DESERT RESEARCH INSTITUTE
UNIVERSITY OF NEVADA SYSTEM

LETTER REPORT:

Fish Springs Survey Results – 1990

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WATER RESOURCES CENTER

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SCOPE

The Desert Research Institute (DRI) and the Washoe County Department of Public Works entered into an agreement whereby DRI would conduct an additional geophysical survey in the Fish Springs Ranch area (Plate 1). The purpose of the survey was to identify unfavorable areas for locating groundwater supply wells and to provide additional information. The underlying concept was that the supply wells in an alluvial environment would be more productive if located away from fault structures with associated clay and gouge material that would decrease the local permeability.

Although faults have been identified on published USGS maps in the Virginia Mountains bordering the south edge of the study area, it is difficult to extrapolate these features and know their range of influence in the alluvial area of interest. Faulting is likely to increase the weathering of local volcanic rocks to clays as well as create fine gouge material that will decrease the porosity and permeability of the subsurface. These conditions would create a poor environment for a production well. Because clays have a high cation exchange capacity, their occurrence may be detected by a decrease in the electrical resistivity. In addition, faulting may result in rapid lateral changes in subsurface electrical properties.

An important consideration of any production well is water quality. The alluvial area of interest is adjacent to a playa where evaporative conditions are known to have created saline waters in the subsurface. Because the pore fluid is the primary conductor of electrical current in most geologic formations, high salinity fluids may be detected by low formation resistivities. It is important to locate production wells away from areas of poor water quality to insure that pumping induced gradients do not draw poor quality water into the well field.

To address the concerns regarding fault zones and water quality, it was considered worthwhile to conduct a geophysical survey to investigate the lateral change in electrical resistivity as a function of depth. This information would identify the location of faults and their range of influence which were not visible on the surface, and may yield insights regarding water quality.

THE TRANSIENT ELECTROMAGNETIC METHOD (TEM)

The geophysical method that was chosen for the study was the Transient Electromagnetic Method (TEM). This method is sensitive to the electrical resistivity of the earth as a function of depth at a given location. By conducting measurements along a survey line, an approximation to a cross section of the electrical resistivity of the earth can be developed.

The method utilizes a transmitter loop (Figure 1), which in this survey was 50 x 50 meters, to introduce an electromagnetic signal into the earth. The current in the loop is controlled by a transmitter which produces a square wave with a very fast (3 microseconds) turn-off time (Figure 2). This produces a transient magnetic field of which the time derivative of the vertical component is detected by a smaller receiver coil located in the center of the transmitter loop. Because of the influence of the earth in the vicinity of the transmitter loop, the magnetic field does not turn off as fast as the current in the transmitter loop. This results in a magnetic field transient (Figure 2), the shape of which is controlled by the electrical resistivity of the material near the transmitter loop. Several thousands of these transients are averaged at each station and recorded by the receiver. As the transient decays, it eventually becomes too weak to be measured accurately; hence, a threshold level is defined below which the transient is not considered accurate. The exact time at which this threshold is reached is a function of the equipment, geology, and stray electromagnetic signals at the time of the measurement.

The transient is used to calculate an apparent resistivity versus time curve. The apparent resistivity at a given time on the transient can be thought of as the resistivity that the earth would have if: 1) the earth was uniform under the site; and 2) it produced the same transient as observed in the field. In a general sense, the depth of investigation increases with increasing time after the start of the transient. Hence, apparent resistivities at greater times are representative of greater depths, whereas apparent resistivities at shorter times are representative of shallower depths. The apparent resistivity differs from resistivity in that it is not an intrinsic property of a homogeneous material, but is a weighted average of the resistivity of a configuration of geologic units.

The resistivity of a clay free, saturated, granular formation can be estimated with Archie's law:

$$\sigma_{fm} = (\sigma_{pf}\ \theta^{m})/a$$

where

σ_{pf} = electrical conductivity of the pore fluid
σ_{fm} = electrical conductivity of the formation
θ = porosity
m = cementation exponent
a = tortuosity

In unconsolidated formations, like the surficial deposits in the study area, typical values for *m* and *a* are 1.4 and 1.0, respectively. This allows an estimate to be made of the

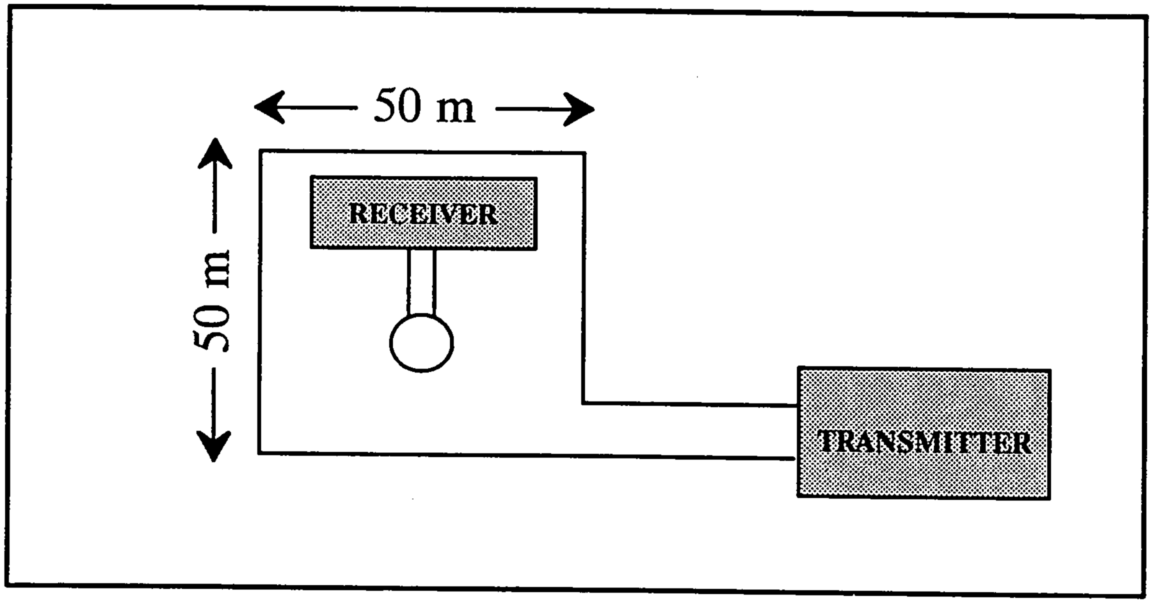

Figure 1. Map View of TEM Equipment Set-up.

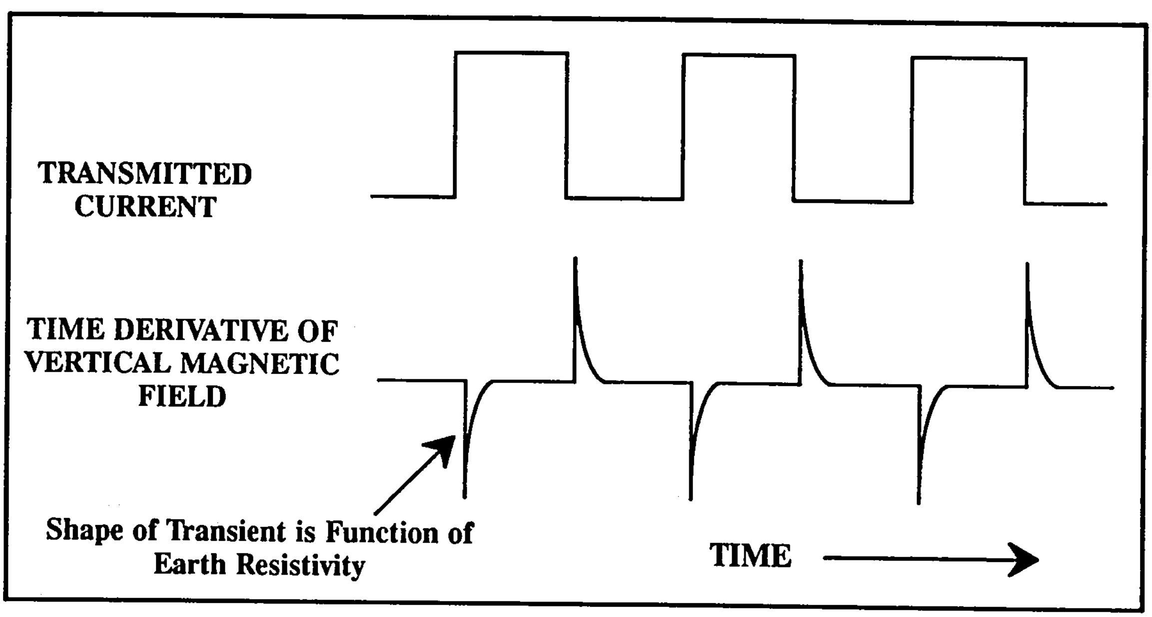

Figure 2. Timing Plot of TEM Signals.

resistivity of saturated surficial formations in the study area for pore fluids of varying quality.

Pore Fluid Electrical (μmho/cm)	Formation Resistivity (ohm–m) (35% porosity)	Formation Resistivity (ohm–m) (20% porosity)
500	85	190
1000	43	95
2000	21	47
4000	10	23
8000	5	11

Unsaturated formations will have a higher resistivity than these values. Formations with high cation exchange clays will have a resistivity lower than these values. Because most alluvial material contains some of these clays, the formation resistivity values will be slightly lower than those listed above.

Numerical models are used to quantify how the resistivity of the earth varies with depth. Models currently available assume that the earth consists of flat–laying homogeneous layers each of differing resistivity. The models are able to calculate what the apparent resistivity versus time curve would be for a given set of layers with a prescribed thickness and resistivity. The resistivity and thickness of layers is adjusted until the model results agree with the field data. When this occurs, the model represents a possible configuration of the subsurface. Figure 3 shows a typical result of this modeling approach. On the left is a plot of apparent resistivity versus time. The squares are actual field data. The continuous line is the apparent resistivity versus time curve that would be generated if the structure of the earth consisted of layers as shown in the right portion of the figure. For the purposes of the model, the bottom layer is assumed to have an infinite thickness. Because only the top of the bottommost layer can be detected, the depth of investigation is slightly greater than the top of the bottommost layer. A limitation of the model is the requirement that the earth consist of homogeneous layers. Where this condition is not met, such as in the vicinity of vertical faulting, the model cannot be used.

The survey parameters chosen for this study are a result of several trade–offs. To have a greater depth of penetration, it is necessary to increase the size of the transmitter loop. This has the adverse effect of decreasing the horizontal resolution because the measurement is averaged over a larger area. Based on preliminary surveys, a transmitter loop size of 50 x 50 meters was selected. In most parts of the study area, this results in depths of investigation of approximately 100 to 150 meters, which is at the bottom of the range that is being considered for drilling. The exact depth of investigation is a function of the geology at each site.

The TEM method differs from the more commonly used resistivity method in two principal ways. First, the TEM method has greater horizontal resolution than the resis-

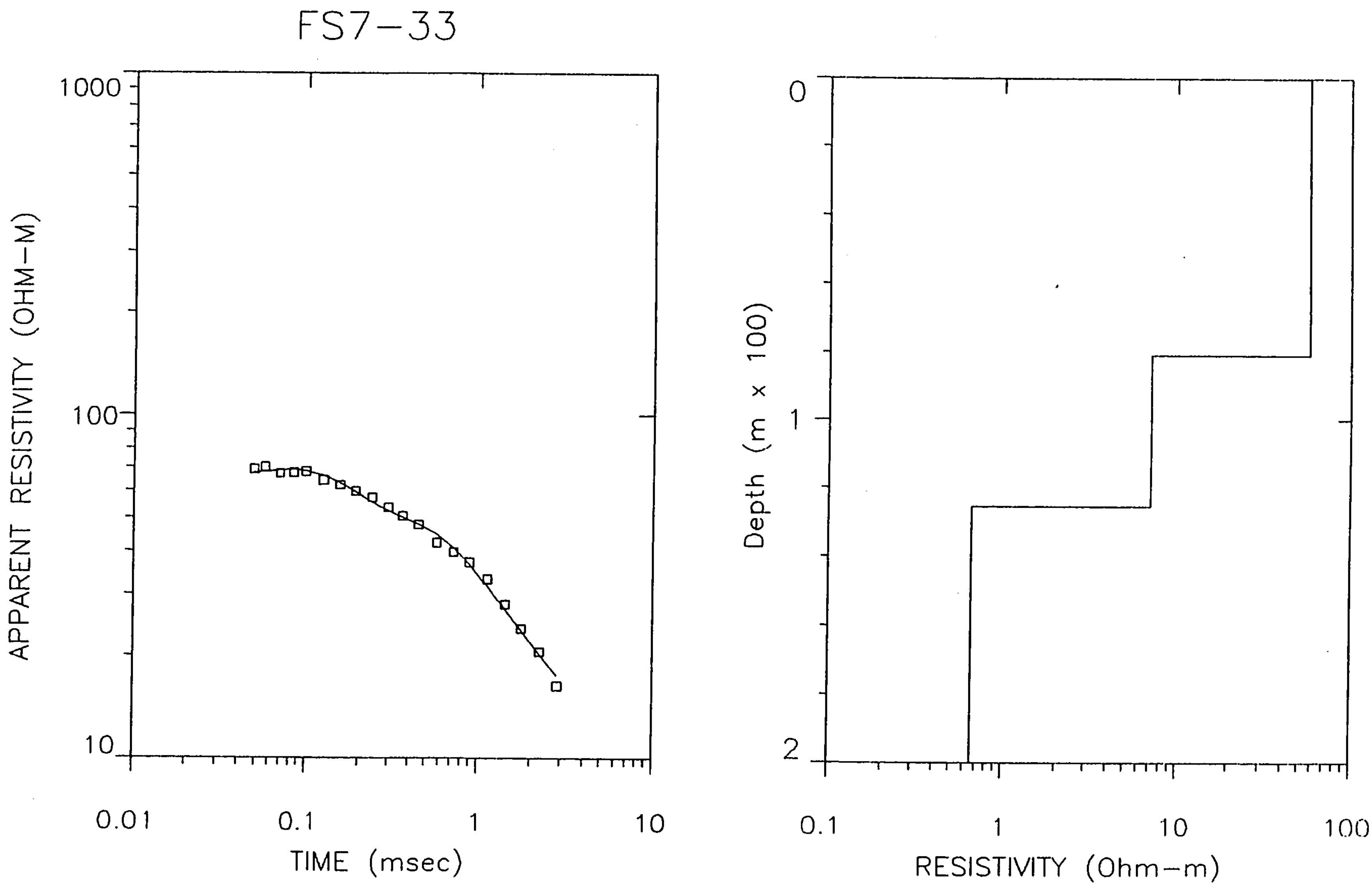

Figure 3. Typical Model Results.

tivity method. For example, to have a depth of investigation of 100 meters with the resistivity method, it would be necessary to average over a horizontal distance of at least 600 meters instead of the 50 to 150 meters horizontally averaged in this study. (The actual horizontal distance over which the TEM method averages is, in part, a function of depth. At shallow depths the horizontal averaging distance is on the same order as the size of the transmitter loop, at greater depths it can be several times the size of the transmitter loop). The second significant difference is that the field operations for the TEM method are more efficient than for the resistivity method.

To construct profiles, stations were located along lines with a 50–meter spacing between successive 50 x 50 meters transmitter loops. Survey lines were marked with orange flagging; station numbers were labeled and marked with blue flagging. At some sites, spacings other than 50 meters were used to provide additional information or to avoid topographic features. The equipment used in this study was a Geonics Ltd. PROTEM system and the modeling program was TEMIX47 from Interplex of Golden, Colorado.

PRESENTATION OF DATA

Plate 1 shows the location of the two survey lines as well as line 1 which was surveyed in September of 1989. The location of these lines was selected by Mike Widmer of Washoe County. Line 7 was located in the primary area of interest in locating production wells. Line 8 was located adjacent to the Cottonwood Test Well to provide additional information about the subsurface in that locality. Also indicated are the line number and station names (a number). Plates 2, 3, and 4 are profiles which were made along the three survey lines. Along the top of the profiles, the station numbers are indicated and can be used to locate the position of interesting features on the base map (Plate 1). The vertical axis on the profiles is not depth, but time after the start of the transient. It is related to depth in the sense that increasing time is increasing depth, but there is not a consistent relationship that can be applied across the whole profile. The color coding is used to indicate the apparent electrical resistivity as a function of location and time. The reds are high resistivities, the blues are low resistivities. Black areas occur where data were not considered valid. This occurred at some sites at later times when the transient signal was too weak and when interference from metallic material near the station caused the entire station to be discarded. The time, horizontal distance, and apparent resistivity scales are the same on all profiles.

High resistivities (red) are characteristic of unsaturated or clay–free deposits saturated with low conductivity water. Low resistivities (blue) are characteristic of saturated material with saline fluids or extensive clays. To interpret the profiles for the purposes of locating less permeable fault zones, it is necessary to look for areas where two features coincide: 1) low resistivities; and 2) rapid lateral changes in apparent resistivity.

Line 7 (Plate 2) shows two areas where rapid lateral changes and low formation resistivities indicate the presence of near–vertical structures. Between stations 9 and 16, apparent resistivities range between 20 and 32 ohm–meters and show little change with depth. This area is also coincident with a slight topographic change in relief and a projection of a fault mapped by the USGS to the south. Rapid lateral changes with low formation resistivities changing little with depth also exist at stations 48 and 49. This feature coincides with the abrupt topographic relief associated with the front of the Virginia Mountain Range to the south. Both features encountered around stations 12 and 49 on line 7 suggest the presence of clay and gouge material that would lower the local permeability making these areas a poor choice for a production well. In contrast to these two features, most of line 7 between stations 17 and 47 consists of resistivities that range between 40 and 80 ohm–meters within the upper 75 meters and decrease with depth. It is only at greater depths that much lower resistivities are encountered, indicating the presence of clays and/or high conductivity solutions.

Modeling results from station 33 line 7, (Figure 3) suggest an 80–meter–thick surficial layer, overlaying a 20–meter–thick layer with a resistivity of approximately 7 ohm–meters. The model further suggests an even deeper layer with a resistivity of less than one ohm–meter. It is important to remember the modeling requires individual layers with different resistivities as input when, in fact, there may be just one stratigraphic unit with resistivity gradually decreasing with depth. The low resistivity values at depth are suggestive of clay and/or high conductivity solutions and may be cause for concern.

Line 8 (Plate 3) consists of only five stations located adjacent to the Cottonwood Test Well in Cottonwood Canyon. The well is located near the intersection of faults mapped by the USGS and the survey was conducted to provide additional information in that locality. Station 1 was located next to exposed volcanic rocks which would account for the relatively high and constant resistivities with depth. The rapid lateral changes across the profile and low resistivities seen at station 5 are indicative of faulting and clay in this area.

DISCUSSION

When lines 7 and 1 are considered together (Plate 5), appropriate locations for production wells can be considered. The rapid lateral changes along with low resistivities centered around stations 12 and 49 on line 7 and station 12 on line 1 indicate the presence of fault structures and clay in these areas. These features and their associated characteristics may significantly decrease the local permeability, suggesting these areas should be avoided in the placement of production wells.

Geophysical evidence coupled with well data suggest the areas with resistivity highs centered around stations 23 and 33 along line 7 and stations 28 and 41 along line

1 would be the best areas for production wells. The water quality within the upper 75 meters at these areas along line 7 is likely to be good. It should be noted that the low resistivities encountered at depth along line 1 are considerably higher than those found along line 7, indicating possibly deeper production potential as one moves south from line 7. Whether or not there is a linear connection between the resistive highs along line 7 and line 1 has not been determined.

The features at station 49 on line 7 and station 12 on line 1 are believed to be associated with a fault located along the front of the Virginia Mountain Range to the south. Whether or not station 12 is indicative of the fault crossing line 1 in the direction of Telephone Pole Canyon or indicating its close proximity as it bends south with the front of the range is not clear. Further surveys may be warranted if well sites are considered along either of these projections.

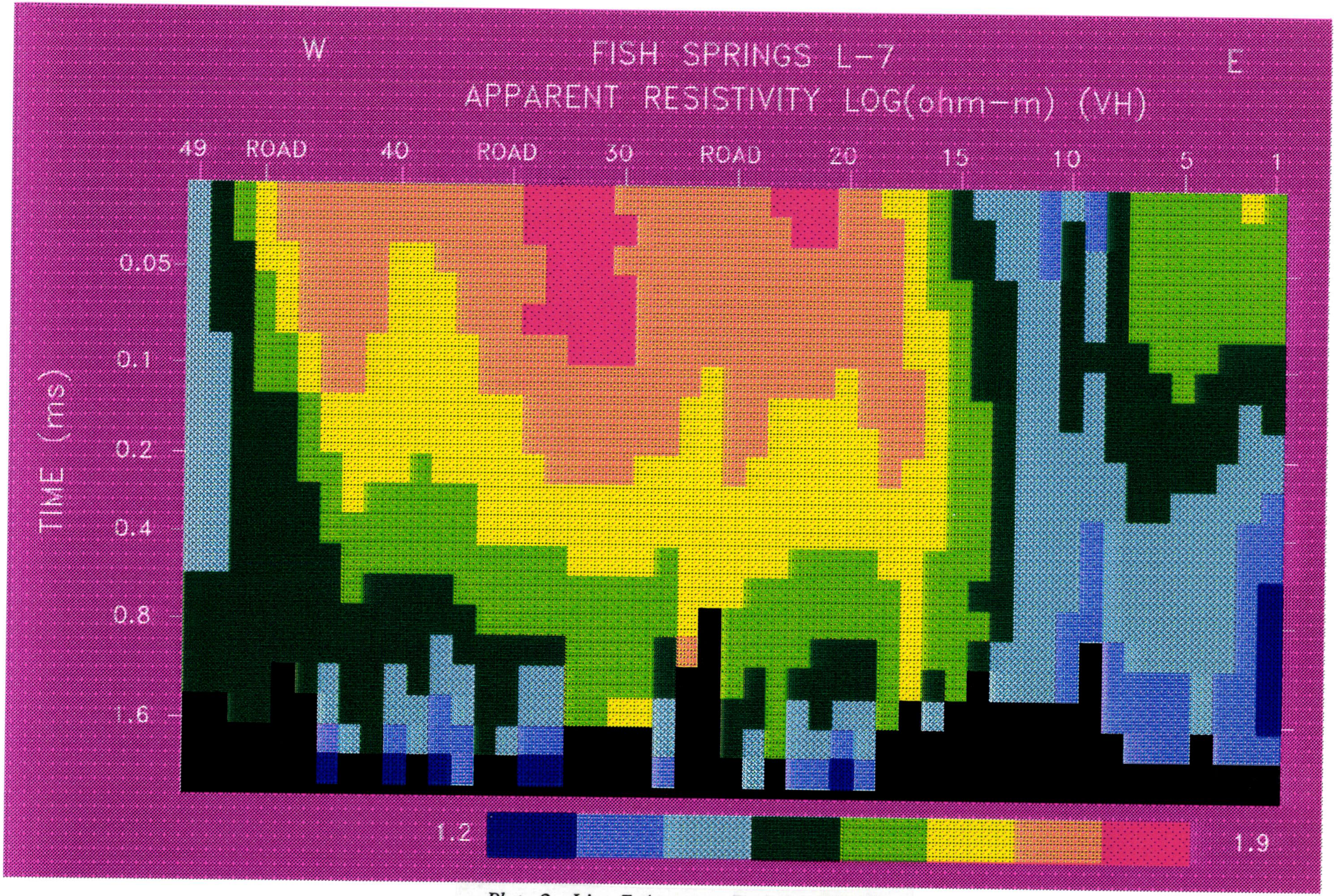

Plate 2. Line 7 Apparent Resistivity Profile.

Plate 3. Line 8 Apparent Resistivity Profile.

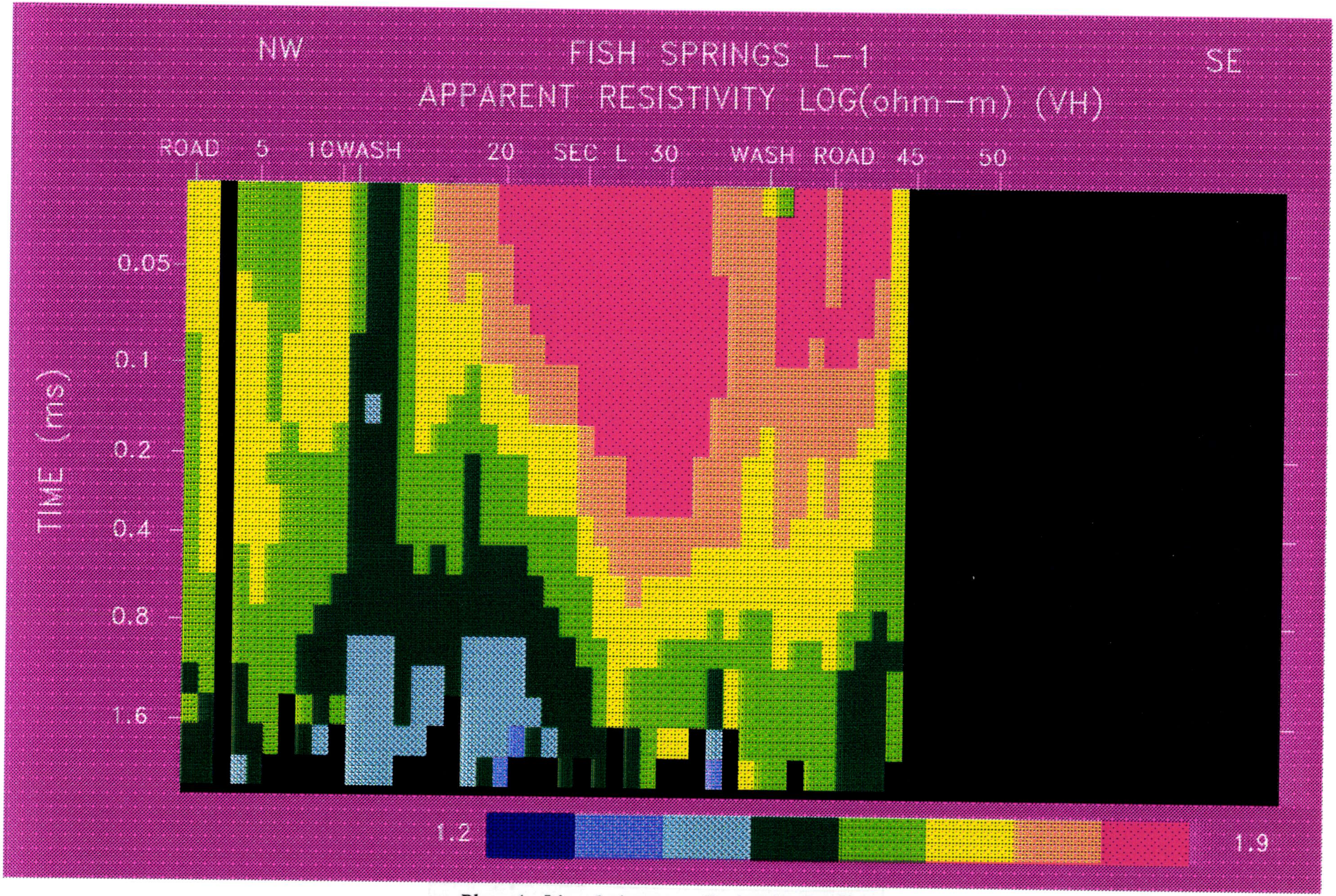

Plate 4. Line 1 Apparent Resistivity Profile.

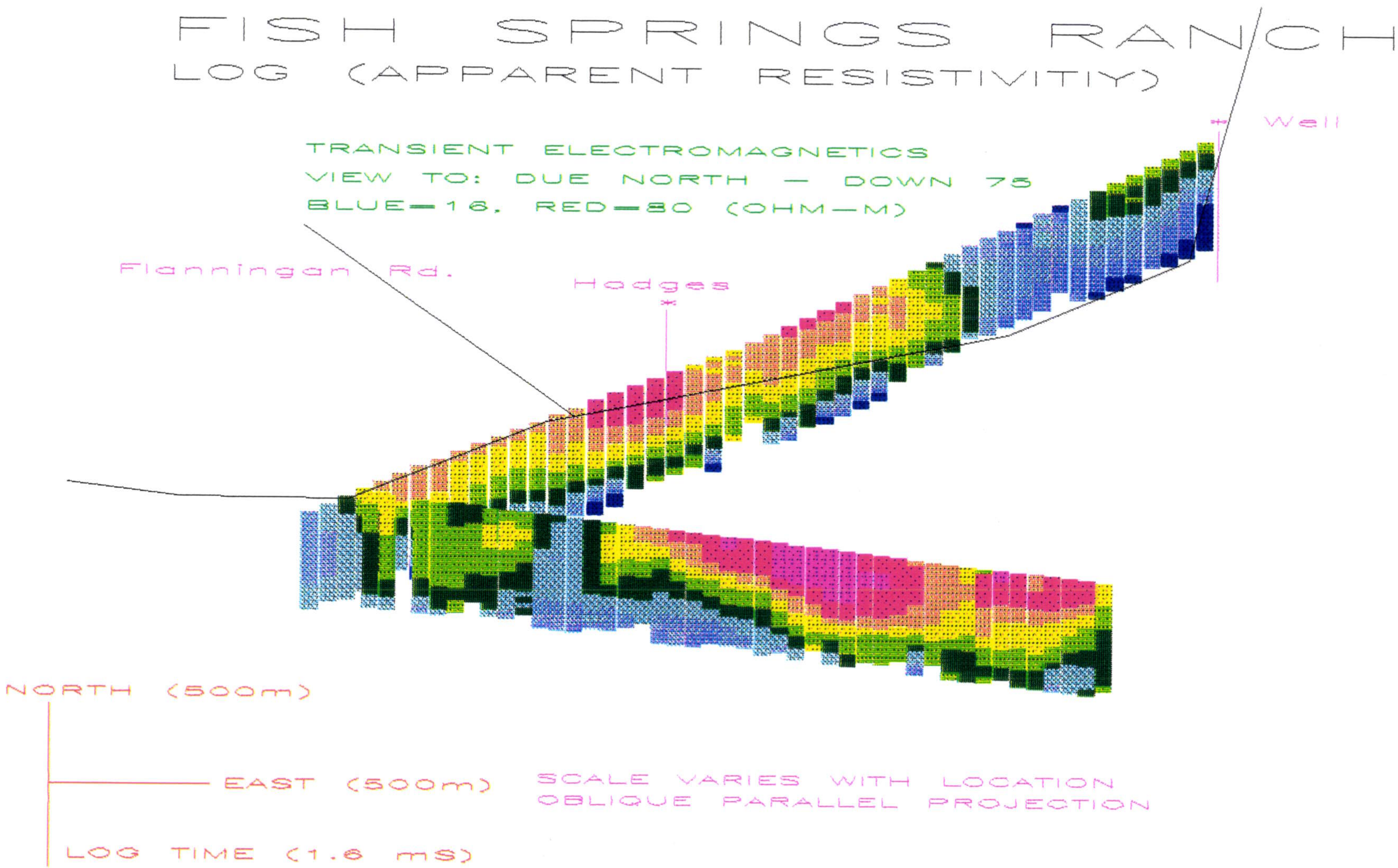

Plate 5. Fence Diagram of Lines 7 and 1.

Plate 1. Base Map of Study Area (Lines 7, 8, and 1).