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REPORT ON

GROUNDWATER GEOPHYSICAL SURVEY

CHEFORNAK, ALASKA

Submitted to:

CHEFORNAK TRADITONAL COUNCIL

c/o Village Safe Water
555 Cordova Street, 4th floor
Anchorage, Alaska 99501

Submitted by:

Golder Associates Inc.
1750 Abbott Road, Suite 200
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May 21, 2004 Job No. 033-5636.000

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Golder Associates

May 21, 2004

Our Ref.: 033-5636

Chefornak Traditional Council
c/o Village Safe Water
555 Cordova Street, 4th Floor
Anchorage, AK 99501

Attention: Mr. Nathan Cornilles, Village Safe Water Engineer

**RE: REPORT ON GROUNDWATER GEOPHYSICAL SURVEY
CHEFORNAK, ALASKA**

Dear Mr. Cornilles:

Golder Associates is pleased to present this Groundwater Geophysical Survey Report for the City of Chefornak, Alaska.

We appreciated the opportunity to work on this project. If you have questions regarding this report, please contact me at 907-344-6001.

Sincerely,

GOLDER ASSOCIATES INC.

Robert G. Dugan, C.P.G.
Principal Engineering Geologist

RGD/ljd

D/F: Chefornak Grndwtr Survey Cover ltr.doc

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1.0 INTRODUCTION

The City of Chefornak (population approximately 440) is currently conducting a water source investigation to obtain a groundwater source adequate to meet the demand of the community. The current water supply is a surface water intake. Previous attempts to obtain additional groundwater supply were largely unsuccessful because of intrusion of saline water into the wells. The village is located adjacent to the floodplain of the Kinia River and is underlain by permafrost.

In an effort to identify favorable groundwater conditions in the areas south of the village, Golder Associates conducted a geophysical survey using the Time Domain Electromagnetic (TDEM) method. The field work was conducted during March 14-19, 2004.

1.1 Objective and Scope

The objective of the study was conduct geophysical soundings to determine the depth to the bottom of permafrost and the depth of the fresh/saline water interface. The geophysical survey was intended to identify potentially favorable areas for groundwater development and to provide information that would guide the next phase of development or exploration.

The scope of work included a field survey of TDEM soundings along two transects extending south of the village and an evaluation of that data to provide guidance for future investigations.

1.2 Geologic Setting and Site History

The village of Chefornak is located on the Yukon-Kuskokwim delta in southwest Alaska. The village is situated on the banks of the Kinia River, near its outlet to the Bering Sea. The river is tidally influenced and brackish. The terrain has less than 100 feet of topographic relief within 4 miles of the village, however Tern Mountain, located 5.5 miles due south of the village, reaches an elevation of 443 feet. A site map is provided in Figure 1.

The region is underlain primarily by deltaic sediments composed primarily of silt, clay and fine sand. Volcanic rocks, likely originating from Tern Mountain, are also present in the stratigraphic column at relatively shallow depth (Beikman, 1974). Wells drilled in the village in 1995 have encountered permafrost from near the surface to a depth of approximately 80 feet (Terrasat, 1997). Wells drilled south of the village in 2002 encountered permafrost to approximately 250 feet. The generalized stratigraphy based on the well logs consists of 5 to 10 feet of frozen silt and sand at the surface, underlain by 5 to 15 feet of frozen basalt. Below the basalt, frozen silt and sand is encountered. The wells in the village encountered 10 to 25 feet of thawed fine sand at about 80 feet. This was underlain by thawed silt to the total depth of the well. The wells at the south end of town encountered 15 to 20 feet of thawed sand at a depth of about 245 feet. Heaving conditions were noted in the well log in the sand.

2.0 METHODOLOGY AND INSTRUMENTATION

2.1 Time Domain Method

The geophysical investigation was performed with a Zonge time domain electromagnetic system (TDEM). TDEM is a geophysical method for mapping the thickness of permafrost, geologic or stratigraphic units and depth to groundwater based on changes in electrical characteristics of materials. The TDEM system consists of a square transmitter loop (typically insulated copper wire 60 to 1500 feet on a side) laid on the ground surface and connected to a regulated current source. The receiver is a smaller multiple-turn coil in the center of the transmitter loop or borehole tool, or a loop coincident with the transmitter loop. A current is run through the transmitter loop and cycled on and off as a square waveform of alternating polarity. The cycling of the transmitter current creates a time-varying primary field that induces eddy currents into the subsurface. These eddy currents create a secondary magnetic field that is measured by the receiver at the ground surface. As the eddy currents decay into the subsurface, they are increasingly influenced by the electrical properties of deeper layers. A series of average potential values for specific time intervals or gates are recorded during the transmitter off cycle. These measurements are used to create a decay curve of normalized voltage versus time. This decay curve is analyzed using modeling techniques to develop a layered model of subsurface geoelectric properties.

The maximum depth of exploration depends on the conductivity of the subsurface, the transmitter loop size, available power from the transmitter, and ambient noise levels. As a general rule, the maximum effective depth of exploration is between one and three times the transmitter loop diameter. The minimum resolution depth is a function of ramp time (the time required to bring the current in the transmitter loop to zero) and the resistivity of the near surface material. The ability to resolve a given layer is dependent on it having sufficient thickness and electrical contrast with the surrounding materials to create an inflection in the decay curve. As the electrical contrast between layers increases, thinner layers can be detected. As a general rule, the vertical resolution is about one-fourth the transmitter loop size and is best at shallow depth and decreases with increasing depth. To increase resolution at depth, a borehole receiver may be used in the profile mode to detect small changes in subsurface geology.

2.2 Field Procedures

A Zonge Engineering GDP-16 receiver, Zero-TEM transmitter and TEM-3 receiver coil were used for this survey. The transmitter loop wires were laid out in a square that was 328 feet by 328 feet. A three staged square wave current was applied to the loop to generate the eddy currents in the ground. Data, gathered for each decay of the eddy current signal (neutral point of the square wave), were used to produce a sounding. The sounding was stacked (summed) 256 times to remove the effects of random noise. In addition, each sounding was recorded three times to assure repeatability of the results. An on-screen display of standard errors was monitored during acquisition to assess the quality of the data being collected. At the completion of each sounding the decay curve was displayed to insure that an adequate level of data quality was being obtained. The data were stored digitally in the instrument for later analysis.

The TDEM data were downloaded to a portable computer and imported into TEMIX-Z Version 4.0 software produced by Interpex Limited. The TDEM data were interpreted using an inversion modeling approach. A resistivity model was developed using borehole geologic information from Well #2.

3.0 RESULTS

A total of thirty soundings were made for this study: One sounding at Well #2; fifteen soundings along Transect 1 (Loops 1 through 15 as shown on Figures 2 and 3); thirteen soundings along Transect 2 (Loops 18 through 30 as shown in Figure 4); and one sounding on the river near the camp (Figure 31). The loop number and station number are shown in Table 1.

A TDEM sounding was conducted near Well #2 to provide some calibration of the TDEM response. Well #2 was drilled to a total depth of 302 feet in August 2002. The well log shows frozen dark silt and clay to a depth of 220 feet. Between 220 and 302 feet, there is predominantly fine sand with a seam of water between 255 and 272 feet. The well was completed between 255 and 275 feet with a screen of unknown slot-size. Well #2 was pump tested at 68 gpm for 48 hours with 15 feet of drawdown.

The following summarizes the interpretation of the TDEM soundings along each of the two transects.

Transect 1 (Loops at Well #2 and 1 through 15)

- A thick highly resistive unit (approximately 4000 ohm-meters) extends from the ground surface to a depth that ranges from 275 to 560 feet. The thickness of this unit generally increases from the Well #2 towards Tern Mountain or from Loop 1 to Loop 15. At Well #2, this unit corresponds to both the frozen and thawed materials encountered at that well. The TDEM response was not able to differentiate between frozen and thawed conditions.
- Below the upper unit, the resistivity decreases to a very low value (generally less than 3 ohm-meters) and then increases to 10 ohm-meters. The low resistivity zone ranges in thickness from 20 to 60 meters and is interpreted to be saline material. However, there is no confirming well data to validate this interpretation.

Transects 2 (Loops 16 through 28)

- On this transect the highly resistive unit (4000 ohm-meters) extends to a depth of 260 to 300 feet. The thickness of this unit is much more uniform compared to Transect 1.
- In the vicinity of Loops 23 and 24, a low resistivity layer (10 ohm-meters) ranging in thickness from 5 to 30 feet is located slightly below the ground surface but within the upper unit.
- A similar low resistivity zone (less than 1 to 5 ohm-meters) ranging in thickness from 20 to 80 meters is found beneath the resistive layer.

The results indicate that there is a fairly uniform TDEM response throughout the survey area. The results are broadly consistent with the stratigraphy observed at Well #2, but the TDEM is not able to differentiate between frozen and thawed materials at depths of 250 feet as observed at Well #2. The survey does appear to define the depth to saline materials at all survey locations, at depths ranging from 300 to 500 feet below ground surface.

4.0 HYDROGEOLOGIC ASSESSMENT

Previous hydrogeologic assessment by Terrasat identified shallow thaw zones at depths of less than 100 feet. A complete version of this report (with figures and tables) was not available for our review, but the text of the report indicates that, when pumped, these zones produced fresh water initially, but then became increasingly saline. This was interpreted to be influx of brackish water from the Kinia River.

Deeper wells installed in 2002 at the south end of the village encountered deeper thaw zones at depths of about 240 feet. When pumped, these zones also produced fresh water initially but became saline (CE2 Engineers, 2002). The well log for Well #2 shows frozen dark silt and clay to a depth of 220 feet. Between 220 and 302 feet, there is predominantly fine sand with a seam of water between 255 and 272 feet. The well was completed between 255 and 275 feet with a screen of unknown slot-size. Well #2 was pump tested at 68 gpm for 48 hours with 15 feet of drawdown.

4.1 TDEM Response

The TDEM sounding near Well #2 produced a uniform resistivity of about 4,000 ohm-meters to a depth of about 310 feet (elevation -280 feet below sea level). The TDEM sounding was not able to resolve the difference between the frozen silt and the unfrozen sand at 220 feet. It was also not able to resolve the basalt layer reported between 16 and 55 feet. The observed resistivity represents the combined response of the materials to a depth of 310 feet. A uniform resistivity of less than 2 ohm-meters was observed below 310 feet (-270 feet elevation). Well #2 was not drilled deep enough to confirm the depth or composition of the low resistivity layer. It is likely however, that this material is saline, clay rich, or both, and does not represent a good water supply target.

From the TDEM cross-sections, the deepest section of high resistivity material is found between Loops 4 and 8 on Transect 1. The depth to saline water is the deepest in this region. This area has the highest likelihood of encountering a suitable water supply, based on the combination of thick sediment and a resistivity similar to or higher than the observed resistivity at Well #2.

Although the TDEM was not able to definitively resolve thawed versus frozen materials, the upper layer does represent a potential target for water supply because an aquifer has previously been developed in this material at Well #2. However, drilling between Loops 5 and 8 will be necessary to determine whether groundwater is available at these locations.

4.2 Hydrogeologic Conceptual Model

Based on well logs and TDEM soundings, a conceptual hydrogeologic schematic cross-section was developed (Figure 5) to show the possible relationships between the permafrost, thawed saturated materials, and saline zone. The schematic focuses on the deeper thawed zone encountered at Well #2. The influx of shallow brackish water into the shallower wells in the village appears to be well documented. Because fresh water is less dense than saline water, it tends to "float" on saline water and a wedge-shaped interface develops between the fresh and saline waters. As the thickness of fresh water increases, the depth to the saline water increases (the fresh water "pushes" the saline water down because of its weight). Theoretically, every foot of fresh water is potentially capable of depressing the saline interface by 40 feet. By the same token, every foot of drawdown in a well is potentially capable of causing the saline interface to rise by 40 feet. This is shown schematically on Figure 6, where saline water "upcones" into the well screen. Well #2 may also be drawing brackish water horizontally from the saline interface, based on its relative proximity to the Kinia River. The drawdown observed in Well #3 during pumping at 65 gpm was about 20 feet, which could cause the saline interface to "upcone". Actual conditions vary significantly because of other factors, but saline intrusion occurs because of the basic density relationship between fresh and saline water.

Based on the TDEM soundings, the depth to the saline interface appears to deepen to a maximum of 500 feet about 3 miles south of the village (between Loops 4 and 8). The elevation of the low resistivity layer does show a channel-like trend on Transect 1, deepening from an elevation of -275 [310] feet at Sounding #2 to an elevation of -540 at Sounding #8. Between Loop 8 and 9 the depth rises to an elevation of about -425 feet and then drops again back to –540 feet. A similar response is not observed on Transect 2, and the elevation of the low resistivity layer is relatively constant at about -275 feet.

The thicker sections of the upper resistive layer represent the best target for ground water supply because:

1. There is a higher probability of encountering suitable sandy thawed zones above the saline interface;
2. Thawed zones could potentially be completed at distances sufficiently distant from the brackish wedge along the Kinia River;
3. Thawed zones could potentially be completed at depths sufficiently above the saline interface to prevent upconing.

Figure 5 shows the presence of recharge entering along the upland areas at Tern Mountain. This has not been confirmed with any field investigation. If suitable groundwater supply is identified between Loops 4 and 8, it will be important to determine whether there is recharge entering the aquifer. If not, over the long-term, groundwater levels will slowly decline to the point where saline upconing could occur to shallow depths. If there is recharge, then a sustainable groundwater supply is possible, and saline intrusion can be effectively managed.

There is insufficient information on static water-levels and seasonal water-level response in Well #2 to provide further details on possible hydrogeologic conditions in the deeper sediments in this areas. We recommend further analysis of existing water-level data (if available) and further testing and monitoring of water-levels in Well #2. This will enable a better assessment of aquifer properties, hydraulic boundaries (including tidal influences), and optimum well yields that could be achieved without causing saline intrusion. It may be possible to use one or more of the existing wells with a more controlled operation and monitoring program.

4.3 Proposed Drilling and Testing Program

Based on the TDEM survey, there appears to be sufficient evidence to warrant further exploration for a deep aquifer along Transect 1, between Loop 4 and Loop 8. In addition to further monitoring of Well #2, we recommend that a test well be installed at Loop 7. A maximum total depth of 500 feet is recommended. If a suitable thickness of aquifer material (at least 20 feet) are encountered below the permafrost (estimated at 250 feet), the drilling could stop at a shallower depth. The well should be logged by a qualified hydrogeologist and drill cuttings collected at 5-foot intervals. Water-levels and field water quality parameters (temperature, conductivity and pH) should be monitored when water is encountered during drilling.

If favorable aquifer material is encountered, the well should be completed with a well screen (similar to Well #2). Previous well screens were 0.10 slot. If possible, we recommend conducting sieve analysis to design the well screen. It is possible that the fine slot-size is contributing to well inefficiency, which would tend to cause higher drawdowns in the well. Testing of the well should include a step drawdown test to determine well efficiency, and a long-term constant rate test of at least 72 hours. The pumping rate and duration should be determined after evaluating the drill log and step drawdown test. Monitoring of the pumping well and Well #2 is recommended. Monitoring of field water quality parameters, particularly specific conductance, should occur throughout all testing. A complete water quality analysis should be conducted on samples collected mid-way and at the end of the test. This analysis should include all anions and cations to allow for geochemical typing and an ion balance of the water. Hydraulic analysis of the test should include an assessment of hydraulic boundary conditions, in addition to aquifer properties.

We also recommend that a complete round of water-level measurements be collected in all accessible wells to determine general groundwater flow conditions and hydraulic gradients. A survey of wellhead elevations is also recommended to accurately determine groundwater elevations.

5.0 LIMITATIONS

Golder services were conducted in a manner consistent with the level of care and skill ordinarily exercised by other members of the geophysical community currently practicing under similar conditions subject to the time limits and financial and physical constraints applicable to the services. Time domain electromagnetic (TDEM) method is remote sensing geophysical methods that may not detect all subsurface strata or contacts because of lack of electrical contrast or limited vertical resolution. Furthermore, the interpretation of electromagnetic soundings is based on modeling which often does not have a unique solution without the use of constraints or controls such as wells or other geophysical data.

6.0 CLOSING

We trust the information presented in this report meets your current requirements. Should you have any questions, or concerns, please do not hesitate to contact Robert Dugan at 907-344-6001.

GOLDER ASSOCIATES INC.

Robert G. Dugan, C.P.G.
Principal Engineering Geologist

John Liu, PhD
Project Geophysicist

RGD/ljd

7.0 REFERENCES

Beikman, Helen M., 1974, Preliminary Geologic Map of Southwest Quadrant of Alaska, U.S. Geological Survey Map MF-611.

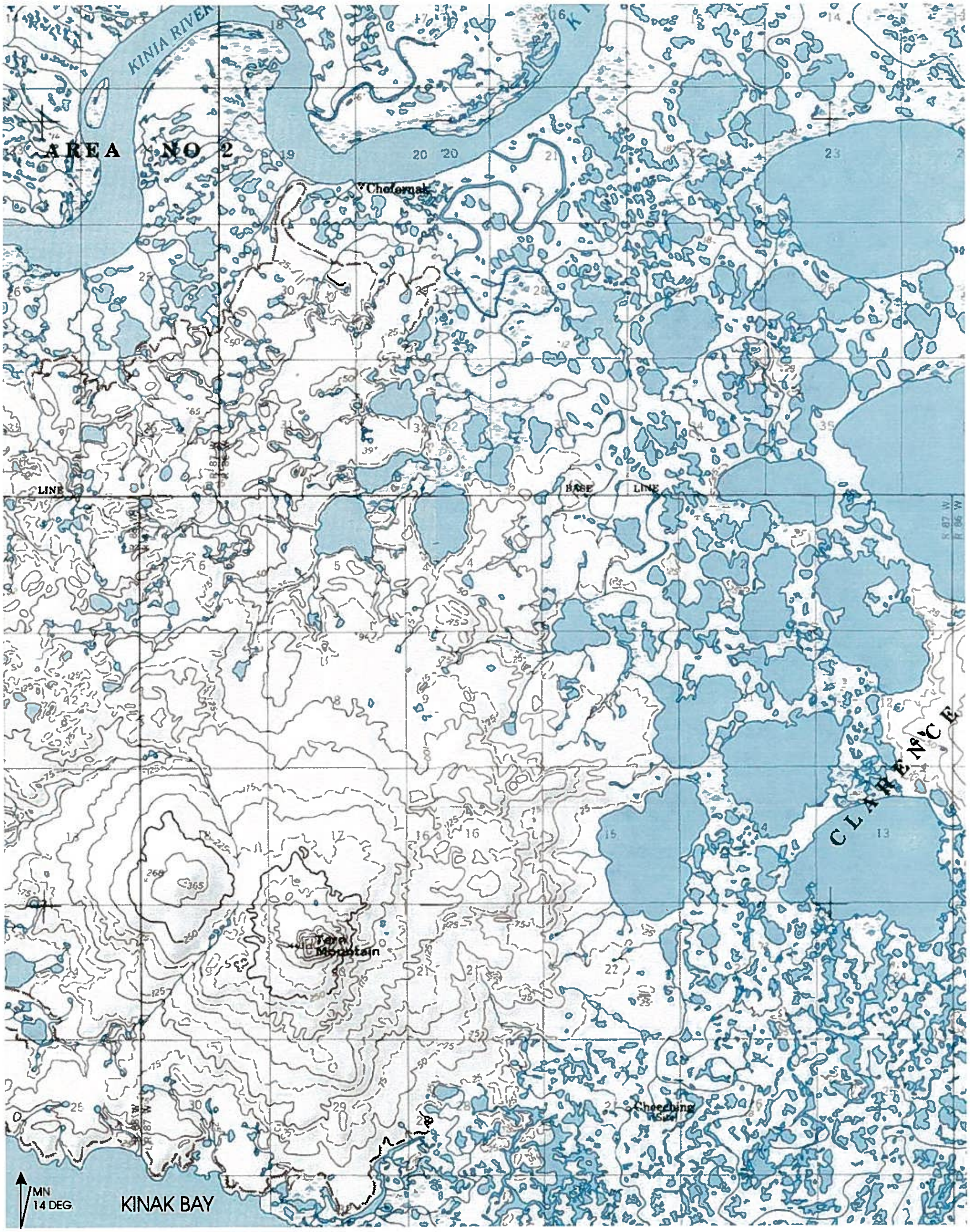
CE2 Engineers, 2002, Drilling Logs and Pump Test Data for Wells 1, 2, and 3, provided by Village Safe Water.

Terrasat, Inc, 1997, Ground Water Exploration Report for Chefornak, Alaska, prepared for Alaska Department of Environmental Conservation Village Safe Water.

TABLE 1

TDEM SOUNDING STATIONS

Sounding No.	Station No. (ft)	Elevation (ft)
Section 1		
WELL2	0	35
LOOP1	1177	24.41
LOOP2	2752	28.11
LOOP3	5000	43.43
LOOP4	6583	40.73
LOOP5	8584	34.64
LOOP6	9814	47.5
LOOP7	11681	36.8
LOOP8	13751	31.6
LOOP9	15471	60.3
LOOP10	16325	73.6
LOOP11	17998	69.31
LOOP12	20517	142.94
LOOP13	22353	183.69
LOOP14	24000	222.67
LOOP15	26536	311.15
Section 2		
LOOP16	1990	34.8
LOOP17	3651	42.9
LOOP18	6204	12.2
LOOP19	8201	15.84
LOOP20	10409	15.3
LOOP21	12337	17.8
LOOP22	14046	16.8
LOOP23	16387	17.6
LOOP24	18908	17
LOOP25	21260	19.1
LOOP26	29577	49.2
LOOP27	16787	17
LOOP28	15987	17



0 1 2 MILES
SCALE

Figure 0

VICINITY MAP
CHEFORNAK

REFERENCE: TOPO! Copyright 2003 National Geographic (www.nationalgeographic.com/topo)
U.S.G.S. TOPOGRAPHIC MAP, CHEFORNAK, ALASKA.

CHEFORNAK/ GEOPHYSICAL STUDY / AK

PROJECT NO.: 033-5636 FILE: FIG1 VICINMAP.CDR DATE: 5/19/04 DRAWN: ACM

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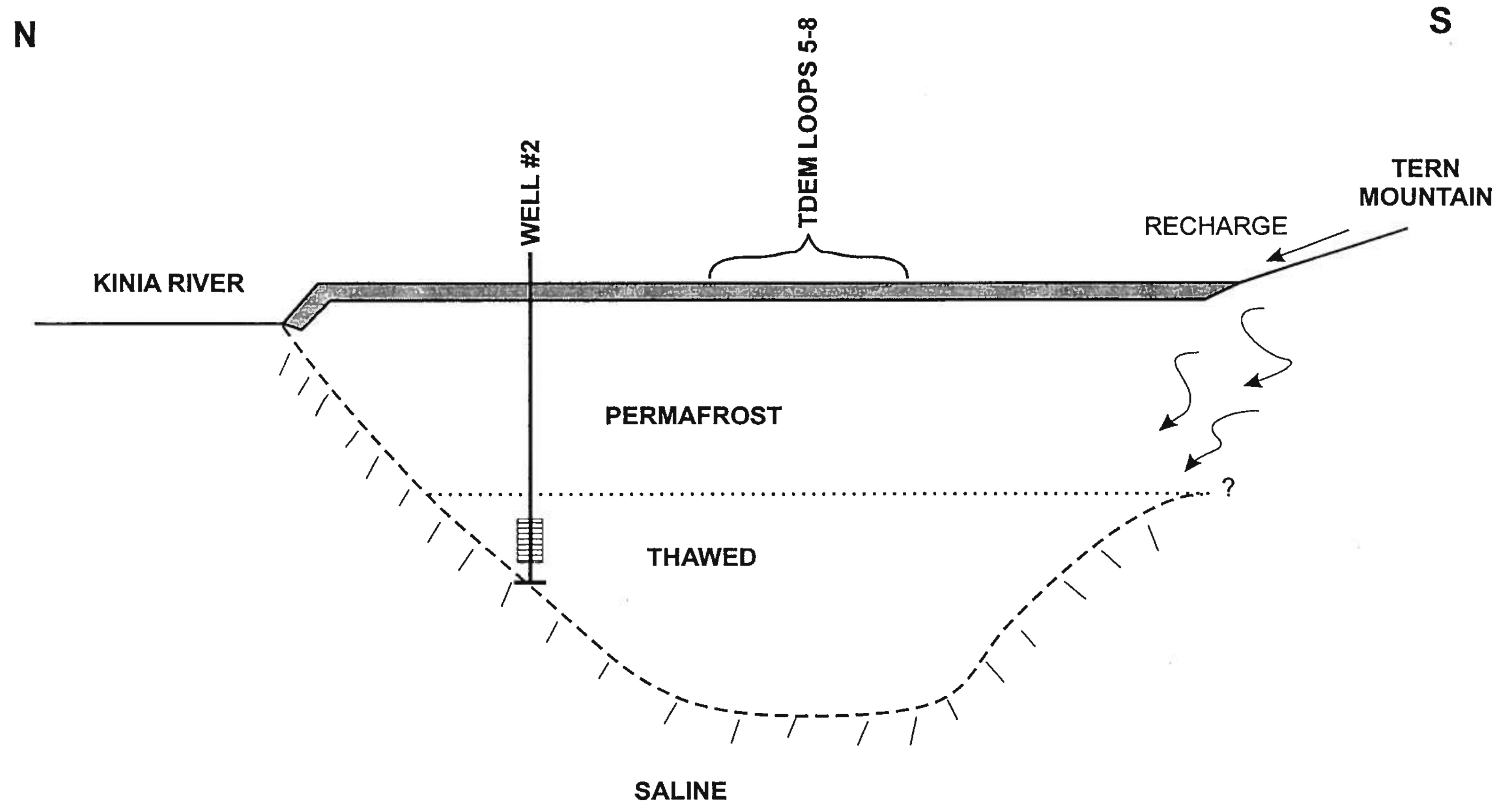

NOT TO SCALE

Figure 5

CONCEPTUAL HYDROGEOLOGIC CROSS-SECTION

VILLAGE SAFE WATER / CHEFORNAK GEOPHYSICAL SURVEY / AK

PROJECT NO.: 033-5636 FILE: FIG5_XSECTION.CDR DATE: 5/21/04 DRAWN: CAV RD

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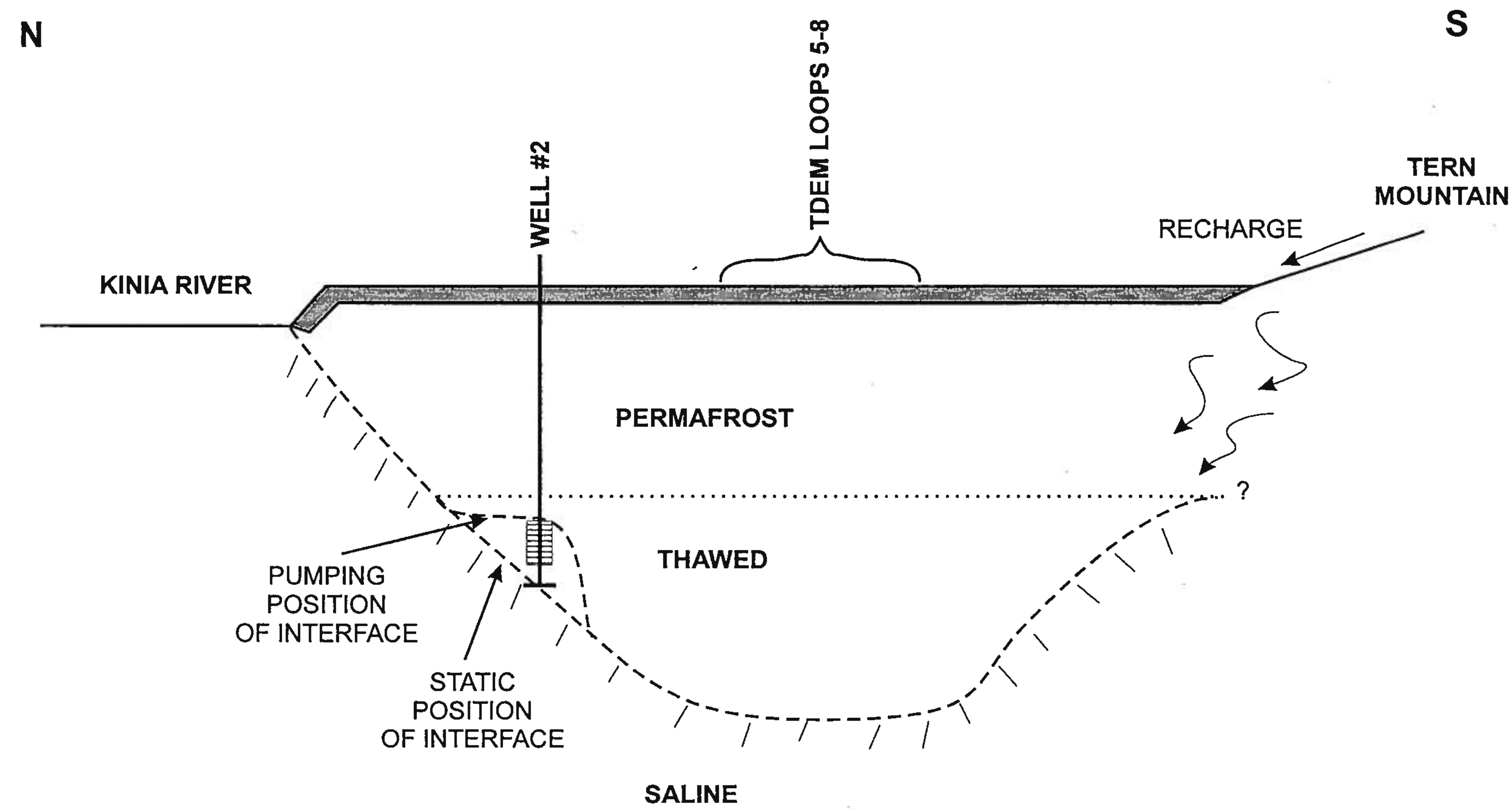

NOT TO SCALE

Figure 6

CONCEPTUAL MIGRATION OF SALINE INTERFACE DURING PUMPING CROSS-SECTION

VILLAGE SAFE WATER / CHEFORNAK GEOPHYSICAL SURVEY / AK

PROJECT NO.: 033-5636 FILE: FIG6_XSECTION.CDR DATE: 5/21/04 DRAWN: CAV

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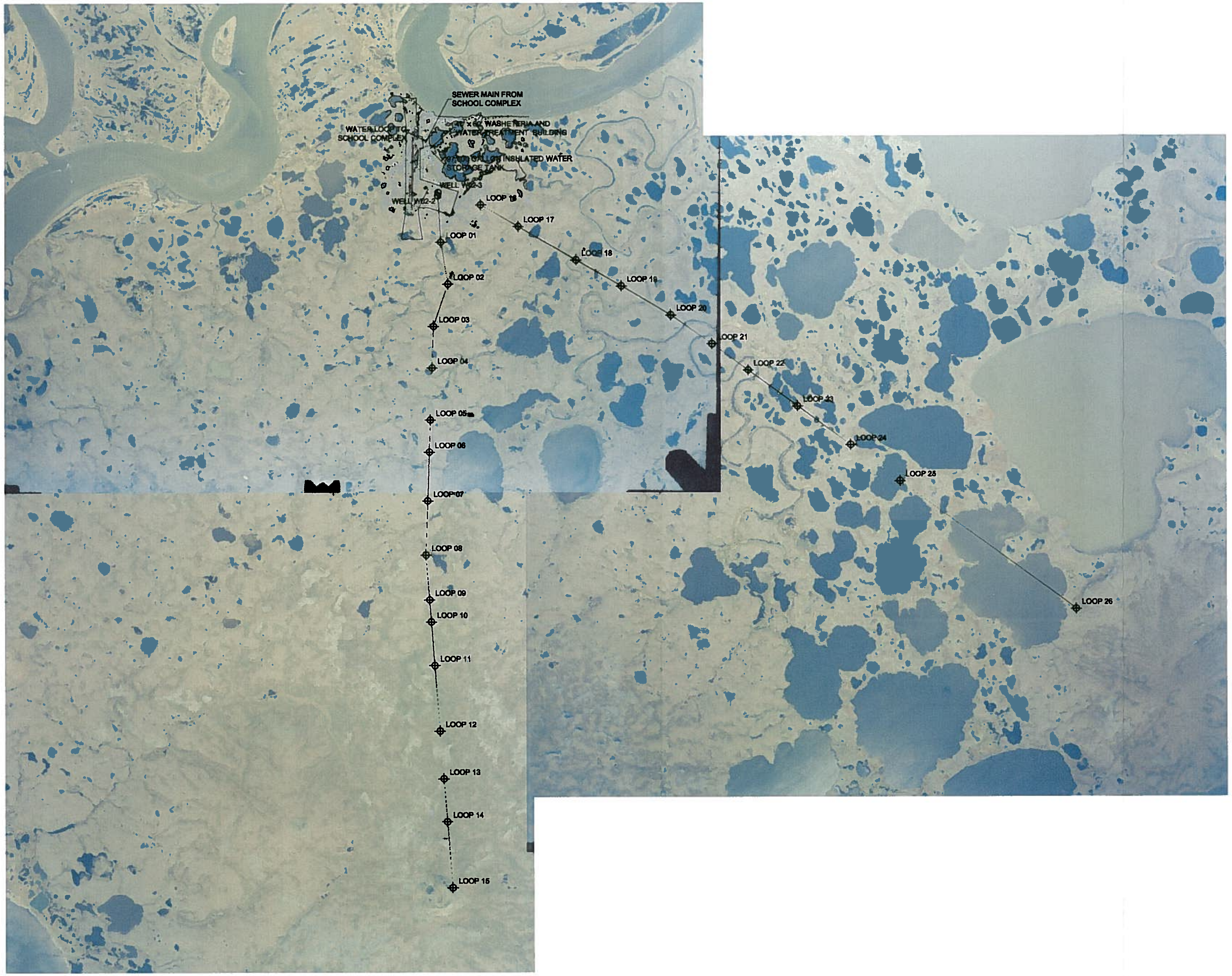

LEGEND

LOOP 13 — SOUNDING LOCATION

0 — 1500 — 3000
SCALE IN FEET

N

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KEY MAP

LEGEND

INSTRUMENTATION

- ZONGE GDP-16 RECEIVER
- ZONGE ZERO TEM TRANSMITTER
- ZONGE TEM-3 RECEIVER COIL

GEODETIC PARAMETERS

DATUM: LOCAL GRID
SPHEROID: LOCAL GRID
PROJECTION: LOCAL GRID

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SUBMITTED TO:

VILLAGE SAFE WATER DEPT. OF ENVIROMENTAL CONVERSATION STATE OF ALASKA

PROJECT:

Chefomak/Geophysical Study/AK

TITLE:

TDEM SOUNDING LOCATIONS

REV	DATE	REVISION DESCRIPTION	SIGNED
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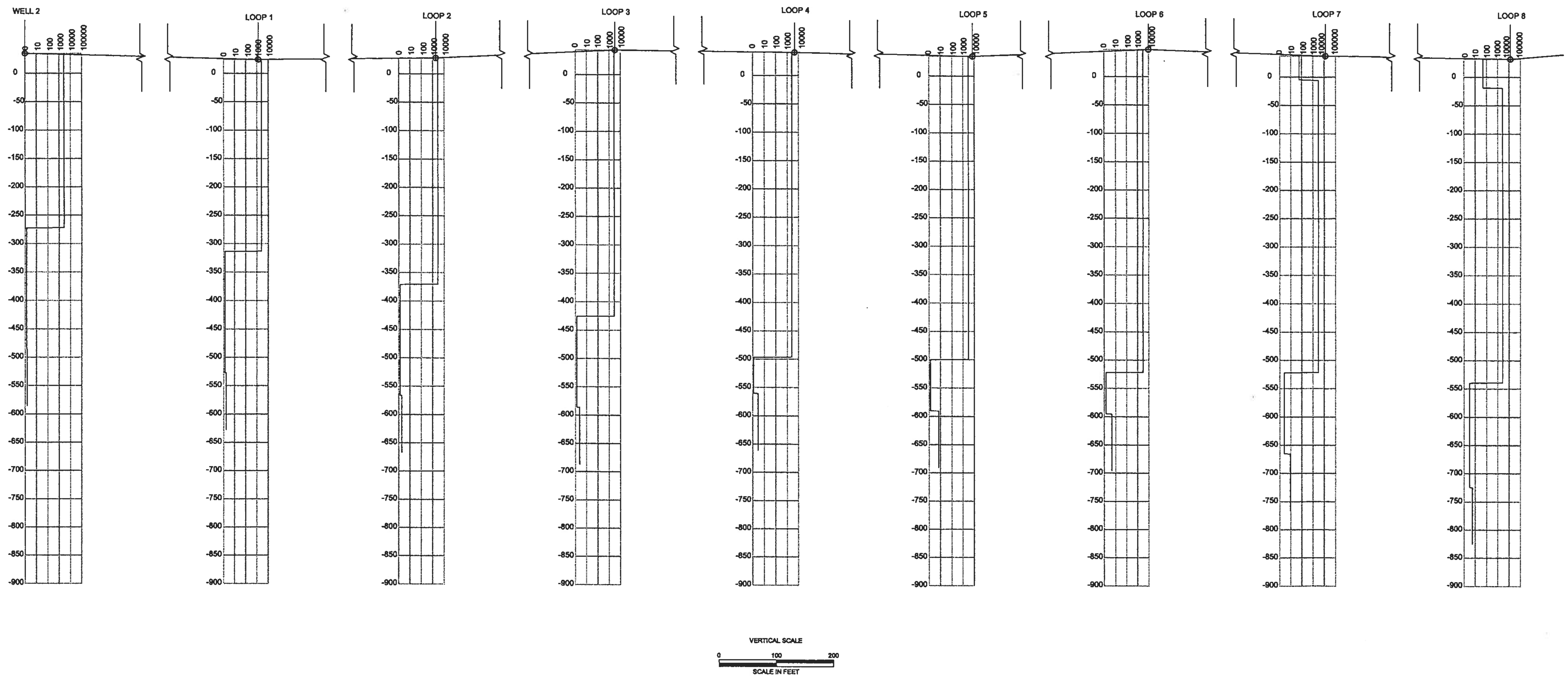
FIGURE 1



KEY MAP

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INSTRUMENTATION

- ZONGE GDP-16 RECEIVER
- ZONGE ZERO TEM TRANSMITTER
- ZONGE TEM-3 RECEIVER COIL

GEODETIC PARAMETERS

DATUM: LOCAL GRID
SPHEROID: LOCAL GRID
PROJECTION: LOCAL GRID

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SUBMITTED TO:

VILLAGE SAFE WATER DEPT. OF ENVIROMENTAL CONVERSATION STATE OF ALASKA

PROJECT:

CHEFORNAK/GEOPHYSICAL STUDY/AK

TITLE:

TDEM SOUNDINGS ON TANSECT 1

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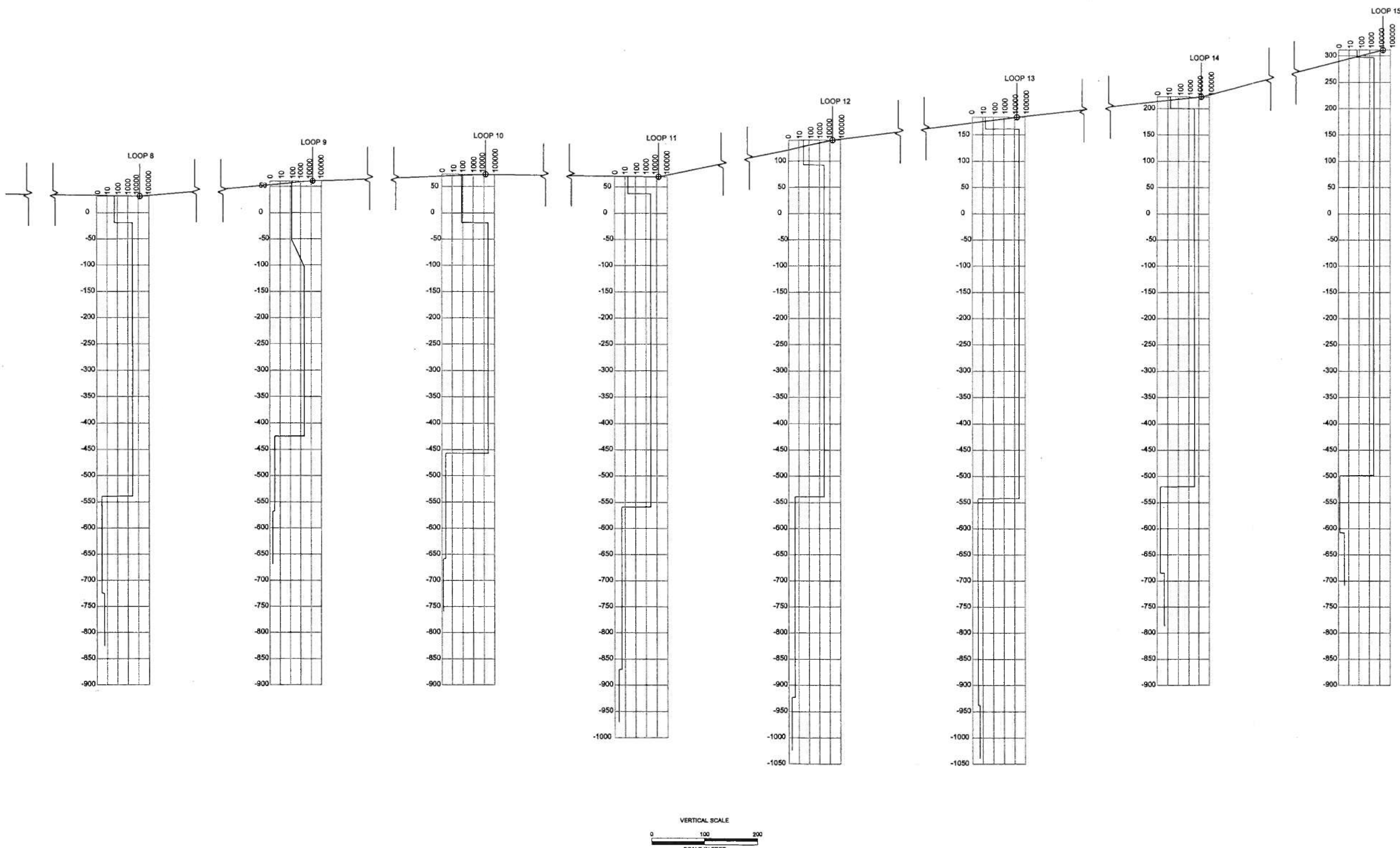
FIGURE 2



KEY MAP

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- ZONGE GDP-16 RECEIVER
- ZONGE ZERO TEM TRANSMITTER
- ZONGE TEM-3 RECEIVER COIL

GEODETIC PARAMETERS

DATUM: LOCAL GRID
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FIGURE 3

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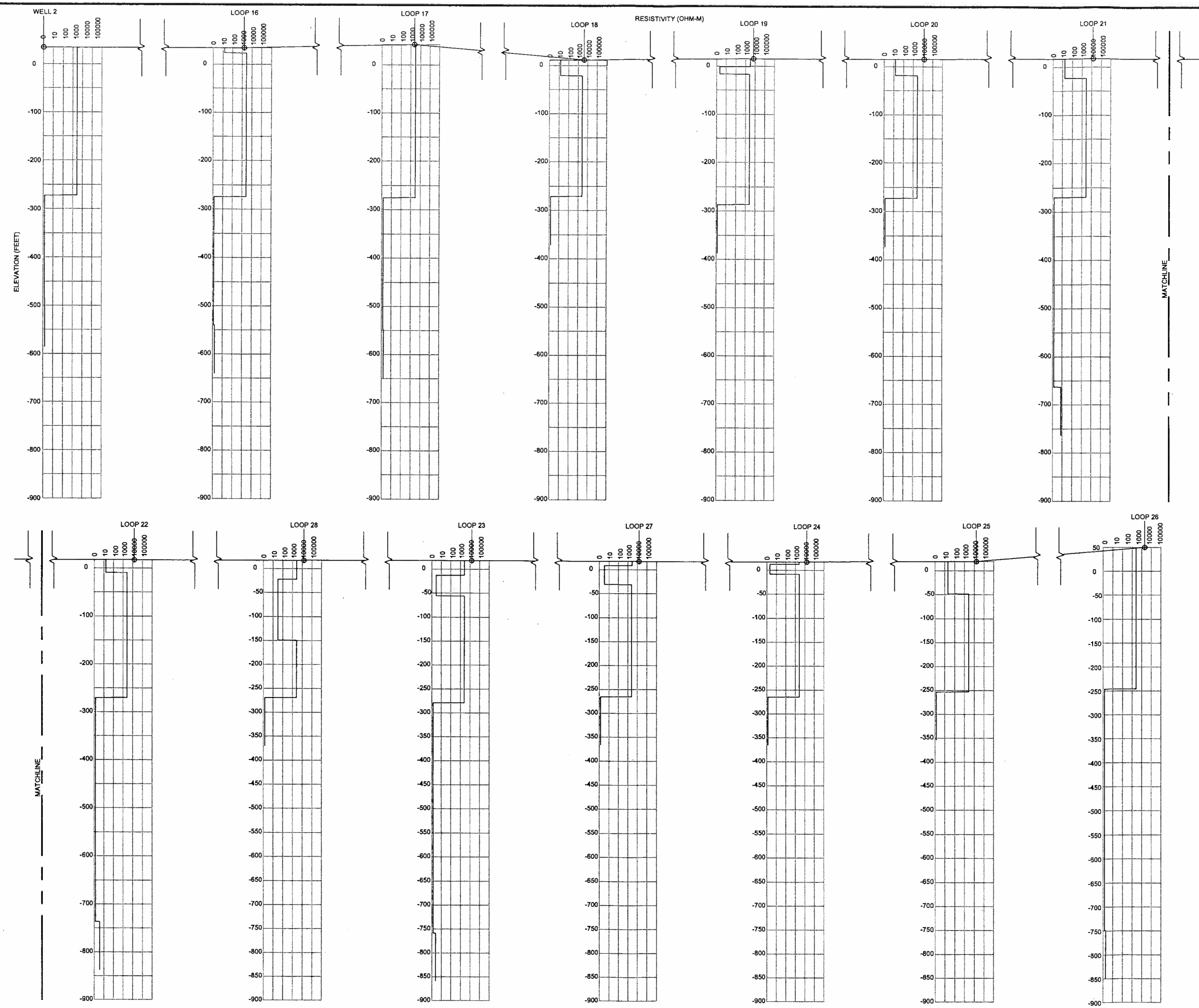

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KEY MAP

LEGEND

VERTICAL SCALE

0 100 200

SCALE IN FEET

INSTRUMENTATION

- ZONGE GDP-16 RECEIVER
- ZONGE ZERO TEM TRANSMITTER
- ZONGE TEM-3 RECEIVER COIL

GEODETIC PARAMETERS

DATUM: LOCAL GRID
SPHEROID: LOCAL GRID
PROJECTION: LOCAL GRID

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TITLE:

TDEM SOUNDINGS ON TANSECT 2

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FIGURE 4