Special Publication SJ97-SP1

TIME DOMAIN ELECTROMAGNETIC MAPPING OF SALT WATER IN THE FLORIDAN AQUIFER IN NORTHEAST & EAST-CENTRAL FLORIDA

ST. JOHNS RIVER WATER MANAGEMENT DISTRICT

NOVEMBER 1996

Prepared For

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Contract Number 96B189

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This is to certify that I, Michael J. Wightman, have reviewed the figures, tables, and text of the following report.

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SEAL

EXECUTIVE SUMMARY

A time domain electromagnetic (TDEM) survey was performed at 7 sites in the St. Johns River Water Management District during the month of June, 1996. The TDEM method is a geophysical technique which, through ground surface based measurement, enables description of the vertical distribution (one-dimensional depth layering) of formation electrical resistivity. As such, TDEM soundings provide a gross approximation of an electrical log as performed in a borehole without the significant expense of drilling, completing, and logging such a borehole. In comparing TDEM soundings to electric logs, the minimum thickness of an interval that can be resolved by TDEM is several orders of magnitude larger than what can be resolved by electric logs. The confidence in the conclusions from TDEM findings can be enhanced when water quality information from nearby wells is available. The objective of the TDEM survey was to determine the depths to the 250 mg/l and 5,000 mg/l isochlors.

The determination of the depth to the 5,000 mg/l isochlor was made at six of the seven sites. Depths ranged from 276 to 2,101 feet (ft) below land surface (bls). At Site 7, Hayfield, the lowermost layer was considered to represent either slightly brackish water or a porosity change in the Lower Floridan aquifer. Accordingly, it was not possible to determine the depth to the 5,000 mg/l isochlor.

The determination of the depth to the 250 mg/l isochlor was made at four of the seven sites. Depths ranged from 932 ft bls (Site 7) to 2,001 ft bls. At Site 7, the placement of the 250 mg/l isochlor may not be valid because the observed resistance of the lowermost layer may have been caused by either a porosity change in the Lower Floridan aquifer or by the presence of brackish water (not salt water) in the lowermost layer. Accordingly, the assumptions used in the empirical relationships to determine the 250 mg/l isochlor were not valid. At Site 6, the 250 mg/l isochlor could not be determined because the geoelectric model for the site could not distinguish the Holocene to Miocene deposits from the Floridan aquifer. As with Site 7, the assumptions used in the empirical relationships to determine the 250 mg/l isochlor were also not valid. At two of the sites, there was no 250 mg/l isochlor (waters appear to be brackish).

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1.0 INTRODUCTION

The St. Johns River Water Management District (SJRWMD) has contracted with Subsurface Detection Investigations, Inc. (SDII) to perform a series of Time Domain Electromagnetic (TDEM) survey measurements in northeast and east-central Florida during the month of June, 1996. This latest series of TDEM soundings is a continuation of similar TDEM programs funded by SJRWMD in previous years (Blackhawk, 1990; Blackhawk, 1991; CEES, 1992; and SDII, 1993, 1994 and 1995). The TDEM method is a geophysical technique which, through ground surface-based measurement, enables description of the vertical distribution (one-dimensional depth layering) of formation electrical resistivity. As such, TDEM soundings provide a gross approximation of an electrical log as performed in a borehole without the significant expense of drilling, completing, and logging such a borehole. In comparing TDEM soundings to electric logs, the minimum thickness of an interval that can be resolved by TDEM is several orders of magnitude larger than what can be resolved by electric logs. As formation resistivity is a direct function of formation lithology, porosity, and pore fluid conductivity, *in situ* determination of formation resistivity offers a means of inferring the water quality within given formations through empirical relationships between assumed porosity, pore-water chloride concentration, and the measured value of resistivity.

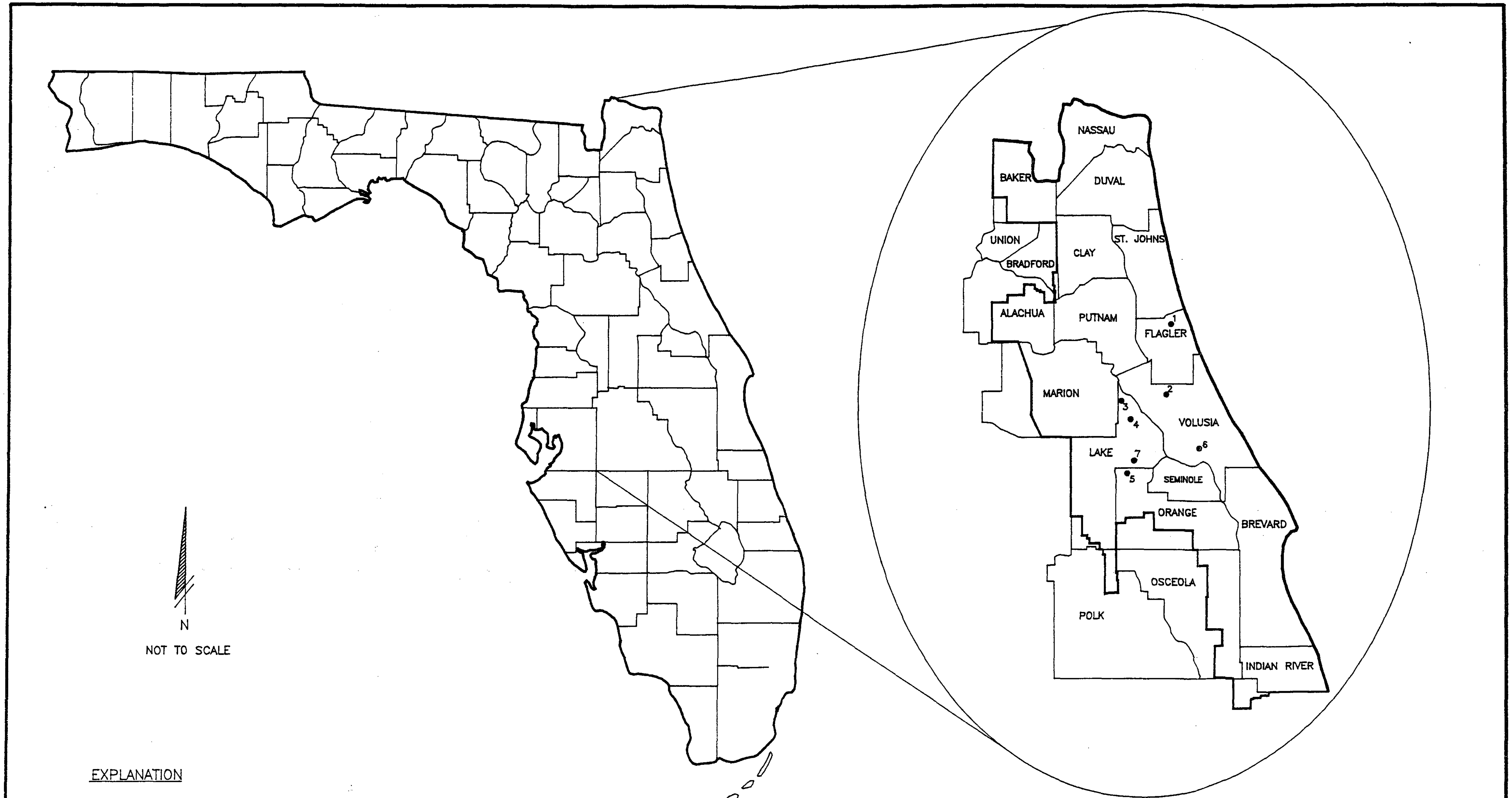
Given this background, SJRWMD has set the objectives of this TDEM survey as:

1. determination of the depth to the saltwater interface (water with chloride concentration greater than 5,000 milligrams per liter [mg/l]);
2. determination of the depth within the aquifer (above the saltwater interface) at which chloride concentration of pore waters equals 250 mg/l;
3. estimation of the chloride content of the saltwater layer assuming values of 25, 30, and 35 percent for porosity of that layer.

The principal strength of TDEM is the detection and mapping of depths to the top of a conductive layer within an otherwise resistive medium. As such, the first objective (chlorides greater than 5,000 mg/l) is the easiest to accomplish and is the best resolved. Determination of the second and third objectives relies on empirical relationships derived from studies of wells in

Seminole County (in east-central Florida) and, therefore, is a less certain and less well-resolved determination.

This report details the field procedures, data quality control and analyses procedures from a total of seven sites as selected by SJRWMD personnel. All the sites were within northeastern and east central Florida. Figure 1-1 presents the locations for the seven TDEM sites.



EXPLANATION

1 ● TDEM SOUNDING LOCATION

—— BOUNDARY OF SJRWMD

ST. JOHNS RIVER WATER MANAGEMENT DISTRICT PALATKA, FLORIDA	SDII SUBSURFACE DETECTION INVESTIGATIONS INCORPORATED	GENERAL SITE LOCATION MAP TDEM MAPPING OF SALT WATER IN FLORIDAN AQUIFER – NORTHEASTERN FLORIDA Designed By: CHR Checked By: MJW Drawn By: SAB Proj. No.: 1010045 DWG No.: LOC–G Date: 08/01/96	Fig. No. 1–1

2.0 HYDROGEOLOGIC SETTING

Ground water is drawn from three principal aquifer systems within SJRWMD (Figure 2-1); the surficial aquifer system, the intermediate aquifer system and the Floridan aquifer system (Scott et al., 1991). The surficial aquifer system consists primarily of Upper Miocene to Holocene age consolidated to poorly indurated siliclastic sediments (Scott et al., 1991). Permeable interbeds within these sediments are locally significant sources of potable water near coastal areas and within St. Johns, Flagler, southern Brevard, Indian River, Seminole, western Clay, and Alachua counties (Fernald and Patton, 1985).

The Miocene-age Hawthorn Group separates the surficial aquifer system from the Floridan aquifer system and creates confining conditions within the Floridan aquifer. The intermediate aquifer system is comprised of high-transmissivity zones within the Hawthorn Group (Figure 2-1). Typically these high-transmissivity zones occur within sandy phosphatic limestone beds. The intermediate aquifer system is a significant source of potable water in southeastern Flagler and eastern Orange counties (Fernald and Patton, 1985).

The primary source of potable water throughout the majority of the SJRWMD is the Floridan aquifer system. The Floridan aquifer is composed of (from oldest to youngest) the Cedar Keys Formation, Oldsmar Formation, Avon Park Formation, Ocala Limestone (where present),the Suwannee Limestone and the lower formations of the Hawthorn Group (where present; Figure 2-1; Scott et al., 1991). The ages of these formations range from Paleocene to Miocene.

Figure 2-1
Lithostratigraphic and Hydrostratigraphic Units
SJRWMD

LITHOSTRATIGRAPHIC UNIT	HYDROSTRATIGRAPHIC UNIT
UNDIFFERENTIATED PLEISTOCENE - HOLOCENE SEDIMENTS ANASTASIA FORMATION CYPRESSHEAD FORMATION NASHUA FORMATION	SURFICIAL AQUIFER SYSTEM
HAWTHORN GROUP STATENVILLE FORMATION COOSAWHATCHIE FORMATION MARKSHEAD FORMATION PENNY FARMS FORMATION	INTERMEDIATE AQUIFER SYSTEM OR CONFINING UNIT
SUWANNEE LIMESTONE	FLORIDAN AQUIFER SYSTEM
OCALA LIMESTONE AVON PARK FORMATION OLDSMAR FORMATION	
CEDAR KEY FORMATION	SUB - FLORIDAN
UNDIFFERENTIATED	CONFINING UNIT

From: SCOTT et al 1991

The Floridan aquifer is subdivided into the Upper and Lower Floridan aquifer by a middle semi-confining unit ranging in thickness from nearly 0 to over 1,000 ft. The middle semi-confining unit is leaky and the hydraulic connection between the Upper and Lower Floridan aquifers is variable (Tibbals, 1990). Depth to the division ranges from approximately 300 to 1,200 ft below mean sea level (bmsl) within SJRWMD (Miller, 1986).

The Ocala Limestone is the most productive aquifer within the Floridan aquifer. Along the east coast and southern portion of SJRWMD, the Cedar Keys and Oldsmar Formations typically contain salt water. Chloride concentrations within the Upper Floridan aquifer are usually less than 50 mg/l in the northern and west central portions of SJRWMD and exceed 250 mg/l in the east central and southern portions of SJRWMD (Fernald and Patton, 1985). Areas of mineralized water in the Floridan aquifer are present within the central and southern portion of SJRWMD. Sources of mineralized water include lateral seawater intrusion, seawater upwelling, and connate water (Scott et al., 1991).

3.0 FIELD ACQUISITION PARAMETERS, EQUIPMENT AND DATA PROCESSING

3.01. Field Acquisition Parameters

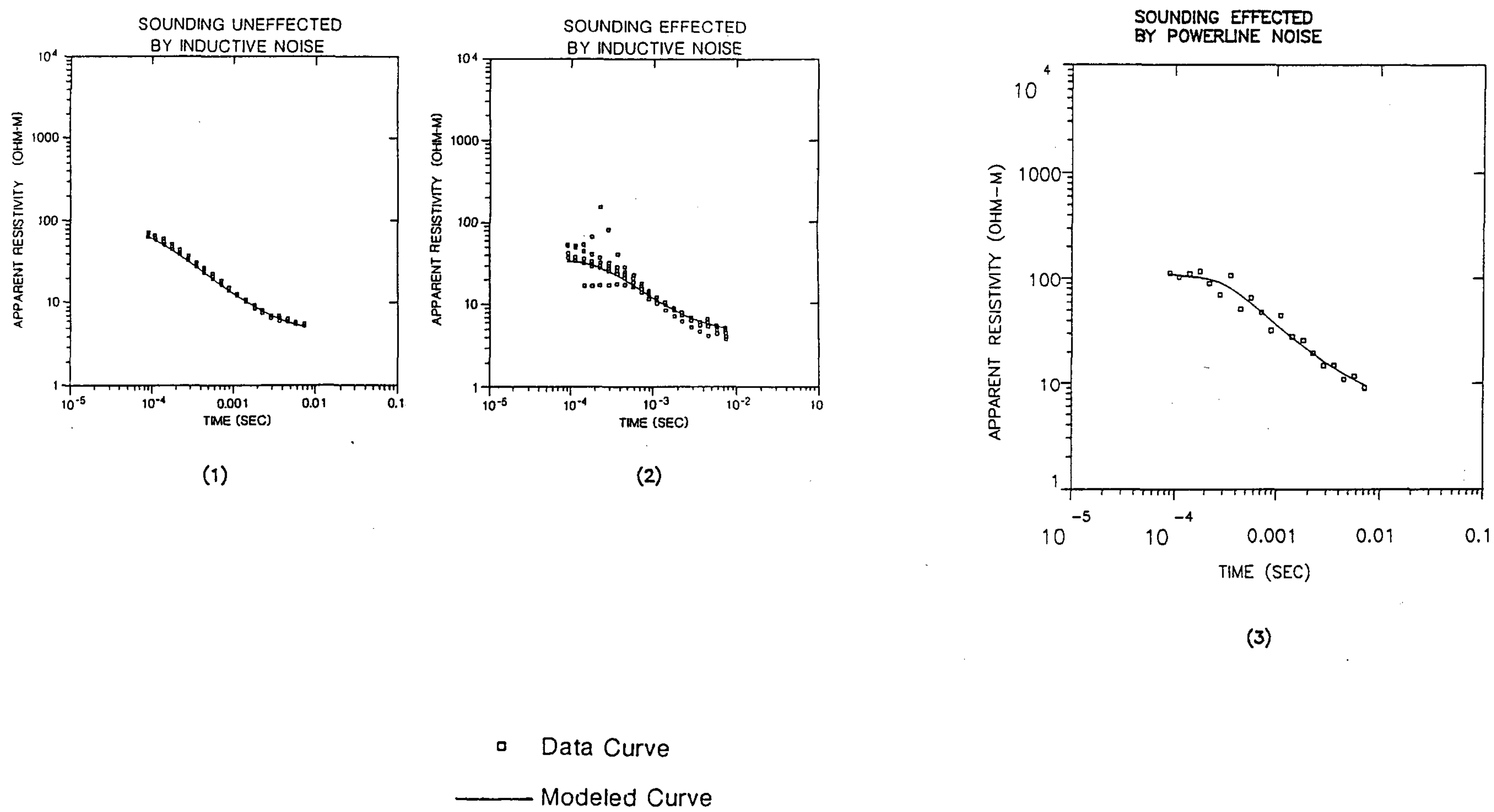
Seven sites were selected by SJRWMD for TDEM soundings. The TDEM method involves the laying of 12 gauge AWG wire in an approximately square or rectangular loop on the ground surface over a large area (on the order of 10^6 ft^2 or greater). This is the transmitter, or Tx loop. The Tx loop is energized by a bi-polar electrical current (up to a maximum of 30 amperes). The response of the ground is sensed by a centrally located (midpoint of the Tx loop) search coil (receiver, or Rx coil). The transient response seen by the receiver is recorded digitally by the data-logging module.

To attain the depth of exploration required to determine the depth to the saltwater interface within SJRWMD, Tx loop sizes ranging from 300 ft x 700 ft up to 1,500 ft x 1,500 ft were employed in the study. Tx loop sizes at individual sites were prescribed by SJRWMD personnel and adjusted in the field to accommodate field logistical constraints such as obvious metal structures, power lines, or limited areas of access. Tx loops were laid out using premarked cables and a compass. Loop dimensions, transmitter currents, and other site-specific information are included in the individual descriptions of the sounding results (Section 5.0).

In addition to the main sounding data set at a given site, SDII also collected quality control (QC) sounding data using an off-center Rx coil location. That is, if there was an obvious, possible source of noise (pipeline or power line, for example) to one side of a Tx loop, then the coupling of the incident pulse from the transmitter with that possible noise source would impart voltage gradients within the loop that would not exist otherwise. In the absence of noise sources, the voltage measured in the loop is very well behaved; it does not vary much with position of the Rx coil. To check for possible interference sources, several soundings are performed 10-15 percent of the Tx loop length away from the initial Rx coil location. It can be shown that the maximum vertical EMF (electromotive force) occurs at the center of the Tx loop and that the EMF remains relatively flat to about 10 percent L (L being the length of one of the sides of the Tx loop) off center (Blackhawk, 1990). If a shallow noise source is affecting the data quality, it would impose a higher EMF gradient in one or more directions off center from the Tx loop. On Figure 3-1, examples of TDEM data that are; 1) unaffected by induction noise, 2) affected by induction noise (as from buried metal pipelines), and 3) affected by powerlines are provided. None of the TDEM sites surveyed during the SDII investigation appeared to have been affected by noise sources.

QC measurements were generally performed at two to four different locations about the loop center. If the data from the off-center Rx location matches the central-loop data, then the data are not noise-affected. If they diverge significantly, the data are noise-affected and should not be used.

The SDII field crew consisted of one project geophysicist, Mr. Charles H. Rhine, who was assisted by two geophysical field technicians. At five of the seven sites, Mr. Rhine was assisted by Mr. Michael J. Wightman, P.G., Senior Geophysicist, Vice-President of Operations. All data reductions and analysis was done by Mr. Wightman. A representative of SJRWMD, Mr. Jody Lee, was also present in the field. Table 3-1 summarizes the daily field activities.



SOURCE: - CEES, 1992

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EXAMPLES OF NOISE AFFECTS UPON TDEM DATA

DESIGNED BY:	MJW	PROJECT NO.:	93742	FIGURE
CHECKED BY:	RJW	DRAWING NO.:	EXM-1	3-1
DRAWN BY:	SBG	DATE:	09/16/93	

Table 3-1
Daily Log of Field Activities

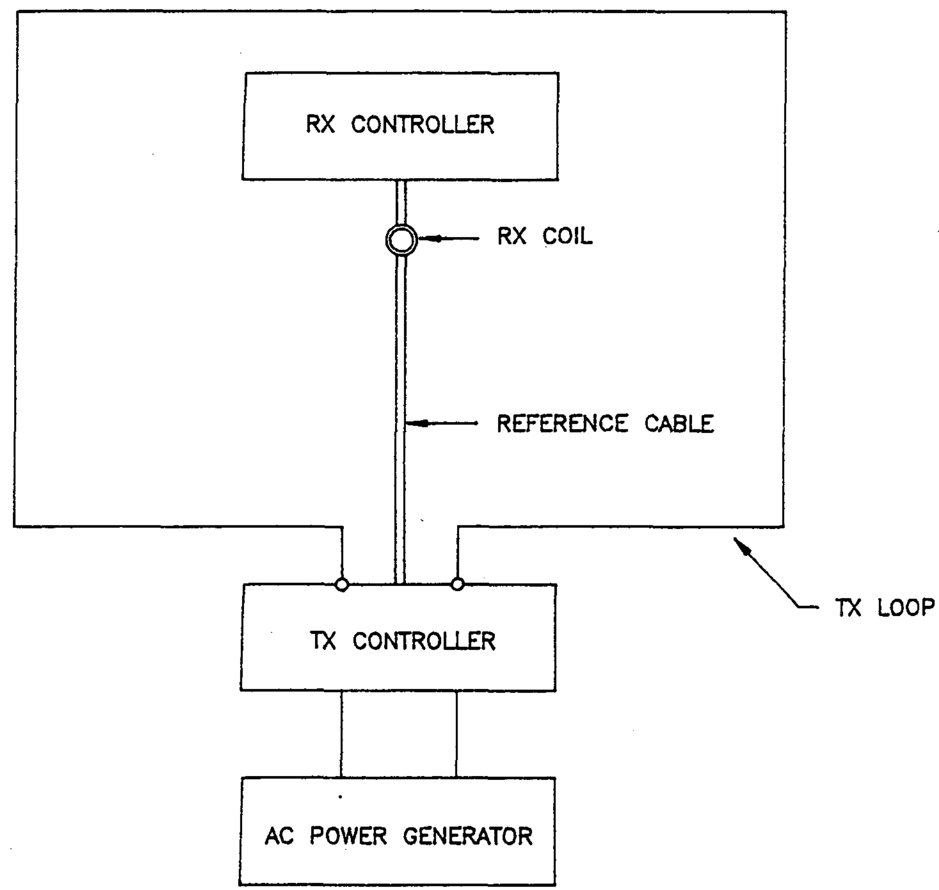
DATE	SITE	ACTIVITIES
6/3/96	ITT/Rayonier	Read EM-37 TDEM sounding
6/4/96	Lake George WMA	Read EM-37 TDEM sounding
6/4/96	Juniper Springs ONF	Read EM-37 TDEM sounding
6/5/96	Alexander Springs ONF	Read EM-37 TDEM sounding
6/5/96	Sorrento	Read EM-37 TDEM sounding
6/6/96	Deltona	Read EM-37 TDEM sounding
6/6/96	Hayfield	Read EM-37 TDEM sounding

3.02. Equipment

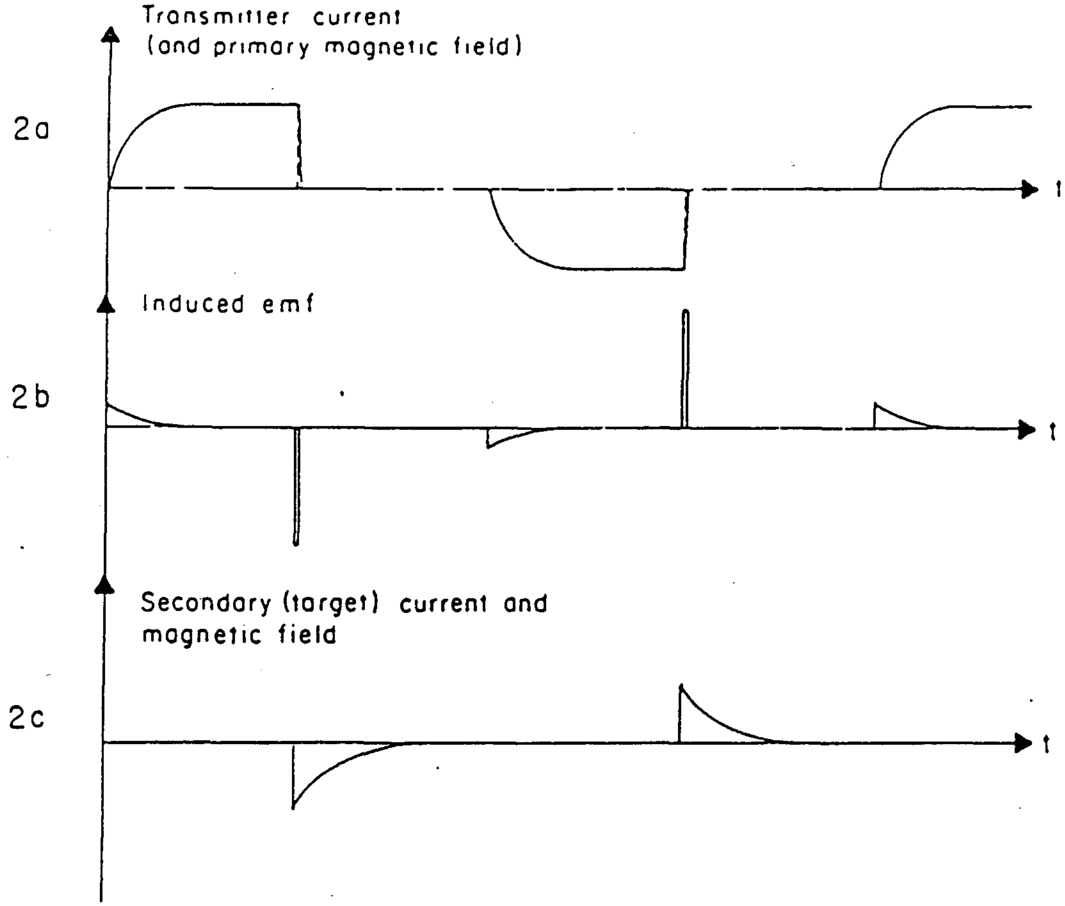
SDII employed the Geonics EM-37 Protem system for the investigation. The principal components of the EM-37 systems are:

- Transmitter (Tx) loop (variable length 12 gauge AWG wire, insulated)
- Gasoline power generator/EM37 transmitter box (maximum 30 ampere, bi-polar square wave)
- Receiver (Rx) coil (100 square meter effective area)
- Protem Receiver Module (system control and parameter selection)

A block diagram of the field setup of the system is given in Figure 3-2. Once setup is completed, a current waveform, as depicted by Figure 3-3, is injected into the Tx loop. The rapid turn-on and turn-off of current in the loop creates a strong EMF which interacts with earth and man-made materials to generate eddy currents within conductive materials. These currents have an associated secondary magnetic field which is detected by the Rx coil as shown on Figure 3-3. Eddy currents close to the Tx coil are induced first and decay below detection limits before deeper currents. Currents in resistive materials also decay faster than currents in conductors. Deeper conductors contribute to responses at later times at the Rx coil than do shallower subsurface features. Thus, by measuring the rate and nature of the decaying magnetic field seen by the Rx coil after Tx shutoff, the distribution of subsurface resistivity can be determined.



ST. JOHNS RIVER WATER MANAGEMENT DISTRICT PALATKA, FLORIDA	SDII SUBSURFACE DETECTION INVESTIGATIONS INCORPORATED	BLOCK DIAGRAM OF EM37 TDEM SOUNDING SETUP EM MAPPING OF SALT WATER AQUIFER		
		DESIGNED BY: CHR CHECKED BY: MJW DRAWN BY: SAB	PROJECT NO.: 1010045 DRAWING NO.: LAY-1 DATE: 08/01/96	FIGURE 3.2



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INCORPORATED

SYSTEM WAVEFORMS
TDEM

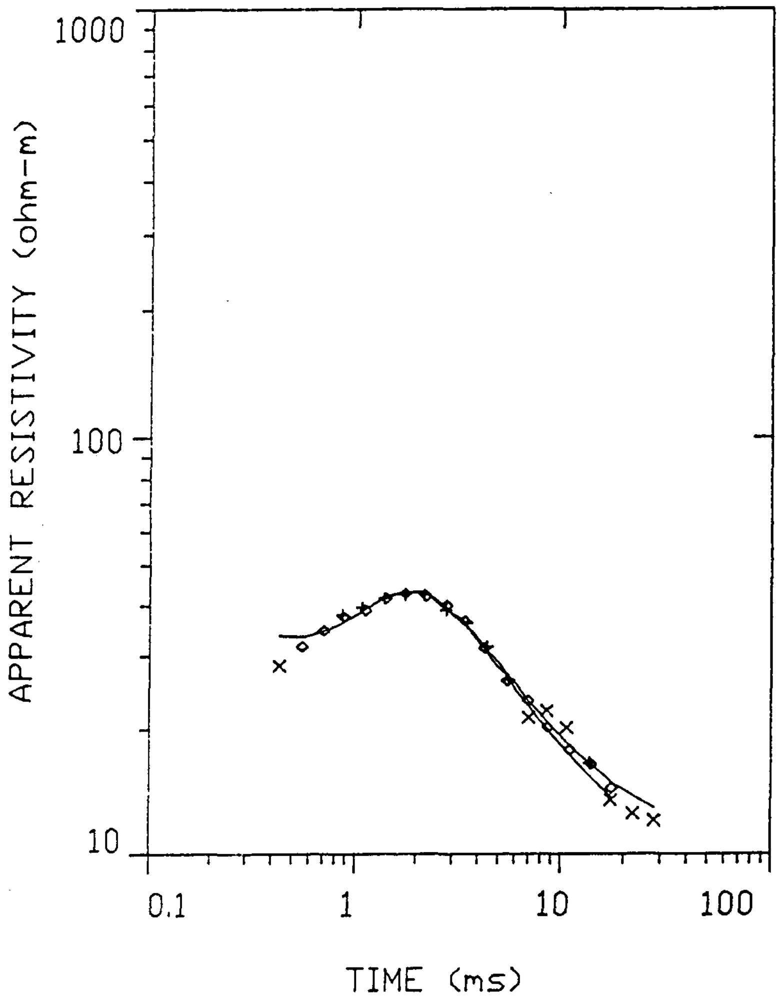
DESIGNED BY: CHR	PROJECT NO.:	1010145	FIGURE
CHECKED BY: MJW	DRAWING NO.:	WVE-1	3-3
DRAWN BY: SAB	DATE:	08/01/96	

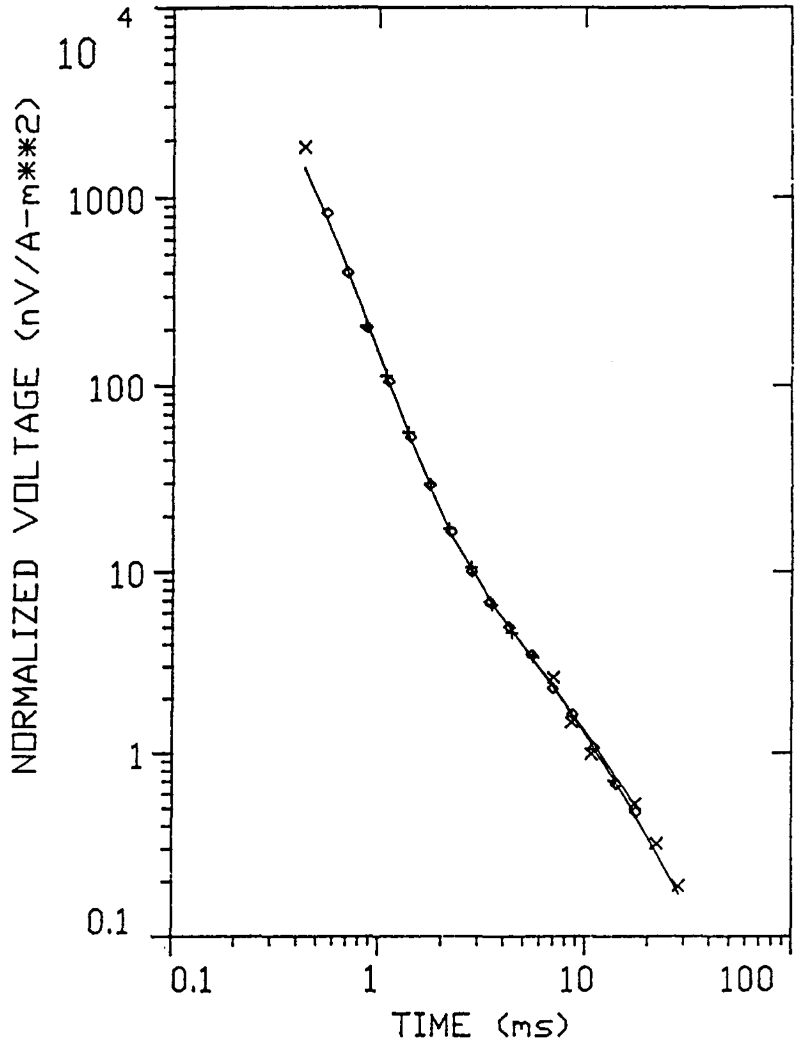
The survey variables that can be selected by the TDEM operator are the size of the Tx coil, Tx coil current (which controls the penetration depth), analog stacking (number of repetitions of summed tests in order to increase signal-to-noise ratio), gain at the receiver, and repetition rate (frequency) of the current cycles. For this investigation SDII used three different frequencies (3 Hz, 7.5 Hz, and 30 Hz) to acquire detailed and overlapping segments of the decay curve which enabled resolution of shallow (30 Hz data) and deeper (3, 7.5 Hz data) portions of the subsurface.

3.03. Data Processing

Data acquired by the Protem receiver is downloaded to a portable computer for data editing, processing, and interpretation (inversion). The primary software program used to process the data was TEMIXGL (Interpex, Ltd.). This program accepts raw data from the Protem receiver module and proceeds through the following general processing steps:

Data Edit - Modification of survey description information, for example, loop size, Tx coil amperage, which may have been entered improperly are performed here. Decay curves for all frequencies and gain values taken at a site are displayed; suspect data points can be deleted and the individual curves for different frequencies and gains are averaged and converted to a single, apparent resistivity versus time (after Tx turn-off) field curve (see Figure 3-4, for an example of voltage data and apparent resistivity versus time curves). The field curve is comprised of 30 data points, where each data point represents an apparent voltage collected at a particular time or time gate. Each frequency has 20 time gates and each frequency overlaps the proceeding or preceding frequency by 10 time gates.





— BEST-FIT MODELED CURVE

□ APPARENT RESISTIVITY VALUES USED IN MODEL

X APPARENT RESISTIVITY VALUES NOT USED IN MODEL

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DEMONSTRATION TDEM SURVEY RESULTS SHOWING NORMALIZED VOLTAGE AND APPARENT RESISTIVITY VERSUS TIME

DESIGNED BY:	CHR	PROJECT NO.:	1010045	FIGURE
CHECKED BY:	MJW	DRAWING NO.:	EXM-2	3-4
DRAWN BY:	SAB	DATE:	08/01/96	

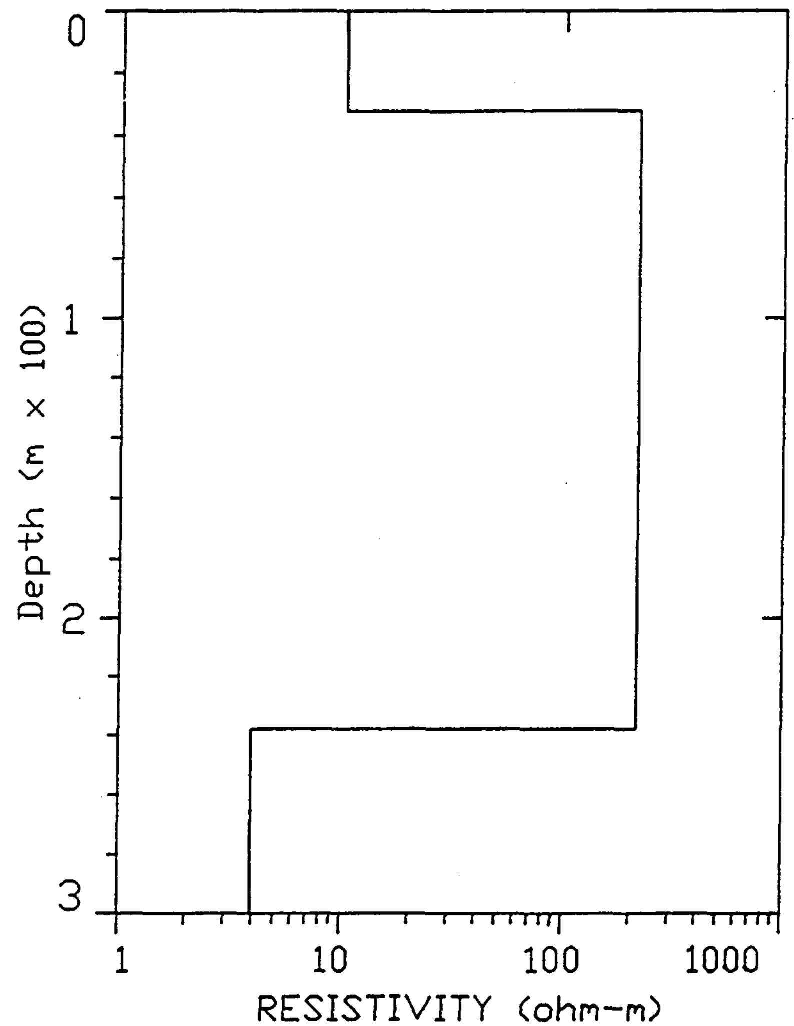
Combining data collected at the 30 Hz and 3 Hz frequency produces one sounding curve with 30 time gates, with an overlap between time gates 10 through 20. Data collected at 7.5 Hz provides apparent resistivity values for time gates 5 through 25. An advantage of using 30, 7.5, and 3 Hz frequencies for all the soundings is that different gains can be used for each frequency. Lower gains can be used at a frequency of 30 Hz to avoid saturating early channels, and higher gains can be used at 3 Hz to amplify weaker signals in later channels. The combined data is interpreted as one sounding curve. The modeled sounding curve does not always appear as a continuous single sounding curve (Figure 3-4). This is because during the modeling process, curves are developed for data collected at each frequency. The calculations for the final geoelectric model, however, are based upon a single average curve which is developed from the data collected at each frequency.

Initial Model - Review of the apparent resistivity curve shape allows a trained geophysicist to make an initial guess as to the true resistivity versus depth (layered) model which would produce the observed data set. After such a model is created, a field curve is calculated from the model and compared with the observed data. The degree of agreement between model and field data is measured statistically and expressed as the fitting error. The geophysicist may then, in an interactive mode, adjust the model to obtain a better fit or can modify the starting model.

As part of the modeling procedure early and late time data is commonly discarded. Typically, apparent resistivity values collected at early times are discarded because the data collected at these times is often not representative of geological conditions because of the affect of the Tx coil shut off not being truly instantaneous. In the final modeling of this data, in may appear that the model curve passes through several of these early time points, but not all the points. In such a case, all the early time data points are discarded because it is not good modeling practice to delete data points from the middle portion of a curve and utilize data points preceding them. Often, later time data is also not representative of geological conditions because the primary EMF field strength has been too dissipated to provide a representative apparent resistivity value. Suspect late time data is also discarded. Poorly fitting data points are marked with a "x", utilized data points are marked with a square (Figure 3-4). Modeled curves quite often demonstrate an upward curvature during early times. This upward curvature is usually due the TDEM response not following theoretical behavior or the affect of the Tx coil shut off not being truly instantaneous. This deviation produces a distortion, however, this distortion has little or no affect on the results from the TDEM survey when the target depth is several hundred ft below land surface (bls).

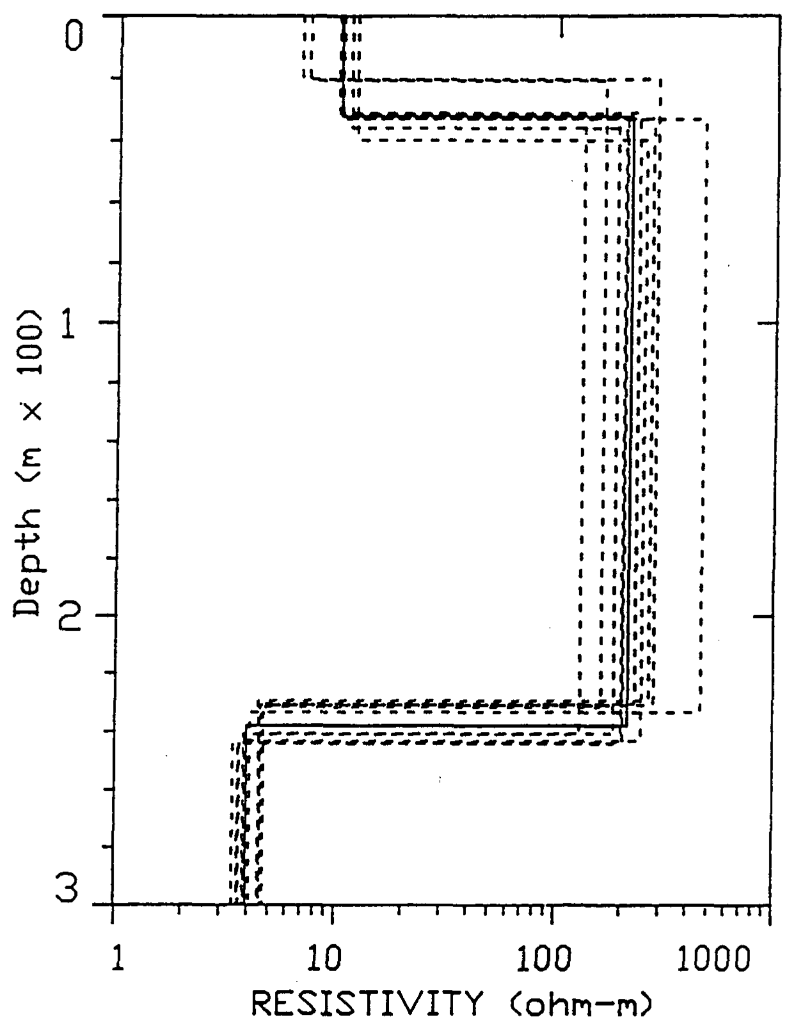
Automatic Inversion - Based upon the initial model, the program will attempt to create a better fit to the observed data using an iterative, Inman Ridge Regression routine to adjust layer thicknesses and resistivities until a minimum error of fit is realized; our goal was to produce models which fit the observed data within a 5% error of fit. This final model is termed the "best fit" model (see Figure 3-5). Only the data points utilized in the determination of the modeled curve are used in calculation of the fitting error.

Equivalence Analysis - Electrical resistivity methods are, as with other geophysical methods, plagued by the so-called "non-uniqueness" problem. That is, while a best-fit model produces an acceptable fit to field data curves, there are several other models having different thicknesses and resistivities which will also provide a "reasonable" fit to the same data. TEMIXGL will produce a suite of models, using the best-fit model as a start, which would produce a reasonably close fit (see Figure 3-6). If the equivalence model segments (layers and resistivities) are tightly constrained then the layering provided by the best-fit model is very good. Those parts of the equivalence models that scatter quite a bit around the best-fit model show less confidence in the absolute values of layer thickness and resistivity. A poorly constrained equivalence model for a given layer means either there are too few data points in the raw data to adequately describe that layer or the data is just not very sensitive to that specific layer.



Fitting Error: 4.091%

ST. JOHNS RIVER WATER MANAGEMENT DISTRICT PALATKA, FLORIDA	SDII SUBSURFACE DETECTION INVESTIGATIONS INCORPORATED	DEMONSTRATION TDEM SURVEY RESULTS SHOWING BEST-FIT MODEL			
		DESIGNED BY: CHR	PROJECT NO.: 1010045		FIGURE 3-5
		CHECKED BY: MJW	DRAWING NO.: EXM-3		
		DRAWN BY: SAB	DATE: 08/01/96		



ST. JOHNS RIVER WATER MANAGEMENT DISTRICT PALATKA, FLORIDA	SDII SUBSURFACE DETECTION INVESTIGATIONS INCORPORATED	DEMONSTRATION TDEM SURVEY RESULTS SHOWING RESULTS OF EQUIVALENCE ANALYSIS	
		DESIGNED BY: CHR CHECKED BY: MJW DRAWN BY: SAB	PROJECT NO.: 1010045 DRAWING NO.: EXM-4 DATE: 08/01/96
		FIGURE 3-6	

It is important to note that the interpretations resulting from the TDEM data are, specifically, one-dimensional models of layer thickness and layer resistivity. That is, if the earth subsurface is not, effectively, a one-dimensional horizontal layer, then the produced model may have inherent error. Also, the depths to levels of chloride concentration and not resistivity rely on empirical relationships between resistivity and chloride concentration. This latter point will be detailed further in Section 4.0.

4.0 TECHNICAL APPROACH TO SATISFYING SURVEY OBJECTIVES

4.01. General

As stated previously, the final product of the *geophysical* investigation is a best-fit, one-dimensional model of layer resistivity versus depth. To satisfy the requirements of the survey, these models must be correlated with models of chloride concentration versus depth. Specifically, the resistivity structure must be viewed in terms of determining the depth of occurrence of the 250 mg/l isochlor and the depth to salt water as defined by the 5,000 mg/l isochlor. To ensure that the results from the 1996 TDEM survey are directly comparable to and compatible with the results of TDEM surveys performed in previous years (Blackhawk, 1990; Blackhawk, 1991; CEES, 1992; and SDII, 1993, 1994 and 1995), SDII will utilize the identical relationships between resistivity and isochlor depths for the Floridan aquifer. These relationships and assumptions are detailed in the following sections. However, it must be realized that correlations of TDEM-derived layer conductivities with specific chloride values are approximate and based on several simplifying assumptions.

4.02. Correlation of Inverted Geoelectrical (Resistivity) Profiles to Cl^- Concentrations

In previous studies, it was presumed that the depth to salt water was such that this interface was inferred to occur within the Floridan aquifer system. The only noted exceptions to this were soundings in the area of Jacksonville where the great depth (>2,000 ft) and the very low resistivity (< 2 ohm-m) of the deep, low resistivity layer placed the interface below the Lower Floridan aquifer (CEES, 1992). For such sites with very low resistivities (<2 ohm-m) and where the depth to salt water is greater than 2,000 ft, the published relationships between resistivity and chloride concentration cannot be used; it is merely presumed that the chloride concentration at these sites exceeds 5,000 mg/l for the saltwater section.

In cases where the electrical response between the Floridan aquifer and overlying sediments are indistinguishable, the hydrostratigraphic units must be combined into a single geoelectric layer. Similar to the situation where the interface is below the Floridan aquifer, the published relationships between resistivity and chloride concentration are generally invalid and the chloride concentration in ground water above the geoelectric layer cannot be determined. However, if the resistivity of the first layer is greater than 80 ohm-m (see discussion below), the chloride concentration in the portion of the Floridan aquifer in this layer can be concluded to be below 250 mg/l, even though this layer contains sediments above the Floridan aquifer. The reason for this is because of the high resistivity. Surficial sediments, Holocene and Miocene deposits, and the Hawthorn Group have low resistivities. A high resistivity (greater than 80 ohm-m) can only be obtained if the chloride concentration were below 250 mg/l (assuming 25% porosity). Conversely, if the Floridan aquifer contains brackish to salt water and if the resistivity of a layer containing a portion of the Floridan aquifer were below 20 ohm-m, it can be concluded that the 250 mg/l isochlor is not present in the Floridan aquifer.

For the majority of soundings conducted previously, the saltwater interface positions were "inferred to occur within the Floridan aquifer system" (Blackhawk, 1990; Blackhawk, 1991; CEES, 1992; and SDII, 1993, 1994 and 1995) and, therefore, the published relationships between resistivity and chloride concentration are applicable. When the saltwater interface occurred within the Floridan aquifer, the following procedure was used in both this and previous studies (Blackhawk, 1990; Blackhawk, 1991; CEES, 1992; and SDII, 1993, 1994 and 1995).

The carbonate rocks of the Floridan aquifer system (as opposed to the highly variable lithologies of overlying formations) are expected to be uniform and, as such, their resistivities are determined principally by porosity and specific conductance of pore fluids. The governing empirical "law" relating formation resistivity (Ro), fluid resistivity (Rw) and porosity (f) in a clay-free lithology is Archie's Law:

$$F = Ro/Rw = af^{m} \qquad (1)$$

where F = "formation factor" and "a" and "m" are empirically derived constants which are specific to a given formation in a given area. Previous TDEM reports have used the values of m = 1.6 and a = 1 from Kwader (1982) as being most appropriate for the Floridan aquifer. These values are from studies of wells completed in the Upper Floridan aquifer in Seminole County, Florida.

Kwader (1982) has also established the following relationship from his study of Seminole County wells:

$$Cl = (3500/Rw) - 153 \qquad (2)$$

where Cl is the equivalent chloride concentration in mg/l and Rw is fluid resistivity in ohm-meters. Extrapolating these expressions by Kwader outside of Seminole County presumes that the relative ionic chemistry (especially a chloride/sulfate ratio of 5:1) remains the same or reasonably close to conditions in that area. Significant chemical variation would cause Equation 2 to be, quite likely, invalid.

Because formation resistivity, Ro, is what the geophysical analysis of TDEM data has produced, a combination of equations (1) and (2) allows for determining a functional relationship between chloride concentration, inferred formation resistivity, and porosity:

$$Cl = (3500f^{1.6}/Ro) - 153 \qquad (3)$$

or, for an assumed 25% porosity for the Upper Floridan aquifer as per previous TDEM reports:

$$Cl = (32{,}163/Ro) - 153 \qquad (4)$$

Linking this relationship to the cited survey objectives, we would expect that a Floridan aquifer with 25% porosity, similar water chemistry (5:1 chloride to sulfate ratio) to the Kwader study, and a 250 mg/l chloride concentration would yield a measured formation resistivity of 80 ohm-m. Higher resistivities than this would indicate fresher water. Chloride concentrations of 5,000 mg/l would correspond to formations resistivities of 6.2 ohm-m; higher concentrations would yield lower resistivities. These values, then, are what we should expect to see for the fresh and saltwater sections of the Floridan aquifer.

One final consideration, besides porosity and similar chemical species/ratios, is made by previous reports (Blackhawk, 1990; Blackhawk, 1991; CEES, 1992; and SDII, 1993, 1994 and 1995) and, again, will be adhered to in this 1996 study. The relationships cited are for a clearly defined, carbonate section within the Floridan aquifer (i.e., beneath Miocene deposits or the Hawthorn Group). If there is a clearly defined thickness of Holocene to Miocene deposits, the Hawthorn Group, or surficial sediments from the electrical sounding results and if that thickness is in agreement with published thicknesses of such deposits for the area of a specific site, then there is presumed to be no affect of the measured formation resistivity for the Floridan aquifer due to interfingering of clay stringers of the Hawthorn Group or Holocene to Miocene deposits. This means that the inversion resistivity results representing the Floridan aquifer layer are valid.

4.03. Determination of Depth to 250 mg/l and 5,000 mg/l Isochlors

The previous discussion of the relationship of formation conductivity to chloride content is particularly applicable to geoelectrical measurements made on a fine, highly resolved scale, such as a borehole electrical log, where an almost continuous measure of resistivity versus depth is available. As known from geophysical logs and water quality studies, the saltwater interface is not a knife-edge interface in the subsurface but is a gradational interface. Within the freshwater section, we would also expect the chloride concentration to follow a gradually increasing-downwards distribution. Therefore, the TDEM sounding, which presents the subsurface as a sequence of a few layers of presumed, uniform resistivity, is not an actual representation of the true subsurface but a low resolution version of it. The saltwater interface (chlorides greater than 5,000 mg/l), which exhibits a much higher gradient of chloride concentration than in the overlying fresher water, comes closest to being a true interface. This is why depth to the saltwater interface from TDEM should be close to the low resistivity layer detected.

Actual reported depth to the 5,000 mg/l isochlor in previous reports (CEES, 1992; SDII, 1993, 1994 and 1995) is determined by the contrast in resistivity of the layers above and below the geoelectrical interface. If the contrast is large (e.g., greater than 80 ohm-m above and less than 20 ohm-m below), then the depth to the 5,000 mg/l isochlor is assumed to be 50 ft below the interface depth determined from geoelectrical inversion. If the contrast is small (e.g., a 20-80 ohm-m layer above and less than 20 ohm-m layer below), the depth to the 5,000 mg/l isochlor is taken as equal to the depth of the interface determined from the geoelectrical inversion. These adjustments are intended to correct for the existence of the transition zone.

The criterion used to define the depth to the 250 mg/l isochlor in previous TDEM surveys for SJRWMD (Blackhawk, 1990; Blackhawk, 1991; CEES, 1992; and SDII, 1993, 1994 and 1995) is also a data-based criterion. That is, the final reported position of this isochlor, relative to the boundary between the Floridan aquifer freshwater geoelectrical layer and the saltwater geoelectrical layer depends upon the layer resistivities above and below the interface as determined by the inversion. Four data classes have been defined based upon a reference value for resistivity of 80 ohm-m for a portion of the Floridan aquifer. We reproduce the following criteria for positioning the 250 mg/l isochlor (CEES, Table 4-2, 1992).

Summarizing Table 4-2 in CEES (1992), if the Floridan freshwater section is in excess of 80 ohm-m while the underlying layer is less than 20 ohm-m (so-called Class A geoelectrical section), then the 250 mg/l isochlor is placed at a position 50 ft higher than the saltwater interface depth defined from geoelectrical inversion.

If the Floridan freshwater section is in excess of 80 ohm-m while the underlying layer is between 20-40 ohm-m (so-called Class B section), then the 250 mg/l isochlor is placed 25 ft above the saltwater interface depth defined from geoelectrical inversion.

If the Floridan freshwater section is in excess of 80 ohm-m and the underlying layer is between 40-80 ohm-m (Class C), then the 250 mg/l isochlor is placed at the interface.

Finally, if there is no contrast (i.e., a uniform layer of > 80 ohm-m; Class D), then we are not seeing an expected saltwater interface within the depth of exploration of the field sounding. Also, there is no detectable/mappable 250 mg/l isochlor.

In the above determinations for the 250 mg/l isochlor, the "depth" to the saltwater interface is the depth to the low resistivity layer taken directly from the TEMIXGL inversion and not the corrected 5,000 mg/l depth as discussed previously.

An underlying assumption of this and Kwader's (1982) work is that the porosity of the limestone, within which estimates of water quality are being made, is constant. By Equation 3 there is an inverse relationship between porosity (f) and formation resistivity (Ro). If porosity should increase, then formation resistivity will decrease for the same given chloride concentration. For example, through a manipulation of Equation 3, it can be shown that for a given chloride concentration of 250 mg/l and formation resistivity of 120 ohm-m that the resultant porosity would be 19.2 percent. Given the same water quality, if the porosity should increase to 33.5 percent, a resultant formation resistivity of 50 ohm-m would be obtained. This becomes particularly important in determining the placement of the 250 mg/l isochlor which is based upon the resistance of the lowermost saltwater-saturated layer. If the resistance of the lowermost saltwater-saturated layer is increased by a change in porosity rather than by a decrease in chloride concentration, then the designation of the geoelectric section as a Class B or Class C section would be in error. The placement of the 250 mg/l isochlor would likewise be in error.

5.0 RESULTS AND DISCUSSION

5.01. Summary of Results

A summary of the 1995 TDEM investigation is presented in this section. The summary includes the resulting geoelectrical inversions, 250 mg/l isochlor depth and the 5000 mg/l isochlor depth. More detailed presentation of the individual site results are contained in the following sections 5.02 through 5.08. Each individual site section will present a site description, site map, apparent resistivity versus time (data) curves, the best-fit geoelectrical section with equivalence analysis, and inferred depths to the 5,000 mg/l (salt water) and 250 mg/l isochlors.

Table 5.1-1 lists the 7 sites with summary information describing site number, name, residing county, latitude, longitude and loop size.

Table 5.1-2 summarizes the results of the TEMIXGL geoelectrical inversion section (number of layers, layer thicknesses and resistivities, and range of equivalence models for each layer parameter).

Table 5.1-3 summarizes the estimated chloride content of the saltwater layer assuming porosities of 25, 30, and 35% for the Floridan Aquifer System.

Table 5.1-4 summarizes the interpreted depths to the 250 mg/l and the 5,000 mg/l isochlors at each site based upon the criteria outlined in Section 4.3 and as utilized in TDEM surveys performed for SJRWMD in previous years (Blackhawk, 1990; Blackhawk, 1991; CEES, 1992/SJ93-SP1; and SDII, 1993, 1994 and 1995). As in previous years, these calculations are made assuming a 25% porosity for the Floridan Aquifer System and a 5:1 chloride-to-sulfate ratio for the ground water chemistry. The estimated chloride-to-sulfate ratios at each of the sites is provided in Table 5.1-4.

Table 5.1-1 **Summary of TDEM Site Survey Information**					
SITE NUMBER	**SITE NAME**	**RESIDING COUNTY**	**LATITUDE**	**LONGITUDE**	**LOOP SIZE (in feet)**
1	ITT / Rayonier	Flagler	29°35'35"N	81°17'41"W	1000 x 1000
2	Lake George WMA	Volusia	29°13'50"N	81°12'11"W	1575 x 550
3	Juniper Springs ONF	Lake	29°09'05"N	81°37'47"W	1000 x 1000
4	Alexander Springs ONF	Lake	29°03'44"N	81°37'18"W	900 x 875
5	Sorrento	Orange	28°46'55"N	81°31'04"W	1500 x 1500
6	Deltona	Volusia	28°52'27"N	81°14'09"W	300 x 700
7	Hayfield	Lake	28°52'02"N	81°30'25"W	1250 x 750

+

Table 5.1-2
Summary of Geoelectric Sections with Range of Equivalence

SITE NAME	NUMBER OF MODELED LAYERS IN GEOELECTRICAL SECTION	LAYER 1						LAYER 2						LAYER 3						TOTAL DEPTH TO DEEPEST CONDUCTOR INTERPRETED AS SALT WATER (Meters)*		
		RESISTIVITY ρ_1 (ohm-m)			THICKNESS h_1 (meters)*			RESISTIVITY ρ_2 (ohm-m)			THICKNESS h_2 (meters)*			RESISTIVITY ρ_3 (ohm-m)			THICKNESS h_3 (meters)*					
		Min	Best	Max	Min	Best	Max	Min	Best	Max	Min	Best	Max	Min	Best	Max	Min	Best	Max	Min	Best	Max
ITT / Rayonier	3	37	41	46	46.3	46.3	46.3	11.5	12	12.5	140	152	162	2.4	2.8	3.3	—	—	—	186	198	208
Lake George WMA	3	45	46	48	32	32	32	67	70	72	248	253	256	1.6	1.9	2.2	—	—	—	280	285	288
Juniper Springs ONF	3	105	137	158	22	36	50	268	279	290	506	520	541	13.5	16.9	20.4	—	—	—	552	557	563
Alexander Springs ONF	3	144	163	186	40	40	40	258	281	305	472	487	501	7.2	11.2	16.6	—	—	—	512	527	541
Sorrento	3	36	38	40	32	32	32	235	247	291	576	593	662	2.9	3.5	7.4	—	—	—	608	625	694
Deltona	2	36	37	37	83	84	85	2.5	2.6	2.7	—	—	—	—	—	—	—	—	—	83	84	85
Hayfield	3	24	26	28	14	14	14	112	119	128	234	270	311	42	51	61	—	—	—	248	284	325

* 1 meter equals 3.281 feet

Table 5.1-3
Estimated Depth to Salt Water and Estimated Chloride Concentrations at Three Porosities

SITE	FORMATION RESISTIVITY (ohm-m)	INTERPRETED DEPTH OF SALT WATER [1] (ft)	CHLORIDE CONCENTRAT-ION (mg/l) =25%	CHLORIDE CONCENTRAT-ION (mg/l) =30%	CHLORIDE CONCENTRAT-ION (mg/l) =35%
ITT / Rayonier	2.8	650	11,334	8,428	6,552
Lake George WMA	1.9	935	16,775	12,492	9,728
Juniper Springs ONF	16.9	1,828	1,750	1,269	958
Alexander Springs ONF	11.2	1,729	2,719	1,992	1,523
Sorrento	3.5	2,051	9,037	6,711	5,211
Deltona	2.6	276	12,218	9,088	7,068
Hayfield	51	932	478	318	215

[1] **Depth Below Land Surface**

Table 5.1-4
Depth to 5,000 mg/l and 250 mg/l Isochlor
as Determined by Time Domain Electromagnetics

SITE	ESTIMATED CHLORIDE TO SULFATE RATIO [1]	INTERPRETED DEPTH 5,000 mg/l ISOCHLOR (ft bls)	INTERPRETED DEPTH 250 mg/l ISOCHLOR (ft bls)
ITT / Rayonier	1:1	650	Not Present
Lake George WMA	5:1	935	Not Present
Juniper Springs ONF	5:1	1,878	1,778
Alexander Springs ONF	5:1	1,779	1,679
Sorrento	5:1	2,101	2,001
Deltona	5:1	276	Cannot Determine
Hayfield	5:1	Cannot Determine	932

[1] **All Chloride-to-Sulfate ratios from Sprinkle, 1981**

The effect of a chloride to sulfate (Cl/SO_4) ratio less than 5:1 would be for waters with equivalent conductivity to have different Cl values. SO_4 is less conductive than Cl for an equivalent mass volume. If for example the ratio is less than 5:1, it will take a higher conductivity (lower resistivity) to get a 250 mg/l chloride value. That is, for sites where the 5:1 ratio is 1:1, resistivities would have to be less than 80 ohm-m to reach a chloride content of 250 mg/l.

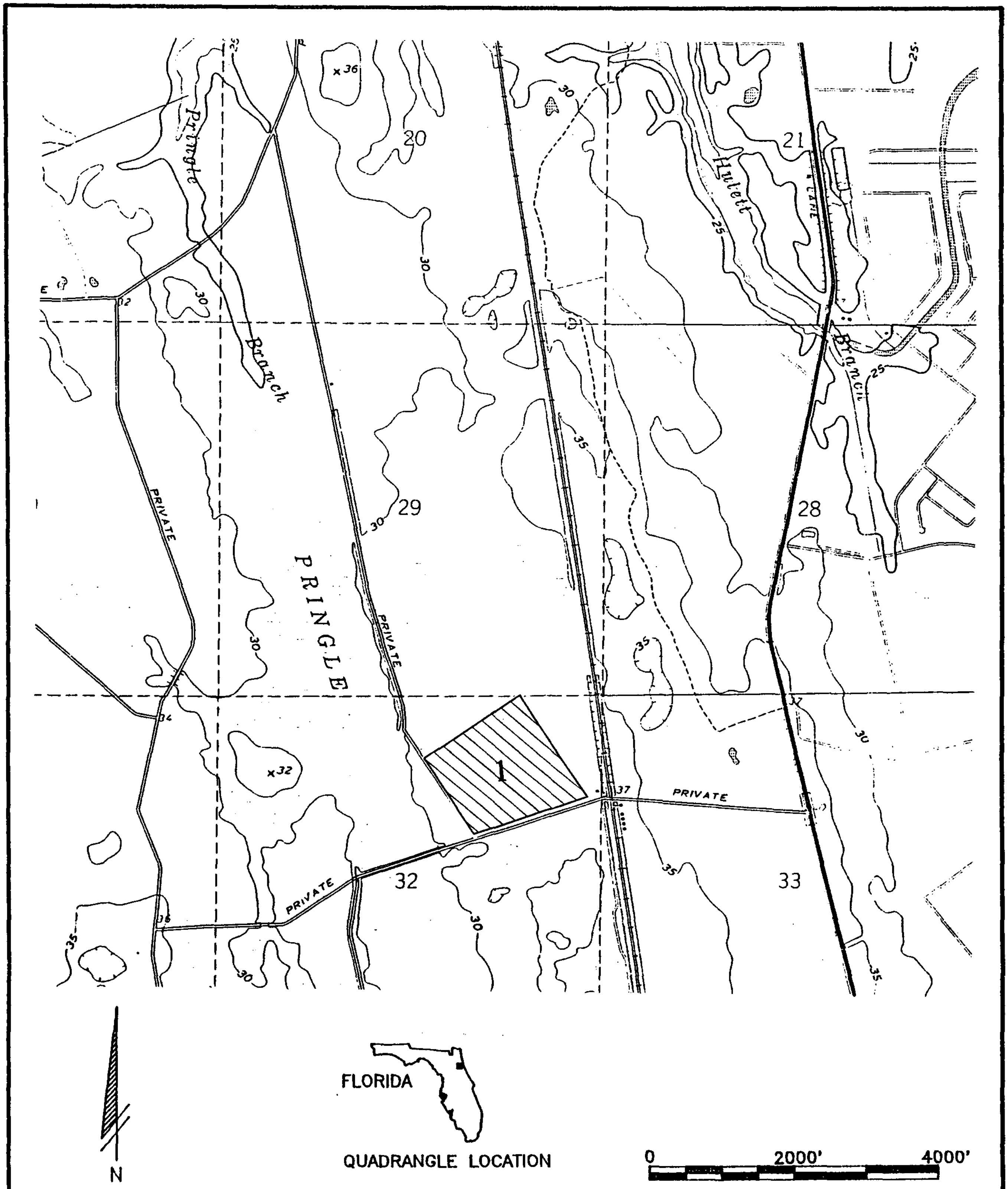
5.02. TDEM Site 1 - ITT / Rayonier

5.02.1. Location Description and Geoelectrical Section

The site is located in Flagler County, Florida (Figure 5.2-1). The site is located within a cleared tree farm. No possible sources of interference were observed within the vicinity of the site. QA soundings were performed 100 ft north and east of the initial Rx coil location. Results from the QA soundings indicate that the apparent resistivity values were unaffected by any interference sources.

The Floridan aquifer occurs at an approximate depth of 120 ft below mean sea level (bmsl) or 152 ft below land surface [(bls) SJRWMD, personal communication] and is overlain by Holocene to Miocene deposits. The base of the Floridan aquifer occurs at approximately 2,040 ft bmsl (Tibbals, 1990). The thickness of the Upper Floridan aquifer is approximately 600 ft and the depth to the top of the Lower Floridan aquifer is approximately 920 ft bmsl (Miller, 1986). The chloride concentration in the upper portion of the Floridan aquifer is above 250 mg/l in this area (Navoy and Bradner, 1987).

The resistivity sounding data and best-fit model inversion are presented on Figure 5.2-2. The interpreted geoelectrical section consists of a three-layer subsurface.



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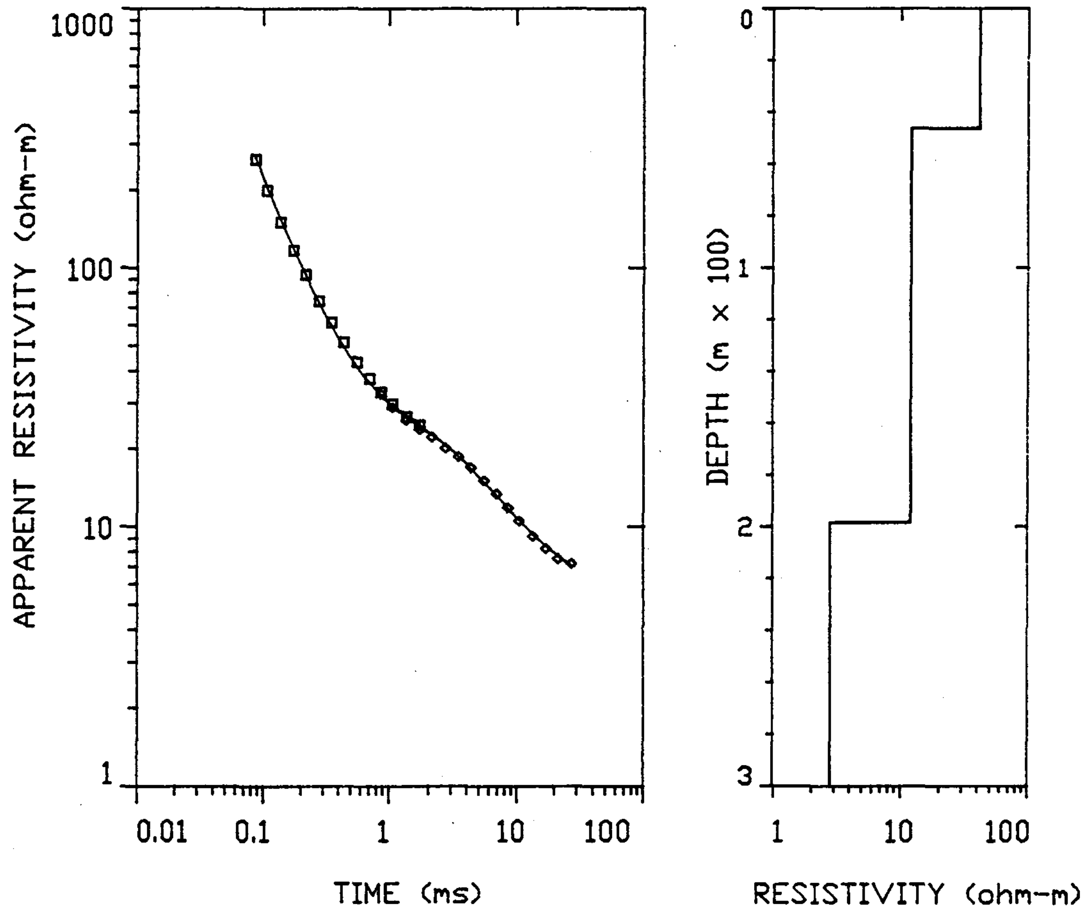
TDEM SURVEY LOCATION MAP
SOUNDING 1 – ITT SITE/RAYONIER
FLAGLER COUNTY, FLORIDA

DESIGNED BY: RJW	PROJECT NO.:	1010045	FIGURE
CHECKED BY: MJW	DRAWING NO.:	LOC-1	5.2-1
DRAWN BY: SAB	DATE:	08/01/96	



—— BEST-FIT MODELED CURVE

□ APPARENT RESISTIVITY VALUES USED IN MODEL

X APPARENT RESISTIVITY VALUES NOT USED IN MODEL

ST. JOHNS RIVER WATER MANAGEMENT DISTRICT PALATKA, FLORIDA	SDII SUBSURFACE DETECTION INVESTIGATIONS INCORPORATED	MEASURED TDEM APPARENT RESISTIVITY AND 1-D INVERSION SITE 1 – ITT SITE/RAYONIER FLAGLER COUNTY, FLORIDA	
		DESIGNED BY: CHR CHECKED BY: MJW DRAWN BY: SAB	PROJECT NO.: 1010045 DRAWING NO.: MDL-1 DATE: 08/01/96
			FIGURE 5.2-2

5.02.2. Geological Interpretation of Geoelectrical Model

The three-layered geoelectrical section consists of a low resistivity (41 ohm-m) upper layer which is considered to be Holocene to Miocene deposits above the Floridan aquifer. The thickness of Layer 1 was fixed at 46.3 m (152 ft). The second layer has even lower resistivity (12 ohm-m) which, because it is less than 80 ohm-m, suggests the Floridan aquifer at this site contains brackish water. The thickness of the brackish section is 152 m (499 ft), placing the depth to the low resistivity (saltwater) layer at 198 m (650 ft) below ground surface. The resistivity of the saltwater saturated layer is 2.8 ohm-m. Layer 1 is considered to be the Holocene to Miocene deposits above the Floridan aquifer, Layer 2 to be the Floridan aquifer (brackish), and Layer 3 to be the salt water near the base of the Upper Floridan aquifer.

5.02.3. Depth to Occurrence of Salt Water

The bottom (third) layer of the geoelectrical model, with a resistivity of 2.8 ohm-m, is interpreted to represent salt water. It occurs at a depth of 650 ft (-618 ft msl). Because the resistivity of Layer 2 (12 ohm-m) is interpreted to represent brackish water within the Floridan aquifer (is less than 80 ohm-m), the interpreted depth to the 5,000 mg/l isochlor is equal to the depth of the geoelectrical interface, or at 650 ft depth (-618 ft msl). The resistivity of Layer 3 (2.8 ohm-m) corresponds to a chloride concentration of 11,334 mg/l assuming a porosity of 25% and the validity and applicability of equation (4) of Section 4.02. It is presumed that because of the expected high chlorinity gradients, this value is sufficiently close to the 5,000 mg/l isochlor that they represent the same effective depth.

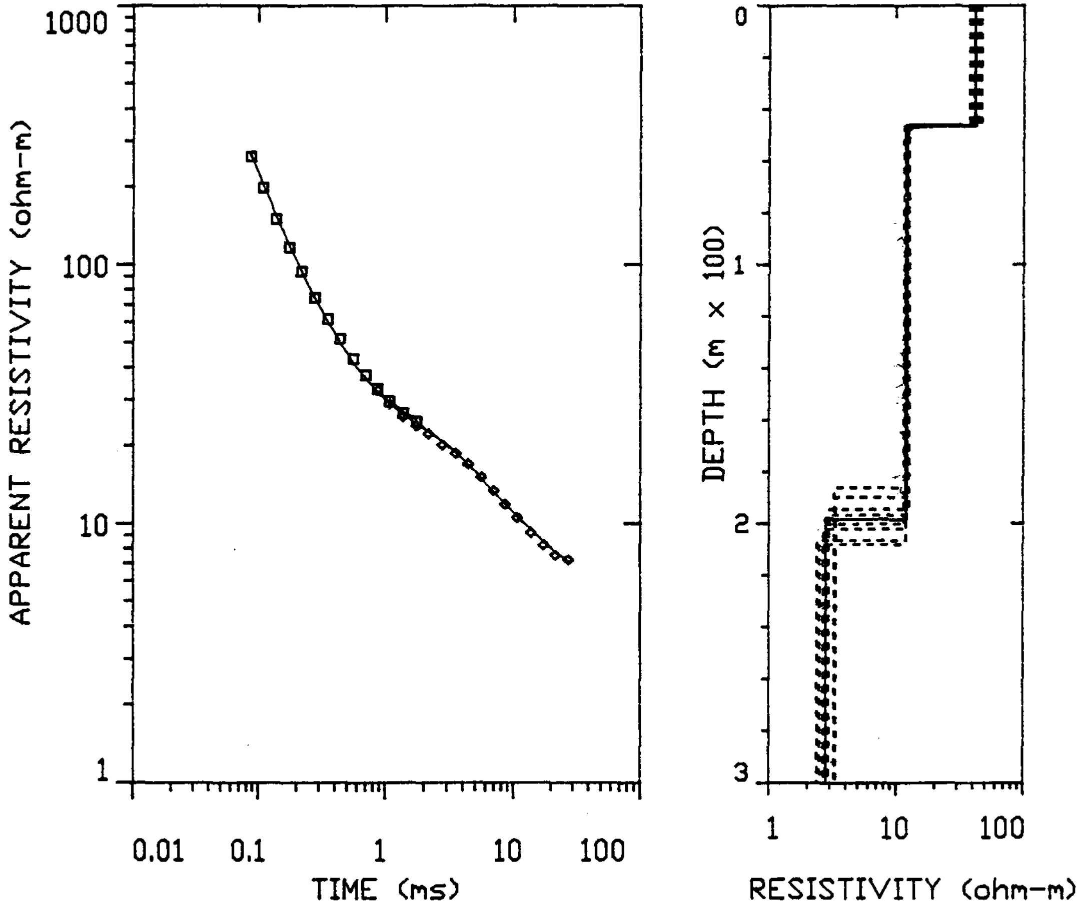
5.02.4. Depth of Occurrence of the 250 mg/l Isochlor

The resistivity of Layer 2, 12 ohm-m, corresponds to a chloride concentration above 250 mg/l, assuming a 25% porosity and the validity and applicability of equation (4) of Section 4.02. As the interpreted chloride concentration exceeds 250 mg/l, the 250 mg/l isochlor does not occur within the Floridan aquifer at this site. This conclusion agrees with Navoy and Bradner (1987) who determined a chloride concentration in excess of 250 mg/l in this area.

5.02.5. Accuracy of Measurement and Interpretation

Figure 5.2-3 is the equivalence analysis at this site and Table 5.2-1 lists the upper and lower bounds of the inverted parameters of the geoelectrical model. The range of equivalence in determining the depth to the low resistivity layer is about ±11 m (36 ft) which is 6% of the total depth. The resistivity of this layer has a range from 2.4 to 3.3 ohm-m. This corresponds to a range in interpreted chloride concentration from 13,248 to 9,593 mg/l, again subject to the same assumptions of porosity and validity of equation (4).

The equivalence range of the resistivity of Layer 2 is from 11.5 to 12.6 which corresponds to a chloride concentration above 250 mg/l. The results of the TDEM study are in agreement with Navoy and Bradner (1987). The chloride-to-sulfate ratio at the site is 1:1 (Table 5.1-4). Accordingly, equation (4) is invalid.



—— BEST–FIT MODELED CURVE

□ APPARENT RESISTIVITY VALUES USED IN MODEL

X APPARENT RESISTIVITY VALUES NOT USED IN MODEL

ST. JOHNS RIVER WATER MANAGEMENT DISTRICT
PALATKA, FLORIDA

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MEASURED TDEM APPARENT RESISTIVITY AND EQUIVALENCE FOR 1–D INVERSION
SITE 1 – ITT SITE/RAYONIER
FLAGLER COUNTY, FLORIDA

DESIGNED BY:	CHR	PROJECT NO.:	1010045	FIGURE
CHECKED BY:	MJW	DRAWING NO.:	EQU–1	5.2–3
DRAWN BY:	SAB	DATE:	08/01/96	

DATA SET: SITE 1

CLIENT:	SJRWMD	DATE:	03-JUNE-96
LOCATION:	ITT SITE	SOUNDING:	1
COUNTY:	FLAGLER COUNTY	ELEVATION:	10.00 m
PROJECT:	SALTWATER INTERFACE DETECTION	EQUIPMENT:	Geonics PROTEM
LOOP SIZE:	305.000 m by 305.000 m	AZIMUTH:	
COIL LOC:	0.000 m (X), 0.000 m (Y)		

SOUNDING COORDINATES: E: 1.0000 N: 1.0000

FITTING ERROR: 3.301 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)		ELEVATION (meters)	CONDUCTANCE (Siemens)
				10.00	
1	41.31	46.30	*	-36.30	1.12
2	12.00	152.1		-188.4	12.67
3	2.80				

"*" INDICATES FIXED PARAMETER

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

LAYER		MINIMUM	BEST	MAXIMUM
RHO	1	37.344	41.315	46.163
	2	11.489	12.008	12.567
	3	2.387	2.803	3.343
THICK	1	46.300	0.000	46.300
	2	139.868	1.000	161.861
DEPTH	1	46.300	46.300	46.300
	2	186.168	198.443	208.161

CURRENT:	19.00 AMPS	EM-57		COIL AREA:	100.00 sq m.
FREQUENCY:	30.00 Hz	GAIN:	4	RAMP TIME:	227.00 muSEC

No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)
1	0.0867	94601.7	91852.7	2.90
2	0.108	82605.5	78910.1	4.47
3	0.138	68330.1	65590.6	4.00

ST. JOHNS RIVER WATER MANAGEMENT DISTRICT PALATKA, FLORIDA	SDII SUBSURFACE DETECTION INVESTIGATIONS INCORPORATED	TDEM SOUNDING DATA TABLE SITE 1 – ITT SITE/RAYONIER FLAGLER COUNTY, FLORIDA PROJECT NO.: 1010045 TABLE: 5.2–1

No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)
4	0.175	54996.4	53876.3	2.03
5	0.218	43779.9	44061.1	-0.642
6	0.278	33871.1	34397.8	-1.55
7	0.351	25191.9	26405.4	-4.81
8	0.438	18863.9	19972.3	-5.87
9	0.558	13411.7	14235.5	-6.14
10	0.702	9392.9	9955.0	-5.98
11	0.858	6828.2	7071.3	-3.56
12	1.06	4677.9	4741.5	-1.36
13	1.37	2943.2	2887.0	1.90
14	1.74	1813.2	1761.4	2.85

CURRENT: 19.00 AMPS EM-57 COIL AREA: 100.00 sq m.
FREQUENCY: 3.00 Hz GAIN: 8 RAMP TIME: 227.00 muSEC

No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)
15	0.857	6981.7	7192.4	-3.01
16	1.06	4876.4	4843.9	0.665
17	1.37	3084.8	2984.1	3.26
18	1.74	1924.2	1852.4	3.73
19	2.17	1225.4	1191.8	2.74
20	2.77	772.2	742.0	3.91
21	3.50	482.8	480.3	0.513
22	4.37	319.3	323.8	-1.40
23	5.56	208.4	213.7	-2.56
24	6.98	140.9	145.2	-3.04
25	8.56	101.8	102.4	-0.661
26	10.64	70.62	70.33	0.412
27	13.70	46.03	44.87	2.51
28	17.40	29.84	28.93	3.03
29	21.70	19.64	19.00	3.24
30	27.70	11.39	11.74	-3.07

PARAMETER RESOLUTION MATRIX:
"F" INDICATES FIXED PARAMETER

P 1	0.98				
P 2	0.00	1.00			
P 3	0.00	0.00	0.95		
F 1	0.00	0.00	0.00	0.00	
T 2	0.00	0.00	0.02	0.00	0.99
	P 1	P 2	P 3	F 1	T 2

ST. JOHNS RIVER WATER MANAGEMENT DISTRICT PALATKA, FLORIDA	SDII SUBSURFACE DETECTION INVESTIGATIONS INCORPORATED	TDEM SOUNDING DATA TABLE SITE 1 – ITT SITE/RAYONIER FLAGLER COUNTY, FLORIDA PROJECT NO.: 1010045 TABLE: 5.2–1

5.02.6. Summary of TDEM Sounding at ITT / Rayonier (Site 1)

- The depth to occurrence of salt water (5,000 mg/l isochlor) is interpreted to be 650 ft (-617 ft msl) and occurs near the base of the Upper Floridan aquifer.

- The ground water within the Floridan aquifer at this site is interpreted to contain an average chloride concentration above 250 mg/l. The 250 mg/l isochlor is not interpreted to be present within the Floridan aquifer.

- The results of the TDEM study are in agreement with Navoy and Bradner (1987).

5.03. TDEM Site 2 - Lake George WMA

5.03.1. Location Description and Geoelectrical Section

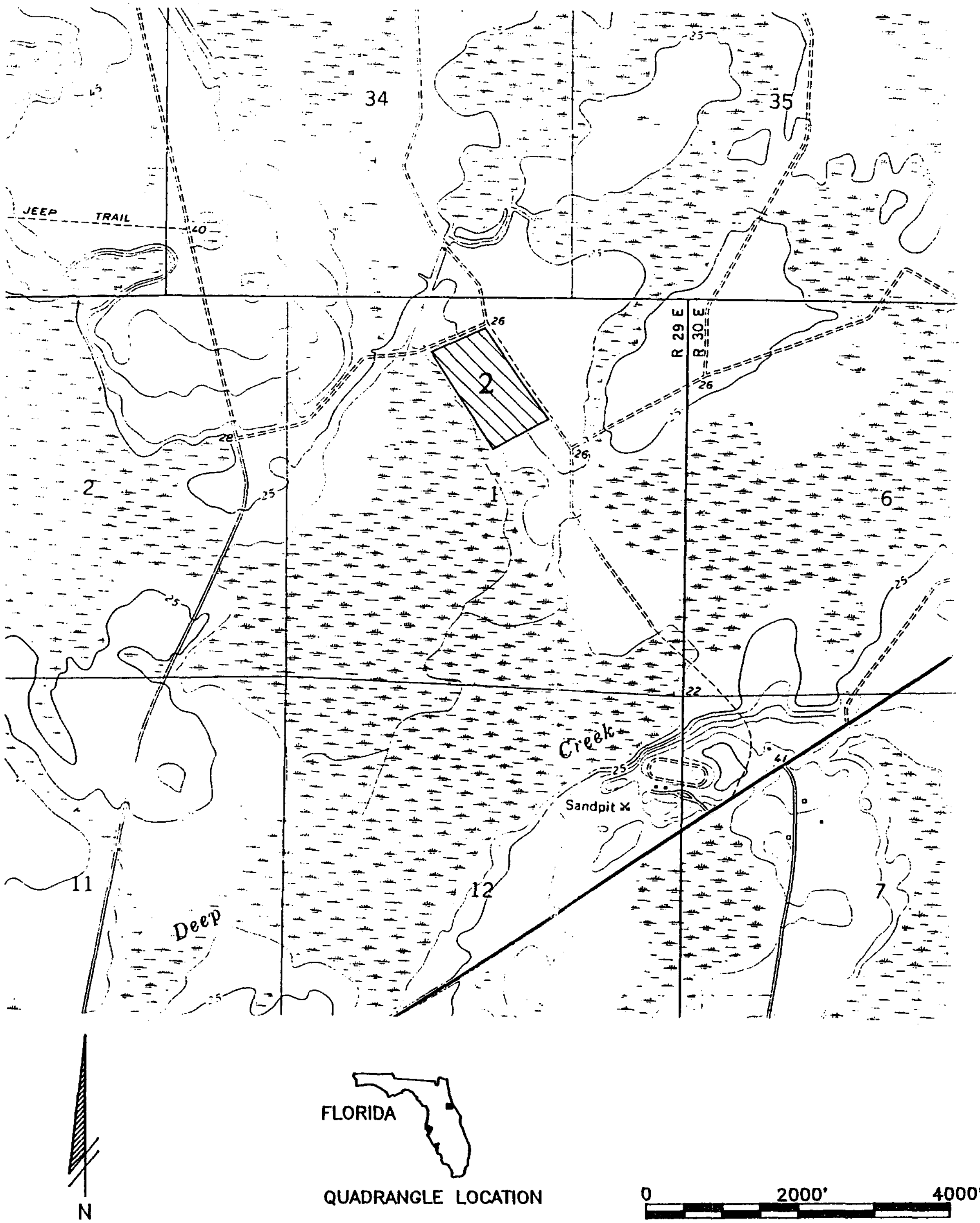
The site is located in north-central Volusia County, Florida (Figure 5.3-1). The site is located within a cleared tree farm. No possible sources of interference were observed within the vicinity of the site. QA soundings were performed 150 ft north and 55 ft east of the initial Rx coil location. Results from the QA soundings indicate that the apparent resistivity values were unaffected by any interference sources.

The Floridan aquifer occurs at an approximate depth of 80 ft bmsl or 105 ft bls (SJRWMD, personal communication) and is overlain by Holocene to Miocene deposits. The base of the Floridan aquifer occurs at approximately 2,020 ft bmsl (Tibbals, 1990). The thickness of the Upper Floridan aquifer is approximately 380 ft and the depth to the top of the Lower Floridan aquifer is approximately 780 ft bmsl (Miller, 1986). Chloride concentration in the upper portion of the Floridan aquifer ranges from 0 to 50 mg/l and the estimated maximum thickness of the freshwater-saturated Floridan aquifer is 600 ft in this area (Rutledge, 1985).

The resistivity sounding data and best-fit model inversion are presented on Figure 5.3-2. The interpreted geoelectrical section consists of a three-layer subsurface.

5.03.2. Geological Interpretation of Geoelectrical Model

The three-layered geoelectrical section consists of a low resistivity (46 ohm-m) upper layer which is considered to be Holocene to Miocene deposits above the Floridan aquifer. The thickness of Layer 1 was fixed at 32 m (105 ft, SJRWMD, personal communication). The second layer has only intermediate resistivity (70 ohm-m) which, because it is less than 80 ohm-m, suggests the Floridan aquifer at this site contains brackish water. The thickness of the brackish section is 253 m (830 ft), placing the depth to the low resistivity (saltwater) layer at 285 m (935 ft) below ground surface. The resistivity of the saltwater saturated layer is 1.9 ohm-m. Layer 1 is considered to be the



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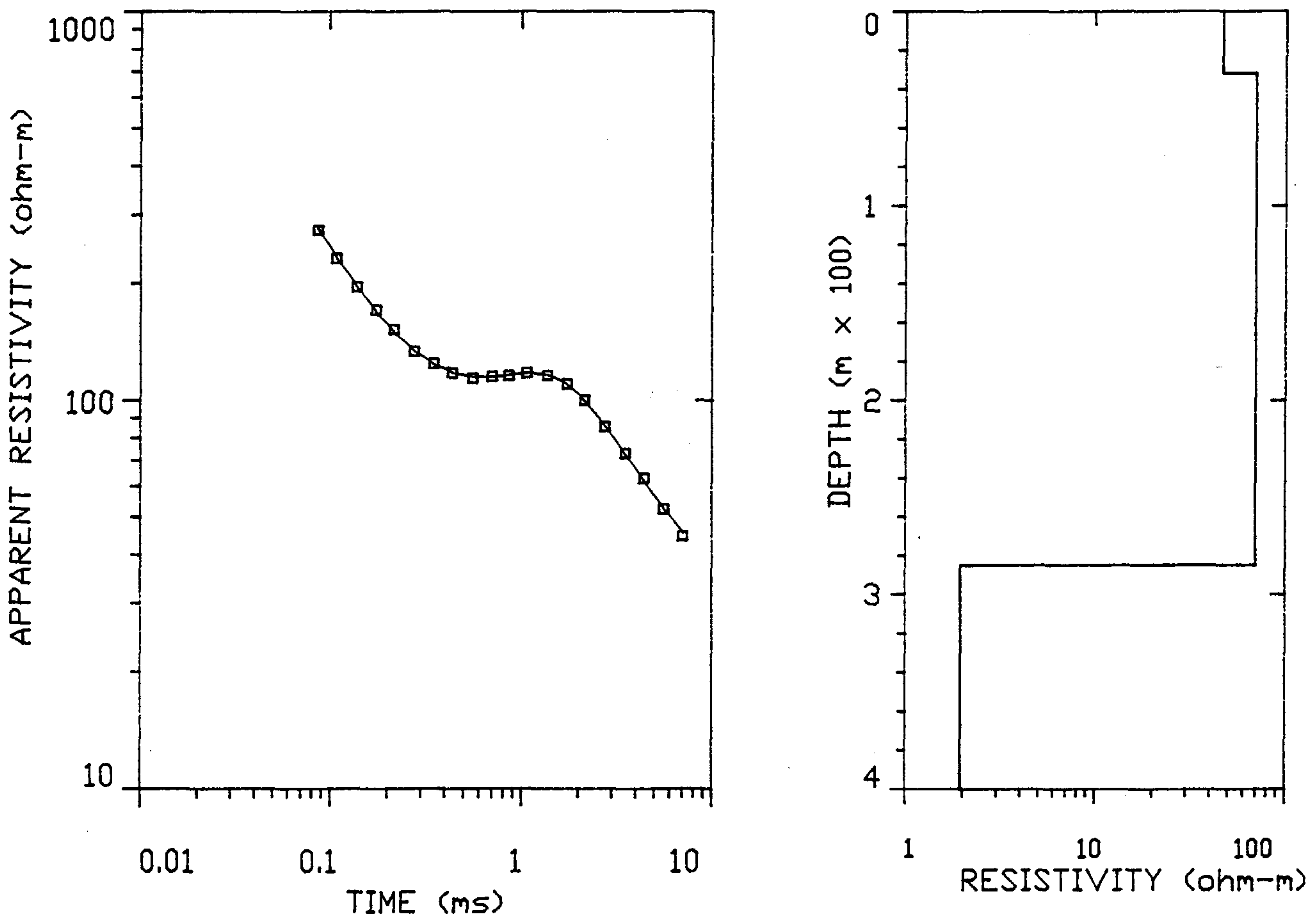
SUBSURFACE DETECTION INVESTIGATIONS INCORPORATED

TDEM SURVEY LOCATION MAP
SOUNDING 2 – LAKE GEORGE WMA SITE
VOLUSIA COUNTY, FLORIDA

DESIGNED BY: RJW	PROJECT NO.:	1010045	FIGURE
CHECKED BY: MJW	DRAWING NO.:	LOC–2	5.3–1
DRAWN BY: SAB	DATE:	08/01/96	



—— BEST-FIT MODELED CURVE

□ APPARENT RESISTIVITY VALUES USED IN MODEL

X APPARENT RESISTIVITY VALUES NOT USED IN MODEL

ST. JOHNS RIVER WATER MANAGEMENT DISTRICT
PALATKA, FLORIDA

SDII
SUBSURFACE DETECTION INVESTIGATIONS INCORPORATED

MEASURED TDEM APPARENT RESISTIVITY AND 1-D INVERSION
SITE 2 - LAKE GEORGE WMA SITE
VOLUSIA COUNTY, FLORIDA

DESIGNED BY:	CHR	PROJECT NO.:	1010045	FIGURE
CHECKED BY:	MJW	DRAWING NO.:	MDL-2	5.3-2
DRAWN BY:	SAB	DATE:	08/01/96	

Holocene to Miocene deposits above the Floridan aquifer, Layer 2 to be the Floridan aquifer (brackish), and Layer 3 to be the salt water within the Lower Floridan aquifer.

5.03.3. Depth to Occurrence of Salt Water

The bottom (third) layer of the geoelectrical model, with a resistivity of 1.9 ohm-m, is interpreted to represent salt water. It occurs at a depth of 935 ft (-910 ft msl). Because the resistivity of Layer 2 (70 ohm-m) is interpreted to represent brackish water within the Floridan aquifer (is less than 80 ohm-m), the interpreted depth to the 5,000 mg/l isochlor is equal to the depth of the geoelectrical interface, or at 935 ft depth (-910 ft msl). The resistivity of Layer 3 (1.9 ohm-m) corresponds to a chloride concentration of 16,775 mg/l assuming a porosity of 25% and the validity and applicability of equation (4) of Section 4.02. It is presumed that because of the expected high chlorinity gradients, this value is sufficiently close to the 5,000 mg/l isochlor that they represent the same effective depth.

5.03.4. Depth of Occurrence of the 250 mg/l Isochlor

The resistivity of Layer 2, 70 ohm-m, corresponds to a chloride concentration above 250 mg/l, assuming a 25% porosity and the validity and applicability of equation (4) of Section 4.02. As the interpreted chloride concentration exceeds 250 mg/l, the 250 mg/l isochlor does not occur within the Floridan aquifer at this site. This conclusion does not agree with Rutledge (1985) who estimated a maximum thickness of approximately 600 ft for water with a chloride concentration less than 250 mg/l in the Floridan aquifer in this area. The top of the Floridan aquifer occurs at an approximate depth of 80 ft bmsl or 105 ft bls at this site (SJRWMD, personal communication).

5.03.5. Accuracy of Measurement and Interpretation

Figure 5.3-3 is the equivalence analysis at this site and Table 5.3-1 lists the upper and lower bounds of the inverted parameters of the geoelectrical model.

The range of equivalence in determining the depth to the low resistivity layer is about ±4 m (13 ft) which is 1% of the total depth. The resistivity of this layer has a range from 1.6 to 2.2

ohm-m. This corresponds to a range in interpreted chloride concentration from 19,949 to 14,467 mg/l, again subject to the same assumptions of porosity and validity of equation (4).

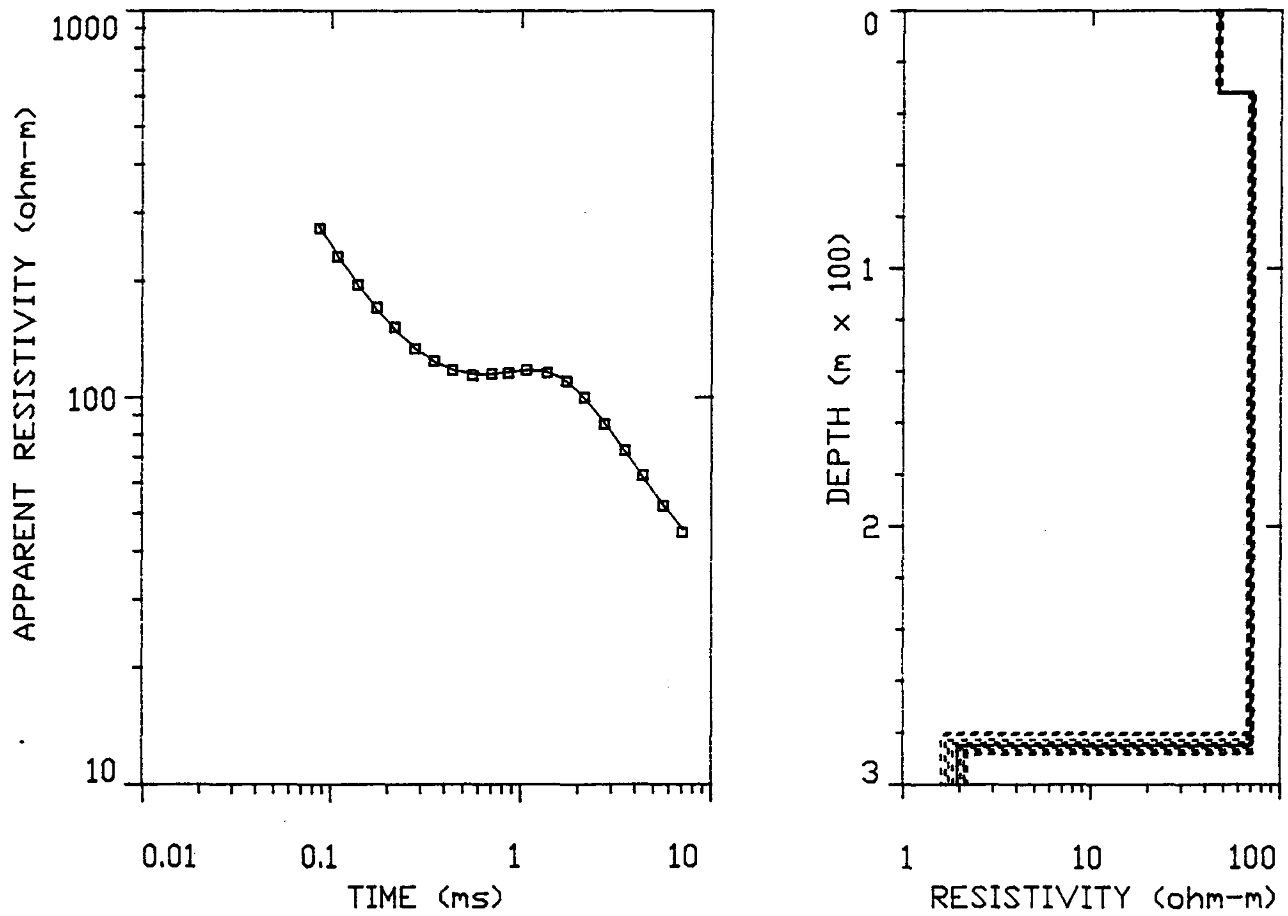
The equivalence range of the resistivity of Layer 2 is from 67 to 72 ohm-m which corresponds to a chloride concentration above 250 mg/l. The results of the TDEM study are not in agreement with Rutledge (1985). The chloride-to-sulfate ratio at the site is 5:1 (Table 5.1-4). Accordingly, equation (4) is valid. The discrepancy in the water quality results between the TDEM survey and Rutledge (1985) is probably due to the averaging of water quality in the Floridan aquifer by TDEM. There is not a sufficient resistivity contrast to locate the 250 mg/l isochlor at this site. As a consequence, TDEM yields an average resistivity for Layer 2. Rutledge (1985) estimated a maximum thickness of approximately 600 ft for water with a chloride concentration below 250 mg/l in this area. However, the thickness of Layer 2 is 830 ft.

5.03.6. Summary of TDEM Sounding at Lake George WMA (Site 2)

- The depth to occurrence of salt water (5,000 mg/l isochlor) is interpreted to be 935 ft (-910 ft msl) and occur within the Lower Floridan aquifer.

- The ground water within the Floridan aquifer at this site is interpreted to contain an average chloride concentration above 250 mg/l. The 250 mg/l isochlor is not interpreted to be present within the Floridan aquifer.

- The results of the TDEM study are not in agreement with Rutledge (1985) who estimated a maximum thickness of approximately 600 ft for water with a chloride concentration below 250 mg/l in the Floridan aquifer in this area.



—— BEST-FIT MODELED CURVE

□ APPARENT RESISTIVITY VALUES USED IN MODEL

X APPARENT RESISTIVITY VALUES NOT USED IN MODEL

ST. JOHNS RIVER WATER MANAGEMENT DISTRICT
PALATKA, FLORIDA

SDII
SUBSURFACE DETECTION INVESTIGATIONS INCORPORATED

MEASURED TDEM APPARENT RESISTIVITY AND EQUIVALENCE FOR 1-D INVERSION
SITE 2 – LAKE GEORGE WMA SITE
VOLUSIA COUNTY, FLORIDA

DESIGNED BY:	CHR	PROJECT NO.:	1010045	FIGURE
CHECKED BY:	MJW	DRAWING NO.:	EQU-2	5.3-3
DRAWN BY:	SAB	DATE:	08/01/96	

DATA SET: SITE 2

CLIENT:	SJRWMD	DATE:	04-JUNE-96
LOCATION:	LAKE GEORGE WMA	SOUNDING:	1
COUNTY:	VOLUSIA COUNTY	ELEVATION:	7.60 m
PROJECT:	SALTWATER INTERFACE DETECTION	EQUIPMENT:	Geonics PROTEM
LOOP SIZE:	480.000 m by 167.000 m	AZIMUTH:	
COIL LOC:	0.000 m (X), 0.000 m (Y)		
SOUNDING COORDINATES:	E: 0.0000	N:	0.0000

FITTING ERROR: 1.224 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)		ELEVATION (meters)	CONDUCTANCE (Siemens)
				7.60	
1	46.35	32.00	*	-24.40	0.690
2	69.73	252.8		-277.2	3.62
3	1.94				

"*" INDICATES FIXED PARAMETER

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

LAYER		MINIMUM	BEST	MAXIMUM
RHO	1	44.986	46.350	48.062
	2	66.874	69.736	72.034
	3	1.601	1.946	2.222
THICK	1	32.000	0.000	32.000
	2	247.997	1.000	256.174
DEPTH	1	32.000	32.000	32.000
	2	279.997	284.882	288.174

CURRENT:	18.40 AMPS	EM-57	COIL AREA:	100.00 sq m.
FREQUENCY:	30.00 Hz	GAIN: 4	RAMP TIME:	230.00 muSEC

No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)
1	0.0867	84381.0	82882.2	1.77
2	0.108	62667.9	61992.9	1.07
3	0.138	43672.0	43629.8	0.0965

ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT
PALATKA, FLORIDA

SDII
SUBSURFACE DETECTION INVESTIGATIONS INCORPORATED

TDEM SOUNDING DATA TABLE
SITE 2 – LAKE GEORGE WMA SITE
VOLUSIA COUNTY, FLORIDA

PROJECT NO.: 1010045
TABLE: 5.3–1

No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)
4	0.175	29648.5	30163.2	-1.73
5	0.218	20345.4	20858.8	-2.52
6	0.278	13441.6	13393.4	0.358
7	0.351	8367.3	8427.4	-0.719
8	0.438	5224.3	5220.6	0.0699
9	0.558	2987.0	2958.8	0.942
10	0.702	1655.4	1663.9	-0.510
11	0.858	996.8	988.6	0.822
12	1.06	564.4	563.3	0.191
13	1.37	308.9	306.3	0.841
14	1.74	183.5	184.1	-0.353
15	2.17	122.3	123.5	-0.936
16	2.77	83.97	84.14	-0.206
17	3.50	59.38	59.73	-0.599
18	4.37	42.58	43.41	-1.95
19	5.56	30.59	30.32	0.864
20	7.03	21.59	21.03	2.59

PARAMETER RESOLUTION MATRIX:
"F" INDICATES FIXED PARAMETER

P 1	0.96				
P 2	0.03	0.97			
P 3	0.06	-0.09	0.60		
F 1	0.00	0.00	0.00	0.00	
T 2	0.00	-0.01	-0.03	0.00	1.00
	P 1	P 2	P 3	F 1	T 2

ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT
PALATKA, FLORIDA

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SUBSURFACE
DETECTION
INVESTIGATIONS
INCORPORATED

TDEM SOUNDING DATA TABLE
SITE 2 – LAKE GEORGE WMA SITE
VOLUSIA COUNTY, FLORIDA

PROJECT NO.: 1010045
TABLE: 5.3–1

5.04. TDEM Site 3 - Juniper Springs ONF

5.04.1. Location Description and Geoelectrical Section

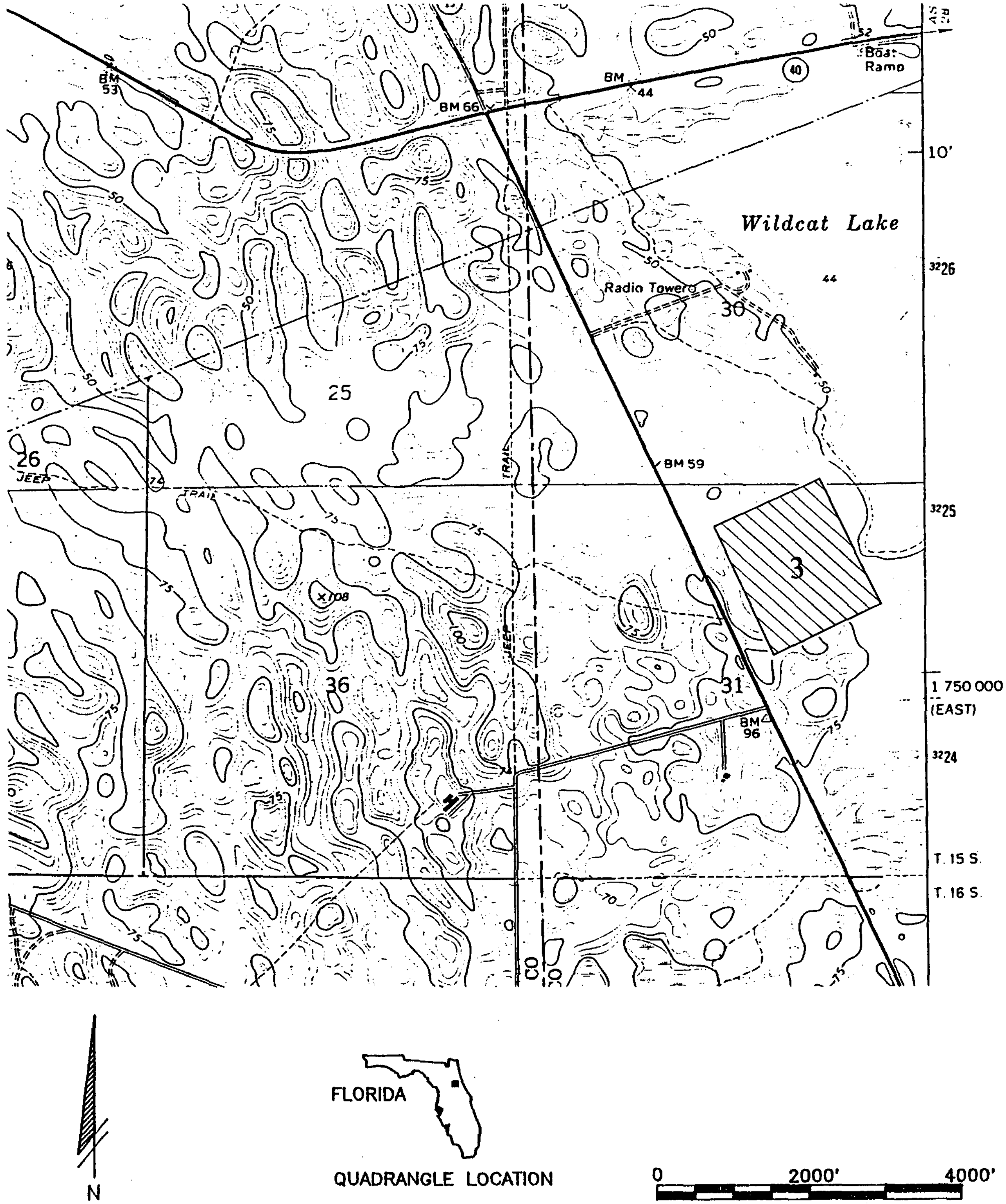
The site is located in north Lake County (Figure 5.4-1). The site was in an open field with low-lying brush. No sources of interference were observed within the vicinity of the site. QA soundings were performed 100 ft west and south of the initial Rx coil location. Results from the QA soundings indicate that the apparent resistivity values were unaffected by any interference sources.

The Floridan aquifer occurs at an approximate depth of 40 ft bmsl or 120 ft bls and is overlain by Holocene to Miocene deposits (SJRWMD, personal communication). The base of the Floridan aquifer occurs at approximately 1,900 ft bmsl (Tibbals, 1990). The thickness of the Upper Floridan aquifer is approximately 300 ft and the depth to the top of the Lower Floridan aquifer is approximately 500 ft bmsl (Miller, 1986).

The resistivity sounding data and best-fit model inversion are presented on Figure 5.4-2. The interpreted geoelectrical section consists of a three-layer subsurface.

5.04.2. Geological Interpretation of Geoelectrical Model

The three-layer geoelectrical section consists of an upper layer with a resistivity of 137 ohm-m which correlates with the Holocene to Miocene deposits above the Floridan aquifer. The thickness of Layer 1 was fixed at 36 m (118 ft, SJRWMD, personal communication). The second layer has high resistivity (279 ohm-m) which means that because it is greater than 80 ohm-m the Floridan aquifer at this site contains fresh water. The thickness of the freshwater section is 520 m (1,706 ft), placing the depth to the low resistivity (saltwater) layer at 557 m (1,828 ft) below ground surface. The resistivity of the saltwater layer is 16.9 ohm-m. Layer 1 is considered to be the Holocene to Miocene deposits above the Floridan aquifer, Layer 2 to be the Floridan aquifer containing fresh water, and Layer 3 to be the salt water near the base of the Lower Floridan aquifer.



ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT
PALATKA, FLORIDA

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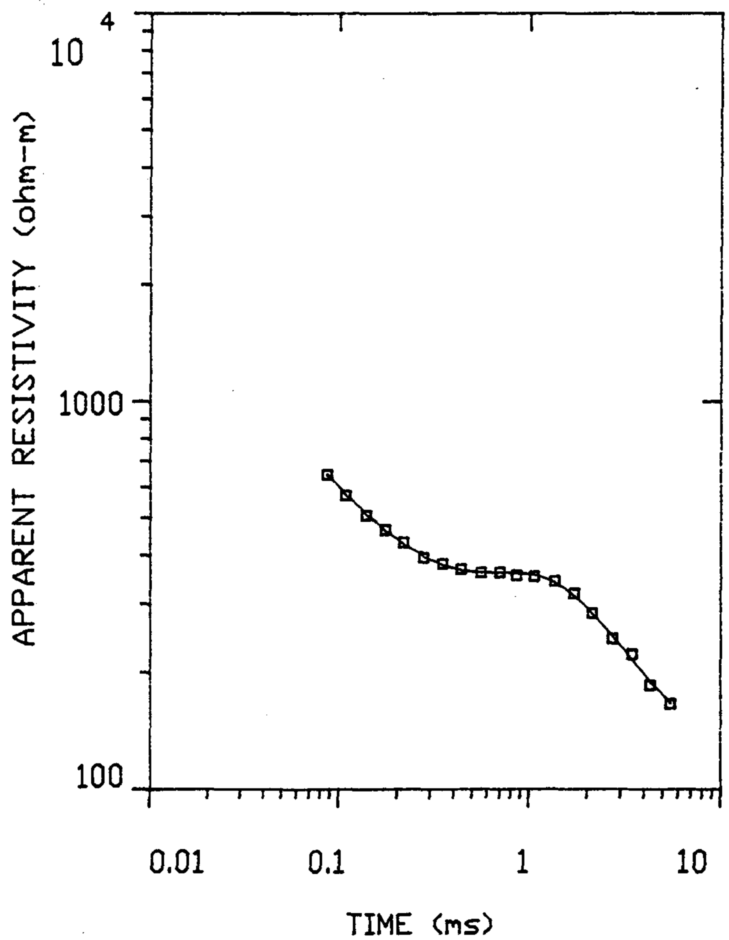
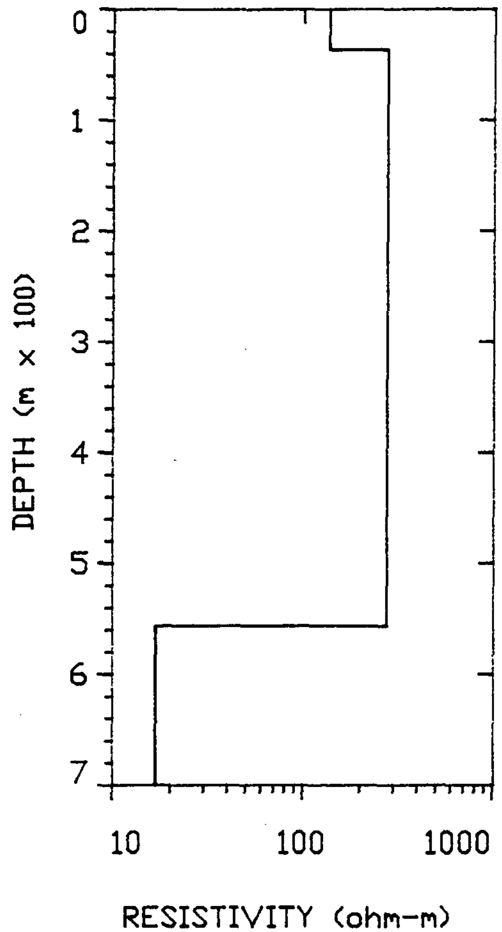
SUBSURFACE DETECTION INVESTIGATIONS INCORPORATED

TDEM SURVEY LOCATION MAP
SOUNDING 3 – JUNIPER SPRINGS ONF SITE
LAKE COUNTY, FLORIDA

DESIGNED BY: RJW	PROJECT NO.:	1010045	FIGURE
CHECKED BY: MJW	DRAWING NO.:	LOC–3	5.4–1
DRAWN BY: SAB	DATE:	08/01/96	





—— BEST-FIT MODELED CURVE

□ APPARENT RESISTIVITY VALUES USED IN MODEL

X APPARENT RESISTIVITY VALUES NOT USED IN MODEL

ST. JOHNS RIVER WATER MANAGEMENT DISTRICT
PALATKA, FLORIDA

SDII
SUBSURFACE DETECTION INVESTIGATIONS INCORPORATED

MEASURED TDEM APPARENT RESISTIVITY AND 1-D INVERSION
SITE 3 - JUNIPER SPRINGS ONF SITE
LAKE COUNTY, FLORIDA

DESIGNED BY:	CHR	PROJECT NO.:	1010045	FIGURE
CHECKED BY:	MJW	DRAWING NO.:	MDL-3	5.4-2
DRAWN BY:	SAB	DATE:	08/01/96	

5.04.3. Depth to Occurrence of Salt Water

The bottom (third) layer of the geoelectrical model, with a resistivity of 16.9 ohm-m, is interpreted to represent salt water. It occurs at a depth of 1,828 ft (-1,748 ft msl). Because the resistivity of Layer 2 (279 ohm-m) is greater than 80 ohm-m, the interpreted depth to the 5,000 mg/l isochlor is taken as 50 ft greater than the depth of the geoelectrical interface, or at a depth of 1,878 ft (-1,798 ft bmsl). The resistivity of Layer 3 (16.9 ohm-m) corresponds to a chloride concentration of 1,750 mg/l, assuming a porosity of 25% and the validity and applicability of equation (4) of Section 4.02. It is presumed that because of the expected high chlorinity gradients, this value is sufficiently close to the 5,000 mg/l isochlor that they represent the same effective depth.

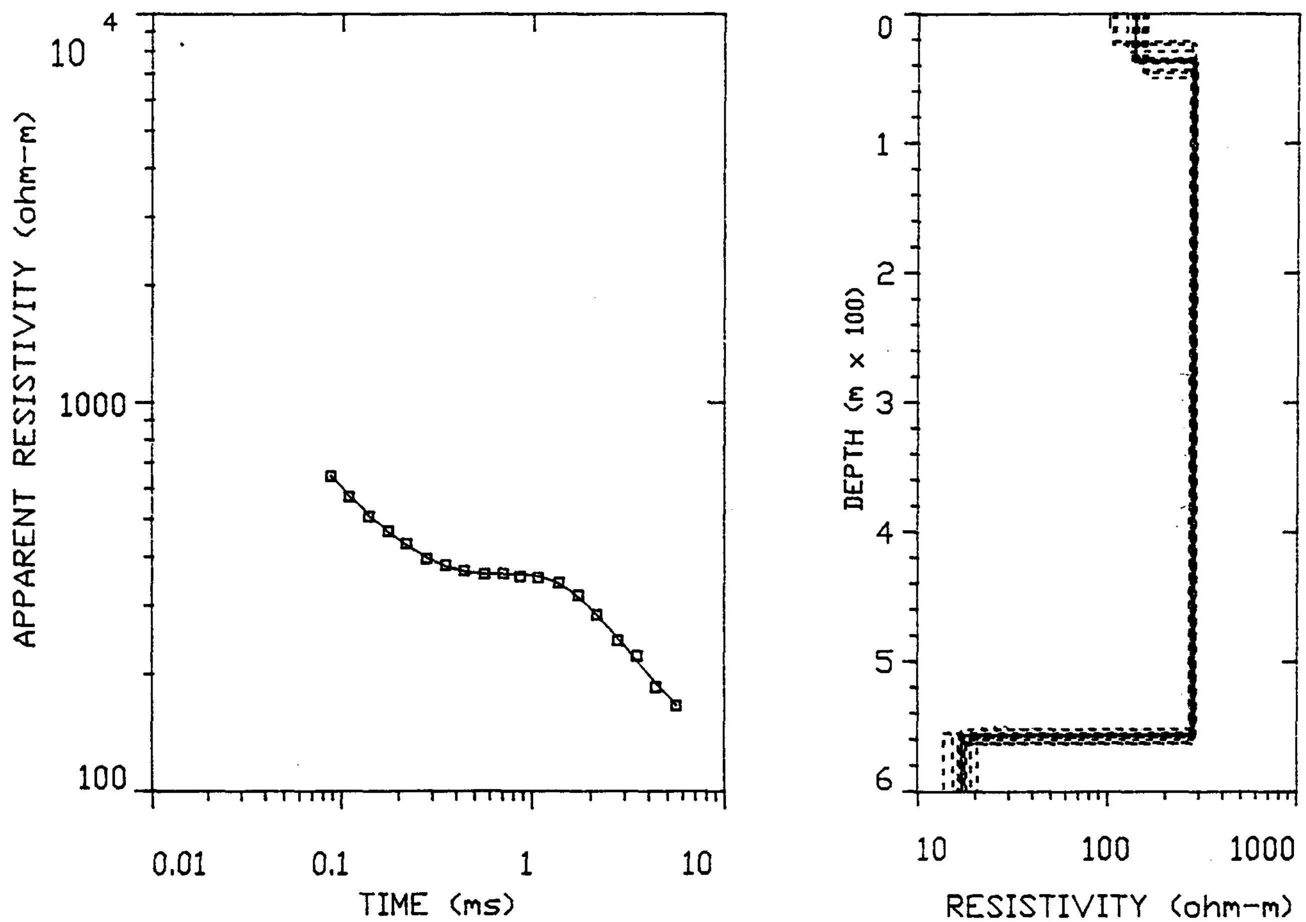
5.04.4. Depth of Occurrence of the 250 mg/l Isochlor

The resistivity of Layer 2 (279 ohm-m) corresponds to a chloride concentration of less than 250 mg/l, assuming a 25% porosity and the validity and applicability of equation (4) of Section 4.02. The 250 mg/l isochlor is placed in the Floridan aquifer at a depth 50 ft above the Layer 3 interface or at 1,778 ft (-1,698 ft msl).

5.04.5. Accuracy of Measurement and Interpretation

Figure 5.4-3 is the equivalence analysis at this site and the inversion table (Table 5.4-1) lists the upper and lower bounds of the inverted parameters of the geoelectrical model.

The range of equivalence in determining the depth to the low resistivity layer is about ±6 m (20 ft) which is 1% of the total depth. The resistivity of this layer has a range of from 13.5 to 20.4 ohm-m. This corresponds to a range in interpreted chloride concentration of from 2,229 to 1,424 mg/l, again subject to the same assumptions of porosity and validity of equation (4).



—— BEST-FIT MODELED CURVE

□ APPARENT RESISTIVITY VALUES USED IN MODEL

X APPARENT RESISTIVITY VALUES NOT USED IN MODEL

ST. JOHNS RIVER WATER MANAGEMENT DISTRICT PALATKA, FLORIDA	SDII SUBSURFACE DETECTION INVESTIGATIONS INCORPORATED	MEASURED TDEM APPARENT RESISTIVITY AND EQUIVALENCE FOR 1-D INVERSION SITE 3 - JUNIPER SPRINGS ONF SITE LAKE COUNTY, FLORIDA	
		DESIGNED BY: CHR CHECKED BY: MJW DRAWN BY: SAB	PROJECT NO.: 1010045 DRAWING NO.: EQU-3 DATE: 08/01/96
		FIGURE 5.4-3	

DATA SET: SITE 3

CLIENT:	SJRWMD	DATE:	04-JUNE-96
LOCATION:	JUNIPER SPRINGS ONF	SOUNDING:	1
COUNTY:	LAKE COUNTY	ELEVATION:	24.50 m
PROJECT:	SALTWATER INTERFACE DETECTION	EQUIPMENT:	Geonics PROTEM
LOOP SIZE:	305.000 m by 305.000 m	AZIMUTH:	

COIL LOC: 0.000 m (X), 0.000 m (Y)
SOUNDING COORDINATES: E: 0.0000 N: 0.0000

FITTING ERROR: 1.785 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	CONDUCTANCE (Siemens)
			24.50	
1	136.9	36.41	-11.91	0.265
2	278.7	520.2	-532.1	1.86
3	16.87			

ALL PARAMETERS ARE FREE

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

LAYER		MINIMUM	BEST	MAXIMUM
RHO	1	104.673	136.963	158.373
	2	268.201	278.732	289.587
	3	13.523	16.873	20.407
THICK	1	21.830	-8.467	49.886
	2	505.902	1.000	540.638
DEPTH	1	21.830	36.415	49.886
	2	552.062	556.687	563.256

CURRENT:	20.00 AMPS	EM-57	COIL AREA:	100.00 sq m.
FREQUENCY:	30.00 Hz	GAIN: 6	RAMP TIME:	230.00 muSEC

No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)
1	0.0867	25659.7	25612.2	0.185
2	0.108	17814.2	17644.1	0.955
3	0.138	11525.3	11408.0	1.01

ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT
PALATKA, FLORIDA

SDII
SUBSURFACE DETECTION INVESTIGATIONS INCORPORATED

TDEM SOUNDING DATA TABLE
SITE 3 – JUNIPER SPRINGS ONF SITE
LAKE COUNTY, FLORIDA

PROJECT NO.: 1010045
TABLE: 5.4–1

No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)
4	0.175	7257.6	7321.2	-0.875
5	0.218	4678.5	4766.3	-1.87
6	0.278	2915.0	2890.0	0.857
7	0.351	1721.4	1742.0	-1.19
8	0.438	1037.6	1048.4	-1.03
9	0.558	584.8	584.2	0.0938
10	0.702	328.3	329.1	-0.242
11	0.858	204.0	199.7	2.11
12	1.06	119.8	117.8	1.61
13	1.37	66.87	67.44	-0.850
14	1.74	41.08	41.72	-1.54
15	2.17	28.19	28.24	-0.179
16	2.77	19.19	18.80	2.02
17	3.50	12.29	12.90	-4.97
18	4.37	9.29	8.98	3.36
19	5.56	5.99	5.96	0.520

PARAMETER RESOLUTION MATRIX:
"F" INDICATES FIXED PARAMETER

P 1	0.79				
P 2	0.02	0.98			
P 3	0.04	-0.06	0.59		
T 1	-0.33	-0.03	-0.06	0.28	
T 2	0.02	0.00	0.00	0.05	0.99
	P 1	P 2	P 3	T 1	T 2

ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT
PALATKA, FLORIDA

SDII
SUBSURFACE DETECTION INVESTIGATIONS INCORPORATED

TDEM SOUNDING DATA TABLE
SITE 3 – JUNIPER SPRINGS ONF SITE
LAKE COUNTY, FLORIDA

PROJECT NO.: 1010045
TABLE: 5.4–1

The equivalence range of the resistivity of Layer 2 is from 268 to 290 ohm-m which corresponds to a chloride concentration of less than 250 mg/l. The chloride-to-sulfate ratio at the site is 5:1 (Table 5.1-4). Accordingly, Equation (4) is valid.

5.04.6. Summary of TDEM Sounding at Juniper Springs ONF (Site 3)

- The depth to occurrence of salt water (5,000 mg/l isochlor) is interpreted to be 1,878 ft (-1,798 ft msl) and occur near the base of the Lower Floridan aquifer.

- The ground water within the Floridan aquifer at this site is interpreted to contain an average chloride concentration of less than 250 mg/l. The 250 mg/l isochlor is interpreted to be present in the Floridan aquifer at a depth of 1,778 ft (-1,698 ft msl).

5.05. TDEM Site 4 - Alexander Springs ONF

5.05.1. Location Description and Geoelectrical Section

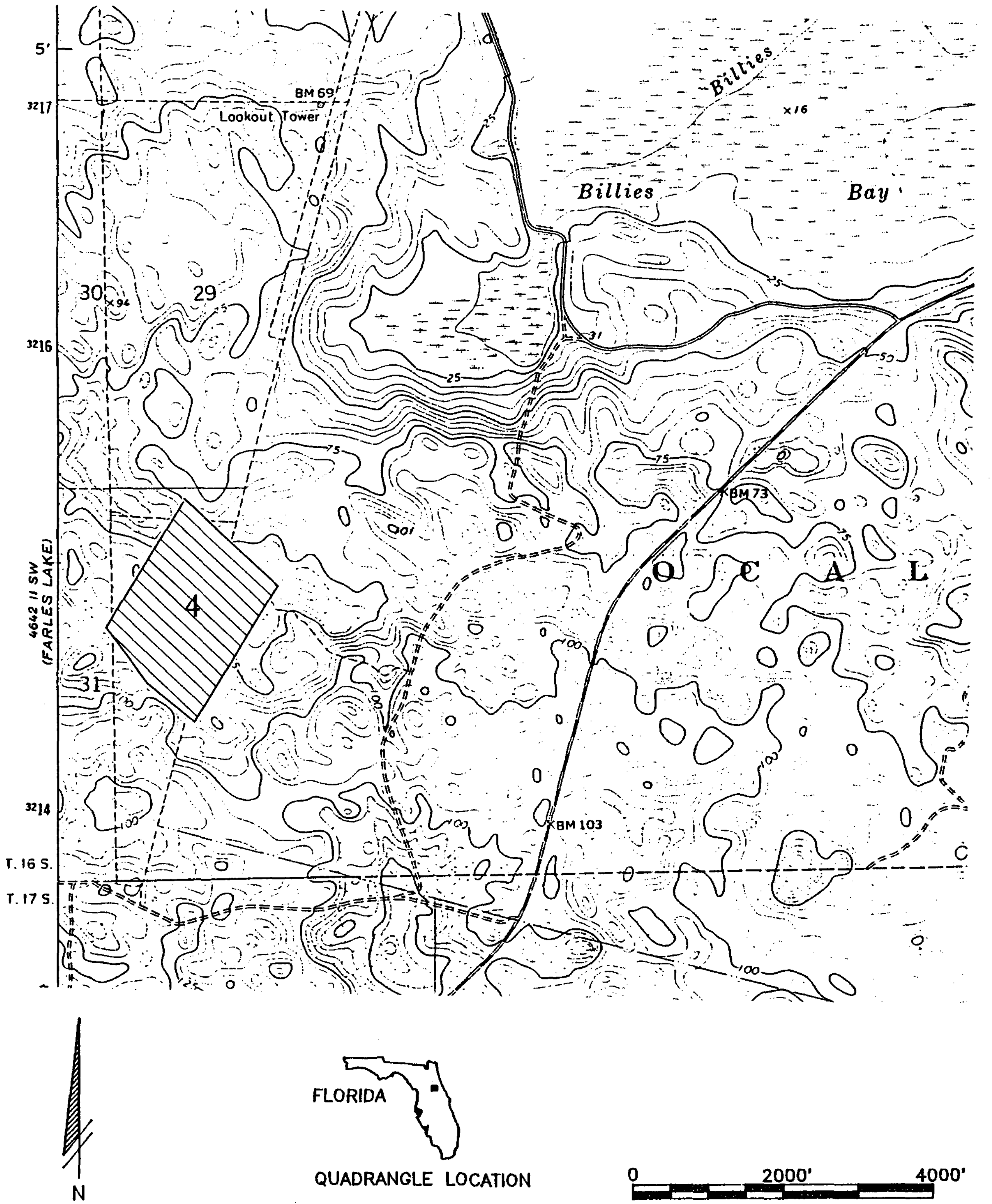
The site is located in north Lake County (Figure 5.5-1). The site was located in a cleared tree farm. No sources of interference were observed within the vicinity of the site. QA soundings were performed 100 ft east and south of the initial Rx coil location. Results from the QA soundings indicate that the apparent resistivity values were unaffected by any interference sources.

The Floridan aquifer occurs at an approximate depth of 60 ft bmsl or 130 ft bls and is overlain by Holocene to Miocene deposits (SJRWMD, personal communication). The base of the Floridan aquifer occurs at approximately 1,950 ft bmsl (Tibbals, 1990). The thickness of the Upper Floridan aquifer is approximately 320 ft and the depth to the top of the Lower Floridan aquifer is approximately 550 ft bmsl (Miller, 1986).

The resistivity sounding data and best-fit model inversion are presented on Figure 5.5-2. The interpreted geoelectrical section consists of a three-layer subsurface.

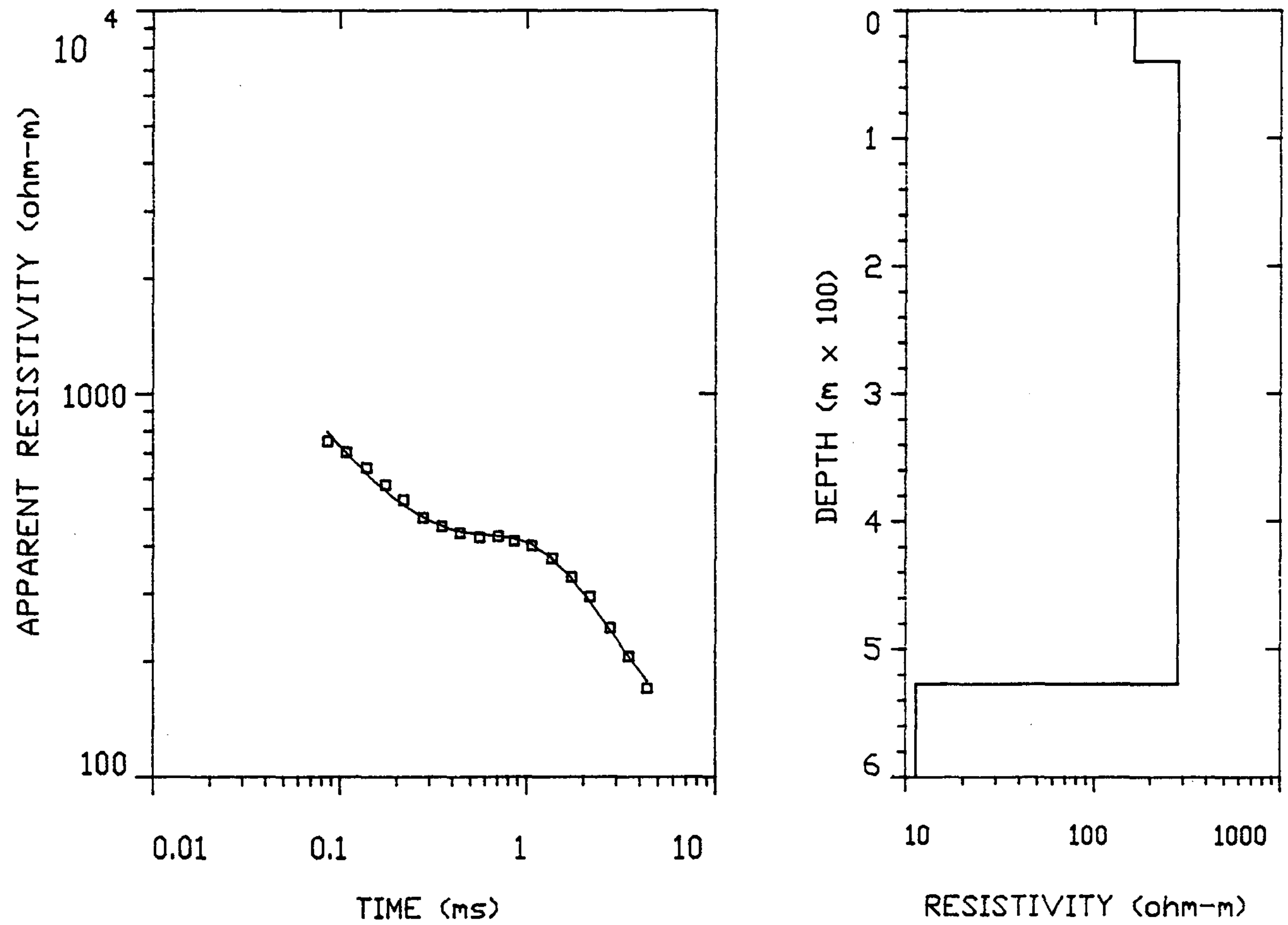
5.05.2. Geological Interpretation of Geoelectrical Model

The three-layer geoelectrical section consists of an upper layer with a resistivity of 163 ohm-m which correlates with the Holocene to Miocene deposits above the Floridan aquifer. The thickness of Layer 1 was fixed at 40 m (131 ft, SJRWMD, personal communication). The second layer has high resistivity (281 ohm-m) which means that because it is greater than 80 ohm-m the Floridan aquifer at this site contains fresh water. The thickness of the freshwater section is 487 m (1,598 ft) placing the depth to the low resistivity (saltwater) layer at 527 m (1,729 ft) below ground surface. The resistivity of the saltwater layer is 11.2 ohm-m. Layer 1 is considered to be the Holocene to Miocene deposits above the Floridan aquifer, Layer 2 to be the Floridan aquifer containing fresh water, and Layer 3 to be the salt water within the Lower Floridan aquifer.



ST. JOHNS RIVER WATER MANAGEMENT DISTRICT PALATKA, FLORIDA	SDII SUBSURFACE DETECTION INVESTIGATIONS INCORPORATED	TDEM SURVEY LOCATION MAP SOUNDING 4 – ALEXANDER SPRINGS ONF SITE LAKE COUNTY, FLORIDA

DESIGNED BY:	RJW	PROJECT NO.:	1010045	FIGURE
CHECKED BY:	MJW	DRAWING NO.:	LOC–4	5.5–1
DRAWN BY:	SAB	DATE:	08/01/96	



—— BEST–FIT MODELED CURVE

□ APPARENT RESISTIVITY VALUES USED IN MODEL

X APPARENT RESISTIVITY VALUES NOT USED IN MODEL

ST. JOHNS RIVER WATER MANAGEMENT DISTRICT
PALATKA, FLORIDA

SDII
SUBSURFACE DETECTION INVESTIGATIONS INCORPORATED

MEASURED TDEM APPARENT RESISTIVITY AND 1–D INVERSION
SITE 4 – ALEXANDER SPRINGS ONF SITE
LAKE COUNTY, FLORIDA

DESIGNED BY:	CHR	PROJECT NO.:	1010045	FIGURE
CHECKED BY:	MJW	DRAWING NO.:	MDL–4	5.5–2
DRAWN BY:	SAB	DATE:	08/01/96	

5.05.3. Depth to Occurrence of Salt Water

The bottom (third) layer of the geoelectrical model, with a resistivity of 11.2 ohm-m, is interpreted to represent salt water. It occurs at a depth of 1,729 ft (-1,660 ft msl). Because the resistivity of Layer 2 (281 ohm-m) is greater than 80 ohm-m, the interpreted depth to the 5,000 mg/l isochlor is taken as 50 ft greater than the depth of the geoelectrical interface, or at a depth of 1,779 ft (-1,710 ft bmsl). The resistivity of Layer 3 (11.2 ohm-m) corresponds to a chloride concentration of 2,719 mg/l, assuming a porosity of 25% and the validity and applicability of equation (4) of Section 4.02. It is presumed that because of the expected high chlorinity gradients, this value is sufficiently close to the 5,000 mg/l isochlor that they represent the same effective depth.

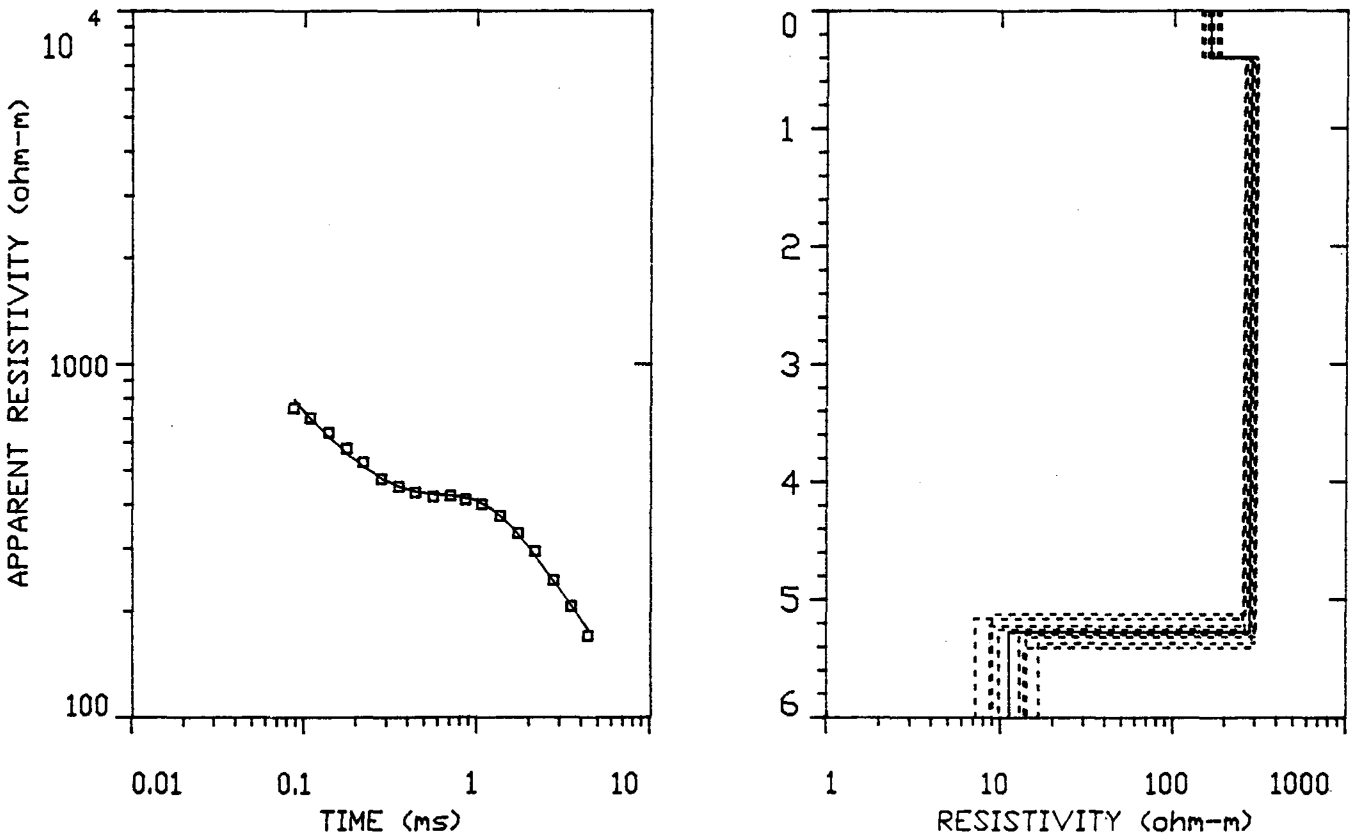
5.05.4. Depth of Occurrence of the 250 mg/l Isochlor

The resistivity of Layer 2,281 ohm-m, corresponds to a chloride concentration of less than 250 mg/l, assuming a 25% porosity and the validity and applicability of equation (4) of Section 4.02. The 250 mg/l isochlor is placed in the Floridan aquifer at a depth 50 ft above the Layer 3 interface or at 1,679 ft (-1,610 ft msl).

5.05.5. Accuracy of Measurement and Interpretation

Figure 5.5-3 is the equivalence analysis at this site and the inversion table (Table 5.5-1) lists the upper and lower bounds of the inverted parameters of the geoelectrical model.

The range of equivalence in determining the depth to the low resistivity layer is about ±14 m (46 ft) which is 3% of the total depth. The resistivity of this layer has a range of from 7.2 to 16.6 ohm-m. This corresponds to a range in interpreted chloride concentration of from 4,314 to 1,785 mg/l, again subject to the same assumptions of porosity and validity of equation (4).



—— BEST–FIT MODELED CURVE

□ APPARENT RESISTIVITY VALUES USED IN MODEL

X APPARENT RESISTIVITY VALUES NOT USED IN MODEL

ST. JOHNS RIVER WATER MANAGEMENT DISTRICT
PALATKA, FLORIDA

SDII
SUBSURFACE DETECTION INVESTIGATIONS INCORPORATED

MEASURED TDEM APPARENT RESISTIVITY AND EQUIVALENCE FOR 1–D INVERSION
SITE 4 – ALEXANDER SPRINGS ONF SITE
LAKE COUNTY, FLORIDA

DESIGNED BY:	CHR	PROJECT NO.:	1010045	FIGURE
CHECKED BY:	MJW	DRAWING NO.:	EQU–4	5.5–3
DRAWN BY:	SAB	DATE:	08/01/96	

DATA SET: SITE 4

CLIENT:	SJRWMD	DATE:	05-JUNE-96
LOCATION:	ALEXANDER SPRINGS ONF	SOUNDING:	1
COUNTY:	LAKE COUNTY	ELEVATION:	21.00 m
PROJECT:	SALTWATER INTERFACE DETECTION	EQUIPMENT:	Geonics PROTEM
		AZIMUTH:	

LOOP SIZE: 274.000 m by 267.000 m
COIL LOC: 0.000 m (X), 0.000 m (Y)
SOUNDING COORDINATES: E: 0.0000 N: 0.0000

FITTING ERROR: 3.501 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)		ELEVATION (meters)	CONDUCTANCE (Siemens)
				21.00	
1	162.7	40.00	*	-19.00	0.245
2	281.4	487.4		-506.4	1.73
3	11.22				

"*" INDICATES FIXED PARAMETER

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

LAYER		MINIMUM	BEST	MAXIMUM
RHO	1	144.249	162.753	186.254
	2	257.701	281.454	304.557
	3	7.176	11.225	16.613
THICK	1	40.000	0.000	40.000
	2	472.407	1.000	501.083
DEPTH	1	40.000	40.000	40.000
	2	512.407	527.436	541.083

CURRENT:	17.00 AMPS	EM-57		COIL AREA:	100.00 sq m.
FREQUENCY:	30.00 Hz	GAIN:	7	RAMP TIME:	302.00 muSEC

No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)
1	0.0867	13720.6	12633.0	7.92
2	0.108	8724.2	8751.8	-0.317
3	0.138	5447.0	5707.0	-4.77

ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT
PALATKA, FLORIDA

SDII
SUBSURFACE DETECTION INVESTIGATIONS INCORPORATED

TDEM SOUNDING DATA TABLE
SITE 4 – ALEXANDER SPRINGS ONF SITE
LAKE COUNTY, FLORIDA

PROJECT NO.: 1010045
TABLE: 5.5–1

No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)
4	0.175	3514.1	3700.4	-5.30
5	0.218	2326.5	2428.4	-4.38
6	0.278	1488.2	1483.3	0.329
7	0.351	896.7	896.4	0.0238
8	0.438	546.5	540.5	1.09
9	0.558	310.4	302.7	2.46
10	0.702	173.1	172.9	0.160
11	0.858	109.3	106.9	2.14
12	1.06	66.35	65.59	1.15
13	1.37	39.73	39.70	0.0872
14	1.74	25.86	26.20	-1.29
15	2.17	17.76	18.58	-4.58
16	2.77	12.82	13.00	-1.45
17	3.50	9.22	9.22	-0.0388
18	4.37	7.04	6.61	6.16

PARAMETER RESOLUTION MATRIX:
"F" INDICATES FIXED PARAMETER

P 1	0.92				
P 2	0.04	0.97			
P 3	0.10	-0.08	0.54		
F 1	0.00	0.00	0.00	0.00	
T 2	0.00	0.00	-0.02	0.00	1.00
	P 1	P 2	P 3	F 1	T 2

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WATER MANAGEMENT DISTRICT
PALATKA, FLORIDA

SDII
SUBSURFACE DETECTION INVESTIGATIONS INCORPORATED

TDEM SOUNDING DATA TABLE
SITE 4 – ALEXANDER SPRINGS ONF SITE
LAKE COUNTY, FLORIDA

PROJECT NO.: 1010045
TABLE: 5.5–1

The equivalence range of the resistivity of Layer 2 is from 258 to 305 ohm-m which corresponds to a chloride concentration of less than 250 mg/l. The chloride-to-sulfate ratio at the site is 5:1 (Table 5.1-4). Accordingly, Equation (4) is valid.

5.05.6. Summary of TDEM Sounding at Alexander Springs ONF (Site 4)

- The depth to occurrence of salt water (5,000 mg/l isochlor) is interpreted to be 1,779 ft (-1,710 ft msl) and occur within the Lower Floridan aquifer.
- The ground water within the Floridan aquifer at this site is interpreted to contain an average chloride concentration of less than 250 mg/l. The 250 mg/l isochlor is interpreted to be present in the Floridan aquifer at a depth of 1,679 ft (-1,610 ft msl).

5.06. TDEM Site 5 - Sorrento

5.06.1. Location Description and Geoelectrical Section

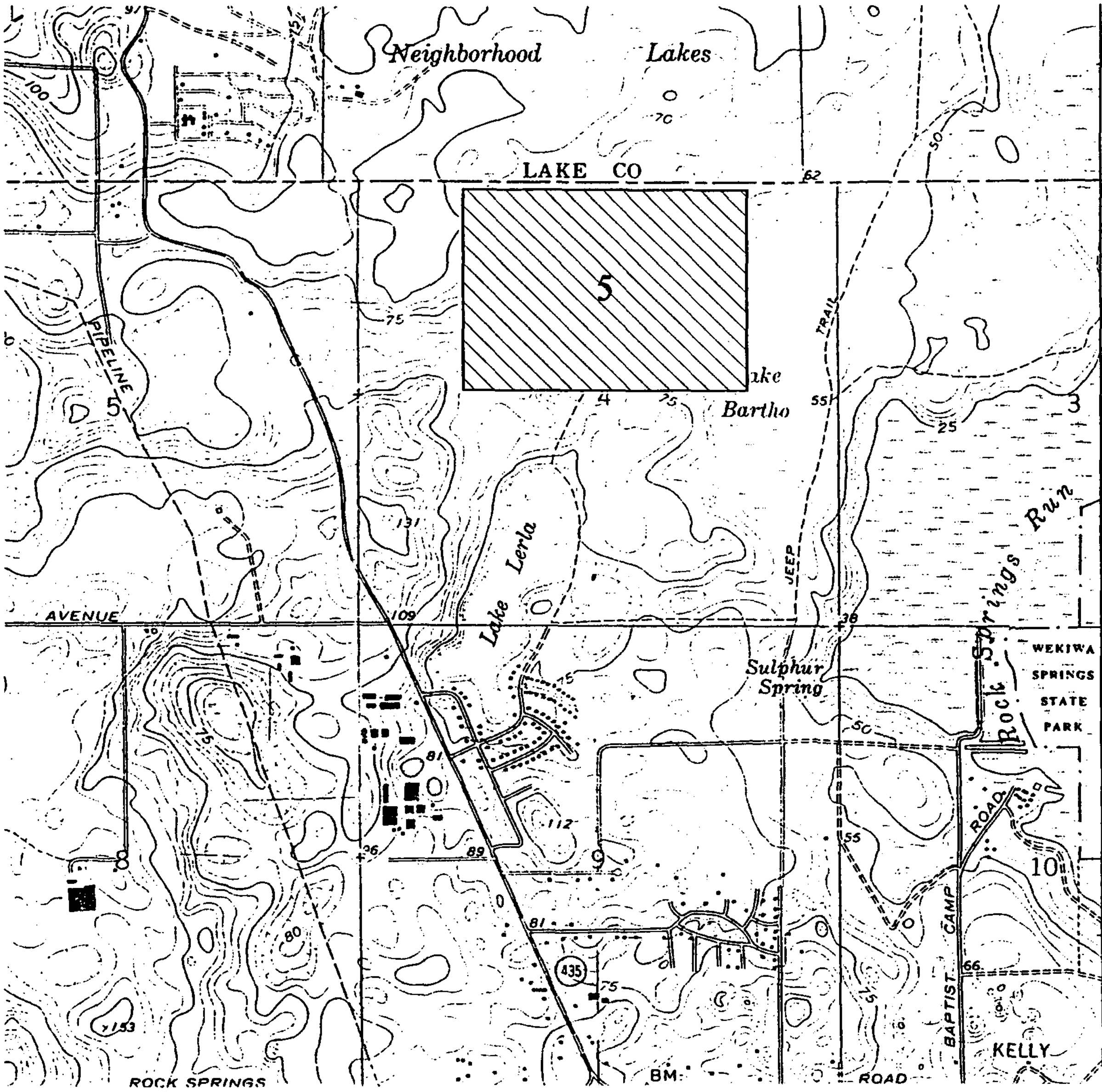
The site is located in northwest Orange County (Figure 5.6-1). The site was an abandoned orange grove. No sources of interference were observed within the vicinity of the site. QA soundings were performed 120 ft west and 150 ft south of the initial Rx coil location. Results from the QA soundings indicate that the apparent resistivity values were unaffected by any interference sources.

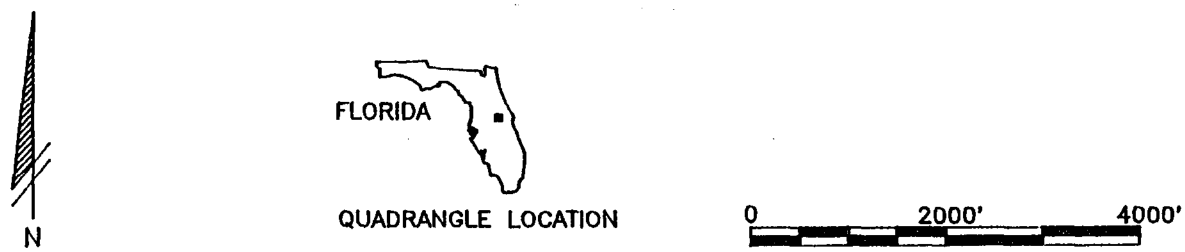
The Floridan aquifer occurs at an approximate depth of 20 ft bmsl or 105 ft bls and is overlain by Holocene to Miocene deposits (SJRWMD, personal communication). The base of the Floridan aquifer occurs at approximately 2,050 ft bmsl (Tibbals, 1990). The thickness of the Upper Floridan aquifer is approximately 320 ft and the depth to the top of the Lower Floridan aquifer is approximately 700 ft bmsl (Miller, 1986).

The resistivity sounding data and best-fit model inversion are presented on Figure 5.6-2. The interpreted geoelectrical section consists of a three-layer subsurface.

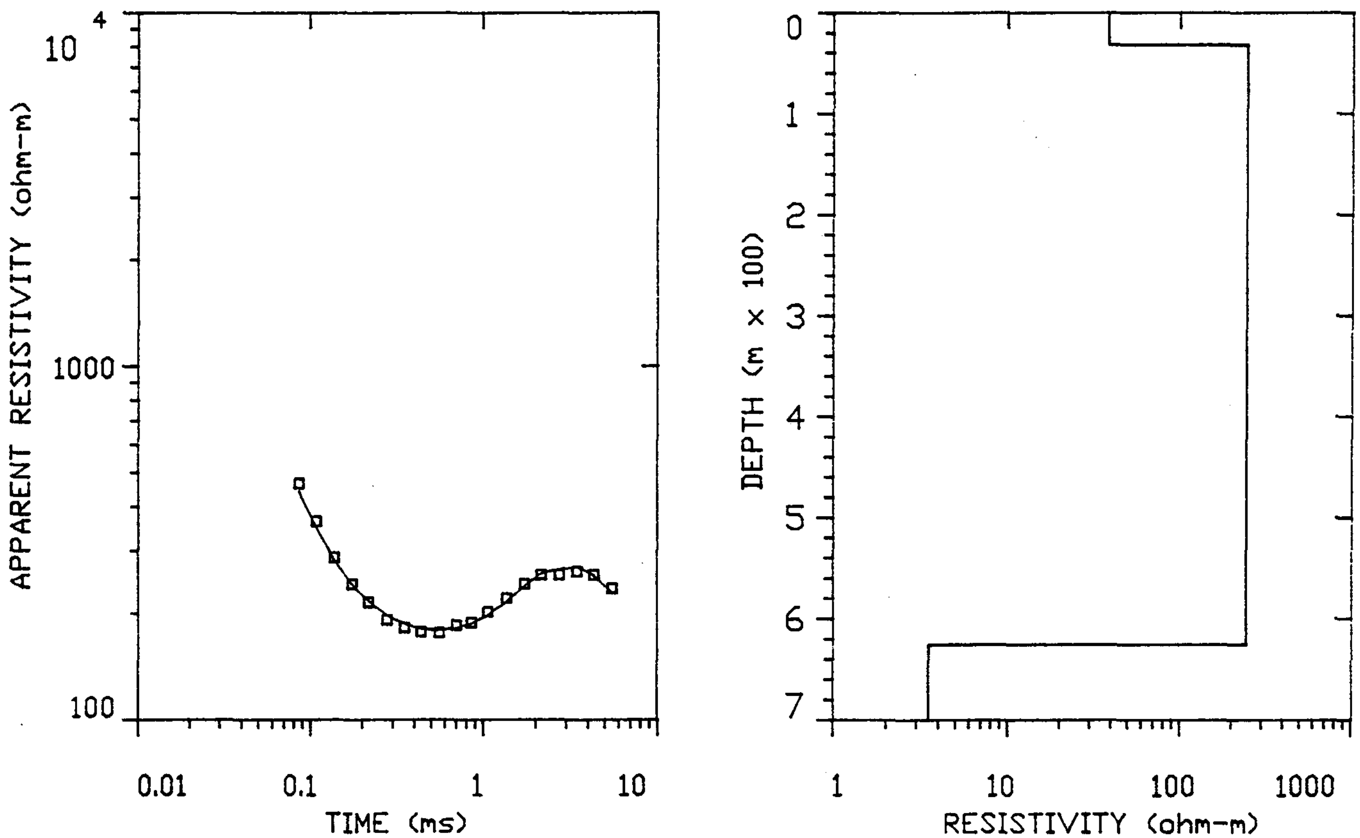
5.06.2. Geological Interpretation of Geoelectrical Model

The three-layer geoelectrical section consists of an upper layer with a resistivity of 38 ohm-m which correlates with the Holocene to Miocene deposits above the Floridan aquifer. The thickness of Layer 1 was fixed at 32 m (105 ft, SJRWMD, personal communication). The second layer has high resistivity (247 ohm-m) which means that because it is greater than 80 ohm-m, the Floridan aquifer at this site contains fresh water. The thickness of the freshwater section is 593 m (1,946 ft) placing the depth to the low resistivity (saltwater) layer at 625 m (2,051 ft) below ground surface. The resistivity of the saltwater layer is 3.5 ohm-m. Layer 1 is considered to be the Holocene to Miocene deposits above the Floridan aquifer, Layer 2 to be the Floridan aquifer containing fresh water, and Layer 3 to be the salt water near the base of the Lower Floridan aquifer.





ST. JOHNS RIVER WATER MANAGEMENT DISTRICT PALATKA, FLORIDA	SDII SUBSURFACE DETECTION INVESTIGATIONS INCORPORATED	TDEM SURVEY LOCATION MAP SOUNDING 5 – SORRENTO SITE ORANGE COUNTY, FLORIDA			
		DESIGNED BY: RJW	PROJECT NO.:	1010045	FIGURE
		CHECKED BY: MJW	DRAWING NO.:	LOC-5	5.6-1
		DRAWN BY: SAB	DATE:	08/01/96	



— BEST-FIT MODELED CURVE

□ APPARENT RESISTIVITY VALUES USED IN MODEL

X APPARENT RESISTIVITY VALUES NOT USED IN MODEL

ST. JOHNS RIVER WATER MANAGEMENT DISTRICT
PALATKA, FLORIDA

SDII
SUBSURFACE DETECTION INVESTIGATIONS INCORPORATED

MEASURED TDEM APPARENT RESISTIVITY AND 1-D INVERSION
SITE 5 - SORRENTO SITE
ORANGE COUNTY, FLORIDA

DESIGNED BY:	CHR	PROJECT NO.:	1010045	FIGURE
CHECKED BY:	MJW	DRAWING NO.:	MDL-5	5.6-2
DRAWN BY:	SAB	DATE:	08/01/96	

5.06.3. Depth to Occurrence of Salt Water

The bottom (third) layer of the geoelectrical model, with a resistivity of 3.5 ohm-m, is interpreted to represent salt water. It occurs at a depth of 2,051 ft (-1,965 ft msl). Because the resistivity of Layer 2 (247 ohm-m) is greater than 80 ohm-m, the interpreted depth to the 5,000 mg/l isochlor is taken as 50 ft greater than the depth of the geoelectrical interface, or at a depth of 2,101 ft (-2,015 ft bmsl). The resistivity of Layer 3 (3.5 ohm-m) corresponds to a chloride concentration of 9,037 mg/l, assuming a porosity of 25% and the validity and applicability of equation (4) of Section 4.02. It is presumed that because of the expected high chlorinity gradients, this value is sufficiently close to the 5,000 mg/l isochlor that they represent the same effective depth.

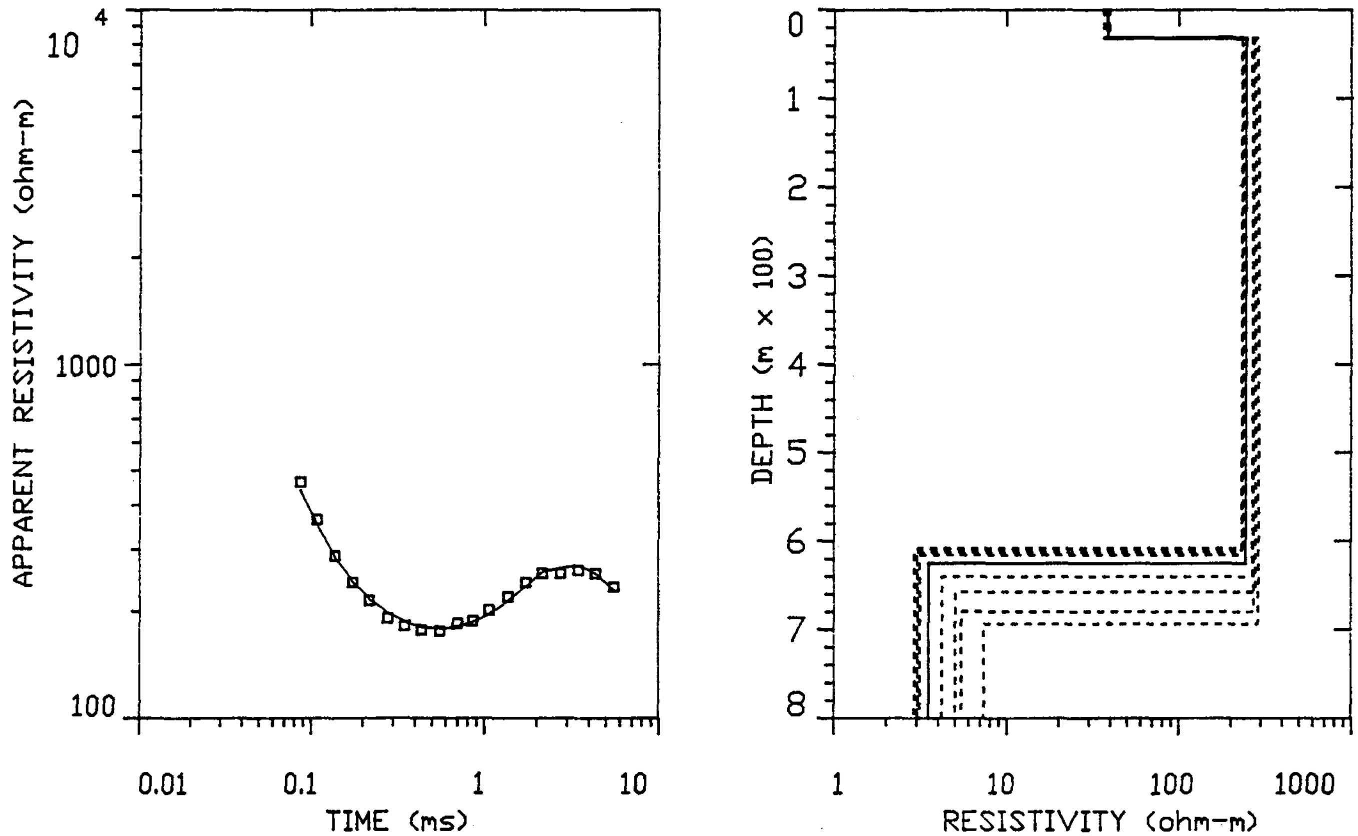
5.06.4. Depth of Occurrence of the 250 mg/l Isochlor

The resistivity of Layer 2, 247 ohm-m, corresponds to a chloride concentration of less than 250 mg/l, assuming a 25% porosity and the validity and applicability of equation (4) of Section 4.02. The 250 mg/l isochlor is placed in the Floridan aquifer at a depth 50 ft above the Layer 3 interface or at 2,001 ft (-1,915 ft msl).

5.06.5. Accuracy of Measurement and Interpretation

Figure 5.6-3 is the equivalence analysis at this site and the inversion table (Table 5.6-1) lists the upper and lower bounds of the inverted parameters of the geoelectrical model.

The range of equivalence in determining the depth to the low resistivity layer is about ±43 m (141 ft) which is 7% of the total depth. The resistivity of this layer has a range of from 2.9 to 7.4 ohm-m. This corresponds to a range in interpreted chloride concentration of from 10,938 to 4,193 mg/l, again subject to the same assumptions of porosity and validity of equation (4).



——— BEST-FIT MODELED CURVE

□ APPARENT RESISTIVITY VALUES USED IN MODEL

X APPARENT RESISTIVITY VALUES NOT USED IN MODEL

ST. JOHNS RIVER WATER MANAGEMENT DISTRICT
PALATKA, FLORIDA

SDII
SUBSURFACE DETECTION INVESTIGATIONS INCORPORATED

MEASURED TDEM APPARENT RESISTIVITY AND EQUIVALENCE FOR 1-D INVERSION
SITE 5 – SORRENTO SITE
ORANGE COUNTY, FLORIDA

DESIGNED BY:	CHR	PROJECT NO.:	1010045	FIGURE
CHECKED BY:	MJW	DRAWING NO.:	EQU-5	5.6-3
DRAWN BY:	SAB	DATE:	08/01/96	

DATA SET: SITE 5

CLIENT: SJRWMD
LOCATION: SORRENTO SITE
COUNTY: ORANGE COUNTY
PROJECT: SALTWATER INTERFACE DETECTION
LOOP SIZE: 457.000 m by 457.000 m
COIL LOC: 0.000 m (X), 0.000 m (Y)
SOUNDING COORDINATES: E: 0.0000 N: 0.0000

DATE: 03-JUNE-96
SOUNDING: 1
ELEVATION: 26.00 m
EQUIPMENT: Geonics PROTEM
AZIMUTH:

FITTING ERROR: 3.846 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)		ELEVATION (meters)	CONDUCTANCE (Siemens)
				26.00	
1	38.35	32.00	*	-6.00	0.834
2	247.4	593.3		-599.3	2.39
3	3.50				

"*" INDICATES FIXED PARAMETER

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

LAYER		MINIMUM	BEST	MAXIMUM
RHO	1	36.482	38.357	39.569
	2	234.676	247.451	291.231
	3	2.908	3.507	7.350
THICK	1	32.000	0.000	32.000
	2	575.643	1.000	661.707
DEPTH	1	32.000	32.000	32.000
	2	607.643	625.316	693.707

CURRENT: 15.00 AMPS EM-57 COIL AREA: 100.00 sq m.
FREQUENCY: 30.00 Hz GAIN: 4 RAMP TIME: 257.00 muSEC

No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)
1	0.0867	70849.3	76929.5	-8.58
2	0.108	59189.0	62493.8	-5.58
3	0.138	45633.3	46356.5	-1.58

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PALATKA, FLORIDA

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INCORPORATED

TDEM SOUNDING DATA TABLE
SITE 5 – SORRENTO SITE
ORANGE COUNTY, FLORIDA

PROJECT NO.: 1010045
TABLE: 5.6–1

No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)
4	0.175	32695.5	32537.6	0.482
5	0.218	22516.7	22233.1	1.25
6	0.278	14557.3	13875.4	4.68
7	0.351	8769.1	8463.4	3.48
8	0.438	5242.3	5102.3	2.67
9	0.558	2897.0	2839.7	1.97
10	0.702	1517.5	1561.1	-2.87
11	0.858	894.3	906.8	-1.39
12	1.06	467.8	485.2	-3.71
13	1.37	218.9	227.1	-3.76
14	1.74	104.9	107.9	-2.84
15	2.17	55.18	54.32	1.54
16	2.77	29.99	28.42	5.22
17	3.50	16.19	15.41	4.83
18	4.37	9.59	9.62	-0.271
19	5.56	5.99	6.28	-4.73

PARAMETER RESOLUTION MATRIX:
"F" INDICATES FIXED PARAMETER

P 1	0.99				
P 2	0.02	0.96			
P 3	0.04	-0.12	0.47		
F 1	0.00	0.00	0.00	0.00	
T 2	0.00	-0.02	-0.08	0.00	0.98
	P 1	P 2	P 3	F 1	T 2

ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT
PALATKA, FLORIDA

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SUBSURFACE
DETECTION
INVESTIGATIONS
INCORPORATED

TDEM SOUNDING DATA TABLE
SITE 5 – SORRENTO SITE
ORANGE COUNTY, FLORIDA

PROJECT NO.: 1010045
TABLE: 5.6–1

The equivalence range of the resistivity of Layer 2 is from 235 to 291 ohm-m which corresponds to a chloride concentration of less than 250 mg/l. The chloride-to-sulfate ratio at the site is 5:1 (Table 5.1-4). Accordingly, Equation (4) is valid.

5.06.6. Summary of TDEM Sounding at Sorrento (Site 5)

- The depth to occurrence of salt water (5,000 mg/l isochlor) is interpreted to be 2,101 ft (-2,015 ft msl) and occur near the base of the Lower Floridan aquifer.

- The ground water within the Floridan aquifer at this site is interpreted to contain an average chloride concentration of less than 250 mg/l. The 250 mg/l isochlor is interpreted to be present in the Floridan aquifer at a depth of 2,001 ft (-1,915 ft msl).

5.07. TDEM Site 6 - Deltona

5.07.1. Location Description and Geoelectrical Section

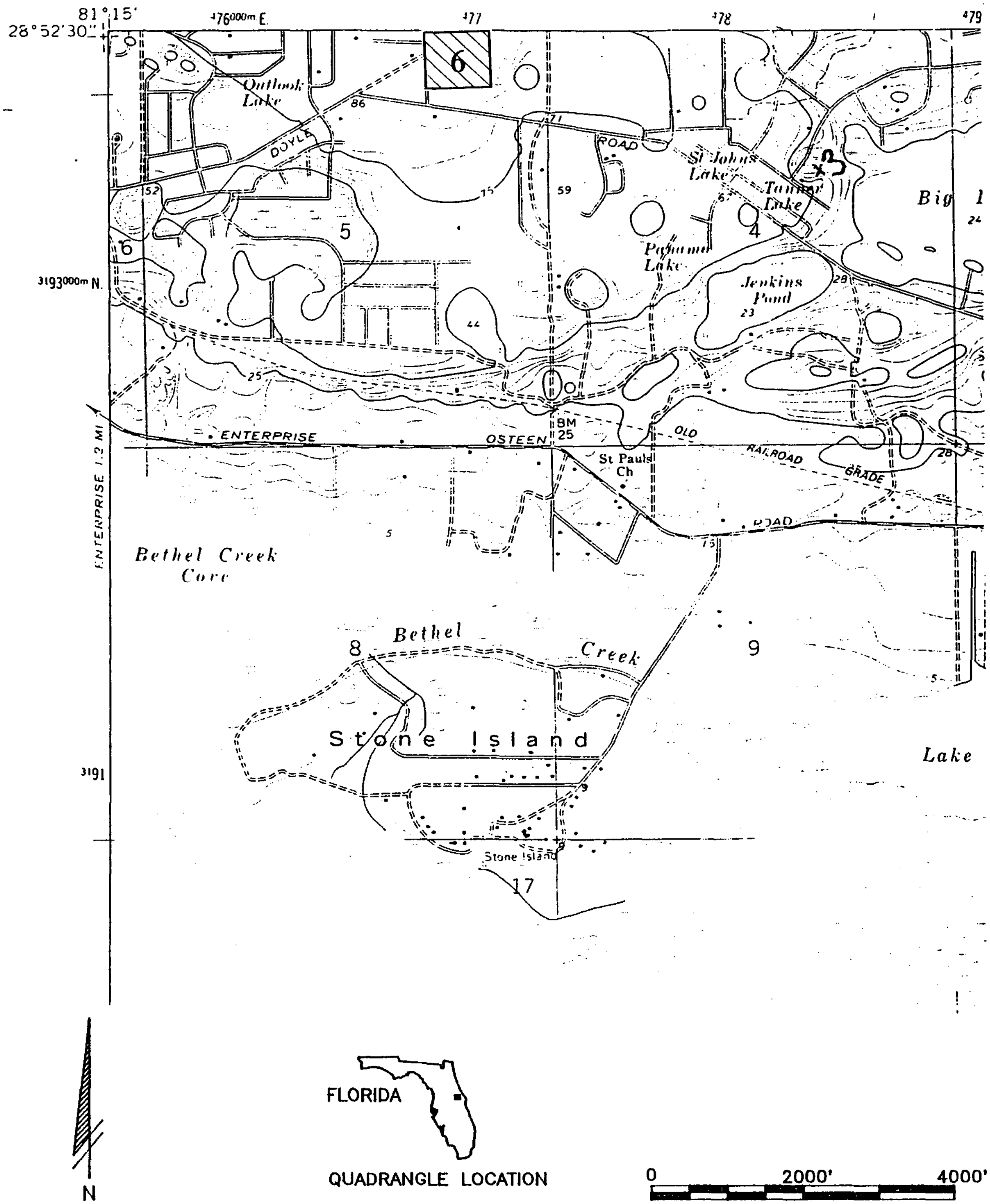
The site is located in southwest Volusia County, Florida (Figure 5.7-1). The site is located within a forested area. No possible sources of interference were observed within the vicinity of the site. QA soundings were performed 60 ft south and 40 ft east of the initial Rx coil location. Results from the QA soundings indicate that the apparent resistivity values were unaffected by any interference sources.

The Floridan aquifer occurs at an approximate depth of 30 ft bmsl or 120 ft bls (SJRWMD, personal communication) and is overlain by Holocene to Miocene deposits. The base of the Floridan aquifer occurs at approximately 2,200 ft bmsl (Tibbals, 1990). The thickness of the Upper Floridan aquifer is approximately 280 ft and the depth to the top of the Lower Floridan aquifer is approximately 700 ft bmsl (Miller, 1986). Chloride concentrations in the Upper Floridan aquifer are less than 250 mg/l and the estimated thickness of the fresh water saturated Floridan aquifer is approximately 150 ft in this area (Rutledge, 1985)

The resistivity sounding data and best-fit model inversion are presented on Figure 5.7-2. The interpreted geoelectrical section consists of a two-layer subsurface.

5.07.2. Geological Interpretation of Geoelectrical Model

There is insufficient electrical resistivity contrast between the Holocene to Miocene deposits and the underlying Floridan aquifer to distinguish the two. Fixing the thickness of the upper layer does not resolve this dilemma; therefore, it can be interpreted that there exists a two-layer geoelectrical section with a 84 m (276 ft) thick surface layer of intermediate resistivity (37 ohm-m) overlying a low resistivity layer (2.6 ohm-m). The Holocene to Miocene deposits and part of the Floridan aquifer system exist as a combined



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PALATKA, FLORIDA

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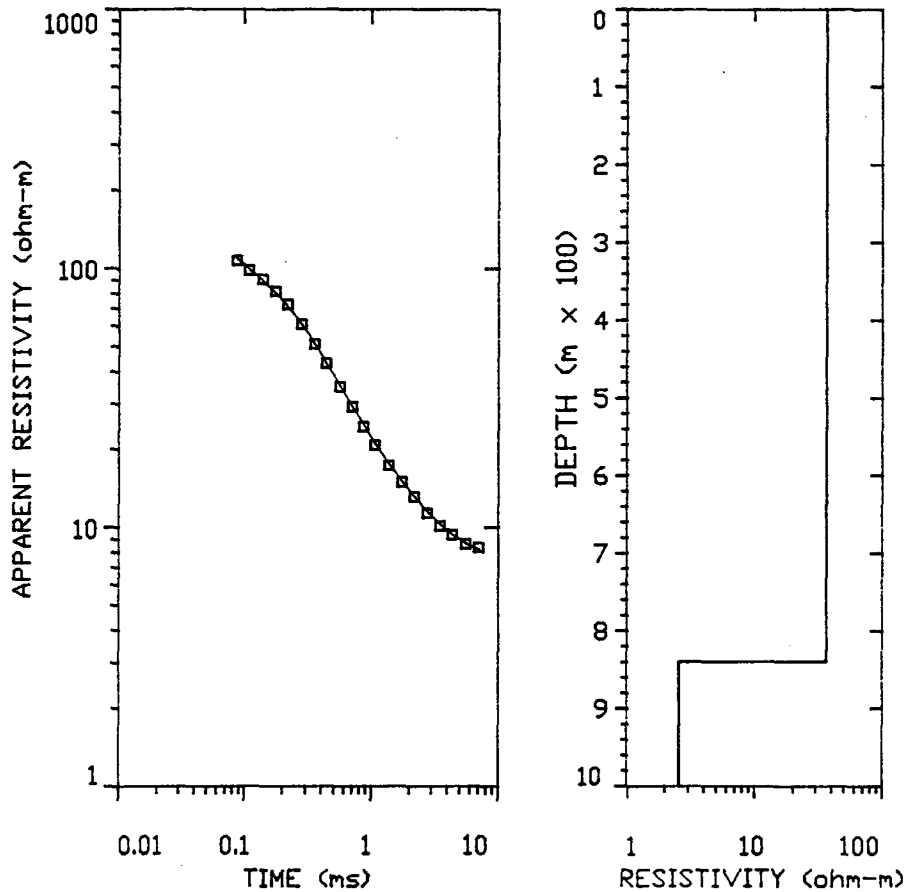
SUBSURFACE
DETECTION
INVESTIGATIONS
INCORPORATED

TDEM SURVEY LOCATION MAP
SOUNDING 6 – DELTONA SITE
VOLUSIA COUNTY, FLORIDA

DESIGNED BY:	RJW	PROJECT NO.:	1010045	FIGURE
CHECKED BY:	MJW	DRAWING NO.:	LOC–6	5.7–1
DRAWN BY:	SAB	DATE:	08/01/96	



—— BEST-FIT MODELED CURVE

□ APPARENT RESISTIVITY VALUES USED IN MODEL

X APPARENT RESISTIVITY VALUES NOT USED IN MODEL

ST. JOHNS RIVER WATER MANAGEMENT DISTRICT PALATKA, FLORIDA	SDII SUBSURFACE DETECTION INVESTIGATIONS INCORPORATED	MEASURED TDEM APPARENT RESISTIVITY AND 1-D INVERSION SITE 6 – DELTONA SITE VOLUSIA COUNTY, FLORIDA	
		DESIGNED BY: CHR CHECKED BY: MJW DRAWN BY: SAB	PROJECT NO.: 1010045 DRAWING NO.: MDL-6 DATE: 08/01/96
			FIGURE 5.7-2

but indistinguishable (geoelectrical) layer, overlying a saltwater saturated Floridan aquifer at a depth of 276 ft bls.

5.07.3. Depth to Occurrence of Salt Water

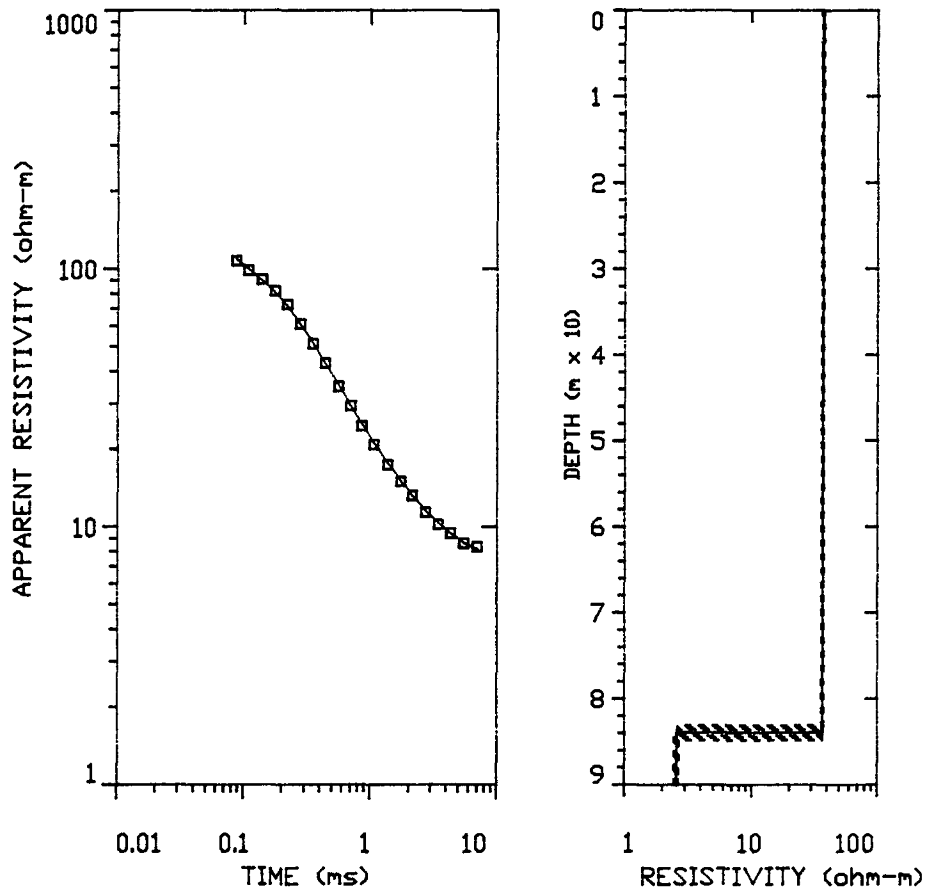
The bottom (second) layer of the geoelectrical model, with a resistivity of 2.6 ohm-m, is interpreted to represent salt water. It occurs at a depth of 276 ft (-186 ft msl). Because the resistivity of Layer 1 (37 ohm-m) is less than 80 ohm-m, the interpreted depth to the 5,000 mg/l isochlor is taken at the depth of the geoelectrical interface, or at 276 ft depth (-186 ft msl). The resistivity of Layer 2 (2.6 ohm-m) corresponds to a chloride concentration of 12,218 mg/l assuming a porosity of 25% and the validity and applicability of equation (4) of Section 4.02. It is presumed that because of the expected high chlorinity gradients, this value is sufficiently close to the 5,000 mg/l isochlor that they represent the same effective depth.

5.07.4. Depth of Occurrence of the 250 mg/l Isochlor

Because of the inability to segregate the Floridan aquifer from the overlying Holocene to Miocene deposits, the effective chloride concentration of Layer 1 cannot be calculated.

5.07.5. Accuracy of Measurement and Interpretation

Figure 5.7-3 is the equivalence analysis at this site and the inversion table (Table 5.7-1) lists the upper and lower bounds of the inverted parameters of the geoelectrical model. The range of equivalence in determining the depth to the low resistivity layer is about ±1 m (3 ft) which is 1% of the total depth. The resistivity of this layer has a range from 2.5 to 2.7 ohm-m. This corresponds to a range in interpreted chloride concentration of 12,712 mg/l to 11,759 mg/l, again subject to the same assumptions of porosity and validity of equation (4).



—— BEST-FIT MODELED CURVE

□ APPARENT RESISTIVITY VALUES USED IN MODEL

X APPARENT RESISTIVITY VALUES NOT USED IN MODEL

ST. JOHNS RIVER WATER MANAGEMENT DISTRICT
PALATKA, FLORIDA

SDII
SUBSURFACE DETECTION INVESTIGATIONS INCORPORATED

MEASURED TDEM APPARENT RESISTIVITY AND EQUIVALENCE FOR 1-D INVERSION
SITE 6 – DELTONA SITE
VOLUSIA COUNTY, FLORIDA

DESIGNED BY:	CHR	PROJECT NO.:	1010045	FIGURE
CHECKED BY:	MJW	DRAWING NO.:	EQU-6	5.7-3
DRAWN BY:	SAB	DATE:	08/01/96	

DATA SET: SITE6

CLIENT: SJRWMD
LOCATION: DELTONA SITE
COUNTY: VOLUSIA COUNTY
PROJECT: SALTWATER INTERFACE DETECTION
LOOP SIZE: 91.400 m by 213.300 m
COIL LOC: 0.000 m (X), 0.000 m (Y)
SOUNDING COORDINATES: E: 0.0000 N: 0.0000

DATE: 06-JUNE-96
SOUNDING: 1
ELEVATION: 27.40 m
EQUIPMENT: Geonics PROTEM
AZIMUTH:

FITTING ERROR: 1.654 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	CONDUCTANCE (Siemens)
			27.40	
1	36.77	83.93	-56.53	2.28
2	2.56			

ALL PARAMETERS ARE FREE

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

LAYER		MINIMUM	BEST	MAXIMUM
RHO	1	36.200	36.775	37.358
	2	2.468	2.569	2.676
THICK	1	83.104	1.000	84.853
DEPTH	1	83.104	83.937	84.853

CURRENT: 13.20 AMPS EM-57 COIL AREA: 100.00 sq m.
FREQUENCY: 30.00 Hz GAIN: 4 RAMP TIME: 108.00 muSEC

No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)
1	0.0867	57191.7	55338.8	3.23
2	0.108	37523.9	36962.5	1.49
3	0.138	23026.6	23361.3	-1.45
4	0.175	14863.2	15191.0	-2.20
5	0.218	10220.7	10487.3	-2.60
6	0.278	7257.6	7259.7	-0.0282
7	0.351	5266.3	5267.2	-0.0175

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TDEM SOUNDING DATA TABLE
SITE 6 – DELTONA SITE
VOLUSIA COUNTY, FLORIDA

PROJECT NO.: 1010045
TABLE: 5.7–1

No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)
8	0.438	3922.7	3950.7	-0.712
9	0.558	2927.0	2917.7	0.318
10	0.702	2141.3	2175.3	-1.58
11	0.858	1698.6	1672.3	1.54
12	1.06	1264.3	1247.6	1.32
13	1.37	884.7	871.2	1.52
14	1.74	609.4	608.8	0.0904
15	2.17	424.6	427.9	-0.766
16	2.77	287.9	284.1	1.31
17	3.50	189.5	186.8	1.40
18	4.37	122.3	122.8	-0.435
19	5.56	76.17	75.79	0.496
20	7.03	44.38	46.00	-3.64

PARAMETER RESOLUTION MATRIX:
"F" INDICATES FIXED PARAMETER

P 1	0.99		
P 2	0.00	0.96	
T 1	0.00	0.01	1.00
	P 1	P 2	T 1

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WATER MANAGEMENT DISTRICT
PALATKA, FLORIDA

SDII
SUBSURFACE DETECTION INVESTIGATIONS INCORPORATED

TDEM SOUNDING DATA TABLE
SITE 6 – DELTONA SITE
VOLUSIA COUNTY, FLORIDA

PROJECT NO.: 1010045
TABLE: 5.7–1

The equivalence range of the resistivity of Layer 1 is from 36 to 37 ohm-m. A corresponding chloride concentration cannot be determined because Layer 1 is in part comprised of Holocene to Miocene deposits. Accordingly, equation (4) may not be valid.

5.07.6. Summary of TDEM Sounding at Deltona (Site 6)

- The depth of occurrence of salt water (5,000 mg/l isochlor) is interpreted to be 276 ft (-186 ft msl), and occur in the Upper Floridan aquifer.

- The quality of ground water within the Floridan aquifer at this site cannot be interpreted because the analysis of the TDEM data does not allow the Holocene to Miocene deposits to be distinguished from the Floridan Aquifer System.

5.08. TDEM Site 7 - Hayfield

5.08.1. Location Description and Geoelectrical Section

The site is located in northeast Lake County (Figure 5.8-1). The site was an open field. No sources of interference were observed within the vicinity of the site. QA soundings were performed 100 ft east and 50 ft north of the initial Rx coil location. Results from the QA soundings indicate that the apparent resistivity values were unaffected by any interference sources.

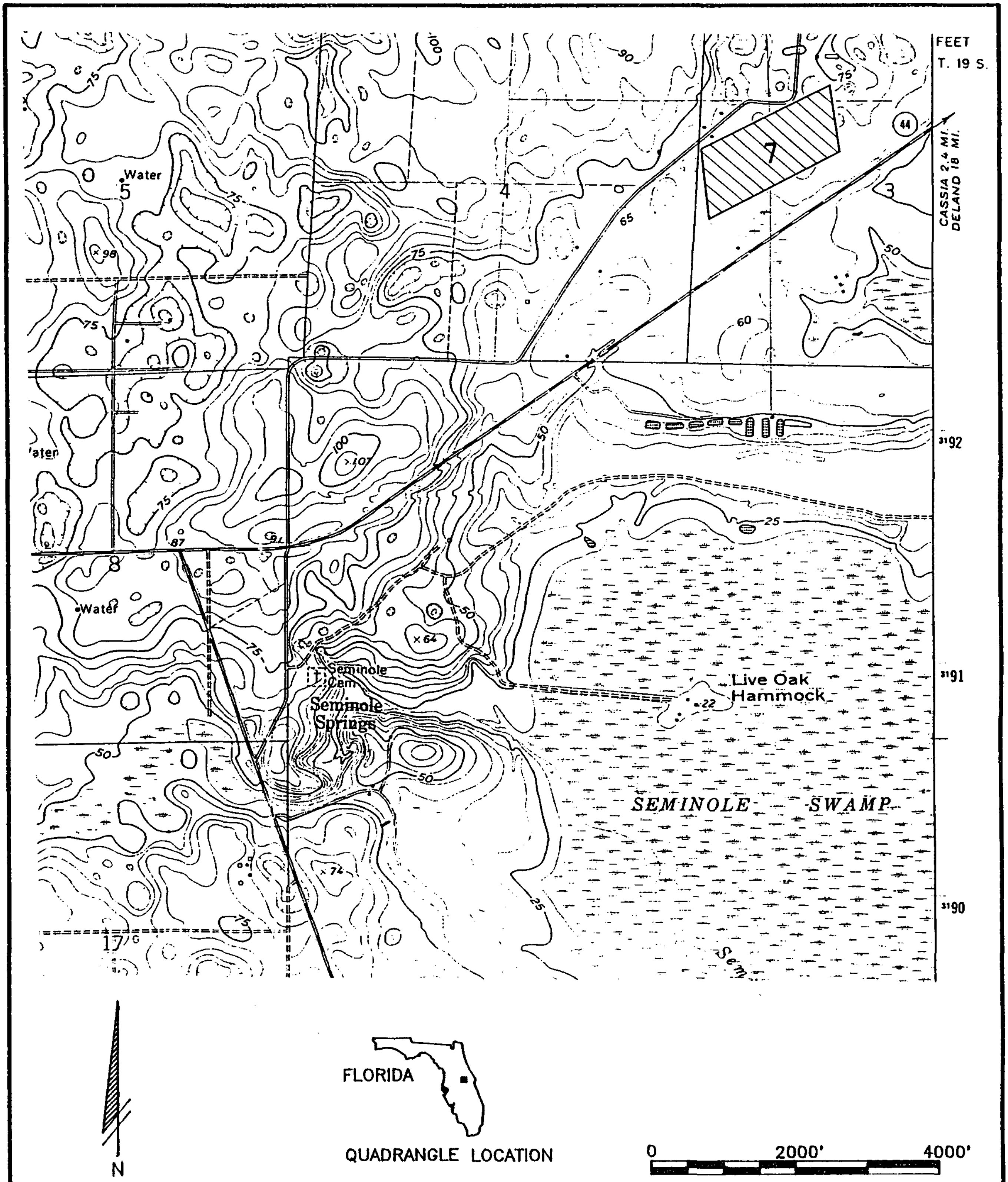
The Floridan aquifer occurs at an approximate depth of 20 ft above msl or 45 ft bls and is overlain by Holocene to Miocene deposits (SJRWMD, personal communication). The base of the Floridan aquifer occurs at approximately 2,050 ft bmsl (Tibbals, 1990). The thickness of the Upper Floridan aquifer is approximately 320 ft and the depth to the top of the Lower Floridan aquifer is approximately 650 ft bmsl (Miller, 1986).

A previous TDEM sounding (site 4, Blackhawk 1991) was performed approximately 2 miles southwest of the Hayfield site. Because of concerns of possible sources of interference in the vicinity of the site, two TDEM soundings with differing loop sizes were performed. Results from the two soundings were then incorporated into a single sounding curve for analysis. Results from the sounding indicated that the depth to the 250 mg/l isochlor was 559 ft bmsl.

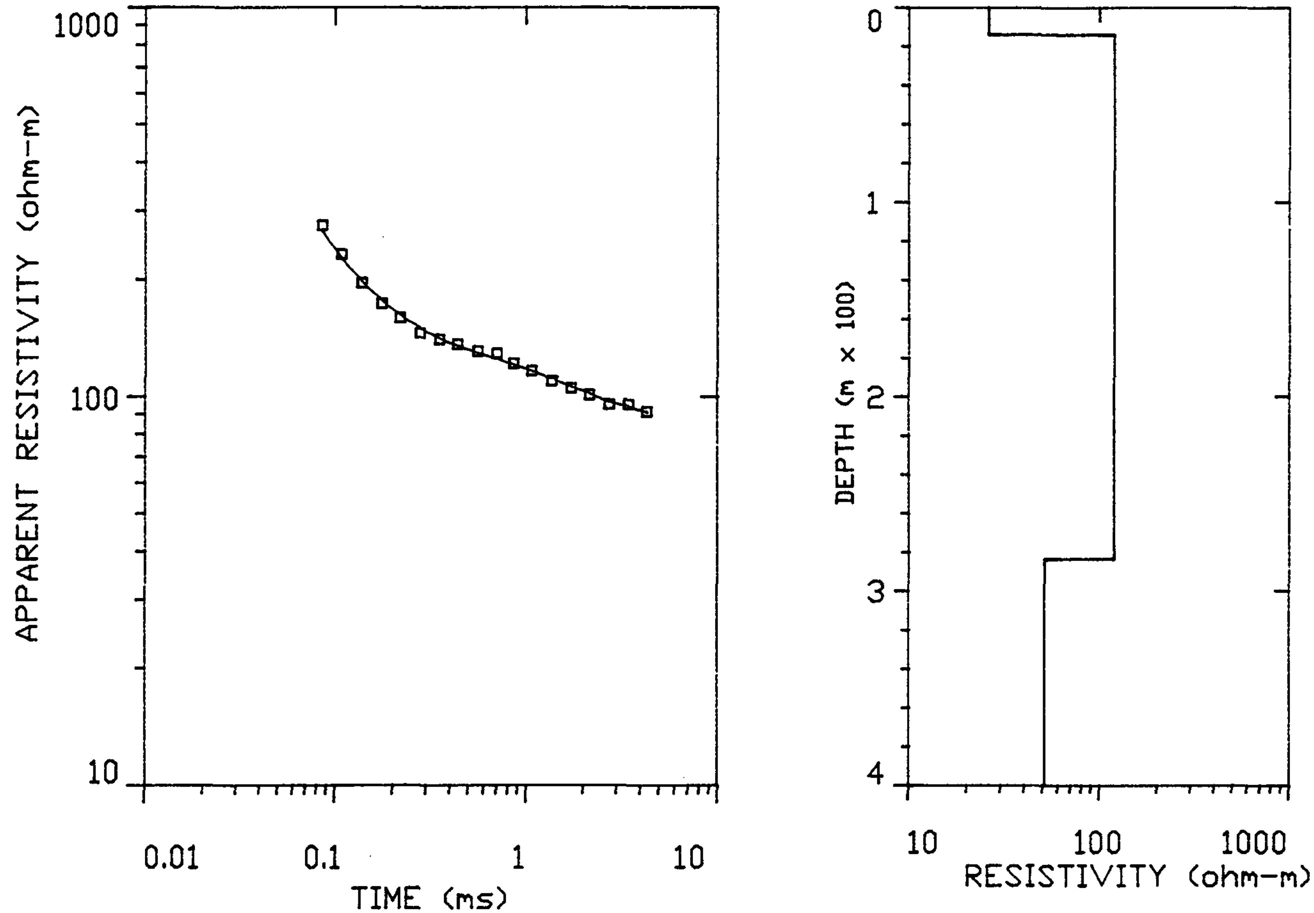
The resistivity sounding data and best-fit model inversion are presented on Figure 5.8-2. The interpreted geoelectrical section consists of a three-layer subsurface.

5.08.2. Geological Interpretation of Geoelectrical Model

The three-layer geoelectrical section consists of an upper layer with a resistivity of 26 ohm-m which correlates with the Holocene to Miocene deposits above the Floridan aquifer. The thickness of Layer 1 was fixed at 14 m (46 ft, SJRWMD, personal



ST. JOHNS RIVER WATER MANAGEMENT DISTRICT PALATKA, FLORIDA	SDII SUBSURFACE DETECTION INVESTIGATIONS INCORPORATED	TDEM SURVEY LOCATION MAP SOUNDING 7 – HAYFIELD SITE LAKE COUNTY, FLORIDA	
		DESIGNED BY: RJW CHECKED BY: MJW DRAWN BY: SAB	PROJECT NO.: 1010045 DRAWING NO.: LOC–7 DATE: 08/01/96
		FIGURE 5.8–1	



—— BEST-FIT MODELED CURVE

□ APPARENT RESISTIVITY VALUES USED IN MODEL

X APPARENT RESISTIVITY VALUES NOT USED IN MODEL

ST. JOHNS RIVER WATER MANAGEMENT DISTRICT
PALATKA, FLORIDA

SDII
SUBSURFACE DETECTION INVESTIGATIONS INCORPORATED

MEASURED TDEM APPARENT RESISTIVITY AND 1-D INVERSION
SITE 7 - HAYFIELD SITE
LAKE COUNTY, FLORIDA

DESIGNED BY:	CHR	PROJECT NO.:	1010045	FIGURE
CHECKED BY:	MJW	DRAWING NO.:	MDL-7	5.8-2
DRAWN BY:	SAB	DATE:	08/01/96	

communication). The second layer has high resistivity (119 ohm-m) which means that because it is greater than 80 ohm-m the Floridan aquifer at this site contains fresh water. The thickness of the freshwater section is 270 m (886 ft) placing the depth to the low resistivity layer at 284 m (932 ft) below ground surface. The resistivity of Layer 3 is 51 ohm-m. Layer 1 is considered to be the Holocene to Miocene deposits above the Floridan aquifer, Layer 2 to be the Floridan aquifer containing fresh water, and Layer 3 to be either a porosity change or brackish water in the Lower Floridan aquifer.

5.08.3. Depth to Occurrence of Salt Water

The bottom (third) layer of the geoelectrical model, with a resistivity of 51 ohm-m, is interpreted to represent either brackish water or a porosity change in the Lower Floridan aquifer. The availability of data does not permit one to distinguish between the above alternatives. It occurs at a depth of 932 ft (-867 ft msl). Because the resistivity of Layer 3 (51 ohm-m) is greater than 20 ohm-m, it is not possible to determine the depth to the 5,000 mg/l isochlor.

5.08.4. Depth of Occurrence of the 250 mg/l Isochlor

The resistivity of Layer 2, 119 ohm-m, corresponds to a chloride concentration of less than 250 mg/l, assuming a 25% porosity and the validity and applicability of equation (4) of Section 4.02. Since the freshwater section has a resistance in excess of 80 ohm-m with an underlying layer with a resistivity in the range of 40-80 ohm-m (class C), the 250 mg/l isochlor is placed at the saltwater interface at a depth of 932 bls (-867 ft msl).

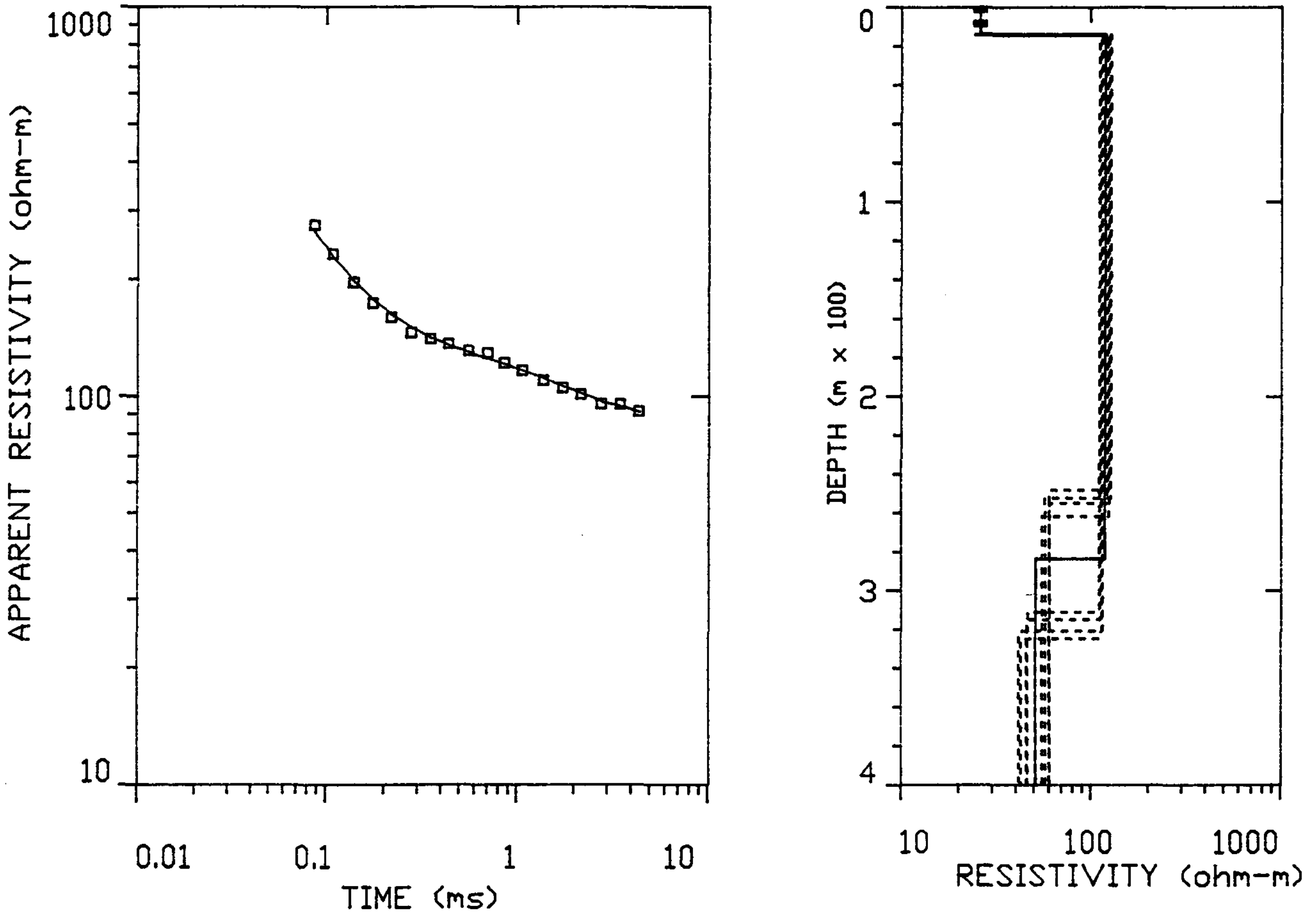
5.08.5. Accuracy of Measurement and Interpretation

Figure 5.8-3 is the equivalence analysis at this site and the inversion table (Table 5.8-1) lists the upper and lower bounds of the inverted parameters of the geoelectrical model.

The range of equivalence in determining the depth to the low resistivity layer is about ±38 m (125 ft) which is 13% of the total depth. The resistivity of this layer has a range of from 42 to 61 ohm-m. This corresponds to a range in interpreted chloride concentration of from 613 to 374 mg/l, again subject to the same assumptions of porosity and validity of equation (4). This layer could represent brackish water. Alternatively, it may represent a porosity change in the Lower Floridan aquifer. Sufficient data does not exist to distinguish between the above alternatives. Because of these alternatives the placement of the 250 mg/l isochlor may not be valid.

The derived depth to the 250 mg/l isochlor (-867 ft msl) does not agree with the results from the TDEM sounding performed by Blackhawk (1991) approximately 2 miles southwest of the site. The Blackhawk (1991) sounding placed the 250 mg/l isochlor at a depth of -559 ft msl or at a depth 308 ft more shallow than the results from the Hayfield site. The difference between the two soundings may have been caused by the impact of cultural interference upon the results of the Blackhawk (1991) sounding.

The equivalence range of the resistivity of Layer 2 is from 112 to 128 ohm-m which corresponds to a chloride concentration of less than 250 mg/l. The chloride-to-sulfate ratio at the site is 5:1 (Table 5.1-4). Accordingly, Equation (4) is valid.



—— BEST-FIT MODELED CURVE

□ APPARENT RESISTIVITY VALUES USED IN MODEL

X APPARENT RESISTIVITY VALUES NOT USED IN MODEL

ST. JOHNS RIVER WATER MANAGEMENT DISTRICT
PALATKA, FLORIDA

SDII
SUBSURFACE DETECTION INVESTIGATIONS INCORPORATED

MEASURED TDEM APPARENT RESISTIVITY AND EQUIVALENCE FOR 1-D INVERSION
SITE 7 - HAYFIELD SITE
LAKE COUNTY, FLORIDA

DESIGNED BY:	CHR	PROJECT NO.:	1010045	FIGURE
CHECKED BY:	MJW	DRAWING NO.:	EQU-7	5.8-3
DRAWN BY:	SAB	DATE:	08/01/96	

DATA SET: SITE7

CLIENT: SJRWMD
LOCATION: HAYFIELD SITE
COUNTY: LAKE COUNTY
PROJECT: SALTWATER INTERFACE DETECTION
LOOP SIZE: 381.000 m by 229.000 m
COIL LOC: 0.000 m (X), 0.000 m (Y)
SOUNDING COORDINATES: E: 0.0000 N: 0.0000

DATE: 06-JUNE-96
SOUNDING: 1
ELEVATION: 27.40 m
EQUIPMENT: Geonics PROTEM
AZIMUTH:

FITTING ERROR: 2.645 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)		ELEVATION (meters)	CONDUCTANCE (Siemens)
				27.40	
1	25.86	14.00	*	13.40	0.541
2	119.2	269.5		-256.1	2.26
3	50.94				

"*" INDICATES FIXED PARAMETER

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

LAYER		MINIMUM	BEST	MAXIMUM
RHO	1	24.025	25.865	27.963
	2	111.878	119.204	127.995
	3	41.575	50.942	60.742
THICK	1	14.000	0.000	14.000
	2	234.156	1.000	310.684
DEPTH	1	14.000	14.000	14.000
	2	248.156	283.551	324.684

CURRENT: 19.00 AMPS EM-57 COIL AREA: 100.00 sq m.
FREQUENCY: 30.00 Hz GAIN: 4 RAMP TIME: 232.00 muSEC

No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)
1	0.0867	84764.8	89612.8	-5.71
2	0.108	63291.7	64790.5	-2.36
3	0.138	44145.8	43413.2	1.65

ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT
PALATKA, FLORIDA

SDII
SUBSURFACE DETECTION INVESTIGATIONS INCORPORATED

TDEM SOUNDING DATA TABLE
SITE 7 – HAYFIELD SITE
LAKE COUNTY, FLORIDA

PROJECT NO.: 1010045
TABLE: 5.8-1

No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)
4	0.175	29312.6	28414.4	3.06
5	0.218	19205.8	18706.1	2.60
6	0.278	11978.1	11446.1	4.44
7	0.351	7071.7	6992.2	1.12
8	0.438	4246.6	4304.3	-1.35
9	0.558	2465.2	2507.4	-1.71
10	0.702	1415.5	1487.3	-5.07
11	0.858	936.3	948.3	-1.28
12	1.06	581.2	582.5	-0.234
13	1.37	339.4	333.4	1.78
14	1.74	199.1	197.1	0.986
15	2.17	121.7	120.2	1.22
16	2.77	71.97	70.66	1.81
17	3.50	40.18	40.98	-1.97
18	4.37	24.59	24.84	-1.02

PARAMETER RESOLUTION MATRIX:
"F" INDICATES FIXED PARAMETER

	P 1	P 2	P 3	F 1	T 2
P 1	0.98				
P 2	0.02	0.98			
P 3	0.03	-0.03	0.80		
F 1	0.00	0.00	0.00	0.00	
T 2	-0.03	0.03	0.13	0.00	0.90

ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT
PALATKA, FLORIDA

SDII
SUBSURFACE DETECTION INVESTIGATIONS INCORPORATED

TDEM SOUNDING DATA TABLE
SITE 7 – HAYFIELD SITE
LAKE COUNTY, FLORIDA

PROJECT NO.: 1010045
TABLE: 5.8–1

5.08.6. Summary of TDEM Sounding at Hayfield (Site 7)

- The lowermost layer is interpreted to represent either slightly brackish water or a porosity change. The 5,000 mg/l isochlor does not appear to have been identified by the TDEM study.

- The ground water within the Floridan aquifer at this site is interpreted to contain an average chloride concentration of less than 250 mg/l. The 250 mg/l isochlor is interpreted to be present in the Floridan aquifer at a depth of 932 ft (-867 ft msl). The results from the TDEM sounding do not agree with the results from a TDEM sounding performed by Blackhawk (1991) approximately 2 miles southwest of the site.

- The placement of the 250 mg/l isochlor may not be valid because of the assumptions made are invalid. The lowermost layer does not represent saltwater but is interpretated to represent either slightly brackish water or a porosity change.

6.0 SUMMARY AND CONCLUSIONS

A TDEM survey was performed at seven sites in the St. Johns River Water Management District during the month of June, 1996. The principal findings of this survey can be summarized as follows:

TDEM is a geoelectrical method which can be used to estimate the vertical variation of resistivity of subsurface formations and/or hydrostratigraphic units. Translating the geophysical measurement of electrical resistivity into a model of geology and water quality depends upon comparison to other available subsurface data, consistency of data sets from nearby soundings from this and prior years, and application of empirical relationships to produce interpreted water-quality results. As outlined in Section 4, the conversions to water quality values (chloride concentrations) are based upon the relationships established using Kwader's (1982) data for Seminole County, as used for SJRWMD in previous studies (Blackhawk, 1990; Blackhawk, 1991; CEES, 1992/SJ93-SP1; SDII, 1993, 1994 and 1995). The formulae employed use assumptions of a 25% porosity, similar water chemistry (specifically, a 5:1 chloride-to-sulfate ratio) as Kwader's data, and that the saltwater interface occurs within the Floridan Aquifer System. With regards the latter point, chloride concentration values are generally presented only for those portions of the geoelectrical section which correspond to the Floridan aquifer.

Under circumstances where there is little contrast in resistivity between the Holocene to Miocene deposits, surficial sediments, or Hawthorn Group and the Floridan aquifer, the chloride concentration of the ground water above the freshwater/saltwater interface cannot generally be determined. This is because of the assumptions implicit in equation (4) are not valid. However, if the resistivity of such a layer is either greater than 80 ohm-m or less than 20 ohm-m, it can be concluded that the chloride concentration in the Upper Floridan aquifer is either below or above 250 mg/l, respectively.

Finally, because the freshwater/saltwater boundary is not an abrupt interface but a transition zone, criteria relating to the relative resistivities above and below the geoelectrical interface were used to establish an empirical definition of depths to the 250 and 5,000 mg/l isochlors. Again, these were the same criteria as used in past years' TDEM surveys (Blackhawk, 1990; Blackhawk, 1991; CEES, 1992/SJ93-SP1; SDII, 1993, 1994 and 1995) in order to maintain consistency from year to year.

6.01. Determining the Depth of the Interface Between Fresh Water and Ground Water of High Chloride Concentration (Greater Than 1,450 mg/l)

As stated in previous years' reports (Blackhawk, 1990; Blackhawk, 1991; CEES, 1992/SJ93-SP1; SDII, 1993, 1994 and 1995), "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%." In accordance with this statement, a deep layer with a resistivity of less than 20 ohm-m was detected at 6 of the 7 sites surveyed. At the Hayfield Site (Site 7), the TDEM system did not have a sufficient depth range to detect the basal saltwater-saturated layer. The remaining 6 sites show variation in depth to this interface to range from approximately 276 to 2051 ft bls. All the interpreted depths place the saltwater interface within the Floridan Aquifer System.

6.02. Water Quality in the Floridan aquifer and Depth of Occurrence of the 250 mg/l Isochlor

Based on the assumptions that: (a) the Floridan aquifer has a porosity of 25%, (b) ground water within the study area have a chemistry similar to those analyzed by Kwader (1982), and (c) equation (4) in Section 4.02 is valid, ground water having chloride concentrations of less than 250 mg/l correspond to geoelectrical layers having resistivities in excess of 80 ohm-m. The distribution of resistivities of the Floridan aquifer show, for the most part, high resistivities and, therefore, fresh waters of less than 250 mg/l are present in the Floridan aquifer at three of the sites. At two of the sites, the average resistivity of the Floridan aquifer was less than 80 ohm-m and brackish water is interpreted to be present. At one of the sites, there was an insufficient resistivity contrast to locate the 250 mg/l isochlor. At another of the sites, the placement of the 250 mg/l isochlor may not have been valid because the observed resistance of the lowermost layer may have been caused by either a porosity change in the Lower Floridan aquifer or by the presence of brackish water (not salt water) in the lowermost layer.

When a layer with a chloride concentration of less than 250 mg/l is interpreted, the position of the 250 mg/l isochlor is fixed by the relative resistivities of the deep, conductive layer and the fresh (resistive) layer above - generally placing it 50 ft above the geoelectrical interface. When the resistivity of the Floridan aquifer is such that the interpreted chloride concentration exceeds 250 mg/l, a depth to the 250 mg/l isochlor was not determined as the entire system is considered to be brackish.

6.03. Summary of TDEM Mapping of Salt Water in the Floridan Aquifer

A total of 111 TDEM soundings have been performed for the District from 1990 to 1995. Results from those soundings are presented in this and previous studies (Blackhawk, 1990; Blackhawk, 1991; CEES, 1992; and SDII, 1993, 1994 and 1995). The estimated depth to salt water has been determined at 100 sites. At 11 of the sites, the depth to salt water could not be determined because either; (a) the suspected depth to salt water was beyond the capability of the TDEM system used for that survey, the lowermost layer in the geoelectric model included sediments from the overlying Holocene to Miocene deposits, or (c) there was not sufficient contrast in the resistivity of the geoelectric layers to confidently estimate the depth to the 5,000 mg/l isochlor.

7.0 REFERENCES

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