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EM34-3 GEOPHYSICAL SURVEY OF APPARENT GROUND
CONDUCTIVITY IN THE RATTLESNAKE CREEK SUBBASIN,
KANSAS

by

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A contribution to the Mineral Intrusion project
of the Kansas Geological Survey

1995

ABSTRACT

A preliminary survey of apparent ground conductivity was completed for the Great Bend Prairie Aquifer in South-Central Kansas as part of the Mineral Intrusion Project. This study, specifically in the lower Rattlesnake Creek Basin, was conducted as a cooperative effort between the Kansas Geological Survey, U.S. Geological Survey, and the Kansas Department of Agriculture, Division of Water Resources. A Geonics EM34-3 ground conductivity meter was used at three sites within the study area, designated the Siefkes, Seep, and Witt Sites. The primary purpose of the study was to determine the relationship between the apparent ground conductivity measured and the salinity of water in the aquifer. A wide variety of measurements were collected, using three intercoil spacings and two dipole orientations. Apparent conductivity values ranged from approximately 20 to 300 millimhos per meter (mmho/m). The higher conductivities were observed at both the Seep and Witt Sites, while most of the data from the Siefkes Site were in the range of 30 to 50 mmho/m. EM well logs at the Siefkes Site indicate relatively fresh water to a depth of approximately 40 m, suggesting that apparent ground conductivities for the Great Bend Prairie Aquifer under low salinity conditions should be less than 50 mmho/m. To gain a better understanding of the changes in ground conductivity with depth, the data were standardized based on the dipole orientation and intercoil spacing for six measurements at each survey point. Weighted averages of the standardized values were used to produce composite plots of the survey lines to a depth of 60 m. Apparent ground conductivities and composite plots indicate that mineral intrusion is occurring along preferred lines of groundwater movement near the Rattlesnake Creek at the Witt and Seep Sites. This is consistent with observed water quality, vegetation, and shallow soil conductivity.

INTRODUCTION

A survey of ground conductivity survey using a Geonics EM34-3 conductivity meter was conducted as a joint effort between the Kansas Geological Survey (KGS), the U.S. Geological Survey (USGS) and the Division of Water Resources (DWR) of the Kansas Department of Agriculture. The survey was completed at three sites in Stafford County, Kansas (Fig. 1), including the Siefkes Site (Fig. 2a), the Witt Site (Fig. 2b), and the Seep Site (Fig. 2c), a site close to a known seep along the Rattlesnake Creek. This investigation was conducted as part of the ongoing Mineral Intrusion Project in the Great Bend Prairie Aquifer, South-Central Kansas, which is a cooperative effort of KGS and Big Bend Groundwater Management District No. 5 (GMD5), supported by the Kansas Water Office. The following individuals took part in the field event: Charles Perry (USGS), Renee Rohs (DWR), and Joe Kruger, Robert Buddemeier, Alex Martinez, Dave Young, Glenn Garneau, Rich Sleezer, Greg Pouch, and John Healey (KGS).

In addition to the KGS-GMD5 study of mineral intrusion in the Great Bend Prairie Aquifer, the Division of Water Resources is currently conducting the Subbasin Water Resources Management Program in the Rattlesnake Creek Subbasin. These two areas of interest overlap since the Great Bend Prairie Aquifer underlies all of the Rattlesnake Creek Subbasin.

An EM38 survey of the very shallow subsurface, downhole geophysical logs, and conductivity data of the Rattlesnake Creek were acquired at the same time as the EM34 data. Results of these observations and integrated interpretations will be presented in subsequent open-file reports.

Physical Setting

Rattlesnake Creek is a tributary of the Lower Arkansas River in South-Central Kansas. Its subbasin lies largely within the Great Bend Prairie, a generally low-relief area interspersed with dune formations that is part of the Arkansas River Lowlands . Rattlesnake Creek over most
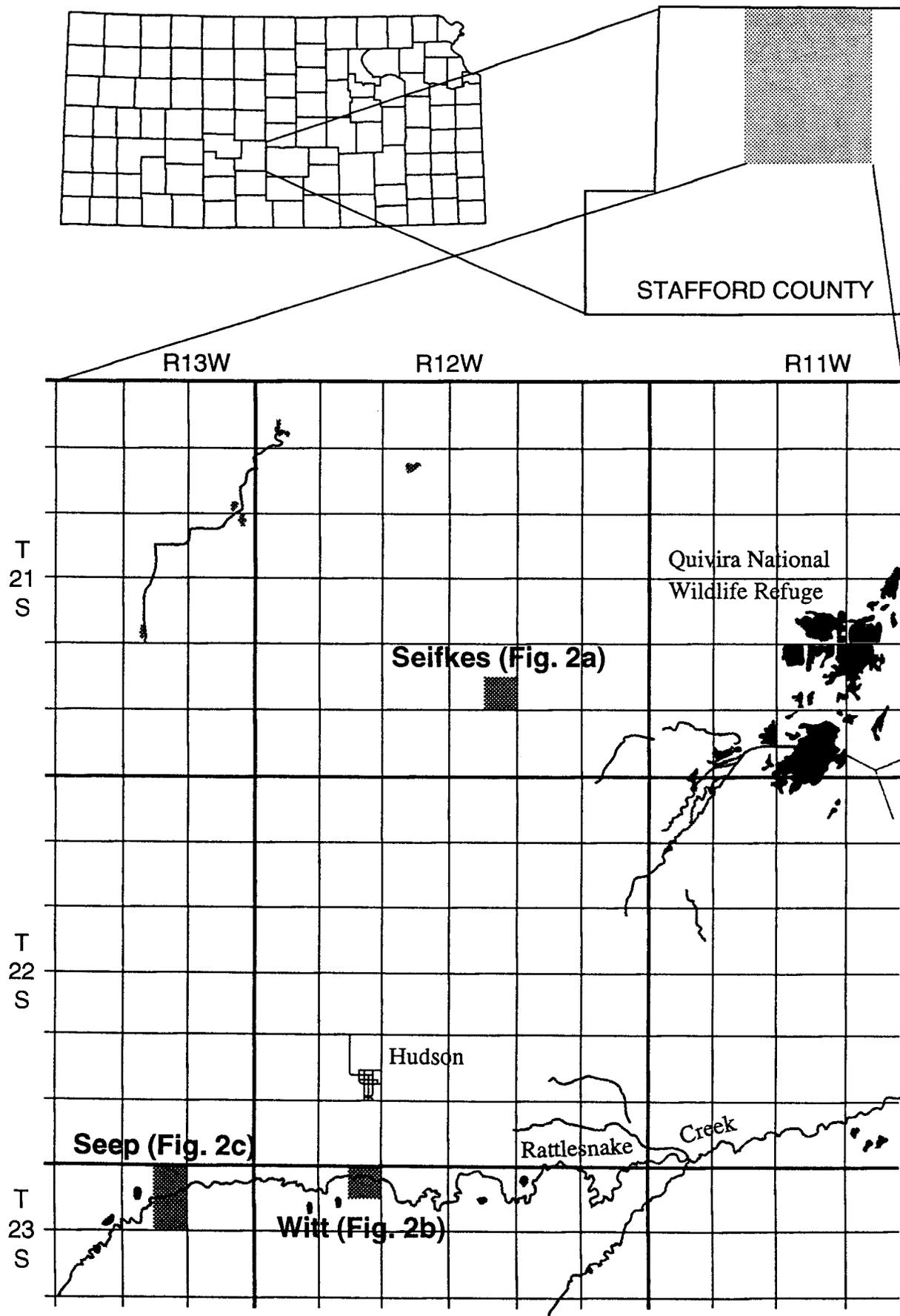
Figure 1. Index map of the study area showing location of individual sites.
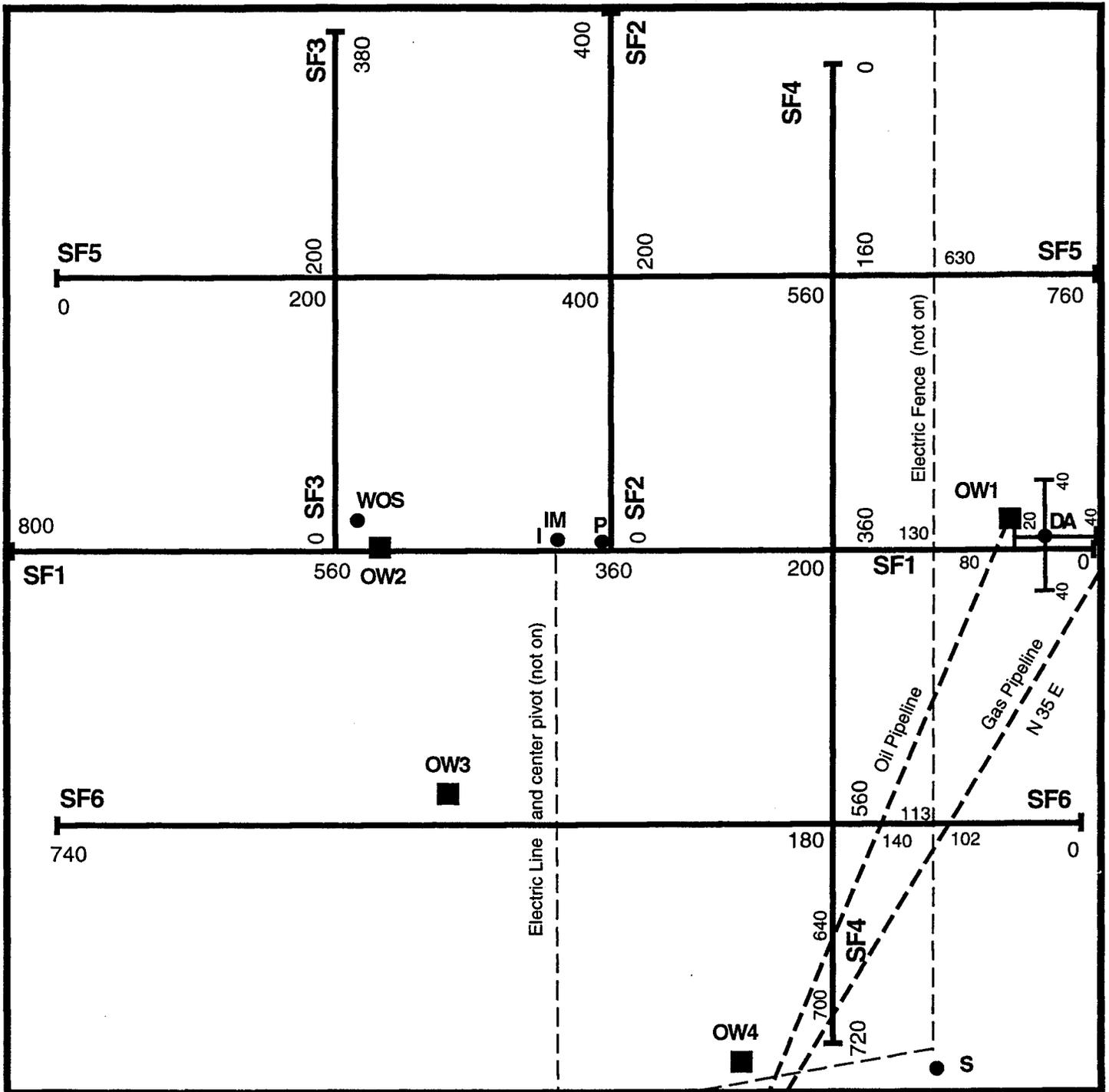
Seifkes Site EM Layout
SE 1/4 Sec 27 T21S-R12W

DA (deep aquifer): SF1 sta 49; 8 m N of line
P (Permian): SF1 sta 365; 1 m N of line
    approx. 480 m N of S end sect 27, 360 m W of E end sect 27
IM (monitoring well near irrigation well): SF1 sta 400; 1m N of line
I (irrigation well): near IM
WOS (west oil supply well): 18 m N of SF1 sta 551; 9 m E of SF3 sta 18
S (stock well): Off lines
OW1 (Oil well): North of SF1 sta 80
OW2 (Oil well): 1 m north of SF1 sta 527
OW3 (Oil well): 25 m north of SF6 sta 481
OW4 (Oil well): 86 m S80W of SF4 sta 720

N

0 m   100 m

Figure 2a. Map of the Siefkes Site.
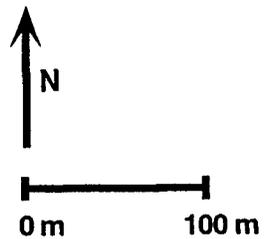
Figure 2b. Map of the Witt Site.
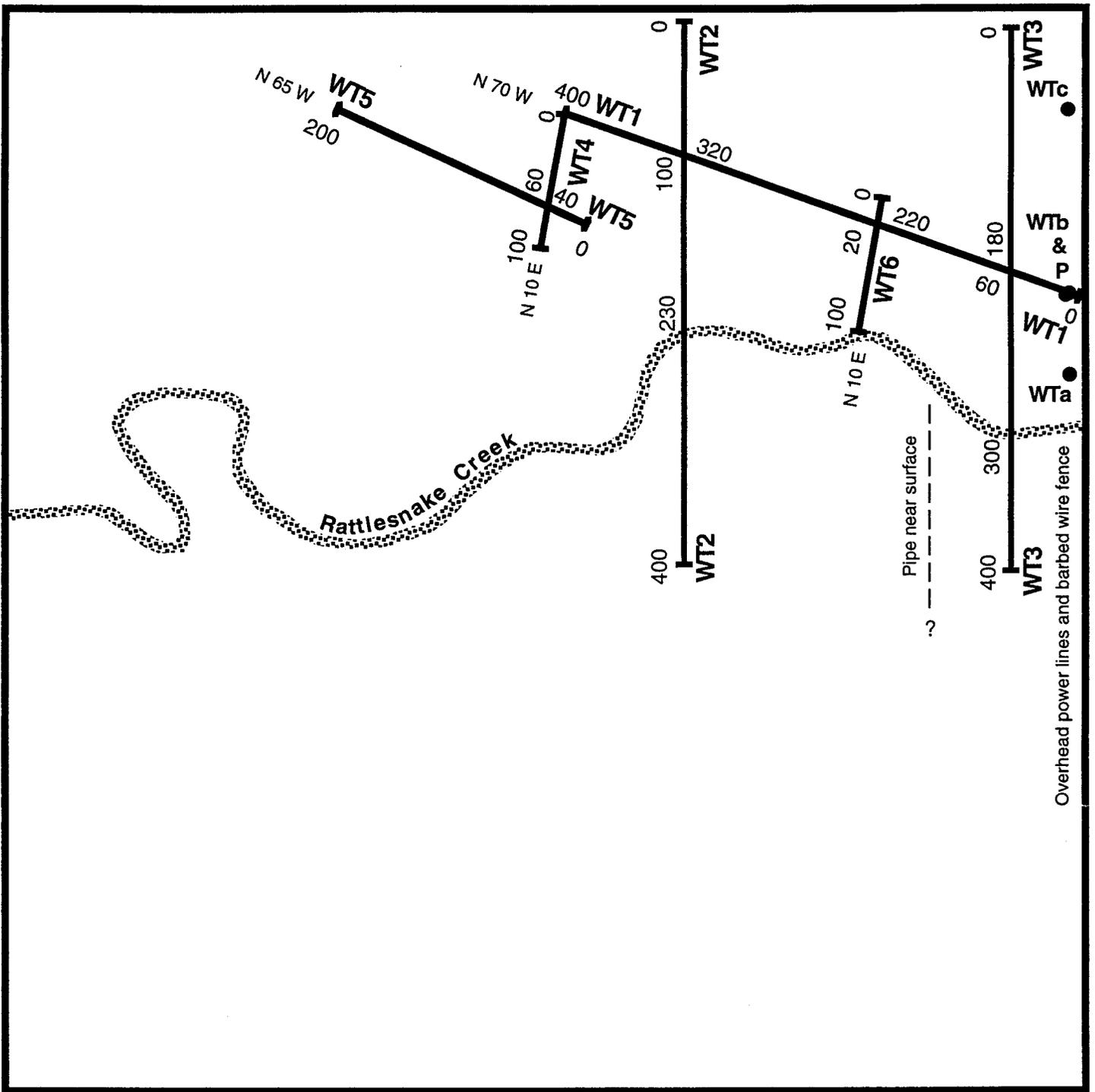
WTa (Water table well): 50 m E of line WT3 sta 255
WTb (Water table well): 1 m N & E of Permian well; line WT1 sta 9
    214 m S of N end of Sec 5; approx 10 m W of E end of Sec 5
P (Permian well): 1 m S & W of WTb; very near line WT1 sta 10
WTc (Water table well): 50 m E of line WT3 sta 60

Witt Site EM Layout
NE 1/4 Sec 5 T23S-R12W

N

0 m   100 m
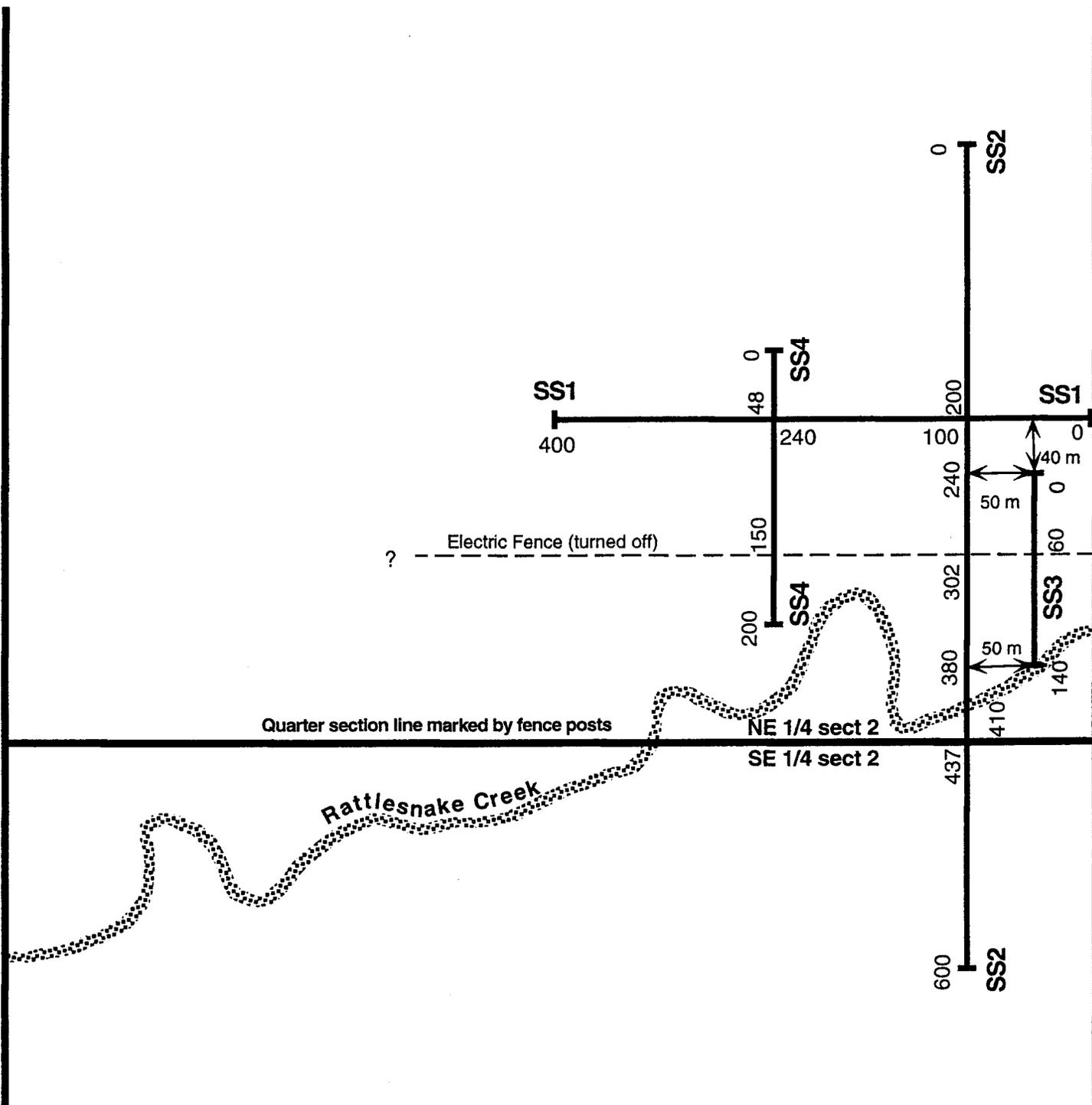
Seep Site EM Layout
part of E 1/2 Sec 2 T23S-R13W

SS2

SS4

SS1

400

SS1

0

40 m

50 m

0

Electric Fence (turned off)

?

SS4

SS3

50 m

Quarter section line marked by fence posts

NE 1/4 sect 2

SE 1/4 sect 2

Rattlesnake Creek

SS2

Line SS1 sta 0 is 100 m N of electric fence and approx.
   220 m N of quarter section line marked by fence posts.
   It is approx. 1 m W of the E end of sect 2 on the boundary
   with sect 1.
The "Seep" is directly E of the electric fence in sect 1 approx.
   20-40 m E of the section boundary between 1 and 2 and on
   the north bank of Rattlesnake Creek.

N

0 m   100 m

Figure 2c. Map of the Seep Site.

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of its length is a perennial stream originating primarily from baseflow, but the reach between St. John and the Quivira National Wildlife Refuge becomes dry during drought years or prolonged dry periods. This is also the reach strongly affected by salt intrusion, and an area of focus of the Mineral Intrusion Project. Some general climatic characteristics of area including the lower Rattlesnake Creek include an average annual precipitation of 30 ± 5" and mean seasonal temperatures ranging from $31\text{-}33^{\circ}$ in winter to $77\text{-}79^{\circ}F$ in summer (Goodin et al. 1995). The r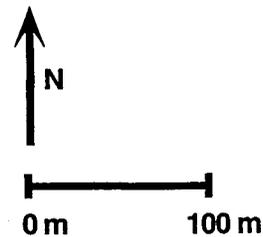egion is almost entirely agricultural, although salt intrusion prevents irrigation and limits land use in the immediate proximity of the lower Rattlesnake Creek.

The loamy and sandy soils of the Great Bend Prairie Region have been formed from parent materials of mainly sand and loess. Much of the drainage area of the Rattlesnake Creek Subbasin is covered with a layer of eolian deposits that results in the dune-type topography that common in the Great Bend Prairie.

Geology and Hydrogeology

Bedrock within the Rattlesnake Creek Subbasin is of Permian and Cretaceous age. West of a line approximately coincident with U.S. Highway 281, Cretaceous deposits underlie the Quaternary alluvial deposits of the Great Bend Prairie aquifer, and act as a confining layer for the fluids in the unerlying Permian deposits. The Permian "red beds" consist of red to brown shale, siltstone, and sandstone with some beds of limestone, dolomite, and anhydrites, that underlie the Great Bend Prairie Aquifer in the eastern part of the subbasin. The Cedar Hills Sandstone, also of Permian age, subcrops east of the Cretaceous deposits. It is typically approximately 50 m below the land surface and is a known source of highly mineralized water (Sophocleous and Perkins, 1993).

<u>Great Bend Prairie Aquifer</u>

Unconsolidated deposits of Tertiary and Quaternary age compose the Great Bend Prairie Aquifer including the Ogallala Formation and undifferentiated fluvial Pleistocene sediments. The early Pleistocene sediments form the Meade Formation whereas the late Pleistocene sediments form the Sandborn Formation. Together, the Ogallala, Meade, and Sandborn formations compose the major water producing zones within the Great Bend Prairie Aquifer. These deposits reach a maximum thickness of approximately 110 m (Fader and Stullken, 1977). A blanket of eolian sand has been deposited over most of the area and is evident from the dune topography. In the Rattlesnake Creek alluvial valley, the alluvial aquifer is composed of poorly sorted sand and gravel approximately 6 m thick, which is hydraulically connected with the Meade Formation below (Sophocleous and Perkins, 1993). Mineralized water upwells from the Permian "red beds" into overlying Quaternary sediments and rises to the surface in low areas, mainly along the Rattlesnake Creek in Stafford County (Buddemeier et al., 1994).

METHODOLOGY

Measurement Methods -- Principles and Instrumentation

The geophysical method chosen for this study uses electromagnetic energy to measure the ground conductivity, which varies depending on the type of material and the water contained within it (Dobrin and Savit, 1988). Because of their efficiency, electromagnetic methods are becoming more widely used to investigate the shallow subsurface. The instrument used in this study is the EM34-3 produced by Geonics Ltd. in Mississauga, Ontario, Canada.

Electromagnetic techniques measure the conductivity of the terrain by imparting an alternating current to a transmitter coil near the ground surface. The current through the transmitter coil produces a magnetic field which in turn induces small currents in the underlying strata. Currents in the strata produce a secondary field which is sensed by a receiver coil. The ratio of the EM field detected by the receiver coil to the EM field produced by the transmitter

coil is directly proportional to the ground conductivity (Struttmann and Anderson, 1992).
Using the ratio of the two fields eliminates the problem of variations in the magnetic fields
(Perry and others, 1993).

As the current passes through the coil, a magnetic field is produced that has a magnetic
dipole perpendicular to the plane of the coil. The EM34-3 can be used in the horizontal and
vertical dipole configurations. For both configurations, the intercoil spacing, or distance
between the transmitter coil and receiver coil, determines the exploration depth of the
instrument. For example, 70% of the response from the horizontal dipole is from the soil or
rock above a depth equal to 0.75 times the intercoil spacing, while 70% of the response from the
vertical dipole response comes from a depth above 1.5 times the coil spacing. These (70%
response) depths are referred to as the exploration depths (McNeill, 1980a.). Intercoil spacings
of 10, 20 and 40 m are normally used with the EM34-3; these spacings with a horizontal dipole
produce measurements of ground conductivity to nominal exploration depths of 7.5, 15 and 30
m, whereas the same spacings have nominal exploration depths of 15, 30, and 60 m with a
vertical dipole. The horizontal dipole tends to produce more accurate measurements of the
ground conductivity because the induced currents are condensed into a smaller area near the
ground surface so that uncertainty of the location of the secondary field is limited. The vertical
dipole is useful, however, in that the induced currents are propagated deeper into the ground.

Survey Sites

The three sites chosen for the electromagnetic ground conductivity survey (Siefkes, Witt,
and Seep sites) were selected on the basis of two primary criteria. These were 1) the presence
and depth of known saltwater features, and 2) subsurface geologic and water quality control
provided by geologic and geophysical logs of nearby observation and irrigation wells. Two of
the locations (Siefkes and Witt) were previously established by the Kansas Geological Survey as
Mineral Intrusion intensive study sites. Test wells at each of these sites have been installed,
logged (downhole EM and gamma ray) and sampled for water quality analysis.

The Siefkes site is irrigated farmland approximately seven miles north of the Rattlesnake Creek in an area of dune topography. Although saline water occurs in the base of the aquifer above the bedrock (which occurs at a depth of approximately 57 m), there is over 40 m of fresh water and unsaturated soil above the saline zone (Buddemeier et al., 1994), placing the expected conductivity signal source near the limits of the vertical dipole exploration depth.

The Witt and Seep sites are both pastureland on the floodplain of Rattlesnake Creek. Both exhibit patches of bare ground, salt-tolerant grasses, and occasional formation of salt crusts on the ground surface. The creek has also acquired substantial range of salinity by the time it reaches these locations. At the Witt site, monitoring wells show significant salinity near the water table and brine intrusion at relatively shallow depths (Young et al., 1995). At the Seep site there are no subsurface data available, but it is immediately adjacent to a substantial saltwater seep that discharges just north of the creekbed and flows into the stream.

Data Collection

Survey lines at each of the three sites were laid out and flagged at intervals of 20 m using a tape measure. Each flagged measurement point was surveyed for elevation using a rod and level; these relative elevations were converted to elevations above sea level by tying them in to known reference points such as wells and bridges. Lateral positioning of the lines were determined by their relationship to section lines, and wells. The survey lines ranged in length from 100 m to 800 m. Six long lines were laid out at the Siefkes Site (total length = 3800 m), six at the Witt Site (total length = 1600 m), and four at the Seep Site (total length = 1340 m). Measurement points, along the lines, were surveyed for location and elevation and flagged prior to using the EM34-3. Six different ground conductivity measurements were taken at each flagged point using three different spacings of the transmitting and receiving coils (10, 20 and 40 m) and two magnetic dipole orientations (horizontal and vertical).

Ground conductivity surveys were conducted by a three-person team. One person carried the transmitter coil and power source, another the receiver coil and meter, and the third recorded

the readings and took note of the characteristics at or near the survey point to identify possible interference by metallic objects, power lines, or telephone lines. Due to the size and weight of the transmitter coil, several people were rotated into and out of the survey team.

RESULTS

Tabulated data are presented in Appendix A. The apparent ground conductivity data and associated field notes are listed in Tables 1.1 through 3.4. In each set of tables, data for the horizontal dipole orientation (HDO) and vertical dipole orientation (VDO) are listed for the 10, 20, and 40 m intercoil spacings for measurement points at specified distances along the transect lines identified and mapped in Figures 2a-c. The Siefkes Site lines start with the prefix SF (Tables 1.1-1.6), the Witt Site lines start with WT (Tables 2.1-2.6), and the Seep Site lines start with SS (Tables 3.1-3.4). At the Siefkes Site, an additional set of lines starting with the prefix DA (Table 1.7) were acquired around the deep aquifer well (DA on Fig. 2a) to better correlate the surface EM data with the well control. Elevations for each measurement point are listed in Tables 4 through 6 in Appendix A.

Some basic statistics were calculated for the apparent ground conductivities measured in the Rattlesnake Creek Subbasin. For each of the study sites the average, mode, and median were calculated for the individual dipole orientation and intercoil spacing combinations (Table 7; Appendix A). At the Siefkes study site, the average values for the ground conductivities measured in the horizontal dipole orientation (HDO) were between 43 and 45 mmho/m while the values in the vertical dipole orientation (VDO) averaged between 27 and 39 mmho/m. At this site, measurements in the HDO increased slightly with exploration depth (increased intercoil spacing) while those in the VDO decreased by a somewhat larger proportion with increased exploration depth. The mode and median values were similar in magnitude and behavior. Except for measurements made in the vicinity of pipelines or fences, few if any of the individual measurements were as high as 70 mmho/m.

At the Witt and Seep sites, average HDO conductivites were highest at the 40 m spacing, but were higher (65-105 mmho/m) than Siefkes site values at all spacings. Average VDO observations varied relatively little with depth, and were significantly higher at the 40 m spacing than was the case for the Siefkes site. However, spatial variability was high, with individual measurements as high as 250 mmho/m at the Witt site and 155 mmho/m at the Seep site. This variability undoubtedly contributed to the dissimilarities in the behavior of mean, mode, and median at these sites (Table 7).

DISCUSSION

Apparent HDO ground conductivities of about 40 millimhos per meter (mmho/m) at the Siefkes Site (Fig. 2a) are normal for unconsolidated sediments of sand and clay. These values are fairly low for saturated conditions, indicating that the underlying aquifer contained primarily fresh water to a depth of at least 30 m. This is consistent with borehole logs and water quality data from the irrigation well. Relatively low apparent ground conductivities (average of 27 mmho/m) measured with the vertical dipole orientation at the 40 m intercoil spacing also suggest a lack of saltwater down to 60 m. However, downhole focused induction electromagnetic logs which read formation conductivity show that below about 40 m, a transition zone to saltwater occurs (Buddemeier et al., 1994; D. Young, pers. commun.). This apparent discrepancy may be due to the fact that even though the vertical dipole orientation at a 40 m intercoil spacing has an exploration depth of 60 m, it is more sensitive at shallower levels where the groundwater is fresher at this site. Other possible complications and distortions of results are discussed in more detail in Appendix B.

Overall, the measurements taken at the Siefkes Site probably indicate the magnitude of the background conductivity signal for Rattlesnake Creek subbasin sediments in the absence of salt water. At the time of the field work, the ground was at or near saturated conditions due to recent rains in the subbasin. This condition provides the best signal possible for understanding mineral intrusion into the freshwater aquifer. There are several wells at the Siefkes Site that can

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be used to tie the ground conductivity readings to the lithology and water quality of the underlying sediments including an irrigation well, a few observation wells, and three oil wells. In the case of the deep aquifer well (DA in Fig. 2a), several additional short survey lines centered on the well were acquired in order to facilitate comparison of the surface and borehole data.

The Witt Site (Fig. 2b) and Seep Site (Fig. 2c) had apparent ground conductivity values that ranged from <10 mmho/m to >200 mmho/m. The high readings, especially in HDO, are consistent with expectations based on surface characteristics, stream and soil salinities, and, at the Witt Site, subsurface data. As at the Siefkes site, VDO measured values were significantly lower, and appeared less sensitive to the known presence of saline waters at depth.

At the Witt Site, the highest ground conductivities measured with the EM38 were along low sandy ridges and embankments that had little or no grass. These ridges and embankments appeared to be the edges of old channels that had been abandoned by the creek and ephemeral stream channels. The high conductivity areas often had a white crust possibly indicating saltwater accumulation and evaporation.

Based on these observations and the available literature and characteristics of the equipment, apparent conductivities for the HDO in the range of 30 to 50 mmho/m can be interpreted as relatively freshwater areas within the Great Bend Prairie Aquifer for the study sites chosen. Variations within this range may be primarily due to changes in lithology such as a change from a sandy layer to a silty clay layer.

Another group of measured apparent ground conductivity values lies between 50 and 100 mmho/m. This range of values appears to represent some groundwater degradation detectable by the instrumentation, but the level of contamination needs to be verified by borehole geophysical techniques or by water sampling and analysis. Cultural interferences such as powerlines and fences or buried pipes may also result in measurements between 50 and 100 mmho/m.

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The third range includes all of the apparent ground conductivity values measured in the study areas that are greater than 100 mmho/m. These measurements almost certainly represent degradation of the groundwater by saltwater (commonly referred to as mineral intrusion in the Great Bend Prairie Aquifer). Both the Witt Site and Seep Site had apparent ground conductivity values in this range. There were no irrigation wells in these areas since the water is too saline to use for irrigation purposes, but test well and stream samples confirm this interpretation.

Finally, another group of values can be further defined with a range greater than 200 mmho/m as measured by the EM34-3 ground conductivity meter. From all of the data gathered in the Great Bend Prairie Aquifer region and some data gathered in Russell County, Kansas (Perry, 1994), this range probably represents most direct source area for mineral intrusion that can be determined using the EM34-3.

Preliminary Assessment

A clearer picture of the utility of the EM survey method and of the salt distributions it is capable of detecting and mapping can be expected to emerge from processing and calibrating the raw field data to take into account instrument responses and additional knowledge about the sites. That will be gradually developed from these original reconnaissance studies.

However, in order to present a qualitative initial picture of how such an analysis might proceed and the types of results to be expected, the data have been processed using empirical procedures developed in a study of saline water in another area of Kansas (Perry, 1994). These procedures are explained and the results presented in Appendix B. Since they have not been optimized or calibrated for the Rattlesnake Creek area, they should be considered indicative rather than definitve at this point.

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SUMMARY AND CONCLUSIONS

One major purpose of this study was to evaluate the mineral intrusion properties in the Great Bend Prairie Aquifer using near-surface geophysical techniques; a second was to evaluate the utility of the technique for further extension of investigations to sites lacking other sources of data.

Data obtained with the EM34-3 ground conductivity meter were used to estimate the changes in the groundwater quality for three study areas including the Siefkes Site, Seep Site, and Witt Site. At each of these sites, the ground conductivity was measured along multiple survey lines with intercoil spacings of 10, 20, and 40 m in both horizontal (HDO) and vertical (VDO) dipole orientations.

At the Siefkes Site, where freshwater conditions dominated the shallow subsurface above 40-45 m, the apparent ground conductivity remained near 40 mmho/m across most of the site. However, values ranged from <10 mmho/m to >150 mmho/m at both the Seep Site and Witt Site, indicating mineral intrusion and resulting groundwater degradation. The measurements were in qualitative agreement with other data and observations on local salinity distribution.

Based on the results of this reconnaissance survey and known characteristics of the sites studied and instruments used, the following conclusions were reached:

• Surface EM ground conductivity measurements with the EM34 or comparable instruments, espcially in the HDO mode, can be a useful technique for locating and mapping saline water over a range of a few tens of meters below ground surface.

• The data measured in the VDO mode is not directly comparable with the HDO data; preliminary standardization and combination of values indicate that such an approach can be used to generate two-dimensional plots of the composite values as pseudo-sections of the ground conductivity with depth. This method should be able to use all of the data collected and provide more detail for the interpretation of the apparent ground conductivities to a depth of 30 m. It may also extend the maximum depth of investigation below 30 m.

• There appears to be substantial potential to use borehole EM logs and shallow surface (EM38) measurements in conjunction with EM34 data to intercalibrate and extend the range of interpretation of the individual methods.

Work is continuing on processing, interpretation, and calibration of the results, and will be presented in subsequent reports.

ACKNOWLEDGEMENTS

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APPENDIX A

Data Tables

Tables 1.1-1.6. Apparent conductivity values for Siefkes Site lines SF1-SF6.

Tables 1.7. Apparent conductivity values for Siefkes deep aquifer well lines (DA).

Tables 2.1-2.6. Apparent conductivity values for Witt Site lines WT1-WT6.

Tables 3.1-3.4. Apparent conductivity values for Seep Site lines SS1-SS4.

Table 4. Elevations for Siefkes Site lines.

Table 5. Elevations for Witt Site lines.

Table 6. Elevations for Seep Site lines.

Table 7. Statistical calculations for the EM-34 apparent conductivities.

Table 1.1 EM34-3 Data for the Mineral Intrusion Project
Date: 5-15-95
Location: Siefkes Site in Stafford County
Crew: Perry, Rohs, Martinez
Apparent Ground Conductivity (mmho/m)

Station	Distance (meters)	10-meter spacing HDO	VDO	20-meter spacing HDO	VDO	40-meter spacing HDO	VDO	Comments
SF1	0	52	58	52	71	46	130	transmitter next to fence
SF1	20	39	36	45	35	52	54	pasture
SF1	40	42	34	43	31	50	62	pasture
SF1	60	45	40	46	40	38	-120	pasture
SF1	80	48	54	31	-88	34	-53	next to pond, parallel with oil rig
SF1	100	49	63	51	85	52	110	next to pond
SF1	120	48	37	48	32	52	41	fence between coils
SF1	140	45	38	48	35	52	34	corn field access road
SF1	160	57	42	54	31	51	27	corn field access road
SF1	180	70	44	57	31	54	29	corn field access road
SF1	200	65	48	60	35	56	29	corn field access road
SF1	220	73	47	63	32	57	26	corn field access road
SF1	240	71	47	60	31	54	29	corn field access road
SF1	260	59	42	52	34	51	31	corn field access road
SF1	280	46	40	46	34	49	34	corn field access road
SF1	300	40	35	44	35	48	32	corn field access road
SF1	320	42	38	46	33	50	32	corn field access road
SF1	340	46	39	47	34	48	31	corn field access road
SF1	360	47	40	47	36	45	26	observation well between coils
SF1	380	48	42	44	35	44	28	close to irrigation well and pivot
SF1	400	46	42	40	41	41	39	next to pivot
SF1	420	41	39	43	34	49	36	corn field access road
SF1	440	36	34	41	34	46	36	corn field access road
SF1	460	36	33	41	34	46	34	between irrigation and oil wells
SF1	480	39	35	42	34	44	36	close to oil well
SF1	500	40	35	43	36	45	35	closer to oil well
SF1	520	33	34	39	34	45	31	east side of oil well
SF1	540	41	38	42	30	45	30	west side of oil well
SF1	560	39	37	41	33	44	32	close to oil well
SF1	580	35	33	38	31	42	32	corn field
SF1	600	34	33	38	31	42	32	corn field
SF1	620	34	33	39	31	43	30	corn field
SF1	640	36	33	39	31	42	32	corn field
SF1	660	35	33	39	31	44	32	corn field
SF1	680	36	34	40	31	42	32	corn field
SF1	700	41	36	43	31	46	31	corn field
SF1	720	43	38	45	34	47	31	corn field
SF1	740	44	38	45	32	47	30	corn field
SF1	760	46	39	45	32	46	30	corn field
SF1	780	43	37	43	31	44	31	corn field
SF1	800	42	36	42	30	44	30	corn field

Table 1.2 EM34-3 Data for the Mineral Intrusion Project
Date: 5-15-95
Location: Siefkes Site in Stafford County
Crew: Perry, Rohs, Young
Apparent Ground Conductivity (mmho/m)

Station	Distance (meters)	10-meter spacing HDO	VDO	20-meter spacing HDO	VDO	40-meter spacing HDO	VDO	Comments
SF2	0	49	40	48	33	49	33	minimum till field
SF2	20	48	40	47	36	50	29	minimum till field
SF2	40	50	41	47	30	47	29	minimum till field
SF2	60	48	42	45	37	49	36	minimum till field
SF2	80	41	36	44	36	47	31	minimum till field
SF2	100	47	37	44	31	45	31	minimum till field
SF2	120	45	39	43	33	46	35	minimum till field
SF2	140	43	37	42	36	45	31	minimum till field
SF2	160	44	37	43	34	46	31	minimum till field
SF2	180	45	39	43	34	45	31	minimum till field
SF2	200	46	39	45	33	47	31	minimum till field
SF2	220	49	42	47	34	47	31	minimum till field
SF2	240	51	42	47	33	46	28	minimum till field
SF2	260	49	43	46	32	42	29	minimum till field
SF2	280	49	40	45	33	44	30	minimum till field
SF2	300	45	38	42	33	45	33	minimum till field
SF2	320	40	36	42	35	44	32	minimum till field
SF2	340	38	36	40	30	42	29	minimum till field
SF2	360	36	34	37	32	41	30	minimum till field
SF2	380	32	32	35	30	40	32	minimum till field
SF2	400	30	30	34	30	43	37	minimum till field

Table 1.3 EM34-3 Data for the Mineral Intrusion Project
Date: 5-15-95
Location: Siefkes Site in Stafford County
Crew: Perry, Rohs, Garneau, Young
Apparent Ground Conductivity (mmho/m)

Station	Distance (meters)	10-meter spacing HDO	VDO	20-meter spacing HDO	VDO	40-meter spacing HDO	VDO	Comments
SF3	0	41	37	41	31	46	34	minimum till field
SF3	20	36	35	41	35	44	35	minimum till field
SF3	40	33	32	39	34	44	33	minimum till field
SF3	60	36	33	42	30	46	32	minimum till field
SF3	80	36	33	40	31	43	32	minimum till field
SF3	100	36	34	38	31	44	34	minimum till field
SF3	120	37	30	37	32	44	34	minimum till field
SF3	140	33	32	36	32	44	33	minimum till field
SF3	160	34	32	36	31	40	29	minimum till field
SF3	180	35	36	38	32	41	32	minimum till field
SF3	200	35	36	41	32	43	31	minimum till field
SF3	220	37	36	41	31	43	32	minimum till field
SF3	240	39	36	42	34	42	33	minimum till field
SF3	260	42	37	42	30	44	29	minimum till field
SF3	280	42	40	42	32	44	30	minimum till field
SF3	300	41	41	42	34	45	30	minimum till field
SF3	320	44	40	45	31	47	28	minimum till field
SF3	340	48	41	50	33	47	28	minimum till field
SF3	360	50	43	50	35	47	25	minimum till field
SF3	380	55	42	50	29	48	25	minimum till field

Table 1.4 EM34-3 Data for the Mineral Intrusion Project
Date: 5-15-95
Location: Siefkes Site in Stafford County
Crew: Perry, Rohs, Garneau
Apparent Ground Conductivity (mmho/m)

Station	Distance (meters)	10-meter spacing HDO	VDO	20-meter spacing HDO	VDO	40-meter spacing HDO	VDO	Comments
SF4	0	32	32	34	30	36	30	
SF4	20	33	31	35	31	38	31	
SF4	40	31	32	36	31	40	30	
SF4	60	31	30	40	31	38	30	
SF4	80	29	30	36	31	41	33	
SF4	100	30	30	34	31	40	32	
SF4	120	34	32	37	29	43	32	
SF4	140	36	34	38	30	45	25	
SF4	160	37	34	37	31	45	28	
SF4	180	36	34	38	31	44	30	
SF4	200	38	33	39	30	44	31	
SF4	220	37	37	40	32	42	32	
SF4	240	38	36	42	33	46	34	
SF4	260	43	37	42	33	45	32	
SF4	280	47	40	47	34	45	30	
SF4	300	53	42	52	33	48	36	
SF4	320	67	44	55	31	51	31	saturated
SF4	340	69	51	59	35	49	28	saturated
SF4	360	67	49	57	32	51	27	saturated
SF4	380	56	50	52	41	49	33	
SF4	400	55	45	51	36	48	32	
SF4	420	51	43	51	39	49	33	
SF4	440	56	43	51	35	51	34	
SF4	460	48	46	52	36	50	31	
SF4	480	46	42	53	38	52	36	
SF4	500	52	41	50	35	50	35	
SF4	520	50	44	49	35	52	34	
SF4	540	50	43	50	35	55	37	saturated
SF4	560	49	41	50	36	56	44	saturated
SF4	580	54	40	53	41	58	64	saturated
SF4	600	61	49	57	59	53	120	
SF4	620	38	100	39	140	20	0	
SF4	640	54	100	45	-180	39	300	
SF4	660	64	47	58	105	18	-175	
SF4	680	64	75	60	115	48	0	near flagged pipeline at an angl
SF4	700	35	83	42	-190	38	-180	cross flagged pipeline
SF4	720	46	43	52	93	44	-170	near flagged pipeline at an angl

Table 1.5 EM34-3 Data for the Mineral Intrusion Project
Date: 5-15-95
Location: Siefkes Site in Stafford County
Crew: Perry, Rohs, Garneau
Apparent Ground Conductivity (mmho/m)

Station	Distance (meters)	10-meter spacing HDO	VDO	20-meter spacing HDO	VDO	40-meter spacing HDO	VDO	Comments
SF5	0	28	27	31	27	37	32	reciever coil in wheat field
SF5	20	35	36	37	29	37	28	minimum tilled field
SF5	40	39	38	41	32	42	27	minimum tilled field
SF5	60	41	40	42	34	44	28	minimum tilled field
SF5	80	41	40	43	34	46	29	minimum tilled field
SF5	100	41	38	42	34	46	28	minimum tilled field
SF5	120	39	38	43	32	45	29	minimum tilled field
SF5	140	39	37	40	32	43	30	minimum tilled field
SF5	160	37	35	41	31	44	30	minimum tilled field
SF5	180	36	33	39	29	42	30	minimum tilled field
SF5	200	36	35	38	33	43	30	minimum tilled field
SF5	220	41	36	40	30	44	31	minimum tilled field
SF5	240	45	40	43	29	44	28	minimum tilled field
SF5	260	43	39	43	32	44	28	minimum tilled field
SF5	280	43	39	43	33	44	30	minimum tilled field
SF5	300	46	40	42	30	44	32	minimum tilled field
SF5	320	42	38	42	31	44	30	minimum tilled field
SF5	340	41	40	43	32	44	32	minimum tilled field
SF5	360	44	40	45	33	44	30	minimum tilled field
SF5	380	44	40	44	32	44	30	minimum tilled field
SF5	400	45	39	43	31	45	31	minimum tilled field
SF5	420	47	41	44	35	46	31	minimum tilled field
SF5	440	48	43	45	36	46	34	minimum tilled field
SF5	460	56	47	50	36	48	33	minimum tilled field
SF5	480	63	42	50	24	45	29	minimum tilled field
SF5	500	43	42	47	35	46	28	minimum tilled field
SF5	520	37	33	40	30	46	34	minimum tilled field
SF5	540	35	33	38	31	46	34	minimum tilled field
SF5	560	35	34	39	30	44	33	minimum tilled field
SF5	580	35	34	37	30	42	31	minimum tilled field
SF5	600	35	31	37	28	40	30	minimum tilled field
SF5	620	33	33	37	30	42	29	minimum tilled field
SF5	640	30	31	36	30	40	30	transmitter near fence
SF5	660	32	33	34	30	40	30	pasture
SF5	680	34	36	37	30	40	30	pasture
SF5	700	37	35	38	30	41	30	pasture
SF5	720	40	37	38	30	42	31	pasture
SF5	740	36	36	36	29	40	33	pasture
SF5	760	25	28	32	33	40	50	near fence and powerlines

Table 1.6 EM34-3 Data for the Mineral Intrusion Project
Date: 5-16-95
Location: Siefkes Site in Stafford County
Crew: Perry, Rohs, Buddemeier, Kruger
Apparent Ground Conductivity (mmho/m)

Station	Distance (meters)	10-meter spacing HDO	VDO	20-meter spacing HDO	VDO	40-meter spacing HDO	VDO	Comments
SF6	-10	41	36	42	31	46	33	transmitter at fence
SF6	5	48	40	44	32	47	32	next to pond
SF6	20	48	40	46	30	54	34	first surveyed flag
SF6	40	48	41	54	34	55	42	on mound
SF6	60	77	49	62	30	38	48	small depression
SF6	80	77	54	68	110	36	-90	middle of depression
SF6	100	46	-36	36	-110	48	-240	over pipeline
SF6	120	68	83	67	55	42	-105	corn field near fence
SF6	140	69	79	37	-65	39	-74	corn field
SF6	160	60	50	56	56	59	92	corn field saturated cond.
SF6	180	46	41	46	36	50	40	corn field saturated cond.
SF6	200	45	38	45	33	49	34	corn field saturated cond.
SF6	220	43	38	44	32	49	34	corn field
SF6	240	42	36	42	32	45	32	corn field
SF6	260	41	36	42	31	45	34	corn field
SF6	280	40	36	41	33	43	32	corn field saturated cond.
SF6	300	40	37	43	34	45	30	corn field saturated cond.
SF6	320	43	36	44	31	48	33	corn field
SF6	340	41	37	43	33	45	36	corn field
SF6	360	41	37	42	36	44	25	corn field
SF6	380	37	34	42	34	47	18	corn field
SF6	400	39	35	42	36	46	36	corn field
SF6	420	38	36	44	36	47	35	corn field
SF6	440	40	35	44	35	48	33	corn field
SF6	460	39	38	44	39	52	35	corn field saturated cond.
SF6	480	39	36	43	36	47	33	corn field saturated cond.
SF6	500	39	37	42	36	46	33	corn field saturated cond.
SF6	520	39	36	42	34	50	34	corn field
SF6	540	38	37	43	35	46	29	corn field
SF6	560	38	35	42	33	47	32	corn field
SF6	580	39	37	44	36	49	31	corn field
SF6	600	41	37	46	35	49	33	corn field
SF6	620	41	37	46	37	50	33	corn field
SF6	640	41	39	44	37	50	32	corn field
SF6	660	40	37	44	36	47	30	corn field
SF6	680	37	35	43	36	49	33	corn field
SF6	700	36	35	43	34	49	30	corn field
SF6	720	39	36	43	34	45	33	corn field
SF6	740	33	35	40	36	48	35	corn field

Table 1.7 EM34-3 Data for the Mineral Intrusion Project

Date: 5-15-95
Location: Siefkes Site in Stafford County
Crew: Perry, Rohs, Martinez

Apparent Ground Conductivity (mmho/m)

Station	Distance (meters)	10-meter spacing		20-meter spacing		40-meter spacing		Comments
		HDO	VDO	HDO	VDO	HDO	VDO	
DA-E	40	46	41	49	50	50	75	near fence
DA-E	30	42	37	44	34	50	50	pasture
DA-E	20	43	36	42	30	50	48	pasture
DA-E	10	39	35	43	30	52	70	east of deep aquifer well
@well	0	39	34	44	33	57	110	@well
DA-W	10	44	36	47	46			receiver next to pond
DA-W	20	49	44					
DA-S	40	56	39	50	31	52	48	pasture
DA-S	30	42	41	48	36	54	48	pasture
DA-S	20	46	40	46	32	56	43	pasture
DA-S	10	42	33	45	31	50	38	south of well
@well	0	42	36	48	33	51	28	@well
DA-N	10	53	39	49	33	48	26	north of well
DA-N	20	60	45	54	22	49	28	pasture
DA-N	30	59	39	47	23	48	34	on access road
DA-N	40	59	44	48	28	50	40	variation in grass type

Table 2.1 EM34-3 Data for the Mineral Intrusion Project

Date: 5-17-95
Location: Witt Site in Stafford County
Crew: Perry, Rohs, Pouch, Kruger
Apparent Ground Conductivity (mmho/m)   Conditions Saturated ground from heavy rain

Station	Distance (meters)	10-meter spacing HDO	VDO	20-meter spacing HDO	VDO	40-meter spacing HDO	VDO	Comments
WT1	0	57	34	60	32	86	47	at fence next to wells (2 fences)
WT1	20	63	34	59	27	83	47	hay field next to creek
WT1	40	58	31	53	28	77	47	hay field
WT1	60	51	27	45	27	75	46	hay field
WT1	80	37	29	42	29	70	48	hay field
WT1	100	42	26	41	29	71	45	hay field
WT1	120	37	27	40	25	69	43	hay field
WT1	140	49	34	50	31	73	41	hay field up from pond
WT1	160	50	34	51	31	75	43	small metal pipe 10m away
WT1	180	59	42	57	35	78	36	hay field
WT1	200	69	36	58	28	83	35	hay field
WT1	220	77	54	70	30	85	38	hay field
WT1	240	93	42	73	25	87	35	hay field
WT1	260	74	39	63	25	78	40	hay field
WT1	280	73	36	55	35	79	46	marshy pasture
WT1	300	59	37	52	33	76	47	hay field
WT1	320	63	35	60	29	76	43	hay field
WT1	340	66	30	56	28	76	45	hay field
WT1	360	56	35	50	31	73	45	hay field
WT1	380	64	32	55	26	76	40	hay field
WT1	400	72	35	58	27	73	43	hay field

Table 2.2 EM34-3 Data for the Mineral Intrusion Project

Date: 5-17-95
Location: Witt Site in Stafford County
Crew: Perry, Rohs, Pouch, Kruger

Apparent Ground Conductivity (mmho/m)   Condition Saturated ground from heavy rain

Station	Distance (meters)	10-meter spacing HDO	VDO	20-meter spacing HDO	VDO	40-meter spacing HDO	VDO	Comments
WT2	0	35	25	35	25	65	42	receiver next to fenc
WT2	20	39	26	35	30	65	46	saturated pasture
WT2	40	56	25	44	22	66	46	saturated pasture
WT2	60	67	34	52	21	70	39	saturated pasture
WT2	80	58	37	52	29	73	39	saturated pasture
WT2	100	61	37	54	31	76	44	saturated pasture
WT2	120	60	44	56	33	80	47	old waterway
WT2	140	93	42	66	31	83	48	old waterway
WT2	160	110	18	74	13	79	31	saturated pasture
WT2	180	65	59	59	44	80	31	saturated pasture
WT2	200	51	32	50	27	85	42	saturated pasture
WT2	220	35	23	49	40	85	51	next to creek
WT2	240	73	53	80	50	120	10	next to creek
WT2	260	105	66	110	47	120	-4	saturated pasture
WT2	280	100	65	100	47	125	43	saturated pasture
WT2	300	61	43	82	66	120	59	near pond
WT2	320	63	44	77	45	110	44	saturated pasture
WT2	340	75	32	70	39	110	35	saturated pasture
WT2	360	87	55	81	31	100	38	saturated pasture
WT2	380	110	50	79	33	100	45	saturated pasture
WT2	400	70	50	63	35	90	48	saturated pasture

Table 2.3 EM34-3 Data for the Mineral Intrusion Project

Date: 5-17-95
Location: Witt Site in Stafford County
Crew: Perry, Rohs, Pouch, Kruger
Apparent Ground Conductivity (mmho/m)   Conditions Saturated ground from heavy rain

Station	Distance (meters)	10-meter spacing HDO	VDO	20-meter spacing HDO	VDO	40-meter spacing HDO	VDO	Comments
WT3	0							
WT3	20	38	24	33	37	72	47	near fence
WT3	40	36	24	32	34	70	44	saturated pasture
WT3	60	44	44	42	33	70	43	saturated pasture
WT3	80	66	20	52	13	74	42	saturated pasture
WT3	100	57	22	53	27	76	43	saturated pasture
WT3	120	44	20	46	23	71	43	saturated pasture
WT3	140	38	20	40	29	73	49	saturated pasture
WT3	160	38	26	43	30	70	48	saturated pasture
WT3	180	52	28	46	25	73	48	saturated pasture
WT3	200	42	37	45	29	75	42	saturated pasture
WT3	220	33	31	46	37	78	45	saturated pasture
WT3	240	31	29	45	38	82	51	saturated pasture
WT3	260	37	33	47	42	83	50	saturated pasture
WT3	280	54	42	59	42	88	53	saturated pasture
WT3	295	71	42	68	39	93	47	next to creek
WT3	305	57	39	65	47	105	42	next to creek
WT3	320	54	49	73	48	110	41	saturated pasture
WT3	340	71	33	74	38	105	48	saturated pasture
WT3	360	60	33	63	45	105	54	saturated pasture
WT3	380	59	35	69	34	90	50	saturated pasture
WT3	400	75	41	65	46	92	44	saturated pasture

Table 2.4 EM34-3 Data for the Mineral Intrusion Project

Date: 5-18-95
Location: Witt Site in Stafford County
Crew: Perry, Rohs, Gateneau, Kruger
Apparent Ground Conductivity (mmho/m)   Conditions Saturated ground from heavy rain

Station	Distance (meters)	10-meter spacing HDO	VDO	20-meter spacing HDO	VDO	40-meter spacing HDO	VDO	Comments
WT4	0	65	40	52	29	72	42	pasture
WT4	20	65	29	55	27	73	43	pasture
WT4	40	140	37	85	52	87	58	pasture
WT4	60	220	45	125	-35	88	12	sandy with white crust
WT4	80	130	69	120	50	89	-6	pasture
WT4	100	97	55	80	34	96	33	pasture

Table 2.5 EM34-3 Data for the Mineral Intrusion Project
Date: 5-18-95
Location: Witt Site in Stafford County
Crew: Perry, Rohs, Gateneau, Kruger
Apparent Ground Conductivity (mmho/m)   Condition Saturated ground from heavy rain

Station	Distance (meters)	10-meter spacing		20-meter spacing		40-meter spacing		Comments
		HDO	VDO	HDO	VDO	HDO	VDO	
WT5	0	150	57	115	17	125	15	pasture
WT5	20	140	100	115	11	110	10	pasture
WT5	40	250	75	150	6	110	25	sandy with white crust
WT5	60	180	78	115	50	98	37	sandy with brown vegetatio
WT5	80	140	85	110	50	90	20	pasture
WT5	100	165	45	130	14	92	6	brown grass
WT5	120	185	42	140	6	90	30	sandy with white crust
WT5	140	150	44	84	38	87	47	pasture (old waterway)
WT5	160	70	50	53	38	81	44	pasture (old waterway)
WT5	180	73	40	60	21	78	43	pasture (old waterway)
WT5	200	74	39	63	30	78	56	pasture (old waterway)

Table 2.6 EM34-3 Data for the Mineral Intrusion Project
Date: 5-18-95
Location: Witt Site in Stafford County
Crew: Perry, Rohs, Gateneau, Kruger
Apparent Ground Conductivity (mmho/m)   Condition Saturated ground from heavy rain

Station	Distance (meters)	10-meter spacing		20-meter spacing		40-meter spacing		Comments
		HDO	VDO	HDO	VDO	HDO	VDO	
WT6	0	55	36	45	25	67	44	pasture
WT6	20	69	46	55	35	70	42	pasture
WT6	40	98	44	69	25	81	36	sandy, high EM38 readings
WT6	60	85	45	75	34	78	35	saturated pasture
WT6	80	72	34	63	38	86	43	pasture
WT6	100	69	48	63	36	84	45	next to creek

Table 3.1 EM34-3 Data for the Mineral Intrusion Project
Date: 5-18-95
Location: Seep Site in Stafford County
Crew: Perry, Rohs, Gateneau, Kruger
Apparent Ground Conductivity (mmho/m)

Station	Distance (meters)	10-meter spacing		20-meter spacing		40-meter spacing		Comments
		HDO	VDO	HDO	VDO	HDO	VDO	
SS1	0	54	48	59	64	110	58	next to fence
SS1	20	50	32	56	45	100	44	next to pond
SS1	40	42	25	51	42	100	40	pasture
SS1	60	34	25	50	43	98	44	pasture
SS1	80	35	24	50	44	98	38	pasture
SS1	100	46	29	56	33	100	34	pasture
SS1	120	68	34	68	38	102	31	saturated (old waterway)
SS1	140	80	33	79	30	100	33	saturated (old waterway)
SS1	160	87	30	73	31	100	37	saturated (old waterway)
SS1	180	65	37	60	37	94	38	saturated (old waterway)
SS1	200	66	36	64	38	93	41	saturated (old waterway)
SS1	220	82	31	66	36	89	38	pasture
SS1	240	70	48	55	43	88	42	pasture
SS1	260	65	50	57	40	90	38	pasture
SS1	280	76	51	64	37	92	38	pasture
SS1	300	79	43	68	37	91	41	pasture
SS1	320	87	39	65	34	91	40	pasture
SS1	340	73	43	63	40	88	42	pasture
SS1	360	72	41	63	38	86	38	pasture
SS1	380	59	46	56	35	88	47	pasture
SS1	400	64	40	56	44	88	48	pasture

Table 3.2 EM34-3 Data for the Mineral Intrusion Project
Date:　　5-18-95
Location:　Seep Site in Stafford County
Crew:　　Perry, Rohs, Gateneau, Kruger
Apparent Ground Conductivity (mmho/m)

Station	Distance (meters)	10-meter spacing		20-meter spacing		40-meter spacing		Comments
		HDO	VDO	HDO	VDO	HDO	VDO	
SS2	0	90	30	58	-4	80	30	pasture
SS2	20	90	36	75	38	82	27	pasture
SS2	40	135	25	84	5	98	34	pasture
SS2	60	105	39	87	32	90	25	pasture
SS2	80	87	0	67	4	100	18	pasture
SS2	100	94	38	98	57	105	40	in small depression
SS2	120	77	79	65	-3	92	38	pasture
SS2	140	58	47	48	37	90	24	saturated pasture
SS2	160	66	30	56	42	90	52	saturated pasture
SS2	180	80	40	65	25	88	40	saturated pasture
SS2	200	56	29	59	34	94	32	saturated pasture
SS2	220	44	25	56	45	100	42	saturated pasture
SS2	240	61	27	65	40	110	40	saturated pasture
SS2	260	70	31	73	37	115	27	saturated pasture
SS2	280	66	32	85	47	125	22	pasture
SS2	300	79	41	100	42	140	18	next to fence
SS2	320	93	53	112	39	150	0	pasture with fence at 90 degree
SS2	340	87	52	105	35	155	-2	pasture
SS2	360	65	49	87	50	140	9	pasture
SS2	380	49	38	74	49	130	28	pasture
SS2	400	48	34	72	43	125	28	next to creek (north side)
SS2	420	34	23	53	36	105	38	next to creek (south side)
SS2	440	37	26	54	40	97	46	pasture
SS2	460	57	24	55	39	110	46	pasture
SS2	480	42	35	65	43	110	30	pasture
SS2	500	98	25	96	8	110	35	pasture
SS2	520	68	45	73	45	100	49	pasture
SS2	540	43	35	52	36	88	48	pasture
SS2	560	45	33	51	39	91	45	pasture
SS2	580	46	14	50	29	86	42	pasture
SS2	600	53	25	54	29	82	39	saturated pasture

Table 3.3 EM34-3 Data for the Mineral Intrusion Project
Date: 5-18-95
Location: Seep Site in Stafford County
Crew: Perry, Rohs, Heely, Kruger
Apparent Ground Conductivity (mmho/m)

Station	Distance (meters)	10-meter spacing HDO	VDO	20-meter spacing HDO	VDO	40-meter spacing HDO	VDO	Comments
SS3	0	55	22	67	34	115	50	next to pond
SS3	20	68	37	84	42	120	30	on birm
SS3	40	75	34	86	36	130	15	low before birm
SS3	60	63	28	86	51	130	15	pasture
SS3	80	39	31	77	50	135	35	pasture
SS3	100	37	34	74	51	130	30	saturated asture
SS3	120	41	30	70	46	125	35	natural levee
SS3	140	45	36	71	46	120	30	sand bar next to creek

Table 3.4 EM34-3 Data for the Mineral Intrusion Project
Date: 5-18-95
Location: Seep Site in Stafford County
Crew: Perry, Rohs, Heely, Kruger
Apparent Ground Conductivity (mmho/m)

Station	Distance (meters)	10-meter spacing HDO	VDO	20-meter spacing HDO	VDO	40-meter spacing HDO	VDO	Comments
SS4	0	66	42	62	52	85	37	pasture
SS4	20	74	40	58	24	92	50	pasture
SS4	40	75	17	61	20	87	28	next to small waterway
SS4	60	76	29	69	41	93	39	pasture
SS4	80	85	49	73	33	100	42	pasture
SS4	100	110	40	92	37	110	45	top of ridge
SS4	120	110	48	89	29	115	28	pasture
SS4	140	66	50	82	45	115	28	top of birm
SS4	160	75	45	94	56	135	40	floodplain
SS4	180	90	50	100	33	130	10	floodplain depression
SS4	200	72	45	100	58	130	8	next to creek (north side)

Table 4 Elevations for Siefkes Site EM-34-3 lines

LINE SF-1		LINE SF-2		LINE SF-3		LINE SF-4		LINE SF-5		LINE SF-6	
Station (m)	Elevation (ft)	Station (m)	Elevation (ft)	Station (m)	Elevation (ft)	Station (m)	Elevation (ft)	Station (m)	Elevation (ft)	Station (m)	Elevation (ft)
0	1836.24	0	1839.60	0	1839.25	0	1841.89	0	1841.14	0	1834.00
20	1840.69	20	1839.75	20	1839.15	20	1843.45	20	1840.42	20	1836.44
40	1839.76	40	1839.69	40	1839.53	40	1842.85	40	1839.58	40	1840.59
60	1836.13	60	1837.77	60	1838.99	60	1843.10	60	1839.42	60	1836.05
80	1834.92	80	1838.50	80	1839.20	80	1843.64	80	1840.00	80	1835.51
100	1834.94	100	1838.22	100	1838.51	100	1844.08	100	1840.65	100	1835.87
120	1836.10	120	1838.39	120	1837.93	120	1842.91	120	1839.94	120	1836.42
140	1838.02	140	1838.73	140	1838.52	140	1841.59	140	1839.52	140	1837.36
160	1838.75	160	1839.12	160	1839.07	160	1841.21	160	1839.69	160	1838.16
180	1838.78	180	1839.68	180	1838.99	180	1841.14	180	1839.18	180	1837.39
200	1838.97	200	1839.24	200	1838.82	200	1841.00	200	1838.82	200	1837.48
220	1839.02	220	1839.43	220	1838.04	220	1840.40	220	1839.23	220	1837.89
240	1839.10	240	1839.54	240	1837.89	240	1839.90	240	1838.54	240	1838.44
260	1839.16	260	1839.78	260	1837.96	260	1839.56	260	1838.54	260	1838.04
280	1839.39	280	1840.00	280	1837.87	280	1838.33	280	1838.49	280	1837.46
300	1840.83	300	1839.57	300	1837.88	300	1838.35	300	1838.87	300	1837.78
320	1840.15	320	1839.29	320	1838.45	320	1838.79	320	1840.04	320	1838.62
340	1839.86	340	1839.90	340	1838.78	340	1838.97	340	1838.88	340	1838.51
360	1839.60	360	1840.50	360	1838.78	360	1838.97	360	1838.83	360	1838.70
380	1839.69	380	1842.28	380	1839.34	380	1838.96	380	1839.20	380	1838.25
400	1839.99	400	1842.64			400	1838.32	400	1839.24	400	1838.65
420	1840.07					420	1838.23	420	1839.17	420	1839.41
440	1841.10					440	1838.33	440	1839.08	440	1839.96
460	1840.78					460	1837.62	460	1839.28	460	1839.55
480	1839.48					480	1838.21	480	1839.73	480	1838.90
500	1838.73					500	1838.25	500	1840.17	500	1839.31
520	1838.02					520	1837.32	520	1841.03	520	1840.29
540	1838.72					540	1837.43	540	1841.37	540	1840.07
560	1839.25					560	1837.39	560	1841.21	560	1841.23
580	1839.81					580	1837.67	580	1842.36	580	1841.23
600	1839.86					600	1838.17	600	1843.53	600	1840.44
620	1839.23					620	1837.99	620	1843.19	620	1840.33
640	1838.46					640	1837.99	640	1843.49	640	1840.50
660	1838.25					660	1837.78	660	1842.90	660	1841.65
680	1838.40					680	1837.04	680	1842.84	680	1843.70
700	1838.65					700	1836.69	700	1841.39	700	1844.98
720	1838.91					720	1839.26	720	1838.83	720	1844.42
740	1839.12							740	1840.29	740	1843.62
760	1839.70							760	1843.03		
780	1840.36										
800	1840.94										

Table 5 Elevations for Witt Site EM-34-3 lines

LINE WT-1		LINE WT-2		LINE WT-3		LINE WT-4		LINE WT-5		LINE WT-6	
Station (m)	Elevation (ft)	Station (m)	Elevation (ft)	Station (m)	Elevation (ft)	Station (m)	Elevation (ft)	Station (m)	Elevation (ft)	Station (m)	Elevation (ft)
0	1843.64	0	1842.64	0	1844.09	0	1841.32	0	1843.16	0	1844.17
20	1843.70	20	1842.37	20	1843.93	20	1841.62	20	1842.69	20	1843.05
40	1844.40	40	1842.01	40	1843.69	40	1841.37	40	1841.66	40	1840.71
60	1844.56	60	1841.86	60	1843.02	60	1841.66	60	1841.80	60	1840.77
80	1845.76	80	1841.47	80	1843.13	80	1843.45	80	1842.10	80	1840.44
100	1844.69	100	1840.79	100	1843.51	100	1842.81	100	1841.78	100	1841.19
120	1844.46	120	1840.63	120	1844.72			120	1841.80		
140	1844.39	140	1840.41	140	1845.32			140	1841.68		
160	1844.57	160	1842.33	160	1845.22			160	1841.96		
180	1843.06	180	1842.57	180	1844.56			180	1842.37		
200	1843.25	200	1840.37	200	1842.65			200	1842.22		
220	1843.05	220	1840.92	220	1842.92						
240	1842.70	240	1840.20	240	1842.55						
260	1842.09	260	1842.24	260	1840.93						
280	1841.75	280	1841.17	280	1839.79						
300	1841.41	300	1841.80	300	1839.37						
320	1840.79	320	1841.13	320	1842.27						
340	1840.97	340	1841.42	340	1842.27						
360	1841.69	360	1842.32	360	1842.36						
380	1841.47	380	1841.72	380	1842.16						
400	1841.32	400	1842.26	400	1842.08						

Table 6 Elevations for Seep Site EM-34-3 lines

LINE SS-1		LINE SS-2		LINE SS-3		LINE SS-4	
Station (m)	Elevation (ft)	Station (m)	Elevation (ft)	Station (m)	Elevation (ft)	Station (m)	Elevation (ft)
0	1855.00	0	1855.36	0	1855.42	0	1857.48
20	1855.40	20	1855.43	20	1856.97	20	1856.72
40	1855.70	40	1855.48	40	1854.67	40	1855.62
60	1855.25	60	1855.60	60	1854.93	60	1856.35
80	1855.55	80	1856.19	80	1853.83	80	1856.72
100	1855.39	100	1855.80	100	1852.97	100	1857.23
120	1855.05	120	1857.25	120	1853.97	120	1857.96
140	1855.02	140	1857.89	140	1852.35	140	1856.50
160	1855.18	160	1857.55	160	1849.17	160	1852.62
180	1855.56	180	1856.33			180	1851.41
200	1855.79	200	1855.39			200	1853.66
220	1855.96	220	1855.09				
240	1855.63	240	1856.19				
260	1855.67	260	1856.99				
280	1855.81	280	1855.39				
300	1856.18	300	1856.10				
320	1856.20	320	1855.93				
340	1856.52	340	1854.91				
360	1856.69	360	1855.01				
380	1857.12	380	1855.17				
400	1857.55	400	1850.97				
		420	1850.97				
		440	1858.52				
		460	1858.67				
		480	1857.98				
		500	1857.81				
		520	1858.32				
		540	1858.34				
		560	1858.56				
		580	1858.44				
		600	1858.40				

Table 7. Apparent Conductivity Statistical Results (mmhos/m)

Intercoil Spacing and Dipole Orientation:

	10 mh	10 mv	20 mh	20 mv	40 mh	40 mv
Siefkes Site						
Average	43.5	39.3	43.9	31.7	45.4	27.3
Mode	41.0	36.0	42.0	31.0	44.0	30.0
Median	41.0	37.0	43.0	33.0	45.0	31.0
Witt Site						
Average	76.1	40.0	65.6	31.6	84.7	40.2
Mode	37.0	34.0	63.0	25.0	73.0	43.0
Median	65.0	37.0	59.0	31.0	80.5	43.0
Seep Site						
Average	67.6	35.9	70.0	37.3	105.1	34.3
Mode	66.0	25.0	56.0	37.0	100.0	38.0
Median	66.0	35.0	66.0	38.0	100.0	38.0

Introduction

This section of the report addresses certain issues of data processing and interpretation in more detail, and applies some semi-empirical relationships derived from a different study to the integration and interpretation of the data collected in the Rattlesnake Creek surveys. The results provide both examples of an approach to the interpretation, and some qualitative interpretations. Because these procedures have not been calibrated and optimized for the specific sites studied, they are presented as provisional examples rather than final results. References cited are found in the bibliography of the main report section.

Background

Electromagnetic (EM) methods are widely used in the mapping of saltwater-freshwater boundaries and the detection of saltwater intrusion along the coasts (Fitterman, 1984; Gillespie and Hargadine, 1994). Several case histories illustrate the efficient and effective use of electromagnetic techniques for mapping saltwater contamination in soil and groundwater (Williams and Fidler, 1983; Kingston, 1985; Street and Engel, 1991; Lahti and Hoekstra, 1991; Gillespie and Hargadine, 1994; Paine et al., 1994). The EM34-3 was used in a groundwater study completed by Lahti and Hoekstra (1991) in determination of the lateral extent of brine migration around evaporation ponds. The instrumentation has also been used in a study of saltwater intrusion in the Saline River Basin in Russell County, Kansas (Perry, 1994). According to Fitterman, (1984) electromagnetic instruments such as the EM34-3 conductivity meter provide an alternative method to drilling by locating the saltwater-freshwater interface from surficial measurements of ground conductivity rather than well monitoring.

Data Processing

In the measurement of ground conductivity, the EM34-3 responds differently in the HDO than in the VDO. These differences are evident in a comparison of true ground conductivities

and the apparent conductivities measured with the instrumentation (Fig. 3). In general, apparent conductivities measured in both the HDO and VDO are lower than the true ground conductivity. However, apparent conductivities taken in the VDO tend to be lower than the corresponding values measured in the HDO (McNeill, 1980b.). This is particularly evident for high true conductivity values where the apparent conductivities taken with the VDO actually decrease compared to increasing true conductivity values (Fig. 3), but those taken with the HDO do not. If the graph in Figure 3 were directly applicable to any site, a correction factor would be easy to calculate. Unfortunately, it is only good for a homogenous half-space where the conductivity is constant. Even though the basic relationship of the curves would remain the same for different sites, the specific values are site specific in cases where the conductivity varies both vertically and laterally.

As would be expected from knowledge of the sites and the instrument characteristics, the data collected in this survey exhibit a wide range of conductivity values in both the HDO and VDO. However, HDO values are consistently higher than the VDO values (Fig. 4). This recurring difference is further examined for both the intercoil spacing and exploration depth.

Calculation of Deviations from the Mean

An alternative method of looking at the absolute measurement values or "raw" apparent ground conductivities is to convert the data to deviations from the mean (Perry, 1994). Each apparent conductivity measurement is converted to a deviation from the mean using the following equation:

$$[(\text{apparent conductivity-mean})/\text{mean}]+1=\text{Deviation from the mean.}$$

This approach facilitates integration and intercomparison of the data by reducing problems associated with systematic differences in the mean and variance of the horizontal and vertical values and with non-linear responses in areas of high conductivity, especially in the VDO. At high true ground conductivity values the response in the VDO quickly drops off and may even result in a negative value of apparent conductivity. In such areas the ratio of the secondary to
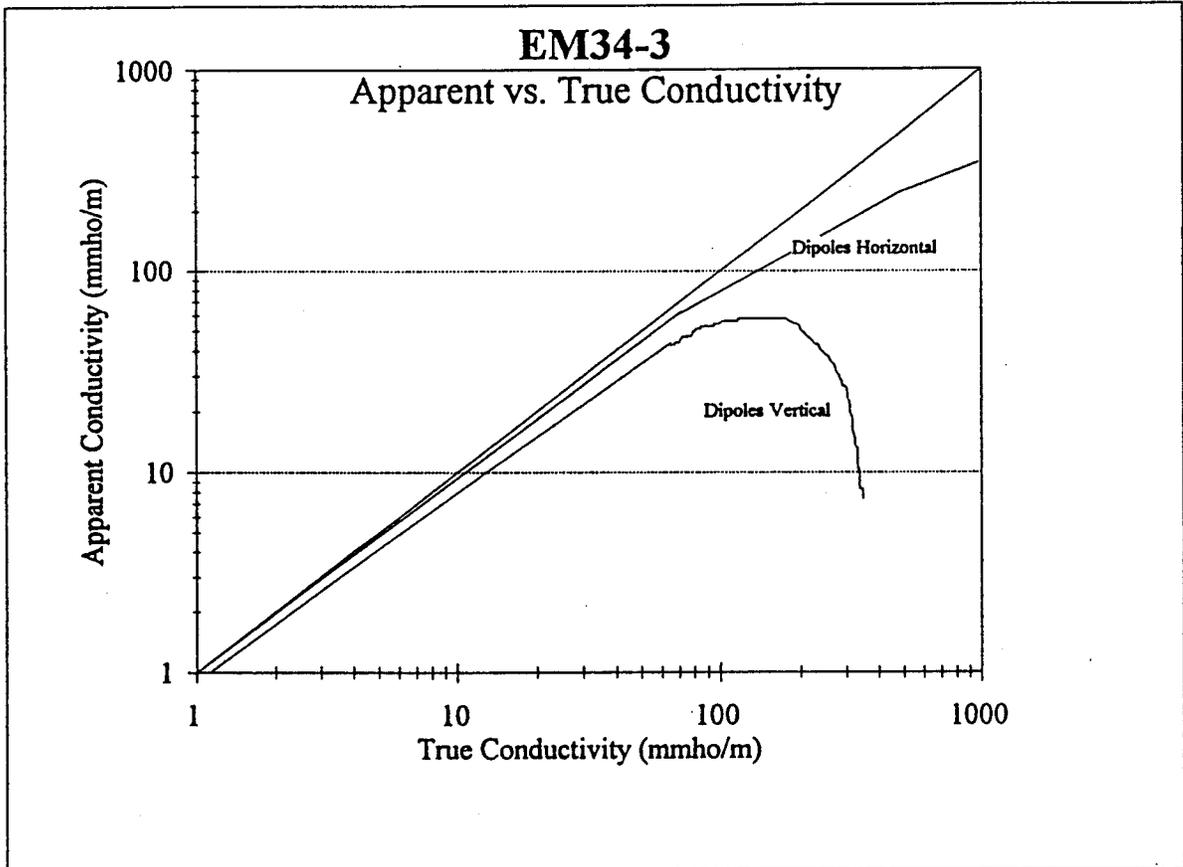
Figure 3. True conductivity versus apparent conductivity for the EM34-3 (McNeill, 1980b.)
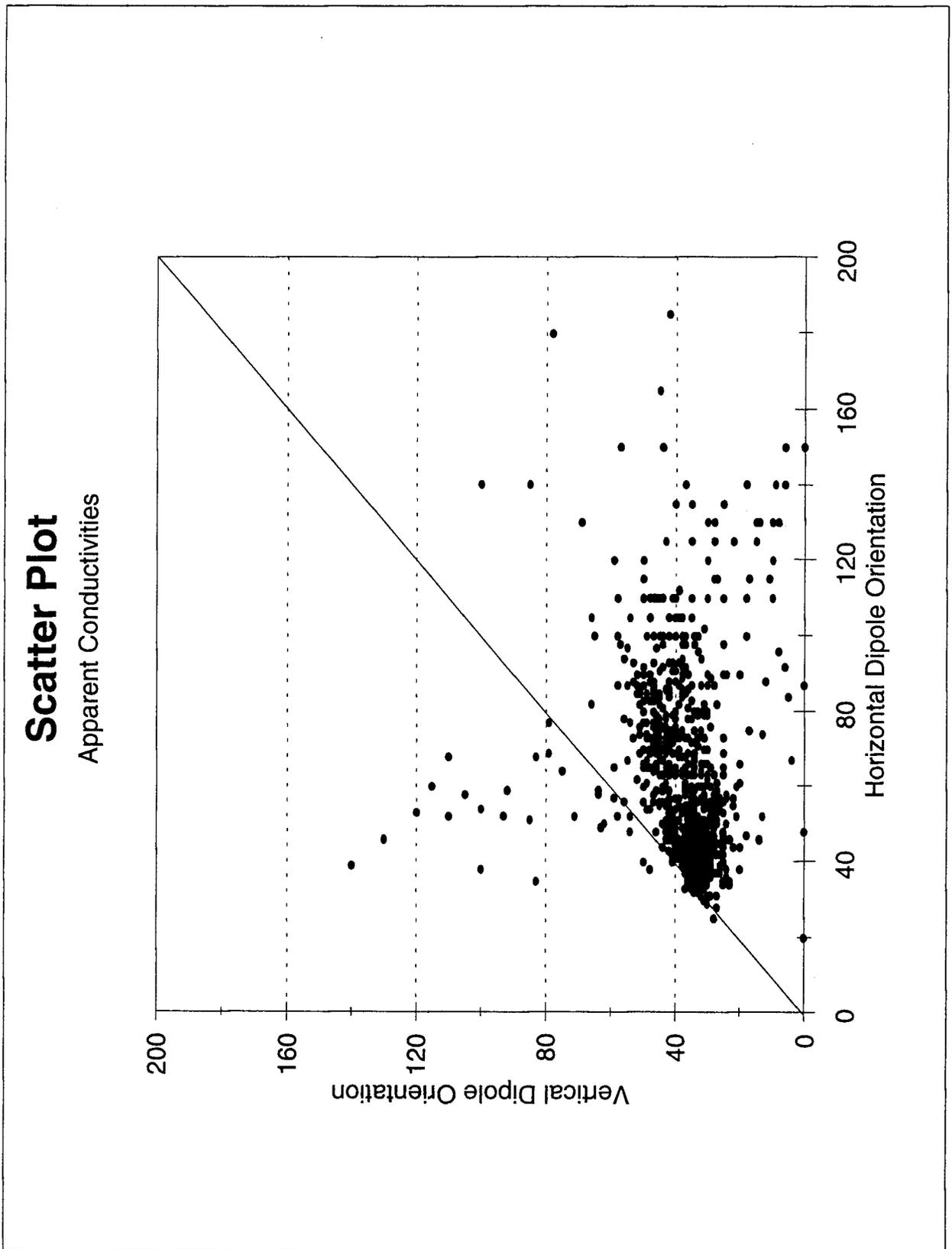
Figure 4. Scatter plot of apparent conductivities for all the data measured in the horizontal dipole orientation (HDO) and vertical dipole orientation (VDO). Each data point represents the common intercoil spacing for the HDO and VDO at a given station.

the primary magnetic fields no longer varies linearly with ground conductivity (McNeill, 1980b.).

A mean is calculated for the conductivity values with the same intercoil spacing and the same diphole orientation using data from all the sites combined. It is necessary to make some initial assumptions about the population of values over which the mean is to be calculated; in this case, whether each site needed to be treated separately, or whether fundamental characteristics other than the presence or absence of mineral intrusion were sufficiently similar so that all of the sites could be grouped together. For the purpose of the preliminary analysis all of the sites were combined. The validity of this assumption needs to be examined in more detail in the further analysis, but it represented a convenient way to obtain a first-order data review. Thus, six means were calculated for the survey, one each for the measurements in VDO and HDO at the 10, 20, and 40 m intercoil spacings averaged over all three sites.

Adjustment of VDO Values

Scatter plots of the calculated deviations from the survey mean were plotted to determine the relationship between the data collected with VDO and that collected with HDO (Figure 4). Because apparent conductivity is more similar to true conductivity in the HDO measurements, HDO values were plotted as the independent variable. Each data point represents the HDO (x) and VDO (y) deviation values for one of the intercoil spacings at a single measurement station. A scatter plot combining all the sites and intercoil separations was also generated (Fig. 5). All of the plots showed similar relationships. A scatter plot of all the deviations shows a one-to-one relationship between the values in the HDO and the VDO at lower deviation values (Fig. 5). At higher HDO deviation values, the VDO values fall off. The relationship between the deviation values is similar to the relationship between the true and apparent conductivities in the VDO. Scatter plots for each site and the three intercoil separations were generated separately and compared. The plots were also used to estimate the point at which the data no longer remain
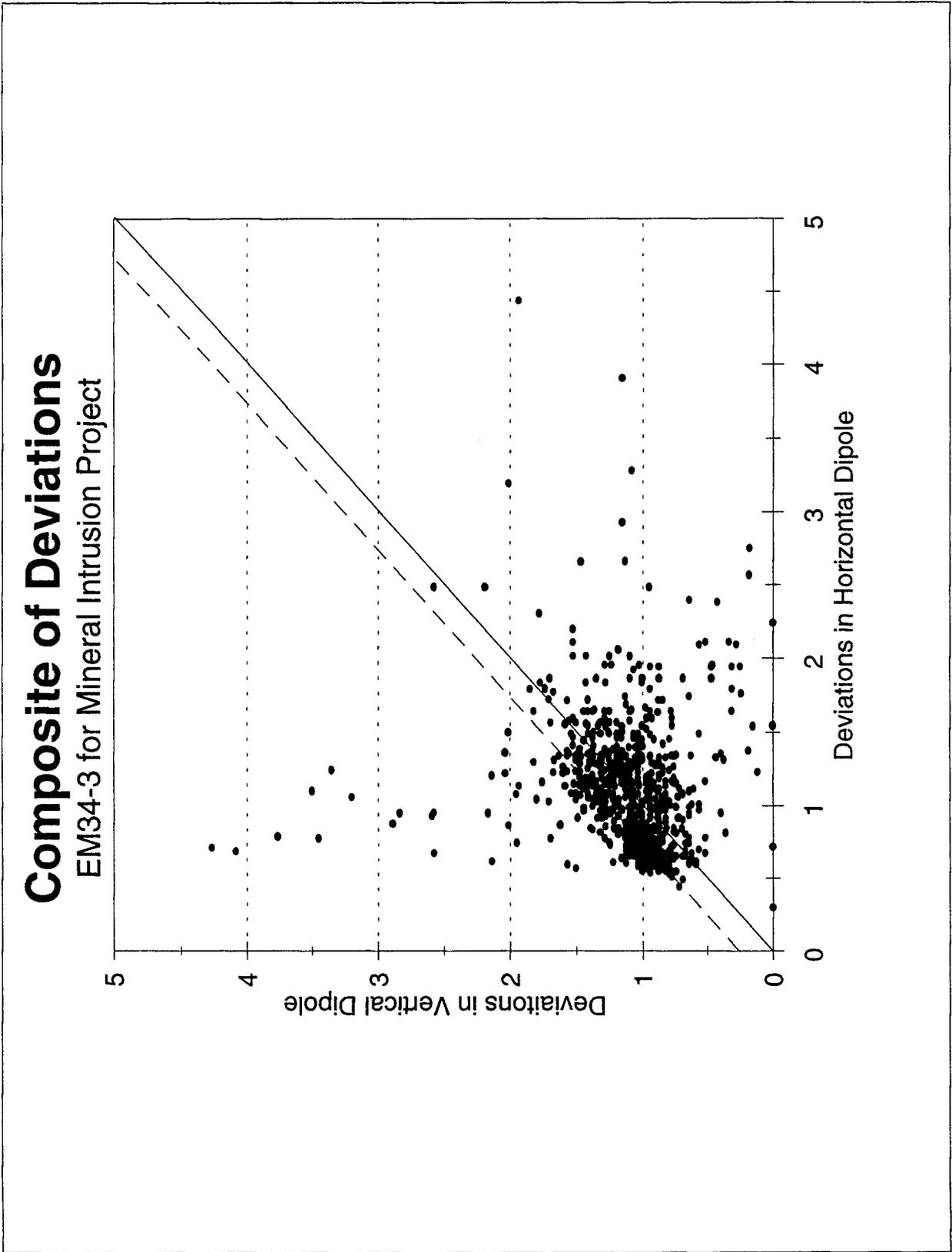
42

Figure 5. Scatter plot composite of the deviation values for all the data measured in the HDO and VDO. Each data point represents the common intercoil spacing for the HDO and VDO at a given station.

linear. Separate scatter plots of the three intercoil spacings suggest that the variability of the deviation data also increases with larger intercoil spacings.

In order to prepare composite values combining the information contained in both the HDO and VDO observations, it is necessary to correct for their intrinsic differences in response. An approximate method of correction was developed as follows. A dashed line with a slope of 1 was drawn through the highest concentration of data and extended into the range of higher deviation values Figure 5. Below 0.8 on the x-axis, VDO deviation and HDO appear equivalent and can be directly combined. Above 0.8 on the x-axis, the data begin to scatter more and VDO values become increasingly smaller than the corresponding HDO values. VDO deviation values were impirically adjusted to conform to the HDO deviation values with the following equation.

Adjusted VDO Deviation Values:

$$If\ X>0.8\ then\ Y=X+B\ where$$

$$X = deviation\ value\ in\ the\ HDO$$

$$Y = adjusted\ deviation\ value\ in\ the\ VDO$$

$$B = y\text{-intercept of the dashed line through the data}$$

Thus, for intercoil spacings where the HDO deviation value is greater than 0.8, the corresponding measured VDO deviation value is replaced by the HDO deviation value plus a constant to make the HDO:VDO relationship linear for relatively high HDO deviation values. Although independent VDO data is lost by this method for higher true conductivity values (corresponding to higher HDO deviation values), it helps to prevent the creation of composite values which are too low, and allows one to combine the results from both the HDO and VDO for all stations and intercoil spacings to create composite values which can then be plotted as a function of depth (Perry, 1994).

<u>Composite Values</u>

Composite plots are generated using the deviation values that are calculated for the apparent conductivities measured in both the HDO and the VDO. The adjusted deviation values for the VDO must be used for areas of relatively high conductivities. Using the two response functions for the three intercoil spacings, composite depth points had been selected to best represent the data obtained in a previous study (Perry, 1994) The chosen composite depths were 1.875 m, 3.75 m, 7.5 m, 11.25 m, 15 m, 22.5 m, 30 m, and 60 m (see Perry, 1994 for a description of how these depths were chosen). For the sake of initial assessment and demonstration these values were used for the data obtained in the Rattlesnake Creek survey.

Since the response in the HDO is more sensitive to the material near the surface, these values were used primarily for the shallow composite depths. For example, the HDO values at the 10 m intercoil spacing or 10 mh (where the symbols h (horizontal) or v (vertical) are used to indicate the dipole orientation) were selected for the 1.875 m composite depth. For the composite depth of 3.75 m an average of the deviations from the data measured in the HDO at the 10 m intercoil spacing and at the 20 m intercoil spacing (average of 10 mh and 20 mh) are used. At greater composite depths, the VDO values have a greater influence on the composite values.

Composite values for the various depths are calculated as shown below:

1.875 m	10 mh
3.75 m	Average of 10 mh and 20 mh
7.5 m	Average of 10 mh, 10 mv, 20 mh
11.25 m	Average of 10 mv and 20 mh
15 m	Average of 20 mh, 20 mv, and 40 mh
22.5 m	Average of 20 mv and 40 mh
30 m	Average of 20 mv and 40 mv
60 m	40 mv

Composite Plots

The calculated composite values for the eight different depths were plotted against distance to create a two-dimensional composite plot for each of the ground conductivity survey

lines at the three sites. These composite plots provide a pseudo-section of the apparent conductivities in the shallow subsurface that can then be interpreted in terms of geology and groundwater quality.

To check the usability of the composite plots with respect to the more typical non-composite plots of just the HDO values, a plot of the apparent ground conductivities for the third survey line at the Witt Site (WT3) measured in the HDO (Fig. 6a) is compared to a similar composite plot (Fig. 6b) of the same line. The length of the survey line is 400 m in each plot but there are only three points per station plotted to a depth of 30 m for the apparent conductivity plot compared to the eight points per station plotted to a depth of 60 m for the composite plot. Although the general trends in the composite plot do not differ greatly from the equivalents in the plot of apparent conductivities, more detail and a deeper level of investigation can be seen in the composite plot. In both types of plots, however, the smoothing process interpolates the values to depths greater than those represented by the data. In addition, the colors associated with the deviation values of the composite plots cannot be directly compared from one survey line to another.

Plots generated for the Siefkes Site have little variation above the composite depth of 30 m where most of the information is located, and only slightly more variation from 30 m to 60 m (Fig. 7a). These data are interpreted as representative of the Great Bend Prairie Aquifer with freshwater conditions down to 40-45 m, and are used as the background signal for other ground conductivity sites. An example of cultural interference is visible in the pseudo-section as an area of unusually high values separated by very low values between stations 0 and 120 (Fig. 7a). In this case, the cultural interference was caused by several pipelines made of steel (Fig. 2a) which affected the measurements in the VDO the most. To observe the natural system, the data with interference from the pipelines should be removed.

Composite plots at the Seep Site have a wider range of values indicating some variation in the quality of the groundwater. The lowest values are near the surface in the pseudo-sections (Fig. 7b). The general trend in the data appears to be increasing values with depth and possibly
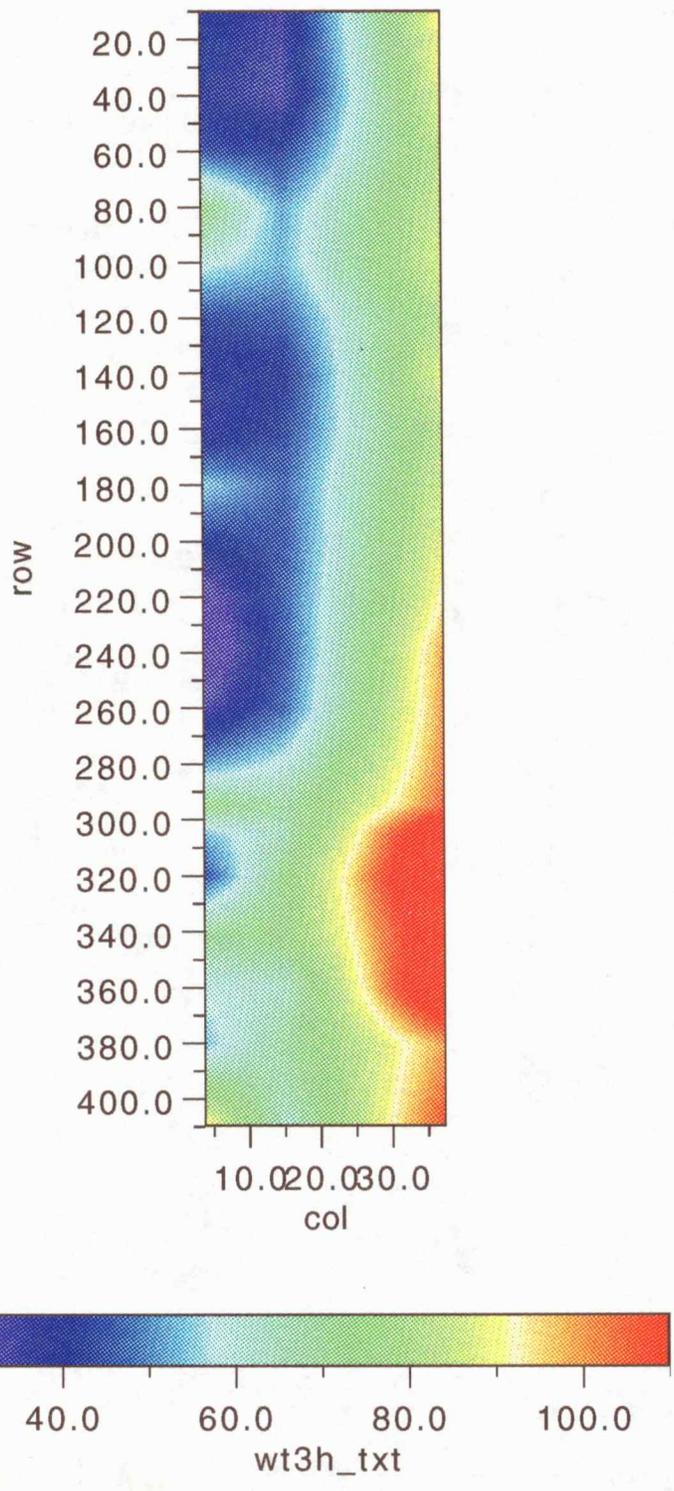
Figure 6a. Plot of the apparent ground conductivities of line WT3. This plot uses three depth points for plotting apparent conductivity to a depth of 30 m.
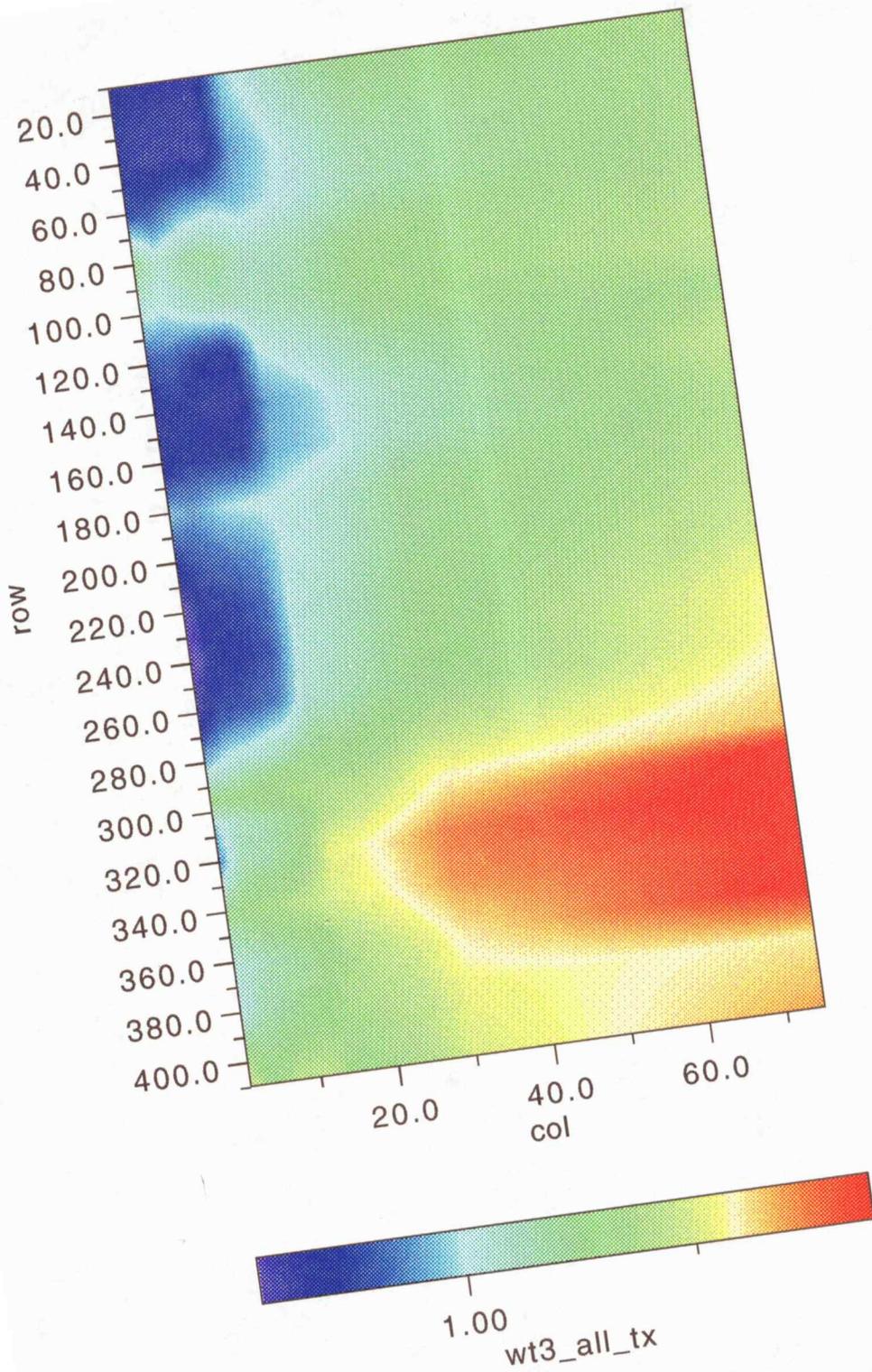
Figure 6b. Composite plot of line WT3. This plot uses eight composite values for plotting deviation values to a depth of 60 m. This plot weights the data according to the response depth.
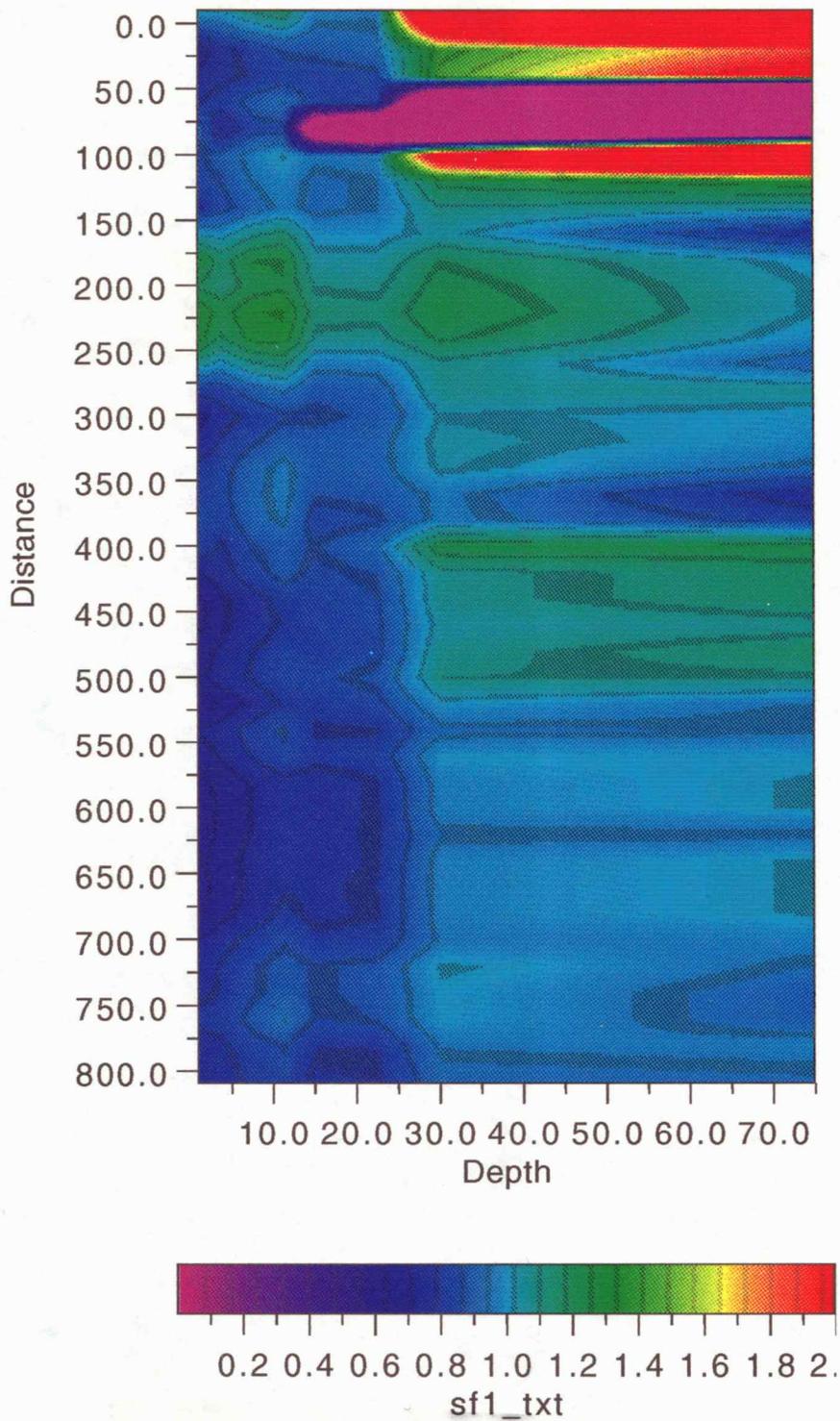
Figure 7a. Composite plot of the data from Siefkes Site line SF1 indicating relatively freshwater conditions over most of the area above 40-45 m (background signal determined for the aquifer) and cultural interference on the east end of the line caused by a metal pipelines at stations 0 and 80.
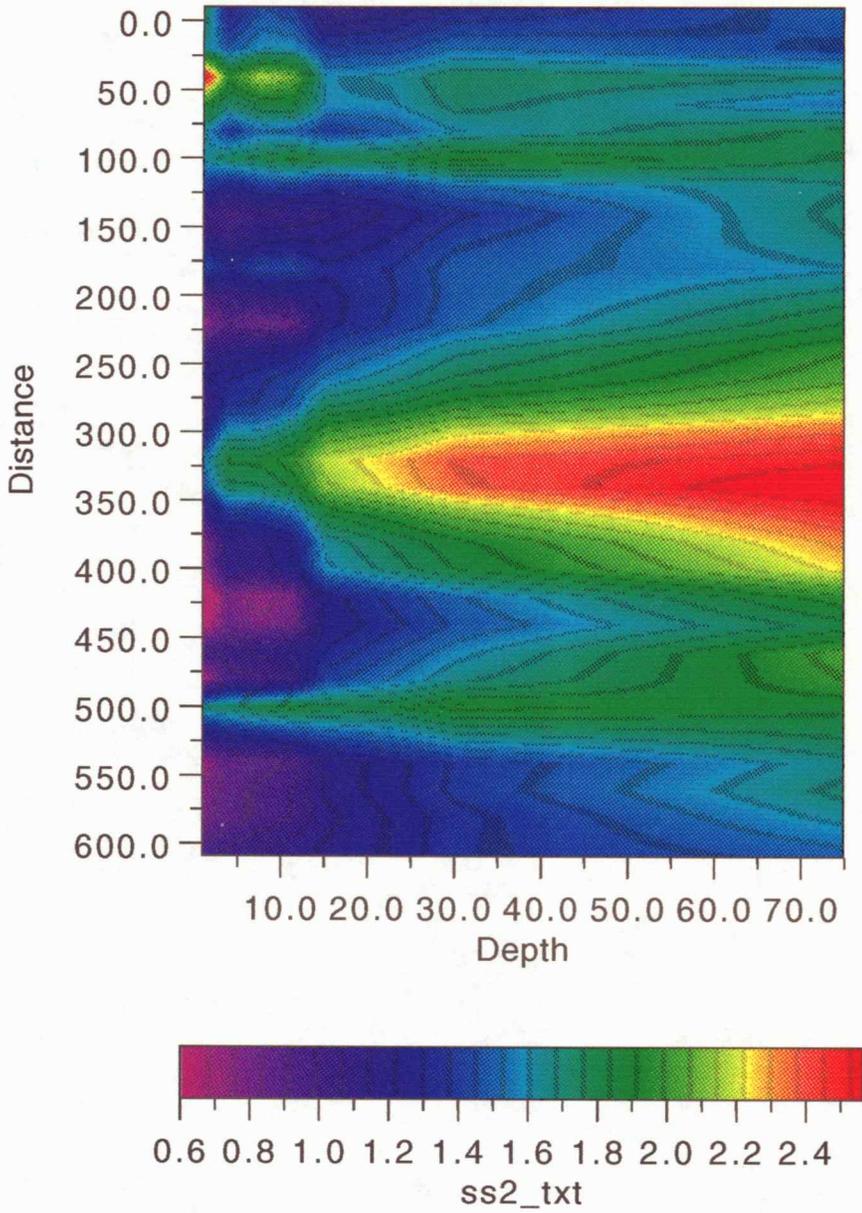
Figure 7b. Composite plot of Seep Site line SS2 showing a wide range of values that are interpreted as variations in the groundwater quality.

along preferred lines of groundwater movement. At the Seep Site the data can be interpreted as indicating relatively freshwater conditions at and near the surface but some mineral intrusion at depth and with groundwater degredation by salt discharge near the surface in some areas.

Values at the Witt Site were similar to those plotted at the Seep Site. Again, the lowest values are near the surface and generally indicate freshwater conditions (Fig. 7c). However, there are areas with high values at depth and also near the surface. The data at this site can be interpreted as representing relatively fresh water near the surface in seemingly isolated areas, mineral intrusion at some greater depths, and the possible movement and collection of saline waters in other areas. Higher values near the surface may also represent areas that are subject to evaporation of saline waters. Composite plots for the other survey lines are presented at the end of this section.

Map-View Plots

Apparent ground conductivity data for each of the study sites were plotted as subsurface maps (Fig. 8). The apparent ground conductivities measured in the HDO are used in the subsurface mapping since they are best representative of the true ground conductivities. A coordinate system was applied to each of the points that were surveyed within each study site. Subsurface maps of the study sites were plotted for the 7.5 m, 15 m, and 30 m response depths. Each survey point was given an X and Y value from the coordinate system, a Z value representing the appropriate response depth, and the measured conductivity value. The conductivities at each response depth were then contoured over the entire study site to produce the subsurface map.

In a map-view plot of the apparent conductivities in the HDO for the 10 m spacing, some features can be delineated at the Witt Site (Fig. 8). An area of high conductivity is found in the northwest corner and represents a decline in the quality of groundwater at the shallow depth of 7.5 m. The two "fingers" in the south part of the image are the result of the data smoothing process and are not necessarily representative of the actual ground conductivity. Further data
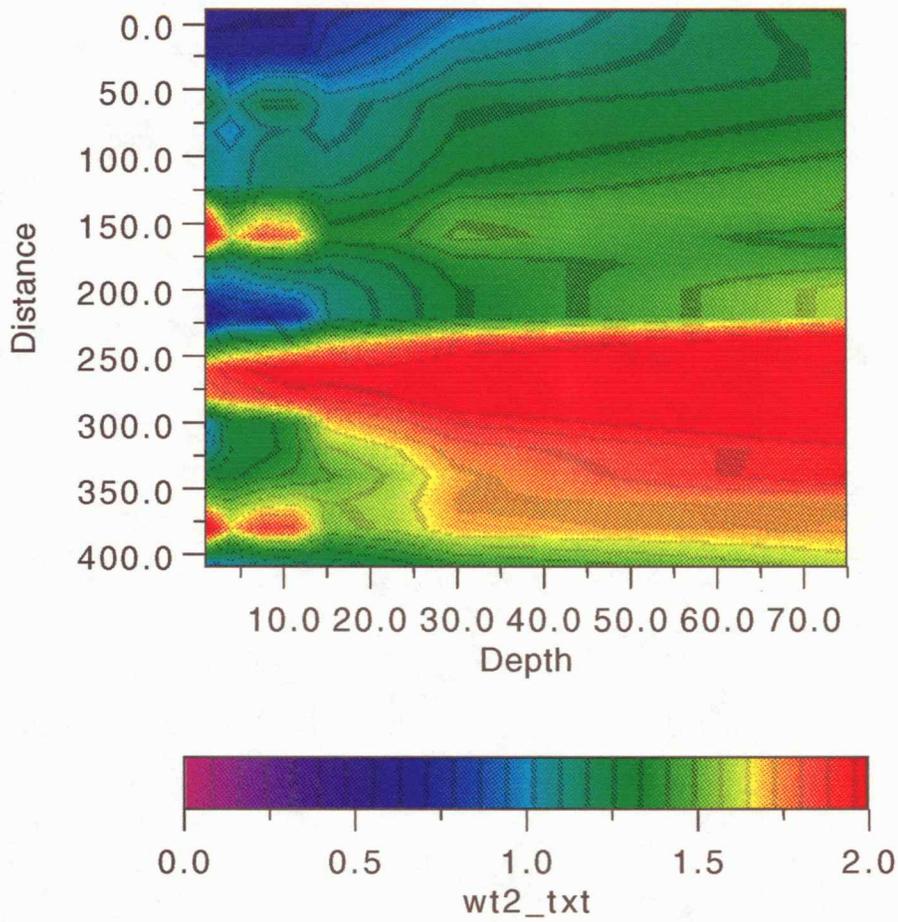
Figure 7c. Composite plot of Witt Site line WT2 showing a wide range of values that are interpreted as variations in the groundwater quality.
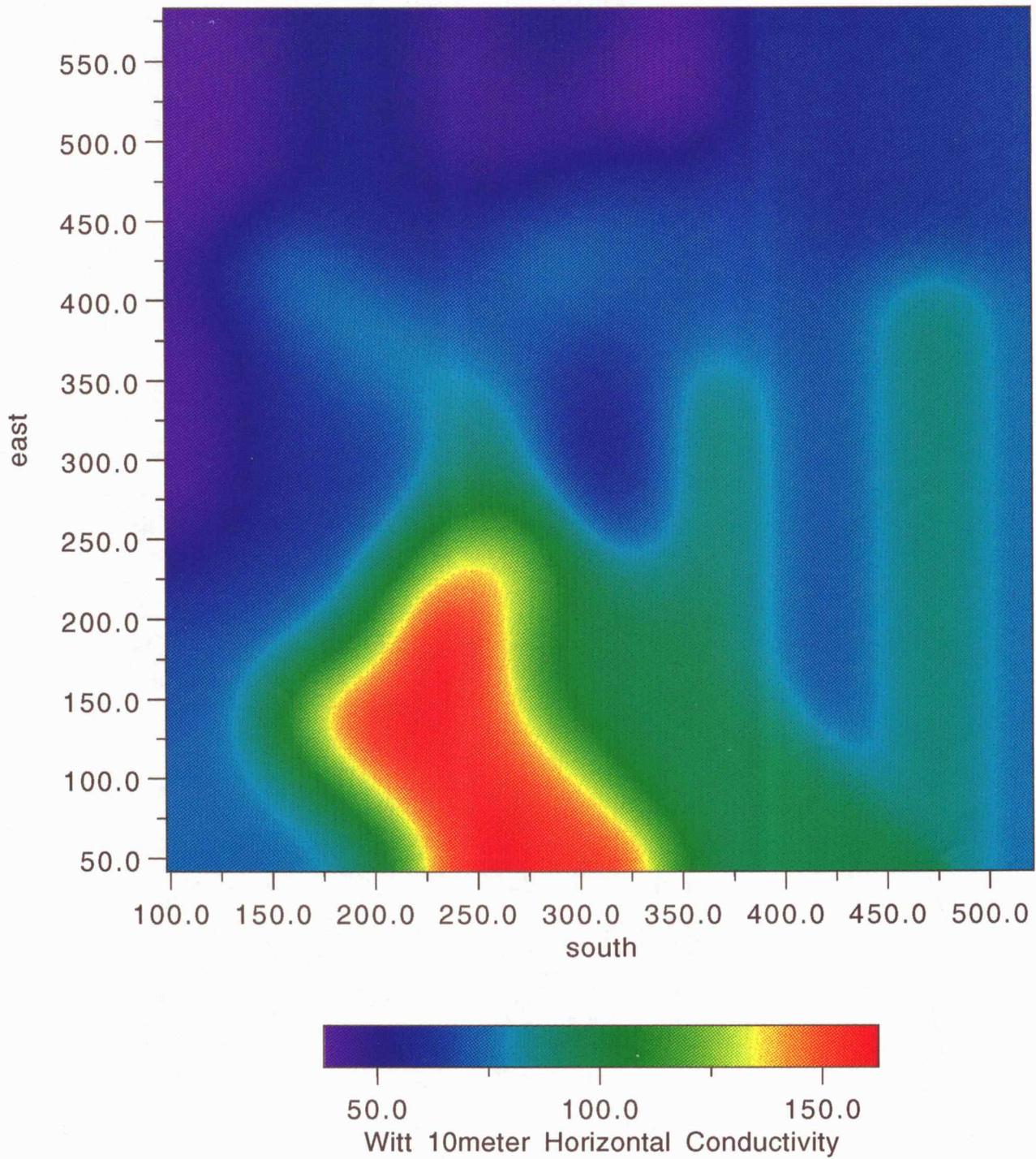
Figure 8. Map view of the apparent ground conductivity values measured at the Witt Site given the intercoil spacing of 10 m and the horizontal dipole orientation. The X-axis increases to the south and the Y-axis increases to the east. North is towards the left of the figure.

collection and study of this site is necessary to properly map the areas of saline water, freshwater, and mineral intrusion in the groundwater system.

Composite Plots of Additional Lines

These composite plots have the line number which they correspond to located below the deviation value color scale (e.g. sf2_txt corresponds to Siefkes line SF2). Lines SF1, SS2, and WT2 are located in the main text in figures 6a-6c respectively. Note that the color scale cannot be directly compared between lines (i.e. the same color represents different deviation values on different plots).

sf2_txt

sf3_txt vs. (row, col)

sf4_txt

sf4_txt vs. (row, col)

Distance

Depth

sf5_txt

sf5_txt vs. (row, col)

sf6_txt

sf6_txt vs. (row, col)

ss1_txt Ratio

ss1_txt vs. (row, col)

Distance vs. Depth contour plot with color scale for ss3_txt ranging from 0.8 to 2.2

ss3_txt vs. (row, col)

ss4_txt vs. (row, col)

wt1_txt

wt1_txt vs. (row, col)

wt3_txt

wt3_txt vs. (row, col)

wt4_txt

wt4_txt vs. (row, col)

wt5_txt

wt5_txt vs. (row, col)

wt6_txt

wt6_txt vs. (row, col)