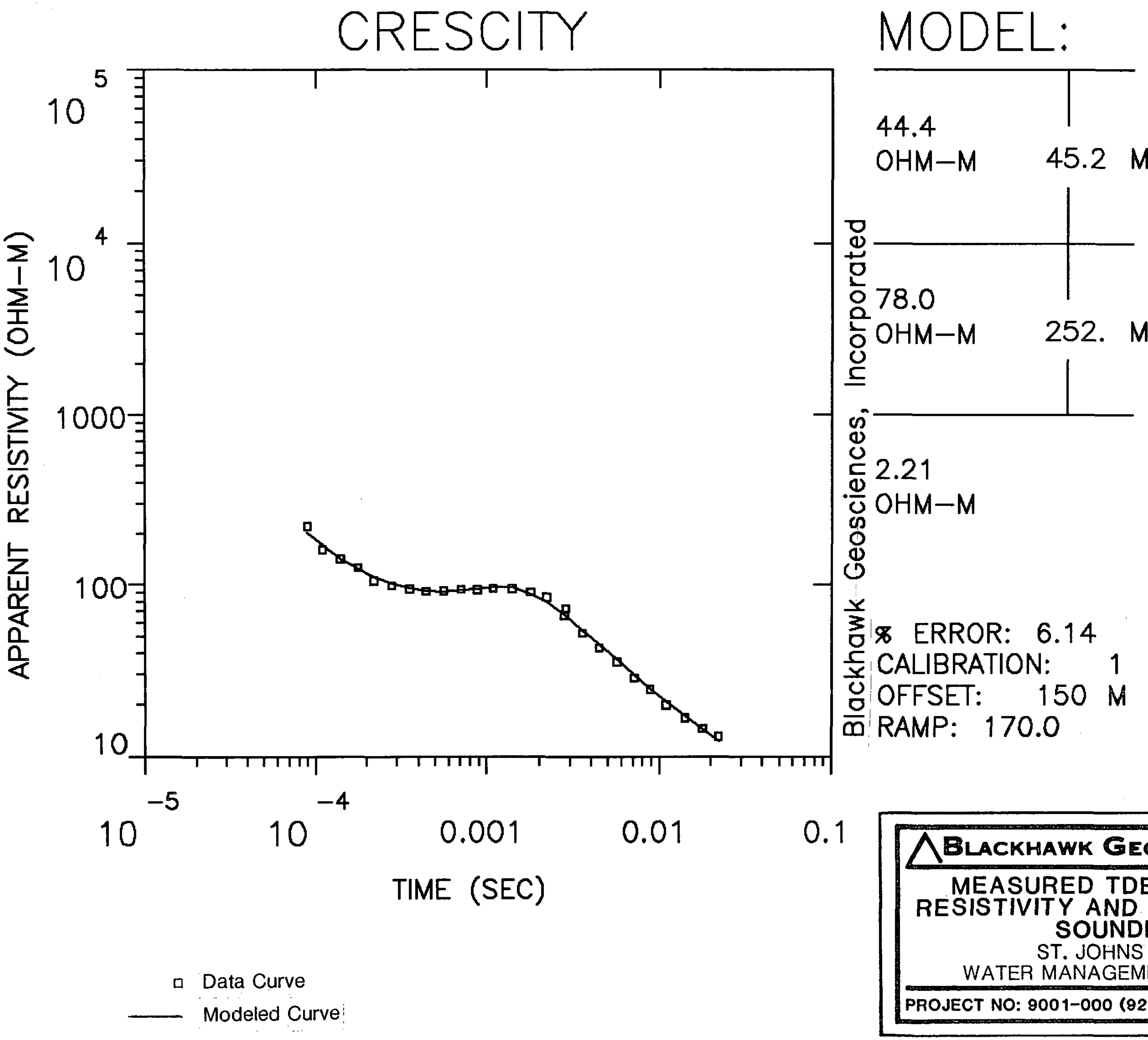


BLACKHAWK GEOSCIENCES, INC.

TDEM SURVEY LOCATION MAP
SOUNDING 7

ST. JOHNS RIVER
WATER MANAGEMENT DISTRCT

PROJECT NO 9001-000 **Figure 5-8.1**



BLACKHAWK GEOSCIENCES, INC.

MEASURED TDEM APPARENT RESISTIVITY AND 1-D INVERSION
SOUNDING 7

ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) **Figure 5-8.2**

5.8.5 Accuracy of Measurement and Interpretation

Figure 5-8.3 shows the evaluation of equivalence for the TDEM sounding at this site, and the inversion table (Table 5-8.1) lists the upper and lower boundary of the parameters of the geoelectric section.

The range of equivalence in determining the depth to the layer of low resistivity (layer 3) is shown on Figure 5-8.3 to be $\pm$ 20 ft (6 m) which is 1% of the total depth. This layer's depth is well resolved. The resistivity of this layer is also well resolved, and corresponds to a chloride content of greater than 10,000 mg/l over the range of equivalence.

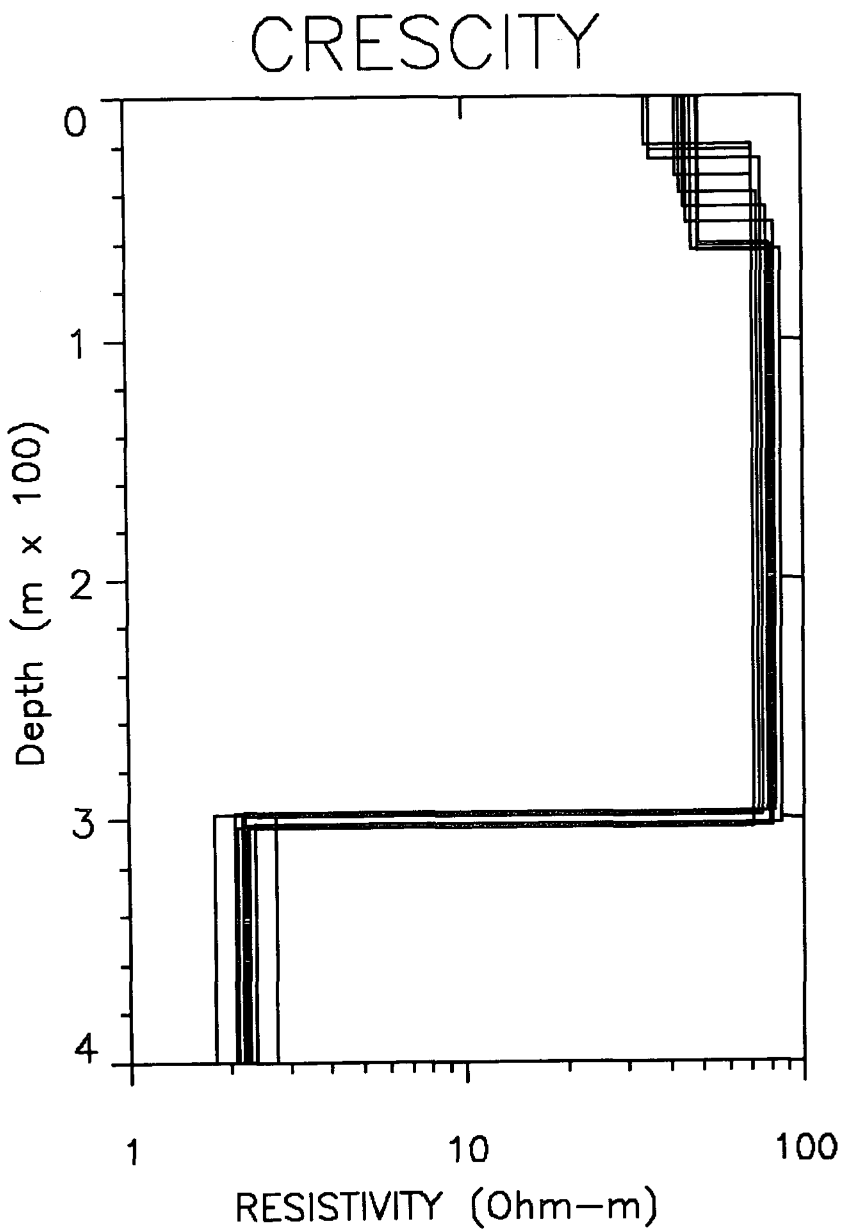
The resistivity of layer 2 shows a range of equivalence of between 70 ohm-m and 86 ohm-m. From these resistivity values chloride concentrations around 250 mg/l are interpreted for the entire Floridan aquifer.

5.8.6 Summary of Results of TDEM Measurements at Crescent City (Site 7)

From the TDEM measurements, the following information about water quality was derived:

(1) The depth of occurrence of saline water and the position of the 5,000 mg/l isochlor was interpreted to be 975 ft (-953 ft msl) and the chloride content of the ground water below this depth was calculated to be greater than 10,000 mg/l.

(2) The best estimate of the chloride content of the Floridan aquifer was calculated to be 259 mg/l. This is inconsistent with data from wells which intersect the Floridan aquifer in this area and cannot be explained by the chloride to sulfate ratio which is less than 5:1. The difference between the interpretation and the well data may be caused by higher than average porosity of the Floridan aquifer in this area.



BLACKHAWK GEOSCIENCES, INC.

EQUIVALENCE IN 1-D INVERSION
SOUNDING 7

ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) **Figure 5-8.3**

CRESCITY

MODEL: 3 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		6.7	22.0		
44.39	45.2	-38.4	-126.1	1.0	1.0
77.95	252.1	-290.5	-953.2	3.2	4.3
2.21					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	8.90E-05	2.20E+02	2.03E+02	8.406	
2	1.10E-04	1.60E+02	1.69E+02	-5.496	
3	1.40E-04	1.42E+02	1.42E+02	-0.447	
4	1.77E-04	1.26E+02	1.24E+02	2.136	
5	2.20E-04	1.06E+02	1.11E+02	-4.774	
6	2.80E-04	9.85E+01	1.01E+02	-2.727	
7	3.55E-04	9.47E+01	9.53E+01	-0.707	
8	4.43E-04	9.18E+01	9.22E+01	-0.333	
9	5.64E-04	9.23E+01	9.11E+01	1.319	
10	7.13E-04	9.38E+01	9.29E+01	0.945	
11	8.81E-04	9.33E+01	9.49E+01	-1.615	
12	1.10E-03	9.48E+01	9.64E+01	-1.583	
13	1.41E-03	9.43E+01	9.64E+01	-2.140	
14	1.80E-03	9.06E+01	8.80E+01	2.971	
15	2.22E-03	8.43E+01	7.91E+01	6.600	
16	2.80E-03	6.57E+01	6.73E+01	-2.377	
17	2.85E-03	7.24E+01	6.63E+01	9.145	
18	3.55E-03	5.21E+01	5.44E+01	-4.229	
19	4.43E-03	4.29E+01	4.51E+01	-4.890	
20	5.64E-03	3.54E+01	3.65E+01	-2.989	
21	7.13E-03	2.86E+01	2.96E+01	-3.606	
22	8.81E-03	2.44E+01	2.48E+01	-1.674	
23	1.10E-02	1.99E+01	2.08E+01	-4.651	
24	1.41E-02	1.67E+01	1.70E+01	-1.705	
25	1.80E-02	1.45E+01	1.43E+01	1.230	
26	2.22E-02	1.31E+01	1.23E+01	6.099	

R: 150. X: 0. Y: 150. DL: 300. REQ: 167. CF: 1.0000
CLHZ ARRAY, 26 DATA POINTS, RAMP: 170.0 MICROSEC, DATA: CRESCITY
2007 0007 250E Z OPR XTL H 2 8+100
Ch.21 = 0.17 Ch.22 = 0.089 Ch.23 = 30 Ch.24 = 9
RMS LOG ERROR: 2.59E-02, ANTILOG YIELDS 6.1355 %

BLACKHAWK GEOSCIENCES, INC.

INVERSION TABLE
SOUNDING 7
ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) **Table 5-8.1**

LATE TIME PARAMETERS

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:

"F" MEANS FIXED PARAMETER

P 1	0.92				
P 2	-0.01	0.98			
P 3	-0.01	-0.02	0.94		
T 1	-0.21	-0.07	-0.04	0.35	
T 2	0.03	0.01	0.01	0.09	0.99
	P 1	P 2	P 3	T 1	T 2

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

LAYER		MINIMUM	BEST	MAXIMUM
RHO	1	34.189	44.389	49.637
	2	70.771	77.951	85.860
	3	1.787	2.212	2.738
THICK	1	19.768	45.152	63.250
	2	239.524	252.077	283.668
DEPTH	1	19.768	45.152	63.250
	2	297.146	297.229	303.498

BLACKHAWK GEOSCIENCES, INC.

INVERSION TABLE CONTINUED
SOUNDING 7
ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) Table 5-8.1

5.9 SEVILLE (SITE 8)

5.9.1 Location and Geoelectric Section

The detailed location map for this sounding is shown in Figure 5-9.1. The sounding data and inverted geoelectric section is shown in Figure 5-9.2 and consists of a three layer section.

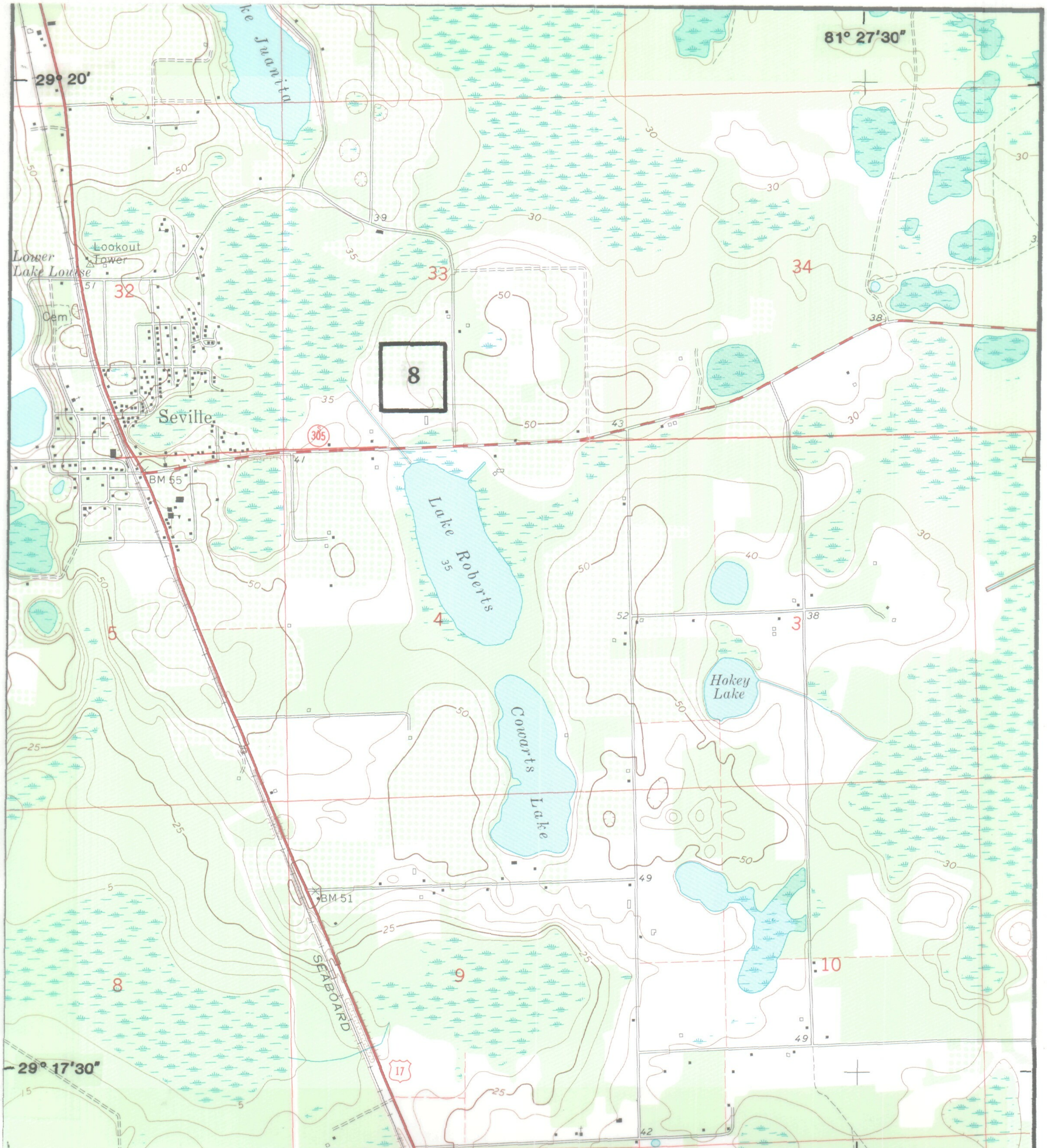
5.9.2 Geologic Interpretation of Geoelectric Section

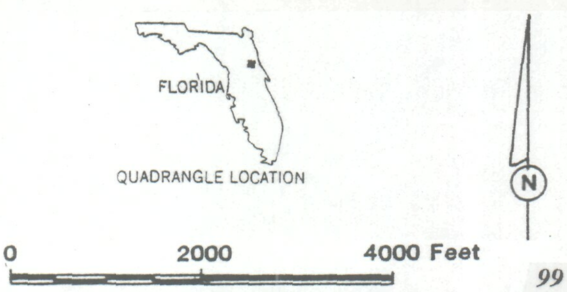
The first layer of the geoelectric section, which has a resistivity of 24 ohm-m and a thickness of 98 ft (29.8 m), corresponds to the Hawthorn Group and younger formations which overlie the Floridan aquifer. This is consistent with the approximately 100 ft depth from surface to the Floridan aquifer based on Miller (1986) and the elevation of the TDEM sounding. The second layer in the section, with a resistivity of 115 ohm-m and a thickness of 733 ft (223.6 m) represents the Floridan aquifer saturated with fresh ground water. Layer 3 of the geoelectric section, which has a resistivity of 6.7 ohm-m, corresponds to the saline water saturated portion of the Floridan aquifer.

5.9.3 Depth of Occurrence of Saline Water

Layer 3 of the geoelectric section, with a resistivity of 6.7 ohm-m, is interpreted to represent saline water and occurs at a depth of 831 ft (-786 ft msl). Since the resistivity of layer 2 (115 ohm-m), which represents fresh water within the Floridan aquifer, is greater than 80 ohm-m, the position of the saline water interface and the 5,000 mg/l isochlor is located 50 ft below the interface between layer 2 and layer 3. The positioning is based on criteria outlined under Task 3 of Section 4. This places the interpreted position of the top of the saline ground water at a depth of 881 ft (-836 ft msl). The resistivity of layer 3 is 6.7 ohm-m which corresponds to a chloride content of 4,640 mg/l, assuming a porosity of 25% and the validity of Figure 4-9.

An estimation of the altitude of the fresh water/salt water interface in the area of the Crescent City Ridge was made in Rutledge (1982). Figure 5-9.3 shows his contour map along with the elevations of the top of the saline water as determined by TDEM at this site and for Site 9. As shown in the figure, there is excellent agreement between Rutledge's estimate of the elevation of the fresh water/salt water interface and that mapped by TDEM. At this site the TDEM mapped interface of -836 ft msl is located between Rutledge's -800 ft msl and -1,000 ft msl contours.



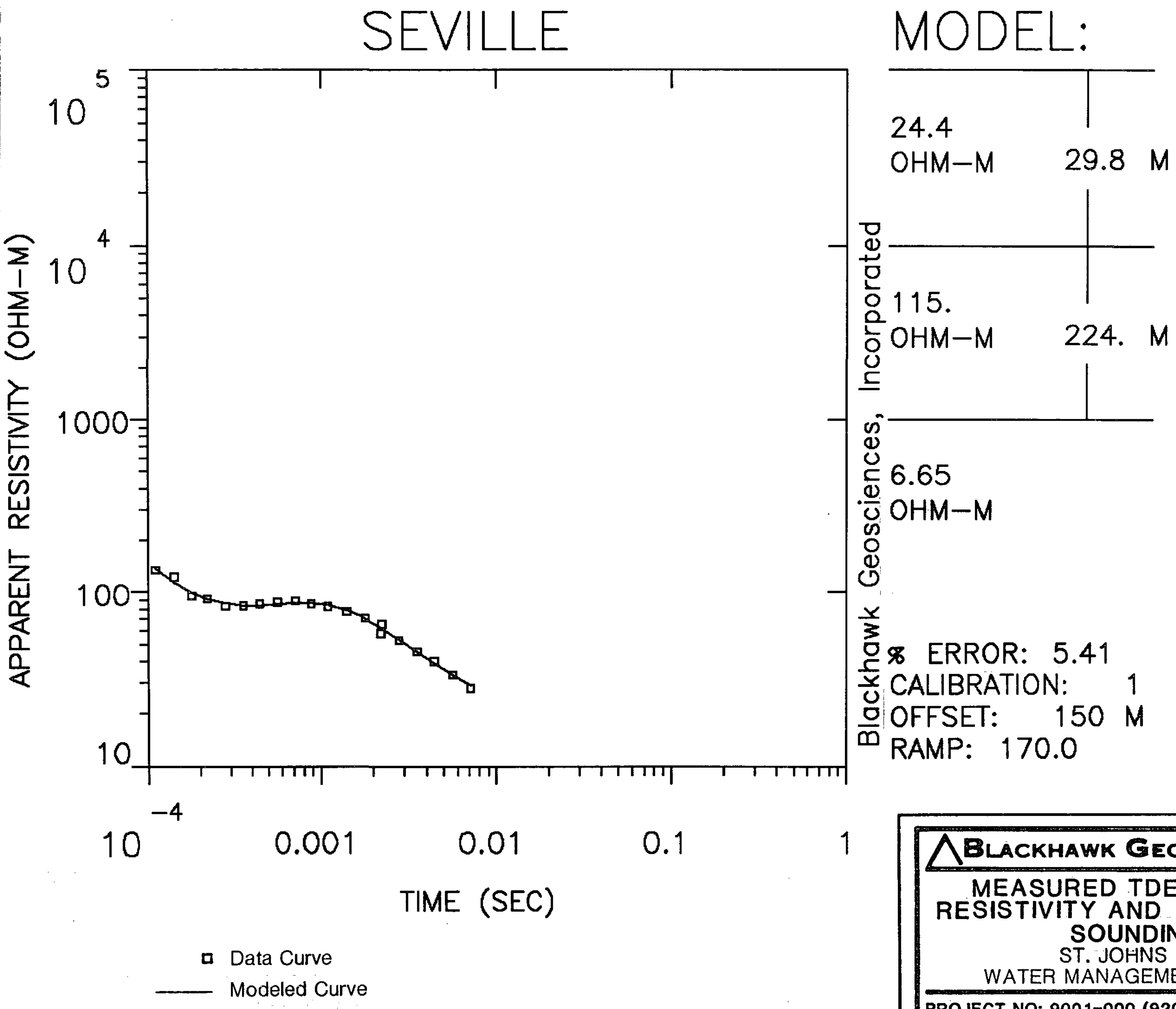


BLACKHAWK GEOSCIENCES, INC.

TDEM SURVEY LOCATION MAP
SOUNDING 8

ST. JOHNS RIVER
WATER MANAGEMENT DISTRCT

PROJECT NO 9001-000 **Figure 5-9.1**



100

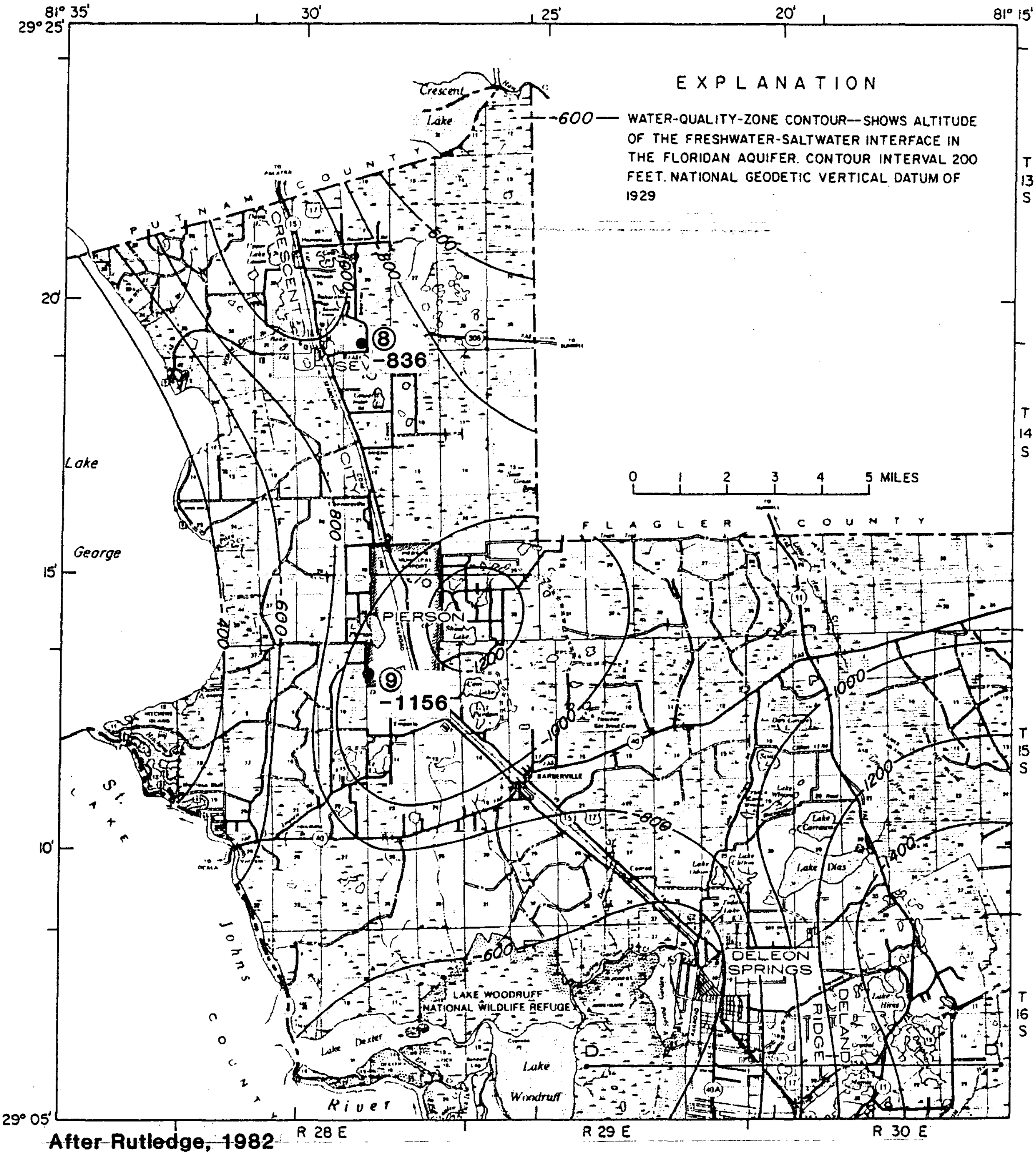
BLACKHAWK GEOSCIENCES, INC.

MEASURED TDEM APPARENT RESISTIVITY AND 1-D INVERSION

SOUNDING 8

ST. JOHNS RIVER WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) **Figure 5-9.2**



After Rutledge, 1982

⑧ -836 Time Domain Electromagnetic Site with interpreted elevation of saline water

BLACKHAWK GEOSCIENCES, INC.

ELEVATION OF FRESH-SALTWATER INTERFACE FROM MODIFIED GHYBEN- HERZBERG PRINCIPAL

ST. JOHNS RIVER WATER MANAGEMENT DISTRICT

PROJECT NO:9001-000 (92022) **Figure 5-9.3**

5.9.4 Depth of Occurrence of the 250 mg/l Isochlor

The resistivity of layer 2 of the geoelectric section, 115 ohm-m, corresponds to a chloride content of less than 150 mg/l assuming a porosity of 25% and the validity of Figure 4-9. Using the criteria outlined in Task 3, Section 4, and illustrated in Figure 4-11, this is a class A type transition zone and the 250 mg/l isochlor is located 50 ft above the interface between Layer 2 and Layer 3 of the geoelectric section. This places the 250 mg/l isochlor at a depth of 781 ft (-736 ft msl). The chloride to sulfate ratio is approximately 5:1 in this area (Sprinkle, 1989) and does not affect the interpreted chloride concentration.

5.9.5 Accuracy of Measurement and Interpretation

Figure 5-9.4 shows the evaluation of equivalence at this site, and the inversion table (Table 5-9.1) lists the upper and lower bounds of the parameters of the geoelectric section.

The range of equivalence in determining the depth to the layer of low resistivity (layer 3) is shown to be about $\pm$ 33 ft (10 m) which is 4% of the total depth. The resistivity of this layer has an equivalence of from 4.8 to 8.9 ohm-m. This range does not change the conclusion that the chloride content of layer 3 is high. At the upper resistivity of 8.9 ohm-m a chloride content of 3,460 mg/l is expected.

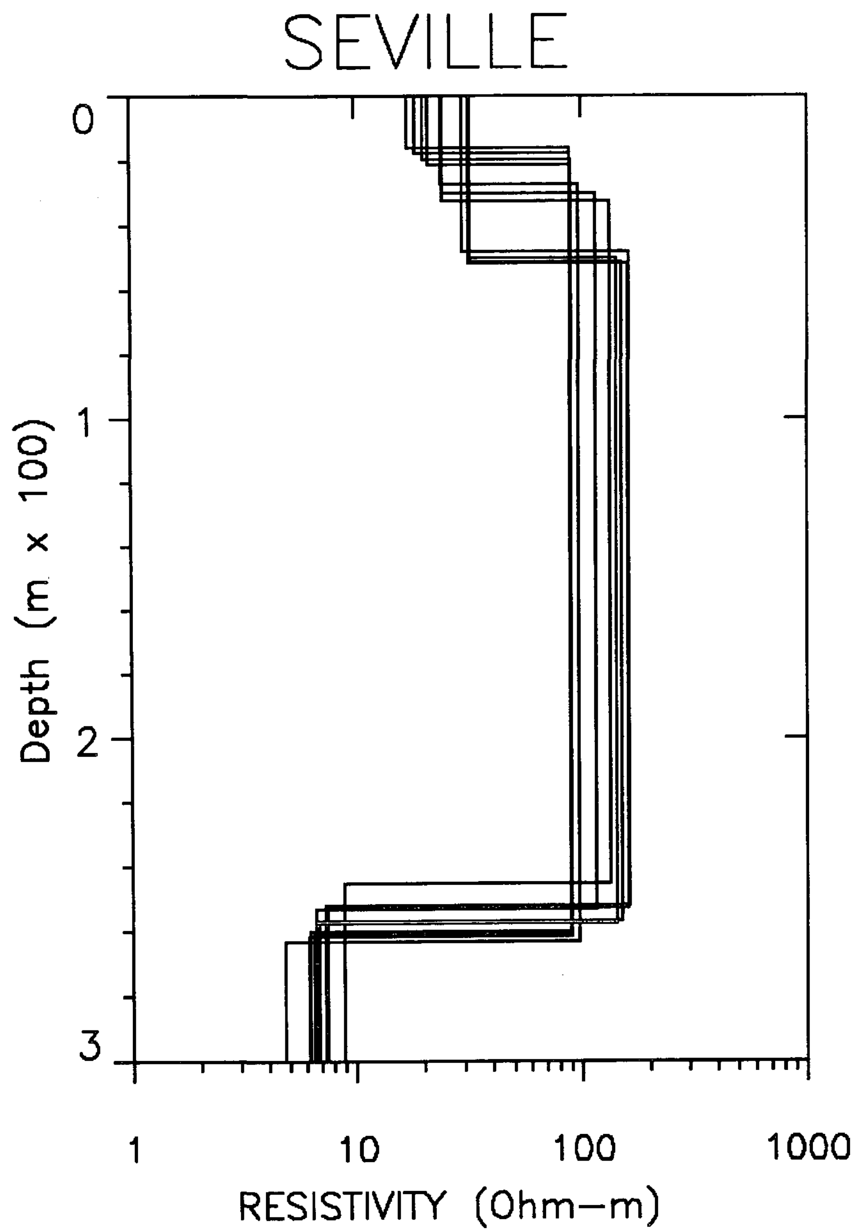
The resistivity of layer 2 shows an equivalence of from 89 ohm-m to 162 ohm-m. Throughout this range, the calculated chloride content of layer 2 is inferred to be less than 250 mg/l.

5.9.6 Summary of Results of TDEM Measurements at Seville (Site 8)

From the TDEM measurements, the following information about water quality was derived:

(1) The depth of occurrence of saline water (5,000 mg/l isochlor) was interpreted to be 881 ft (-836 ft msl) and the chloride content below that depth was inferred to be 4,270 mg/l. The depth to saline water interpreted from the TDEM sounding is in excellent agreement with the depth to the fresh water/salt water interface estimated by Rutledge (1982).

(2) The 250 mg/l isochlor was interpreted to occur at a depth of 781 ft (-736 ft msl). Ground water within the Floridan aquifer above this depth is estimated to have an average chloride concentration less than 150 mg/l. The chloride to sulfate ratio for this area is 5:1 and is consistent with the assumptions used to estimate the chloride concentration.



BLACKHAWK GEOSCIENCES, INC.

EQUIVALENCE IN 1-D INVERSION
SOUNDING 8

ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) Figure 5-9.4

SEVILLE

MODEL: 3 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		13.7	45.0		
24.36	29.8	-16.1	-52.8	1.2	1.2
115.37	223.6	-239.7	-786.4	1.9	3.2
6.65					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	1.10E-04	1.34E+02	1.36E+02	-1.555	
2	1.40E-04	1.23E+02	1.14E+02	7.812	
3	1.77E-04	9.51E+01	9.98E+01	-4.701	
4	2.20E-04	9.15E+01	9.16E+01	-0.083	
5	2.80E-04	8.30E+01	8.63E+01	-3.773	
6	3.55E-04	8.34E+01	8.40E+01	-0.715	
7	4.43E-04	8.57E+01	8.39E+01	2.081	
8	5.64E-04	8.80E+01	8.53E+01	3.117	
9	7.13E-04	8.93E+01	8.69E+01	2.744	
10	8.81E-04	8.56E+01	8.72E+01	-1.885	
11	1.10E-03	8.25E+01	8.50E+01	-2.978	
12	1.41E-03	7.71E+01	7.87E+01	-2.093	
13	1.80E-03	7.09E+01	7.00E+01	1.288	
14	2.20E-03	5.77E+01	6.19E+01	-6.737	
15	2.22E-03	6.55E+01	6.15E+01	6.559	
16	2.80E-03	5.27E+01	5.28E+01	-0.163	
17	3.55E-03	4.55E+01	4.50E+01	1.249	
18	4.43E-03	3.99E+01	3.88E+01	2.840	
19	5.64E-03	3.35E+01	3.33E+01	0.543	
20	7.13E-03	2.80E+01	2.89E+01	-3.222	

R: 150. X: 0. Y: 150. DL: 300. REQ: 167. CF: 1.0000
CLHZ ARRAY, 20 DATA POINTS, RAMP: 170.0 MICROSEC, DATA: SEVILLE
2107 0008 0000 Z OPR XTL L 2 12+1000
Ch.21 = 0.17 Ch.22 = 0.89 Ch.23 = 30 Ch.24 = 90
RMS LOG ERROR: 2.29E-02, ANTILOG YIELDS 5.4111 %
LATE TIME PARAMETERS

BLACKHAWK GEOSCIENCES, INC.

INVERSION TABLE
SOUNDING 8
ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) Table 5-9.1

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:

"F" MEANS FIXED PARAMETER

P 1	0.84				
P 2	-0.12	0.80			
P 3	0.00	-0.05	0.89		
T 1	-0.29	-0.28	-0.03	0.44	
T 2	0.04	0.05	0.02	0.09	0.98
	P 1	P 2	P 3	T 1	T 2

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

LAYER		MINIMUM	BEST	MAXIMUM
RHO	1	17.185	24.365	32.342
	2	88.974	115.368	161.955
	3	4.771	6.648	8.894
THICK	1	15.762	29.804	51.519
	2	201.430	223.612	245.073
DEPTH	1	15.762	29.804	51.519
	2	245.337	253.416	263.476

BLACKHAWK GEOSCIENCES, INC.

INVERSION TABLE CONTINUED

SOUNDING 8

ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) Table 5-9.1

5.10 PIERSON (SITE 9)

5.10.1 Location and Geoelectric Section

The detailed location map for this sounding is shown in Figure 5-10.1. The sounding data and inverted geoelectric section is shown in Figure 5-10.2 and consists of a four layer section.

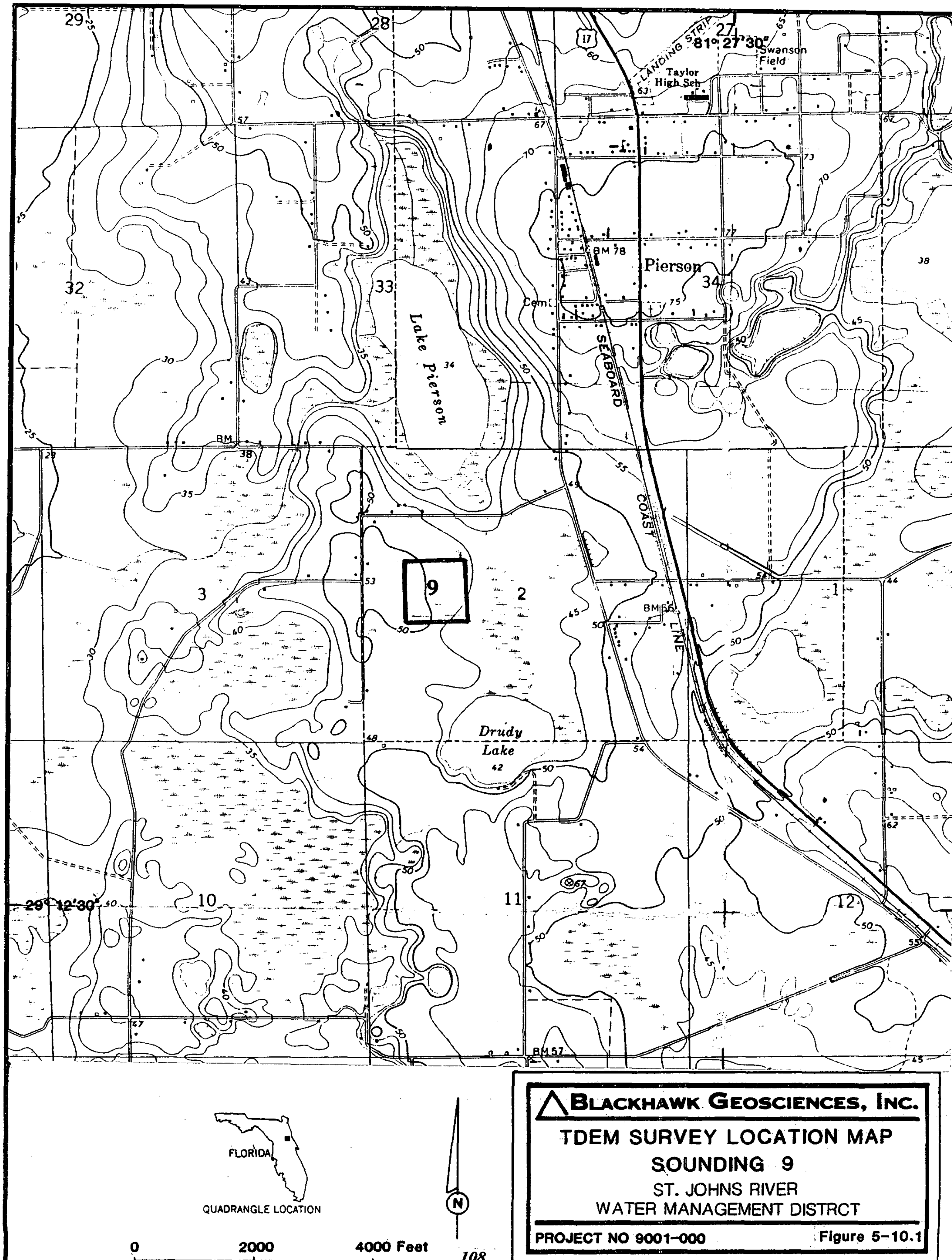
5.10.2 Geologic Interpretation of Geoelectric Section

The first two layers of the geoelectric section, with resistivities of 89 ohm-m and 20 ohm-m, and a combined thickness of 138 ft (42 m), corresponds to the Hawthorn Group and younger formations which overlie the Floridan aquifer. This is consistent with the depth to the top of the Floridan aquifer of approximately 100 ft, based on Miller (1986) and the elevation of the sounding. The third layer in the section, with a resistivity of 262 ohm-m and a thickness of 1,016 ft (310 m), represents the Floridan aquifer saturated with fresh ground water. Layer 4 of the geoelectric section, which has a resistivity of 2.9 ohm-m, corresponds to the saline water saturated portion of the Floridan aquifer.

5.10.3 Depth of Occurrence of Saline Water

Layer 4 of the geoelectric section, with a resistivity of 2.9 ohm-m, is interpreted to represent saline water and occurs at a depth of 1,154 ft (-1,106 ft msl). Since the resistivity of layer 3 (262 ohm-m), which represents fresh water within the Floridan aquifer is greater than 80 ohm-m, the position of the saline water interface (5,000 mg/l isochlor) is located at a depth 50 ft below the interface between layer 3 and layer 4. The positioning is based on criteria outlined under Task 3, Section 4. This places the interpreted depth to the top of the saline water at 1,204 ft (-1,156 msl). The resistivity of layer 4 is 2.9 ohm-m, which corresponds to a chloride content of > 10,000 mg/l, assuming a porosity of 25% and the validity of Figure 4-9.

An estimation of the elevation of the fresh water/salt water interface in the area of the Crescent City Ridge was made in Rutledge (1982). Figure 5-9.2 shows his contour map along with the elevations of the top of saline water as determined by TDEM for this site and for Site 8. There is excellent agreement between Rutledge's estimate of the elevation of the fresh water/salt water interface and that mapped by TDEM. At this site, the TDEM mapped interface of -1,156 msl is located between Rutledge's -1,000 ft msl and -1,200 ft msl contours.



BLACKHAWK GEOSCIENCES, INC.

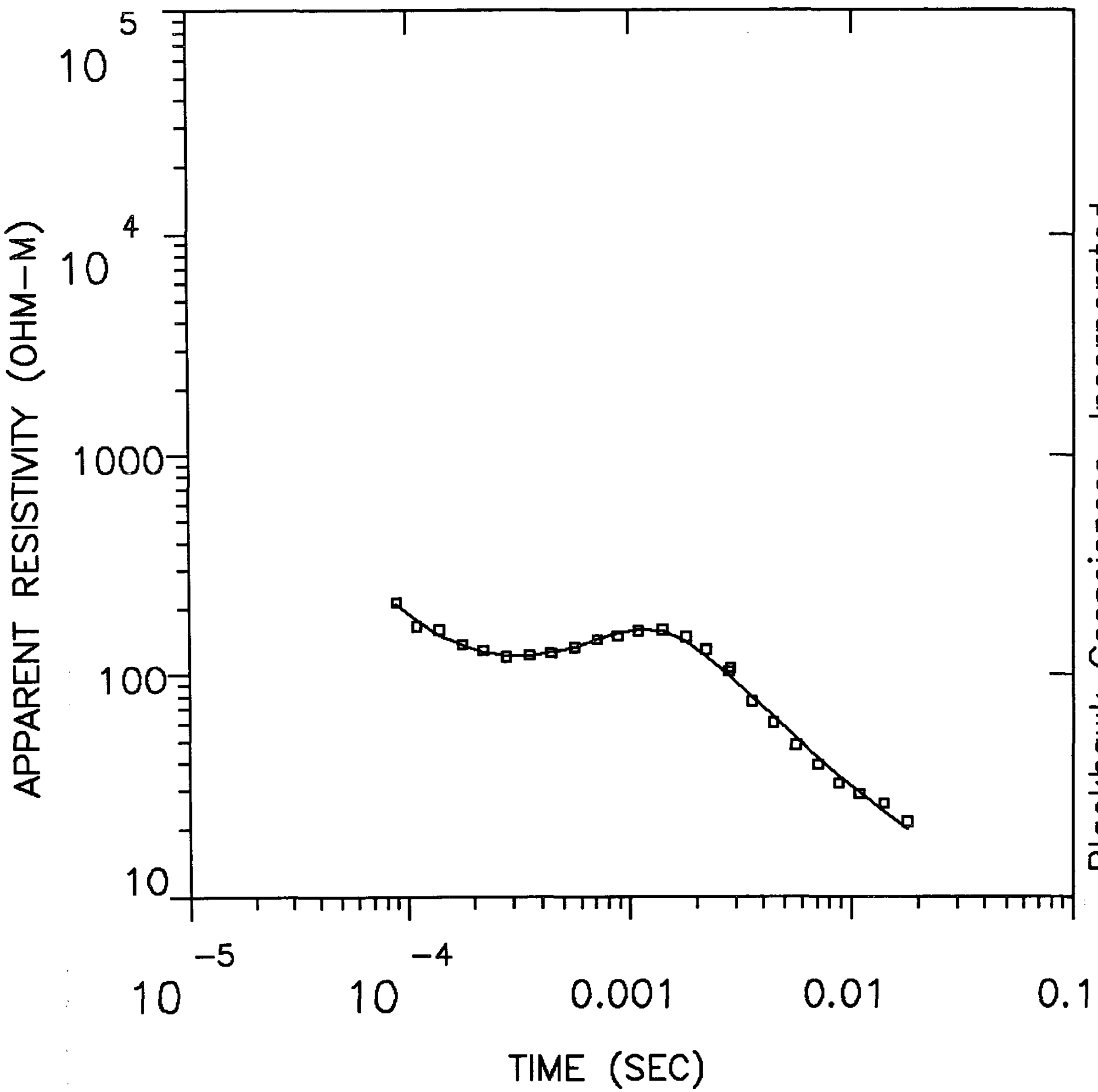
TDEM SURVEY LOCATION MAP
SOUNDING 9

ST. JOHNS RIVER
WATER MANAGEMENT DISTRCT

PROJECT NO 9001-000

Figure 5-10.1

PIERSON



□ Data Curve

—— Modeled Curve

MODEL:

89.2 OHM-M	25 M
19.5 OHM-M	17.0 M
262. OHM-M	310. M
2.94 OHM-M	

% ERROR: 8.03
CALIBRATION: 1
OFFSET: 150 M
RAMP: 170.0

BLACKHAWK GEOSCIENCES, INC.

MEASURED TDEM APPARENT RESISTIVITY AND 1-D INVERSION
SOUNDING 9
ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) **Figure 5-10.2**

5.10.4 Depth of Occurrence of the 250 mg/l Isochlor

The resistivity of layer 3 of the geoelectric section, 262 ohm-m, corresponds to a chloride content of less than 50 mg/l, assuming a porosity of 25% and the validity of Figure 4-9. Using the criteria outlined in Task 3, Section 4, and illustrated in Figure 4-11, this is a class A type transition zone and the 250 mg/l isochlor is located 50 ft above the interface between layer 3 and layer 4 of the geoelectric section. This places the 250 mg/l isochlor at a depth of 1,104 ft (-1,056 ft msl). The chloride to sulfate ratio in this area of 5:1 (Sprinkle, 1989) is consistent with the assumptions utilized in interpreting chloride content.

5.10.5 Accuracy of Measurement and Interpretation

Figure 5-10.3 shows the evaluation of equivalence at this site and the inversion table (Table 5-10.1) lists the upper and lower bounds of the parameters of the geoelectric section.

The range of equivalence in determining the depth to the layer of low resistivity (layer 4) is shown to be about ± 30 ft (9 m) which is 3% of the total depth. The resistivity of this layer has an equivalence range from 1.9 ohm-m to 4.3 ohm-m. For this range of resistivities the corresponding chloride content exceeds 5,000 mg/l.

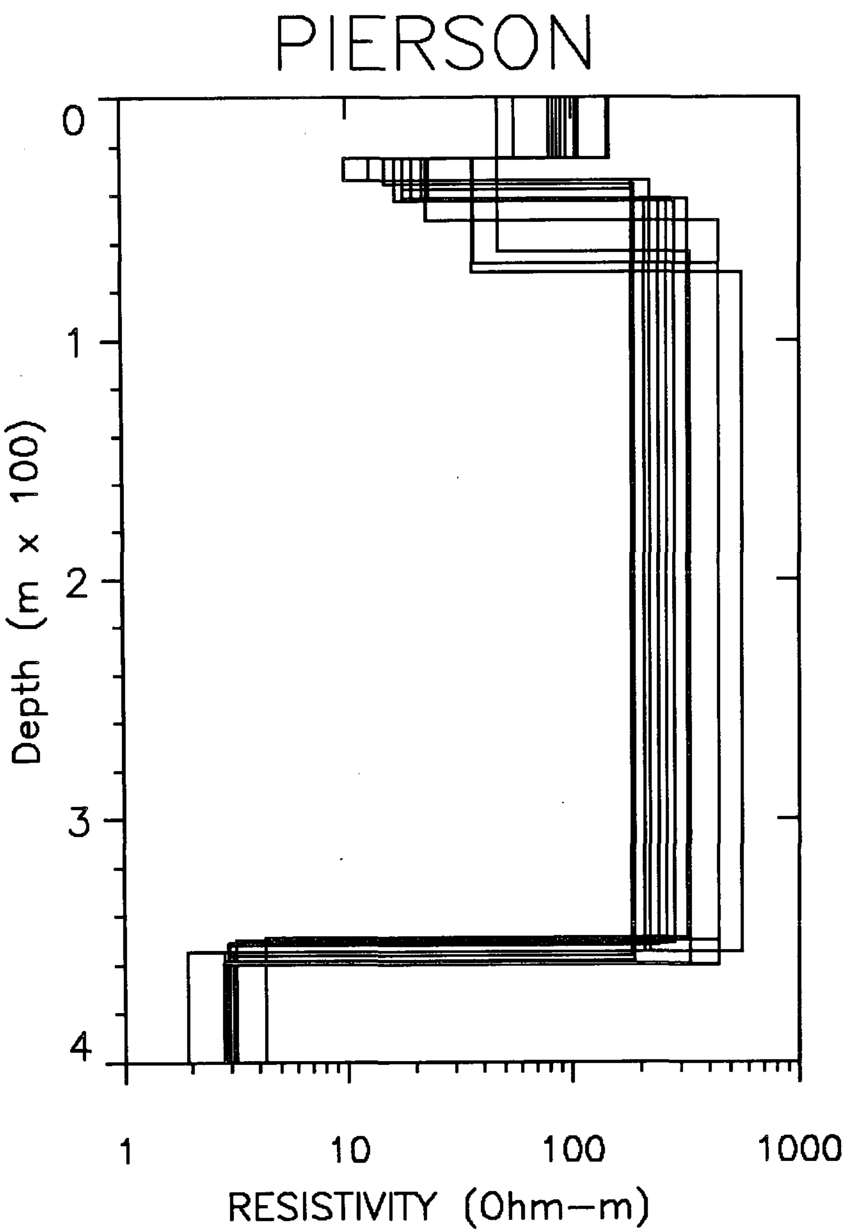
The range of equivalence for the resistivity of layer 3 of the geoelectric section is from 182 to 556 ohm-m. Over this range of resistivities the corresponding chloride content is less than 50 mg/l.

5.10.6 Summary of Results of TDEM Measurements at Pierson (Site 9)

From the TDEM measurements, the following information about water quality was observed:

(1) The depth of occurrence of saline water (5,000 mg/l isochlor) was interpreted to be 1,204 ft (-1,156 ft msl) and the chloride content below that depth was inferred to be greater than 10,000 mg/l. The depth to saline water interpreted from the TDEM sounding is in agreement with the depth to the fresh water/salt water interface estimated by Rutledge (1982).

(2) The 250 mg/l isochlor was interpreted to occur at a depth of 1,104 ft (-1,056 ft msl). Ground water within the Floridan aquifer above this depth is estimated to have a chloride content of less than 50 mg/l. The chloride to sulfate ratio of 5:1 in the area should not affect this estimate.



BLACKHAWK GEOSCIENCES, INC.

EQUIVALENCE IN 1-D INVERSION
SOUNDING 9
ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) **Figure 5-10.3**

PIERSON

MODEL: 4 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		14.6	48.0		
89.19	25.0	-10.4	-34.0	0.3	0.3
19.50	17.0	-27.4	-89.8	0.9	1.2
262.27	309.8	-337.2	-1106.2	1.2	2.3
2.94					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	8.90E-05	2.14E+02	2.09E+02	2.616	
2	1.10E-04	1.67E+02	1.76E+02	-5.577	
3	1.40E-04	1.60E+02	1.52E+02	5.512	
4	1.77E-04	1.38E+02	1.36E+02	1.029	
5	2.20E-04	1.29E+02	1.27E+02	1.179	
6	2.80E-04	1.21E+02	1.23E+02	-1.741	
7	3.55E-04	1.23E+02	1.23E+02	0.085	
8	4.43E-04	1.26E+02	1.26E+02	0.079	
9	5.64E-04	1.33E+02	1.34E+02	-0.618	
10	7.13E-04	1.44E+02	1.44E+02	-0.099	
11	8.81E-04	1.49E+02	1.54E+02	-3.154	
12	1.10E-03	1.58E+02	1.61E+02	-1.648	
13	1.41E-03	1.60E+02	1.58E+02	1.691	
14	1.80E-03	1.49E+02	1.42E+02	5.169	
15	2.22E-03	1.30E+02	1.21E+02	7.347	
16	2.80E-03	1.03E+02	9.96E+01	3.804	
17	2.85E-03	1.07E+02	9.80E+01	9.337	
18	3.55E-03	7.56E+01	8.00E+01	-5.539	
19	4.43E-03	6.08E+01	6.50E+01	-6.494	
20	5.64E-03	4.81E+01	5.21E+01	-7.576	
21	7.13E-03	3.93E+01	4.22E+01	-6.931	
22	8.81E-03	3.22E+01	3.51E+01	-8.197	
23	1.10E-02	2.89E+01	2.93E+01	-1.323	
24	1.41E-02	2.62E+01	2.39E+01	9.349	
25	1.80E-02	2.16E+01	2.00E+01	7.858	

R: 150. X: 0. Y: 150. DL: 300. REQ: 167. CF: 1.0000

CLHZ ARRAY, 25 DATA POINTS, RAMP: 170.0 MICROSEC, DATA: PIERSON

BLACKHAWK GEOSCIENCES, INC.

INVERSION TABLE
SOUNDING 9
ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) Table 5-10.1

```
2107 0009 0000 Z  OPR XTL L 2 10+1000
Ch.21 = 0.17  Ch.22 = 0.89  Ch.23 = 30  Ch.24 = 90
RMS LOG ERROR:    3.35E-02, ANTILOG YIELDS     8.0287 %
LATE TIME PARAMETERS


      * Blackhawk Geosciences, Incorporated  *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER
P 1  0.25
P 2  0.28  0.62
P 3 -0.12 -0.10  0.63
P 4 -0.02  0.02 -0.05  0.90
F 1  0.00  0.00  0.00  0.00  0.00
T 2 -0.03 -0.35 -0.29  0.01  0.00  0.48
T 3  0.00  0.02  0.02  0.00  0.00  0.03  1.00
       P 1   P 2   P 3   P 4   F 1   T 2   T 3
```

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

LAYER		MINIMUM	BEST	MAXIMUM
RHO	1	47.072	89.189	146.877
	2	9.801	19.502	47.084
	3	182.783	262.275	556.524
	4	1.912	2.941	4.285
THICK	1	25.000	25.000	25.000
	2	8.942	17.000	46.813
	3	282.800	309.791	322.645
DEPTH	1	25.000	25.000	25.000
	2	33.942	42.000	71.813
	3	349.062	351.791	360.390

BLACKHAWK GEOSCIENCES, INC.

INVERSION TABLE CONTINUED
SOUNDING 9
ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) Table 5-10.1

5.11 MITCHELL-HAMMOCK (SITE 10)

5.11.1 Location and Geoelectric Section

The detailed location map for this sounding is shown in Figure 5-11.1. The sounding data and inverted geoelectric section is shown in Figure 5-11.2 and it consists of a three layer section.

5.11.2 Geologic Information of Geoelectric Section

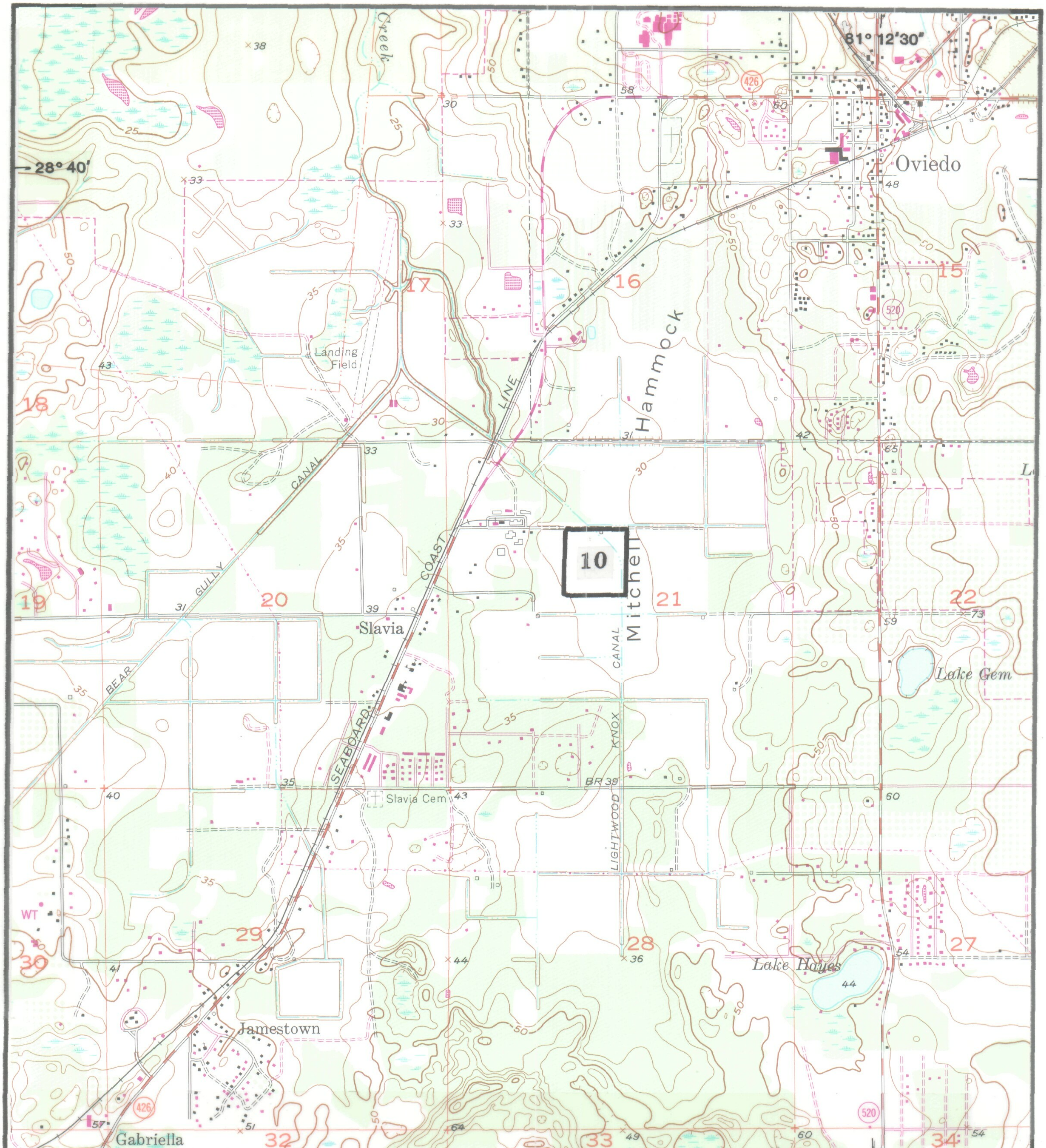
The first layer of the geoelectric section, with a resistivity of 38 ohm-m and a thickness of 86 ft (26 m), represents the Hawthorn Group and younger formations which overlie the Floridan aquifer which is consistent with Tibbals (1977) estimate of a depth from the surface to the top of the Floridan of less than 100 ft. The second layer in the section, with a resistivity of 217 ohm-m and a thickness of 1,468 ft (448 m), corresponds to the Floridan aquifer saturated with fresh ground water. The third layer of the geoelectric section, which has a resistivity of 10 ohm-m, represents the saline water saturated portion of the Floridan aquifer.

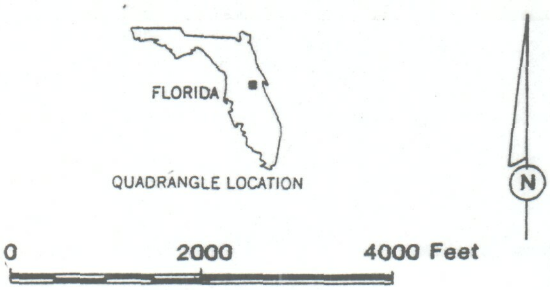
5.11.3 Depth of Occurrence of Saline Water

The third layer of the geoelectric section, with a resistivity of 10 ohm-m, is interpreted to represent saline water and occurs at a depth of 1,554 ft (-1,523 ft msl). Since the resistivity of layer 2 (217 ohm-m) which represents fresh water within the Floridan aquifer is greater than 80 ohm-m, the position of the saline water interface (5,000 mg/l isochlor) is located at a depth of 50 ft below the interface between layer 2 and layer 3. The positioning is based on criteria outlined under Task 3, Section 4. This places the interpreted depth to the top of the saline water at 1,604 ft (-1,573 ft msl). The resistivity of Layer 3 is 10 ohm-m which corresponds to a chloride content of 3,060 mg/l assuming a porosity of 25% and the validity of Figure 4-9.

5.11.4 Depth of Occurrence to the 250 mg/l Isochlor

The resistivity of layer 2 of the geoelectric section, 217 ohm-m, corresponds to a chloride content of less than 50 mg/l, assuming a porosity of 25% and the validity of Figure 4-9. Using the criteria outlined under Task 3, Section 4, and illustrated in Figure 4-11, this is a class A type transition zone and the 250 mg/l isochlor is located 50 ft above the interface between layer 2 and layer 3 of the geoelectric section.





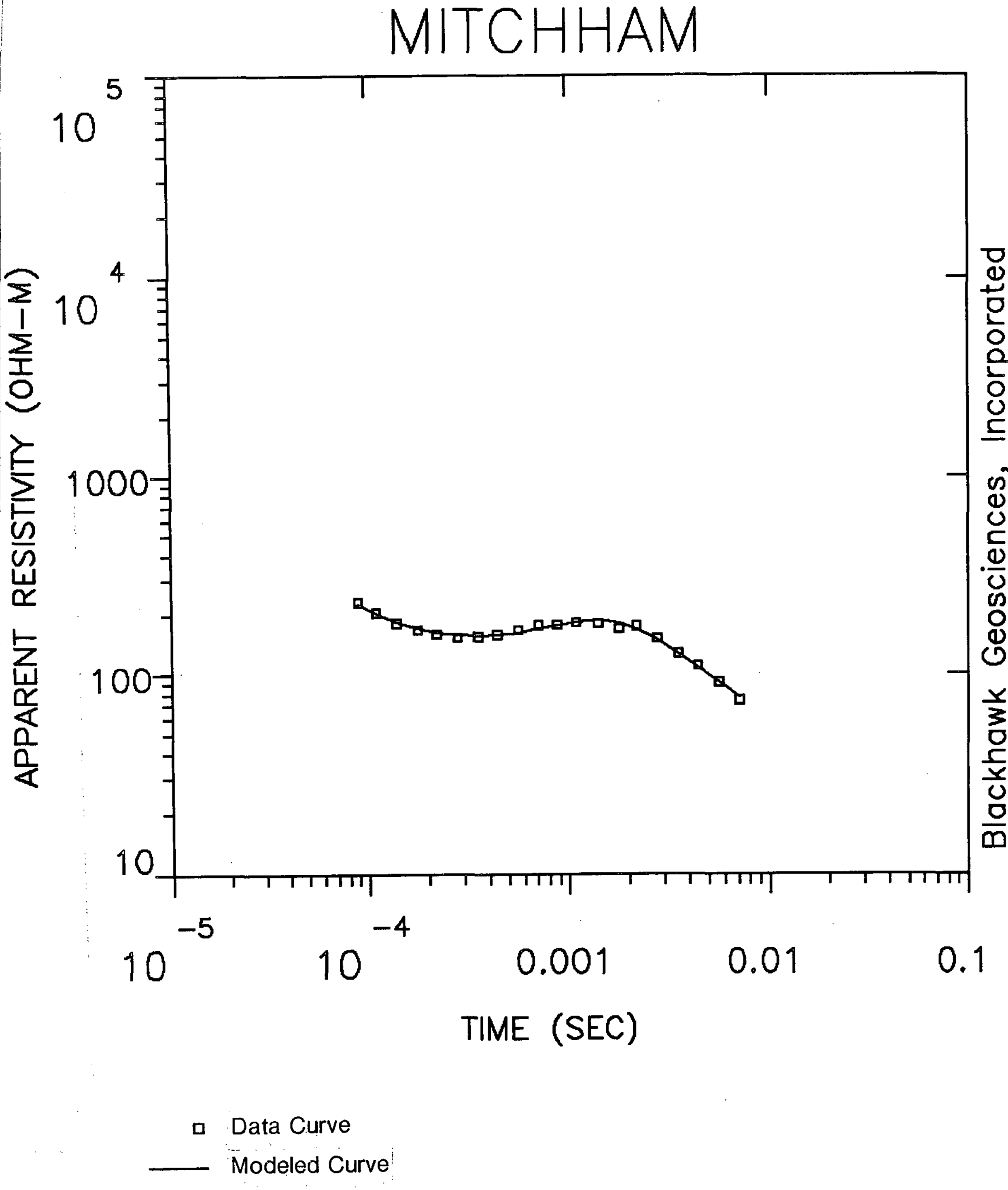
BLACKHAWK GEOSCIENCES, INC.

TDEM SURVEY LOCATION MAP
SOUNDING 10

ST. JOHNS RIVER
WATER MANAGEMENT DISTRCT

PROJECT NO 9001-000

Figure 5-11.1



MODEL:

37.8 OHM-M	26.3 M
217. OHM-M	448. M
10.3 OHM-M	

% ERROR: 4.18
CALIBRATION: 1
OFFSET: 150 M
RAMP: 160.0

BLACKHAWK GEOSCIENCES, INC.

MEASURED TDEM APPARENT RESISTIVITY AND 1-D INVERSION
SOUNDING 10

ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) **Figure 5-11.2**

This places the 250 mg/l isochlor at a depth of 1,504 ft (-1,473 ft msl). The chloride to sulfate ratio should be approximately 5:1 and is consistent with assumptions utilized in interpreting chloride concentrations.

5.11.5 Accuracy of Measurement and Interpretation

Figure 5-11.3 shows the evaluation of equivalence at this site and the inversion table (Table 5-11.1) lists the upper and lower bounds of the parameters of the geoelectric section.

The range of equivalence in determining the depth to the layer of low resistivity (layer 3) is shown to be about $\pm$ 40 ft (12 m) which is 3% of the total depth. The resistivity of this layer has an equivalence range from 6.7 ohm-m to 15 ohm-m. This corresponds to a range in interpreted chloride content from 4,650 mg/l to 1,990 mg/l.

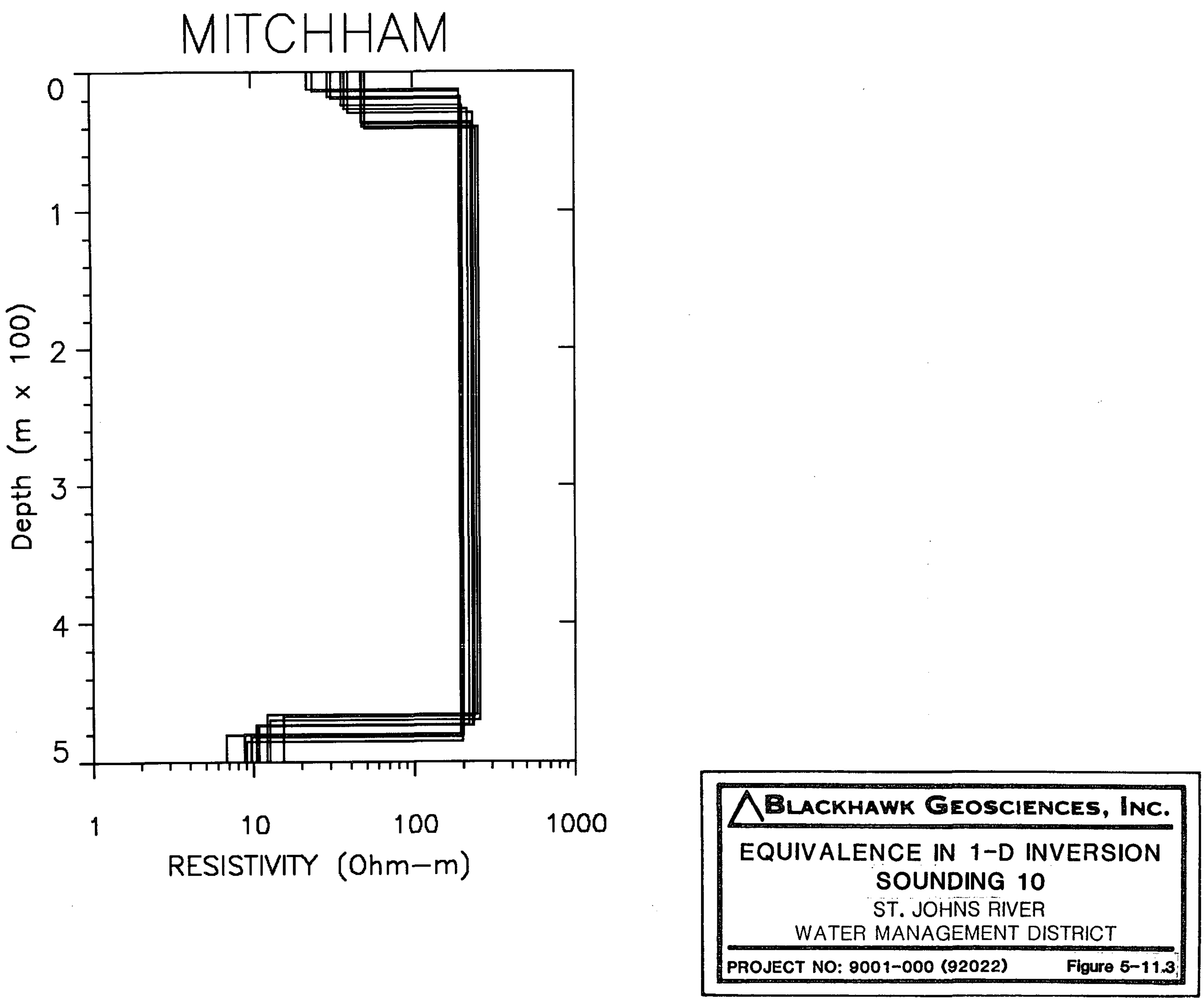
The equivalence of layer 2 resistivity is from 190 ohm-m to 250 ohm-m. Throughout this range the interpreted chloride content is less than 50 mg/l.

5.11.6 Summary of Results of TDEM Measurements at Mitchell-Hammock (Site 10)

From the TDEM measurements, the following information about water quality was derived:

(1) The depth of occurrence of saline water (5,000 mg/l isochlor) was interpreted to be 1,604 ft (-1,573 ft msl), and the chloride content below that depth was inferred to be 3,060 mg/l.

(2) The 250 mg/l isochlor was interpreted to occur at a depth of 1,504 ft (-1,473 ft msl) and ground water within the Floridan aquifer above this depth was estimated to have a chloride content of less than 50 mg/l. The chloride to sulfate ratio of approximately 5:1 should not affect interpreted chloride content.


MITCHHAM
0
1
2
3
4
5
Depth (m x 100)
1
10
100
1000
RESISTIVITY (Ohm-m)
BLACKHAWK GEOSCIENCES, INC.
EQUIVALENCE IN 1-D INVERSION
SOUNDING 10
ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT
PROJECT NO: 9001-000 (92022)
Figure 5-11.3

MITCHHAM

MODEL: 3 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		9.4	31.0		
37.84	26.3	-16.8	-55.1	0.7	0.7
217.33	447.5	-464.3	-1523.4	2.1	2.8
10.30					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	8.90E-05	2.32E+02	2.27E+02	2.277	
2	1.10E-04	2.04E+02	2.02E+02	1.217	
3	1.40E-04	1.81E+02	1.82E+02	-0.859	
4	1.77E-04	1.67E+02	1.70E+02	-1.745	
5	2.20E-04	1.59E+02	1.62E+02	-1.971	
6	2.80E-04	1.53E+02	1.58E+02	-2.898	
7	3.55E-04	1.54E+02	1.57E+02	-1.325	
8	4.43E-04	1.59E+02	1.58E+02	0.302	
9	5.64E-04	1.67E+02	1.63E+02	2.766	
10	7.13E-04	1.77E+02	1.70E+02	4.530	
11	8.81E-04	1.78E+02	1.77E+02	0.131	
12	1.10E-03	1.83E+02	1.85E+02	-1.071	
13	1.41E-03	1.81E+02	1.88E+02	-3.892	
14	1.80E-03	1.70E+02	1.82E+02	-6.636	
15	2.20E-03	1.75E+02	1.69E+02	3.138	
16	2.80E-03	1.52E+02	1.49E+02	2.350	
17	3.55E-03	1.27E+02	1.27E+02	0.098	
18	4.43E-03	1.10E+02	1.08E+02	2.019	
19	5.64E-03	9.13E+01	9.05E+01	0.848	
20	7.13E-03	7.37E+01	7.65E+01	-3.622	

R: 150. X: 0. Y: 150. DL: 300. REQ: 167. CF: 1.0000

CLHZ ARRAY, 20 DATA POINTS, RAMP: 160.0 MICROSEC, DATA: MITCHHAM

2207 0010 0000 Z OPR XTL H 2 8+100

Ch.21 = 0.16 Ch.22 = 0.089 Ch.23 = 15 Ch.24 = 9

RMS LOG ERROR: 1.78E-02, ANTILOG YIELDS 4.1832 %

LATE TIME PARAMETERS

BLACKHAWK GEOSCIENCES, INC.

INVERSION TABLE
SOUNDING 10
ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) Table 5-11.1

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:

"F" MEANS FIXED PARAMETER

P 1	0.75				
P 2	-0.06	0.96			
P 3	-0.03	-0.05	0.75		
T 1	-0.35	-0.10	-0.06	0.50	
T 2	0.02	0.01	0.01	0.03	1.00
	P 1	P 2	P 3	T 1	T 2

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

LAYER		MINIMUM	BEST	MAXIMUM
RHO	1	22.220	37.836	50.274
	2	191.430	217.333	252.803
	3	6.732	10.303	15.343
THICK	1	12.477	26.255	40.417
	2	425.550	447.523	469.853
DEPTH	1	12.477	26.255	40.417
	2	465.967	473.779	485.525

BLACKHAWK GEOSCIENCES, INC.

INVERSION TABLE CONTINUED
SOUNDING 10
ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) Table 5-11.1

5.12 YANKEE LAKE (SITE 11)

5.12.1 Location and Geoelectric Section

The detailed location map for this sounding is shown in Figure 5-12.1. The sounding data and inverted geoelectric section is shown in Figure 5-12.2 and consists of a three layer section.

5.12.2 Geologic Interpretation of Geoelectric Section

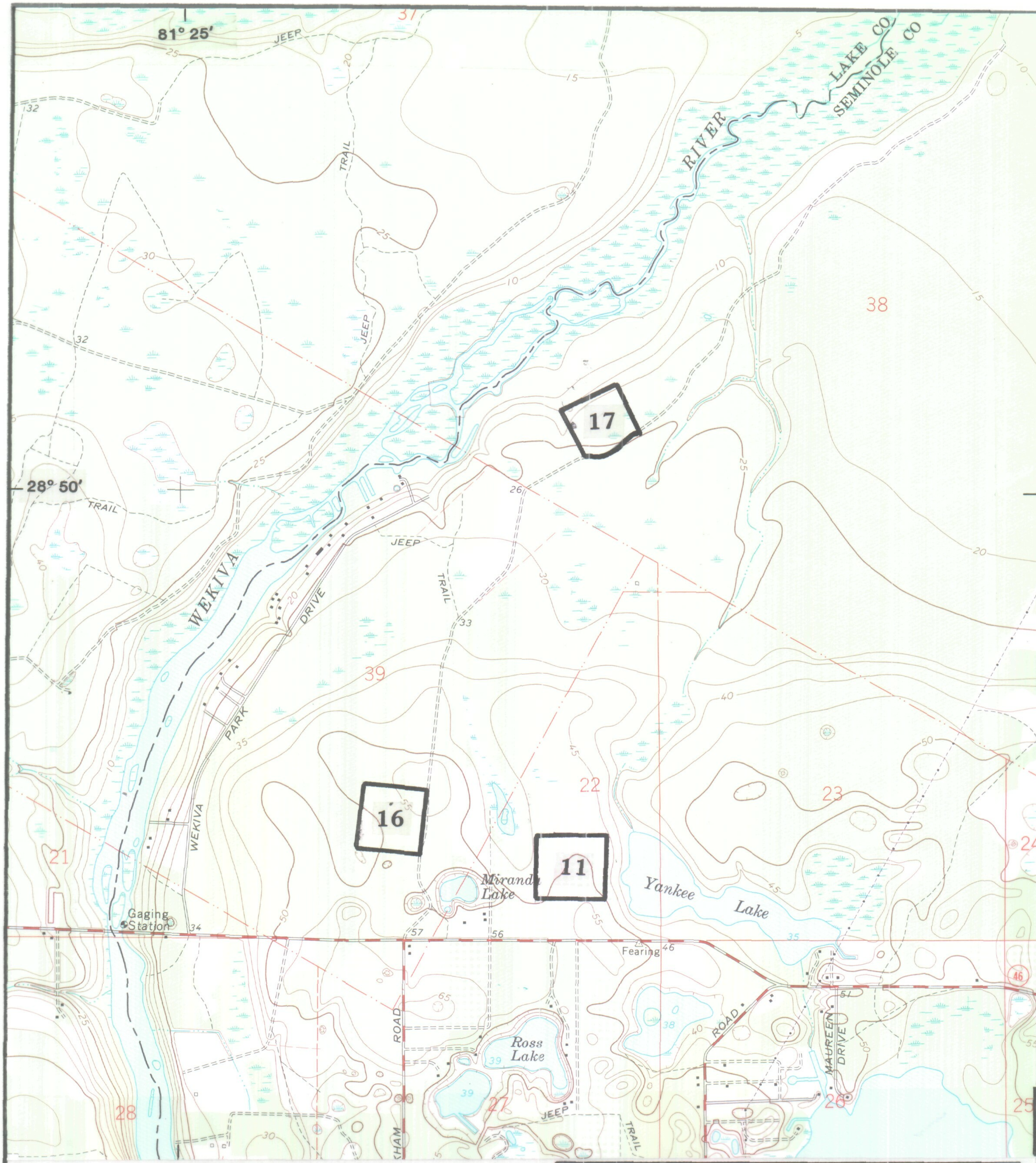
The first layer of the geoelectric section with a resistivity of 131 ohm-m and a thickness of 98 ft (30 m) represents the Hawthorn Group and younger formations overlying the Floridan aquifer. The thickness of this layer was fixed in the inversion based on data on the depth from surface (100 ft) to the Floridan aquifer in Tibbals (1977). In this case electrical resistivity cannot distinguish between the upper Floridan and the sediments overlying it. The second layer in the section with a resistivity of 111 ohm-m and a thickness of 845 ft (258 m) corresponds to the Floridan aquifer inferred to contain fresh ground water. The third layer of the geoelectric section which has a resistivity of 7.1 ohm-m represents the saline water saturated portion of the Floridan aquifer.

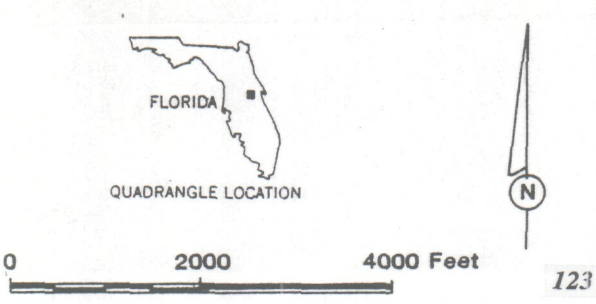
5.12.3 Depth of Occurrence of Saline Water

The third layer of the geoelectric section with a resistivity of 7.1 ohm-m, is interpreted to represent saline water and occurs at a depth of 943 ft (-893 ft msl). Since the resistivity of layer 2 (111 ohm-m), which represents fresh water within the Floridan aquifer, is greater than 80 ohm-m, the position of the saline water interface (5,000 mg/l isochlor) is located at a depth of 50 ft below the interface between layer 2 and layer 3. The positioning is based on criteria outlined under Task 3, Section 4. This places the interpreted depth to the top of the saline water (5,000 mg/l isochlor) at 993 ft (-943 ft msl). The resistivity of layer 3 is 7.1 ohm-m which corresponds to a chloride content of 4,377 mg/l, assuming a porosity of 25% and the validity of Figure 4-9.

5.12.4 Depth of Occurrence of the 250 mg/l Isochlor

The resistivity of layer 2 of the geoelectric section, 111 ohm-m, corresponds to a chloride content of less than 150 mg/l, assuming a porosity of 25% and the validity of Figure 4-9. Using the criteria outlined under Task 3, Section 4, and illustrated in Figure 4-11, this is a class A type transition zone and the 250 mg/l isochlor is located between layer 2 and layer 3 of the geoelectric section. This places the





BLACKHAWK GEOSCIENCES, INC.

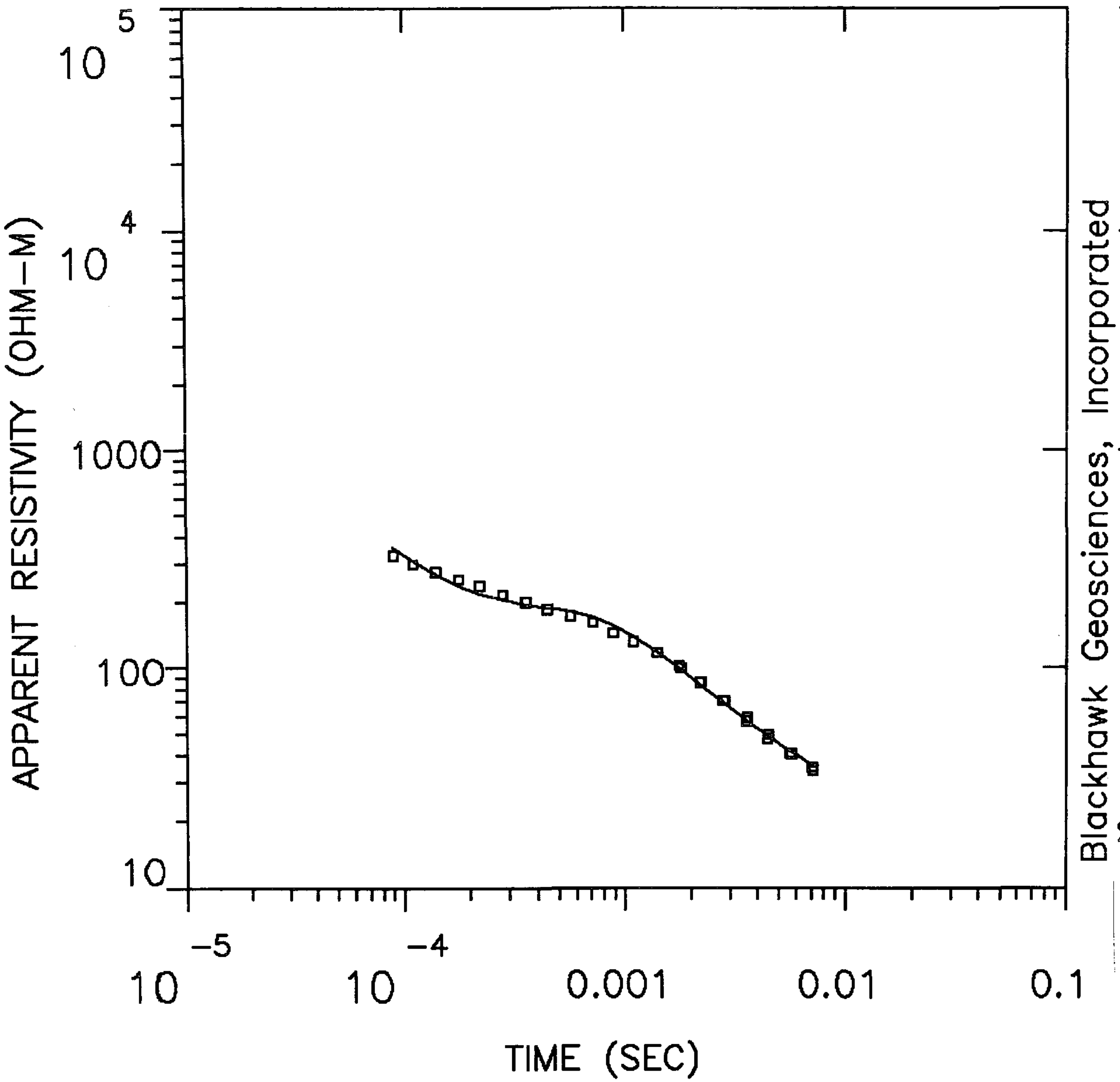
TDEM SURVEY LOCATION MAP
SOUNDING 11, 16, & 17

ST. JOHNS RIVER
WATER MANAGEMENT DISTRCT

PROJECT NO 9001-000

Figure 5-12.1

YANKEELK



□ Data Curve

—— Modeled Curve

MODEL:

Resistivity	Thickness
131. OHM–M	30 M
112. OHM–M	258. M
7.08 OHM–M	

% ERROR: 6.72
CALIBRATION: 1
OFFSET: 150 M
RAMP: 160.0

BLACKHAWK GEOSCIENCES, INC.

MEASURED TDEM APPARENT RESISTIVITY AND 1-D INVERSION SOUNDING 11

ST. JOHNS RIVER WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) **Figure 5–12.2**

250 mg/l isochlor at a depth of 893 ft (-843 ft msl). The chloride to sulfate ratio of 5:1 for Seminole County is consistent with the assumptions utilized in estimating chloride content.

5.12.5 Accuracy of Measurement and Interpretation

Figure 5-12.3 shows the evaluation of equivalence at this site and the inversion table (Table 5-12.1) lists the upper and lower bounds of the parameters of the geoelectric section.

The range of equivalence in determining the depth to the layer of low resistivity (layer 3) is shown to be about $\pm$ 43 ft (13 m), which is about 5% of the total depth. The resistivity of this layer has an equivalence range of 5.1 to 9.7 ohm-m. This corresponds to a range in interpreted chloride content from 6,150 mg/l to 3,160 mg/l.

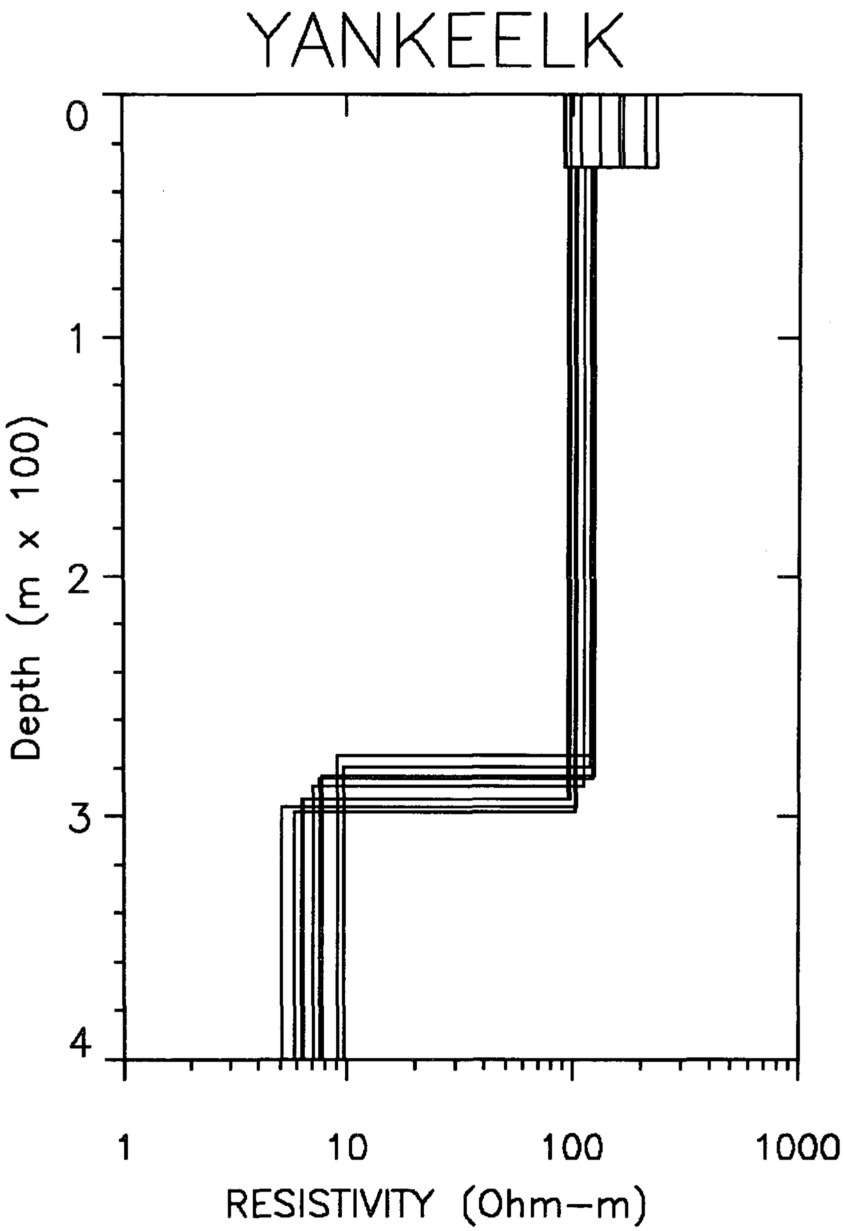
The equivalence range of the resistivity of layer 2 is from 95 ohm-m to 125 ohm-m. Throughout this range the interpreted chloride content is less than 250 mg/l which does not alter any of the interpretations from this sounding.

5.12.6 Summary of Results of TDEM Measurements at Yankee Lake (Site 11)

From the TDEM measurements, the following information about water quality was derived:

(1) The depth of occurrence of saline water (5,000 mg/l isochlor) was interpreted to be 993 ft (-943 ft msl) and the chloride content below that depth was inferred to be 4,380 mg/l.

(2) The 250 mg/l isochlor was interpreted to occur at a depth of 893 ft (-843 ft msl) and ground water within the Floridan aquifer above this depth was estimated to have a chloride content of less than 150 mg/l. The chloride to sulfate ratio of 5:1 for Seminole County should not affect the estimated chloride content.



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BLACKHAWK GEOSCIENCES, INC.

EQUIVALENCE IN 1-D INVERSION
SOUNDING 11

ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) **Figure 5-12.3**

YANKEELK

MODEL: 3 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		15.2	50.0		
131.01	30.0	-14.8	-48.4	0.2	0.2
111.89	257.6	-272.3	-893.4	2.3	2.5
7.08					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	8.90E-05	3.27E+02	3.57E+02	-8.373	
2	1.10E-04	2.98E+02	3.09E+02	-3.372	
3	1.40E-04	2.75E+02	2.68E+02	2.741	
4	1.77E-04	2.54E+02	2.38E+02	6.710	
5	2.20E-04	2.37E+02	2.19E+02	8.393	
6	2.80E-04	2.16E+02	2.04E+02	5.917	
7	3.55E-04	2.00E+02	1.95E+02	2.604	
8	4.43E-04	1.86E+02	1.88E+02	-0.956	
9	5.64E-04	1.72E+02	1.81E+02	-4.535	
10	7.13E-04	1.61E+02	1.70E+02	-5.401	
11	8.81E-04	1.44E+02	1.57E+02	-7.686	
12	1.10E-03	1.32E+02	1.39E+02	-5.089	
13	1.41E-03	1.18E+02	1.17E+02	0.173	
14	1.77E-03	1.03E+02	9.90E+01	3.588	
15	1.80E-03	1.00E+02	9.79E+01	2.170	
16	2.20E-03	8.55E+01	8.36E+01	2.316	
17	2.22E-03	8.64E+01	8.29E+01	4.282	
18	2.80E-03	7.07E+01	6.93E+01	2.117	
19	2.85E-03	7.09E+01	6.83E+01	3.854	
20	3.55E-03	5.69E+01	5.78E+01	-1.572	
21	3.60E-03	5.93E+01	5.72E+01	3.705	
22	4.43E-03	4.74E+01	4.92E+01	-3.686	
23	4.49E-03	4.95E+01	4.87E+01	1.559	
24	5.64E-03	4.06E+01	4.16E+01	-2.312	
25	5.70E-03	4.04E+01	4.13E+01	-2.053	
26	7.13E-03	3.52E+01	3.56E+01	-1.085	
27	7.19E-03	3.39E+01	3.54E+01	-4.253	

R: 150. X: 0. Y: 150. DL: 300. REQ: 167. CF: 1.0000

BLACKHAWK GEOSCIENCES, INC.

INVERSION TABLE
SOUNDING 11
ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) Table 5-12.1

CLHZ ARRAY, 27 DATA POINTS, RAMP: 160.0 MICROSEC, DATA: YANKEELK

2207 0011 0000 Z OPR XTL L 3 12+1000

Ch.21 = 0.16 Ch.22 = 0.89 Ch.23 = 15.5 Ch.24 =

RMS LOG ERROR: 2.82E-02, ANTILOG YIELDS 6.7196 %

LATE TIME PARAMETERS

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:

"F" MEANS FIXED PARAMETER

P 1	1.00				
P 2	0.00	1.00			
P 3	0.00	0.00	1.00		
F 1	0.00	0.00	0.00	0.00	
T 2	0.00	0.00	0.00	0.00	1.00
	P 1	P 2	P 3	F 1	T 2

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

LAYER		MINIMUM	BEST	MAXIMUM
RHO	1	90.600	131.009	236.172
	2	95.188	111.890	125.562
	3	5.109	7.082	9.670
THICK	1	30.000	30.000	30.000
	2	244.858	257.557	268.419
DEPTH	1	30.000	30.000	30.000
	2	274.858	287.557	298.419

BLACKHAWK GEOSCIENCES, INC.

INVERSION TABLE CONTINUED
SOUNDING 11
ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) Table 5-12.1

5.13 ASTOR FARMS (SITE 12)

5.13.1 Location and Geoelectric Section

The detailed location map for this sounding is shown in Figure 5-13.1. The sounding data and inverted geoelectric section is shown in Figure 5-13.2 and consists of a three layer section.

5.13.2 Geologic Interpretation of Geoelectric Section

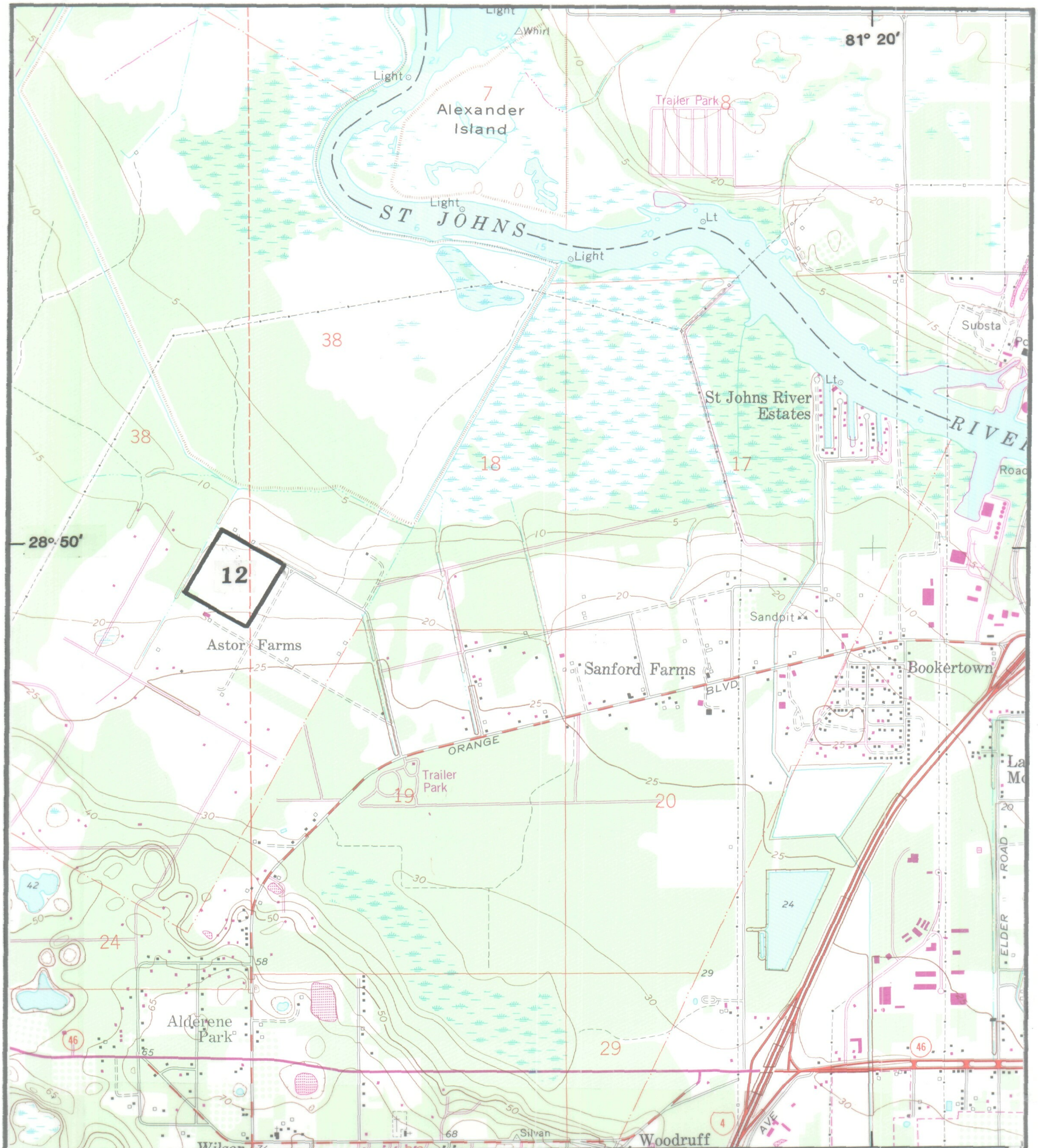
The first layer of the geoelectric section with a resistivity of 48 ohm-m and a thickness of 68 ft (21 m) represents the Hawthorn Group and younger formations overlying the Floridan aquifer. The thickness of this layer was fixed in the inversion based on data contained in Tibbals (1977) on the depth from the surface to the Floridan aquifer (≈ 70 ft). In this case electrical resistivity cannot be used to distinguish between the Floridan aquifer and sediments overlying it. The second layer in the section, with a resistivity of 49 ohm-m and a thickness of 939 ft (286 m), corresponds to the brackish water saturated Floridan aquifer. The third layer of the geoelectric section, which has a resistivity of 8.4 ohm-m, represents the saline water saturated portion of the Floridan aquifer.

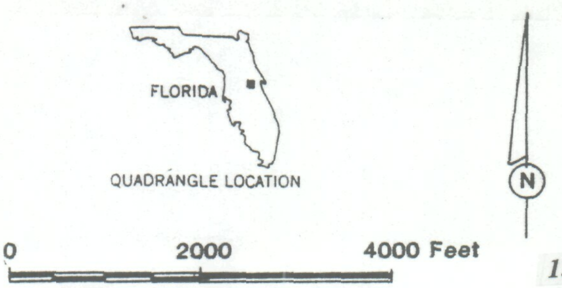
5.13.3 Depth of Occurrence of Saline Water

The third layer of the geoelectric section, with a resistivity of 8.4 ohm-m, is interpreted to represent saline water and occurs at a depth of -1,007 ft (-990 ft msl). Since the resistivity of layer 2 (49 ohm-m), which represents brackish water within the Floridan aquifer, is less than 80 ohm-m, the position of the saline water is located at the interface between layer 2 and layer 3. The positioning is based on criteria outlined under Task 3, Section 4. This places the interpreted depth to the top of the saline water interface (5,000 mg/l isochlor) at 1,007 ft (-990 ft msl). The resistivity of layer 3 is 8.4 ohm-m, which corresponds to a chloride content of 3,676 mg/l, assuming a porosity of 25% and the validity of Figure 4-9.

5.13.4 Depth of Occurrence of the 250 mg/l Isochlor

The resistivity of layer 2 of the geoelectric section, 49 ohm-m, corresponds to a chloride content of 503 mg/l, assuming a porosity of 25% and the validity of Figure 4-9. Since the interpreted chloride content exceeds 250 mg/l, the 250 mg/l isochlor does not occur within the Floridan aquifer at this site. Tibbals (1977) indicates the chloride concentration to be between 101 and 250 mg/l at this site. The



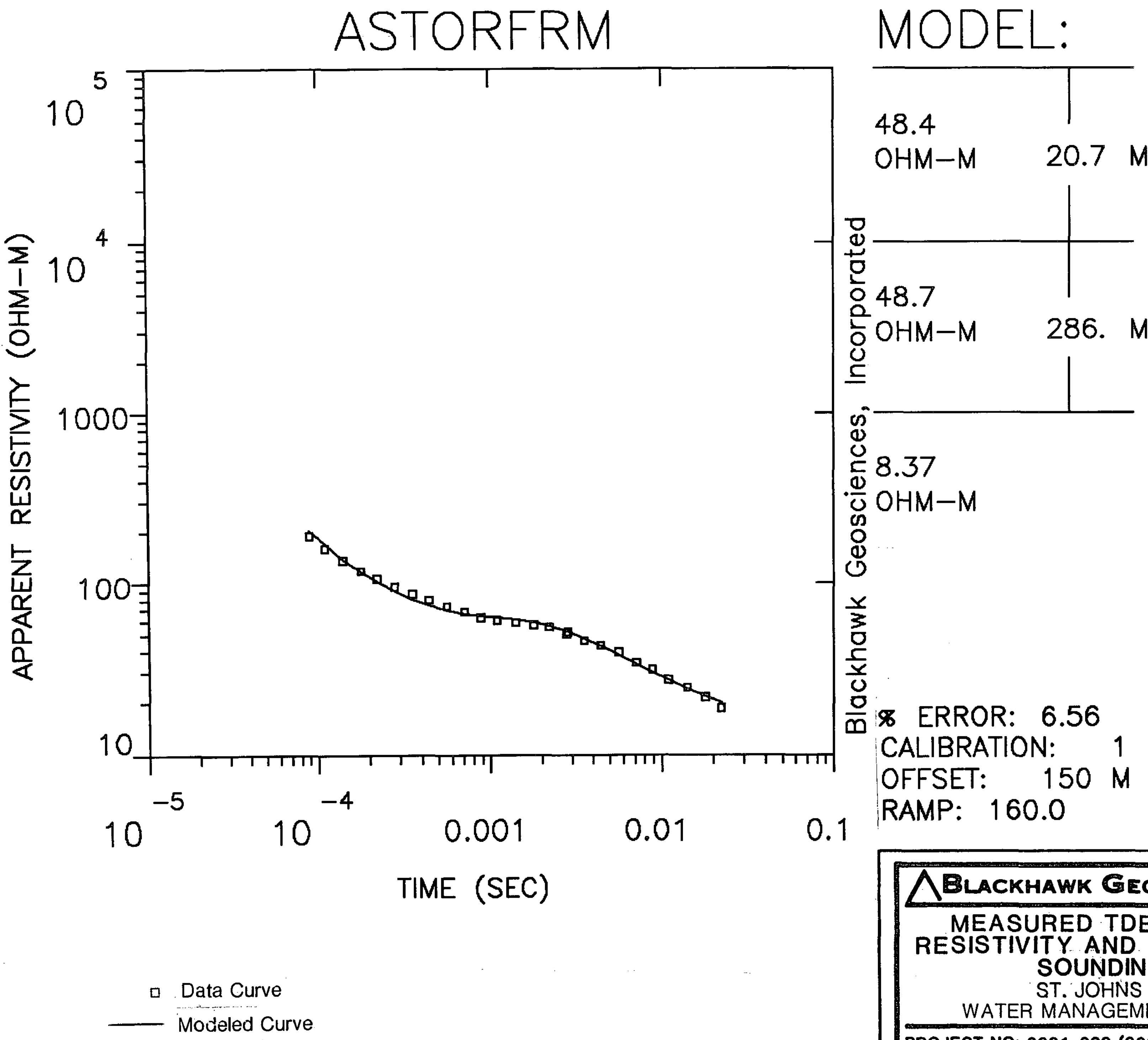


BLACKHAWK GEOSCIENCES, INC.

TDEM SURVEY LOCATION MAP
SOUNDING 12

ST. JOHNS RIVER
WATER MANAGEMENT DISTRCT

PROJECT NO 9001-000 **Figure 5-13.1**



BLACKHAWK GEOSCIENCES, INC.

MEASURED TDEM APPARENT RESISTIVITY AND 1-D INVERSION
SOUNDING 12
ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) **Figure 5-13.2**

chloride to sulfate ratio in Seminole County is approximately 5:1. The site, however, is located at the boundary of regions with chloride concentrations between 101 mg/l and 250 mg/l and chloride concentrations between 251 mg/l and 1,000 mg/l on the map of Tibbals (1977).

5.13.5 Accuracy of Measurement and Interpretation

Figure 5-13.3 shows the evaluation of equivalence at this site and the inversion table (Table 5-13.1) lists the upper and lower bounds of the parameters of the geoelectric section.

The range of equivalence in determining the depth to the layer of low resistivity (layer 3) is shown to be about $\pm$ 100 ft (30 m), which is 10% of the total depth. The resistivity of this layer has an equivalence range of from 6.3 ohm-m to 10.7 ohm-m. This corresponds to a range in interpreted chloride content from 4,952 mg/l to 2,853 mg/l.

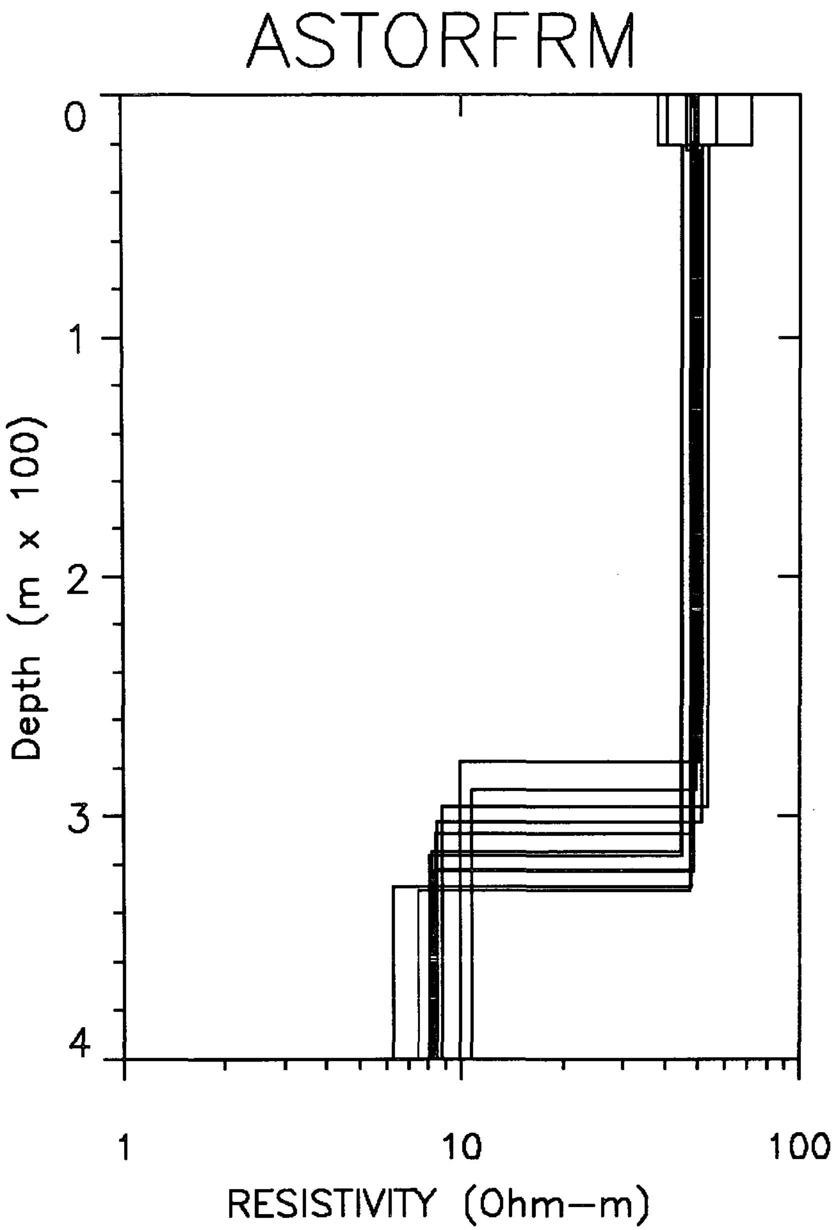
The equivalence range of the resistivity of layer 2 is from 44 to 54 ohm-m. Over this resistivity range the interpreted chloride content is greater than 250 mg/l.

5.13.6 Summary of Results of TDEM Measurements at Astor Farms (Site 12)

From the TDEM measurements, the following information about water quality was derived:

(1) The depth of occurrence of saline water (5,000 mg/l isochlor) was interpreted to be 1,007 ft (-990 ft msl) and the chloride content below that depth was inferred to be 3,676 mg/l.

(2) The ground water within the Floridan aquifer at this site was interpreted to contain an average chloride concentration of 503 mg/l. Consequently, the 250 mg/l isochlor is not expected to be present within the Floridan aquifer. The chloride to sulfate ratio within Seminole County is approximately 5:1 and is consistent with the assumptions utilized in interpreting chloride concentrations.



BLACKHAWK GEOSCIENCES, INC.

EQUIVALENCE IN 1-D INVERSION

SOUNDING 12

ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) Figure 5-13.3

ASTORFRM

MODEL: 3 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		5.2	17.0		
48.45	20.7	-15.6	-51.1	0.4	0.4
48.68	286.3	-301.9	-990.5	5.9	6.3
8.37					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	8.90E-05	1.90E+02	2.06E+02	-7.656	
2	1.10E-04	1.60E+02	1.69E+02	-5.609	
3	1.40E-04	1.37E+02	1.39E+02	-1.775	
4	1.77E-04	1.18E+02	1.18E+02	0.716	
5	2.20E-04	1.07E+02	1.03E+02	4.097	
6	2.80E-04	9.56E+01	9.02E+01	5.972	
7	3.55E-04	8.69E+01	8.10E+01	7.313	
8	4.43E-04	7.99E+01	7.46E+01	7.008	
9	5.64E-04	7.37E+01	6.97E+01	5.726	
10	7.13E-04	6.83E+01	6.64E+01	2.819	
11	8.81E-04	6.32E+01	6.45E+01	-2.129	
12	1.10E-03	6.07E+01	6.32E+01	-3.977	
13	1.41E-03	5.88E+01	6.17E+01	-4.645	
14	1.80E-03	5.70E+01	5.95E+01	-4.233	
15	2.22E-03	5.53E+01	5.66E+01	-2.423	
16	2.80E-03	5.06E+01	5.25E+01	-3.687	
17	2.85E-03	5.17E+01	5.22E+01	-1.003	
18	3.55E-03	4.62E+01	4.76E+01	-2.974	
19	4.43E-03	4.32E+01	4.28E+01	0.942	
20	5.64E-03	3.95E+01	3.79E+01	4.302	
21	7.13E-03	3.42E+01	3.36E+01	1.929	
22	8.81E-03	3.12E+01	3.02E+01	3.267	
23	1.10E-02	2.74E+01	2.72E+01	0.685	
24	1.41E-02	2.46E+01	2.42E+01	1.453	
25	1.80E-02	2.17E+01	2.19E+01	-0.987	
26	2.22E-02	1.87E+01	2.01E+01	-7.020	

R: 150. X: 0. Y: 150. DL: 300. REQ: 167. CF: 1.0000

CLHZ ARRAY, 26 DATA POINTS, RAMP: 160.0 MICROSEC, DATA: ASTORFRM

BLACKHAWK GEOSCIENCES, INC.

INVERSION TABLE
SOUNDING 12
ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) Table 5-13.1

2307 0012 0000 Z OPR XTL L 2 10+1000

Ch.21 = 0.16 Ch.22 = 0.89 Ch.23 = 15.5 Ch.24 =

RMS LOG ERROR: 2.76E-02, ANTILOG YIELDS 6.5597 %

LATE TIME PARAMETERS

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:

"F" MEANS FIXED PARAMETER

P 1	0.39				
P 2	0.14	0.92			
P 3	0.04	-0.04	0.46		
T 1	-0.01	0.00	0.00	0.01	
T 2	-0.04	0.03	0.14	0.07	0.90
	P 1	P 2	P 3	T 1	T 2

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

LAYER		MINIMUM	BEST	MAXIMUM
RHO	1	38.037	48.446	71.838
	2	44.530	48.684	53.807
	3	6.298	8.374	10.707
THICK	1	4.896	20.745	55.728
	2	254.633	286.332	317.275
DEPTH	1	4.896	20.745	55.728
	2	277.182	307.077	330.590

BLACKHAWK GEOSCIENCES, INC.

INVERSION TABLE CONTINUED

SOUNDING 12

ST. JOHNS RIVER

WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) Table 5-13.1

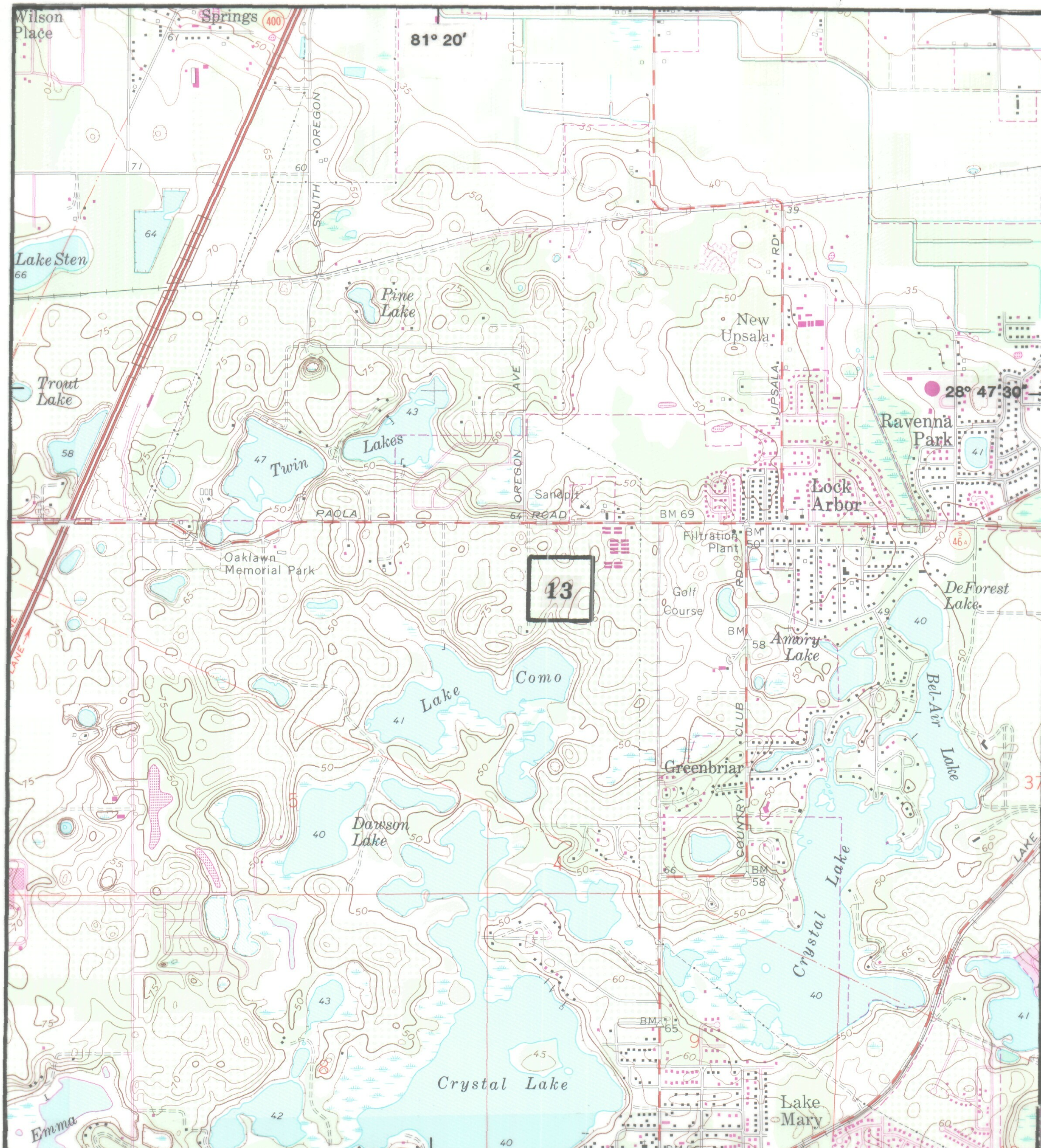
5.14 SANFORD (SITE 13)

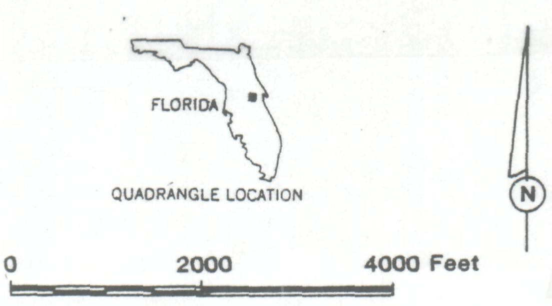
5.14.1 Location

The detailed location map for this sounding is shown in Figure 5-14.1.

5.14.2 Discussion

The sounding at this site is distorted by inductive interference from man-made metallic objects. Figure 5-14.2 shows the four quality control readings superimposed on the same graph. The apparent resistivity curves from the four readings should approximately overlie one another in the absence of significant inductive noise. The quality control readings from this site show an unacceptable variance and indicates that this sounding may be distorted. After the sounding was taken it was learned that the area was an orange grove. It is possible that underground metal irrigation pipes are present in the area and these pipes likely caused distortion of the TDEM data.





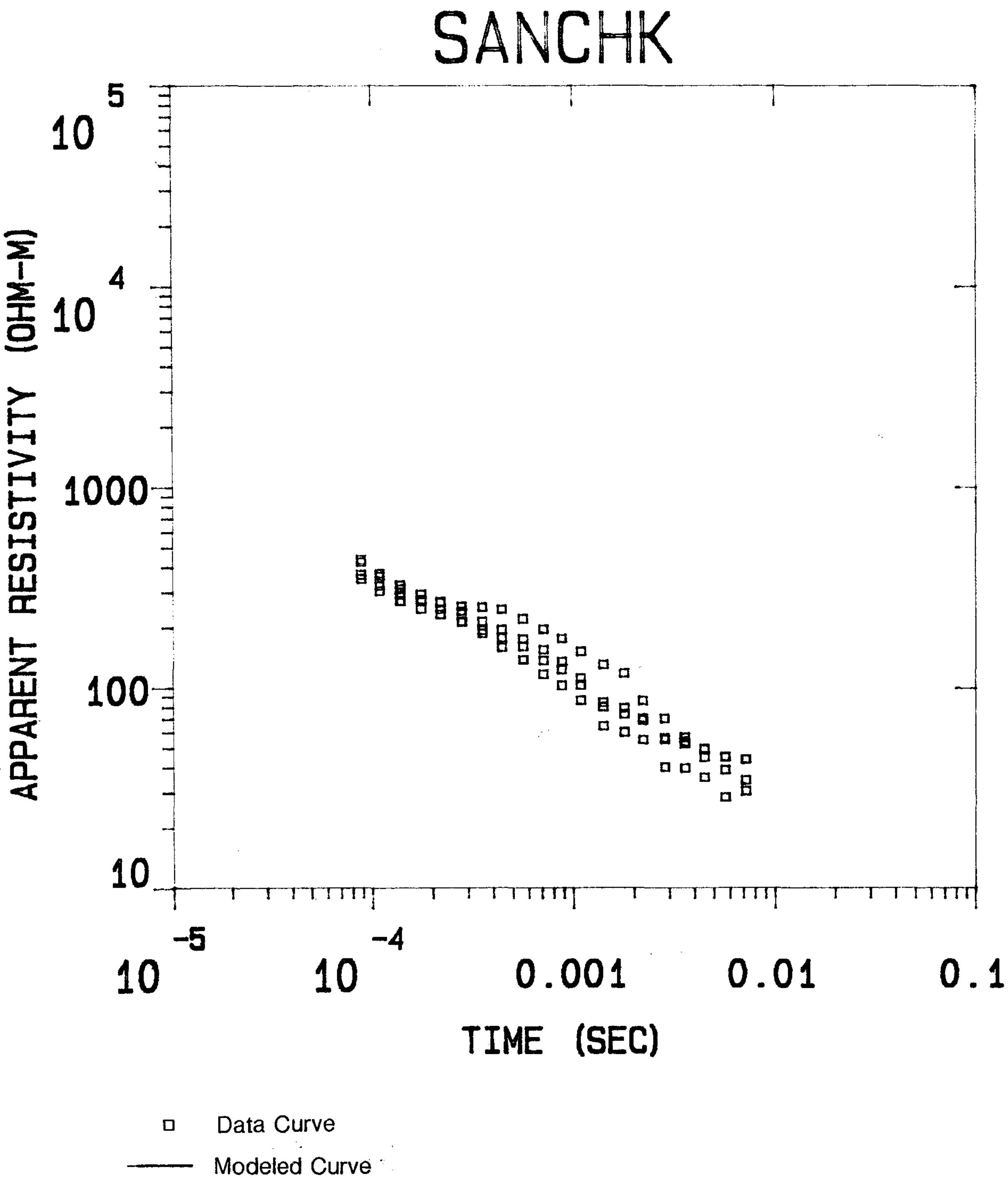
BLACKHAWK GEOSCIENCES, INC.

TDEM SURVEY LOCATION MAP

SOUNDING 13

ST. JOHNS RIVER
WATER MANAGEMENT DISTRCT

PROJECT NO 9001-000 **Figure 5-14.1**



BLACKHAWK GEOSCIENCES, INC.

MEASURED TDEM APPARENT RESISTIVITY AND 1-D INVERSION
SOUNDING 13
ST. JOHNS RIVER WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022)

Figure 5-14.2

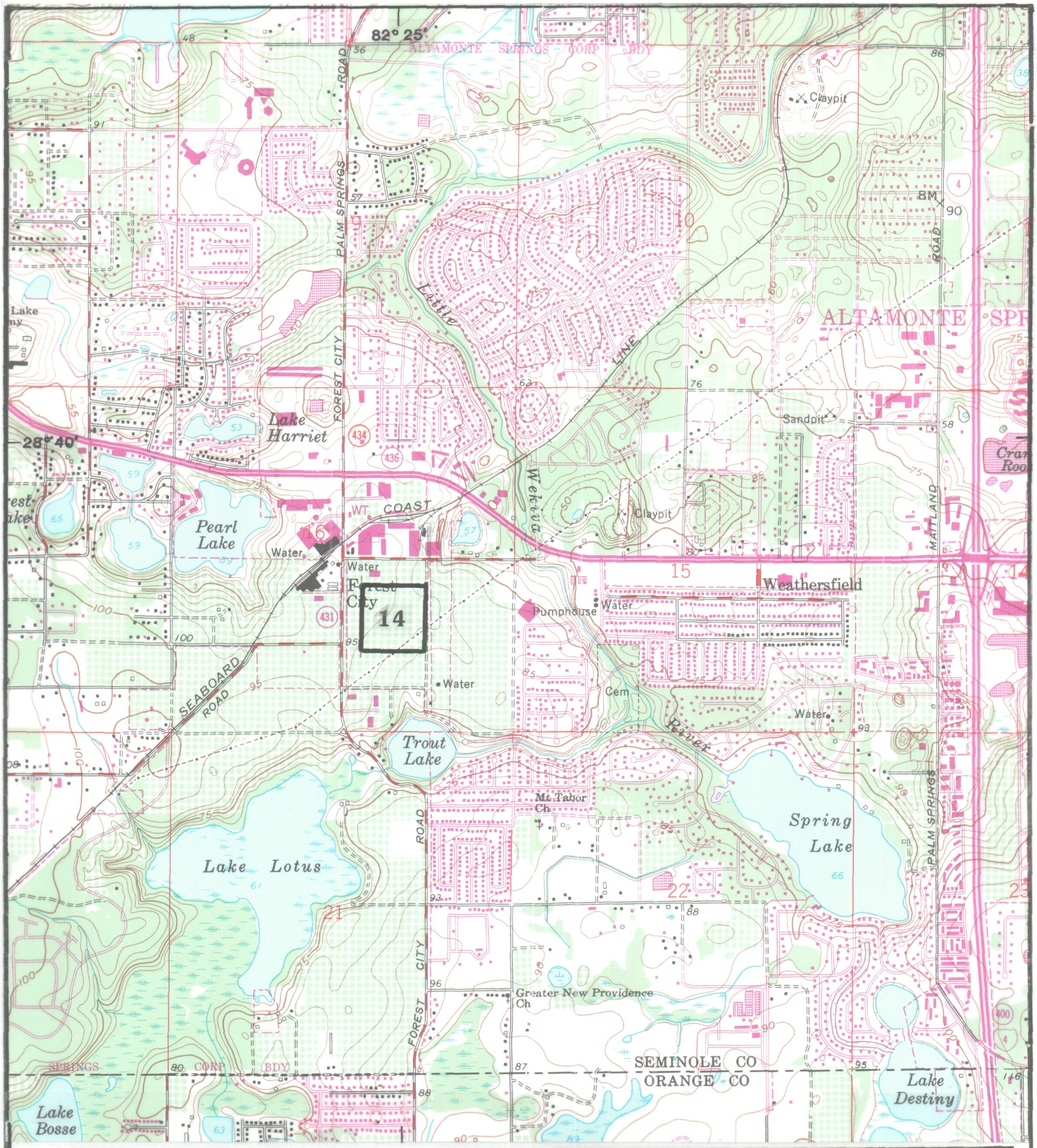
5.15 ALTAMONTE SPRINGS (SITE 14)

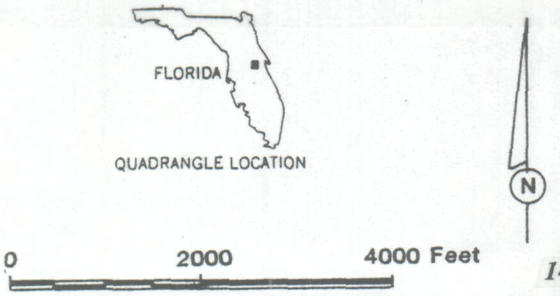
5.15.1 Location

The detailed location map for this sounding is shown in Figure 5-15.1.

5.15.2 Discussion

The sounding at this site is distorted by underground pipes. Upon completion of the sounding it was discovered that the site was an orange grove. This increased the likelihood of buried pipelines within and adjacent to the TDEM sounding location. A series of four quality control readings were taken within the transmitter loop area shown in Figure 5-15.2. The data shows evidence of power line noise but the divergence of the data from the four readings is only moderate. A water well approximately 200 ft northwest of the transmitter loop's edge is 1,115 ft deep and produces water with chlorides less than 50 mg/l. Interpretation of the sounding data indicates a conductor at a depth of 822 ft. The discrepancy between the well and the TDEM sounding indicates the sounding is distorted.



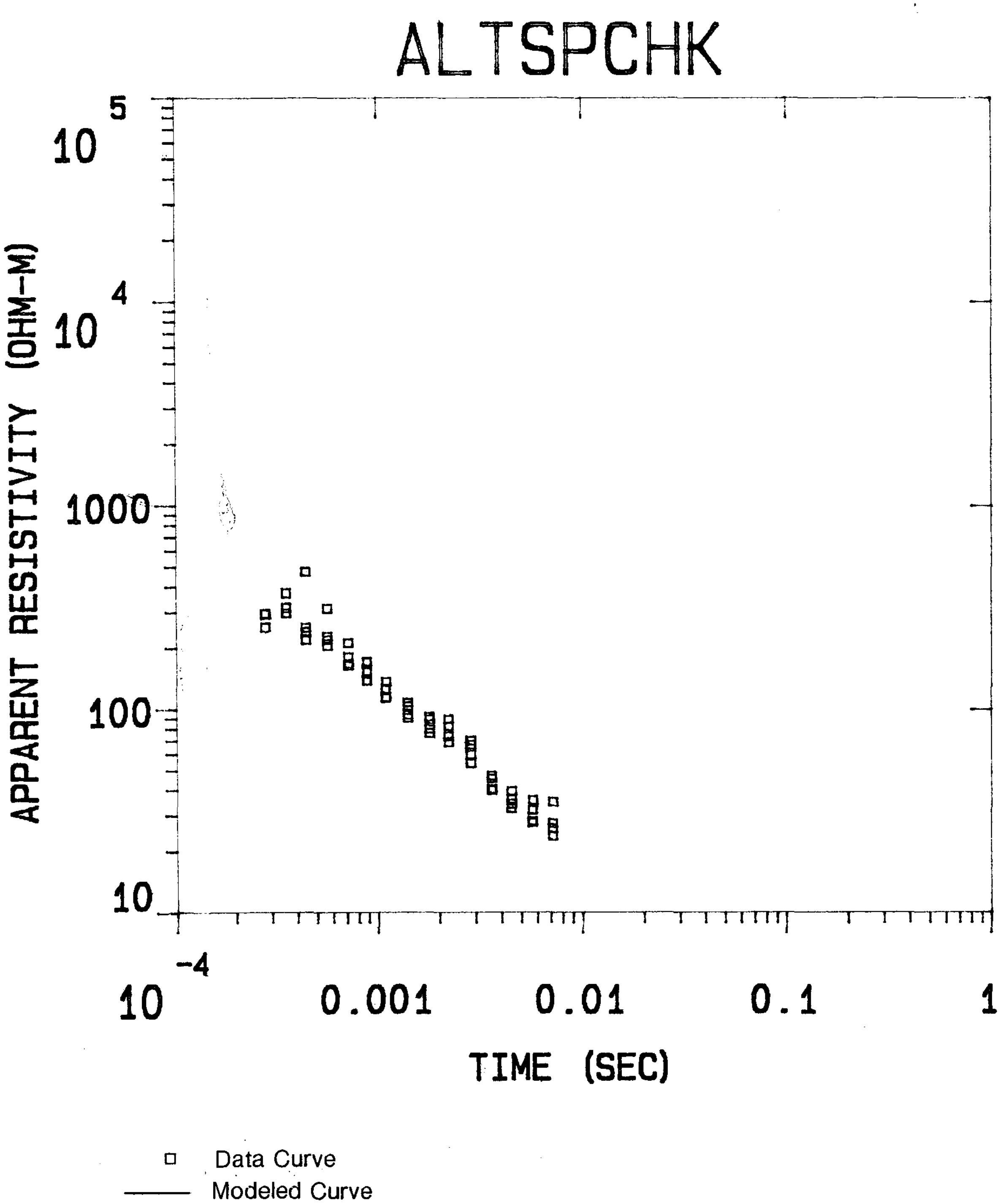


BLACKHAWK GEOSCIENCES, INC.

TDEM SURVEY LOCATION MAP
SOUNDING 14

ST. JOHNS RIVER
WATER MANAGEMENT DISTRCT

PROJECT NO 9001-000 Figure 5-15.1



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BLACKHAWK GEOSCIENCES, INC.

MEASURED TDEM APPARENT RESISTIVITY AND 1-D INVERSION
SOUNDING 14
ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) Figure 5-15.2

5.16 LAKE EMMA (SITE 15)

5.16.1 Location and Geoelectric Section

The detailed location map for this sounding is shown in Figure 5-16.1. The sounding data and inverted geoelectric section is shown in Figure 5-16.2 and consists of a three layer section.

5.16.2 Geologic Interpretation of Geoelectric Section

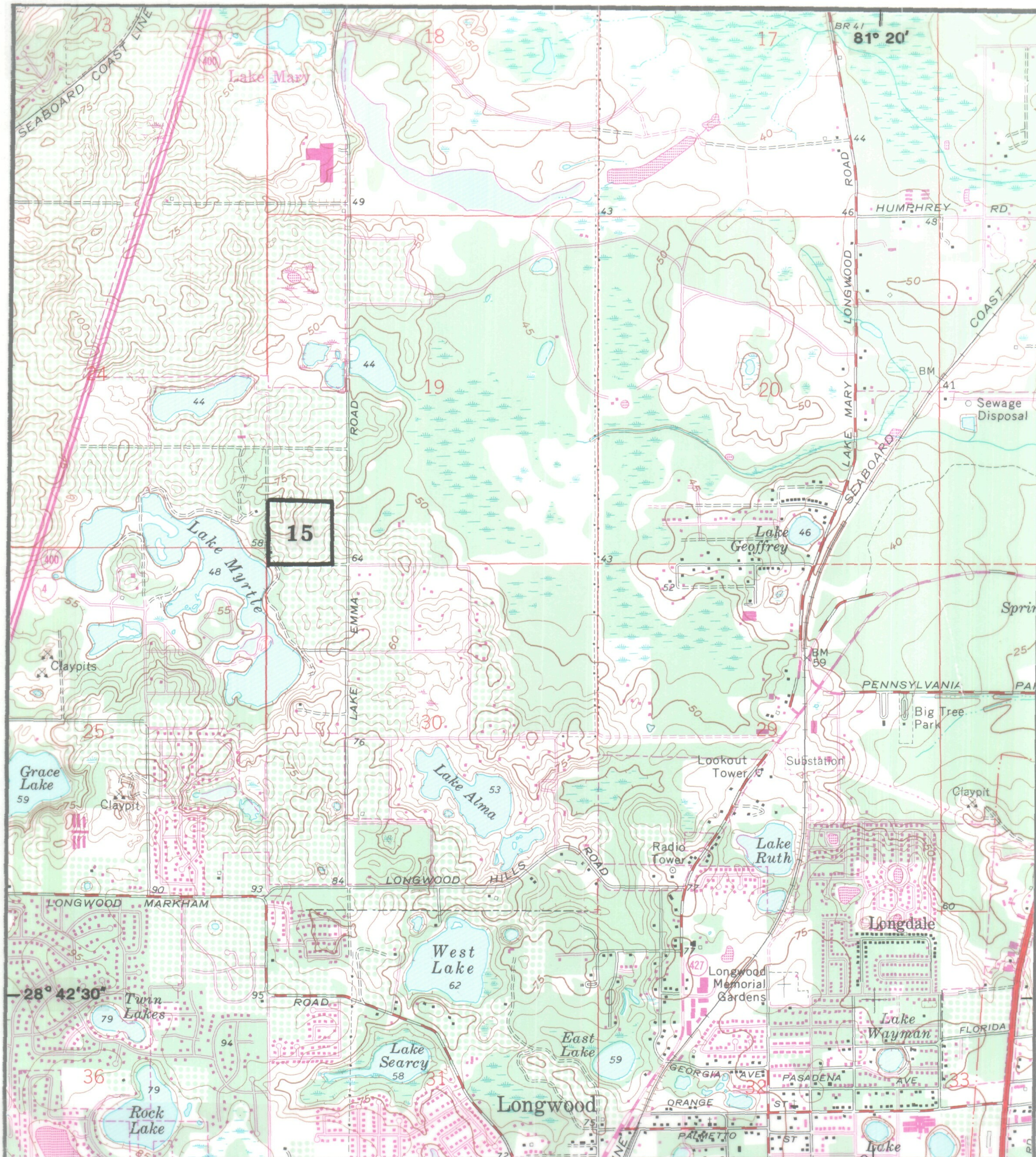
The first layer of the interpreted geoelectric section, with a resistivity of 105 ohm-m and a thickness of 65 ft (20 m) represents the Hawthorn Group and younger formations overlying the Floridan aquifer. The thickness of this layer was fixed in the inversion based on the depth to the Floridan aquifer for this area given in Tibbals (1977) which is approximately 60 to 70 ft from the ground surface. In this case resistivity contrasts between the Upper Floridan and the sediments overlying it was insufficient to map their boundary. The second layer in the section, with a resistivity of 172 ohm-m and a thickness of 1,115 ft (340 m) corresponds to the fresh ground water saturated portion of the Floridan aquifer. The third layer of the geoelectric section with a resistivity of 15 ohm-m represents the brackish to saline water saturated portion of the Floridan aquifer.

5.16.3 Depth of Occurrence of Saline Water

The third layer of the geoelectric section, with a resistivity of 15 ohm-m, is interpreted to represent brackish-saline water and occurs at a depth of 1,182 ft (-1,117 ft msl). Since the resistivity of layer 2 (172 ohm-m), which represents fresh water within the Floridan aquifer, is greater than 80 ohm-m, the position of the saline water interface is located 50 ft below the interface between layer 2 and layer 3. The positioning is based on criteria outlined under Task 3, Section 4. This places the interpreted depth to the top of the saline water (5,000 mg/l isochlor) at 1,232 ft (-1,167 ft msl). The resistivity of layer 3 is 15 ohm-m which corresponds to a chloride content of 2,000 mg/l, assuming a porosity of 25% and the validity of Figure 4-9.

5.16.4 Depth of Occurrence of the 250 mg/l Isochlor

The resistivity of layer 2 of the geoelectric section, 172 ohm-m, corresponds to a chloride content of less than 100 mg/l, assuming a porosity of 25% and the validity of Figure 4-9. Using the criteria outlined in Task 3, Section 4, and illustrated in Figure 4-9, this is a class A type transition zone and the



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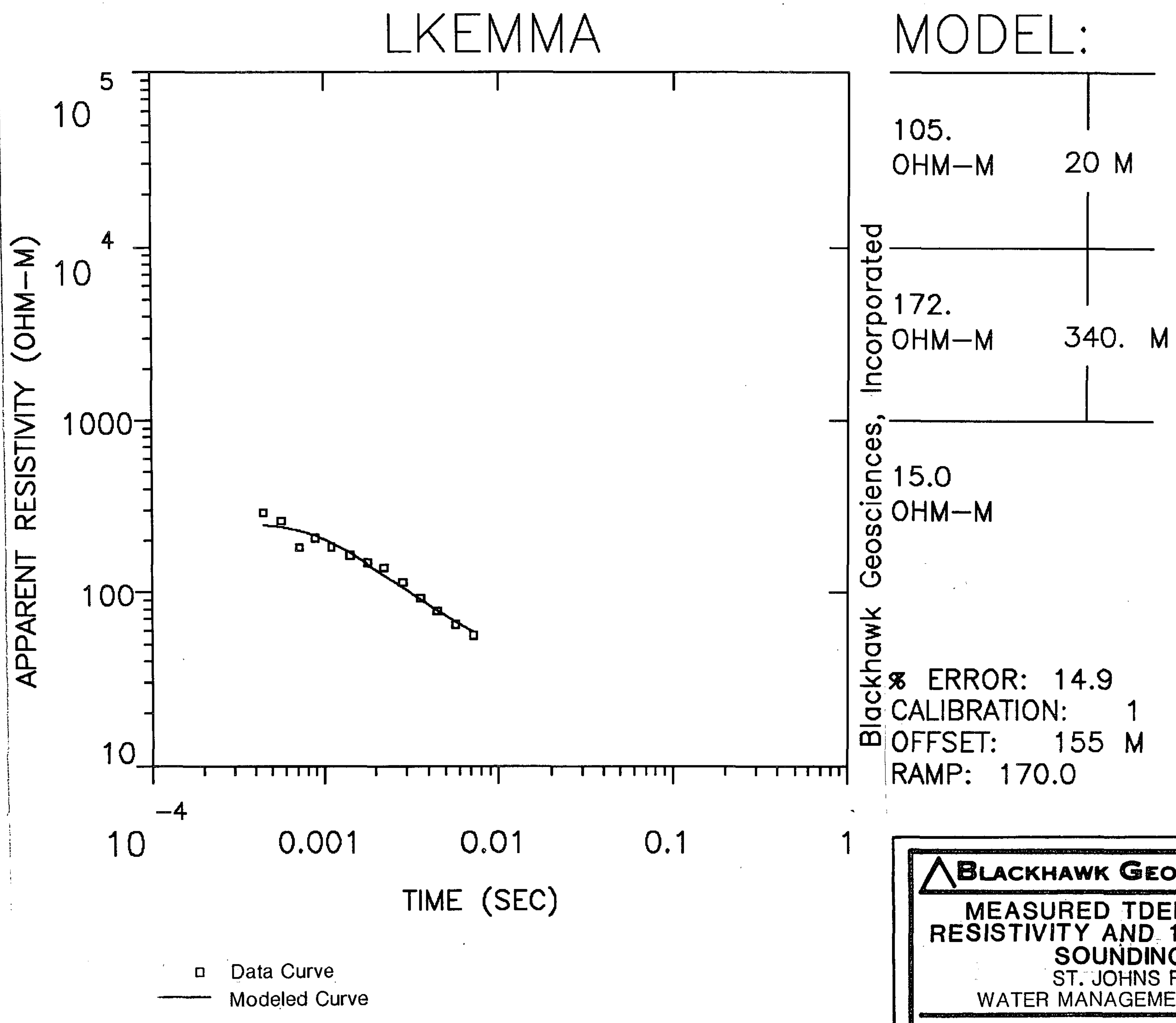
BLACKHAWK GEOSCIENCES, INC.

TDEM SURVEY LOCATION MAP
SOUNDING 15

ST. JOHNS RIVER
WATER MANAGEMENT DISTRCT

PROJECT NO 9001-000 **Figure 5-16.1**



BLACKHAWK GEOSCIENCES, INC.

MEASURED TDEM APPARENT RESISTIVITY AND 1-D INVERSION SOUNDING 15

ST. JOHNS RIVER WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) **Figure 5-16.2**

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250 mg/l isochlor is located 50 ft above the interface between layer 2 and layer 3 of the geoelectric section. This places the 250 mg/l isochlor at a depth of 1,132 ft (-1,067 ft msl). The chloride to sulfate ratio for Seminole County is approximately 5:1 and is consistent with the assumptions utilized in estimating chloride content.

5.16.5 Accuracy of Measurement and Interpretation

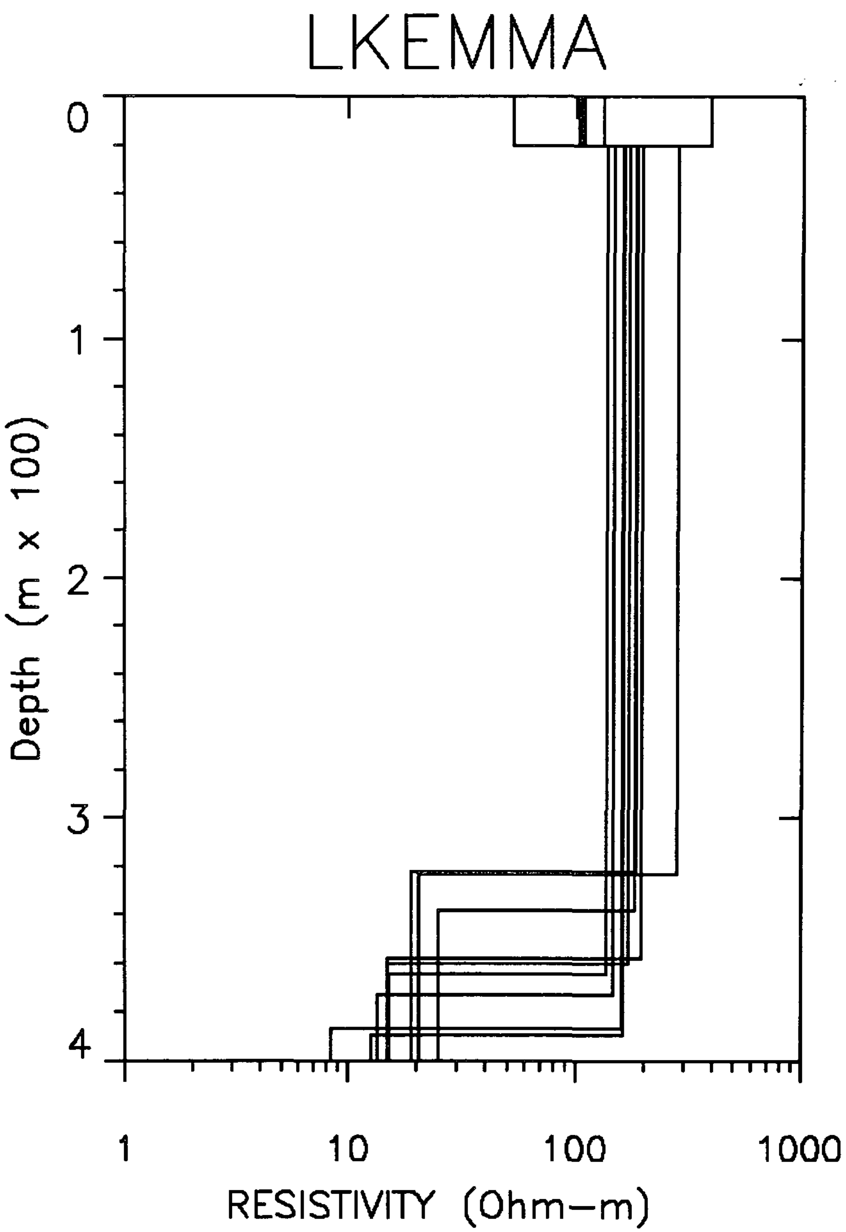
Figure 5-16.3 shows the evaluation of equivalence at this site, and the inversion table (Table 5-16.1) lists the upper and lower bounds of the parameters of the geoelectric section.

The range of equivalence in determining the depth to the layer of low resistivity (layer 3) is shown to be about $\pm$ 120 ft (36 m) which is 10% of the total depth. The resistivity of this layer has a range of equivalence from 8.3 to 25 ohm-m. At the high end of the equivalence range, 25 ohm-m, the interpreted chloride content is approximately 1,130 mg/l and is slightly outside the chloride range utilized in positioning the 250 mg/l isochlor. The difference is not large enough to alter the positioning of the isochlor.

The resistivity of layer 2 shows an equivalence of from 137 ohm-m to 282 ohm-m. Throughout this range the interpreted chloride content is less than 250 mg/l.

The data from this sounding shows evidence of power line noise. The noise, however, does not appear severe enough to distort the sounding and its interpreted geoelectric section, although the total RMS error is high (14.9%). The high error is the result of noisy data points. The average curve through these points (model curve) is probably close to what the data would show in the absence of power line noise. The quality control readings shown in Figure 5-16.4, are noisy but show only slight evidence of inductive coupling affecting the sounding. The quality control readings which are offset from the other data points in the central portion of the curve may be the result of their proximity to power lines. Experience at the Altamonte Springs (Site 14) location, however, indicates the influence of inductive noise may be quite subtle. This sounding may be undistorted but the results are somewhat suspect.

The depth to saline water of 1,232 ft is consistent with other soundings and drill hole data in the area. Soundings distorted by pipelines and other linear conductive features tend to underestimate the depth to low resistivity layers. Because of this the depth of 1,232 ft interpreted in the sounding would be a minimum depth to saline water if this sounding is distorted by inductive noise.



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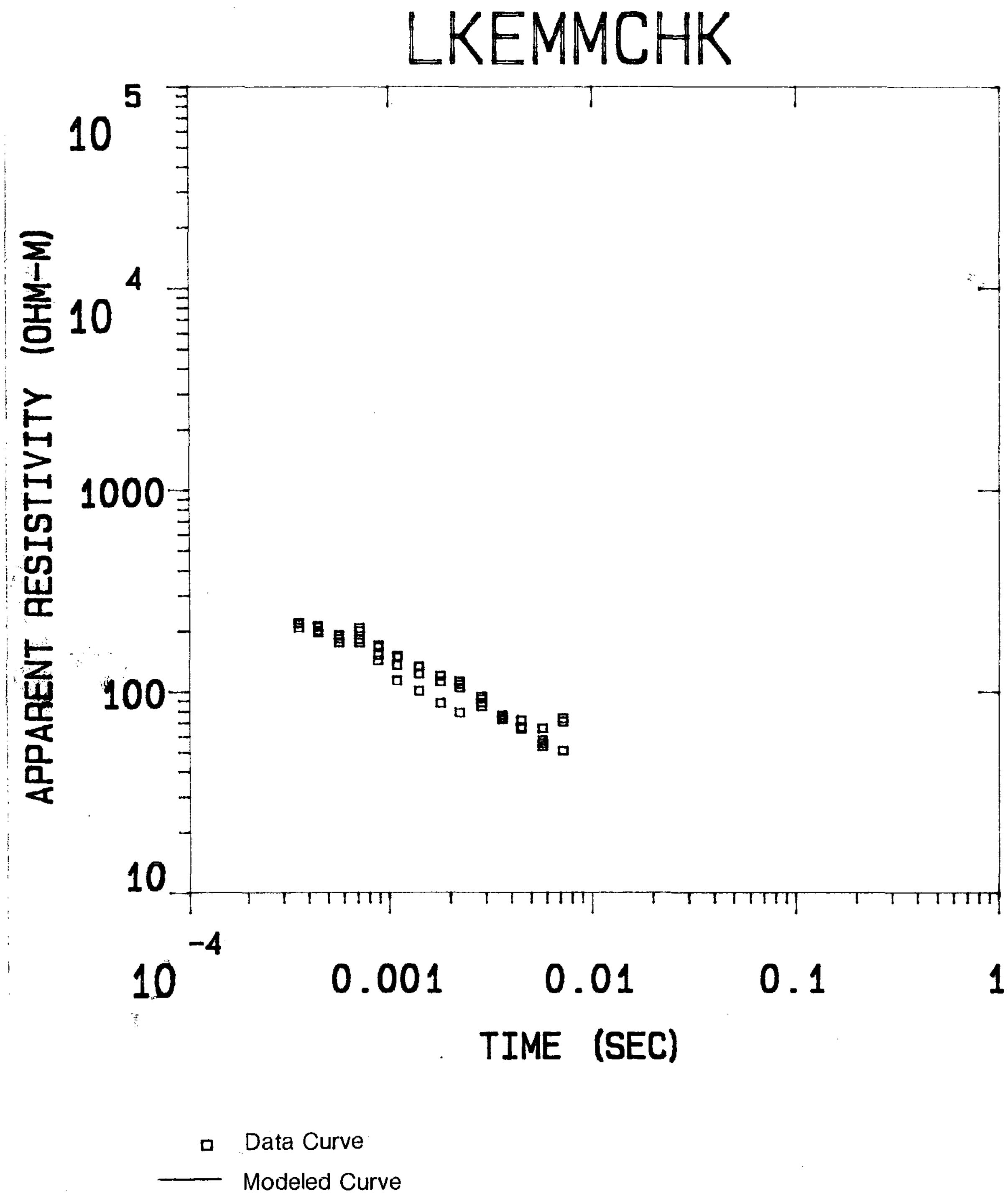
BLACKHAWK GEOSCIENCES, INC.

EQUIVALENCE IN 1-D INVERSION
SOUNDING 15

ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) Figure 5-16.3



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BLACKHAWK GEOSCIENCES, INC.

MEASURED TDEM APPARENT RESISTIVITY AND 1-D INVERSION SOUNDING 15
ST. JOHNS RIVER WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) Figure 5-16.4

LKEMMA

MODEL: 3 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		19.8	65.0		
105.48	20.0	-0.2	-0.6	0.2	0.2
171.85	340.1	-340.3	-1116.5	2.0	2.2
15.01					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	4.43E-04	2.90E+02	2.47E+02	17.357	
2	5.64E-04	2.60E+02	2.40E+02	8.370	
3	7.13E-04	1.82E+02	2.29E+02	-20.348	
4	8.81E-04	2.07E+02	2.15E+02	-3.503	
5	1.10E-03	1.83E+02	1.96E+02	-6.375	
6	1.41E-03	1.65E+02	1.70E+02	-3.239	
7	1.80E-03	1.49E+02	1.46E+02	2.447	
8	2.22E-03	1.39E+02	1.26E+02	10.400	
9	2.85E-03	1.15E+02	1.06E+02	7.774	
10	3.60E-03	9.27E+01	9.09E+01	2.065	
11	4.49E-03	7.79E+01	7.88E+01	-1.156	
12	5.70E-03	6.54E+01	6.81E+01	-3.903	
13	7.19E-03	5.64E+01	5.96E+01	-5.318	

R: 155. X: 0. Y: 155. DL: 310. REQ: 172. CF: 1.0000
CLHZ ARRAY, 13 DATA POINTS, RAMP: 170.0 MICROSEC, DATA: LKEMMA
2407 0015 0000 Z OPR XTL H 2 10÷100
Ch.21 = 0.17 Ch.22 = 0.089 Ch.23 = 35 Ch.24 = 9
RMS LOG ERROR: 6.04E-02, ANTILOG YIELDS 14.9125 %
LATE TIME PARAMETERS

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER
P 1 0.04
P 2 0.17 0.88
P 3 0.00 -0.08 0.30

BLACKHAWK GEOSCIENCES, INC.

INVERSION TABLE
SOUNDING 15
ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) Table 5-16.1

F 1	0.00	0.00	0.00	0.00	
T 2	-0.01	0.03	0.09	0.00	0.96
	P 1	P 2	P 3	F 1	T 2

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

LAYER		MINIMUM	BEST	MAXIMUM
RHO	1	52.978	105.480	390.421
	2	136.519	171.852	282.340
	3	8.354	15.009	25.051
THICK	1	20.000	20.000	20.000
	2	302.366	340.136	369.401
DEPTH	1	20.000	20.000	20.000
	2	322.366	360.136	389.401

BLACKHAWK GEOSCIENCES, INC.

INVERSION TABLE CONTINUED
SOUNDING 15
ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) Table 5-16.1

5.16.6 Summary of Results of TDEM Measurements at Lake Emma (Site 15)

From the TDEM measurements, the following information about water quality was derived:

(1) The depth of occurrence of saline water (5,000 mg/l isochlor) was interpreted to be 1,232 ft (-1,167 ft msl) and the chloride content below this depth was inferred to be 2,000 mg/l.

(2) The 250 mg/l isochlor was interpreted to occur at a depth of 1,132 ft (-1,067 ft msl). Ground water within the Floridan aquifer above this depth is estimated to have a chloride content of less than 100 mg/l. According to Tibbals (1977) chloride is less than 25 mg/l at this site. The chloride to sulfate ratio for Seminole County is approximately 5:1 and is consistent with the assumptions utilized in estimating chloride content.

(3) The quality control readings may indicate some inductive interference, and the results are suspect. The interpreted depth to saline water is, however, consistent with other TDEM soundings and well data in the area.

5.17 LOWER WEKIVA I (SITE 16)

5.17.1 Location and Geoelectric Section

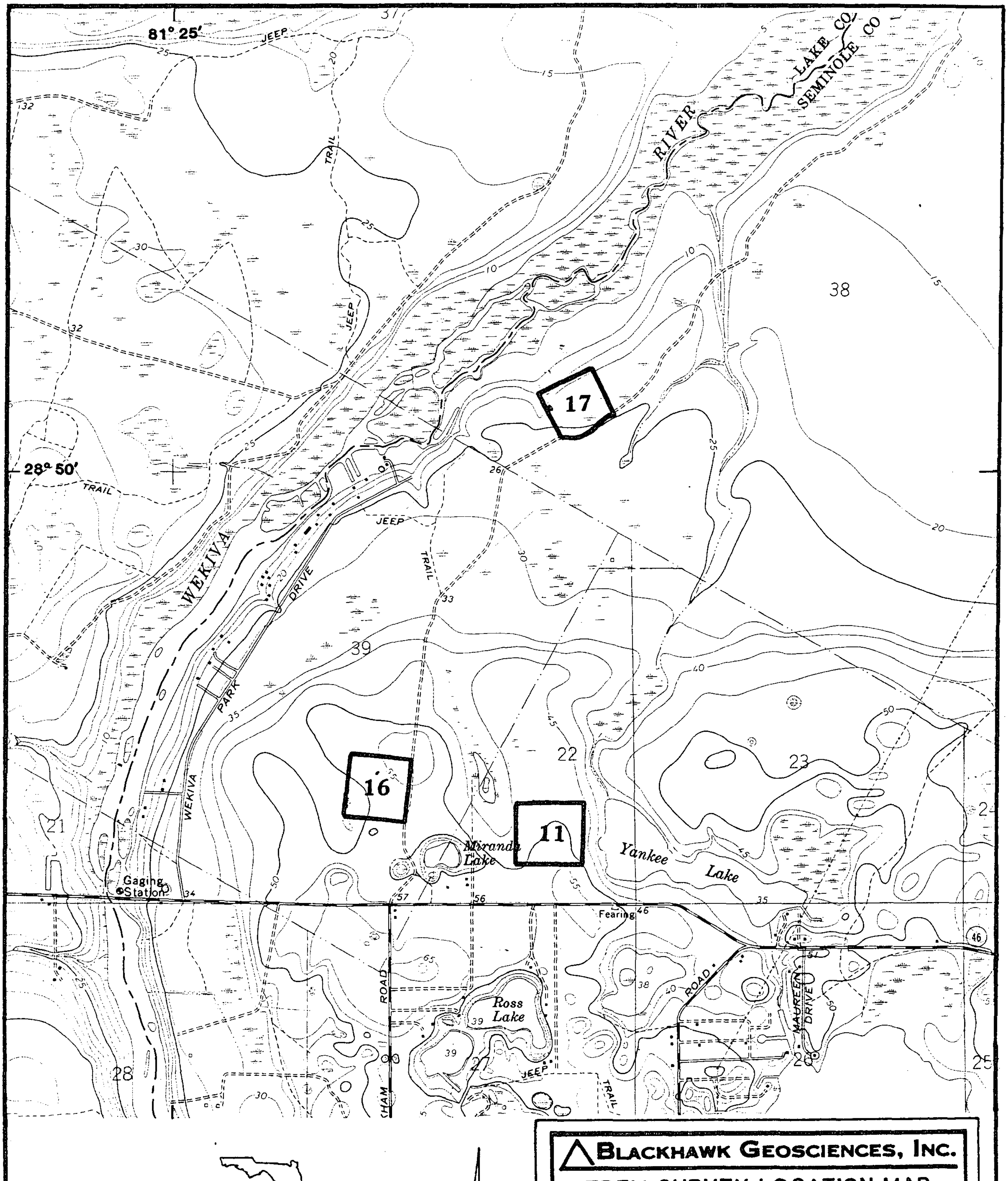
The detailed location map for this sounding is shown in Figure 5-17.1. The sounding data and inverted geoelectric section is shown in Figure 5-17.2 and consists of a four layer section.

5.17.2 Geologic Interpretation of Geoelectric Section

The first layer of the interpreted geoelectric section, with a resistivity of 236 ohm-m and a thickness of 65 ft (20 m), represents the Hawthorn Group and younger formations overlying the Floridan aquifer. The thickness of this layer was fixed in the inversion based on the depth from ground surface to the Floridan aquifer for this area given in Tibbals (1977) of approximately 65 ft. The second layer of the section has a resistivity of 745 ohm-m and a thickness of 180 ft (55 m). It is located at the depth at which the top of the Floridan aquifer is thought to occur. The high resistivity of this layer indicates the upper portion of the Floridan aquifer is saturated with fresh water and/or the porosity of the Floridan is significantly less than the average value of 25%. The third layer of geoelectric section has a resistivity of 57 ohm-m and a thickness of 822 ft (250 m) and likely corresponds to a brackish water saturated portion of the Floridan aquifer. The fourth layer of the section, with a resistivity of 6.0 ohm-m, represents the Floridan aquifer which is saturated with saline water. This site is the only one of the present survey in which three layers, - fresh water, brackish water and saline water, - are mapped within the Floridan aquifer.

5.17.3 Depth of Occurrence of Saline Water

The fourth layer of the geoelectric section, with a resistivity of 6.0 ohm-m, is interpreted to represent saline water and occurs at a depth of 1,068 ft (-1,015 ft msl). Since the resistivity of layer 3 (57 ohm-m) is less than 80 ohm-m, the position of the saline water interface (5,000 mg/l isochlor) is located at the interface between layer 3 and layer 4 of the geoelectric section. The positioning is based on criteria outlined under Task 3, Section 4. The resistivity of layer 4 is 6.0 ohm-m which corresponds to a chloride content of 5,200 mg/l, assuming 25% porosity and the validity of Figure 4-9.

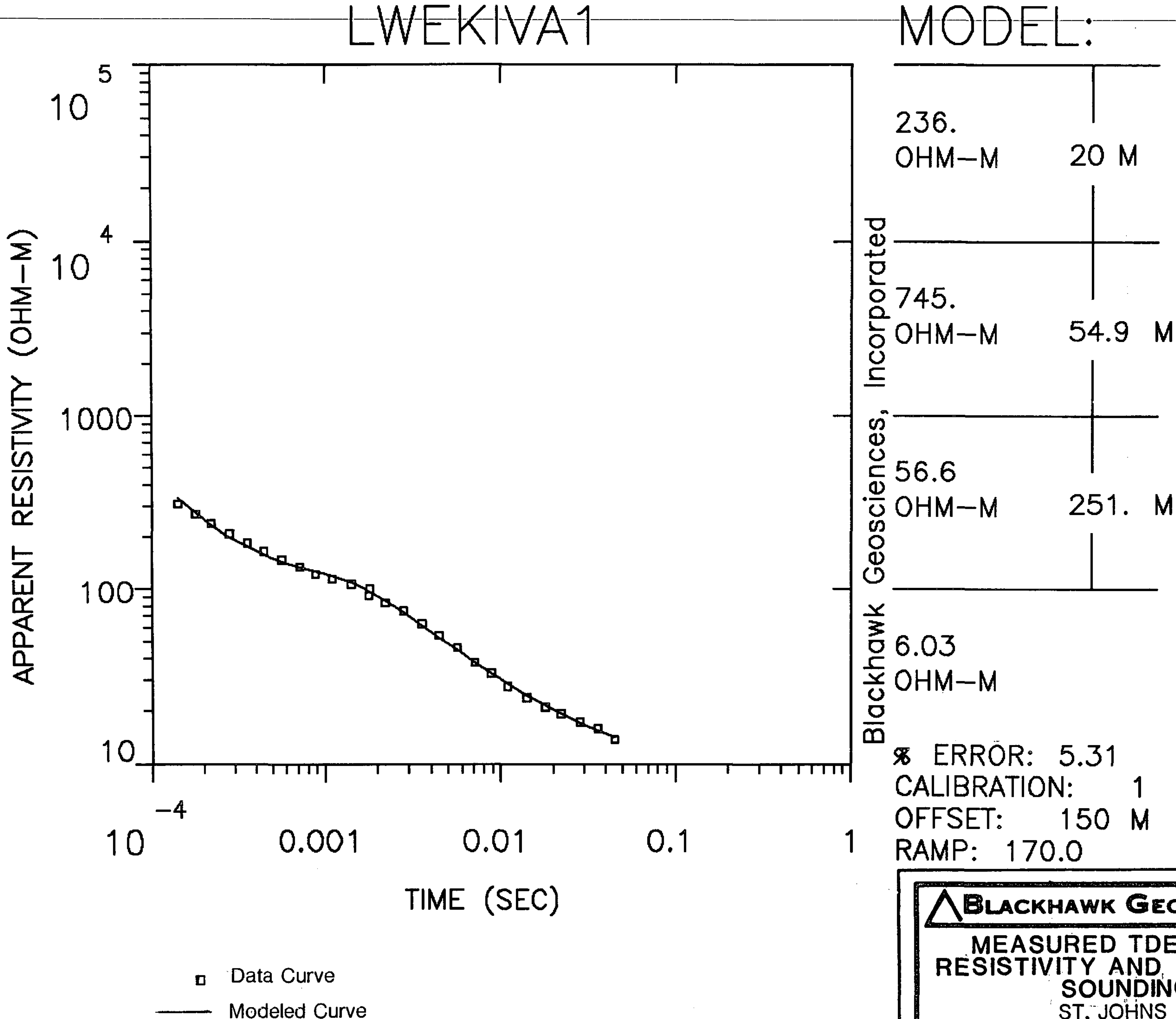


BLACKHAWK GEOSCIENCES, INC.

TDEM SURVEY LOCATION MAP
SOUNDING 11, 16,&17

ST. JOHNS RIVER
WATER MANAGEMENT DISTRCT

PROJECT NO 9001-000 Figure 5-17.1



BLACKHAWK GEOSCIENCES, INC.

MEASURED TDEM APPARENT RESISTIVITY AND 1-D INVERSION SOUNDING 16

ST. JOHNS RIVER WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) **Figure 5-17.2**

5.17.4 Depth of Occurrence of the 250 mg/l Isochlor

At this site layer 2 of the interpreted geoelectric section represents fresh water within the Floridan aquifer, while layer 3 of the section represents brackish water within the Floridan. The resistivity of layer 2 (745 ohm-m) corresponds to a chloride content of less than 50 mg/l, while the resistivity of 57 ohm-m for layer 3 corresponds to a chloride content of 411 mg/l, assuming a porosity of 25% and the validity of Figure 4-9 for both layers. Utilizing the criteria outlined under Task 3, Section 4, and illustrated in Figure 4-11, this is a class C transition zone and the position of the 250 mg/l isochlor is at the interface between layer 2 and layer 3 at a depth of 246 ft (-193 ft msl). The chloride to sulfate ratio of 5:1 for the Floridan aquifer within Seminole County is consistent with the assumptions utilized in interpreting the chloride content.

5.17.5 Accuracy of Measurement and Interpretation

Figure 5-17.3 shows the evaluation of equivalence at this site and the inversion table (Table 5-17.1) lists the upper and lower bounds of the parameters of the geoelectric section.

The range of equivalence in determining the depth to the layer of low resistivity (layer 4) is shown to be about ± 35 ft (10 m) which is about 3% of the total depth. The resistivity of this layer has a range of equivalence from 5.3 ohm-m to 6.9 ohm-m, which corresponds to a chloride content greater than 4,500 mg/l throughout the range.

The resistivity of layer 3 shows an equivalence range from 48 ohm-m to 63 ohm-m, which corresponds to a chloride content from 517 mg/l to 358 mg/l. The resistivity range of layer 2, from 337 ohm-m to 2,360 ohm-m, corresponds to a chloride concentration less than 50 mg/l. The equivalence in determining the depth to the interface between layer 2 and layer 3 is shown to be ± 66 ft (20 m) or about 27% of the total depth to the interface. The depth to this interface is not well resolved for this sounding.

LWEKIVA1

MODEL: 4 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		16.2	53.0		
235.88	20.0	-3.8	-12.6	0.1	0.1
745.43	54.9	-58.7	-192.7	0.1	0.2
56.56	250.6	-309.3	-1014.9	4.4	4.6
6.03					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	1.40E-04	3.09E+02	3.33E+02	-7.444	
2	1.77E-04	2.70E+02	2.75E+02	-1.566	
3	2.20E-04	2.40E+02	2.33E+02	2.819	
4	2.80E-04	2.08E+02	1.99E+02	4.584	
5	3.55E-04	1.84E+02	1.74E+02	5.935	
6	4.43E-04	1.64E+02	1.57E+02	4.741	
7	5.64E-04	1.47E+02	1.44E+02	2.264	
8	7.13E-04	1.34E+02	1.34E+02	0.367	
9	8.81E-04	1.22E+02	1.26E+02	-3.498	
10	1.10E-03	1.14E+02	1.20E+02	-4.909	
11	1.41E-03	1.07E+02	1.09E+02	-1.932	
12	1.77E-03	9.15E+01	9.73E+01	-5.943	
13	1.80E-03	1.00E+02	9.66E+01	3.695	
14	2.20E-03	8.31E+01	8.60E+01	-3.390	
15	2.80E-03	7.48E+01	7.34E+01	1.860	
16	3.55E-03	6.28E+01	6.17E+01	1.841	
17	4.43E-03	5.42E+01	5.26E+01	2.907	
18	5.64E-03	4.61E+01	4.44E+01	3.813	
19	7.13E-03	3.79E+01	3.77E+01	0.603	
20	8.81E-03	3.29E+01	3.27E+01	0.353	
21	1.10E-02	2.76E+01	2.86E+01	-3.490	
22	1.41E-02	2.39E+01	2.46E+01	-2.653	
23	1.80E-02	2.11E+01	2.16E+01	-2.032	
24	2.22E-02	1.94E+01	1.93E+01	0.331	
25	2.85E-02	1.73E+01	1.71E+01	1.203	
26	3.60E-02	1.59E+01	1.56E+01	2.435	
27	4.49E-02	1.38E+01	1.42E+01	-2.523	

BLACKHAWK GEOSCIENCES, INC.

INVERSION TABLE
SOUNDING 16
ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) Table 5-17.1

R: 150. X: 0. Y: 150. DL: 300. REQ: 167. CF: 1.0000

CLHZ ARRAY, 27 DATA POINTS, RAMP: 170.0 MICROSEC, DATA: LWEKIVA1

2507 0016 0000 Z OPR XTL H 2 8+100

Ch.21 = 0.17 Ch.22 = 0.089 Ch.23 = 15 Ch.24 = 9

RMS LOG ERROR: 2.25E-02, ANTILOG YIELDS 5.3146 %

LATE TIME PARAMETERS

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:

"F" MEANS FIXED PARAMETER

P 1	0.62						
P 2	0.00	0.01					
P 3	0.00	-0.01	0.99				
P 4	0.00	0.00	0.00	0.99			
F 1	0.00	0.00	0.00	0.00	0.00		
T 2	0.04	0.09	0.02	0.00	0.00	0.96	
T 3	-0.01	-0.02	0.00	0.00	0.00	0.01	1.00
	P 1	P 2	P 3	P 4	F 1	T 2	T 3

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

LAYER		MINIMUM	BEST	MAXIMUM
RHO	1	100.773	235.877	1292.307
	2	337.187	745.432	2357.263
	3	48.347	56.563	63.402
	4	5.258	6.026	6.856
THICK	1	20.000	20.000	20.000
	2	43.065	54.898	79.370
	3	228.761	250.595	263.796
DEPTH	1	20.000	20.000	20.000
	2	63.065	74.898	99.370
	3	316.531	325.493	335.803

BLACKHAWK GEOSCIENCES, INC.

INVERSION TABLE CONTINUED
SOUNDING 16

ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) Table 5-17.1

5.17.6 Summary of Results of TDEM Measurements at Lower Wekiva I (Site 16)

From the TDEM measurements, the following information about water quality was derived:

(1) The depth of occurrence of saline water (5,000 mg/l isochlor) was interpreted to be 1,068 ft (-1,015 ft msl) and the chloride content below this depth was inferred to be 5,200 mg/l.

(2) The 250 mg/l isochlor was interpreted to occur at a depth of 246 ft (-193 ft msl). This depth was not well resolved by the sounding. Ground water within the Floridan aquifer above this depth is estimated to have an average chloride concentration less than 50 mg/l chloride, and between elevations of -193 ft msl and -1,105 ft msl the ground water is inferred to have an average chloride concentration in excess of 250 mg/l. According to Tibbals (1977) the chloride concentration of the Upper Floridan in this area ranges from 25 to 100 mg/l. The estimated chloride to sulfate ratio for Seminole County is 5:1 and is consistent with the assumptions utilized in estimating chloride concentrations.

5.18 LOWER WEKIVA II (SITE 17)

5.18.1 Location and Geoelectric Section

The detailed location map for this sounding is shown in Figure 5-18.1. The sounding data and inverted geoelectric section is shown in Figure 5-18.2 and consists of a three layer geoelectric section.

5.18.2 Geologic Interpretation of Geoelectric Section

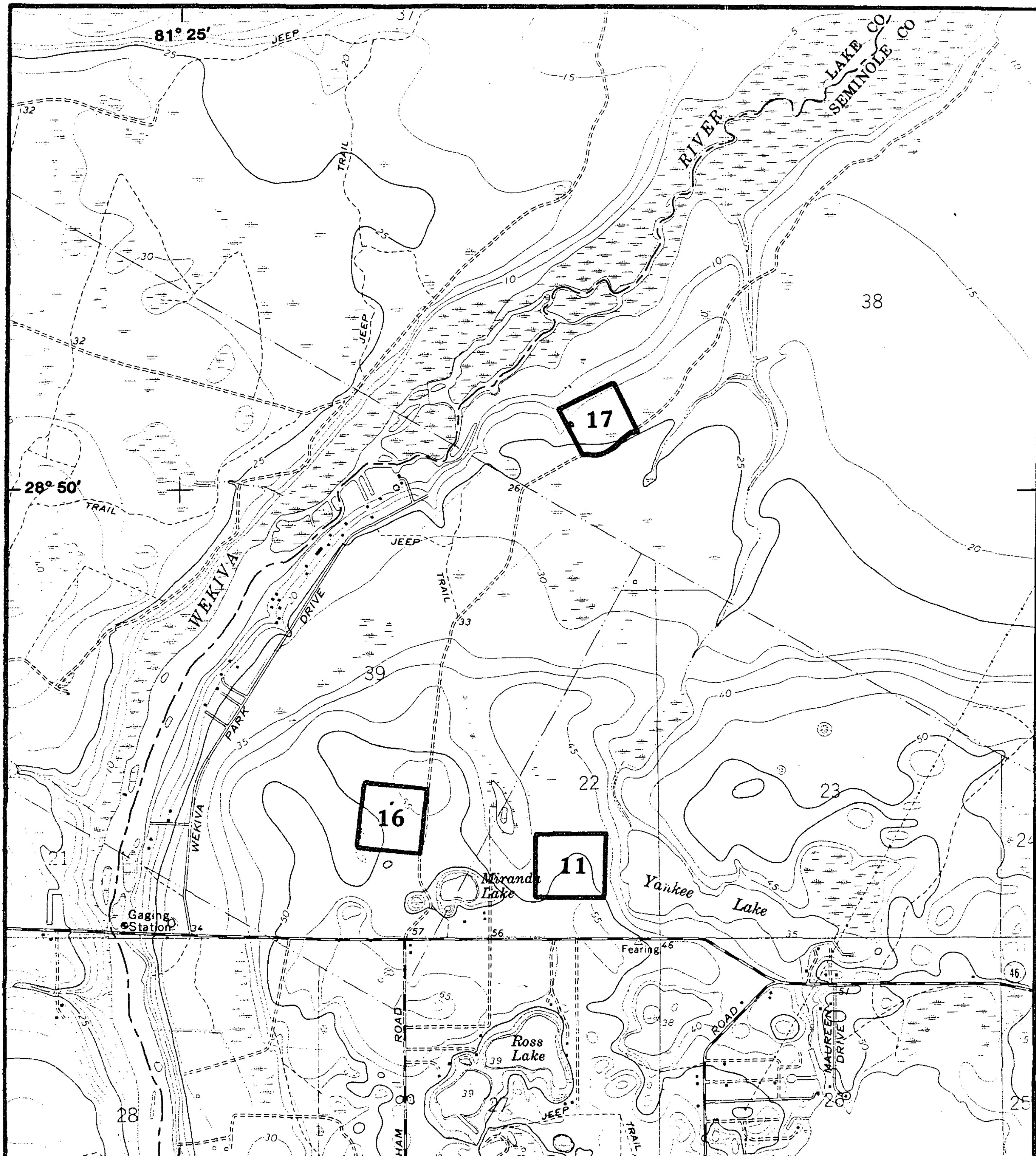
The first layer of the interpreted geoelectric section, with a resistivity of 66 ohm-m and a thickness of 49 ft (15 m), represents the Hawthorn Group and younger formations which overlie the Floridan aquifer. The depth below the ground surface to the top of the Floridan aquifer, based on Tibbals (1977), ranges from 75 to 100 ft in this area. The second layer in the section, with a resistivity of 35 ohm-m and a thickness of 169 ft (52 m) corresponds to the brackish water saturated portion of the Floridan aquifer. The third layer in the geoelectric section, with a resistivity of 11 ohm-m, represents the saline water saturated portion of the Floridan aquifer.

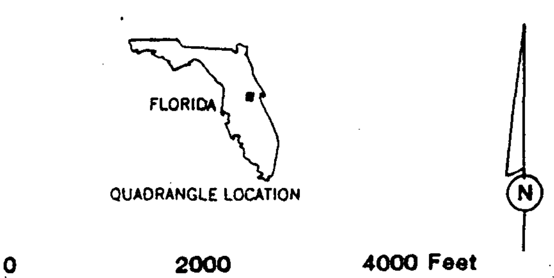
5.18.3 Depth of Occurrence of Saline Water

The third layer of the geoelectric section, with a resistivity of 11 ohm-m, is interpreted to represent saline water and occurs at a depth of 219 ft (-197 ft msl). Since the resistivity of layer 2 (35 ohm-m), which represents brackish water within the Floridan is less than 80 ohm-m, this entire section of the Floridan aquifer is expected to contain ground water with a chloride concentration greater than 250 mg/l. The depth to saline water (5,000 mg/l isochlor) is located at the interface between layer 2 and layer 3. The positioning is based on criteria outlined under Task 3, Section 4. The resistivity of layer 3 is 11 ohm-m, which corresponds to a chloride content of 2,770 mg/l, assuming a 25% porosity and the validity of Figure 4-9.

5.18.4 Depth of Occurrence of the 250 mg/l Isochlor

The resistivity of layer 2 of the geoelectric section (35 ohm-m) corresponds to a chloride content of 766 mg/l, assuming a porosity of 25% and the validity of Figure 4-9. Since the interpreted chloride content of the upper Floridan aquifer exceeds 250 mg/l, the 250 mg/l isochlor does not occur at this site. According to Tibbals (1977) chloride concentration ranges from 251 to 1,000 mg/l at this site. The





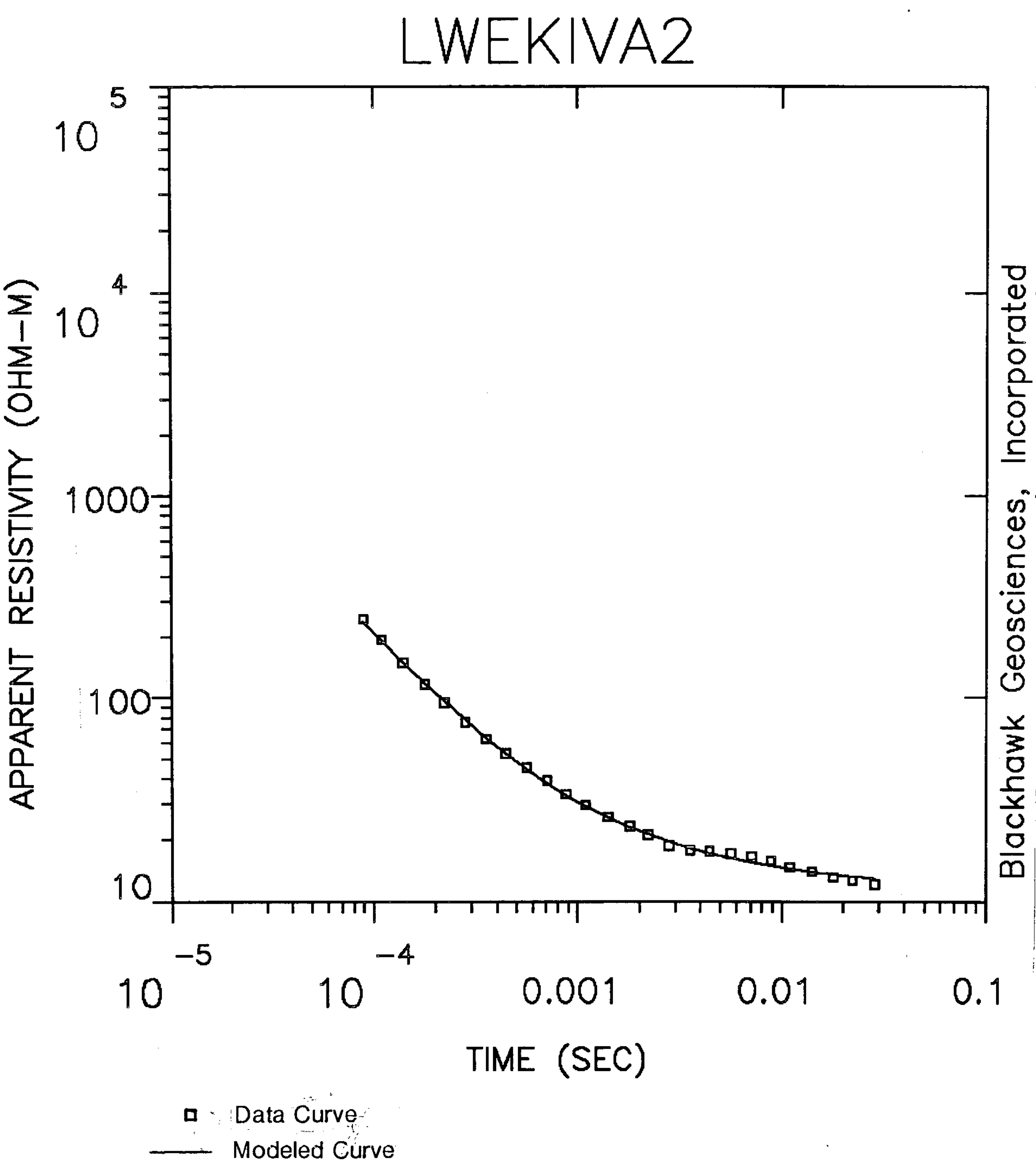
BLACKHAWK GEOSCIENCES, INC.

TDEM SURVEY LOCATION MAP
SOUNDING 11, 16,&17

ST. JOHNS RIVER
WATER MANAGEMENT DISTRCT

PROJECT NO 9001-000

Figure 5-18.1



MODEL:

64.4 OHM-M 15 M

35.4 OHM-M 51.6 M

11.0 OHM-M

% ERROR: 4.95
CALIBRATION: 1
OFFSET: 150 M
RAMP: 170.0

BLACKHAWK GEOSCIENCES, INC.

MEASURED TDEM APPARENT RESISTIVITY AND 1-D INVERSION SOUNDING 17

ST. JOHNS RIVER WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) **Figure 5-18.2**

chloride to sulfate ratio in Seminole County is approximately 5:1 and is consistent with assumptions made in estimating chloride content.

5.18.5 Accuracy of Measurement and Interpretation

Figure 5-18.3 shows the evaluation of equivalence at this site, and the inversion table (Table 5-18.1) lists the upper and lower bounds of the parameters of the geoelectric section.

The range of equivalence in determining the depth to the layer of low resistivity (layer 3) is shown to be about $\pm$ 23 ft (7 m) which is 11% of the total depth. The resistivity of this layer has a range of equivalence from 10.5 ohm-m to 11.7 ohm-m, which corresponds to a chloride content of greater than 2,600 mg/l throughout the range.

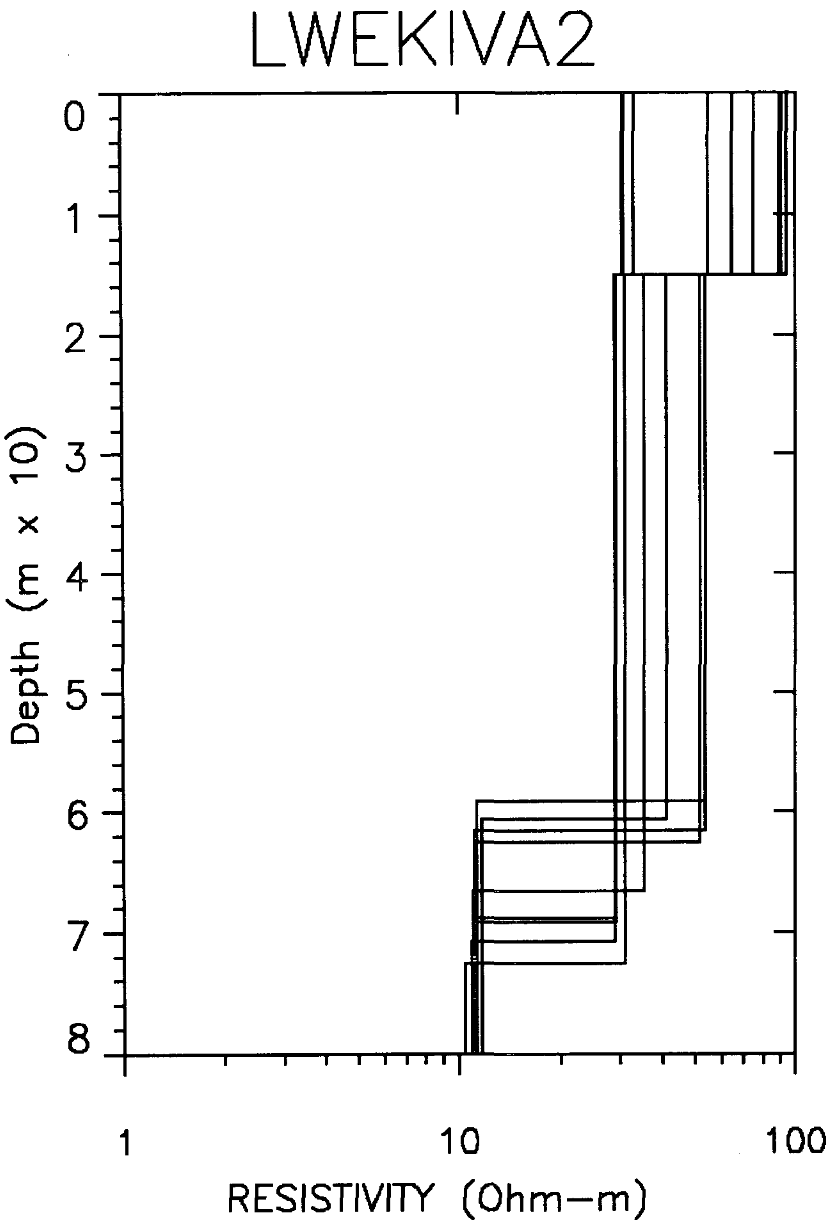
The resistivity of layer 2 has a range of equivalence from 29 to 54 ohm-m. The interpreted chloride content throughout this range is greater than 250 mg/l.

5.18.6 Summary of Results of TDEM Measurements at Lower Wekiva II (Site 17)

From the TDEM measurements, the following information about water quality was derived:

(1) The depth of occurrence of saline water (5,000 mg/l isochlor) was interpreted to be 219 ft (-197 ft msl) and the chloride content below this depth was inferred to be 2,770 mg/l.

(2) The interpreted chloride concentration in the Floridan aquifer above 219 ft was 766 mg/l. The 250 mg/l isochlor is not present within the Floridan at this site. According to Tibbals (1977) chloride concentration ranges from 251 to 1,000 mg/l at this site. The chloride to sulfate ratio for Seminole County is approximately 5:1 and should not affect the estimation of chloride concentration.



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BLACKHAWK GEOSCIENCES, INC.

EQUIVALENCE IN 1-D INVERSION
SOUNDING 17
ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) Figure 5-18.3

LWEKIVA2

MODEL: 3 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		6.7	22.0		
64.42	15.0	-8.3	-27.2	0.2	0.2
35.44	51.6	-59.9	-196.6	1.5	1.7
11.04					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	8.90E-05	2.45E+02	2.37E+02	3.509	
2	1.10E-04	1.94E+02	1.90E+02	2.008	
3	1.40E-04	1.49E+02	1.49E+02	-0.072	
4	1.77E-04	1.16E+02	1.18E+02	-1.510	
5	2.20E-04	9.43E+01	9.63E+01	-2.067	
6	2.80E-04	7.57E+01	7.74E+01	-2.222	
7	3.55E-04	6.24E+01	6.32E+01	-1.142	
8	4.43E-04	5.30E+01	5.29E+01	0.366	
9	5.64E-04	4.53E+01	4.41E+01	2.598	
10	7.13E-04	3.89E+01	3.76E+01	3.402	
11	8.81E-04	3.35E+01	3.30E+01	1.641	
12	1.10E-03	2.95E+01	2.92E+01	1.120	
13	1.41E-03	2.58E+01	2.57E+01	0.527	
14	1.80E-03	2.32E+01	2.31E+01	0.551	
15	2.22E-03	2.11E+01	2.12E+01	-0.649	
16	2.80E-03	1.86E+01	1.96E+01	-4.917	
17	3.55E-03	1.78E+01	1.82E+01	-2.542	
18	4.43E-03	1.75E+01	1.72E+01	2.082	
19	5.64E-03	1.71E+01	1.62E+01	5.210	
20	7.13E-03	1.66E+01	1.55E+01	7.032	
21	8.81E-03	1.58E+01	1.49E+01	5.992	
22	1.10E-02	1.47E+01	1.44E+01	2.206	
23	1.41E-02	1.40E+01	1.39E+01	0.519	
24	1.80E-02	1.31E+01	1.35E+01	-2.742	
25	2.22E-02	1.26E+01	1.32E+01	-4.275	
26	2.85E-02	1.21E+01	1.29E+01	-6.396	

R: 150. X: 0. Y: 150. DL: 300. REQ: 167. CF: 1.0000

CLHZ ARRAY, 26 DATA POINTS, RAMP: 170.0 MICROSEC, DATA: LWEKIVA2

BLACKHAWK GEOSCIENCES, INC.

INVERSION TABLE
SOUNDING 17
ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) Table 5-18.1

2607 0017 0000 Z OPR XTL H 2 8+100

Ch.21 = 0.16 Ch.22 = 0.089 Ch.23 = 15.5 Ch.24 =

RMS LOG ERROR: 2.10E-02, ANTILOG YIELDS 4.9466 %

LATE TIME PARAMETERS

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:

"F" MEANS FIXED PARAMETER

P 1	0.29				
P 2	0.36	0.80			
P 3	0.00	0.00	1.00		
F 1	0.00	0.00	0.00	0.00	
T 2	-0.08	0.05	0.00	0.00	0.98
	P 1	P 2	P 3	F 1	T 2

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

LAYER		MINIMUM	BEST	MAXIMUM
RHO	1	30.424	64.424	93.759
	2	28.987	35.438	53.634
	3	10.508	11.044	11.690
THICK	1	15.000	15.000	15.000
	2	44.154	51.633	57.512
DEPTH	1	15.000	15.000	15.000
	2	59.154	66.633	72.512

BLACKHAWK GEOSCIENCES, INC.

INVERSION TABLE CONTINUED
SOUNDING 17
ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) Table 5-18.1

5.19 CAMP BLANDING (SITE 18)

5.19.1 Location and Geoelectric Section

The detailed location map for this site is shown in Figure 5-19.1. The sounding data and inverted geoelectric section is shown in Figure 5-19.2 and consists of a three layer geoelectric section.

5.19.2 Geologic Interpretation of Geoelectric Section

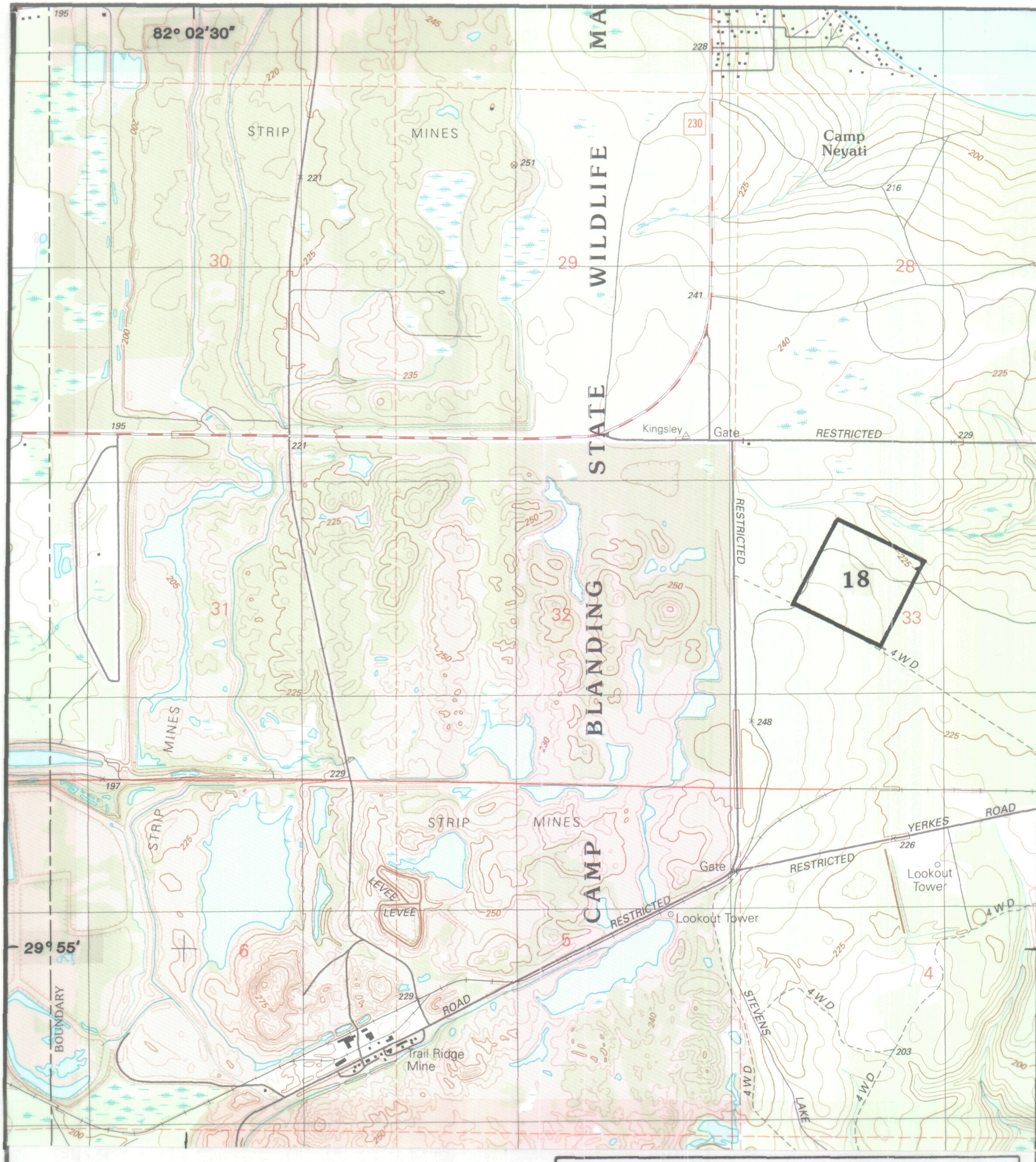
The first layer of the interpreted geoelectric section, with a resistivity of 60 ohm-m and a thickness of 410 ft (125 m), represents the Hawthorn Group and younger formations which overlie the Floridan aquifer. The thickness of this layer was fixed in the inversion based on the depth to the Floridan aquifer given in Miller (1986) which is approximately 400 ft below the ground surface. The resistivity contrast between the Floridan aquifer and the overlying sediments was insufficient to resolve the boundary. The second layer of the section, with a resistivity of 125 ohm-m and a thickness of 2,317 ft (706 m), corresponds to the fresh water saturated portion of the Floridan aquifer, and a portion of the low porosity confining layer underlying the Floridan. The third layer of the geoelectric section, with a resistivity of 1.2 ohm-m, corresponds to saline water within geologic formations with porosities greater than 10% located approximately 800 ft beneath the Floridan aquifer based on Figure 5-2.4.

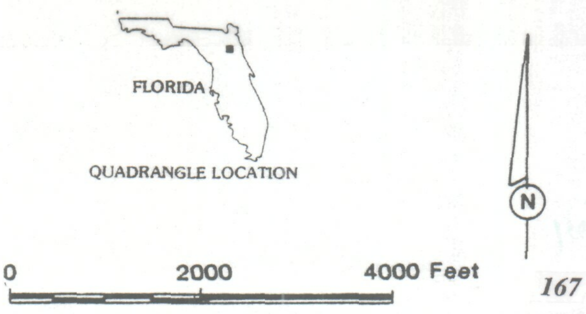
5.19.3 Depth of Occurrence of Saline Water

The third layer of the geoelectric section, with a resistivity of 1.2 ohm-m, is interpreted to represent saline water in formations with porosities greater than 10% and occurs at a depth of 2,727 ft (-2,492 ft msl). This layer occurs approximately 800 ft below the Floridan aquifer, and therefore, the 5,000 mg/l isochlor is not expected within the Floridan aquifer.

5.19.4 Depth of Occurrence of the 250 mg/l Isochlor

The resistivity of layer 2 of the geoelectric section (124 ohm-m) corresponds to a chloride content less than 150 mg/l, assuming a porosity of 25% and the validity of Figure 4-9. This is consistent with information from Sprinkle (1989) which indicates that the chloride content of the Floridan aquifer in this area is less than 250 mg/l. Since a layer with a resistivity of less than 80 ohm-m was not detected within the Floridan aquifer, the 250 mg/l isochlor is not present in the Floridan at this site. The chloride to



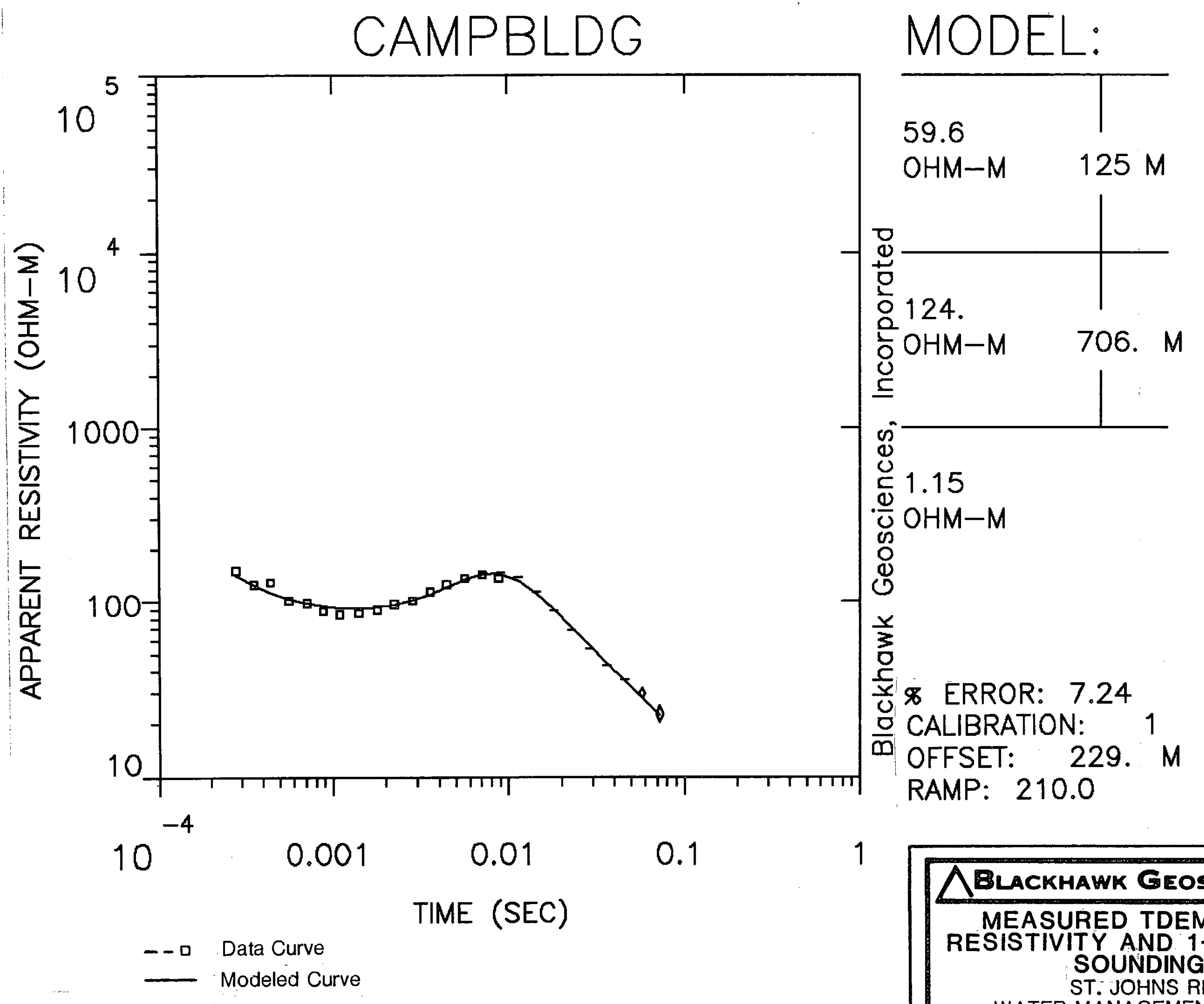


BLACKHAWK GEOSCIENCES, INC.

TDEM SURVEY LOCATION MAP
SOUNDING 18

ST. JOHNS RIVER
WATER MANAGEMENT DISTRCT

PROJECT NO 9001-000 Figure 5-19.1



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BLACKHAWK GEOSCIENCES, INC.

MEASURED TDEM APPARENT RESISTIVITY AND 1-D INVERSION SOUNDING 18

ST. JOHNS RIVER WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) **Figure 5-19.2**

sulfate ratio is approximately 5:1 (Sprinkle, 1989) and is consistent with the assumptions utilized in estimating chloride content.

5.19.5 Accuracy of Measurement and Interpretation

Figure 5-19.3 shows the evaluation of equivalence at this site, and the inversion table (Table 5-19.1) lists the upper and lower bounds of the parameters of the geoelectric section.

The range of equivalence in determining the depth to the layer of low resistivity (layer 3) is shown to be about $\pm$ 130 ft (40 m) which is 5% of the total depth. The resistivity of this layer has a range of equivalence from 0.5 ohm-m to 2.1 ohm-m. The depth to saline water, as determined by the TDEM sounding, is significantly below the base of the Floridan aquifer as determined by Krause and Randolph (1989) and shown in Figure 5-2.4.

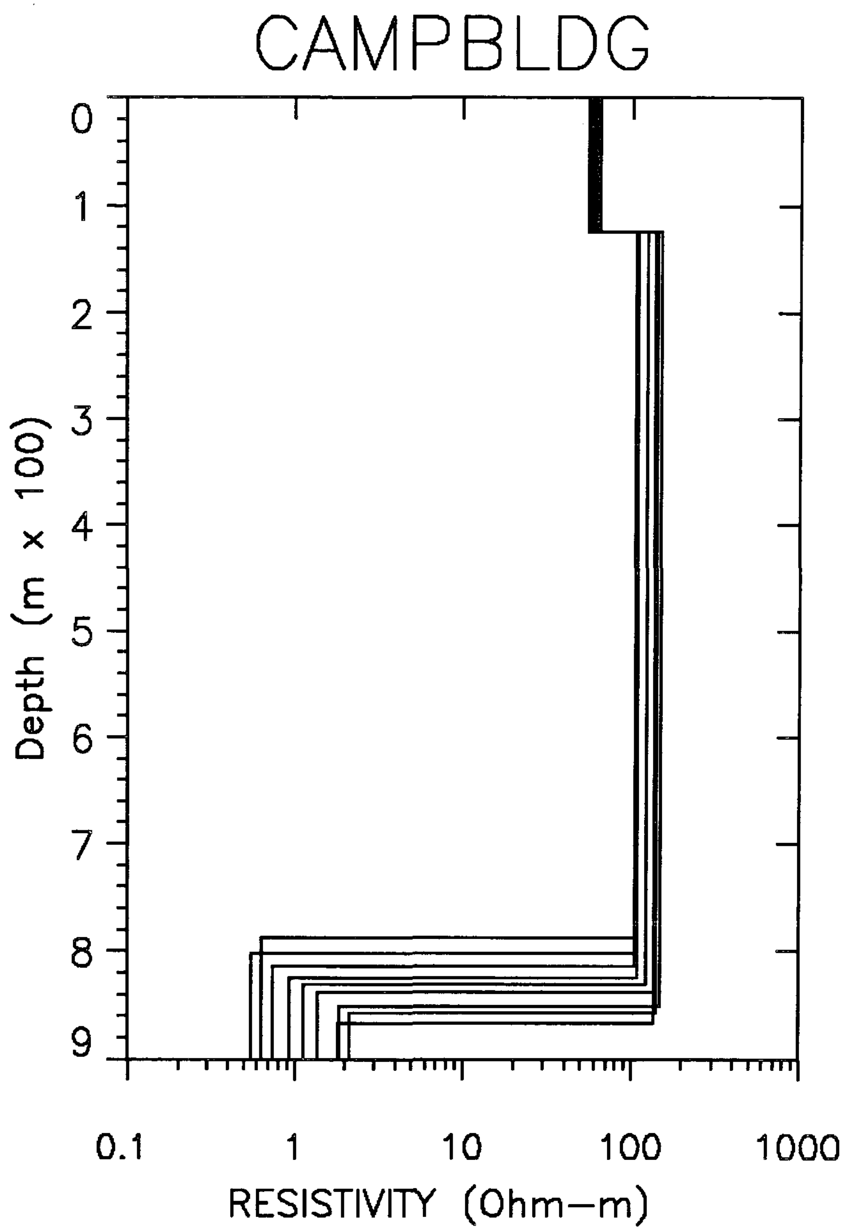
The resistivity of layer 2 shows an equivalence of from 106 to 149 ohm-m, and corresponds to a chloride content of less than 250 mg/l.

5.19.6 Summary of Results of TDEM Measurements at Camp Blanding (Site 18)

From the TDEM measurements, the following information about water quality was derived:

(1) The depth of occurrence of saline water within a formation whose porosity is in excess of 10% was interpreted to be 2,727 ft (2,492 ft msl). This is below the Floridan aquifer so that the 5,000 mg/l isochlor is not present within the Floridan at this site. Saline water may exist in formations between the Floridan aquifer and the mapped low resistivity zone, but bulk porosities in this zone would have to be low (< 10%).

(2) A zone of resistivity less than 80 ohm-m was not detected within the Floridan aquifer. This indicates the 250 mg/l isochlor does not occur within the Floridan aquifer. The ground water within the Floridan is interpreted to have a chloride concentration of less than 150 mg/l over its entire depth. The chloride to sulfate ratio in this region is approximately 5:1 which does not affect the estimation of chloride concentration.



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BLACKHAWK GEOSCIENCES, INC.

EQUIVALENCE IN 1-D INVERSION
SOUNDING 18
ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) Figure 5-19.3

CAMPBLDG

MODEL: 3 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		71.6	235.0		
59.59	125.0	-53.4	-175.1	2.1	2.1
124.29	706.2	-759.6	-2492.1	5.7	7.8
1.15					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	2.80E-04	1.51E+02	1.42E+02	6.174	
2	3.55E-04	1.25E+02	1.24E+02	0.817	
3	4.43E-04	1.30E+02	1.12E+02	15.404	
4	5.64E-04	1.01E+02	1.03E+02	-2.300	
5	7.13E-04	9.79E+01	9.76E+01	0.313	
6	8.81E-04	8.85E+01	9.43E+01	-6.131	
7	1.10E-03	8.45E+01	9.24E+01	-8.569	
8	1.41E-03	8.63E+01	9.19E+01	-6.089	
9	1.80E-03	9.00E+01	9.31E+01	-3.424	
10	2.22E-03	9.67E+01	9.59E+01	0.750	
11	2.83E-03	1.01E+02	1.01E+02	-0.414	
12	3.57E-03	1.13E+02	1.10E+02	3.157	
13	4.43E-03	1.25E+02	1.20E+02	4.204	
14	5.64E-03	1.36E+02	1.33E+02	1.740	
15	5.71E-03	-1.33E+02	1.34E+02	-198.930	
16	7.13E-03	1.42E+02	1.43E+02	-0.780	
17	7.20E-03	-1.46E+02	1.44E+02	-201.376	
18	8.81E-03	1.36E+02	1.44E+02	-5.713	
19	9.07E-03	-1.47E+02	1.44E+02	-202.454	
20	1.14E-02	-1.38E+02	1.31E+02	-205.097	
21	1.44E-02	-1.13E+02	1.11E+02	-202.294	
22	1.81E-02	-8.91E+01	8.96E+01	-199.412	
23	2.29E-02	-6.87E+01	7.11E+01	-196.614	
24	2.88E-02	-5.38E+01	5.61E+01	-195.819	
25	3.63E-02	-4.30E+01	4.43E+01	-197.013	
26	4.57E-02	-3.58E+01	3.52E+01	-201.835	
27	5.76E-02	-2.98E+01	2.80E+01	-206.532	
28	7.26E-02	-2.28E+01	2.25E+01	-201.394	

BLACKHAWK GEOSCIENCES, INC.

INVERSION TABLE
SOUNDING 18
ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) Table 5-19.1

R: 229. X: 0. Y: 229. DL: 457. REQ: 254. CF: 1.0000

CLHZ ARRAY, 28 DATA POINTS, RAMP: 210.0 MICROSEC, DATA: CAMPBLDG

SITE 18 CAMP BLANDING

RMS LOG ERROR: 3.04E-02, ANTILOG YIELDS 7.2425 %

LATE TIME PARAMETERS

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:

"F" MEANS FIXED PARAMETER

	P 1	P 2	P 3	F 1	T 2
P 1	1.00				
P 2	0.00	1.00			
P 3	0.00	0.00	0.99		
F 1	0.00	0.00	0.00	0.00	
T 2	0.00	0.00	0.00	0.00	1.00

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

	LAYER	MINIMUM	BEST	MAXIMUM
RHO	1	55.167	59.589	64.780
	2	105.517	124.285	149.142
	3	0.553	1.147	2.144
THICK	1	125.000	125.000	125.000
	2	662.800	706.206	742.132
DEPTH	1	125.000	125.000	125.000
	2	787.800	831.206	867.132

BLACKHAWK GEOSCIENCES, INC.

INVERSION TABLE CONTINUED

SOUNDING 18

ST. JOHNS RIVER

WATER MANAGEMENT DISTRICT

PROJECT NO: 9001-000 (92022) Table 5-19.1

6.0 SUMMARY AND CONCLUSIONS

A time domain electromagnetic (TDEM) survey was performed at 17 sites in the St. Johns River Water Management District and one in Georgia during the month of July 1992. Several aspects of the survey are summarized below.

From a TDEM survey the resistivity layering (geoelectric section) of the subsurface is derived. To correlate the resistivity values measured to water quality certain manipulations and assumptions were made, such as:

(i) two factors mainly influence the formation resistivity of the Floridan aquifer - concentration of dissolved solids and porosity. These two factors cannot be separated from surface electrical measurements. To derive water quality a realistic range of porosity for the Floridan aquifer needed to be assumed. A porosity of 25% was consistently used for the carbonate rocks of the Floridan aquifer at all 18 sites (NW Florida Water Management District, 1983);

(ii) the relation between formational resistivity and equivalent chloride content also is influenced by chemical composition of ground water, i.e., chloride to sulfate ratio which is 5:1 for Seminole County. In correlating resistivity to chloride content the relationship between these two parameters observed by Kwader (1986) in Seminole County, was assumed to be valid throughout the SJRWMD.

Resistivity values not only depend on ionic concentration and porosity, but also on lithology, - particularly clay content. The lithology of the carbonate rocks of the Floridan are expected to be consistent, but major variation in clay content for the Hawthorn Group and younger sediments overlaying the Floridan aquifer may exist. For that reason water quality was inferred only for the carbonate rocks within the Floridan aquifer. In addition, water quality cannot be estimated for geologic formations below the Floridan aquifer since the assumptions stated above are not valid.

At several of the TDEM sounding sites, the high sulfate to chloride ratios reported are inconsistent with the assumptions utilized in developing the relationship between formation resistivity and chloride content. At these sites the 250 mg/l isochlor could not be reliably determined.

At some sites a resistivity boundary was not mapped at the interface between the Hawthorn Group and younger formations and the carbonate rocks of the Floridan aquifer, because of similar resistivities for the two formations. In those cases, the thickness of the sediments above the Floridan was fixed in the inversions based on published information.

The contact between fresh water and saline ground water is not abrupt, and generally a transition zone of intermediate salinities is present. This zone is normally about 100 ft thick and a set of criteria has been developed to estimate the position of both the saline water interface and 250 mg/l isochlor relative to resistivity boundaries.

6.1 DETERMINING THE DEPTH OF THE INTERFACE BETWEEN FRESH WATER AND GROUND WATER OF HIGH CHLORIDE CONCENTRATION (GREATER THAN 1,450 mg/l)

Ground water with a chloride content greater than 1,450 mg/l is characterized in the Floridan aquifer by resistivities less than 20 ohm-m when the aquifer has a porosity of about 25%. A layer with a resistivity less than or equal to 20 ohm-m was detected at all 18 sites at depths varying from about 220 ft to 3,300 ft below the surface.

At six of the sites, 1-5 and 18, in the area around Jacksonville, Florida, the depth of exploration required to detect the saline water interface exceeded 2,000 ft. To achieve exploration depth in excess of 2,000 ft, the EM42 was utilized. The exploration depth of the EM42 is greater than the EM37, mainly because (i) higher transmitter output power, (ii) receiver coils with larger effective area, and (iii) digital recording resulting in improved signal to noise. For the remaining sites, the EM37 TDEM system was used to make the soundings.

At one of the 18 sites, Ponte Vedra, a nearby well penetrated the interface of high chloride concentrations. The interpretation of the depth to the interface derived from the TDEM data and that observed in the well correspond to within 8%. At another site, Garden Street, an electric log from a well adjacent to the TDEM sounding site indicated a low resistivity zone at a depth of approximately 2,930 ft below the surface. This is within 5% of the depth of 3,100 ft to a low resistivity zone interpreted from the TDEM sounding. At most of the other sites, the depth to the interface was consistent with regional information, such as that published by Tibbals (1990). For sites 1, 2, 3, 4 and 18, however, the depth to a low resistivity layer is below the bottom of the Floridan aquifer as mapped by Krause and Randolph (1989). This indicates that saline water (greater than 5,000 mg/l chloride) does not occur within the Floridan aquifer.

6.2 WATER QUALITY IN THE FLORIDAN AQUIFER AND DEPTH OF OCCURRENCE OF 250 mg/l ISOCHLOR

Assuming a porosity of 25% and validity of the relation between chloride concentration and formation resistivity, ground water with chloride concentrations less than 250 mg/l are expected at formation resistivities greater than 80 ohm-m. At some sites formation resistivities in the carbonate rocks of the Floridan aquifer were below 80 ohm-m for the entire depth interval above the interface with highly saline water. In those cases chloride concentrations greater than 250 mg/l are expected for the entire Floridan aquifer. At other sites resistivities greater than 80 ohm-m were determined for the upper portion of the aquifer. Often a boundary was observed between resistivities greater than 80 ohm-m and less than 20 ohm-m at some depths, and for those situations the depth to the 250 mg/l isochlor was determined based on criteria set forth in the report. At several sites around Jacksonville, high sulfate concentrations within the ground water of the Floridan aquifer invalidated the scheme developed for interpreting chloride concentrations. For these sites the depth of occurrence of the 250 mg/l isochlor could not be mapped.

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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.

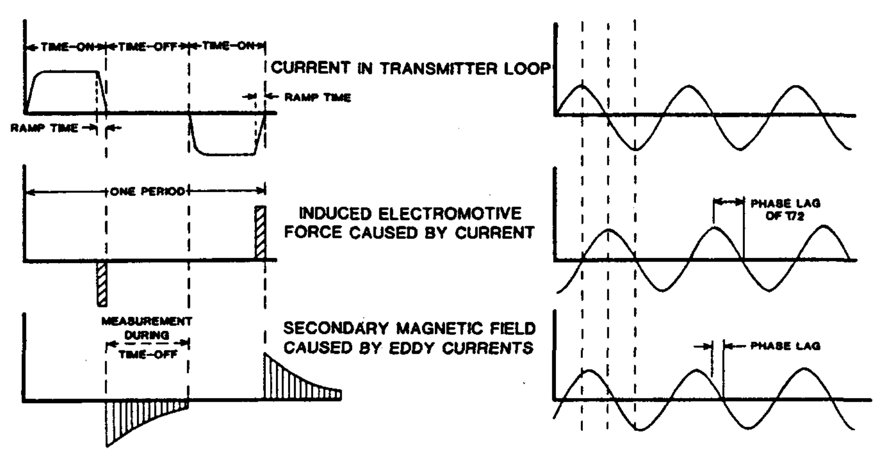

Fig. 1. System waveforms in time domain EM (TDEM) and frequency domain EM (FDEM).

The receiver measures the emf due to the secondary magnetic field of these eddy currents induced in the subsurface, and in the case of FDEM, the emf measured by the receiver is the sum of (1) the primary magnetic field (emf_p due to currents in the transmitter), and (2) the secondary magnetic field (emf_s due to eddy current flow in the ground). Thus,

$$emf_t = emf_p + emf_s$$

where subscript t, p and s refer to total, primary, and secondary magnetic field, respectively. Clearly, emf_s is the only component containing information about the subsurface. Unfortunately, in most situations, the amplitude of emf_s is only one part in 10^4 parts of emf_p. Thus, in FDEM, a small component of emf containing all the useful information about the subsurface must be measured in the presence of a large component containing no information.

In the EM-31 and EM-34 ground conductivity is determined by measuring only the component of emf_s that is in quadrature phase (90^o out-of-phase) with emf_p. Unfortunately, theory shows that the in-phase component is more sensitive to ground conductivity. Measuring only the quadrature phase component limits the accuracy, exploration depth, and utility of FDEM systems.

TDEM improves the situation, because measurements are made during the time the transmitter is off. During off-time the only component of emf measured by the receiver is emf_s. Emf_s is determined in the absence of emf_p, greatly improving its accuracy of measurements.

Question.-- Briefly explain how subsurface resistivities are derived from TDEM measurements.

Answer.-- A TDEM system consists of a transmitter and a receiver. The transmitter configuration often used in ground water and environmental applications is a square loop of insulated wire laid on the ground surface (Figure 2). A multi-turn air coil receiver (about 1 m diam) is placed in the center of the loop. The sizes of the transmitter loops employed are mainly dependent upon the required exploration depth and geoelectric section. Typically, the side of a square is about one-half to two-thirds of the required exploration depth. Thus, for exploration depths to about 200 ft, 75 ft by 75 ft transmitter loops may be employed.

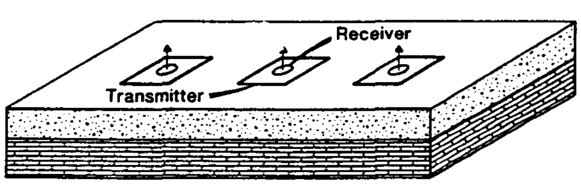

Fig. 2. Transmitter-receiver array in TDEM.

The current waveform driven through the transmitter loops is shown in Figure 1. The waveform consists of equal periods of time-on and time-off. The base frequencies employed in the Geonics instrumentation we employ can be varied from 300 hz, 30 hz, 3 hz and 0.3 hz. These frequencies result in on/off intervals of 0.833, 8.33, 83.3 and 833 msec, respectively.

The current driven through the transmitter loops creates a primary magnetic field. During the rapid current turn-off this primary magnetic field is time-variant and in accordance with Faraday's Law there will be an electromagnetic induction during this time (Figure 1b). This electromagnetic induction in turn results in eddy current flow in the subsurface. The intensity of these currents at a certain time and depth depends on ground conductivity.

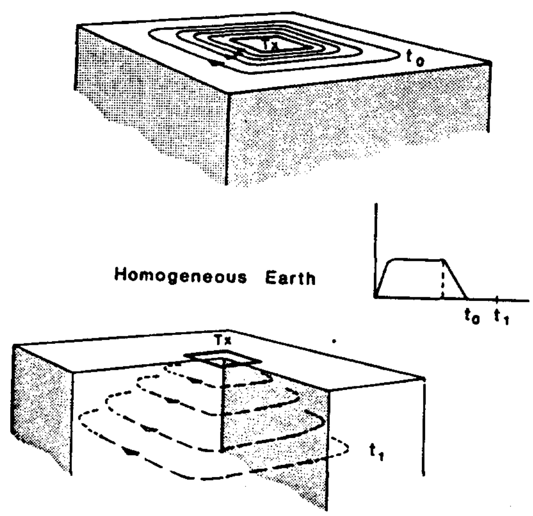

Fig. 3. Current distribution in FDEM at two times after current turn-off.

In near horizontally layered ground, the eddy currents are horizontal closed rings concentric about the center of the transmitter loop. A schematic illustration of these currents is shown in Figure 3. Immediately after turn-off (t_0) the currents are concentrated near the surface, and with increasing time currents are induced at greater depth (t_1).

The receiver measures the emf due the secondary magnetic field caused by these ground eddy currents (Figure 1c). At early time, when the currents are mainly concentrated near the surface, the emf measured will mainly reflect the electrical resistivity of near surface layers. With increasing time, as currents are induced at greater depth, the emf measured will progressively be more influenced by properties of deeper layers. Thus, in TDEM exploration, depth is mainly a function of time of measurement after turn-off.

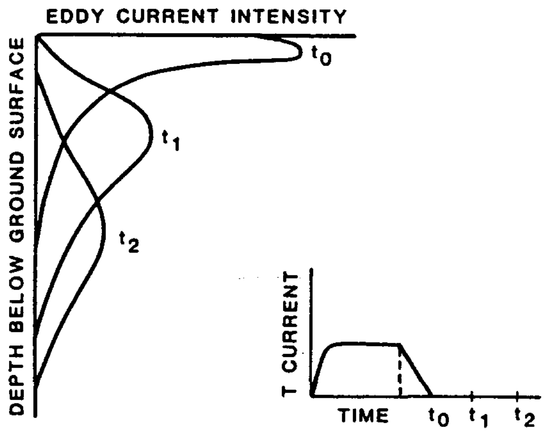

Fig. 4. Schematic illustration of eddy current distribution at different times after turn-off.

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.

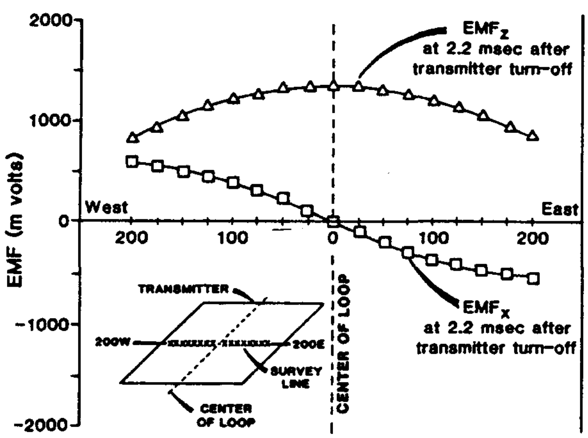

Fig. 5. Spatial behavior of emfs due to vertical (emf_z) and horizontal (emf_x) magnetic field on a profile through the center of square transmitter loop at one time (2.2 millisec) after turn-off.

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.

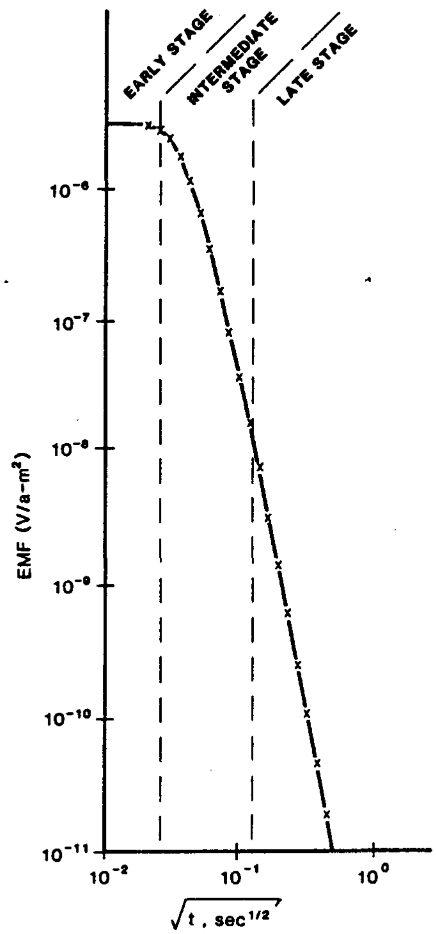

Fig. 6. Typical transient behavior of emf_z in center of square transmitter loop.

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.

The processing and display of TDEM data is in many respects similar to that used in other electrical and electromagnetic methods. The objective of processing TDEM data is to obtain a solution for the resistivity stratification of the subsurface that matches the observed transient.

L022S001

MODEL: 5 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)
2.81	9.3
17.77	33.1
3.01	46.1
39.42	44.8
6.76	

TIMES	DATA LATE MEASURED	CALC LATE	% ERROR
8.90E-05	7.23E+01	7.87E+01	-8.071
1.10E-04	4.75E+01	5.11E+01	-6.997
1.40E-04	3.30E+01	3.38E+01	-2.527
1.77E-04	2.39E+01	2.45E+01	-2.280
2.20E-04	1.83E+01	1.91E+01	-4.201
2.80E-04	1.49E+01	1.55E+01	-3.952
3.55E-04	1.28E+01	1.35E+01	-5.770
4.43E-04	1.13E+01	1.22E+01	-7.412
5.64E-04	1.02E+01	1.05E+01	-3.135
7.13E-04	9.22E+00	9.31E+00	-0.981
8.85E-04	8.14E+00	8.43E+00	-3.402
1.10E-03	7.39E+00	7.52E+00	-1.740
1.41E-03	6.83E+00	6.72E+00	+1.519
1.78E-03	6.36E+00	6.36E+00	+0.002
2.21E-03	6.02E+00	6.06E+00	-0.722
2.83E-03	5.82E+00	5.86E+00	-0.728
3.57E-03	5.80E+00	5.87E+00	-1.050
4.46E-03	5.74E+00	5.82E+00	-1.432
5.67E-03	5.83E+00	5.92E+00	-1.612
7.16E-03	6.01E+00	5.98E+00	+0.543
8.81E-03	5.98E+00	6.05E+00	-1.133
1.10E-02	6.26E+00	6.17E+00	+1.339

RMS ERROR: 5.7275%

Table 1. Inversion table.

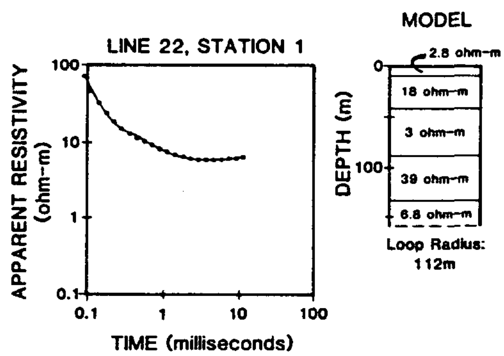

Fig. 7. Example of TDEM apparent resistivity curve and inverted geoelectric section.

The inversion of measured TDEM data into vertical resistivity stratification can be performed on a PC. An example of a data set derived for a sounding is given in Figure 7 and Table 1. In the apparent resistivity curve shown on the left (Figure 7) the measured data at each time gate is superimposed on a model curve of the geoelectric section shown on the right. This geoelectric section represents the best one-dimensional match to the experimental data. In addition to this visual display, an inversion table (Table 1) is obtained that lists (column 4) the error between measured and computed emf at each time gate, as well as an overall RMS error. The data shown on Figure 7 are typical of data quality common to TDEM soundings. Typically, 20 to 30 data points are obtained equally spaced on a logarithmic scale of time. Thus, clearly there is a major difference between TDEM soundings and profiling with the EM-31 and EM-34 (where only a few data points at different effective depths are obtained).

Question.-- If TDEM is a major improvement in electrical geophyics, why has it not been extensively used in ground water and environmental applications?

Answer.-- TDEM has been in common use in the search for base and precious metals, and for deep electrical soundings in support of hydrocarbon and geothermal exploration for about 15 years. The reason for its sparse use so far in ground water and environmental investigations was that no equipment was heretofore available for the often shallow depth (< 100 ft) requirements, common to environmental investigations.

Equipment for shallow exploration recently became available, opening a whole new range of applications for this powerful electrical measurement technique. Figure 8 shows the exploration depth range covered by various instruments.

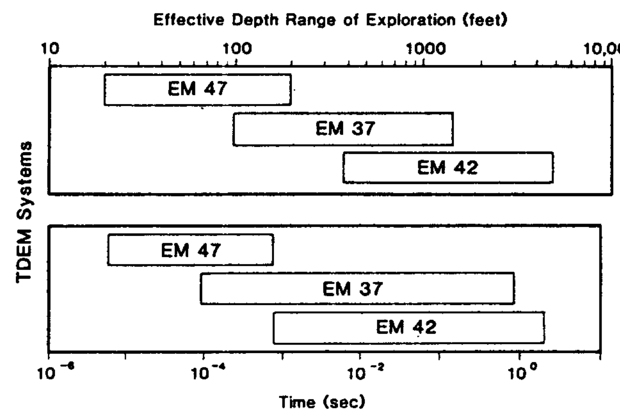

Fig. 8. Effective depth range of exploration and time range of measurement of various TDEM systems.

Question.-- What is geologic noise and why is TDEM less sensitive to such noise?

Answer.-- We define geologic noise as variation in subsurface conditions that obscures the exploration objective. Consider the schematic geologic cross section of the Floridan aquifer (Figure 9). The limestones may be overlain by overburden, likely varying laterally and vertically in soil type and thickness. At some depth in the aquifer an interface between saline and fresh water may occur, and an important exploration objective could be the mapping of this interface. Geologic noise for this objective is the change in soil type and thickness of the overburden. This noise can be very large in direct current resistivity, CSAMT and electromagnetic induction profiling.

Geologic noise is a function of the exploration objective. For example, if the objective in the setting of Figure 9 would have been the mapping of overburden thickness and type (e.g., to delineate areas of prime aquifer recharge), then what was geologic noise before becomes the exploration objective. Geologic noise is often the major cause of poor data quality in geophysical surveys for environmental and ground water applications.

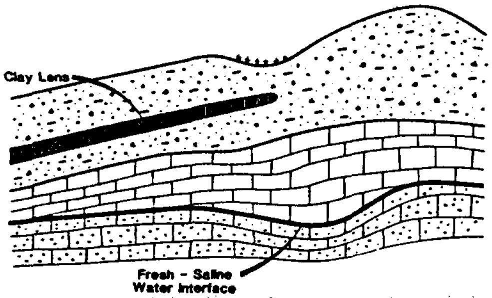

Fig. 9. Schematic geologic section of Floridan aquifer.

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.

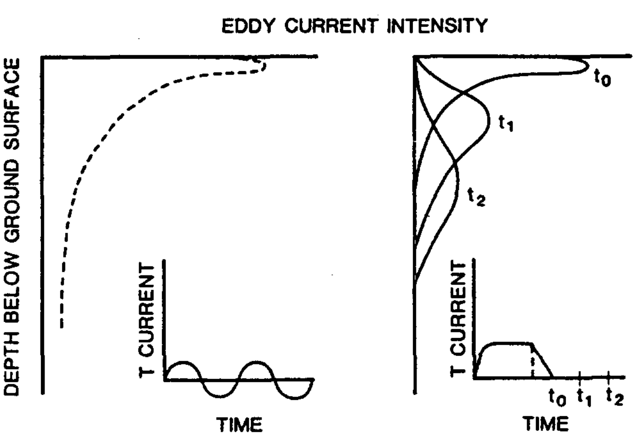

Fig. 10. Eddy current intensity in FDEM and TDEM.

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.

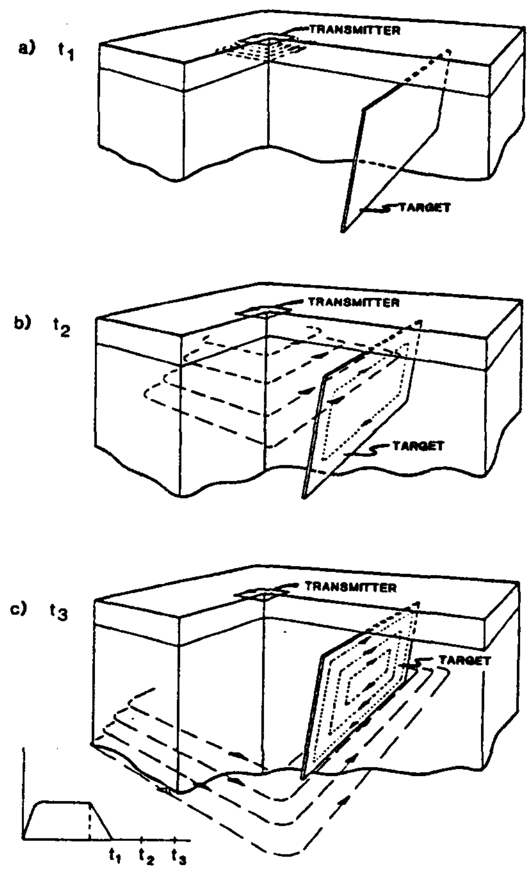

Fig. 11. Illustration of eddy current flow induced in overburden, host rock, and fracture or shear zones at different times.

Thus, in all electrical and electromagnetic methods the geoelectric section is derived by measuring resistance to current flow. We cannot selectively cause current flow in fractures and shear zones, but currents will also be induced in overburden, host rock, fractures and shear zones. The challenge is to isolate the response due to a fracture from the total response, which also contains contributions due to current flow in overburden and host rock.

TDEM is the most effective method for recognizing fractures and shear zones under overburden cover. Figure 11 conceptually explains the physical principles involved. It schematically shows a near vertical fracture zone below overburden cover, and a nearby TDEM source loop induces eddy current flow in the subsurface. At early time (t_0) eddy currents are dominantly situated in the overburden because current flow has not yet reached the fracture. Therefore, a measurement of emf at time, t_0, will not reflect the presence of a fracture zone. At later time currents are induced in the fracture, and because the fracture zone is likely less resistive than adjacent host rock, currents will be preferentially oriented in the fracture plane. In this intermediate time range the emf will contain major contributions due to currents in overburden, host rock and fractures. Currents in overburden may still dominate and fracture zones may be barely detectable. Since the fracture is less resistive than adjacent host rock, currents will decay faster in host rock than in the fracture, and there will be a time range where the fracture has maximum detectability.

To map fractures and shear zones, often different modes of surveying are employed than for determining vertical resistivity stratification (soundings). Figure 12 shows several survey modes. If the strike of the fracture is known a long transmitter loop may be laid out, and profiles are run with a receiver across the fracture zone. Also, a loop-loop array may be employed.

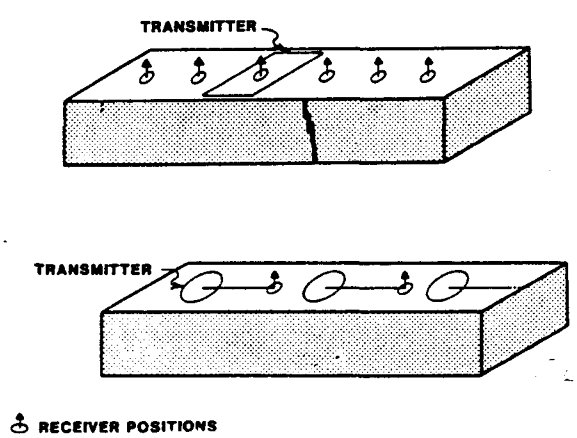

Fig. 12. Transmitter-receiver arrays useful in fracture mapping.

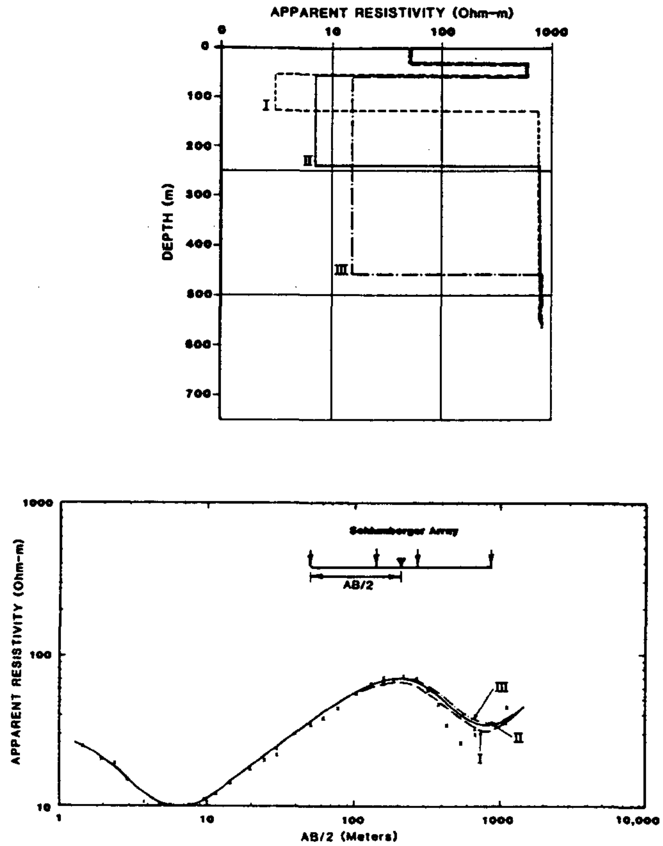

Fig. 13. Schlumberger measured apparent resistivities (a) superimposed on three one-dimensional geoelectric sections (b).

Question.-- I am from Missouri. Show me an example comparing TDEM with another electrical measurement technique next to a drill hole.

Answer.-- In a ground water survey on the coastal plain in Israel, one of the exploration objectives was to map the thickness of alluvium overlying a carbonate bedrock. A drill hole at the survey site showed depth to bedrock at about 168 m (550 ft).

The Institute of Petroleum Research and Geophysics, prior to the arrival of our TDEM crew, conducted a Schlumberger resistivity sounding near the drill hole. The results are given in Figure 13. Measurements were made to AL/2-spacing of 2,000 m (an array length of 4,000 m). The measured apparent resistivity data are superimposed on the forward models of three geoelectric sections. The three geoelectric sections are shown on the right. Clearly, the data can be fitted to any of the three models. Yet, depth to bedrock between the three sections was varied by more than 300 m. The Institute, therefore, quickly decided that Schlumberger resistivity soundings were not a viable method, because not only was a large effort required to explore to a depth of 168 m (4,000 m of line length), but its vertical resolution was meaningless.

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.

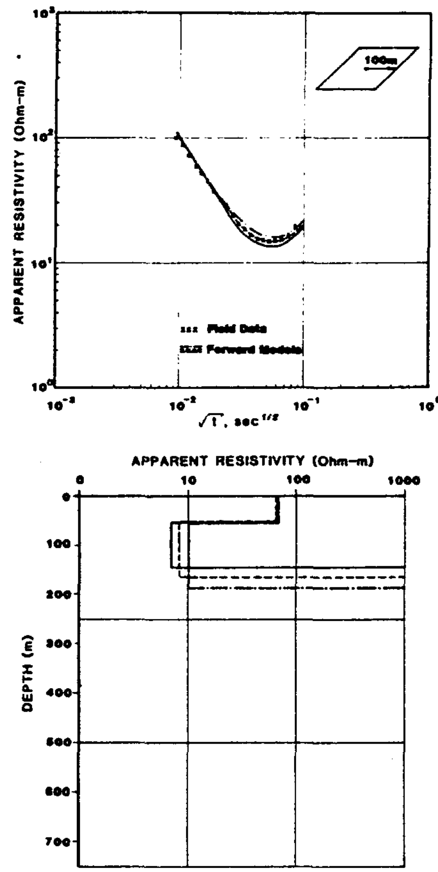

Fig. 14. TDEM measured apparent resistivities (a) superimposed on three one-dimensional geoelectric sections.

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