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Verification of Geophysically Determined Depths to Saltwater Near the Herring River (Cape Cod National Seashore), Wellfleet, Massachusetts

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This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature. Any use of trade names is for descriptive purposes and does not imply endorsement by the U.S. Geological Survey.

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ABSTRACT

The results of this study confirm the location of the previously determined freshwater-saltwater interface near the Herring River, Wellfleet, Massachusetts. Surface electromagnetic measurements are compared with driller's logs, water conductivity data, and induction logs from observation wells drilled in the study area. Terrain conductivity meter measurements recorded earlier along survey lines correlate with a brackish water saturated zone having a specific conductance in excess of 1800 μS/cm. Transient electromagnetic soundings confirm this interpretation and also locate a deeper, more conductive zone saturated with seawater. Throughout the study area the vertical separation between the water-table level in domestic water wells and the top of the brackish water zone was determined to range from 13 to 29 m. At the five observation wells, including the two in the flood plain of the Herring River, an elevation difference of almost 20 m was found between the water table level and the terrain conductivity meter determined conductor. These findings support the idea that increasing tidal flow in the Herring River by adjusting the tidal control structure at the mouth of the river will not have an adverse effect on domestic water wells in the area.

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1. INTRODUCTION

Since the early 1900's a dike has existed across the mouth of the Herring River near Wellfleet, Massachusetts adjacent to the Cape Cod National Seashore. The dike was originally built to control mosquitoes, reclaim estuary land, enhance wildlife habitat, and provide flood control. The original dike was replaced by a sluice-tide-gate structure in 1974. Studies funded by the National Park Service (NPS) have determined that the restricted tidal flow in the Herring River has caused stream acidification, episodes of stream anoxia resulting in fish kills, and mosquito control problems (Roman and other, 1987). The work of Roman and others suggests that increased tidal flow through the tide-control structure would have beneficial effects on the ecosystem. A potential problem associated with this course of action is that the numerous domestic wells drilled in the highlands to the east of the Herring River might be subject to saltwater intrusion as a result of increased tidal flow. To investigate this possibility, surface geophysical measurements were made in the area to locate the freshwater-saltwater interface (FWSWI) (Fitterman and others, 1989). Based upon the geophysical measurements it was estimated that the vertical separation between the elevation of the FWSWI and the water-well levels ranged from 13 to 29 m in the study area, and that the separation increased with distance from the river. Furthermore it was recommended that observation wells be drilled in the study area and induction logs be run as a check on the geophysical interpretation. The observation wells would also provide a direct means of monitoring changes in the FWSWI.

This report summarizes the previous geophysical work, describes the drilling results, and laboratory resistivity measurements. The geophysical interpretation and drilling results are compared.

2. SUMMARY OF SURFACE GEOPHYSICS

Three electromagnetic geophysical techniques were used to determine the depth to the FWSWI. These included terrain conductivity meter (TCM) profiling, transient electromagnetic sounding (TEM), and very low frequency resistivity (VLF) profiling. A description of these methods and data interpretation procedures can be found in a companion report (Fitterman and others, 1989). Geophysical measurements were carried out in three areas: Great Pasture (Lines 1 and 2), Newcomb Heights (Line 4), and Chequesset Neck (Line 3) (see Figure 1). All of the geophysical traverses go from the Herring River toward the highlands to the east. The TCM data served as the primary data set as it had the greatest coverage. The TCM data were acquired at three intercoil spacings (10, 20, and 40 m) and two coil orientations (horizontal and vertical dipole abbreviated as HDP and VDP respectively). The TEM data provided greater vertical resolution, however, there were fewer measurements. The VLF resistivity provided the least information and was of limited use. Interpreted cross sections made using these data are described below.

2.1 Great Pasture Traverses

Two traverses (Lines 1 and 2) were made from the Herring River through the Great Pasture Subdivision (Figure 2). TCM and VLF resistivity data were obtained every 10 m along the profiles. TCM data were taken at three intercoil spacings at most of the stations. Only the 40-m spacing data were collected on the eastern portion of Line 1 due to the consistency of the 20-m and 10-m readings. Three TEM soundings were made. TEM sounding WFL 3 may have been influenced by the presence of a buried pipe near the marsh to the north of High Toss Road and was not used in the interpretation.

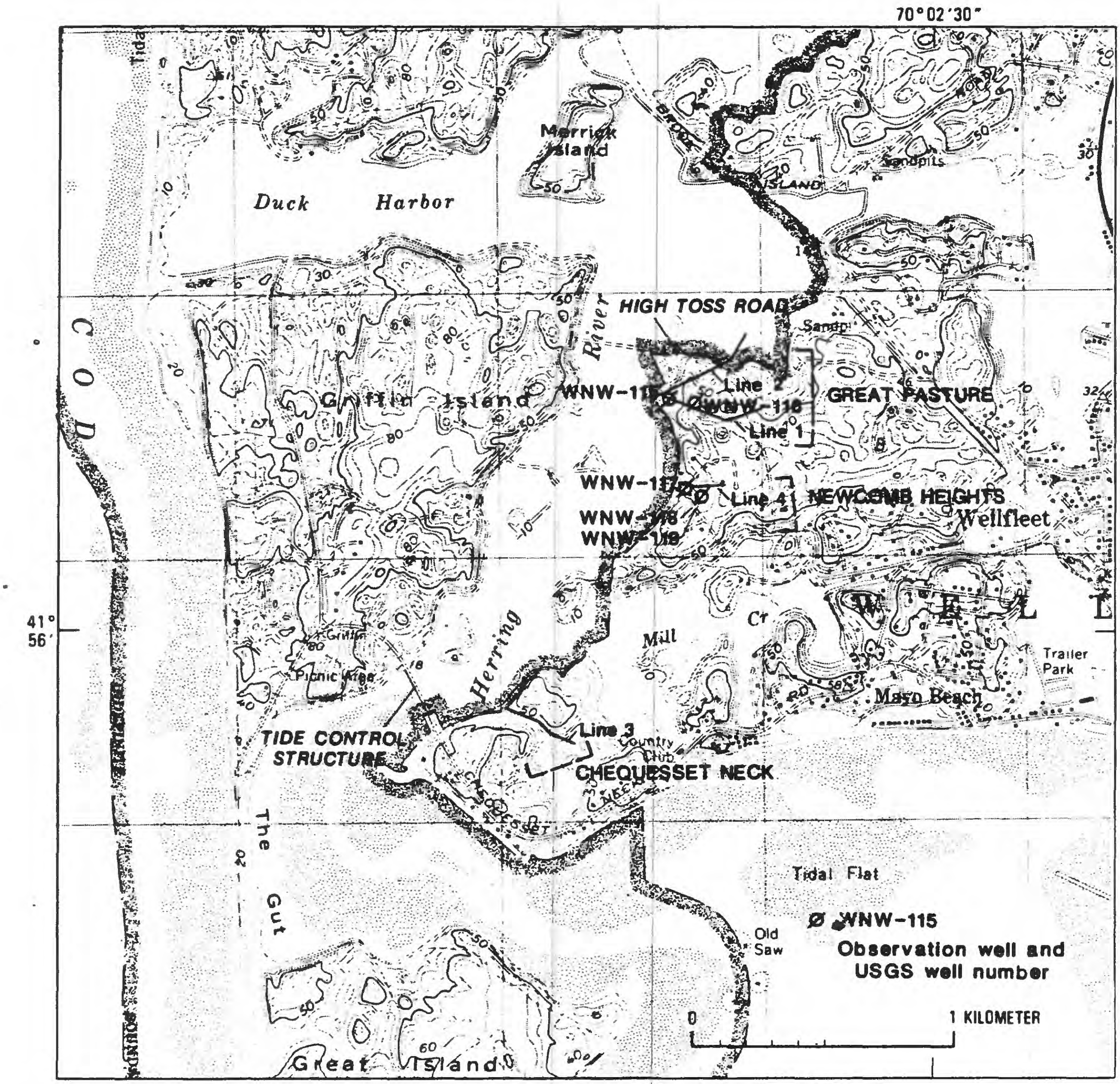
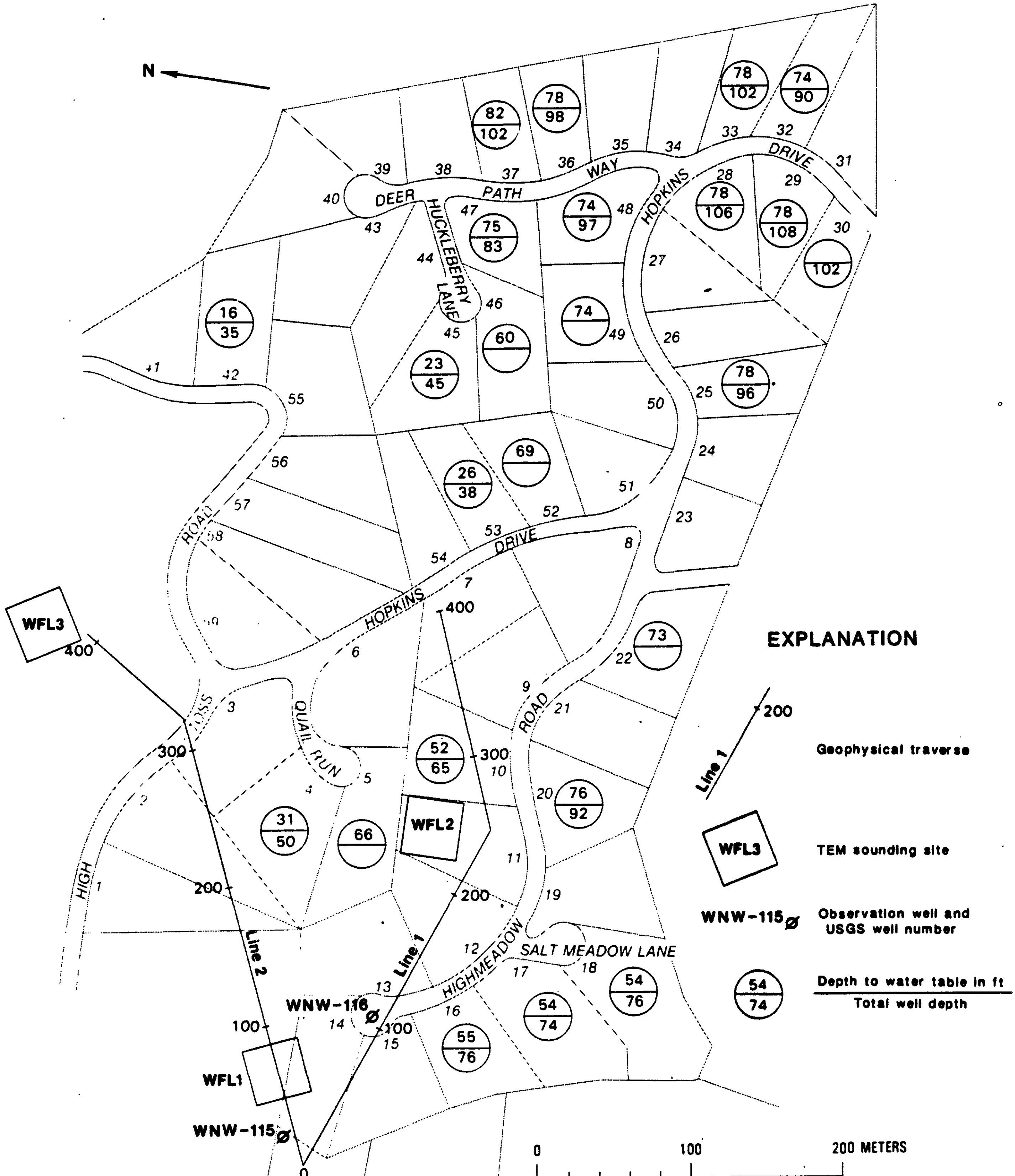


Figure 1 Map of the Herring River study area Wellfleet, Massachusetts. The locations of the geophysical traverses and observation wells are indicated.



GREAT PASTURE TRAVERSES

Figure 2 Great Pasture traverse location map showing survey lines, TEM sounding loops (large squares), and observation wells. The circled numbers are the depths to the water table (upper number) and total well depth (lower number) in ft in domestic water wells. The gray numbers and lines are lot numbers and property boundaries respectively. Exact location of the domestic well inside the property boundary is not known. The numbers along the geophysical lines are station numbers in meters.

The TCM data from Line 1 are generally fit with a two-layer model consisting of a resistive upper layer (90-3000 ohm-m) which is underlain by a conductive second layer (2.5-4.0 ohm-m) (Figures 3 and 4). The upper layer varies in thickness from 19 m at the west end of the line, thickening to 54 m near station 220. There is good agreement between the TCM and VLF determined models from stations 0 to 240, however, the VLF determined interface is considerably deeper further east. This may be due to the assumed value used for the second layer resistivity in the VLF interpretation being incorrect.

Interpretation of TEM sounding WFL 2 requires a three-layer model with resistivities decreasing with depth. The first layer resistivity could not be resolved and was constrained to a value of 900 ohm-m. Its thickness is estimated to be 26 m. The interface between the second and third layers at a depth of 47 m corresponds to the interface determined by the TCM and VLF data. Using the TEM interpreted model to compute a TCM response, fairly good agreement was found between the measurements at station 220 for the 40 m spacing data (Figure 4).

The cross section constructed from the Line 2 data (Figures 5 and 6) shows results similar to those of Line 1. The data are fit with a two-layer model that becomes more conductive with depth. The first layer resistivities range from 200-5000 ohm-m over the western 290 m of the line. The second layer resistivity is relatively constant (4-6 ohm-m). The first layer depth increases from 20 m on the west end of the line to a maximum depth of 32 m near station 130 before becoming shallower in the eastward direction, mimicking the topography as High Toss Road is approached. Line 2 crosses High Toss Road at station 310 and shows the influence of a buried pipe that caused reduced, and sometimes negative, conductivity values. As a result, the interpretation is questionable from here eastward. The model from station 320 was carried eastward only to illustrate that the 40-m HDP data, which would be minimally influenced by the presence of a pipe, were fit with moderate success. As there are neither homes nor domestic wells in the marsh, the poor data quality are not considered significant to the results of this study.

2.2 Newcomb Heights Traverse

The Newcomb Heights traverse (Line 4), situated in the subdivision of the same name, is located about 500 m south of the Great Pasture traverses (see Figure 1). A single 170-m-long line of TCM and VLF measurements was made starting along the road to the east of the Herring River and proceeding up the bluff into the subdivision (Figure 7). One TEM sounding was made at the east end of the line. The TCM data show a gradual decrease in conductivity in the eastward direction caused by the deepening of the FWSWI in that direction (Figure 8). The data are interpreted with a two-layer model consisting of a resistive first layer (250-1000 ohm-m) underlain by a conductive second layer (2.0-ohm-m). The depth to the conductive layer increases from 20 m on the west end of the line to more than 40 m on the east end of the line. The VLF interpretation agrees with the TCM model only on the west end of the line. The TEM data, which were interpreted using a three-layer model, suggest the presence of a transition zone and put the conductive layer slightly shallower than the TCM interpretation. The TCM results computed using the TEM model appear to be a bit too conductive compared to the observations. The difference in the interpreted models may be due to topographic effects on the TCM data.

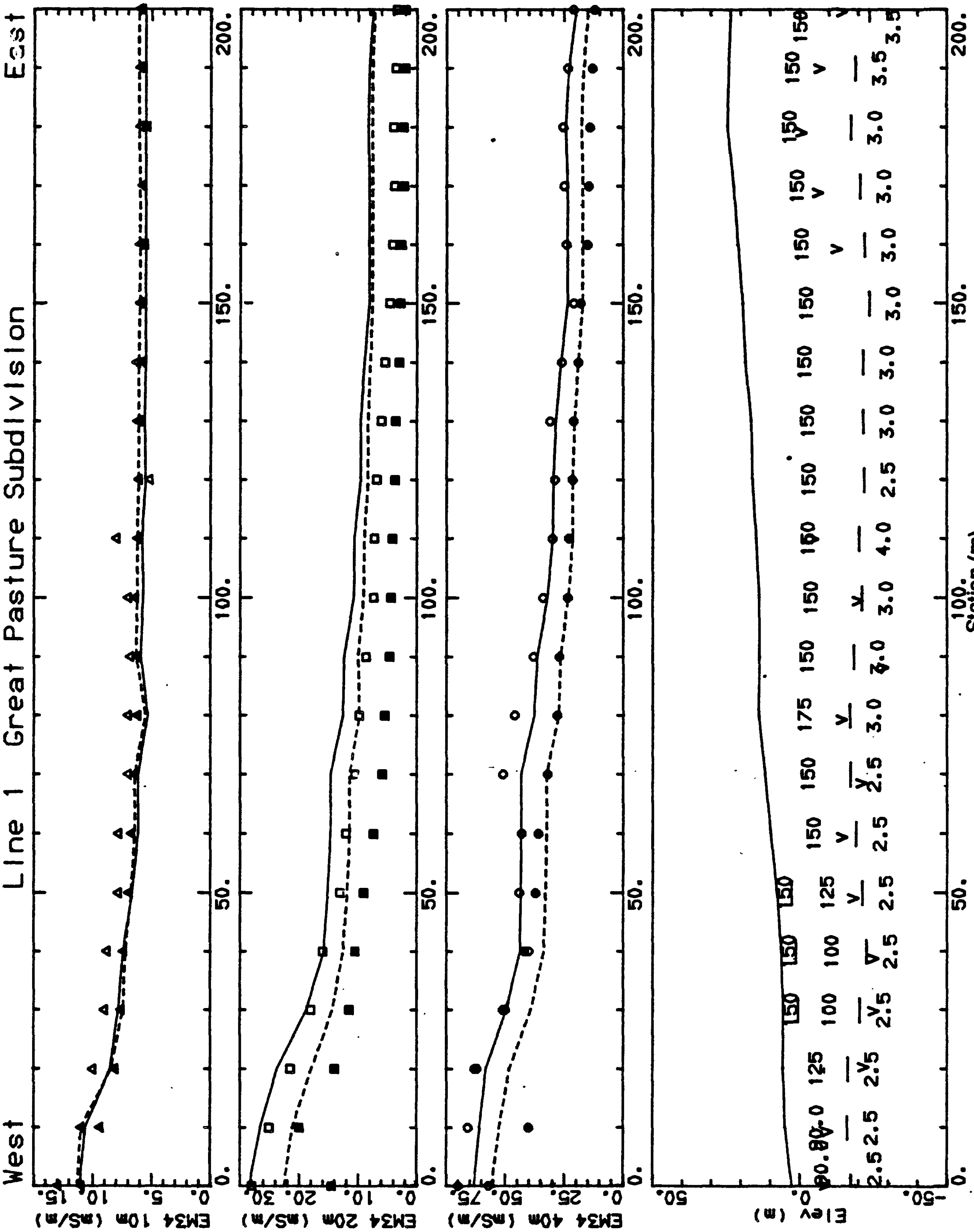


Figure 3 Great Pasture Subdivision terrain conductivity meter data and interpreted cross section for Line 1, x=0-200 m. The open symbols (△□○) and solid lines are the observed and computed VDP data respectively. The filled symbols (▲■●) and dashed lines are the observed and computed HDP data respectively. The numbers in the cross section are the interpreted layer resistivities in ohm-m. The short horizontal lines are the layer boundaries. The v's represent the top of the conductive second layer determined from VLF measurements.

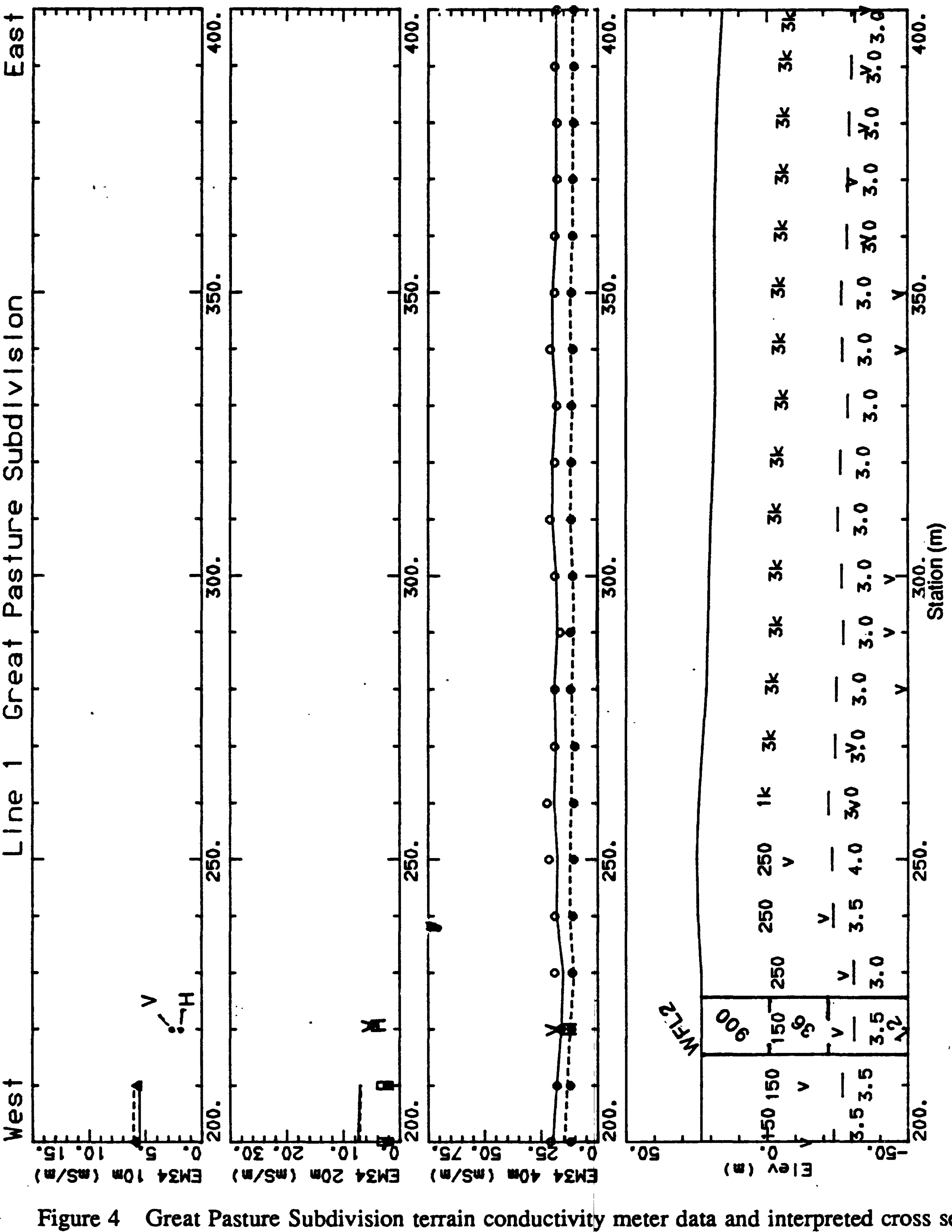


Figure 4 Great Pasture Subdivision terrain conductivity meter data and interpreted cross section for Line 1, x=200-400 m. Tilted numbers near station 220 are the interpreted layer resistivities from TEM sounding WFL 2. The V's and H's on the TCM plots at station 220 are the computed response based upon the interpreted model from TEM sounding WFL 2.

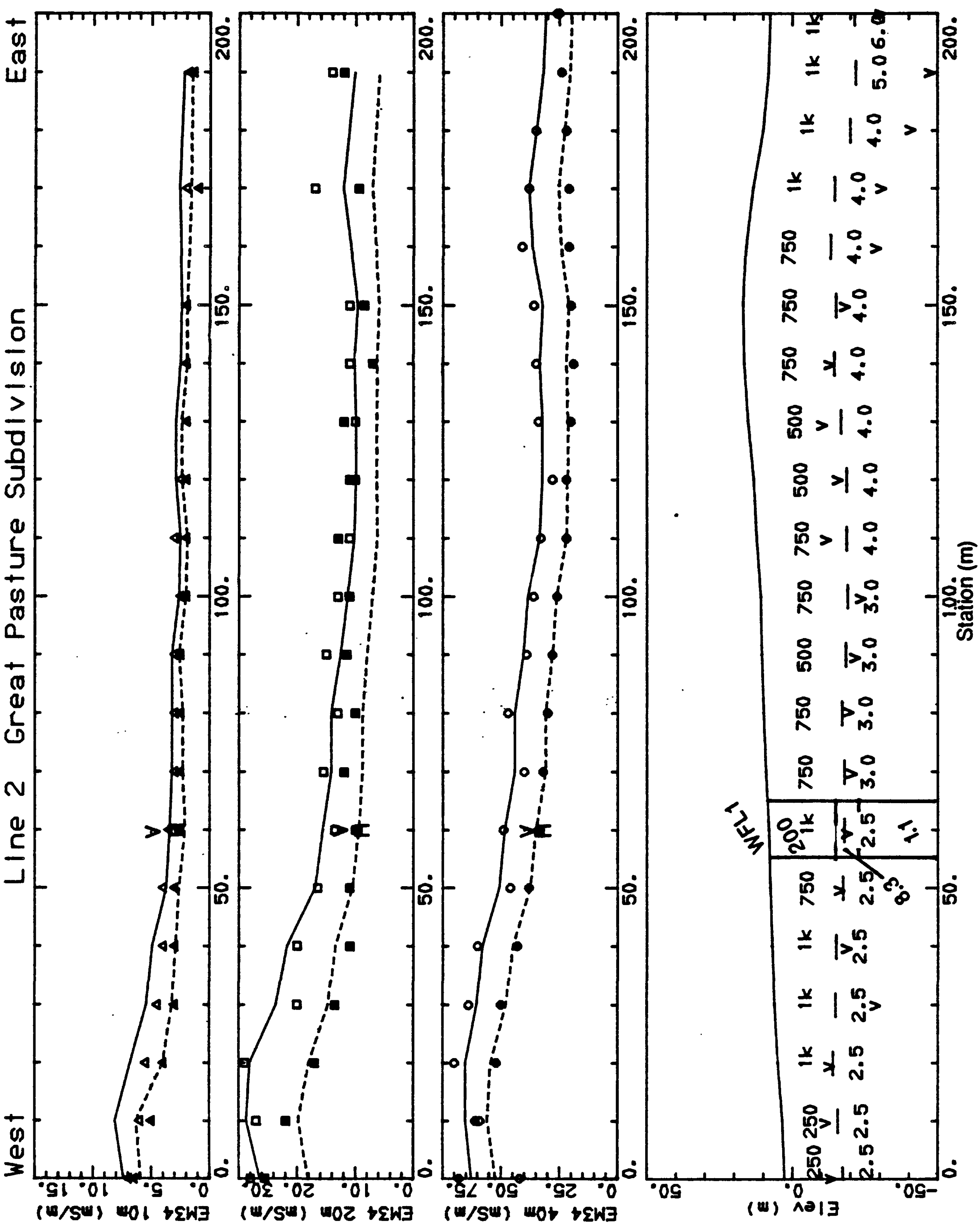


Figure 5 Great Pasture Subdivision terrain conductivity meter data and interpreted cross section for Line 2, x=0-200 m. Tilted numbers near station 60 are the interpreted layer resistivities from TEM sounding WFL 1. The V's and H's on the TCM plots are the computed response based upon the interpreted model from TEM sounding WFL 1.

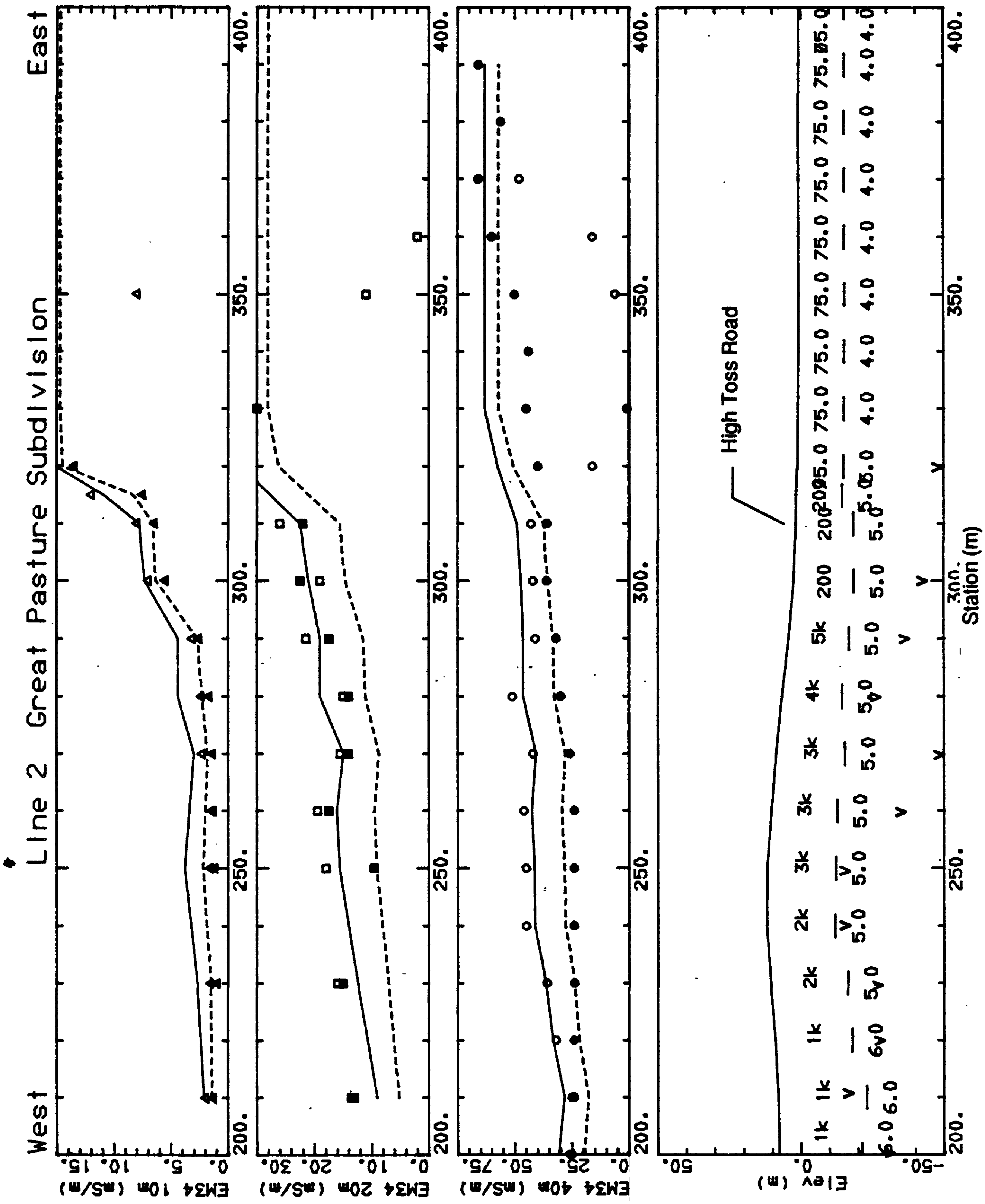


Figure 6 Great Pasture Subdivision terrain conductivity meter data and interpreted cross section for Line 2, x=200-400 m. The line crosses High Toss Road near station 310.

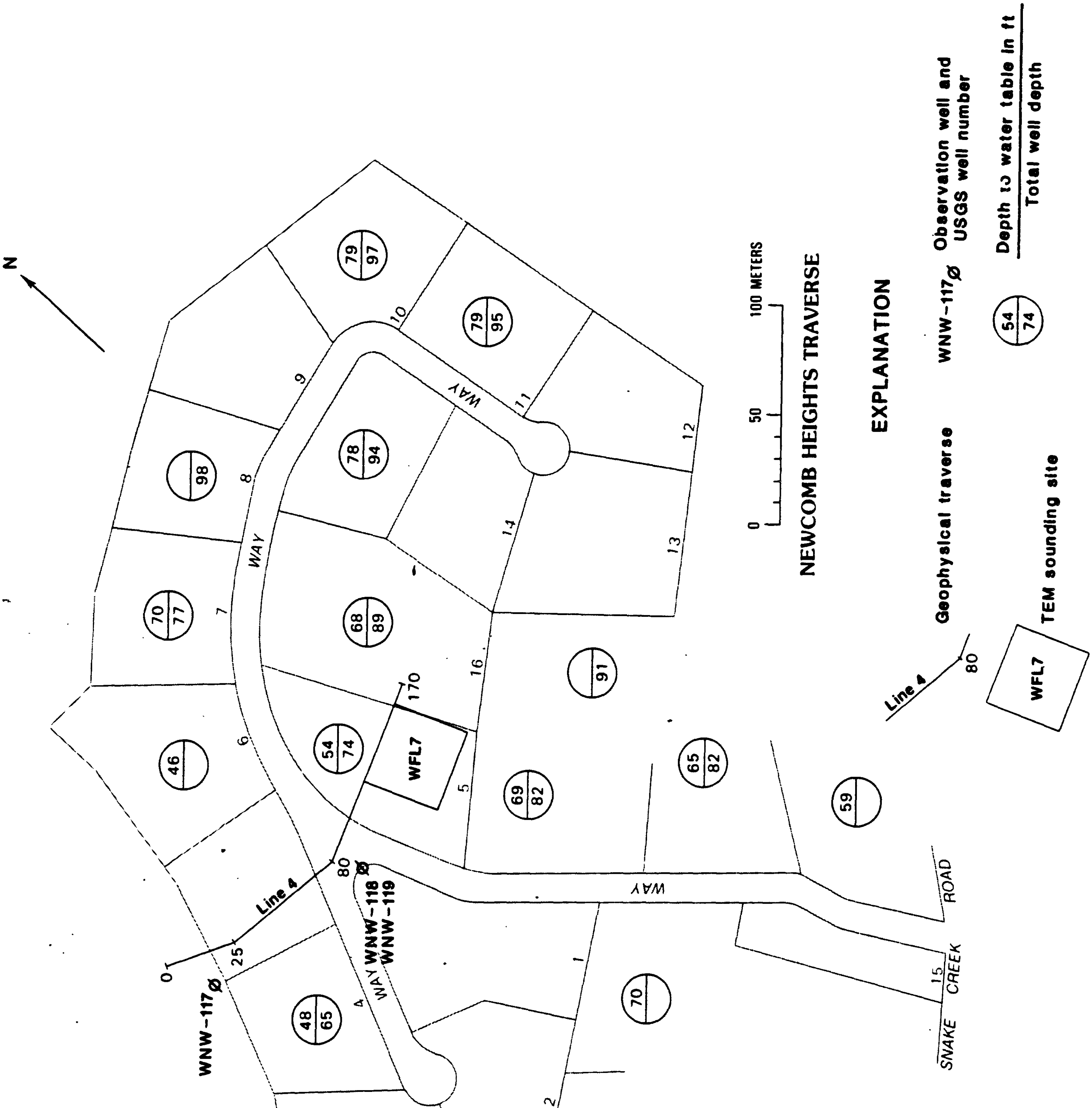


Figure 7 Newcomb Heights traverse location map showing survey line, TEM sounding loop, and observation wells. The circled numbers are the depths to the water table (upper number) and total well depth (lower number) in ft in domestic water wells. The gray numbers and lines are lot numbers and property boundaries respectively. Exact location of the well inside the property boundary is not known. The numbers along the geophysical line are station numbers in meters.

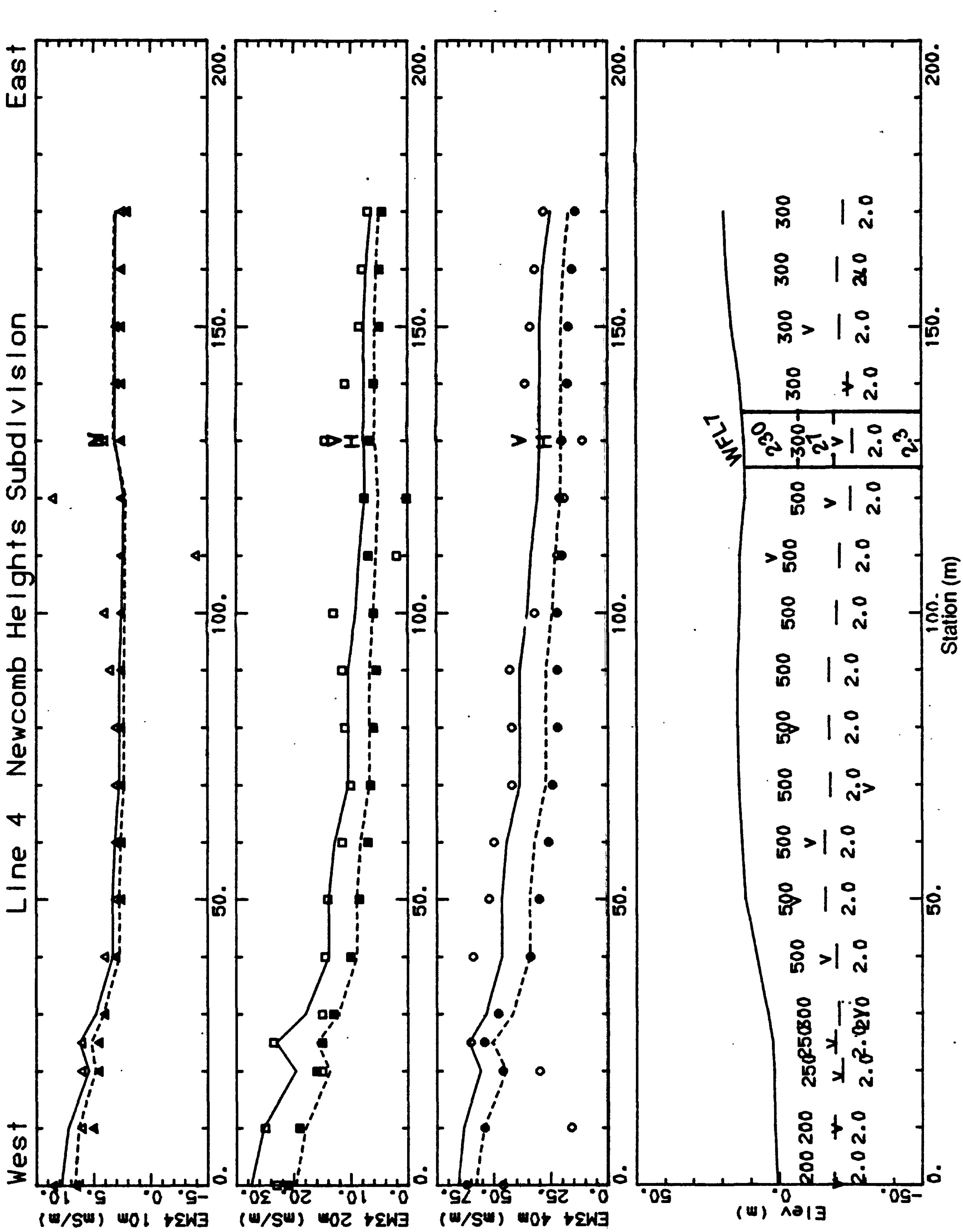


Figure 8 Newcomb Heights Subdivision terrain conductivity meter data and interpreted cross section for Line 4, x=0-170 m. Tilted numbers near station 130 are the interpreted layer resistivities from TEM sounding WFL 7. The V's and H's on the TCM plots are the computed response based upon the interpreted model from TEM sounding WFL 7.

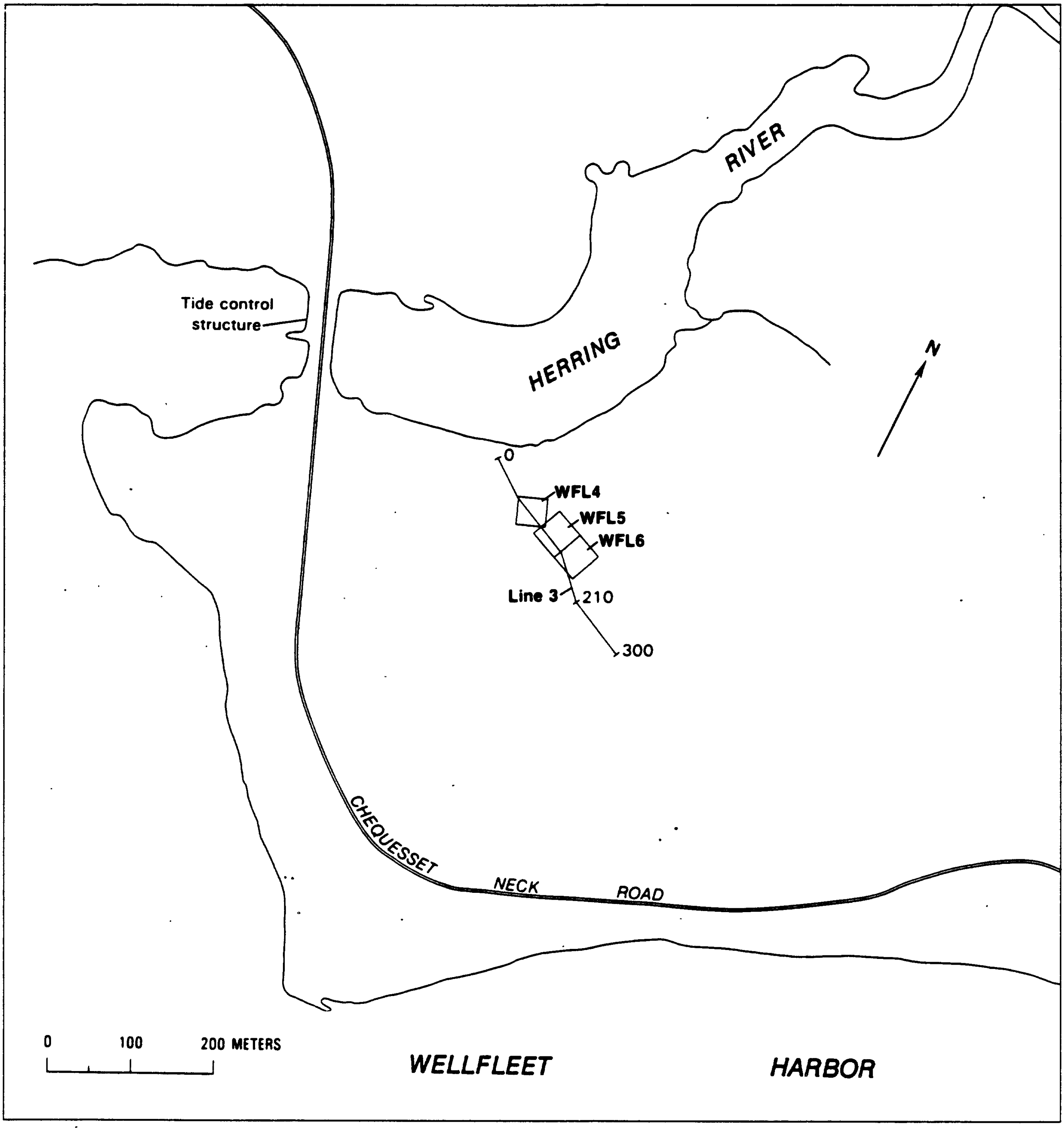


Figure 9 Chequesset Neck traverse location map showing survey line and TEM sounding loops. The numbers along the geophysical line are station numbers in meters.

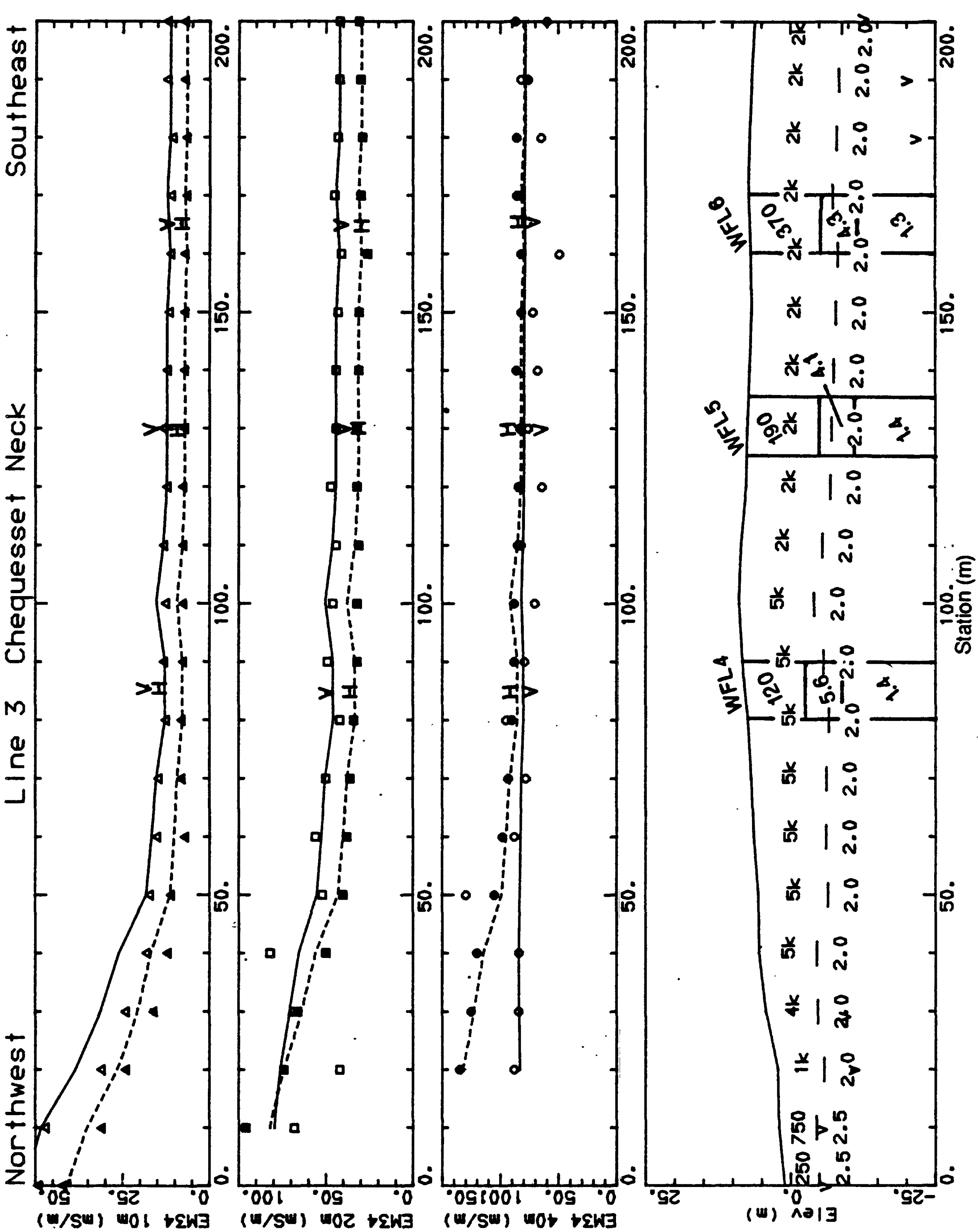


Figure 10 Chequesset Neck traverse terrain conductivity meter data and interpreted cross sections for Line 3, x=0-200 m. Tilted numbers near stations 85, 130, and 165 are the interpreted layer resistivities from TEM soundings WFL 4, WFL 5, and WFL 6 respectively. The V's and H's on the TCM plots are the computed response based upon the interpreted model from the TEM sounding near that station.

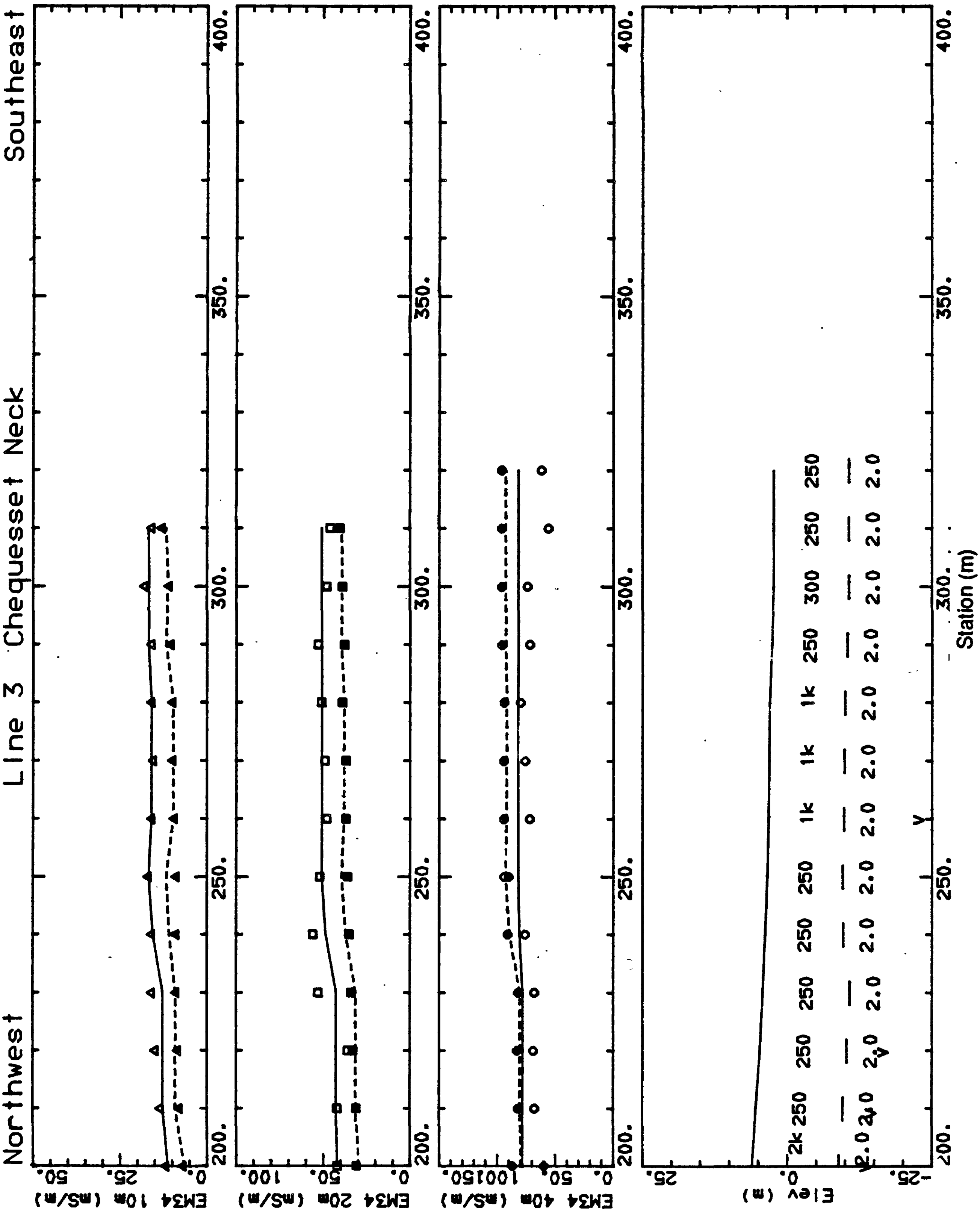


Figure 11 Chequesset Neck traverse terrain conductivity meter data and interpreted cross sections for Line 3, x=200-320 m.

2.3 Chequesset Neck Traverse

The Chequesset Neck traverse (Line 3) was made about 200 m upstream of the tidal control structure near the mouth of the Herring River (Figure 9). The TCM data are fit with a two-layer model that consists of a resistive first layer (250-5000 ohm-m) underlain by a conductive layer of nearly constant resistivity (2.0-2.5 ohm-m) (Figures 10 and 11). The first layer thickness increases from a value of 6 m near the river to a maximum of about 15 m in the vicinity of station 200 before decreasing slightly in the southeast direction in response to a decrease in elevation. The three TEM soundings are modeled by a three-layer model with the resistivity decreasing with depth. The second layer resistivity is low enough (4.1-5.6 ohm-m) that it suggests the presence of brackish water. The middle of this transition zone corresponds to the top of the conductive layer in the TCM model. Very little VLF data were collected as frozen ground prevented planting the electrodes. Where VLF data were obtained, the agreement with the TCM interpretations was not very good. The TCM response computed from the TEM model gives good agreement with the observations indicating that a three-layer model might be used to model all the TCM data.

3. LABORATORY RESISTIVITY MEASUREMENTS

In an attempt to determine the resistivity values expected for freshwater and saltwater saturated materials common to the study area, a sample of sand was collected from a shallow hole in the study area. Water samples were collected from a nearby well and the ocean. The sand was packed into a cylindrical sample holder and its resistivity measured over a wide frequency range under natural moisture content (3.1 weight percent), as well as saturation with well water and seawater. The resistivity of the water samples was also determined. The results are shown in Table 1 for a frequency of 1000 Hz. The well water had a resistivity of 102.7 ohm-m, while the resistivity of the seawater was 0.273 ohm-m, about 375 times lower. Under conditions of natural moisture content, the sand had a resistivity of over 5000 ohm-m. Saturation with freshwater lowered the resistivity to 410 ohm-m. These high resistivity values are in line with the first layer resistivities determined from the TCM and TEM modeling discussed in the previous section. Introduction of saltwater into the sample reduced its resistivity to 1.45 ohm-m, a value less than the second layer resistivity of the TCM models, but similar to values modeled for the third layer of the Great Pasture and Chequesset Neck TEM soundings. While we only have the results of a single sample to report, much of the study area is composed of very clean sand similar to our sample (Strahler, 1966; Oldale, 1968, 1969; LeBlanc and others, 1986).

The laboratory data can be used to estimate a minimum resistivity value for the freshwater saturated aquifer. To do this it is necessary to assume the following: 1) the sand sample used in the laboratory measurement is typical of the study area, 2) the effects of sample disturbance and repacking before making the laboratory measurement are minimal, 3) a maximum total dissolved solid (TDS) level for drinkable water is 1000 mg/l, and 4) the specific electrical conductivity of the aquifer water (σ_0) follows the typical, statistically determined relationship to TDS, namely

$$\sigma_0\ [\mu S/cm] = TDS\ [mg/l]/A \qquad (1)$$

where A is a constant between 0.55 and 0.75 (Freeze and Cherry, 1979, p. 140). The first and second assumptions are probably the most likely to be wrong, but without additional information it is the best that can be done. The maximum allowable TDS level chosen is conservatively low. From equation (1), the fluid conductivity would range from 1300-1800 μS/cm, corresponding to a fluid resistivity of 5.5-7.5 ohm-m. From the data in Table 1, the ratio of sample resistivity (ρ) to fluid resistivity (ρ_0), termed the formation factor F, can be determined. For the two measurements reported F ranges from 4.0-5.5. Thus a conservative estimate of the minimum resistivity of a similar sample saturated with 1000-mg/l-TDS water would be 22-40 ohm-m.

The analysis of the laboratory measurements indicates that the resistive first layer in the TCM models is due to fresh-water saturated sand, and the conductive second layer is caused by sand saturated with brackish water (TDS=1000-10,000 mg/l) (Freeze and Cheery, 1979, p. 84). The very conductive layer (<1.5 ohm-m) detected by the TEM soundings is due to the presence of seawater saturated sand (TDS>10,000 mg/l).

Table 1 Sample resistivities measured at 1000 Hz

Sample	Porosity	Fluid resistivity ρ_0(ohm-m)	Sample resistivity ρ (ohm-m)
well water	–	102.7	–
seawater	–	0.273	–
sand, natural moisture, 3.1 percent		–	5450
sand, well water, saturated	0.197	102.7	410
sand, seawater, saturated	0.203	0.273	1.45

Table 2 Water levels for wells in study area.

Well Number	Depth below measuring point (feet)	Date	Time
WNW-115	4.64	5-03-90	–
WNW-115	4.79	9-18-90	13:20
WNW-116	47.65	5-03-90	–
WNW-116	47.92	9-18-90	12:00
WNW-117	6.93	5-03-90	17:30
WNW-117	6.85	9-18-90	14:20
WNW-118	43.88	5-03-90	15:45
WNW-118	44.08	9-18-90	15:45
WNW-119	no screen		

4. OBSERVATION WELL DRILLING PROGRAM

Five observation wells were drilled in May 1990 near the Great Pasture and Newcomb Heights traverses to determine geology, measure water conductivity, and run induction logs to measure formation conductivity (see Figures 1, 2, and 7). No wells were drilled at the Chequesset Neck location due to access problems and the sparsity of domestic wells in the area. The wells were drilled using a 7.5 in. (19 cm) hollow-stem auger. Water samples were taken during drilling and specific conductance measured in the field. The wells were cased with 2 in. (5.1 cm) diameter PVC casing that was plugged at the bottom. Twenty feet (6.1 m) of slotted PVC screen was placed in all but one well (WNW-119) at a depth determined from the water conductance measurements such that the FWSWI interface was within the screened interval. Well depths ranged from 91 to 127 ft (27.7-38.7 m) (Table 2). Details of well location, driller's log, well construction, water levels, water conductance, and tabulated induction logs can be found in the Appendix.

5. COMPARISON OF SURFACE GEOPHYSICS AND OBSERVATION WELL RESULTS

Driller's and induction logs from the observations wells can be used to confirm the geophysical interpretation at selected sites thereby assessing the overall reliability of the interpretation. The driller's logs are found in the Appendix. All of the wells encountered sand ranging from fine to coarse with no mention of clay. The absence of clay is important as it means the resistivity values obtained from laboratory measurements on a sand sample give values that are applicable to the interpretation. The induction logs were run in all wells in September 1990. The induction log data are reported in the Appendix in conductivity units, however, they were converted to resistivity units on the figures in this section to simplify comparison with the geophysical interpretations.

5.1 Well WNW-115

Located slightly to the west of Line 2 in the Great Pasture Subdivision near station 30, well WNW-115 was drilled to a total depth of 91 ft (27.7 m). The first 37 ft (11.3 m) encountered primarily coarse sand with a small amount of medium sand (see Figure A-2). The lower 54 ft (16.4 m) is coarse and medium sand. The induction log (Figure 12) is characterized by a constant resistivity zone of about 150 ohm-m from a depth of 1 to 13 m. The sharp rise in resistivity at the shallowest portion of the log is caused by the metal around the top of the well. A similar artifact is seen on several of the other induction logs. Below 13 m the resistivity drops to a minimum of 20 ohm-m at 16 m depth followed by a small peak at 18 m before decreasing further. Resistivity values of less than about 6.5 ohm-m in the induction log are not considered reliable due to the full-scale setting used for the measurement. The flat trace at a resistivity value of 2.5 ohm-m is caused by the instrument becoming completely saturated.

The TCM interpretation has a first-layer resistivity of 1000 ohm-m to a depth of 21 m. This resistivity value is not well resolved, and a value closer to the induction log value could be used in fitting the data. The second layer has a resistivity of 2.5 ohm-m. The fact that this value is the same as the saturation value of the induction log has no significance. The model from TEM sounding WFL 1, which is located about 50 m from the well site at an elevation 5.6 m higher, consists of three layers. The resistivity is 198 ohm-m from the surface to a depth of 24.7 m, then drops to a value of 8.3 ohm-m until a depth of about 34 m where a final value of 1.1 ohm-m is attained. The third layer resistivity is essentially the same as the laboratory determined value for seawater saturated sand. The deeper location of the conductive second layer in the TEM model compared to the TCM model may be attributed to the fact that the TEM sounding was at a higher elevation where the depth to saltwater would be expected to be greater.

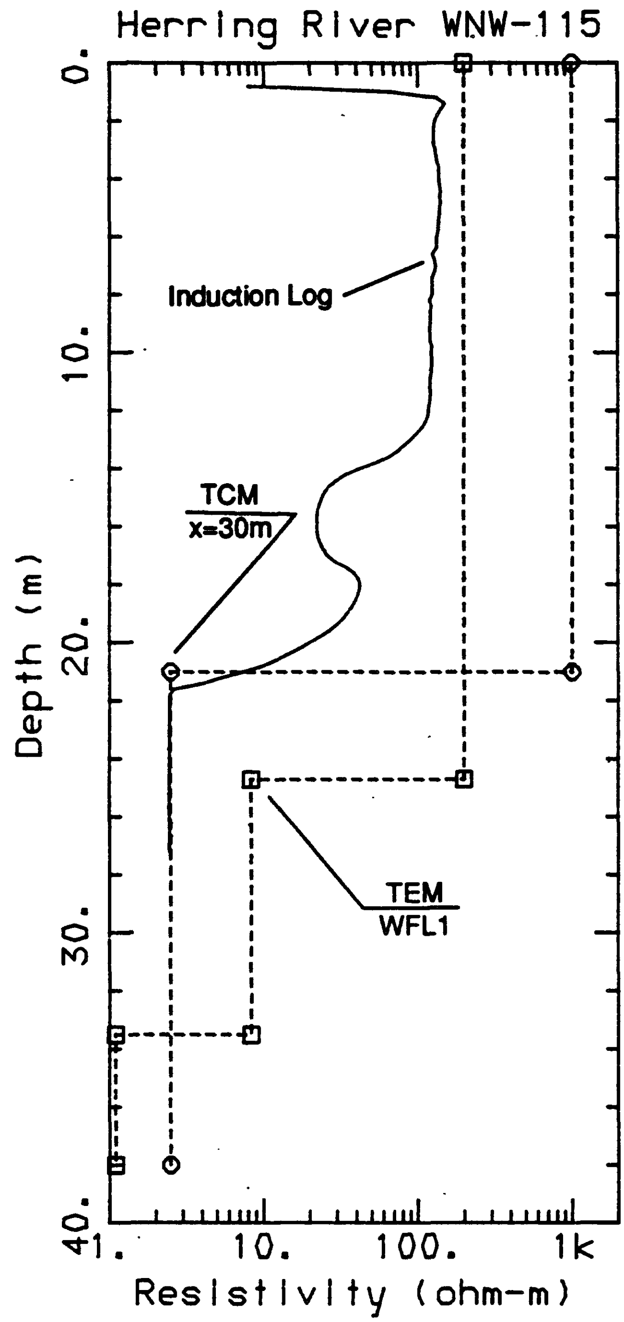


Figure 12 Induction log from well WNW-115 in the Great Pasture Subdivision. The interpreted resistivity-depth functions from the TCM model near station 30 on Line 2 and TEM sounding WFL 1 are also shown.

The TCM interpretation did a very good job of detecting the resistivity decrease found in the well. Water sample measurements from the well found that the specific conductance did not exceed 1800 μS/cm (see Table A-1), considered to be the maximum conductivity value for freshwater (Freeze and Cherry, 1979), until a depth of 64 ft (19.8 m). This is in very good agreement with the TCM determined depth of 21 m to the conductive layer.

5.2 Well WNW-116

Well WNW-116 is located between stations 100 and 120 along Line 1 in the Great Pasture Subdivision (see Figure 2). The well has a total depth of 127 ft (40.0 m). The well encountered primarily medium sand with some fine and coarse sand and cobbles (see Figure A-4). The induction log (Figure 13) is characterized by a resistive zone (150-200 ohm-m) for the first 32 m at which depth the resistivity starts to decrease monotonically until the instrument became saturated. The specific conductance reaches a value of 2400 μS/cm at a depth of 119 ft (37.5 m) indicative of brackish water (see Table A-2). The interpreted TCM data near the well is in remarkably good agreement with the induction log. The model consists of a 150-ohm-m layer to a depth of 35 m underlain by a 4.0 ohm-m layer. TEM soundings WFL 1 and WFL 2 give depths to the conductive saltwater layer of 33.5 m and 47.5 m respectively. These values bracket the TCM and well log determined depths. They were measured over 100 m from the well at significantly different elevations, so better agreement is not expected. The TEM results also show a transition into the saltwater whereas the TCM results do not. This is attributed to the greater resolution of the TEM method.

5.3 Well WNW-117

Located on the Newcomb Heights Subdivision traverse near station 10 at the lower end of Line 4 (see Figure 7), well WNW-117 was drilled to a depth of 96 ft (30.2 m). Drill cuttings were primarily medium and fine sand without any clay (see Figure A-6). Very good agreement was obtained between the TCM interpretation and the induction log (Figure 14). The TCM model has a 21-m-thick, 200-ohm-m first layer overlying a 2.0-ohm-m second layer that corresponds to the saltwater saturated zone. The induction log varies between 80 and 180 ohm-m in the first 19 meters before dropping sharply. The specific conductance of water samples does not exceed 1800 μS/cm until a depth of 72 ft (22.7 m) (see Table A-3).

5.4 Well WNW-118

Well WNW-118 is one of two adjacent wells drilled near the middle of Line 4 (station 80) in the Newcomb Heights Subdivision highlands east of the Herring River (see Figure 7). The total depth of the well was 121 ft (38.2 m) (see Figure A-8). No driller's log was recorded for this well, but well WNW-119 which is located only 2 m away encountered medium sand with minor amounts of fine and coarse sand and cobbles (see Figure A-9). The induction log (Figure 15) is similar to those described previously with a high resistivity section followed by a sharp decrease in resistivity near the bottom of the well. The TCM interpretation gave higher resistivities for the resistive material, but this value is subject to some uncertainty. The second layer of the TCM model starts at a depth of 32 m which agrees with the decrease in the well log resistivity. The TEM model for sounding WFL 7 made about 50 m away had a first layer resistivity more in line with the well log values. A transition zone with a resistivity of 27.3 ohm-m was required to fit the TEM data. The bottom layer resistivity of the TCM and TEM models are essentially the same, 2.0 and 2.3 ohm-m respectively,

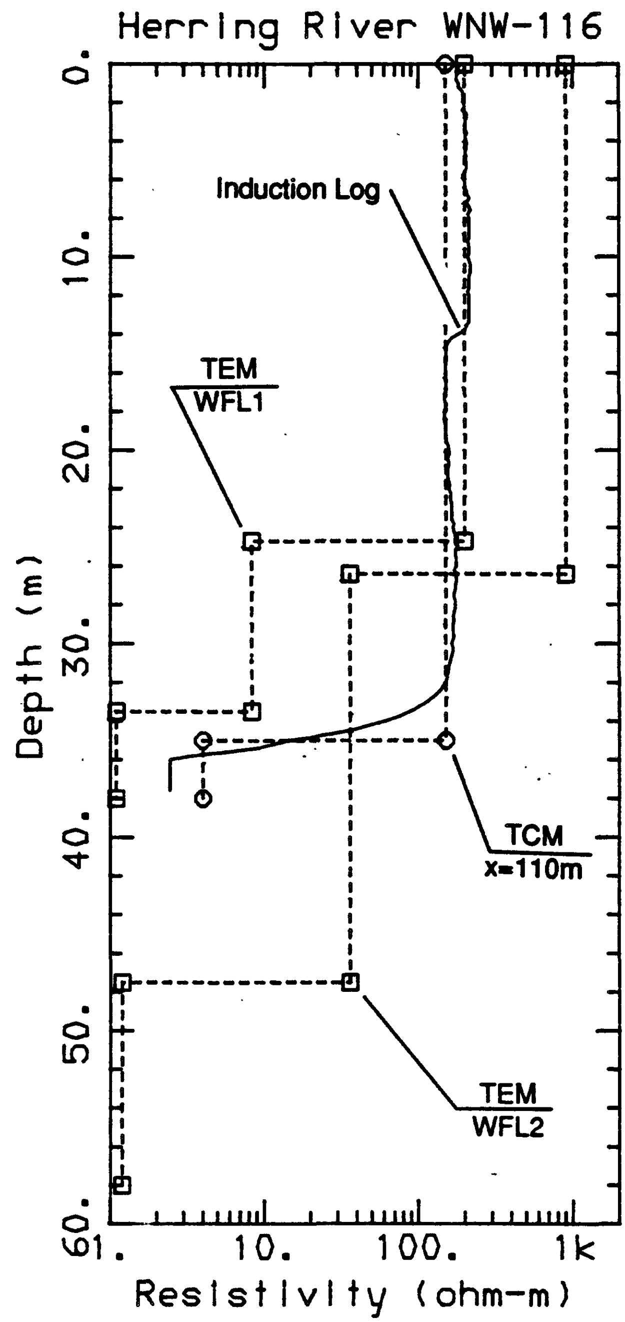


Figure 13 Induction log from well WNW-116 in the Great Pasture Subdivision. The interpreted resistivity-depth functions from the TCM model near stations 100-120 on Line 1 and TEM soundings WFL 1 and WFL 2 are shown.

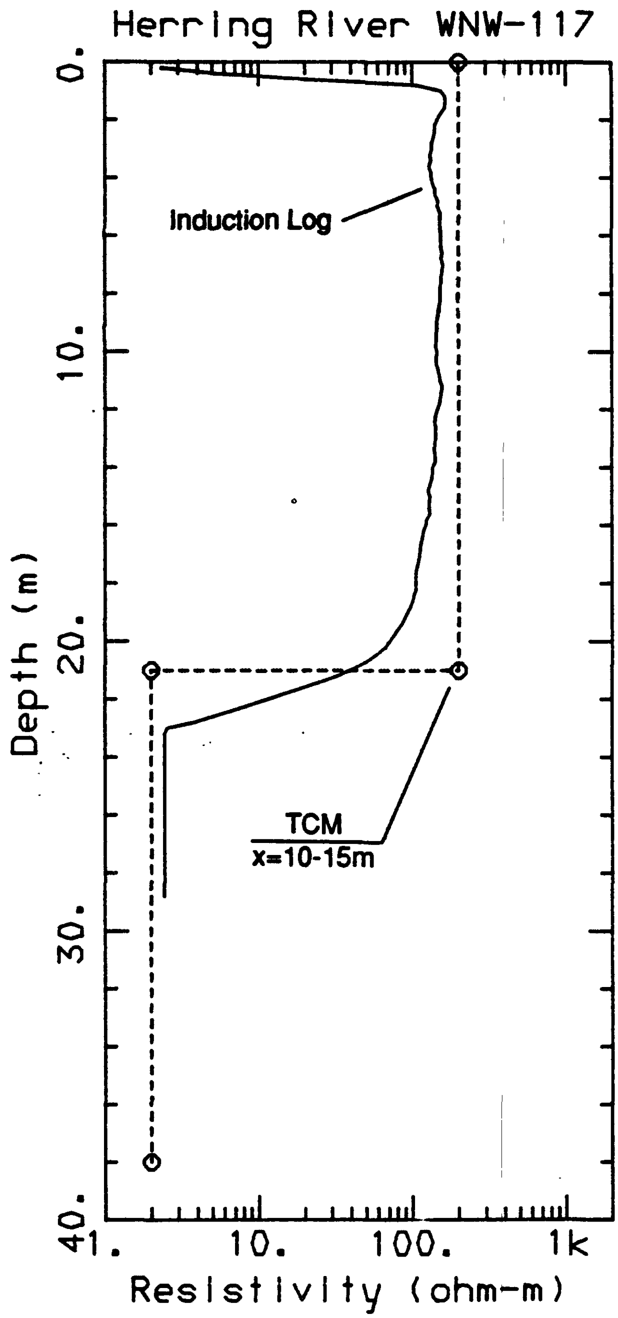


Figure 14 Induction log from well WNW-117 in the Newcomb Heights Subdivision. The interpreted resistivity-depth function from the TCM model near stations 10-15 on Line 4 is shown.

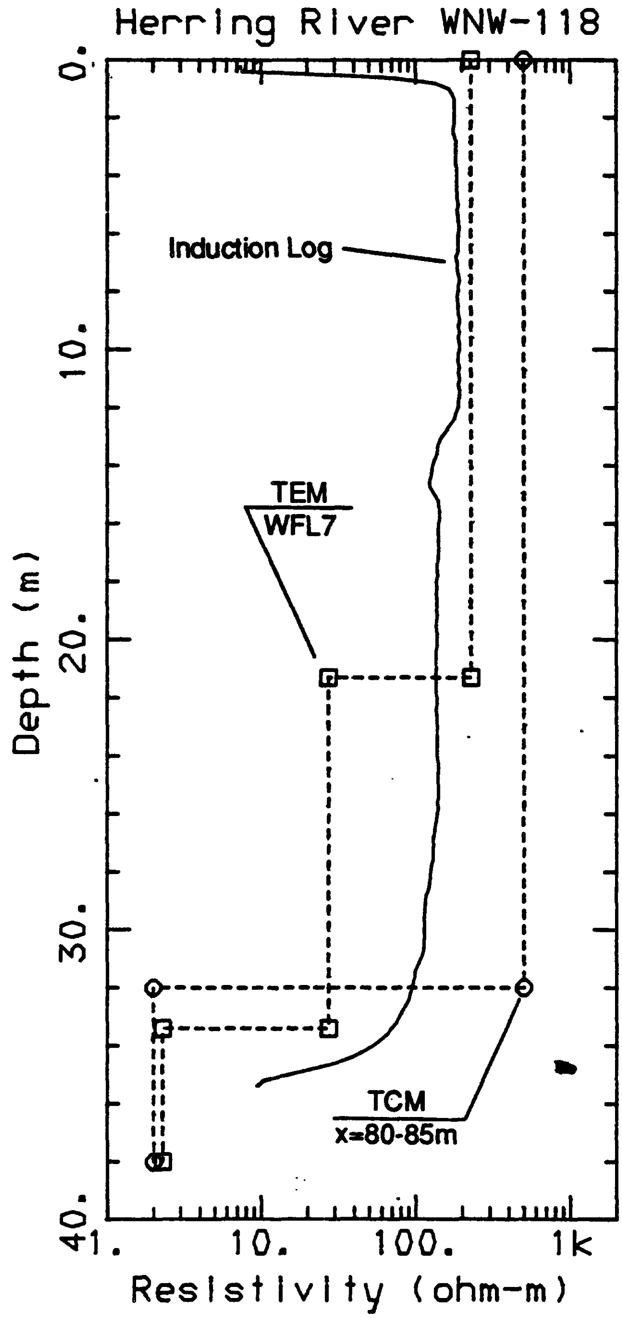


Figure 15 Induction log from well WNW-118 in the Newcomb Heights Subdivision. The interpreted resistivity-depth functions from the TCM model near stations 80-85 on Line 4 and TEM sounding WFL 7 are shown.

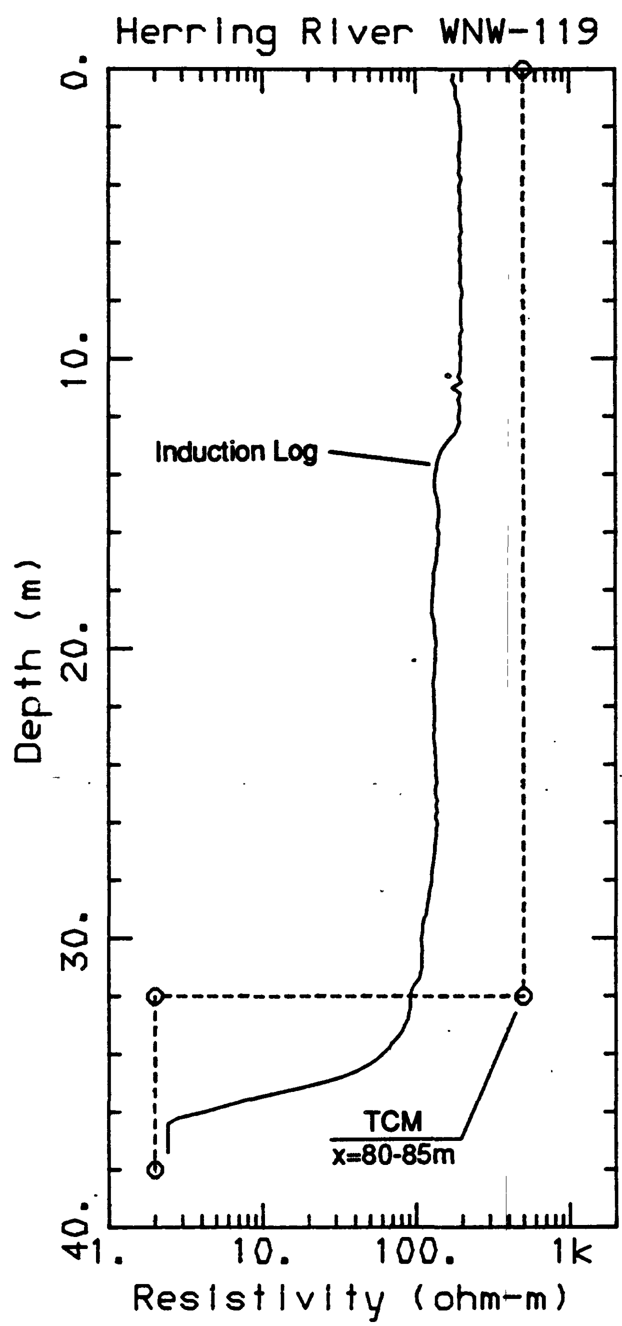


Figure 16 Induction log from well WNW-119 in the Newcomb Heights Subdivision. The interpreted resistivity-depth function from the TCM model near stations 80-85 on Line 4 is shown.

corresponding to a saltwater saturated zone. Water samples had specific conductances in excess of 1820 µS/m starting at a depth of 110 ft (34.6 m) (Table A-4).

5.5 Well WNW-119

Well WNW-119 was drilled adjacent to WNW-118 in the Newcomb Heights Subdivision as an experiment to determine if similar information could be obtained from an unscreened well using only induction logs. The induction log for this well (Figure 16) is virtually the same as the log from WNW-118. The driller's log reports medium sand with minor amounts of fine and coarse sand, cobbles, and gravel (see Figure A-9). No clay was found.

6. DISCUSSION OF RESULTS

The drilling and induction log data confirm the reliability of the TCM and TEM interpretations reported previously (Fitterman and others, 1989). The conductive layer at the bottom of the TCM models corresponds to a zone of decreased water quality with a specific conductance in excess of 1800 µS/cm corresponding to an estimated TDS of greater than 1000 mg/l. Water of this qualify is often termed brackish and does not meet Federal secondary drinking water guidelines (Environmental Protection Agency, 1979), however, in some parts of the country such water is used when no other primary source of water is available. The brackish water zone is probably a transition zone between near surface freshwater and seawater at greater depth. Seawater has a TDS value of 35000 mg/l; a TDS value of greater than 2000-3000 mg/l is generally too salty to drink (Freeze and Cheery, 1979, p. 84). The TEM models are in general agreement with the TCM results. There are some differences in the interpretations due to the difference in resolution and depth of exploration of the two methods. The TEM models generally show a transition zone that is shallower than the TCM conductor. A conductor, that is more conductive than the TCM conductive zone, is found below the transition zone. This TEM conductor is thought to be seawater saturated material.

7. CONCLUSIONS

The original interpretation of the geophysical data is considered to be correct based upon the drilling program confirmation. The original conclusion that the TCM determined conductive zone is due to seawater saturated material needs to be modified. The TCM conductor corresponds to a zone of brackish water that rests atop seawater saturated material. The brackish water is the result of dispersion and mixing of the freshwater and the seawater below. The vertical distance between the brackish water and the water level in observation wells was between 18 and 22 m. This is also true for the wells along High Toss Road in the flood plain of the Herring River. These vertical separation estimates are in line with those reported in Fitterman and others (1989, p. 29), which were reported to be 13-29 m on the east side of the river. Estimated increases in the static-water and high-tide levels in the Herring River resulting from the tide gates being completely opened would be less than 0.5 m (Roman and others, 1979, p. 37). Such a small level increase, compared to the large vertical separation between the base of the freshwater zone and the local water table elevation, makes it unlikely that increased tidal flow will significantly alter the thickness of the freshwater lens in wells in the highlands east of High Toss Road. It is recommended, however, that periodic logging of the observation wells be done to monitor possible movement of the saltwater interface.

For wells along High Toss Road there is almost 20 m of vertical separation between the water table level and the TCM conductor level, however, increased saltwater flow into the river as a result of increasing the tide gate openings will disrupt the existing equilibrium between the freshwater and saltwater regions in the lowlands. Wells in the lowlands along the road could potentially draw saltwater due to infiltration from the surface or repositioning of the freshwater lens. It would be prudent to monitor the location of the transition zone until a new equilibrium is established should increased tidal flow be allowed.

ACKNOWLEDGEMENT

John Portnoy (NPS) assisted with the planning, logistical support, and field work. We are grateful for all of the help he provided. The drilling operation was supervised by Bruce P. Hansen (USGS, Marlborough, Mass.). Paul Friesz (USGS, Marlborough, Mass.) collected the induction log data. Edgar Ethington (USGS, Denver, Colo.) carried out the laboratory resistivity measurements. This study was funded by the Cape Cod National Seashore, National Park Service.

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APPENDIX: OBSERVATION WELL DATA

This appendix details the observation well data. General locations of the five observation wells can be found on Figures 1, 2, and 7 in the main body of the report. Specific conductance, temperature, and salinity logs were collected at the time the wells were drilled in May 1990. Induction logs were run in September 1990 using a Geonics EM39. The large, alternating polarity conductivity values in the first meter of the logs is caused by the protective curb box around the well bore. The induction logger full-scale setting was 30 mS/m which gives a maximum reliable conductivity reading of 150 mS/m. Numbers in excess of this value, which are found at the bottom of most logs, are lower than the true value by an indeterminate amount.

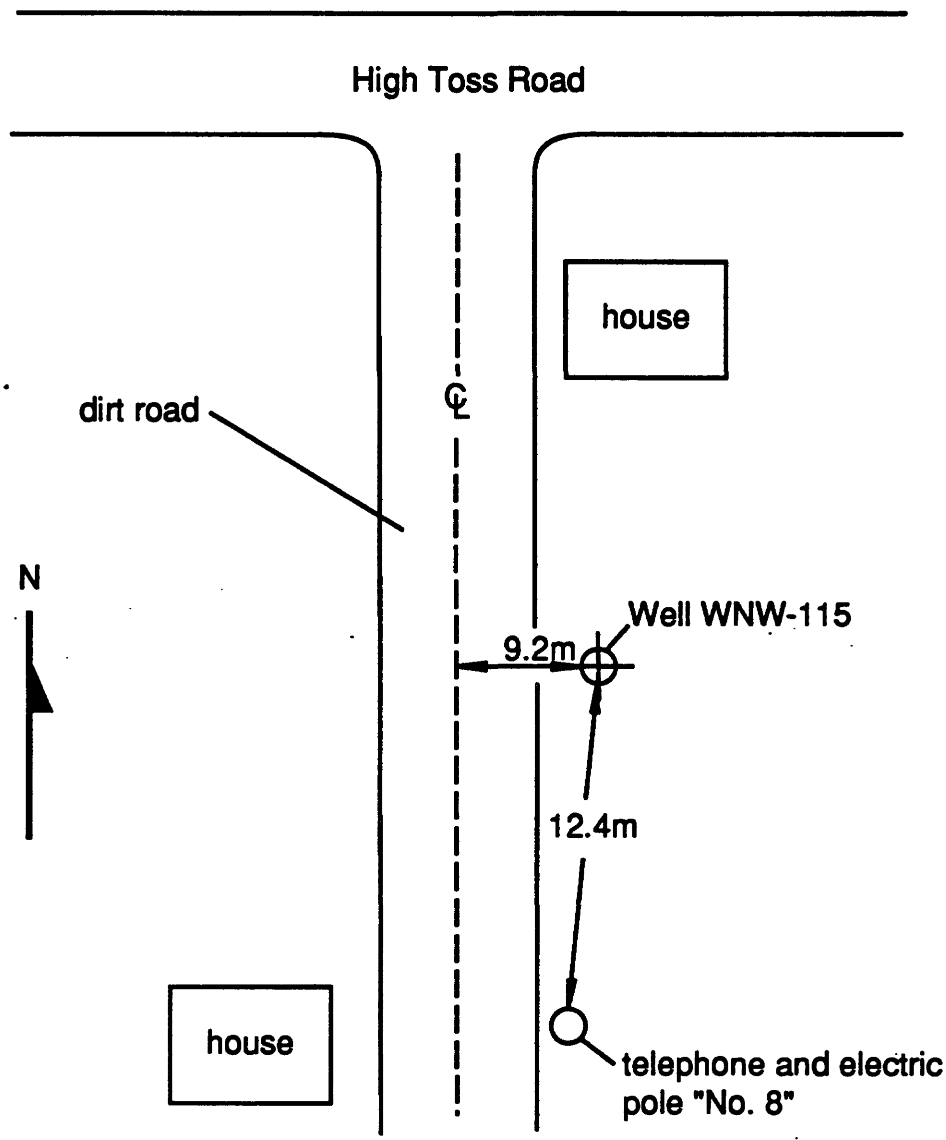

Figure A-1 Detailed location of well WNW-115.

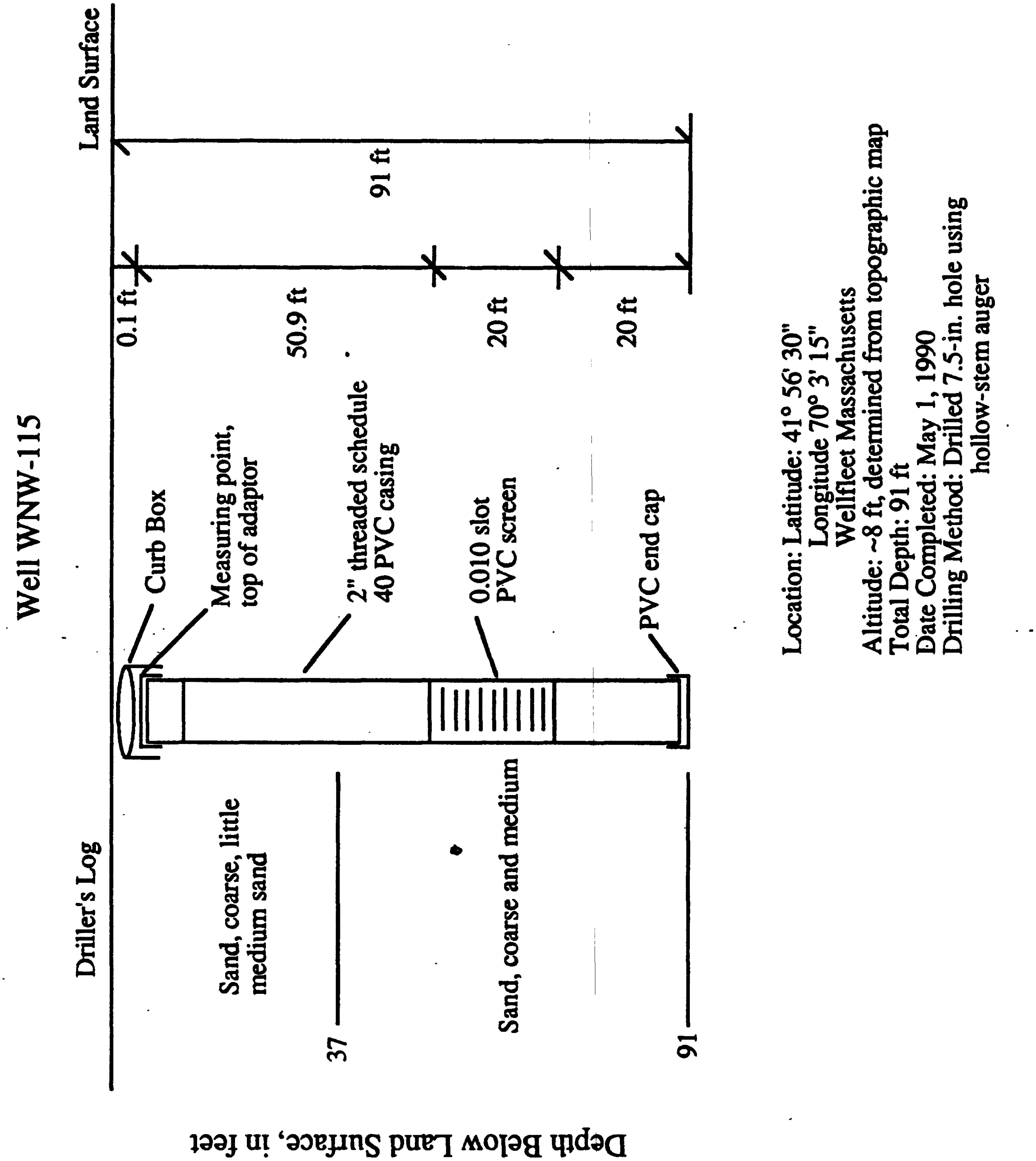

Figure A-2 Construction detail and driller's log for well WNW-115.

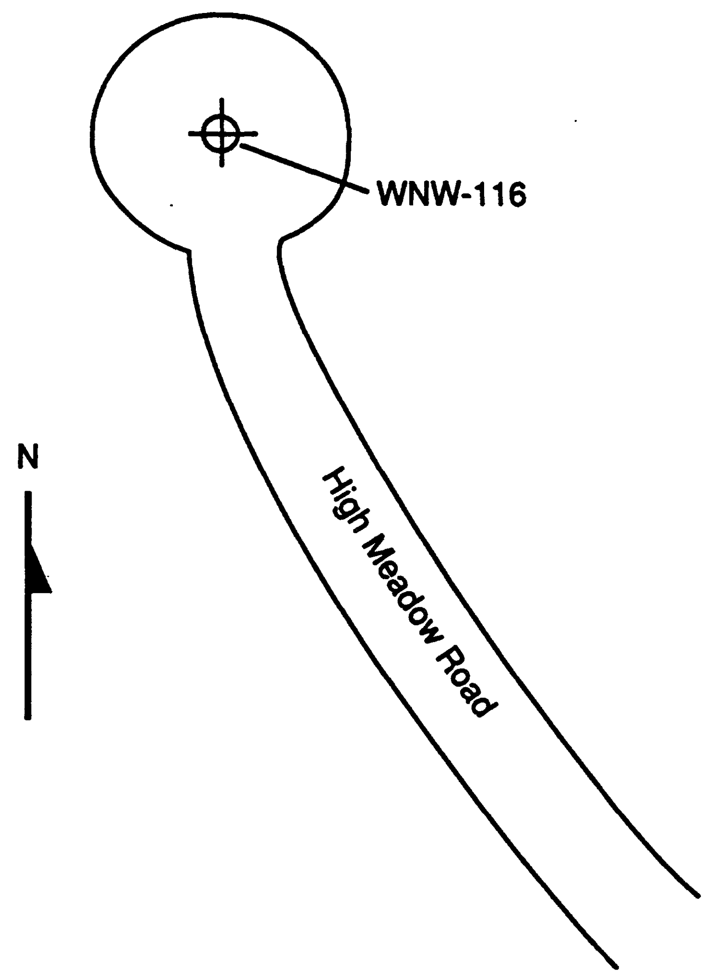

Figure A-3 Detailed location of well WNW-116.

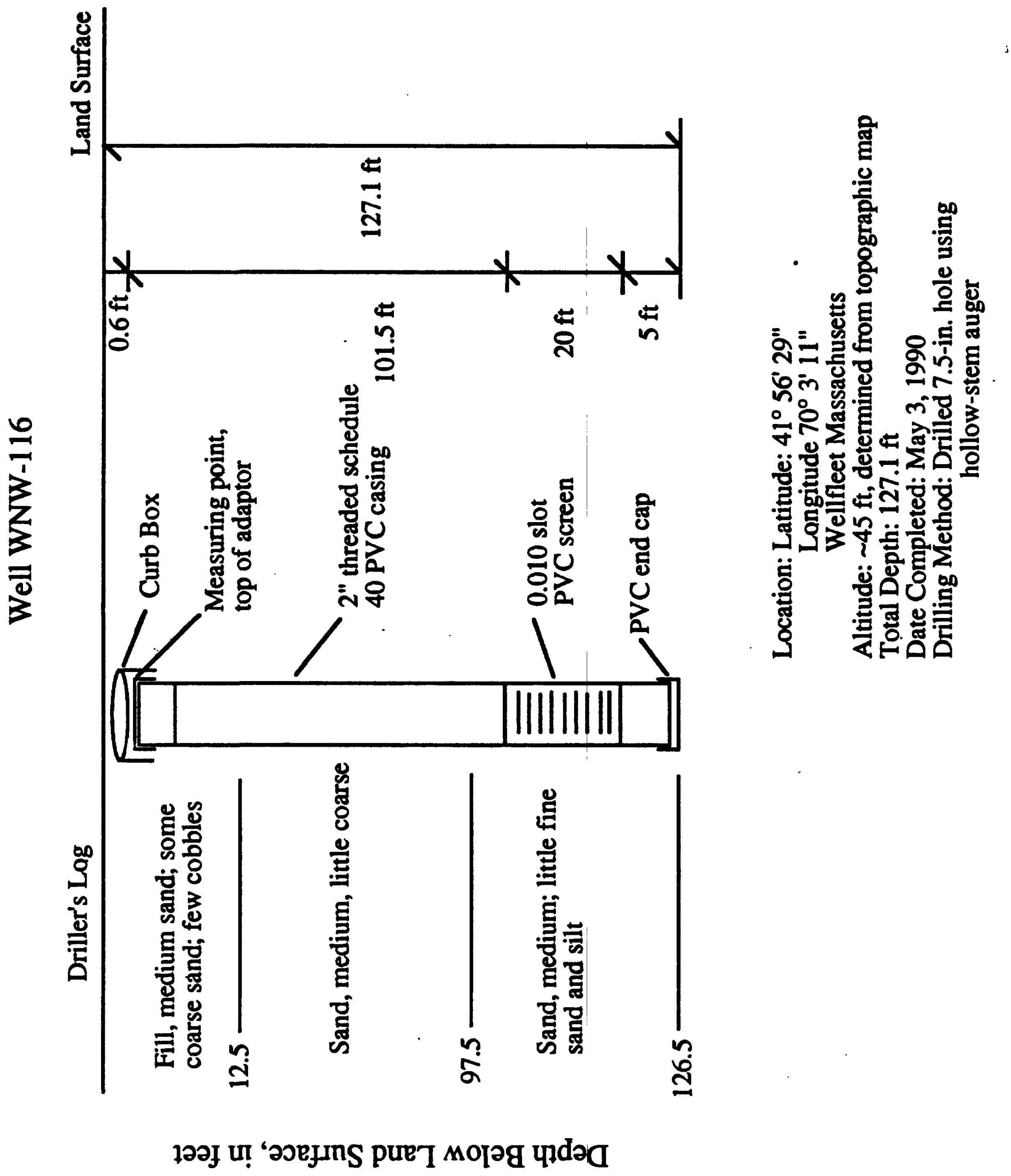

Figure A-4 Construction detail and driller's log for well WNW-116.

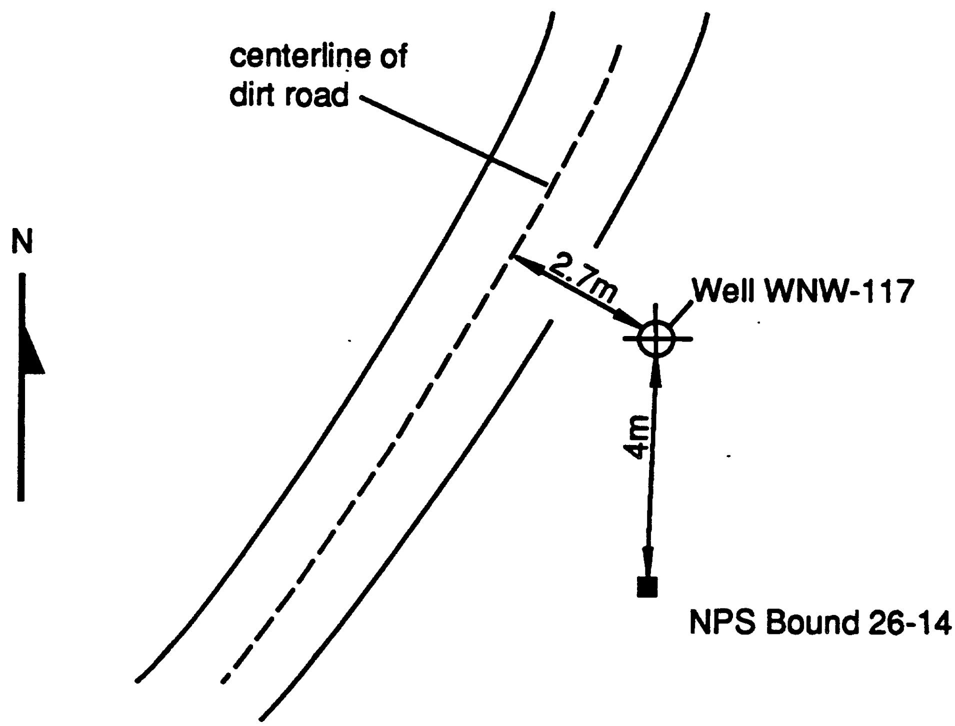

Figure A-5 Detailed location of well WNW-117.

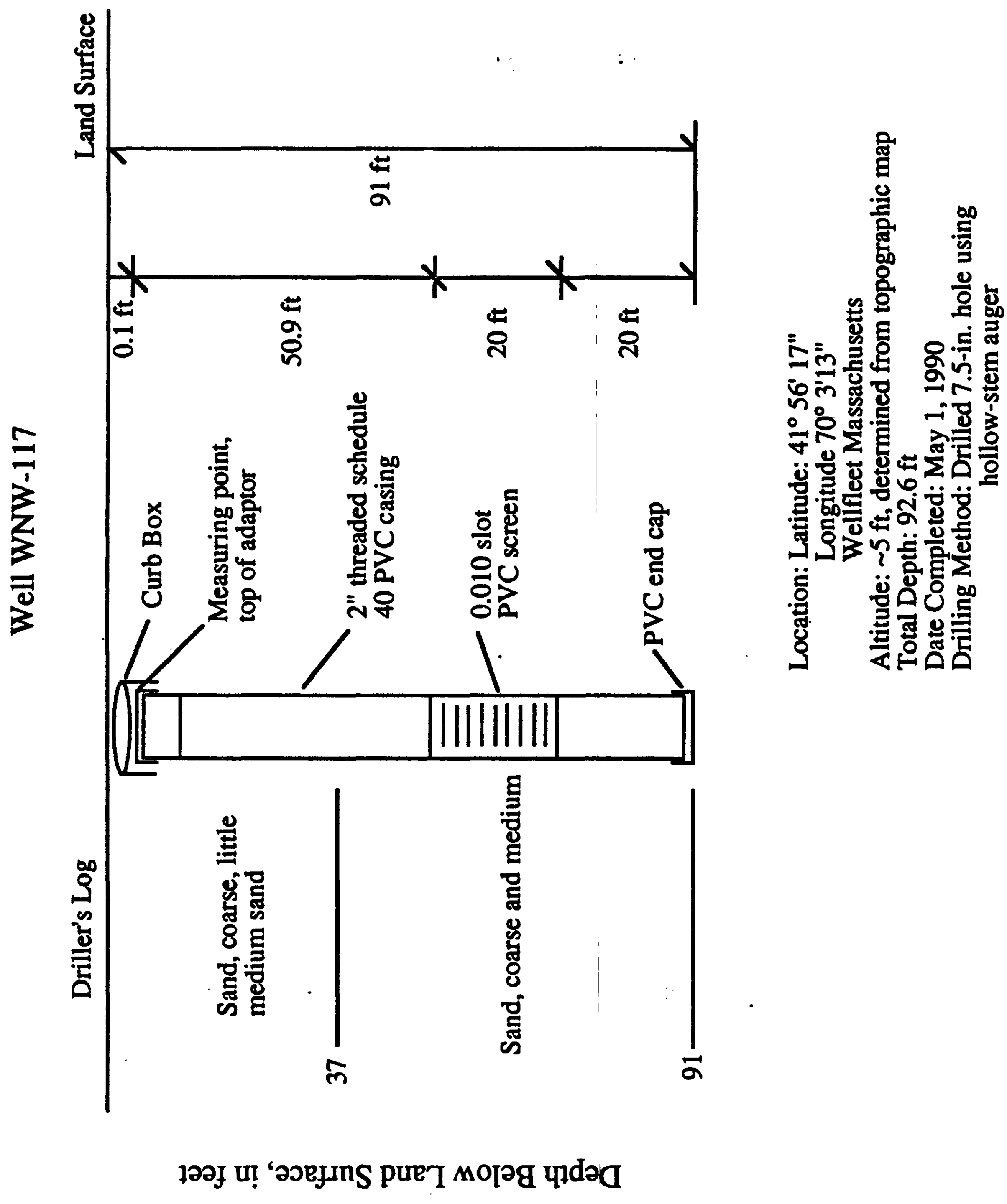

Figure A-6 Construction detail and driller's log for well WNW-117.

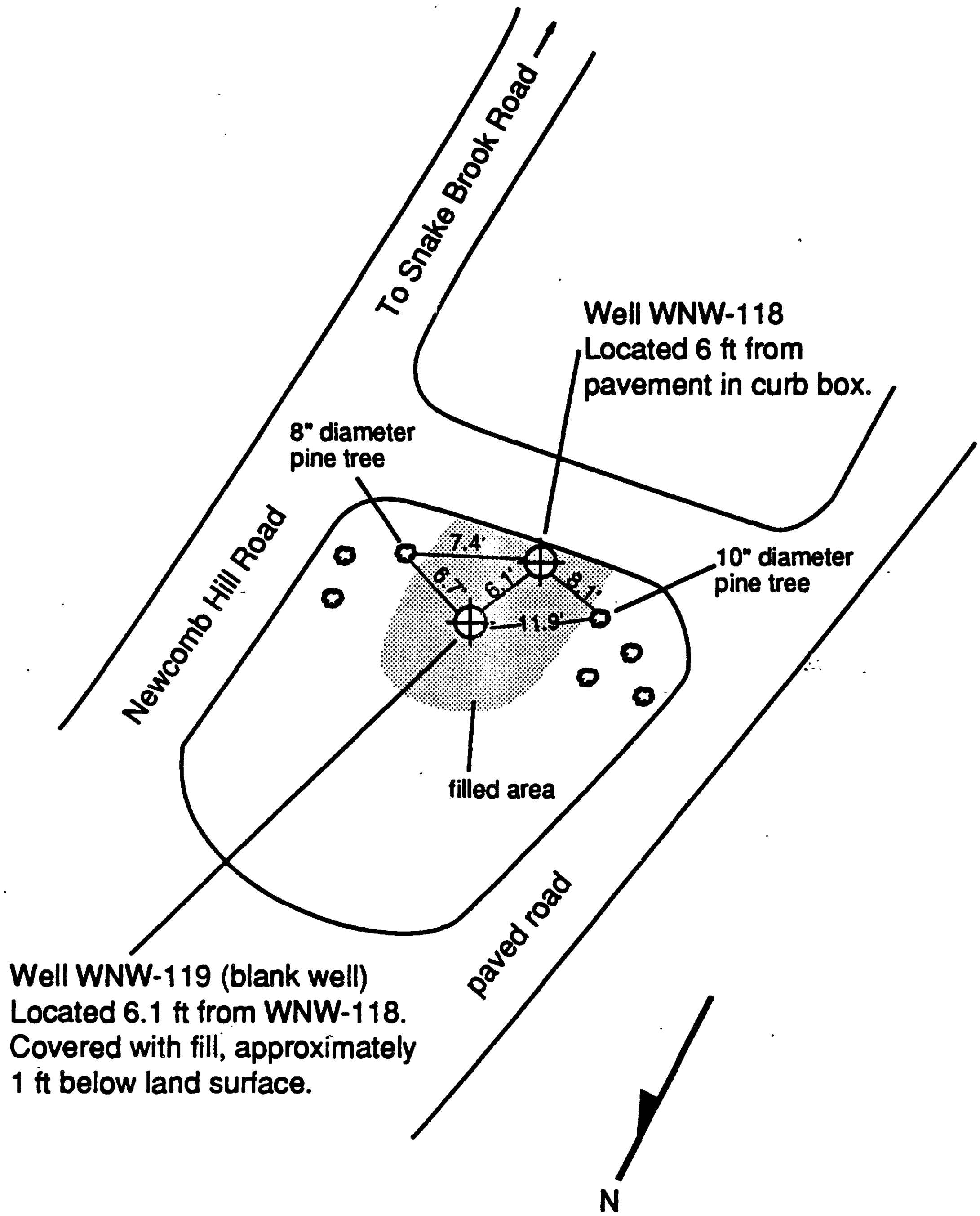

Figure A-7 Detailed location of wells WNW-118 and WNW-119.

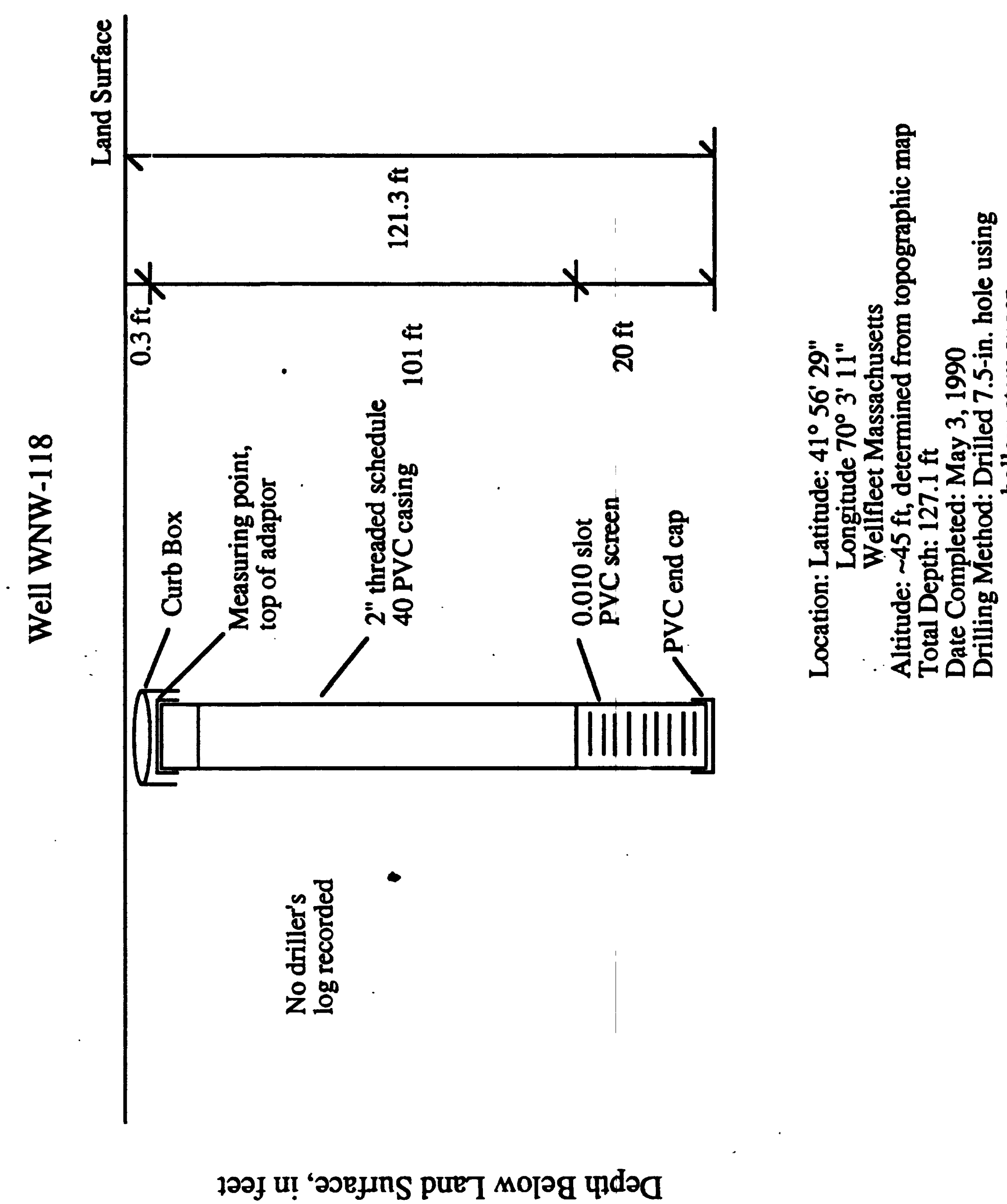

Figure A-8 Construction detail for well WNW-118.

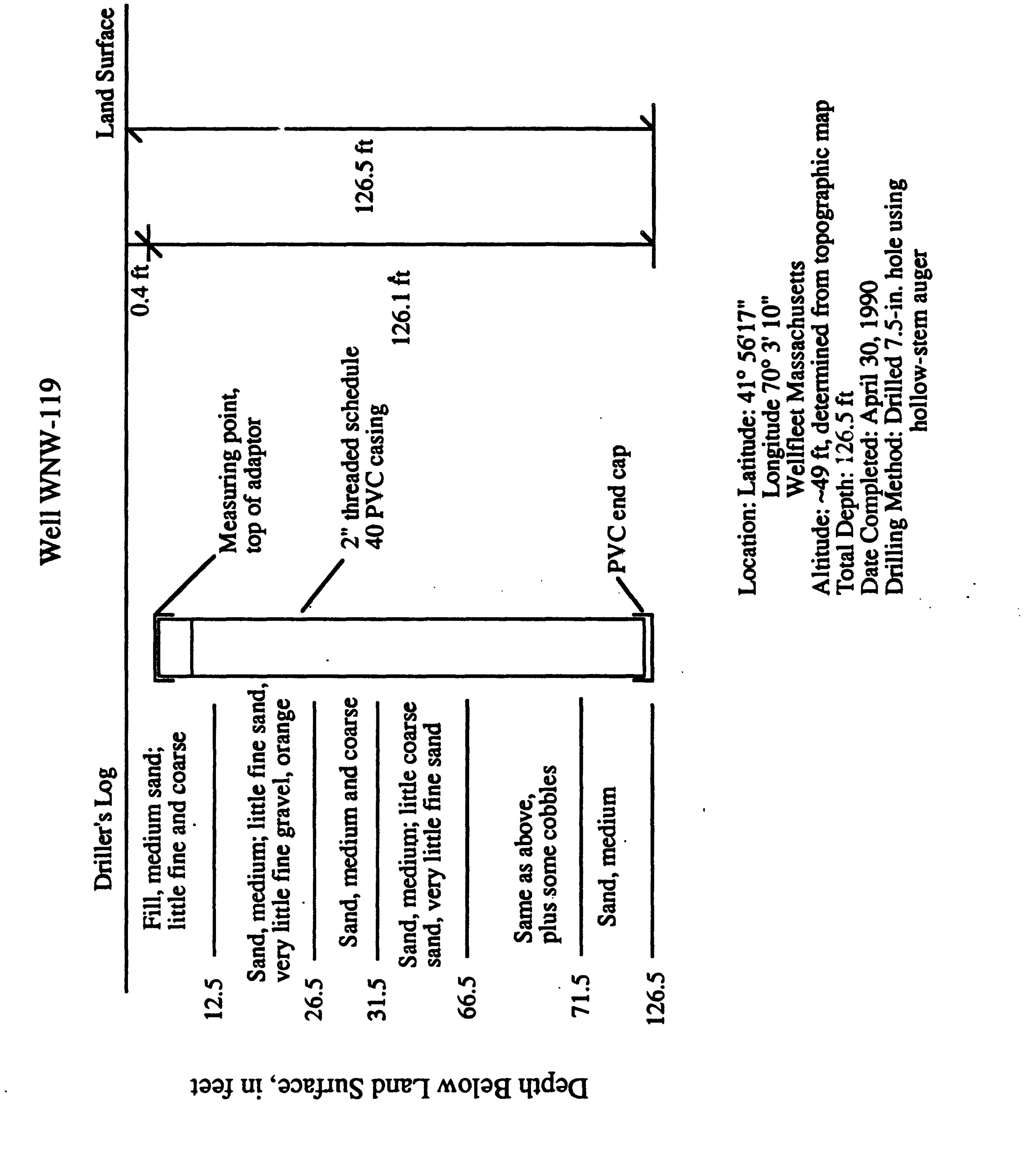

Figure A-9 Construction detail and driller's log for well WNW-119.

Table A-1 Specific conductance, temperature, and salinity logs for well WNW-115, May 3, 1990. [Specific conductance readings are not temperature compensated; salinity readings are temperature compensated; ATOS is approximate top of screen; ABOS is approximate bottom of screen.]

Depth below measuring point (ft)	Specific conductance (µS/cm)	Temperature (°C)	Salinity (ppt)	Remarks
10	–	8.1	–	–
20	–	8.8	–	–
30	–	9.5	–	–
40	–	10.0	–	–
50	–	10.2	–	ATOS
52	700	10.2	–	–
54	1300	10.5	–	–
56	1320	10.5	–	–
58	1320	10.5	.8	–
60	1450	10.5	.9	–
62	1510	10.5	.95	–
64	1780	10.6	1.0	–
66	2410	10.5	1.5	–
68	3400	10.5	2.3	–
69	4000	10.5	3.0	–
70	4900	10.5	4.2	ABOS
71	7200	10.5	6.1	–
74	14900	10.5	12.9	–
76	21900	10.8	18.9	–
78	25900	10.8	22.6	–
80	27800	10.9	24.5	–
82	28800	10.9	25.2	–
84	29200	10.9	25.9	–
86	29600	10.9	26.1	–
88	29900	10.9	26.1	–
90	29900	–	–	–

Table A-2 Specific conductance, temperature, and salinity logs for well WNW-116, May 3, 1990. [Specific conductance readings are not temperature compensated; salinity readings are temperature compensated; ATOS is approximate top of screen; ABOS is approximate bottom of screen.]

Depth below measuring point (ft)	Specific conductance (µS/cm)	Temperature (°C)	Salinity (ppt)	Remarks
90	88	10.5	–	–
96	99	10.5	–	–
98	105	10.5	–	–
100	110	10.5	–	–
103	170	10.5	–	ATOS
104	248	10.5	–	–
105	370	10.5	–	–
106	439	10.5	–	–
107	478	10.5	–	–
108	620	10.5	–	–
109	650	10.5	–	–
110	650	10.1	–	–
115	710	10.2	.2	–
117	790	–	–	–
118	850	10.5	–	–
119	2400	10.5	2.9	–
119.5	7000	–	–	–
120	10500	10.8	8.8	–
121	12900	10.8	9.5	–
122	13100	10.8	–	ABOS

Table A-3 Specific conductance, temperature, and salinity logs for well WNW-117, May 3, 1990. [Specific conductance readings are not temperature compensated; salinity readings are temperature compensated; ATOS is approximate top of screen; ABOS is approximate bottom of screen.]

Depth below measuring point (ft)	Specific conductance (µS/cm)	Temperature (°C)	Salinity (ppt)	Remarks
10	100	8.1	–	–
20	–	9.0	–	–
30	200	10.1	–	–
40	480	10.5	–	–
45	490	10.6	.1	–
50	480	10.5	–	–
55	460	10.6	–	ATOS
60	420	10.6	–	–
62	710	10.7	–	–
65	920	10.8	–	–
70	1200	10.8	.7	–
72	2000	10.9	1.3	–
73	4100	10.8	3.0	–
74	5800	10.8	4.8	–
75	5900	10.8	4.8	–
76	6100	10.8	5.0	ABOS
77	6100	10.8	–	–
78	6100	10.8	–	–
79	6100	–	–	–

Table A-4 Specific conductance, temperature, and salinity logs for well WNW-118, May 3, 1990. [Specific conductance readings are not temperature compensated; salinity readings are temperature compensated; ATOS is approximate top of screen; ABOS is approximate bottom of screen.]

Depth below measuring point (ft)	Specific conductance (μS/cm)	Temperature (°C)	Salinity (ppt)	Remarks
50	–	12.2	–	–
55	–	11.8	–	–
60	–	11.4	–	–
65	–	11.2	–	–
70	–	11.0	–	–
75	80	10.9	–	–
80	82	10.8	–	–
85	82	10.7	–	–
90	105	10.7	–	–
95	105	10.6	–	–
100	110	10.6	–	–
101	210	10.7	–	ATOS
102	498	10.6	–	–
103	800	10.6	–	–
104	910	10.6	.3	–
105	1110	10.6	.5	–
106	1310	10.7	.8	–
107	1500	10.8	.9	–
108	1650	10.8	1.0	–
109	1740	10.8	1.0	–
110	1820	10.8	1.1	–
111	1970	10.9	1.2	–
112	2100	10.9	1.3	–
113	2160	10.9	1.4	–
114	2220	10.9	1.5	–
115	2380	10.9	1.6	–
116	2790	10.9	1.9	–
117	3200	10.9	2.2	–
118	4500	10.9	3.3	–
119	4680	11.0	3.5	–
120	4300	11.0	3.1	ABOS

Table A-5 Induction log from well WNW-115 run in the uphole direction, September 18, 1990.
[Depth in meters; conductivity in mS/m; inphase in ppt]

Depth	Cond	Inphase
0.2	-501.0	-30.3
0.4	408.4	461.3
0.6	-301.5	-468.4
0.8	124.8	-60.8
1.0	14.8	-3.7
1.2	7.6	-0.4
1.4	6.7	0.2
1.6	7.1	0.4
1.8	7.5	0.4
2.0	7.8	0.5
2.2	7.9	0.5
2.4	7.9	0.5
2.6	7.9	0.3
2.8	7.9	0.8
3.0	7.7	0.5
3.2	7.6	0.5
3.4	7.5	0.4
3.6	7.3	0.5
3.8	7.3	0.5
4.0	7.3	0.5
4.2	7.2	0.4
4.4	7.1	0.4
4.6	7.2	0.4
4.8	7.1	0.5
5.0	7.2	0.5
5.2	7.2	0.5
5.4	7.3	0.4
5.6	7.4	0.5
5.8	7.4	0.5
6.0	7.6	0.5
6.2	7.6	0.5
6.4	7.6	0.5
6.6	8.1	0.5
6.8	7.8	0.5
7.0	7.7	0.5
7.2	7.8	0.5
7.4	8.1	0.5
7.6	8.1	0.4
7.8	8.1	0.5
8.0	8.1	0.4
8.2	8.4	0.4
8.4	8.2	0.4
8.6	8.3	0.4
8.8	8.3	0.3
9.0	8.3	0.4
9.2	8.4	0.5
9.4	8.3	0.3
9.6	8.3	0.4
9.8	8.1	0.4
10.0	8.2	0.4
10.2	8.1	0.5
10.4	8.1	0.5
10.6	8.2	0.5
10.8	8.3	0.5
11.0	8.4	0.4
11.2	8.4	0.5
11.4	8.3	0.4
11.6	8.4	0.4
11.8	8.5	0.4
12.0	8.6	0.4
12.2	8.7	0.4
12.4	9.0	0.5
12.6	9.5	0.5
12.8	10.3	0.5
13.0	11.2	0.4
13.2	12.4	0.5
13.4	13.7	0.5
13.6	15.5	0.5
13.8	18.9	0.5
14.0	24.1	0.5
14.2	29.4	0.4
14.4	33.6	0.5
14.6	37.5	0.4
14.8	40.0	0.5
15.0	41.8	0.5
15.2	43.1	0.3
15.4	44.3	0.3
15.6	44.9	0.4
15.8	45.1	0.3
16.0	45.3	0.2
16.2	45.1	0.2
16.4	44.2	0.4
16.6	42.7	0.4
16.8	40.9	0.4
17.0	38.7	0.5
17.2	34.8	0.4
17.4	29.3	0.2
17.6	26.0	0.4
17.8	24.3	0.3
18.0	23.8	0.4
18.2	24.2	0.4
18.4	24.8	0.3
18.6	25.8	0.3
18.8	27.1	0.3
19.0	28.9	0.3
19.2	30.9	0.3
19.4	33.8	0.2
19.6	37.6	0.2
19.8	43.1	0.2
20.0	50.2	0.1
20.2	58.6	0.2
20.4	69.9	0.1
20.6	83.4	0.1
20.8	102.2	0.0
21.0	136.4	0.0
21.2	188.0	0.0
21.4	248.8	0.0
21.6	382.5	-0.1
21.8	408.6	-0.1
22.0	408.6	-3.4
22.2	408.6	-4.2
22.4	408.5	-4.7
22.6	408.5	-5.1
22.8	408.5	-5.5
23.0	408.5	-5.7
23.2	408.5	-6.0
23.4	408.5	-6.2
23.6	408.5	-6.4
23.8	408.5	-6.6
24.0	408.5	-6.8
24.2	408.5	-7.0
24.4	408.5	-7.1
24.6	408.5	-7.2
24.8	408.5	-7.3
25.0	408.5	-7.4
25.2	408.5	-7.5
25.4	408.5	-7.7
25.6	408.4	-7.7
25.8	408.5	-7.7
26.0	408.5	-7.7
26.2	408.4	-7.6
26.4	408.5	-7.6
26.6	408.5	-7.7
26.8	408.4	-8.0
27.0	408.4	-8.1
27.2	408.4	-8.3

Table A-6 Induction log from well WNW-116 run in the uphole direction, September 18, 1990. [Depth in meters; conductivity in mS/m; inphase in ppt]

Depth	Cond	Inphase	Depth	Cond	Inphase	Depth	Cond	Inphase
0.0	5.3	-0.3	10.0	4.8	0.3	20.0	6.4	0.5
0.2	5.6	0.3	10.2	4.7	0.9	20.2	6.3	0.5
0.4	5.4	0.3	10.4	4.6	0.6	20.4	6.5	0.4
0.6	5.7	0.3	10.6	4.6	0.6	20.6	6.4	0.4
0.8	5.7	0.4	10.8	4.6	0.6	20.8	6.4	0.5
1.0	5.5	0.3	11.0	4.7	0.7	21.0	6.5	0.5
1.2	5.5	0.4	11.2	4.7	0.7	21.2	6.5	0.5
1.4	5.2	0.4	11.4	4.7	0.8	21.4	6.5	0.4
1.6	5.1	0.3	11.6	4.7	0.8	21.6	6.4	0.4
1.8	5.1	0.2	11.8	4.8	0.8	21.8	6.3	0.5
2.0	5.1	0.2	12.0	4.7	0.8	22.0	6.4	0.5
2.2	5.0	0.5	12.2	4.7	0.8	22.2	6.2	0.5
2.4	5.2	0.3	12.4	4.7	0.8	22.4	6.2	0.4
2.6	4.9	0.5	12.6	4.7	0.7	22.6	6.2	0.4
2.8	4.9	0.5	12.8	4.7	0.7	22.8	6.1	0.4
3.0	5.0	0.6	13.0	4.7	0.7	23.0	6.1	0.6
3.2	5.0	0.5	13.2	4.7	0.6	23.2	6.1	0.4
3.4	5.0	0.5	13.4	4.7	0.6	23.4	6.1	0.4
3.6	4.9	0.5	13.6	4.9	0.6	23.6	6.1	0.5
3.8	5.0	0.5	13.8	5.0	0.6	23.8	5.9	0.5
4.0	4.9	0.5	14.0	5.5	0.5	24.0	6.0	0.5
4.2	4.9	0.5	14.2	6.1	0.4	24.2	5.9	0.5
4.4	4.9	0.5	14.4	6.4	0.4	24.4	5.8	0.5
4.6	5.0	0.5	14.6	6.6	0.4	24.6	5.8	0.4
4.8	4.9	0.5	14.8	6.6	0.5	24.8	5.8	0.4
5.0	5.0	0.5	15.0	6.6	0.5	25.0	5.6	0.4
5.2	4.9	0.5	15.2	6.6	0.5	25.2	5.8	0.5
5.4	4.9	0.6	15.4	6.6	0.4	25.4	5.8	0.5
5.6	5.0	0.5	15.6	6.7	0.3	25.6	5.7	0.5
5.8	5.2	0.5	15.8	6.7	0.4	25.8	5.7	0.5
6.0	5.1	0.5	16.0	6.6	0.4	26.0	5.7	0.4
6.2	5.0	0.5	16.2	6.7	0.5	26.2	5.9	0.5
6.4	5.0	0.5	16.4	6.6	0.4	26.4	5.7	0.5
6.6	4.9	0.4	16.6	6.6	0.4	26.6	5.7	0.5
6.8	4.8	0.3	16.8	6.6	0.3	26.8	5.7	0.4
7.0	4.7	0.6	17.0	6.7	0.5	27.0	5.8	0.5
7.2	4.9	0.1	17.2	6.8	0.4	27.2	5.8	0.5
7.4	4.7	0.0	17.4	6.8	0.4	27.4	5.9	0.4
7.6	4.6	0.7	17.6	6.7	0.4	27.6	5.9	0.5
7.8	4.8	0.5	17.8	6.7	0.4	27.8	5.8	0.5
8.0	4.7	0.5	18.0	6.8	0.4	28.0	5.8	0.4
8.2	4.7	0.6	18.2	6.8	0.4	28.2	5.8	0.4
8.4	4.7	0.4	18.4	6.8	0.4	28.4	5.9	0.5
8.6	4.7	0.7	18.6	6.7	0.4	28.6	6.0	0.5
8.8	4.7	0.6	18.8	6.7	0.4	28.8	5.9	0.4
9.0	4.7	0.6	19.0	6.7	0.3	29.0	6.0	0.5
9.2	4.8	0.6	19.2	6.7	0.2	29.2	6.0	0.4
9.4	4.7	0.7	19.4	6.7	0.4	29.4	6.0	0.4
9.6	4.7	0.5	19.6	6.6	0.5	29.6	5.9	0.4
9.8	4.7	0.7	19.8	6.4	0.4	29.8	6.0	0.5

Table A-6 continued

Depth	Cond	Inphase
30.0	6.1	0.4
30.2	6.0	0.4
30.4	6.0	0.4
30.6	6.1	0.4
30.8	6.2	0.3
31.0	6.3	0.4
31.2	6.4	0.3
31.4	6.4	0.3
31.6	6.5	0.2
31.8	6.6	0.1
32.0	6.8	-0.3
32.2	7.0	-0.2
32.4	7.3	0.2
32.6	7.7	-0.1
32.8	8.3	0.5
33.0	8.9	-0.1
33.2	9.8	-0.1
33.4	10.8	-0.1
33.6	12.3	0.0
33.8	14.0	0.0
34.0	16.6	0.1
34.2	20.6	0.5
34.4	25.3	0.2
34.6	33.2	0.0
34.8	46.3	-0.2
35.0	69.4	-0.2
35.2	88.1	-0.1
35.4	110.1	-0.2
35.6	174.9	-0.1
35.8	295.5	-0.1
36.0	408.7	-0.2
36.2	408.6	-3.5
36.4	408.6	-4.3
36.6	408.6	-5.0
36.8	408.6	-5.5
37.0	408.6	-5.9
37.2	408.6	-6.4
37.4	408.6	-6.6
37.6	408.6	-6.7

Table A-7 Induction log from well WNW-117 run in the uphole direction, September 18, 1990. [Depth in meters; conductivity in mS/m; inphase in ppt]

Depth	Cond	Inphase	Depth	Cond	Inphase	Depth	Cond	Inphase
0.0	-493.0	-25.5	10.0	6.9	0.2	20.0	14.2	0.2
0.2	424.4	325.3	10.2	7.0	0.3	20.2	15.1	0.2
0.4	192.2	-420.3	10.4	7.0	0.1	20.4	16.8	0.2
0.6	51.3	-21.4	10.6	6.8	0.2	20.6	18.8	0.2
0.8	9.4	-1.7	10.8	6.7	0.2	20.8	21.5	0.2
1.0	6.5	-0.2	11.0	6.6	0.4	21.0	25.4	0.2
1.2	6.1	0.1	11.2	6.4	0.4	21.2	31.0	0.2
1.4	6.1	0.2	11.4	6.5	0.3	21.4	39.7	0.1
1.6	6.2	0.5	11.6	6.6	0.3	21.6	51.8	0.0
1.8	6.6	0.1	11.8	6.7	0.4	21.8	67.7	0.1
2.0	6.9	0.2	12.0	6.9	0.2	22.0	87.4	0.0
2.2	7.2	0.3	12.2	7.1	0.2	22.2	114.5	0.0
2.4	7.2	0.4	12.4	7.2	0.4	22.4	151.0	0.0
2.6	7.3	0.4	12.6	7.1	0.4	22.6	199.5	0.0
2.8	7.5	0.4	12.8	7.1	0.4	22.8	264.6	0.0
3.0	7.5	0.4	13.0	7.1	0.4	23.0	395.5	-0.1
3.2	7.7	0.3	13.2	7.2	0.4	23.2	409.4	-0.3
3.4	7.6	0.3	13.4	7.2	0.3	23.4	409.4	-2.3
3.6	7.8	0.2	13.6	7.1	0.4	23.6	409.3	-4.2
3.8	7.6	0.2	13.8	7.1	0.4	23.8	409.3	-4.8
4.0	7.5	0.3	14.0	7.4	0.4	24.0	409.3	-5.3
4.2	7.4	0.4	14.2	7.4	0.4	24.2	409.3	-5.7
4.4	7.1	0.4	14.4	7.5	0.4	24.4	409.3	-6.1
4.6	7.1	0.5	14.6	7.7	0.4	24.6	409.3	-6.4
4.8	6.8	0.4	14.8	7.9	0.4	24.8	409.3	-6.7
5.0	6.9	0.4	15.0	7.7	0.4	25.0	409.3	-7.0
5.2	6.6	0.4	15.2	7.8	0.4	25.2	409.3	-7.2
5.4	6.6	0.4	15.4	7.8	0.4	25.4	409.3	-7.4
5.6	6.6	0.3	15.6	7.7	0.4	25.6	409.3	-7.6
5.8	6.5	0.3	15.8	8.1	0.4	25.8	409.3	-7.6
6.0	6.5	0.3	16.0	8.2	0.4	26.0	409.3	-7.7
6.2	6.5	0.3	16.2	8.5	0.4	26.2	409.3	-7.7
6.4	6.5	0.3	16.4	8.6	0.4	26.4	409.3	-7.8
6.6	6.4	0.3	16.6	8.8	0.4	26.6	409.3	-7.9
6.8	6.5	0.3	16.8	8.9	0.4	26.8	409.3	-7.9
7.0	6.3	0.4	17.0	9.0	0.3	27.0	409.3	-8.0
7.2	6.4	0.3	17.2	9.1	0.3	27.2	409.3	-8.1
7.4	6.5	0.3	17.4	9.3	0.3	27.4	409.3	-8.2
7.6	6.5	0.3	17.6	9.5	0.3	27.6	409.3	-8.3
7.8	6.6	0.3	17.8	9.5	0.3	27.8	409.3	-8.5
8.0	6.6	0.2	18.0	9.5	0.3	28.0	409.3	-8.5
8.2	6.6	0.4	18.2	9.5	0.4	28.2	409.3	-8.7
8.4	6.7	0.3	18.4	9.8	0.3	28.4	409.3	-8.8
8.6	6.7	0.4	18.6	10.0	0.3	28.6	409.3	-8.9
8.8	6.8	0.4	18.8	10.3	0.3	28.8	409.3	-8.9
9.0	6.9	0.3	19.0	10.8	0.3			
9.2	6.9	0.3	19.2	11.3	0.3			
9.4	7.0	0.3	19.4	11.8	0.3			
9.6	7.0	0.3	19.6	12.6	0.3			
9.8	7.1	0.3	19.8	13.3	0.3			

Table A-8 Induction log from well WNW-118 run in the uphole direction, September 18, 1990.
[Depth in meters; conductivity in mS/m; inphase in ppt]

Depth	Cond	Inphase	Depth	Cond	Inphase	Depth	Cond	Inphase
0.0	408.3	461.6	10.0	5.2	0.6	20.0	7.3	0.7
0.2	-301.6	-385.0	10.2	5.3	0.6	20.2	7.3	0.4
0.4	131.2	-67.8	10.4	5.3	0.6	20.4	7.4	0.1
0.6	16.2	-4.6	10.6	5.2	0.6	20.6	7.4	-0.7
0.8	7.6	-0.4	10.8	5.3	0.8	20.8	7.4	-0.3
1.0	6.1	0.2	11.0	5.2	0.8	21.0	7.4	1.6
1.2	5.8	0.6	11.2	5.3	0.8	21.2	7.5	0.3
1.4	5.6	0.4	11.4	5.2	0.8	21.4	7.4	0.6
1.6	5.6	0.5	11.6	5.2	0.7	21.6	7.4	0.5
1.8	5.6	0.5	11.8	5.3	0.6	21.8	7.4	0.5
2.0	5.6	0.5	12.0	5.3	0.6	22.0	7.3	0.4
2.2	5.6	0.6	12.2	5.5	0.6	22.2	7.3	0.5
2.4	5.7	0.6	12.4	5.6	0.6	22.4	7.4	0.4
2.6	5.7	0.7	12.6	6.0	0.4	22.6	7.3	0.5
2.8	5.5	0.2	12.8	6.4	0.6	22.8	7.3	0.4
3.0	5.5	0.3	13.0	6.8	0.4	23.0	7.3	0.4
3.2	5.5	0.7	13.2	7.1	0.4	23.2	7.3	0.5
3.4	5.5	0.2	13.4	7.3	0.6	23.4	7.3	0.5
3.6	5.5	0.6	13.6	7.3	0.6	23.6	7.3	0.5
3.8	5.4	0.5	13.8	7.6	0.5	23.8	7.3	0.5
4.0	5.4	0.6	14.0	7.8	0.5	24.0	7.3	0.5
4.2	5.4	0.5	14.2	7.9	0.5	24.2	7.2	0.5
4.4	5.4	0.3	14.4	8.0	0.5	24.4	7.1	0.5
4.6	5.4	0.9	14.6	8.2	0.5	24.6	7.2	0.5
4.8	5.4	0.6	14.8	8.0	0.5	24.8	7.2	0.5
5.0	5.3	0.7	15.0	7.6	0.5	25.0	7.2	0.5
5.2	5.4	0.7	15.2	7.2	0.5	25.2	7.2	0.4
5.4	5.3	0.7	15.4	7.1	0.4	25.4	7.2	0.4
5.6	5.3	0.6	15.6	7.0	0.5	25.6	7.3	0.5
5.8	5.2	0.7	15.8	7.0	0.4	25.8	7.2	0.5
6.0	5.3	0.6	16.0	7.1	0.5	26.0	7.3	0.4
6.2	5.3	0.7	16.2	7.2	0.4	26.2	7.4	0.4
6.4	5.3	0.7	16.4	7.1	0.4	26.4	7.5	0.5
6.6	5.3	0.6	16.6	7.1	0.4	26.6	7.6	0.5
6.8	5.5	0.6	16.8	7.1	0.5	26.8	7.7	0.5
7.0	5.4	0.6	17.0	7.2	0.4	27.0	7.7	0.4
7.2	5.4	0.7	17.2	7.2	0.4	27.2	7.8	0.4
7.4	5.3	0.6	17.4	7.3	0.4	27.4	7.8	0.4
7.6	5.2	0.6	17.6	7.3	0.3	27.6	7.8	0.4
7.8	5.3	0.6	17.8	7.2	0.2	27.8	8.0	0.5
8.0	5.3	0.6	18.0	7.4	0.3	28.0	8.1	0.4
8.2	5.4	0.5	18.2	7.3	0.2	28.2	8.1	0.4
8.4	5.3	0.8	18.4	7.4	0.2	28.4	8.2	0.4
8.6	5.3	0.7	18.6	7.3	0.2	28.6	8.3	0.4
8.8	5.3	0.7	18.8	7.3	0.2	28.8	8.6	0.4
9.0	5.2	0.8	19.0	7.4	0.2	29.0	8.7	0.4
9.2	5.3	0.7	19.2	7.3	0.4	29.2	8.8	0.4
9.4	5.2	0.7	19.4	7.4	0.4	29.4	8.8	0.4
9.6	5.3	0.6	19.6	7.4	0.4	29.6	8.9	0.4
9.8	5.2	0.6	19.8	7.3	0.5	29.8	8.8	0.3

Table A-8 continued

Depth	Cond	Inphase
30.0	8.9	0.4
30.2	8.8	0.4
30.4	8.9	0.4
30.6	8.9	0.4
30.8	9.0	0.3
31.0	9.3	0.3
31.2	9.7	0.4
31.4	10.1	0.4
31.6	10.2	0.4
31.8	10.4	0.4
32.0	10.6	0.3
32.2	10.9	0.4
32.4	11.1	0.4
32.6	11.6	0.3
32.8	12.2	0.3
33.0	12.8	0.3
33.2	13.4	0.3
33.4	14.5	0.3
33.6	15.4	0.2
33.8	17.0	0.2
34.0	19.0	0.2
34.2	21.9	0.2
34.4	26.0	0.1
34.6	33.3	0.1
34.8	46.6	0.1
35.0	67.0	0.1
35.2	96.5	0.0
35.4	107.4	0.0

Table A-9 Induction log from well WNW-119 run in the uphole direction, September 18, 1990.
[Depth in meters; conductivity in mS/m; inphase in ppt]

Depth	Cond	Inphase	Depth	Cond	Inphase	Depth	Cond	Inphase
0.0	-119.0	-31.4	10.0	5.1	0.8	20.0	7.5	0.7
0.2	5.7	0.2	10.2	5.1	0.8	20.2	7.5	0.7
0.4	5.8	0.4	10.4	5.1	0.7	20.4	7.5	0.4
0.6	5.5	0.4	10.6	5.3	0.7	20.6	7.6	-4.2
0.8	5.5	0.5	10.8	5.0	0.7	20.8	7.6	-1.6
1.0	5.5	0.5	11.0	5.8	0.7	21.0	7.7	-2.0
1.2	5.3	0.5	11.2	5.1	0.6	21.2	7.8	0.8
1.4	5.2	0.5	11.4	5.3	0.7	21.4	7.7	0.5
1.6	5.2	0.5	11.6	5.2	0.7	21.6	7.7	0.7
1.8	5.2	0.5	11.8	5.2	0.8	21.8	7.7	0.5
2.0	5.1	0.4	12.0	5.3	0.8	22.0	7.6	0.5
2.2	5.1	0.5	12.2	5.2	0.7	22.2	7.6	0.4
2.4	5.1	0.5	12.4	5.4	0.6	22.4	7.6	0.5
2.6	5.2	0.5	12.6	5.6	0.5	22.6	7.7	0.4
2.8	5.2	0.5	12.8	6.1	0.5	22.8	7.6	0.3
3.0	5.3	0.5	13.0	6.5	0.5	23.0	7.7	0.4
3.2	5.2	0.6	13.2	6.9	0.4	23.2	7.6	0.5
3.4	5.2	0.1	13.4	7.1	0.5	23.4	7.5	0.5
3.6	5.3	0.4	13.6	7.3	0.5	23.6	7.5	0.5
3.8	5.0	0.4	13.8	7.4	0.6	23.8	7.4	0.5
4.0	5.2	0.6	14.0	7.5	0.4	24.0	7.5	0.5
4.2	5.2	0.5	14.2	7.6	0.5	24.2	7.4	0.5
4.4	5.1	0.5	14.4	7.6	0.5	24.4	7.4	0.5
4.6	5.1	0.8	14.6	7.5	0.6	24.6	7.3	0.5
4.8	5.2	0.5	14.8	7.3	0.6	24.8	7.5	0.5
5.0	5.1	0.6	15.0	7.2	0.6	25.0	7.5	0.5
5.2	5.1	0.6	15.2	7.1	0.5	25.2	7.3	0.5
5.4	5.1	0.6	15.4	7.1	0.5	25.4	7.4	0.4
5.6	5.0	0.6	15.6	7.2	0.6	25.6	7.3	0.5
5.8	5.2	0.6	15.8	7.3	0.5	25.8	7.5	0.5
6.0	5.1	0.5	16.0	7.1	0.5	26.0	7.3	0.4
6.2	5.2	0.5	16.2	7.2	0.4	26.2	7.4	0.4
6.4	5.1	0.5	16.4	7.2	0.4	26.4	7.4	0.5
6.6	5.2	0.6	16.6	7.3	0.4	26.6	7.5	0.4
6.8	5.1	0.5	16.8	7.3	0.4	26.8	7.6	0.5
7.0	5.1	0.6	17.0	7.4	0.3	27.0	7.6	0.5
7.2	5.1	0.5	17.2	7.5	0.2	27.2	7.7	0.5
7.4	5.2	0.6	17.4	7.7	0.2	27.4	7.8	0.5
7.6	5.0	0.6	17.6	7.7	0.2	27.6	7.9	0.4
7.8	5.0	0.7	17.8	7.7	0.2	27.8	8.0	0.4
8.0	5.1	0.7	18.0	7.8	0.3	28.0	8.0	0.4
8.2	5.1	0.8	18.2	7.8	0.3	28.2	8.1	0.4
8.4	5.1	0.8	18.4	7.9	0.2	28.4	8.3	0.4
8.6	5.1	0.7	18.6	7.9	0.2	28.6	8.3	0.4
8.8	5.1	0.7	18.8	7.9	0.3	28.8	8.5	0.4
9.0	5.0	0.8	19.0	7.7	0.5	29.0	8.6	0.5
9.2	5.2	0.7	19.2	7.6	0.4	29.2	8.7	0.5
9.4	5.2	0.6	19.4	7.6	0.6	29.4	9.0	0.4
9.6	5.1	0.8	19.6	7.5	0.5	29.6	9.1	0.3
9.8	5.2	0.8	19.8	7.4	0.4	29.8	9.1	0.3

Table A-9 continued

Depth	Cond	Inphase
30.0	9.3	0.4
30.2	9.2	0.4
30.4	9.1	0.4
30.6	9.2	0.4
30.8	9.2	0.3
31.0	9.2	0.2
31.2	9.4	0.4
31.4	9.6	0.4
31.6	10.3	0.4
31.8	10.8	0.4
32.0	11.0	0.3
32.2	11.0	0.4
32.4	11.0	0.4
32.6	11.2	0.4
32.8	11.4	0.3
33.0	12.0	0.3
33.2	12.4	0.3
33.4	13.2	0.3
33.6	14.3	0.3
33.8	15.2	0.3
34.0	16.7	0.2
34.2	18.4	0.1
34.4	21.0	0.2
34.6	24.7	0.2
34.8	30.9	0.1
35.0	42.1	0.1
35.2	61.3	0.1
35.4	90.1	0.0
35.6	131.5	0.0
35.8	177.5	0.0
36.0	240.2	-0.1
36.2	352.1	-0.1
36.4	412.0	-0.3
36.6	411.9	-3.6
36.8	411.9	-4.6
37.0	411.9	-5.4
37.2	411.9	-5.9
37.4	411.8	-6.4