Hydrogeology of the Rock River Watershed, Minnesota, and Associated Off-Channel Habitats of the Topeka Shiner

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SUMMARY OF FINDINGS

The Topeka shiner (*Notropis topeka*) is a native species minnow that was once common in headwater streams of the Midwest and western prairie. The species is estimated to have had a wide range across several states but is now restricted to portions of these areas. The species is in decline in Kansas, Missouri, Nebraska, and Iowa. The Topeka shiner now exists in less than 10 percent of its historic geographic range in highly fragmented populations. The U.S. Fish and Wildlife Service (USFWS) listed the species as endangered on January 14, 1999. Recent studies in Minnesota have shown that relatively abundant populations appear to be surviving across much of the southwestern portion of the state in the Big Sioux watershed.

Research has shown that off-channel habitats (OCHs—ponds and meander cut-offs) may be particularly important to the species' survival by acting as sanctuaries or critical habitats in the species' life cycle. We suspected these habitats were fed mostly by ground water from the surficial alluvial aquifer associated with the river system. Therefore, a better understanding of the shallow ground-water system appeared important to protecting the species in this area. In an area where aquifers typically have limited capacity, large ground-water appropriations from shallow aquifers, near OCHs, could dewater them. Poorly planned ground-water appropriations could, in this manner, result in the loss of habitat.

The project had three main phases. The first phase was an assessment of the species' distribution. In spring 2002, populations of Topeka shiners were documented at 29 OCHs by capturing all the swimming aquatic organisms with a one- or two-person seine and visually identifying the Topeka shiner individuals. Previous assessments showed that the in-stream occurrences of the Topeka Shiner are fairly evenly distributed within the river system. Similarly, the species was found in most of the OCHs. Together, these data underscore the generally favorable conditions that appear to exist in this area for the species.

The second phase was an assessment of ground-water and surface-water interactions at the OCHs. Ground water maintains a steady temperature that is close to the mean annual air temperature. We measured sediment temperatures with a temperature probe beneath the OCHs during late summer and found moderate to strong ground-water connections at most of the OCHs.

The third phase of the project was the creation of a series of maps describing the regional boundaries, base elevation, water-table elevation, and saturated thickness of the Rock River valley alluvial aquifer. The base of the surficial aquifer elevation map was created from a combination of existing well and soil boring information from the County Well Index and surface resistivity image data collected by the Minnesota Department of Natural Resources (DNR) for this project at 60 locations. The water-table elevation was created by interpolating shallow water-table soil information, elevations of surface-water features, and historical water-level measurements from water-table wells. The main map product, the saturated thickness map of the aquifer, was derived by subtracting the gridded elevations of the aquifer base from the gridded elevations of the water-table elevation.

The saturated thickness map shows a fairly regular pattern of aquifer thickness laterally across the aquifer with the thicker portions existing in the center of the Rock River valley. The northern portion of the Rock River valley aquifer, especially around Edgerton, has a greater maximum thickness range (approximately 60 feet to 80 feet) than the maximum thickness range (approximately 40 feet to 50 feet) of the southern portion of the aquifer.

The Rock River portion of the aquifer also appears to be significantly thicker than the aquifer beneath the major tributaries. Therefore, the OCHs in the tributary areas would be more vulnerable than most of the OCHs in the Rock River valley. Any of the identified OCHs, and others that have not yet been identified, could be affected by adjacent, large-capacity pumping activities.

Acquisition of a DNR ground-water appropriation permit requires completion of an interference pumping test to determine whether the requested volume of water will affect water levels in nearby wells or aquatic resources. We recommend monitoring water levels in these and other unidentified OCHs that are within the possible critical radius during any pumping tests conducted for a permit application.

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INTRODUCTION

The Topeka shiner (*Notropis topeka*) is a native species minnow that was once common in headwater streams of the Midwest and western prairie. The species is estimated to have had a wide range across several states but is now restricted to portions of these areas (Figure 1). The species is in decline in Kansas, Missouri, Nebraska, and Iowa. The Topeka shiner now exists in less than 10 percent of its historic geographic range in highly fragmented populations (Dahle, 2001). The U.S. Fish and Wildlife Service (USFWS) listed the species as endangered on January 14, 1999. Recent studies in Minnesota (Hatch, 2001, and Dahle, 2001) have shown that relatively abundant populations appear to be surviving across much of the southwestern portion of the state in the Big Sioux watershed (Figure 2).

Past research has focused on the relative abundances of Topeka shiner populations occupying in-channel habitat (stream channels) versus off-channel habitat (ponds and meander cut-off channels) (Dahle, 2001). Off-channel habitats (OCHs) may be particularly important to the species' survival by acting as sanctuaries or critical habitats in the species' life cycle (Dahle, 2001). Since these OCHs are all shallow surface-water bodies within the river and creek floodplains, we strongly suspected that these OCHs were fed mostly by ground water from the surficial alluvial aquifer associated with the river system. Therefore, if the species' survival was affected by the integrity of the OCHs and the integrity of the OCHs was largely dependant on the shallow ground-water system, a better understanding of the shallow ground-water system appeared to be important for protecting the species in this area.

Identification and Life History of the Topeka Shiner

The Topeka shiner is a small (up to 75 millimeters long) prairie minnow. It has an olive-yellow back with dark-edged scales and silvery-white sides and belly. A dark stripe runs along the fish's sides and extends to the head. All of the fins are plain except for the tail fin, which has a triangular black spot at its base. There is a dark stripe on the back in front of the dorsal fin. Breeding males have orange-red fins and orange-tinted heads and bodies. The upper jaw does not extend beyond the front of the eye. Numerous breeding tubercles (small, bluish-white bumps) are located on the snout, head, and anterior portion of the body. The breeding tubercles are largest and most numerous around the head.

Food items range from zooplankton to plant material. According to Dahle (2001), 75 percent of the diet consists of microcrustaceans and insects, but the Topeka shiner also consumes plant matter and algae. Therefore, the species is considered an omnivore.

Topeka shiners spawn from late May until mid-July, usually on the edge of green or orange-spotted sunfish nests. This proximity means the shiners' developing eggs benefit from the sunfish's parental care, which includes fanning the nest to remove silt and other debris and protecting it from predators (Kerns, 1999). Males aggressively defend small territories around the nest from other Topeka shiners. Although females entering a defended territory may be chased away, a persistent female will be accepted by the male (Katula, 1998, as cited in Hatch, 2001). Topeka shiner females produce clutches of eggs (groups of eggs that become ready for spawning at about the same time). A single clutch varies from 150 eggs to 800 eggs depending on the size and condition of the female. The eggs hatch in about 5 days, and after 4 more days the larvae begin to feed (Hatch, 2001).

Habitat and Species Survival

Since water quality, sedimentation, and turbidity are comparable across the Topeka shiners' entire Midwest range, these factors appear not to hinder population survival in Minnesota (Hatch, 2001; Dahle, 2001; and Wall and others, 2001). Predation is not believed to be a primary threat to Minnesota's current population (Dahle and Hatch, 2002).

Of course, good hydrology management practices such as riparian zone protection, reduced channelization, minimized nutrient runoff, and decreased impoundment development are valuable to maintain the overall health of prairie streams. For the Topeka shiner, ground-water levels and flow appear to be vitally important to the future survival of the species, which depend on habitat with ground-water seepage (USFWS, 1993; Stark and others, 1999;

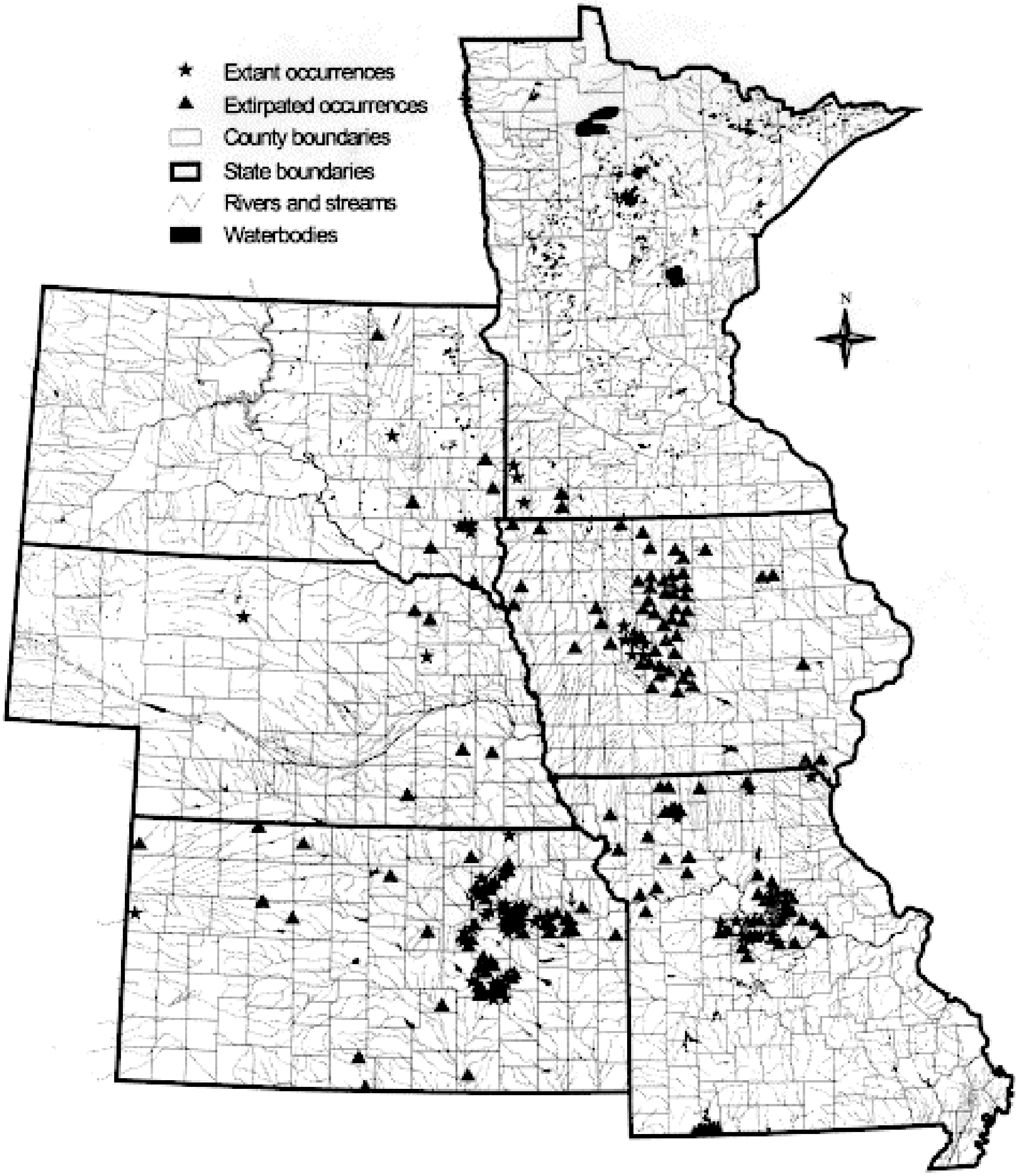

Figure 1. *Topeka Shiner Rangewide Distribution (adapted from U.S. Fish and Wildlife Service and Kansas Ecological Services, 1997).*

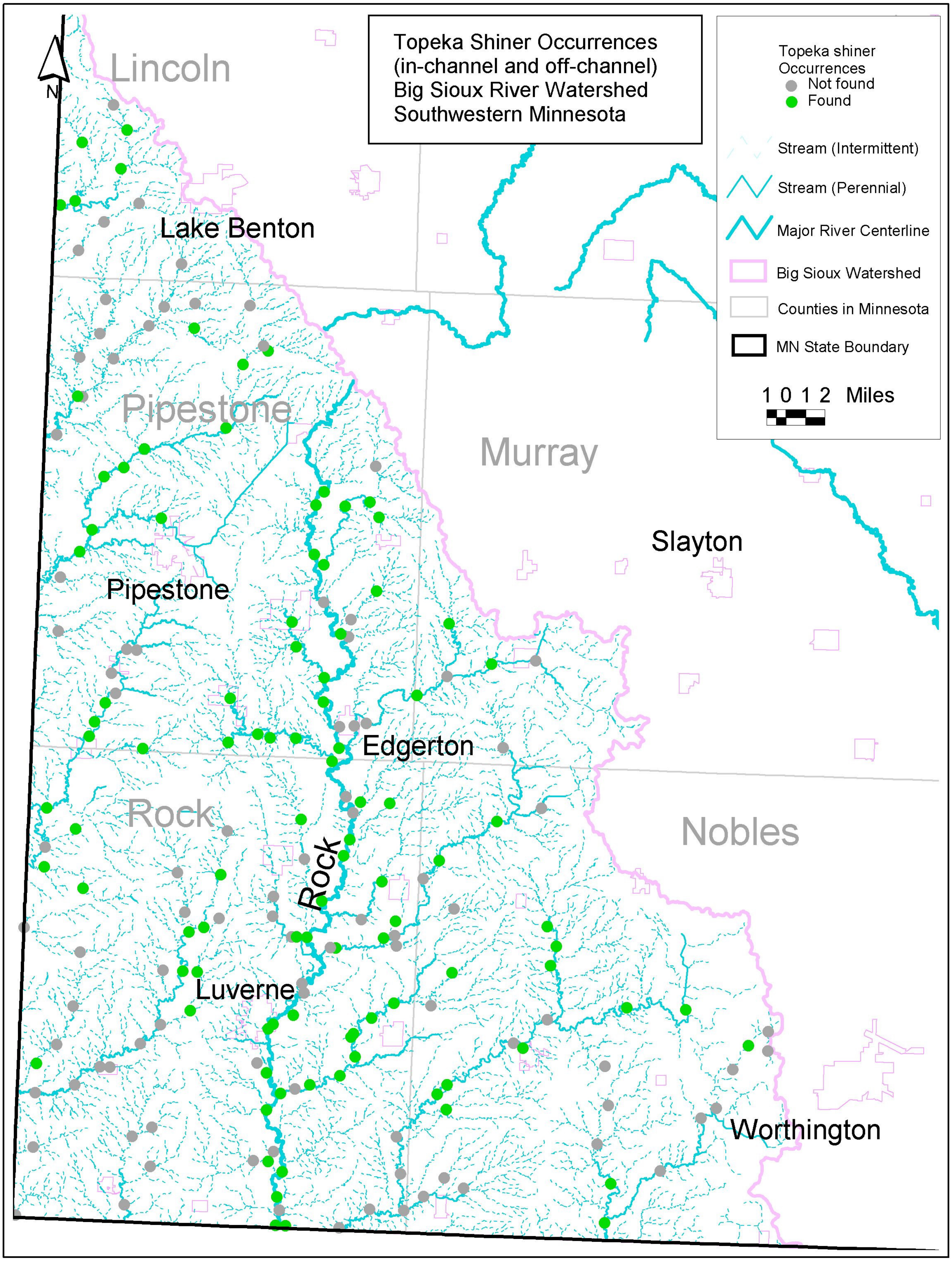

Figure 2. Big Sioux Watershed and Topeka Shiner Occurrences.

and Wall and others, 2001) to help survive periods of drought and winters.

PROJECT PURPOSE

In 2001, the Minnesota Department of Natural Resources (DNR) received a grant from the USFWS cooperative endangered species conservation fund program for hydrogeological research of the Topeka shiner habitats in southwestern Minnesota. The results of this research can be used to help guide any development that might affect surface- or ground-water resources in the area where the Topeka shiner occurs. Specifically, we recognized that large ground-water appropriations from the shallow aquifer, near the OCHs, could dewater them. Poorly planned ground-water appropriations could, in this manner, result in the loss of habitat.

A main product of this project is a saturated thickness map of the shallow aquifer in the Rock River watershed. If appropriators can be encouraged to locate wells away from the OCHs in the thicker portions of the aquifer, habitat loss through ground-water appropriation can be minimized. For most appropriators, use of deep aquifers in this area is generally not feasible. Some limited studies in this region have shown that the buried Quaternary sand or the still deeper Cretaceous sandstone aquifers often cannot provide adequate ground-water quantity or quality (Berg, 1997, and Lindgren, 1997).

The project had three main phases: 1) assessment of the species' distribution, 2) assessment of ground-water and surface-water interaction, and 3) hydrogeological mapping and Topeka Shiner occurrences. The purpose of the first phase was to determine where the species could be found in the various OCHs that had been identified. The purpose of the second phase was to test the possibility of OCH recharge by the shallow aquifer system. The third phase of the project was designed to create a set of hydrogeological maps that could be used to help guide water resource management in the watershed.

ASSESSMENT OF THE SPECIES' DISTRIBUTION

Previous studies (Dahle, 2001, and Hatch, 2001) had evaluated many of the suitable OCHs within the Minnesota portion of the Big Sioux watershed (which includes the Rock River watershed). Populations of Topeka shiners were documented by capturing all the swimming aquatic organisms with a one- or two-person seine and visually identifying the Topeka shiner individuals. A subsequent assessment was made in spring 2001 by Patrick Ceas (written commun, 2001). He assessed most of the sites that had been visited previously. Figure 3 shows the locations of 31 OCHs that were assessed. Of these sites, five were not sampled, three were dry, and three had none of the target species present. The species was identified at the remainder of the sites.

ASSESSMENT OF GROUND-WATER AND SURFACE-WATER INTERACTION

Most of the OCHs appear to stay filled with water year-round, thus maintaining viable Topeka shiner habitats. We assumed that these persistent, water-filled conditions were the result of steady ground-water inflow. Figure 4 shows a similar situation where the base of the surface-water body is below the water table, thus maintaining a connection between the ground water and the surface water. To test this assumption at the OCHs, we tried two techniques to determine a ground-water connection: 1) minipiezometer (hydraulic potentiomanometer) head measurements and 2) sediment temperature measurements.

Minipiezometer Head Measurements

The first technique relies on equipment that can measure the relative head difference between the surface-water body and the underlying aquifer (Lee and Cherry, 1978; Winter and others, 1988). A small tube with a cylindrical screen on one end is pushed into the shallow aquifer under the surface-water body. This tube acts like a small well. The water in the shallow aquifer has a hydraulic head, which can be measured by connecting the small well,

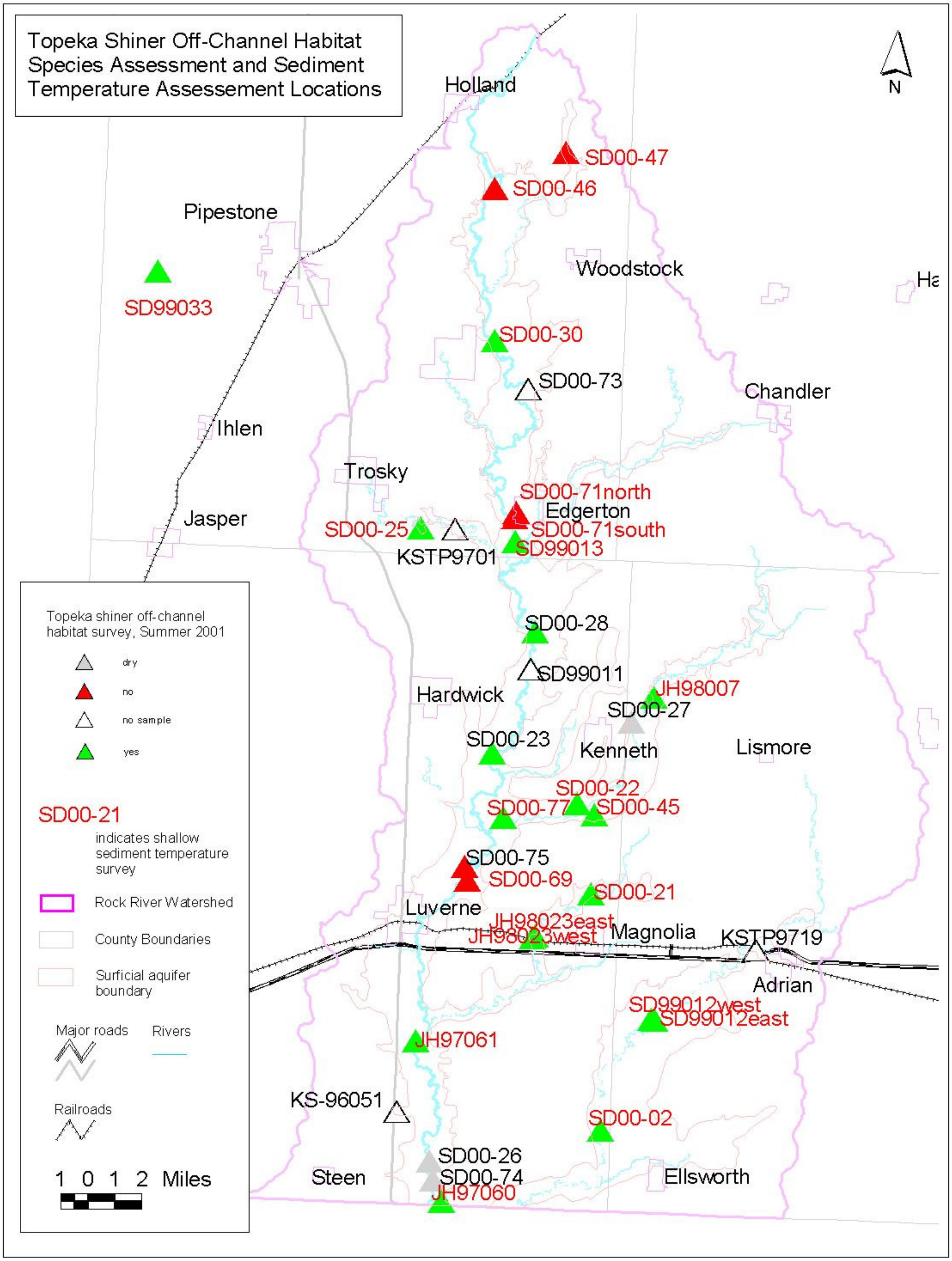

Figure 3. *Locations of Off-Channel Habitat and Sediment Temperature Assessments.*

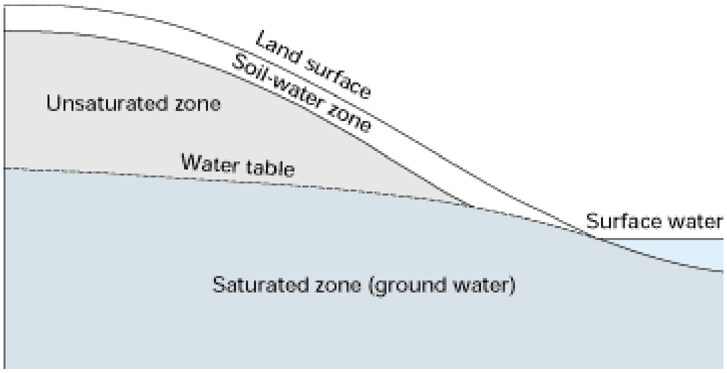

Figure 4. *Ground-Water and Surface-Water Connection. Surface-water bodies (rivers, lakes, ponds, wetlands) are oftern just a surface expression of the water table (Winter and others, 1998).*

with tubing, to a manometer board. This board is also connected to the surface water with another tube. The whole apparatus is then filled with water by a hand pump and then opened to the atmosphere. The relative head measurements from the surface- and ground-water systems can be measured from the manometer board. If the ground-water measurement is higher than the surface-water measurement, ground-water inflow is indicated.

We successfully completed this procedure at two of the OCHs (SD0077 and SD0071north) and obtained small measurements indicating ground-water inflow (0.5 millimeter [mm] and 7 mm, respectively). At several other sites, however, we were unable to obtain accurate results or any results at all. The main problem was the fine-grained nature of the sediment beneath the OCHs. All of these sites are within the floodplain areas. The sediment beneath these sites is very clayey, which slows water flowing into the small well screen to a rate that is too slow for the technique to be practical. Another problem was caused by the gases generated from decaying organic matter in the sediment. This gas generation caused bubbles to accumulate in the tubing, which ruined any chance of obtaining accurate measurements of the water levels. Due to these problems, this technique was abandoned for the remainder of the sites.

Sediment Temperature Measurements

The second technique, sediment temperature measurements, was much more successful. Ground water maintains a steady temperature that is close to the mean annual air temperature (Driscoll, 1986). Silliman and Booth (1993) provides one of the best published examples connecting sediment temperature and hydrologic measurements (Figure 5). During daytime, the surface-water temperature of the gaining portion of the stream (the portion that has ground-water inflow) was from 5 degrees to 15 degrees Fahrenheit (F) warmer than the sediment temperature, which remained fairly constant during the 10-day measurement period. Conversely, the surface-water and sediment temperatures were roughly the same on the losing reach (section of ground-water outflow) of the stream.

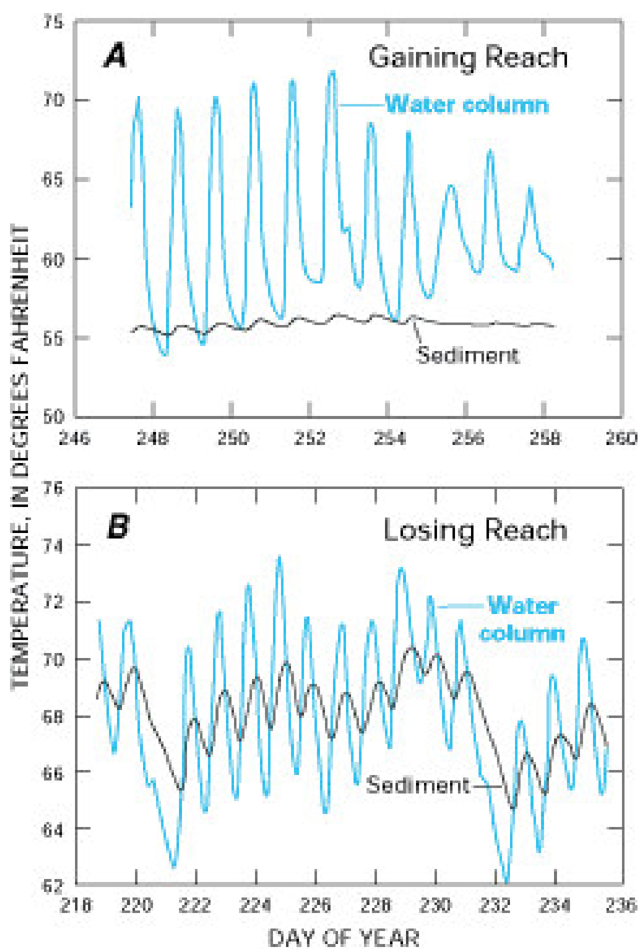

Figure 5. *Sediment Temperature in Gaining and Losing Reaches of Juday Creek, Indiana (adapted from Silliman and Booth, 1993).*

We measured sediment temperatures beneath the OCHs during late summer and found temperature differences between the surface water and the underlying sediments, which we interpreted as evidence of ground-water inflow. The sediment temperature was measured within the ponds, near the perimeter. A temperature probe was placed in the substrate about 2 feet to 2.5 feet below the water surface and left in place until the probe reached ambient sediment temperature. The location was recorded using a Trimble mapping grade geographic positioning system (GPS) receiver accurate to approximately 1 foot to 2 feet. Maps of the temperature measurement data are included in Appendix A.

According to the Minnesota Climatology Office, the mean annual air temperature for this region ranges from 43 degrees to 46 degrees F (Figure 6). The coldest sediment temperature we recorded was 52 degrees. Therefore, all of our temperature measurements of sediment indicate some mixing with surface water or recently infiltrated precipitation.

The temperature survey sites were interpreted in terms of the strength of the ground-water connection. If most of the probe locations showed sediment temperatures more than 5 degrees lower than the surface-water temperatures, the site was classified as having a strong ground-water connection. If about half of the probe locations showed sediment temperatures more than 5 degrees lower than the surface water temperatures, the site was considered to have a moderate ground-water connection. If few of the probe locations had sediment temperatures 5 degrees lower than surface-water temperatures, the ground-water connection was considered weak. Figure 7 shows a summary of these classifications. Moderate to strong ground-water connections were found at most of the OCHs.

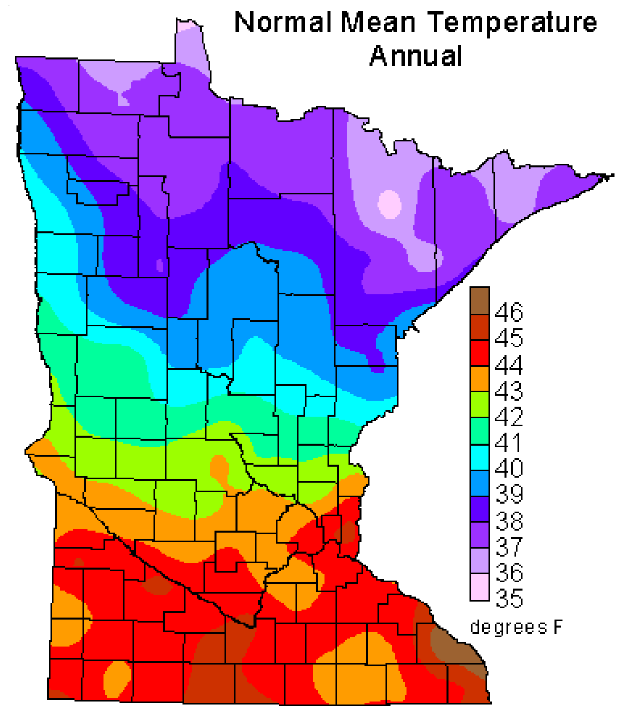

Figure 6. *Mean Annual Air Temperature in Minnesota (Minnesota DNR, 2003).*

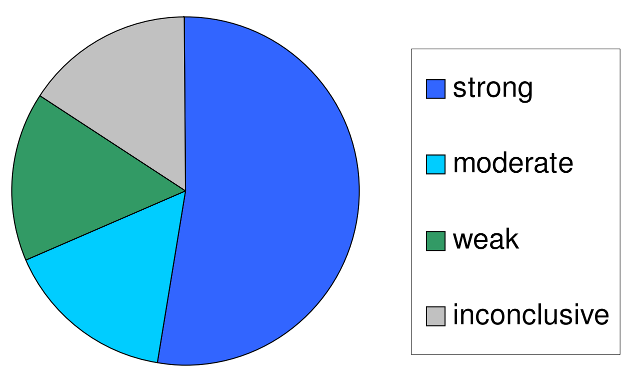

Figure 7. *Pond Sediment Temperature Surveys: temperature connection between ground water and surface water. Of the 20 ponds checked, 16 contained Topeka shiners during at least one survey. The connection between ground water (based on probes of pond sediment) and surface water was rated as follows:* ***strong****, most probe sites five or more degrees colder than surface water;* ***moderate****, about half probe sites five or more degrees colder than surface water;* ***weak****, few probe sites five or more degrees colder than surface water.*

HYDROGEOLOGICAL MAPS AND TOPEKA SHINER OCCURRENCES

Surface Digital Elevation Model and Data Distribution

Four large, folded hydrogeologic and topographic maps are included with this report (Figures 8 through 11). Figure 8 shows the locations of the

Topeka shiner OCHs and in-stream survey sites, data locations of surface resistivity imaging, well and test hole locations, locations of 2002 DNR permitted ground-water appropriations, and the main extent of the Rock River valley alluvial aquifer and its tributaries. The in-stream occurrences of the Topeka shiner are fairly evenly distributed within the river system. Similarly, the species was found in most of the OCHs. Together, these data underscore the generally favorable conditions that appear to exist in this area for the species. A half-mile radius circle (buffer zone) is shown around each of the OCHs that contained or could contain Topeka shiners. This buffer is included mostly as a highlighting device since OCHs were one of the primary focuses of this investigation.

The main extent of the Rock River valley alluvial aquifer is shown with a red line on Figures 8, 9, and 10. This line represents the boundaries of the area that was evaluated for this project. It does not represent all the surficial aquifer boundaries of all the tributaries in the watershed. Furthermore, not all of the major tributary aquifer boundaries are included in this area because of a lack of information in the upstream areas. We did, however, try to characterize those portions of the surficial aquifer that encompass the OCHs. This line was derived from well and soil-boring information contained in the Minnesota Geological Survey's County Well Index (CWI), surface resistivity images collected for this project, topography, soil survey information, and Quaternary geological maps (Patterson, 1995).

The surface resistivity line locations are shown on all the large maps. The line locations were selected for various reasons. Data were collected in areas where no well or soil-boring data existed, or where the well or soil boring data were inadequate to fully characterize the true thickness of the surficial aquifer. Some of the drill hole data in the area end in sand or gravel and were, therefore, too shallow to determine the depth to the base of the aquifer. This was especially true in the Rock River valley area from south of Luverne to the Iowa border. We also tried to characterize both the edges and thickest portions of the aquifer. At several locations we were able to identify the edge of the aquifer (lines 3, 5, 14, 15, 33, 37, 40, 41, 43, 48, and 60). Some of the thickest portions of the aquifer are shown on lines 24, 27, 31, 32, 50, 52, and 59. Finally, we tried to collect aquifer thickness data near the OCHs, if none existed, to help characterize the aquifer at those locations.

We generally worked in public road right-of way areas and avoided private land to minimize time spent on obtaining property access permission. As a result, we could not always obtain data at ideal locations or at ideal orientations. Some road ditches were too narrow or overgrown for setting up our data-gathering equipment. We also did not work directly over buried power lines or under overhead power lines to avoid the interference of secondary currents created by these electrical sources.

Water-Table Elevation Map

Figure 9 shows a water-table map of the Rock River valley alluvial aquifer. The water-table map was one of two component maps used to make a main product of this project: the Saturated Thickness Map (Figure 11). The other component map is shown on Figure 10 (Base of Surficial Aquifer Elevation). The contour elevation data from both Figures 9 and 10 were interpolated into 30-meter data grids. The grid data from Figure 10 were subtracted from the grid data of Figure 9 to produce a saturated thickness contour map that is shown on Figure 11.

The water-table map was made in two phases. The first phase was to represent all the nonwell water-table information that exists as an ArcView point shapefile. This information includes locations of perennial streams, wetlands, and shallow water-table soils. The surface elevations for these features were derived from the DNR state topographic digital elevation model (DEM). The depth to water table was subtracted from these surface elevations in areas of shallow water-table soils based on the seasonal high water table indicated in the respective soil surveys (Rock, Nobles, Murray, and Pipestone counties) by the Natural Resources Conservation Service. Water-table elevations beneath intermittent streams that were not in shallow water-table soil areas were also estimated by using an assumed depth to water table value of 7 feet (1 foot deeper than the maximum depth used in soil surveys). These data were interpolated into a 30-meter grid. Ten-foot contours were derived from this grid. In the second phase of the map creation, the contours were adjusted to fit the well data from CWI and indications of water table from the resistivity images.

Most of the lines were located in areas underlain by a shallow water table. By design, our resistivity data were not detailed enough to resolve a water table at a depth of a few feet. In other areas where we would have expected a deeper water table that might be resolved, the water table does not seem to appear, possibly due to the very high resistivity values of the aquifer material. Images that show a water table as high resistivity values abruptly underlain by lower resistivity include lines 7, 24, and 25 (Appendix B).

The water table at any location can vary several feet seasonally or annually. The areas on the map that contain little or no well information are more representative of spring—wet year conditions. Areas where water-level information based on wells or soil borings was available may be more representative of lower, average conditions. The saturated thickness map (Figure 11) should be understood in a similar fashion since it is a derivative of the water-table map.

Base of Surficial Aquifer Elevation and Surficial Resistivity Images

Figure 10, as described in the previous section, is the base component of the saturated thickness map (Figure 11). This map was created from a combination of existing well and soil-boring information from CWI and surface resistivity image data collected by the DNR for this project. These surface resistivity images consist of color-contoured resistivity data (Appendix B). A general description of the surface resistivity method and theory is included in Appendix B.

We considered the surface resistivity imaging method of aquifer characterization superior to more traditional methods (drilling) for several reasons. The logistical reasons included faster field acquisition time for collecting data from 50 feet to 100 feet deep. We usually spent 3 hours to 5 hours to acquire data for a 56-electrode line (825 feet at a spacing of 15 feet per electrode). There was no need to locate onsite buried utilities, no boreholes had to be sealed, no site cleanup was required, fewer access problems were encountered, and no access permission was required. The scientific advantages included greater stratigraphic certainty and lateral understanding. In many places, the aquifer consists of two layers of sand and gravel separated by a discontinuous layer of clay. The interbedded clay layer could be misinterpreted as the base of the aquifer if layers are identified by drilling. In some places, the first clay layer is the base of the aquifer and in other places it is not. The resistivity images have the advantage of imaging beneath the interbedded clay layer, thereby assessing the true aquifer thickness. We also had the advantage of assessing lateral changes well beyond a point location that only would have been assessed by a drill hole.

To estimate the base elevation of the surficial sand and gravel that constitutes the aquifer, we had to determine what resistivity value or range of resistivity values represent the top of the clayey till beneath the aquifer. We made this determination by collecting resistivity data directly over two U.S. Geological Survey (USGS) observation well locations (Figure 10). The resistivity value at each of these sites that corresponded with the depth of the aquifer base shown on the well logs was the value we used to interpret the base of aquifer elevation on each of the resistivity images.

Clay resistivity values range from 10 ohm-meters to 100 ohm-meters (AGI Sting Manual, 2002). Since the clayey glacial till at the base of the aquifer is a mixture of clay, silt, and sand, a value higher than 10 ohm-meters was expected. Unfortunately, the calibration of our resistivity meter was too low for the first 17 lines of data that we collected. The relative resistivity values were still useful, however, and the data were incorporated into the maps of Figures 10 and 11 using the following correlation methods. We ran correlation resistivity lines at the same USGS observation well (559145) twice, first for the initial low calibration and later for the higher corrected calibration. Correlation with the well log data (559145) at resistivity line location 8 indicated an aquifer base resistivity value of approximately 13 ohm-meters. The meter calibration was corrected after line 17. Line 49, collected at the same well location (559145), showed a base of aquifer resistivity value of approximately 40 ohm-meters.

The Rock River valley alluvial aquifer is, in many places, a two-layer system: a surficial sand and gravel layer (10 feet to 30 feet thick) underlain by a discontinuous clay layer of variable thickness (1 foot to 20 feet), which is underlain by another sand and gravel layer. This layering was noted by Lindgren and Landon (2000) and is evident in well logs and resistivity images (line 7, 18, 24, 25, 31, 38, and 51) throughout the valley. This layering probably resulted from two phases of glacial outwash deposition during the Late Wisconsinan (Patterson, 1995). Since the intervening clay layer does not appear to be continuous over large areas, the two sand and gravel layers were not considered to be separate aquifers. However, locally continuous areas may create a leaky barrier between the two layers.

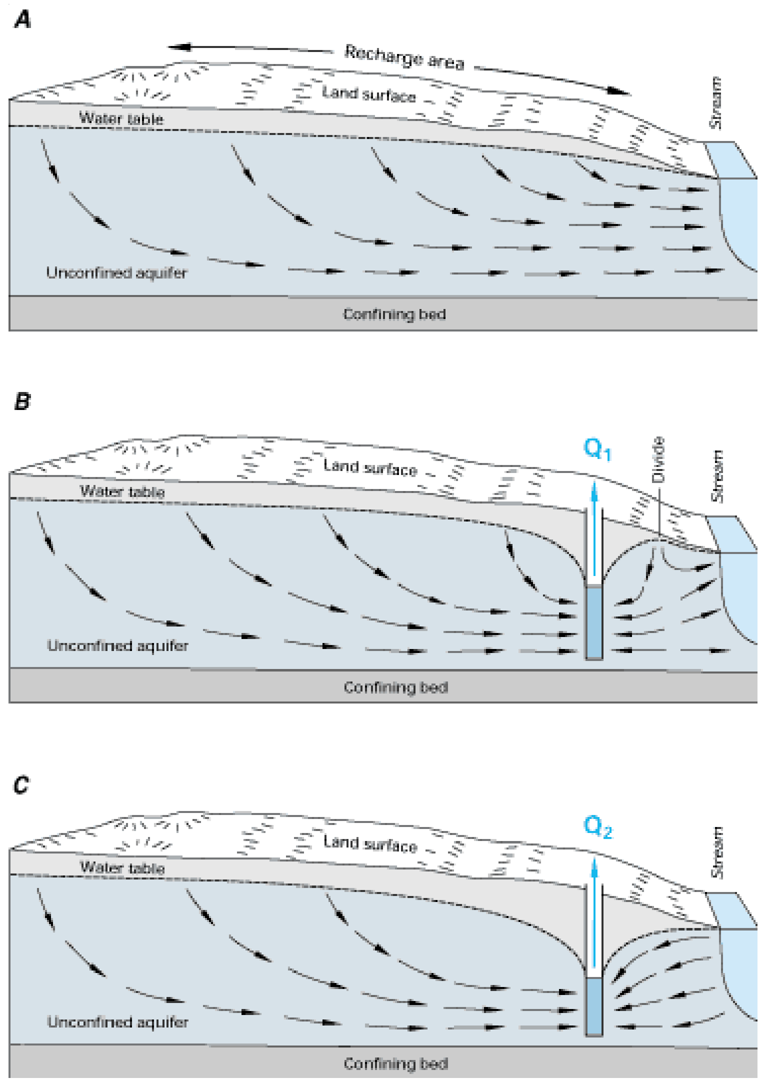

Figure 12. *Cone of Depression Created by Pumping Well. In a schematic hydrologic setting where ground water discharges to a stream under natural conditions (A), placement of a well pumping at a rate (Q1) near the stream will intercept part of the ground water that would have discharged to the stream (B). If the well is pumped at an even greater rate (Q2), it can intercept additional water that would have discharged to the stream in the vicinity of the well and can draw water from the stream to the well (Winter and others, 1998).*

Map of Surficial Aquifer Saturated Thickness

Saturated thickness refers to the portion of the sand and gravel deposit that has pore spaces completely full of water (Figure 4). As we have shown in the sediment temperature phase of this project, the OCHs are dependant on ground-water inflow from the saturated portion of the surficial aquifer. OCHs in the thinner portions of the aquifer are more vulnerable to high-capacity pumping or other dewatering activities than OCHs are in the thicker portions of the aquifer. Figure 12 shows a schematic hydrogeological cross section where ground water, which normally feeds the surface-water body, is intercepted by a pumping well. Figure 13 illustrates this phenomenon with two hypothetical well discharge examples. The first example shows the cone of depression (area of depressed water levels caused by pumping) created by a high-capacity well pumping from an aquifer with a saturated thickness of 30 feet, which is typical of many areas along the edges of the Rock River and its major tributaries. In this example, the cone of depression extends beyond the edge of model boundaries (more than 2000 feet). In the second example, the well discharge (400 gallons per minute [gpm]) and aquifer hydraulic conductivity (ability of the aquifer to transmit water) have been kept the same. The saturated thickness, however, has been doubled to 60 feet. This condition is more typical of the thicker, more central portions of the aquifer. In the second example, the cone of depression has a radius no greater than approximately 700 feet.

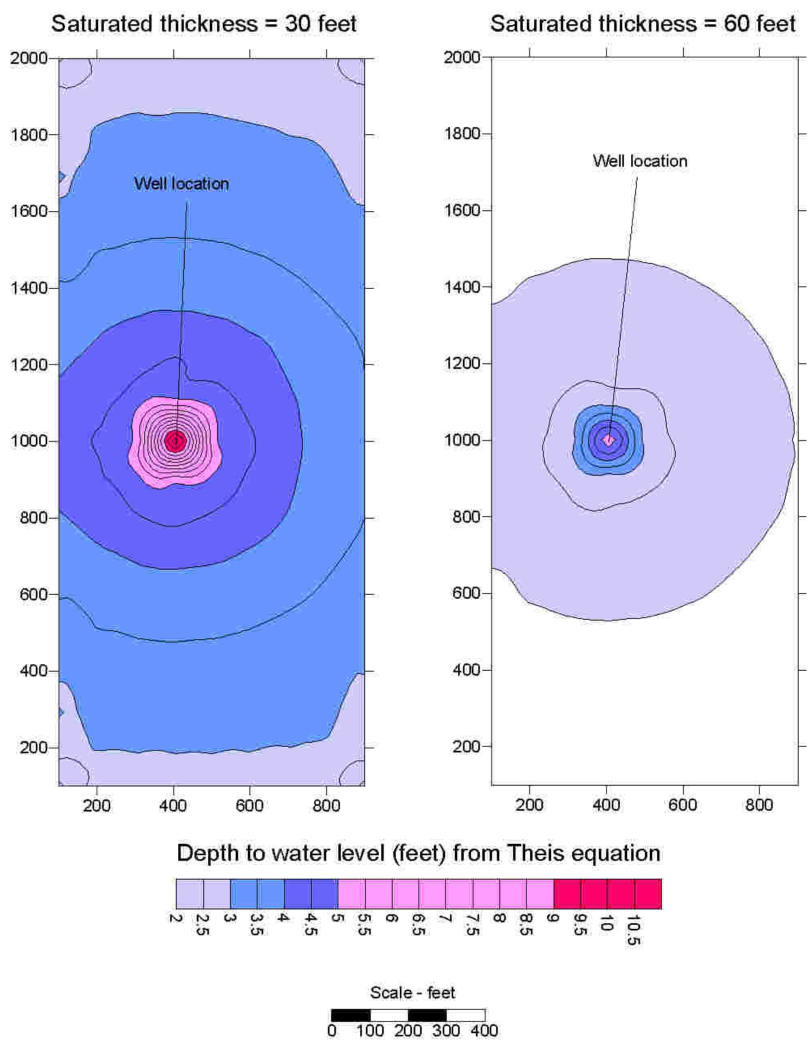

***Figure 13.** Well drawdown example. Well discharge = 400 gallons per minute and hydraulic conductivity = 2842 gallons per day per foot of drawdown. The time period is the same for both examples*

These simple analytical models were based on the assumption that there are no nearby impediments to ground-water flow (barrier boundaries). In fact, the actual hydraulic conditions in the aquifer are more complex due to the barrier boundary situation and other factors, but the overall effect of aquifer thickness would remain the same.

A fairly regular pattern of aquifer thickness seems to exist laterally across the aquifer with the thicker portions existing in the center of the Rock River valley. The Rock River portion of the aquifer also appears to be significantly thicker than the aquifer beneath the major tributaries. The northern portion of the Rock River valley aquifer, especially around Edgerton, appears to be thicker than the southern portion of the aquifer. The Chanarambie Creek valley meets the Rock River near Edgerton. This tributary appears to be the most deeply incised (Figure 8) and may have been one of the most important glacial outwash pathways that contributed to the thickness in the northern portion.

OFF-CHANNEL HABITATS AND AQUIFER THICKNESS

Due to the relationships between aquifer thickness and valley width discussed in the previous section, some of the OCHs are more vulnerable to human-made dewatering conditions than others. In general, the OCHs in the tributary areas would be more vulnerable than most of the OCHs in the Rock River valley. This includes two sites in the Kanaranzi Creek area, two sites in the Elk Creek area, three sites in the Champepadan Creek valley, two sites in the Poplar Creek area, and one site along the East Branch Rock River. Table 1 (follows page 13) is a summary of Topeka shiner occurrences, sediment temperature survey results, and estimated aquifer saturated thickness at each of the known OCHs.

Any of the identified OCHs and others that have not yet been identified could be affected by adjacent, large-capacity pumping activities. A more detailed assessment of individual OCH vulnerabilities will depend on the exact nature of future development proposals in the area.

RECOMMENDATIONS

We recommend that a pumping test be required for large ground-water appropriation permit applications in this study area. The pumping test will determine whether the requested volume of water will affect water levels in nearby wells or aquatic resources. We recommend monitoring water levels in these and other unidentified OCHs that are within the critical drawdown radius during any pumping tests conducted for a permit application.

After years of survey and research on this species (e.g., Dahle, 2001, and Hatch, 2001), biologists now understand that it is not likely that some OCHs always support Topeka shiners while others never do. Rather, it appears that the presence or absence of Topeka shiners in any OCH in any year results from very complex events affecting the movement of the fish into an OCH during a flood event and the survival of those fish within the OCH once it is cut off from the stream. These events include where the fish are at the outset of the flood event, choices the fish make in escaping fast water, how that escape is affected by turbulence and currents, whether or not a predator species also wound up in the OCH, hydrologic conditions within the OCH once it is cut off from the stream, and other factors. Consequently, any evaluation of the impact of a proposed water appropriation on Topeka shiners should not be limited to those OCHs in which the fish have been known to occur but should include the impact of the appropriation on any other OCH within the potential impact area, regardless of whether there is a record of Topeka shiners occurring within the OCH.

The critical habitat proposal for this species is based on land elevations at or below the bankfull levels of the floodplain. We do not have a clear understanding how the OCHs relate to these criteria or if all of these habitats are protected under these circumstances. Accurately establishing this critical habitat area may require a better digital elevation model than currently exists for this project area. Answering these questions could be part of any subsequent investigations.

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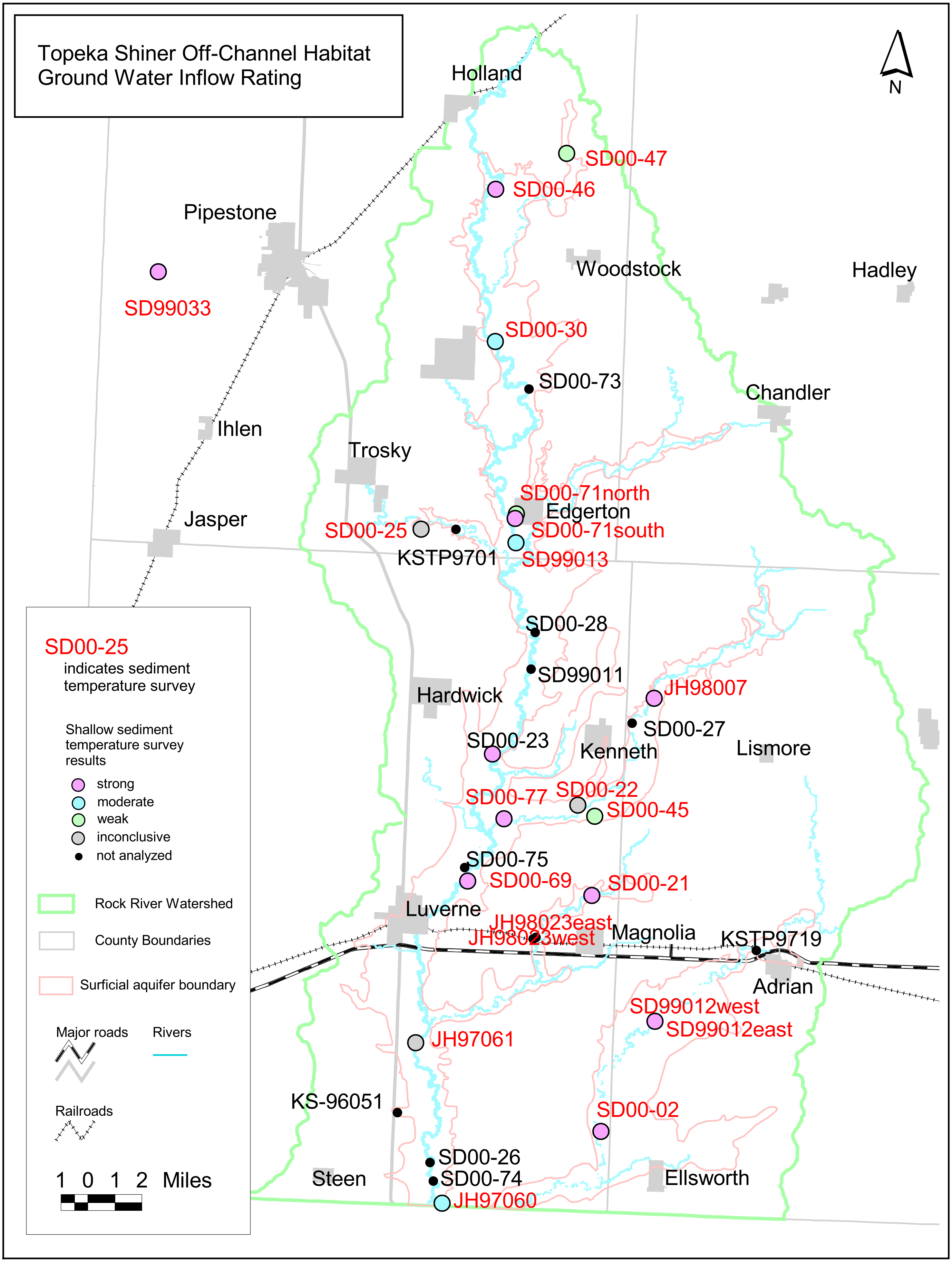
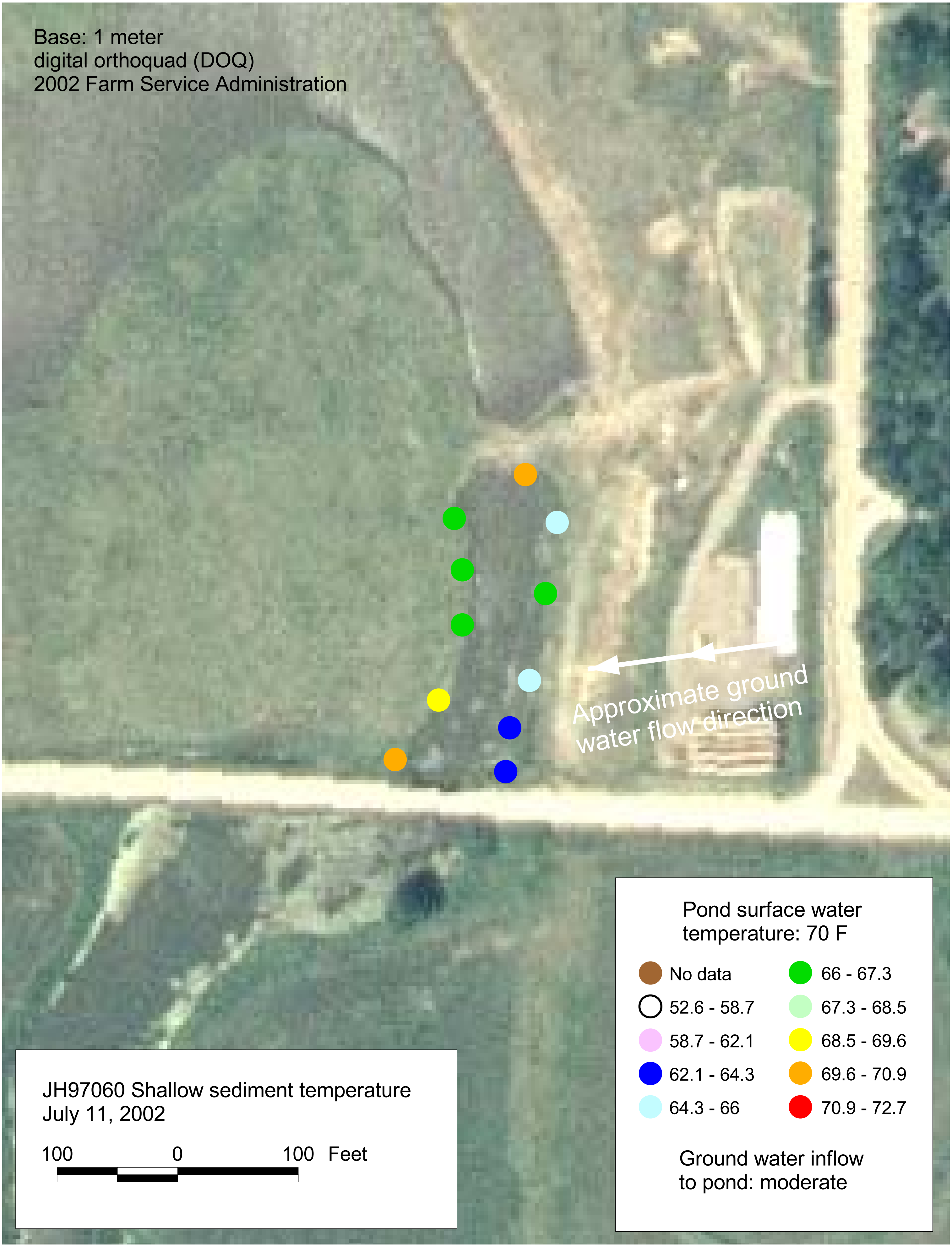
Table 1. Project Data Summary for Off-Channel Habitats

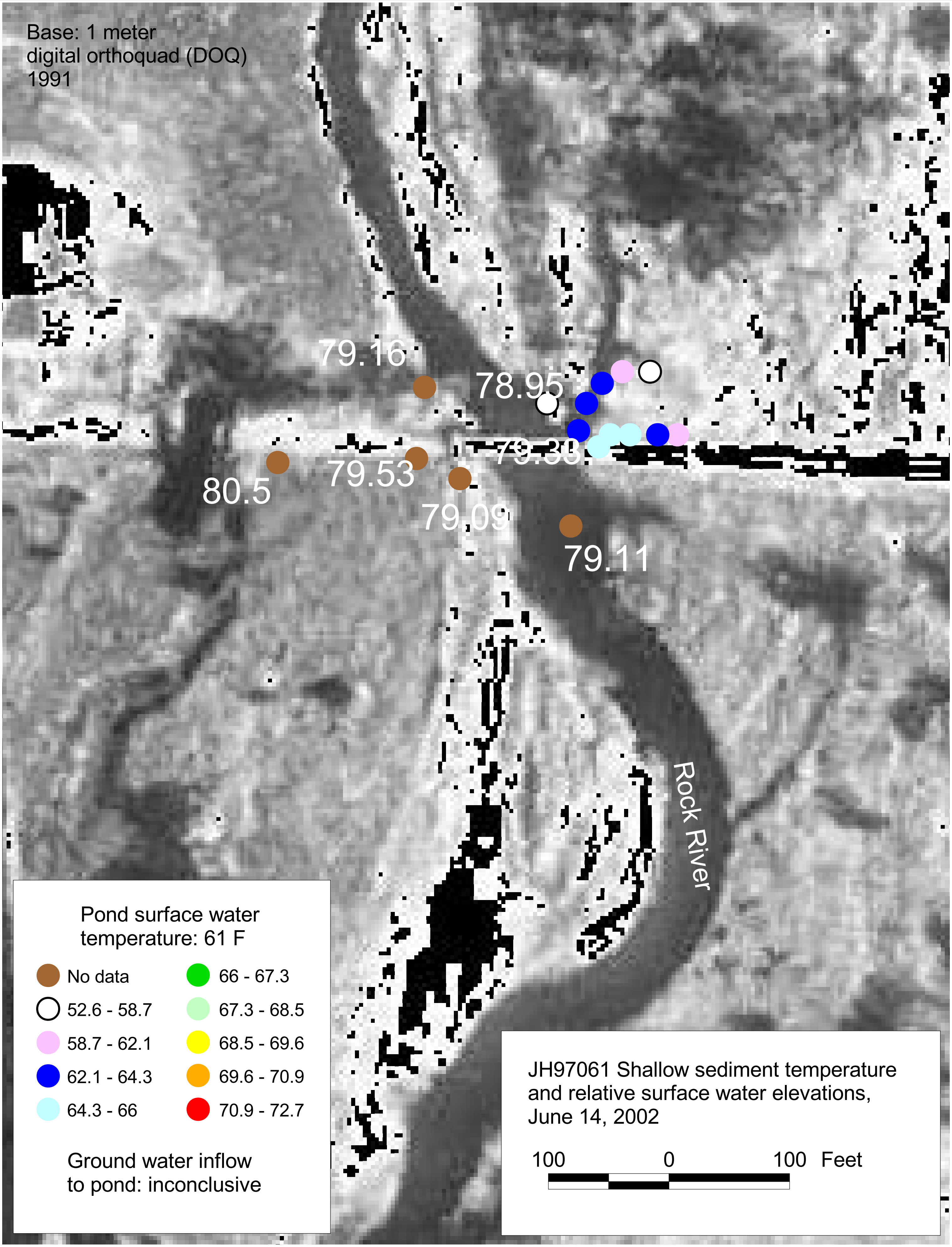
Site identification	Stream	County	Date of sediment temperature survey	Ground-water inflow	Estimated saturated thickness (feet)	Date of 2001 species survey	Topeka shiner occurrence in OCH, 2001	Topeka shiner occurrence in OCH before 2001	Topeka shiner occurrence in-channel, 2001
JH97060	Rock River	Rock	7/11/2002	moderate	15-45	9/27/01	yes	yes	yes
JH97061	Rock River	Rock	6/14/2002	inconclusive	35-45	9/27/01	yes	yes	no
JH98007	Champepedan Cr.	Nobles	9/13/2001	strong	10-30	10/3/01	yes	yes	no
JH98023east	Elk Creek	Rock	NA	NA	20-30	9/26/01	yes	yes	yes
JH98023west	Elk Creek	Rock	NA	NA	20-30	9/26/01	yes	yes	yes
KS-96051	Ash Creek	Rock	NA	NA	15-25	no sample	no sample	no	no sample
KSTP9701	Poplar Creek	Pipestone	NA	NA	10-15	10/4/01	no sample	yes	no sample
KSTP9719	Kanaranzi Creek	Nobles	NA	NA	20-40	no sample	no sample	no	no sample
SD00-02	Kanaranzi Creek	Rock	9/5/2002	strong	20-25	8/21/01	yes	no	yes
SD00-21	Elk Creek	Rock	7/2/2002	strong	15-40	9/27/01	yes	yes	yes
SD00-22	Champepedan Cr.	Rock	9/13/2001	inconclusive	15-25	9/27/01	yes	yes	no
SD00-23	Rock River	Rock	6/13/2002	strong	45-50	10/3/01	yes	yes	no
SD00-25	Poplar Creek	Pipestone	9/14/2001	inconclusive	10-15	10/4/01	yes	yes	no sample
SD00-26	Rock River	Rock	NA	NA	50-55	9/27/01	dry	yes	no sample
SD00-27	Champepedan Cr.	Nobles	NA	NA	20-25	8/21/01	dry	no	no sample
SD00-28	Rock River	Rock	NA	NA	50-55	8/21/01	yes	no	yes
SD00-30	Rock River	Pipestone	7/25/2001	moderate	15-25	8/21/01	yes	no	yes
SD00-45	Champepedan Cr.	Rock	8/29/2001	weak	20-30	8/21/01	yes	no	yes
SD00-46	Rock River	Pipestone	7/25/2001	strong	5-20	10/4/01	no	yes	no
SD00-47	Rock River	Pipestone	7/24/2001	weak	25-30	8/21/01	no	no	no
SD00-69	Rock River	Rock	7/2/2002	strong	40-50	8/23/01	no	no	yes
SD00-71north	Rock River	Rock	8/28/2001	weak	55-60	8/21/01	no	no	yes
SD00-71south	Rock River	Rock	8/28/2001	strong	45-50	8/21/01	no	no	yes
SD00-73	Rock River	Pipestone	NA	NA	25-30	no sample	no sample	no	no sample
SD00-74	Rock River	Rock	NA	NA	20-30	8/23/01	dry	no	no
SD00-74south	Rock River	Rock	NA	NA	20-30	8/23/01	yes	no	yes
SD00-75	Rock River	Rock	NA	NA	40-50	8/21/01	no	no	no sample
SD00-77	Champepedan Cr.	Rock	6/13/2002	strong	15-35	8/23/01	yes	no	no
SD99011	Rock River	Rock	NA	NA	20-50	10/3/01	no sample	yes	no sample
SD99012east	Kanaranzi Creek	Nobles	9/3/2002	strong	25-30	9/26/01	yes	yes	yes
SD99012west	Kanaranzi Creek	Nobles	NA	NA	30-35	9/26/01	yes	yes	yes
SD99013	Rock River	Pipestone	6/12/2002	moderate	45-50	10/4/01	yes	yes	yes
SD99033	Pipestone Creek	Pipestone	8/27/2001	strong	NA	8/21/01	yes	yes	yes

Appendix A – Sediment Temperature Survey Maps

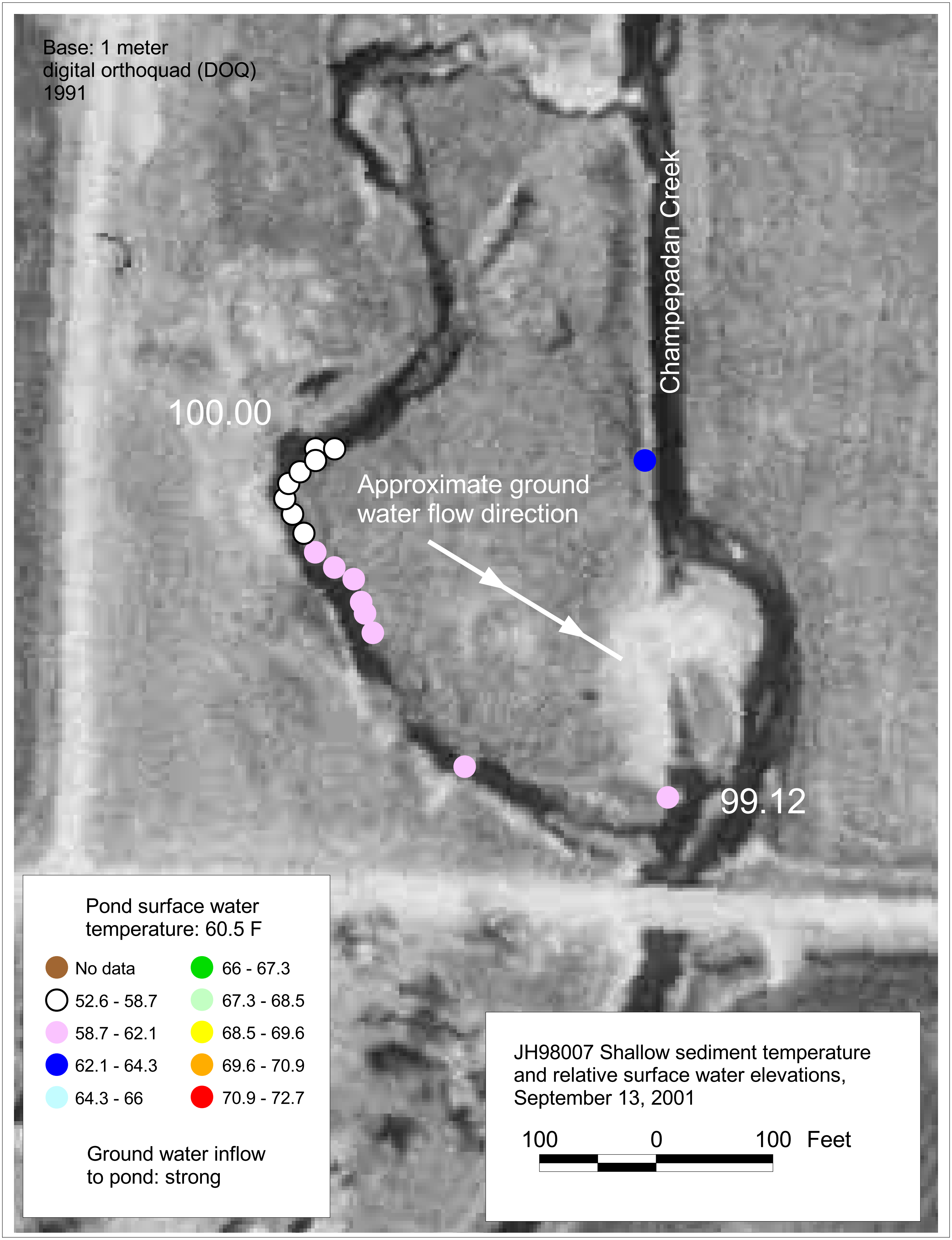


Topeka Shiner Off-Channel Habitat
Ground Water Inflow Rating
N
Holland
SD00-47
SD00-46
Pipestone
SD99033
Woodstock
Hadley
SD00-30
SD00-73
Chandler
Ihlen
Trosky
SD00-71north
Edgerton
SD00-71south
Jasper
SD00-25
KSTP9701
SD99013
SD00-28
SD99011
Hardwick
JH98007
SD00-27
SD00-23
Kenneth
Lismore
SD00-77
SD00-22
SD00-45
SD00-75
SD00-69
SD00-21
Luverne
JH98023east
JH98023west
Magnolia
KSTP9719
Adrian
SD99012west
SD99012east
JH97061
KS-96051
SD00-02
SD00-26
SD00-74
Steen
Ellsworth
JH97060
SD00-25
indicates sediment temperature survey
Shallow sediment temperature survey results
strong
moderate
weak
inconclusive
not analyzed
Rock River Watershed
County Boundaries
Surficial aquifer boundary
Major roads
Rivers
Railroads
1 0 1 2 Miles

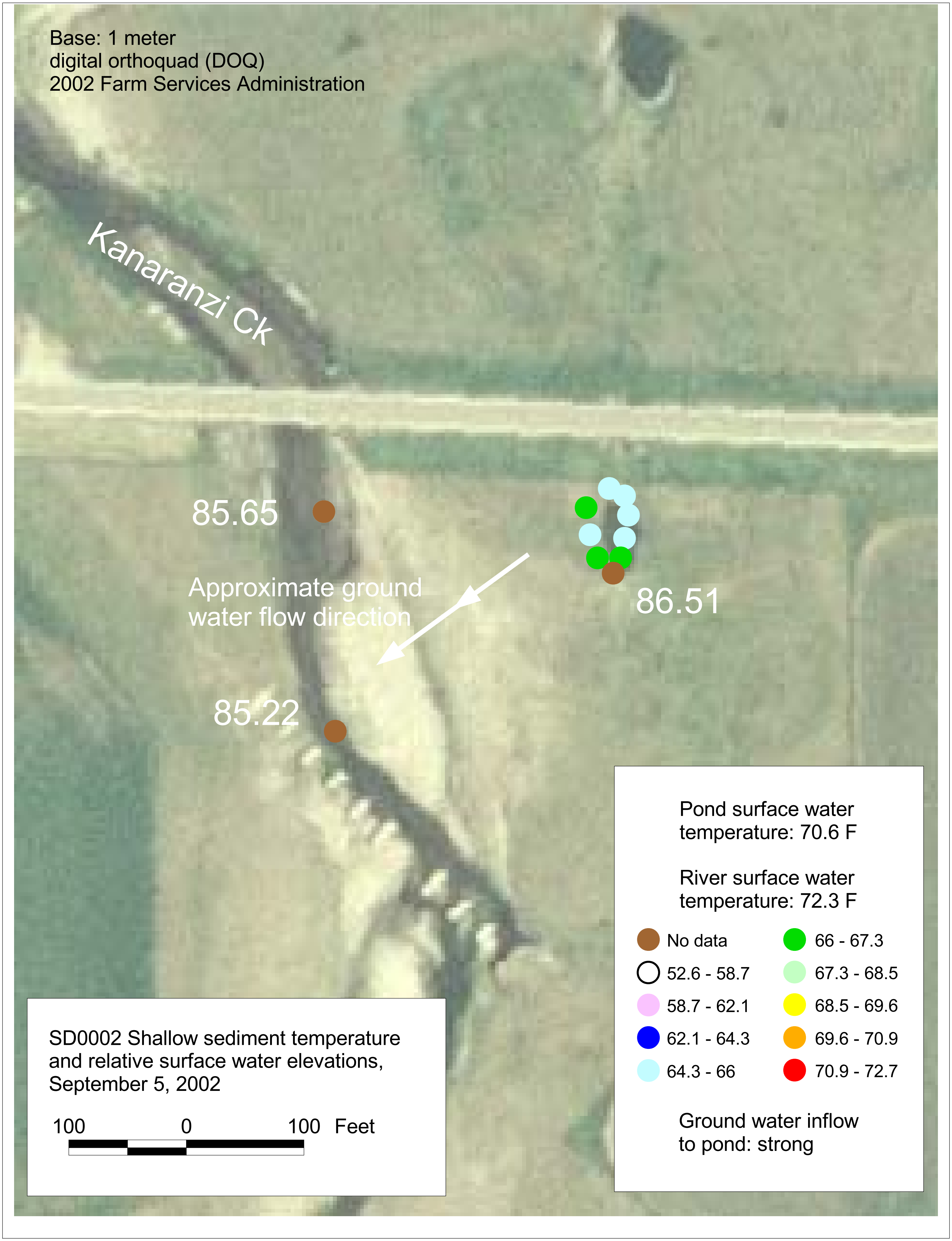

Base: 1 meter
digital orthoquad (DOQ)
2002 Farm Service Administration
Approximate ground
water flow direction
Pond surface water
temperature: 70 F
No data
52.6 - 58.7
58.7 - 62.1
62.1 - 64.3
64.3 - 66
66 - 67.3
67.3 - 68.5
68.5 - 69.6
69.6 - 70.9
70.9 - 72.7
Ground water inflow
to pond: moderate
JH97060 Shallow sediment temperature
July 11, 2002
100
0
100
Feet



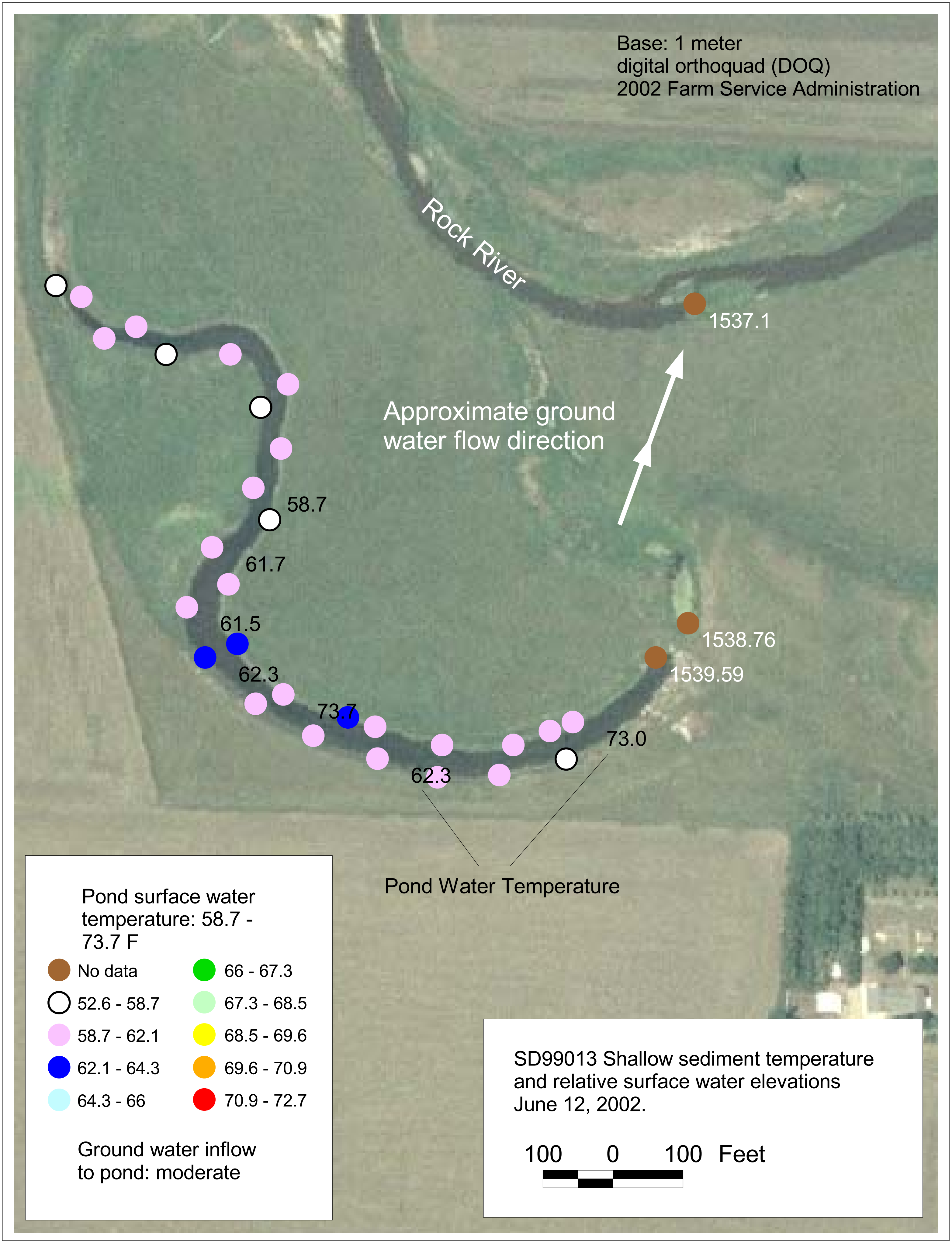
Base: 1 meter
digital orthoquad (DOQ)
1991
79.16
78.95
80.5
79.53
79.09
79.11
Rock River
Pond surface water
temperature: 61 F
No data
52.6 - 58.7
58.7 - 62.1
62.1 - 64.3
64.3 - 66
66 - 67.3
67.3 - 68.5
68.5 - 69.6
69.6 - 70.9
70.9 - 72.7
Ground water inflow
to pond: inconclusive
JH97061 Shallow sediment temperature
and relative surface water elevations,
June 14, 2002
100
0
100 Feet

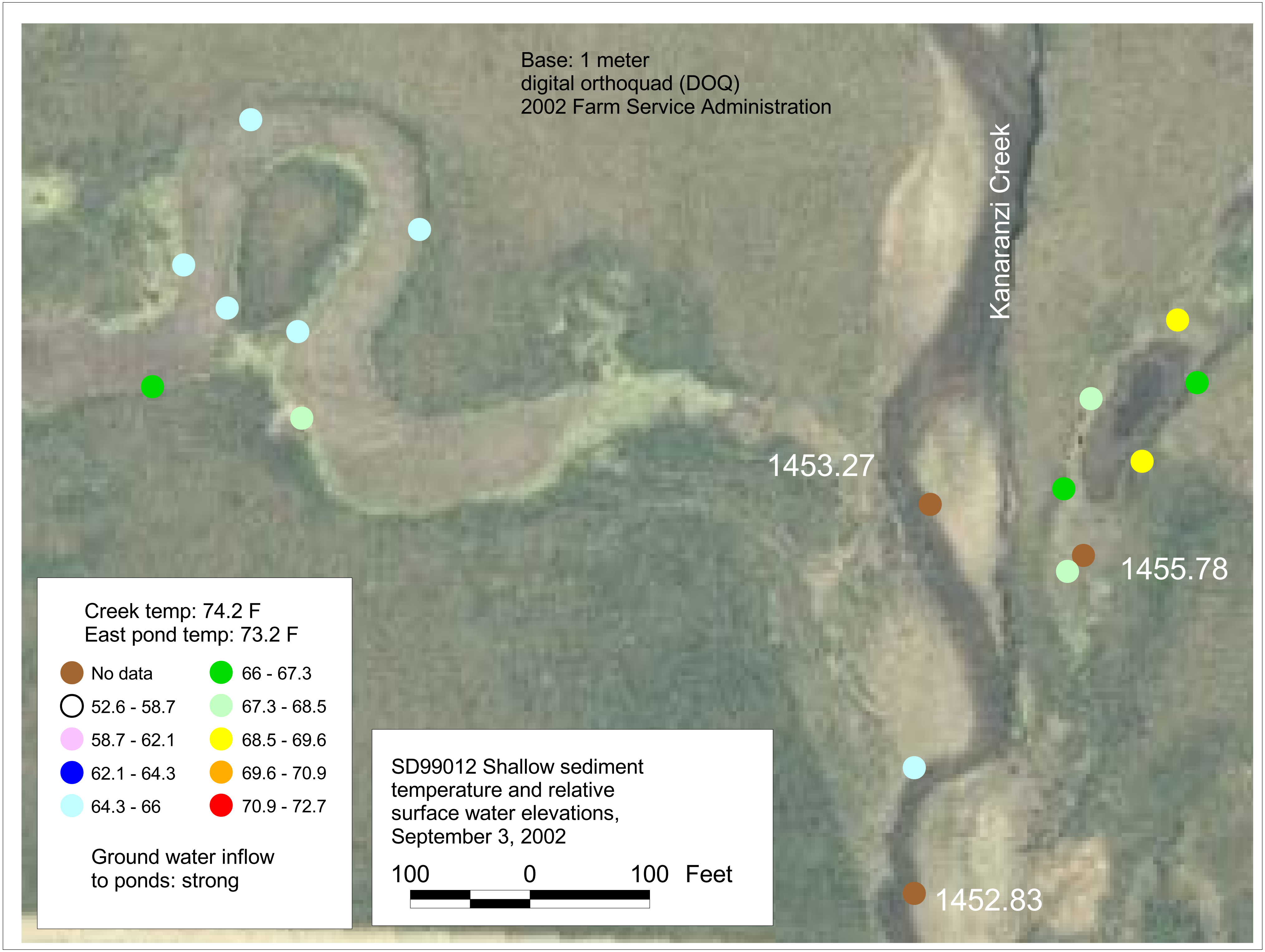


Base: 1 meter
digital orthoquad (DOQ)
1991
Champepadan Creek
100.00
Approximate ground
water flow direction
99.12
Pond surface water
temperature: 60.5 F
No data
52.6 - 58.7
58.7 - 62.1
62.1 - 64.3
64.3 - 66
66 - 67.3
67.3 - 68.5
68.5 - 69.6
69.6 - 70.9
70.9 - 72.7
Ground water inflow
to pond: strong
JH98007 Shallow sediment temperature
and relative surface water elevations,
September 13, 2001
100 0 100 Feet

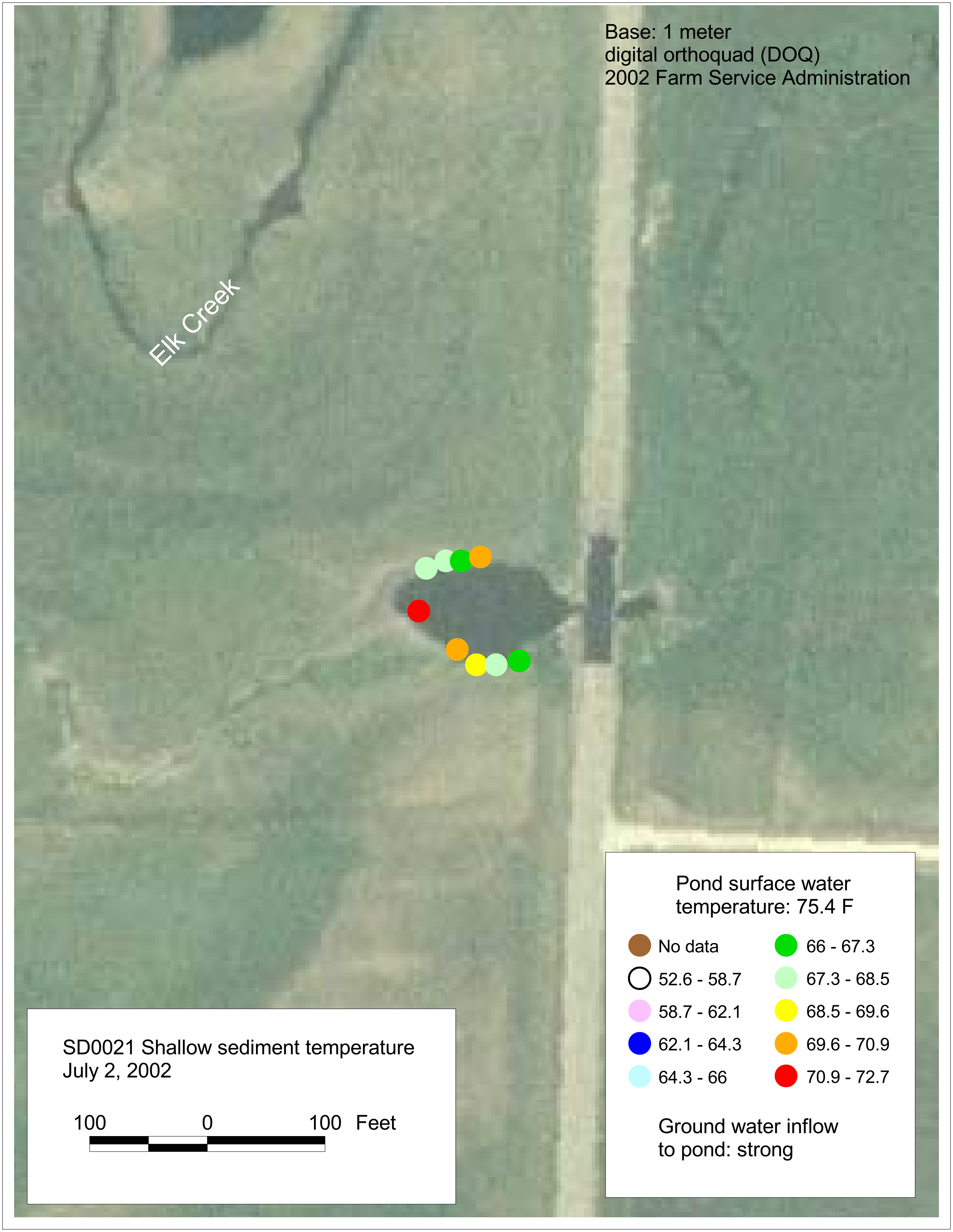


Base: 1 meter
digital orthoquad (DOQ)
2002 Farm Services Administration
Kanaranzi Ck
85.65
86.51
Approximate ground
water flow direction
85.22
Pond surface water
temperature: 70.6 F
River surface water
temperature: 72.3 F
No data
52.6 - 58.7
58.7 - 62.1
62.1 - 64.3
64.3 - 66
66 - 67.3
67.3 - 68.5
68.5 - 69.6
69.6 - 70.9
70.9 - 72.7
Ground water inflow
to pond: strong
SD0002 Shallow sediment temperature
and relative surface water elevations,
September 5, 2002
100
0
100
Feet

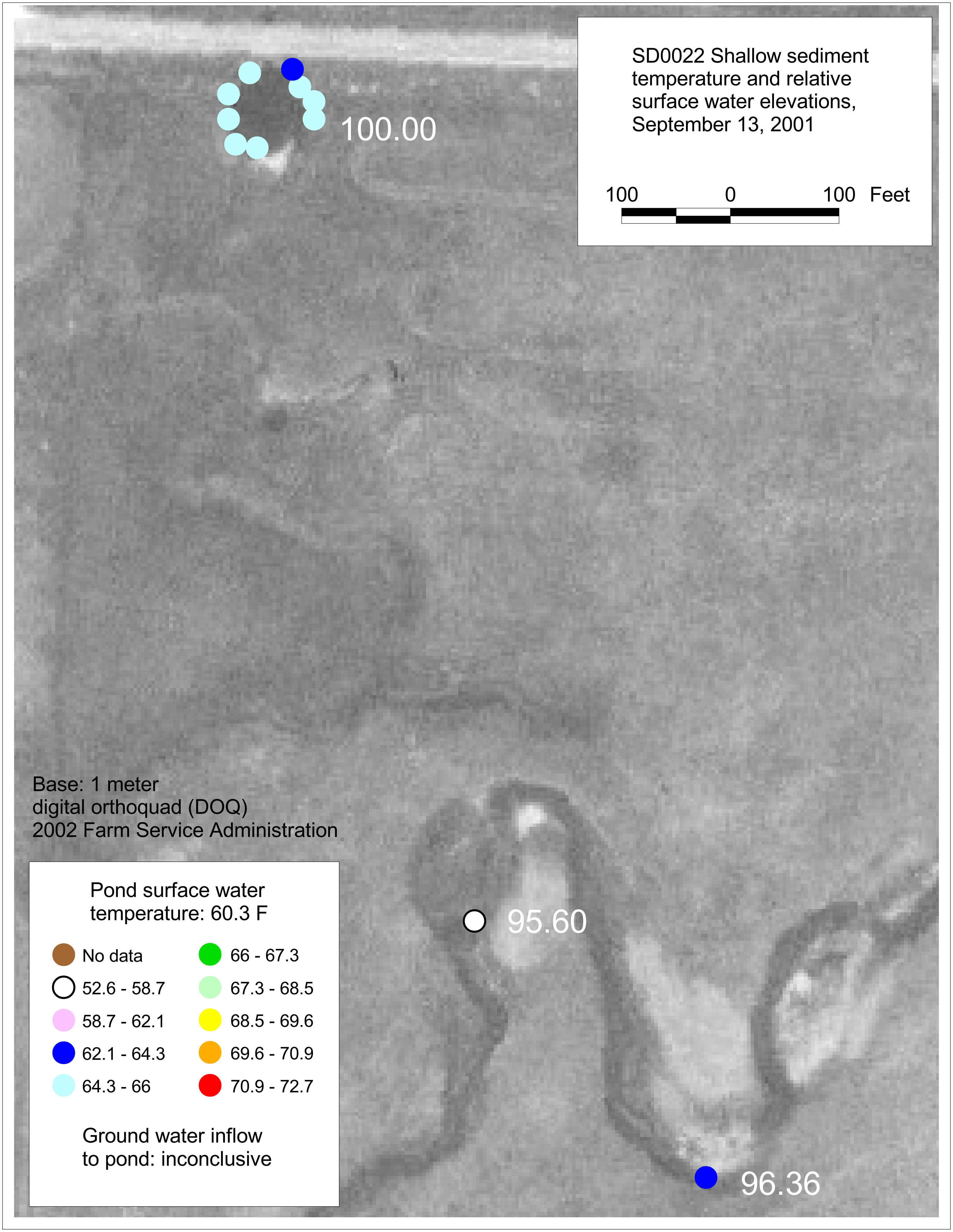

Base: 1 meter
digital orthoquad (DOQ)
2002 Farm Service Administration
Rock River
1537.1
Approximate ground
water flow direction
58.7
61.7
61.5
62.3
73.7
62.3
73.0
1538.76
1539.59
Pond Water Temperature
Pond surface water
temperature: 58.7 -
73.7 F
No data
52.6 - 58.7
58.7 - 62.1
62.1 - 64.3
64.3 - 66
66 - 67.3
67.3 - 68.5
68.5 - 69.6
69.6 - 70.9
70.9 - 72.7
Ground water inflow
to pond: moderate
SD99013 Shallow sediment temperature
and relative surface water elevations
June 12, 2002.
100 0 100 Feet



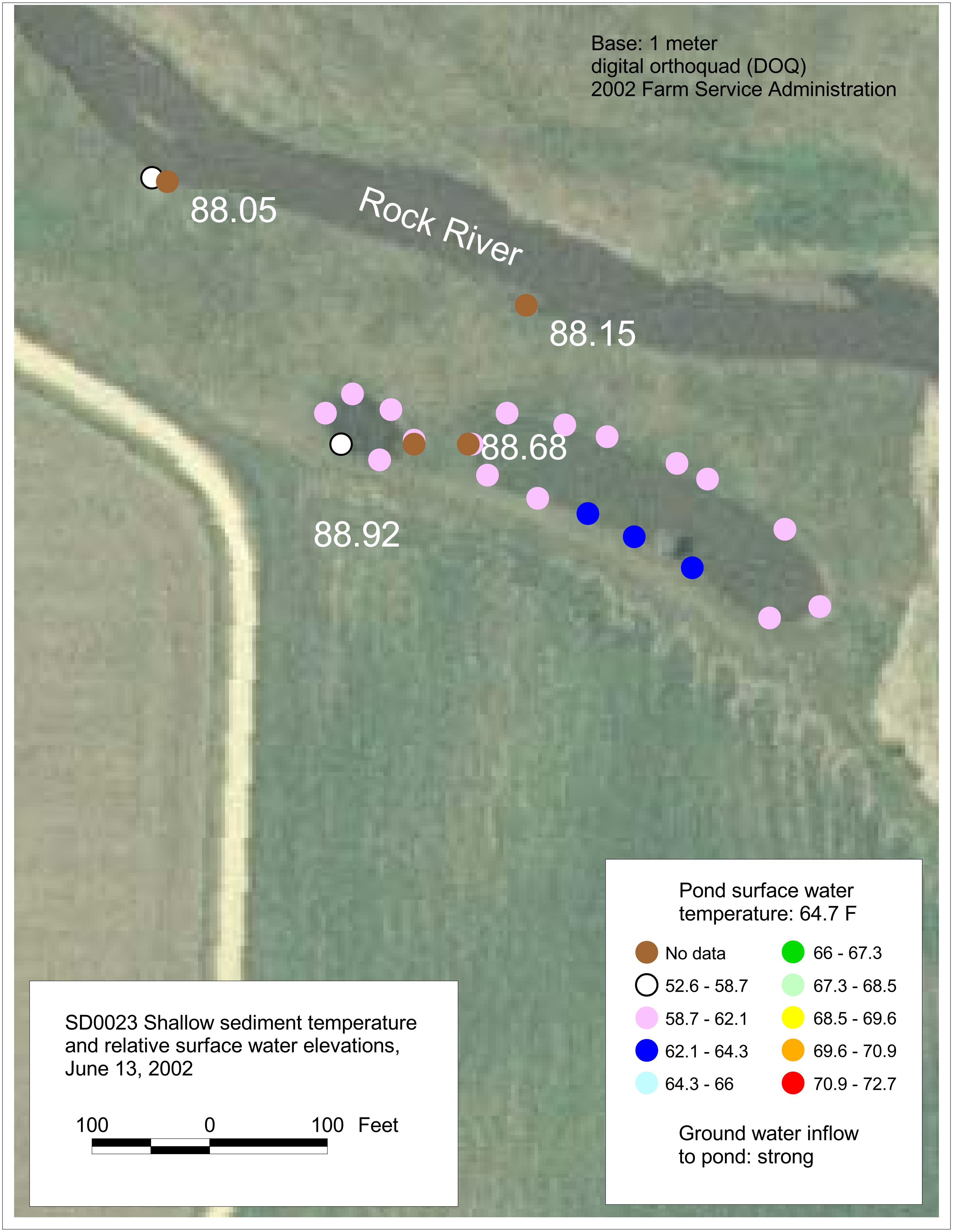
Base: 1 meter
digital orthoquad (DOQ)
2002 Farm Service Administration
Kanaranzi Creek
1453.27
1455.78
1452.83
Creek temp: 74.2 F
East pond temp: 73.2 F
No data
52.6 - 58.7
58.7 - 62.1
62.1 - 64.3
64.3 - 66
66 - 67.3
67.3 - 68.5
68.5 - 69.6
69.6 - 70.9
70.9 - 72.7
Ground water inflow
to ponds: strong
SD99012 Shallow sediment
temperature and relative
surface water elevations,
September 3, 2002
100
0
100
Feet

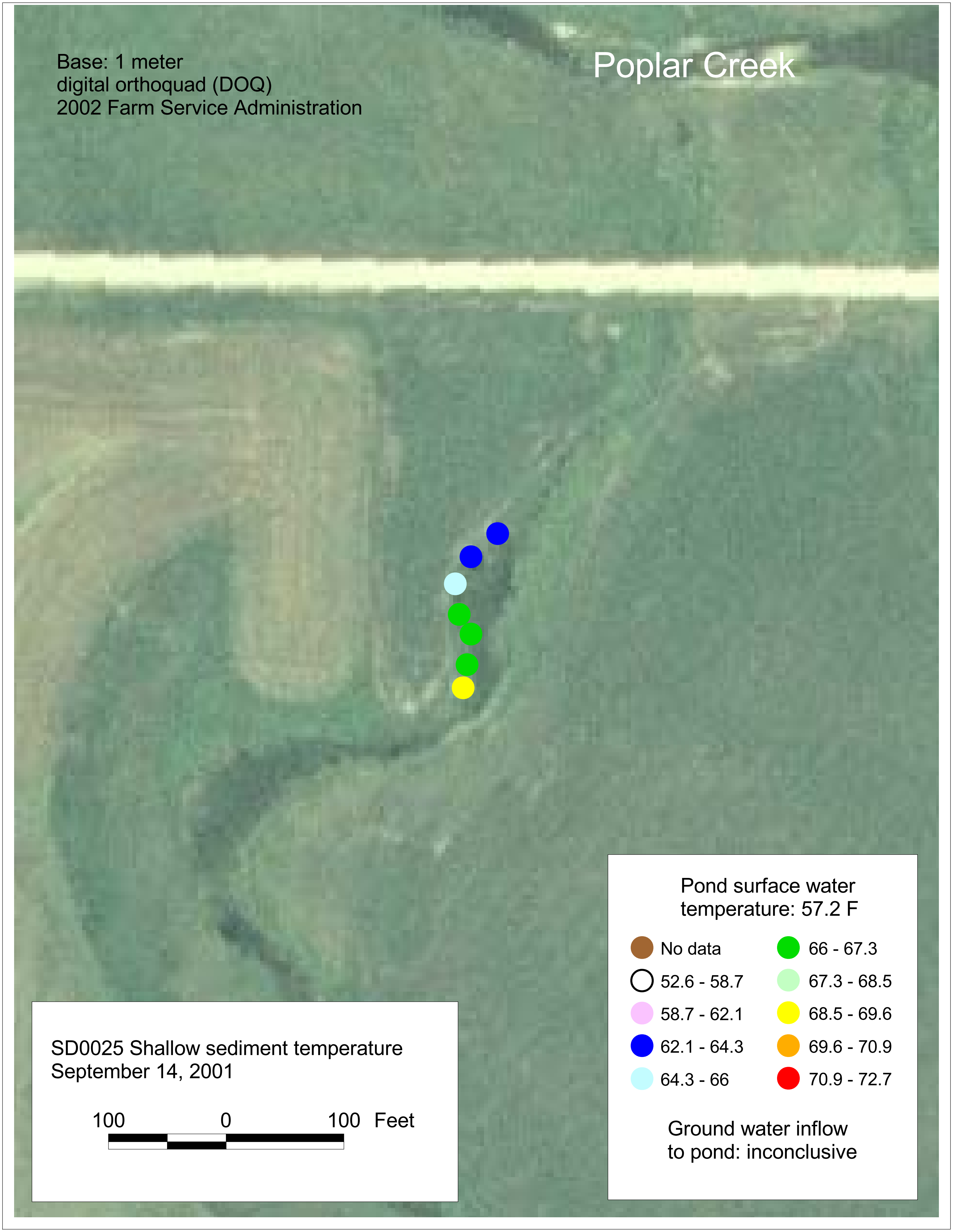


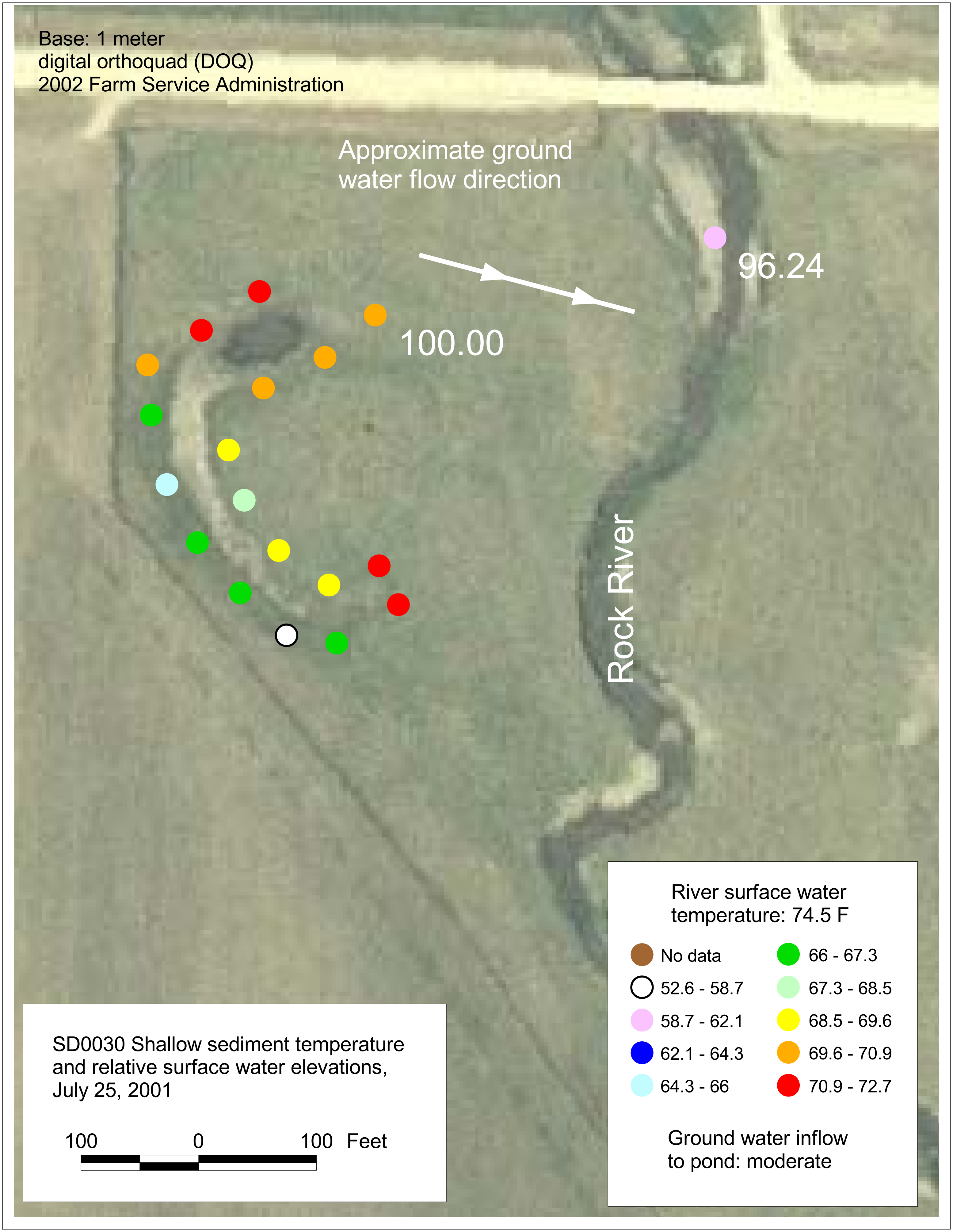
Base: 1 meter
digital orthoquad (DOQ)
2002 Farm Service Administration
Elk Creek
Pond surface water
temperature: 75.4 F
No data
52.6 - 58.7
58.7 - 62.1
62.1 - 64.3
64.3 - 66
66 - 67.3
67.3 - 68.5
68.5 - 69.6
69.6 - 70.9
70.9 - 72.7
Ground water inflow
to pond: strong
SD0021 Shallow sediment temperature
July 2, 2002
100
0
100
Feet



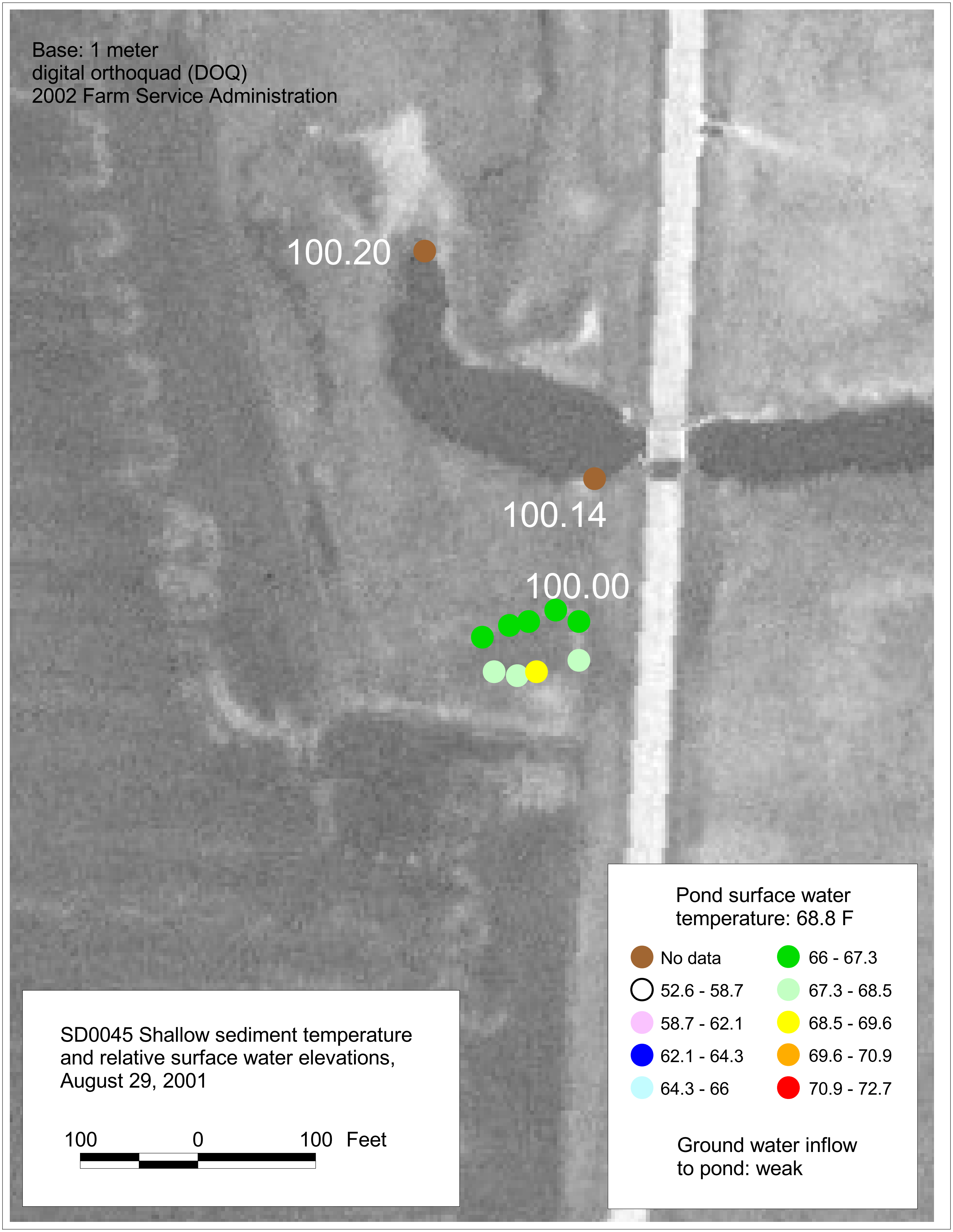
SD0022 Shallow sediment temperature and relative surface water elevations, September 13, 2001
100 0 100 Feet
100.00
95.60
96.36
Base: 1 meter digital orthoquad (DOQ) 2002 Farm Service Administration
Pond surface water temperature: 60.3 F
No data
52.6 - 58.7
58.7 - 62.1
62.1 - 64.3
64.3 - 66
66 - 67.3
67.3 - 68.5
68.5 - 69.6
69.6 - 70.9
70.9 - 72.7
Ground water inflow to pond: inconclusive

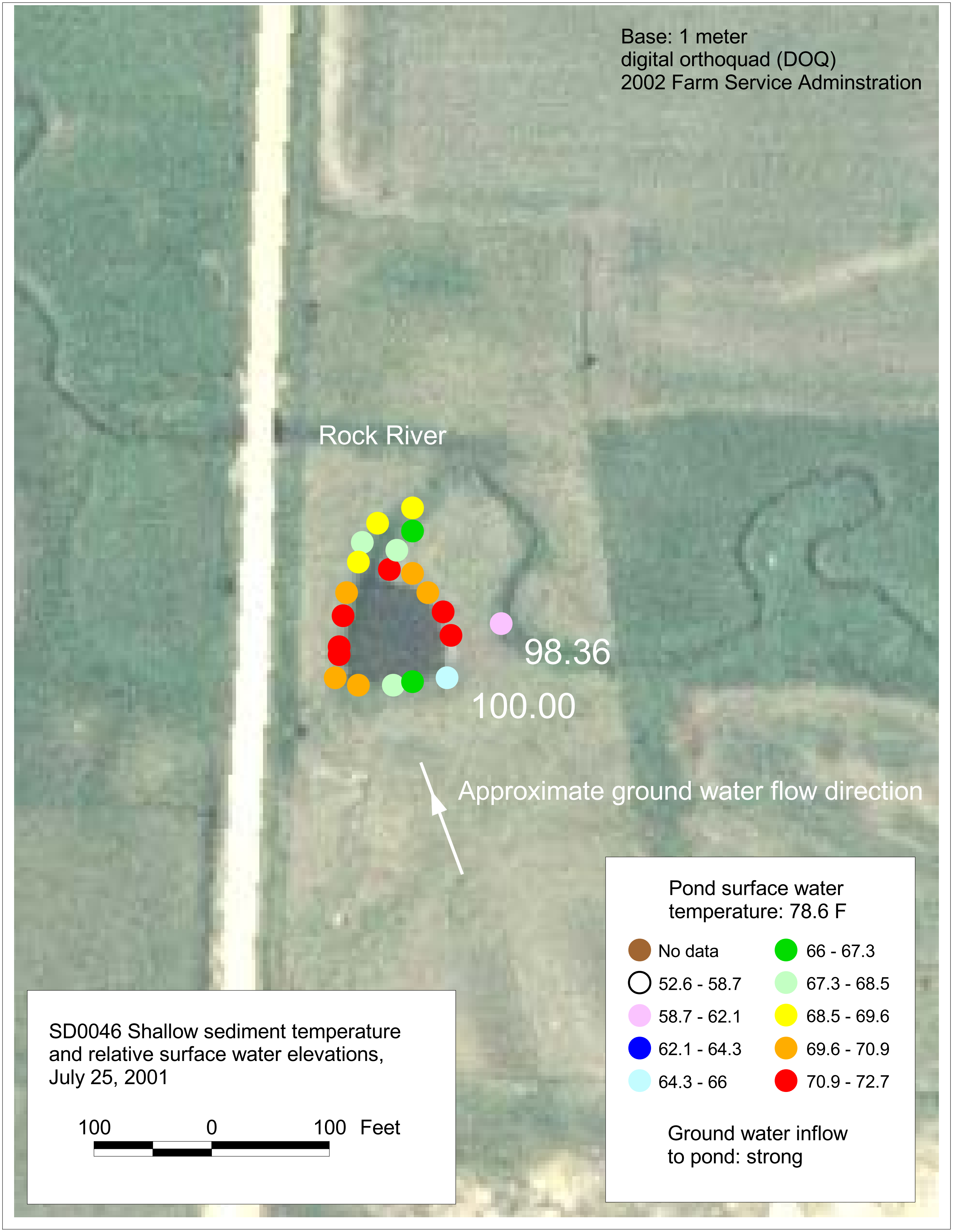

Base: 1 meter
digital orthoquad (DOQ)
2002 Farm Service Administration
Rock River
88.05
88.15
88.68
88.92
Pond surface water
temperature: 64.7 F
No data
52.6 - 58.7
58.7 - 62.1
62.1 - 64.3
64.3 - 66
66 - 67.3
67.3 - 68.5
68.5 - 69.6
69.6 - 70.9
70.9 - 72.7
Ground water inflow
to pond: strong
SD0023 Shallow sediment temperature
and relative surface water elevations,
June 13, 2002
100
0
100
Feet

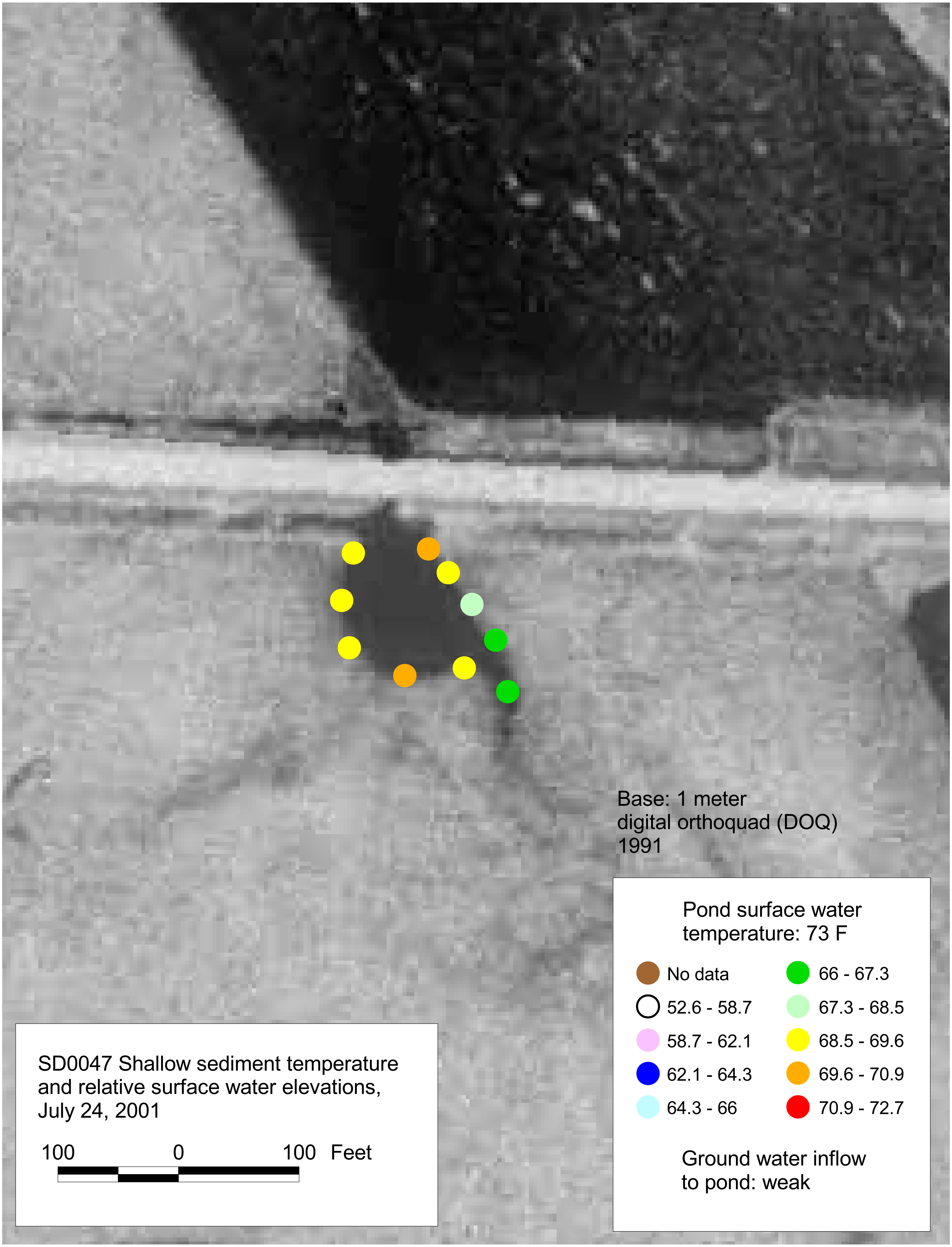

Base: 1 meter
digital orthoquad (DOQ)
2002 Farm Service Administration
Poplar Creek
Pond surface water
temperature: 57.2 F
No data
52.6 - 58.7
58.7 - 62.1
62.1 - 64.3
64.3 - 66
66 - 67.3
67.3 - 68.5
68.5 - 69.6
69.6 - 70.9
70.9 - 72.7
Ground water inflow
to pond: inconclusive
SD0025 Shallow sediment temperature
September 14, 2001
100
0
100
Feet

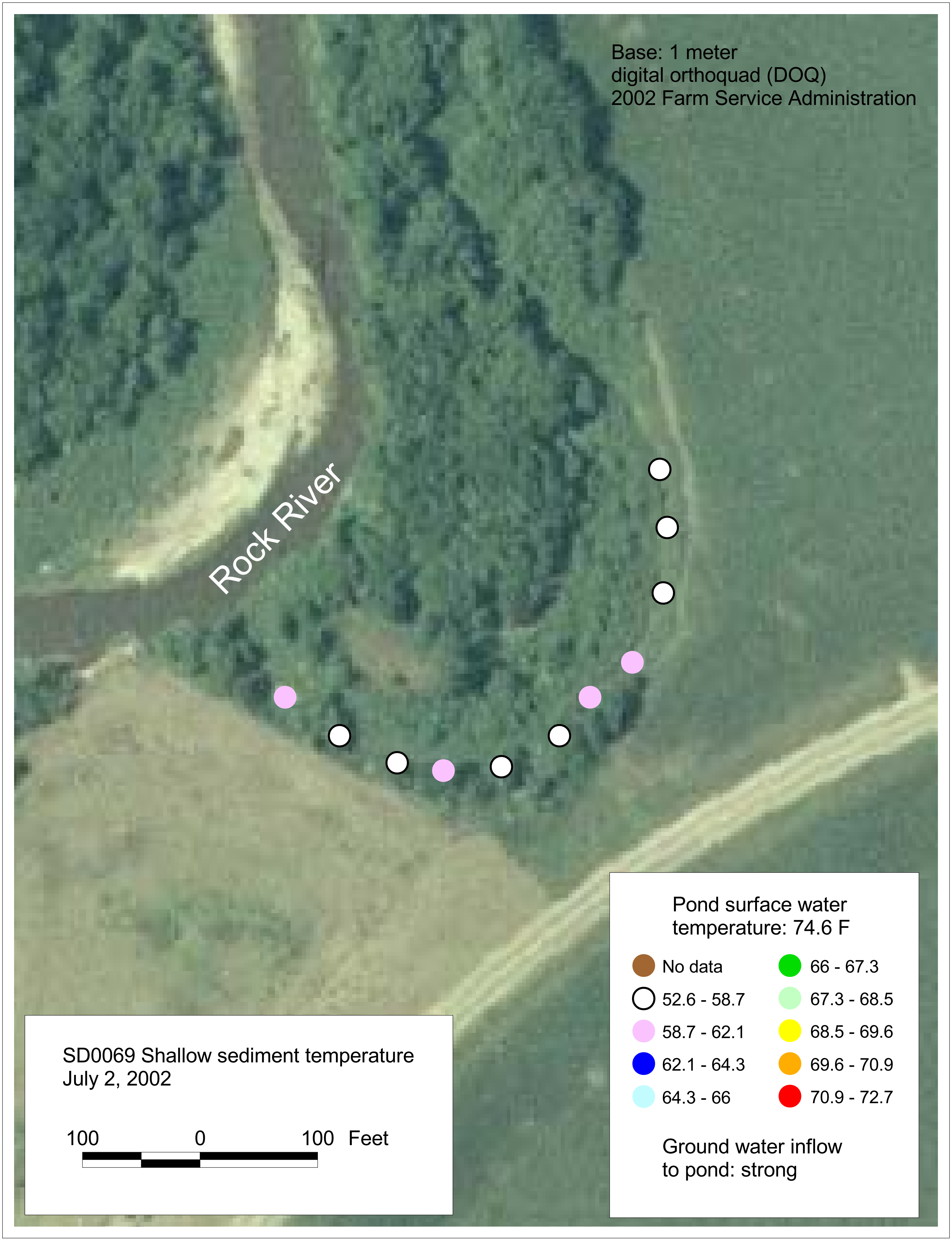


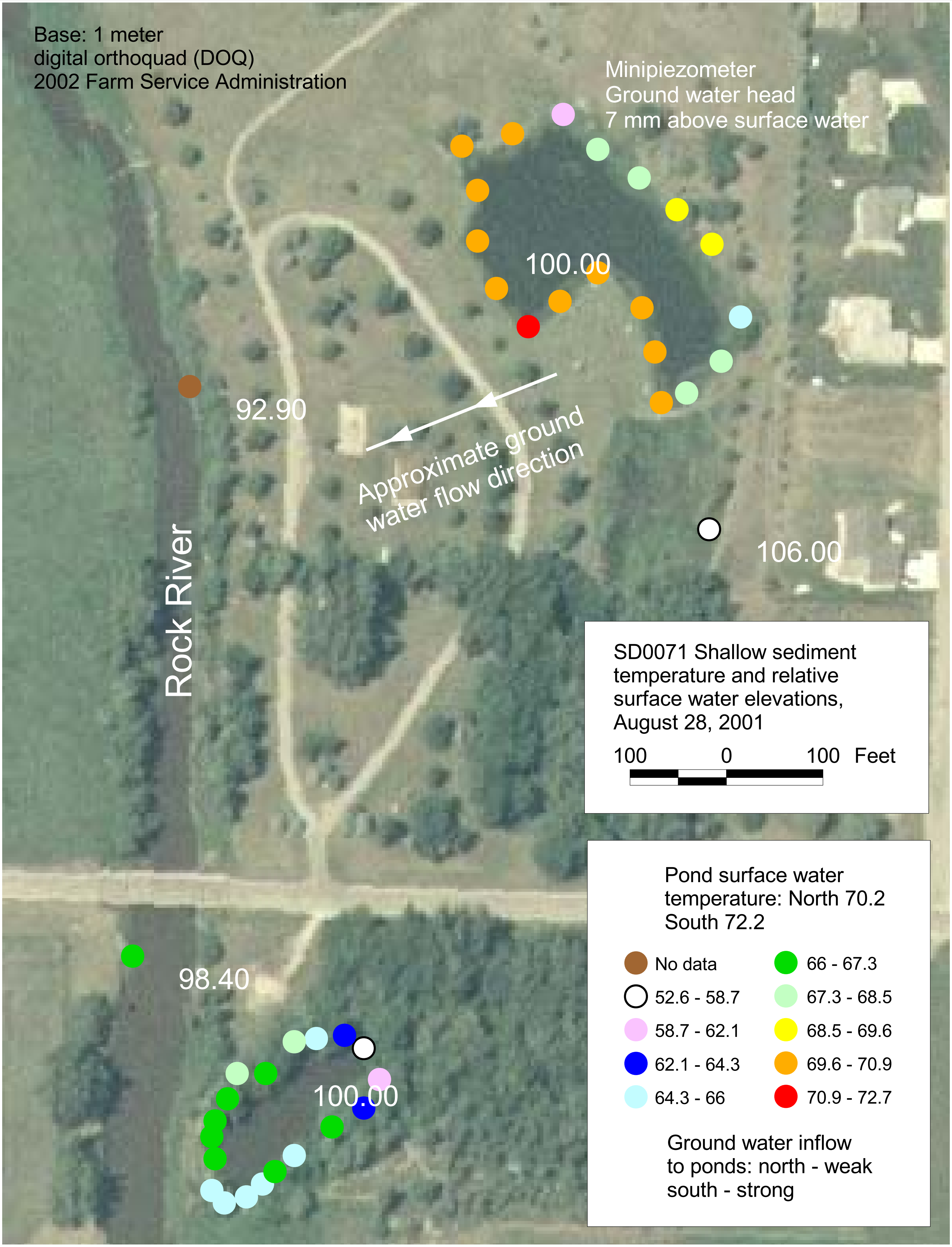
Base: 1 meter
digital orthoquad (DOQ)
2002 Farm Service Administration
Approximate ground water flow direction
96.24
100.00
Rock River
River surface water temperature: 74.5 F
No data
52.6 - 58.7
58.7 - 62.1
62.1 - 64.3
64.3 - 66
66 - 67.3
67.3 - 68.5
68.5 - 69.6
69.6 - 70.9
70.9 - 72.7
Ground water inflow to pond: moderate
SD0030 Shallow sediment temperature and relative surface water elevations, July 25, 2001
100
0
100
Feet

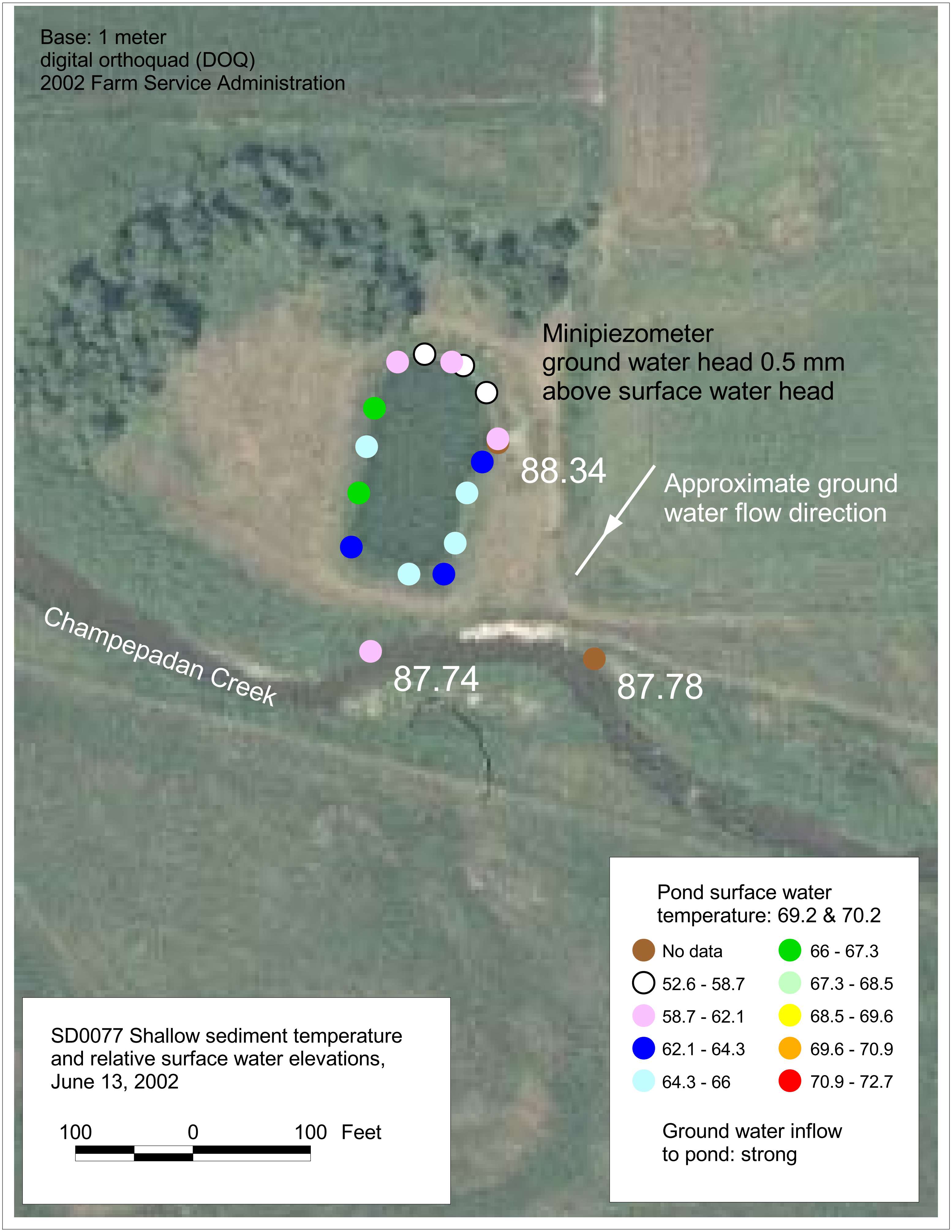

Base: 1 meter
digital orthoquad (DOQ)
2002 Farm Service Administration
100.20
100.14
100.00
Pond surface water
temperature: 68.8 F
No data
52.6 - 58.7
58.7 - 62.1
62.1 - 64.3
64.3 - 66
66 - 67.3
67.3 - 68.5
68.5 - 69.6
69.6 - 70.9
70.9 - 72.7
Ground water inflow
to pond: weak
SD0045 Shallow sediment temperature
and relative surface water elevations,
August 29, 2001
100
0
100
Feet

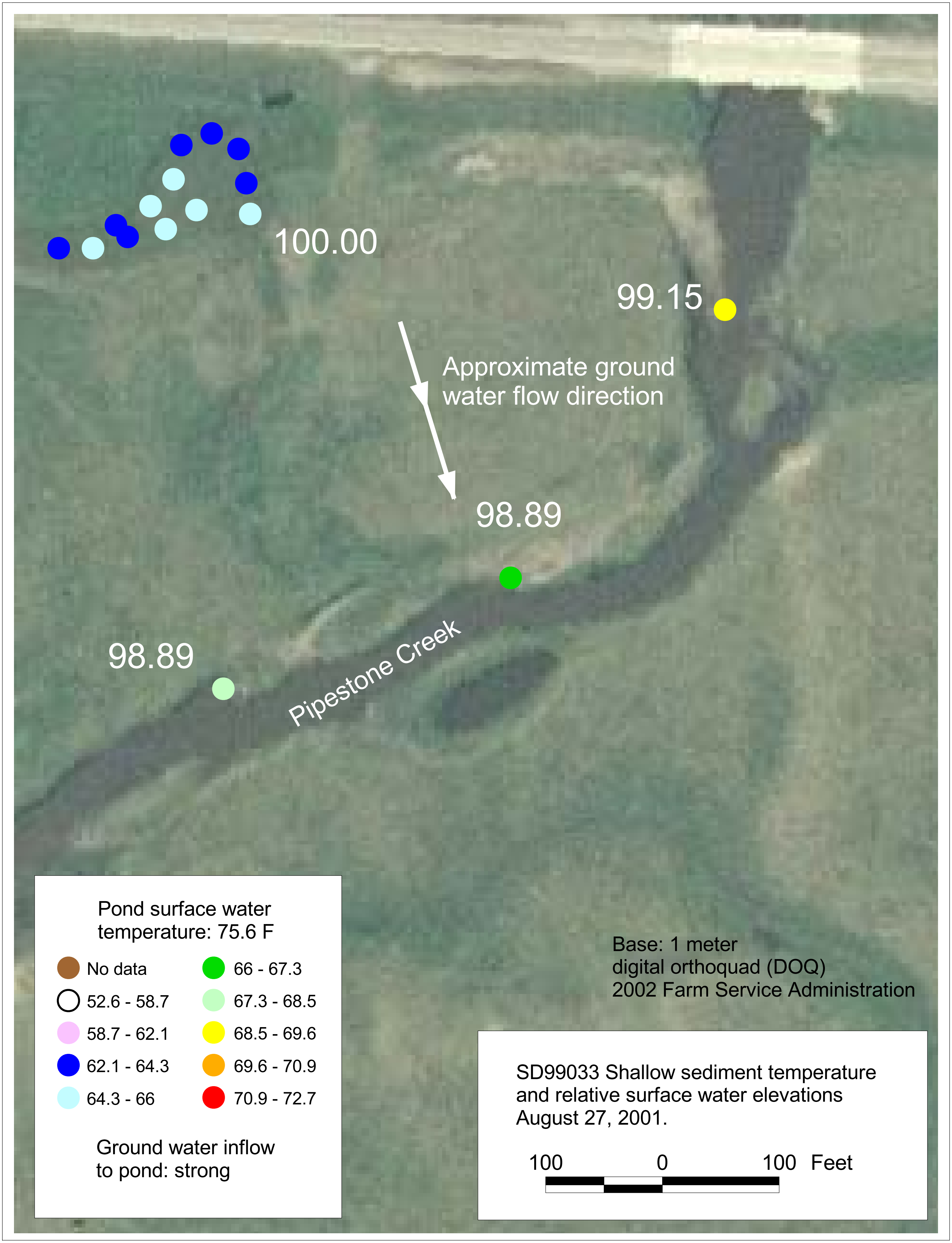

Base: 1 meter
digital orthoquad (DOQ)
2002 Farm Service Adminstration
Rock River
98.36
100.00
Approximate ground water flow direction
Pond surface water
temperature: 78.6 F
No data
52.6 - 58.7
58.7 - 62.1
62.1 - 64.3
64.3 - 66
66 - 67.3
67.3 - 68.5
68.5 - 69.6
69.6 - 70.9
70.9 - 72.7
Ground water inflow
to pond: strong
SD0046 Shallow sediment temperature
and relative surface water elevations,
July 25, 2001
100
0
100
Feet


Base: 1 meter
digital orthoquad (DOQ)
1991
Pond surface water
temperature: 73 F
No data
52.6 - 58.7
58.7 - 62.1
62.1 - 64.3
64.3 - 66
66 - 67.3
67.3 - 68.5
68.5 - 69.6
69.6 - 70.9
70.9 - 72.7
Ground water inflow
to pond: weak
SD0047 Shallow sediment temperature
and relative surface water elevations,
July 24, 2001
100
0
100
Feet


Base: 1 meter
digital orthoquad (DOQ)
2002 Farm Service Administration
Rock River
Pond surface water
temperature: 74.6 F
No data
52.6 - 58.7
58.7 - 62.1
62.1 - 64.3
64.3 - 66
66 - 67.3
67.3 - 68.5
68.5 - 69.6
69.6 - 70.9
70.9 - 72.7
Ground water inflow
to pond: strong
SD0069 Shallow sediment temperature
July 2, 2002
100
0
100
Feet


Base: 1 meter
digital orthoquad (DOQ)
2002 Farm Service Administration
Minipiezometer
Ground water head
7 mm above surface water
100.00
92.90
Approximate ground
water flow direction
106.00
Rock River
98.40
100.00
SD0071 Shallow sediment
temperature and relative
surface water elevations,
August 28, 2001
100 0 100 Feet
Pond surface water
temperature: North 70.2
South 72.2
No data
52.6 - 58.7
58.7 - 62.1
62.1 - 64.3
64.3 - 66
66 - 67.3
67.3 - 68.5
68.5 - 69.6
69.6 - 70.9
70.9 - 72.7
Ground water inflow
to ponds: north - weak
south - strong


Base: 1 meter
digital orthoquad (DOQ)
2002 Farm Service Administration
Minipiezometer
ground water head 0.5 mm
above surface water head
88.34
Approximate ground
water flow direction
Champepadan Creek
87.74
87.78
Pond surface water
temperature: 69.2 & 70.2
No data
52.6 - 58.7
58.7 - 62.1
62.1 - 64.3
64.3 - 66
66 - 67.3
67.3 - 68.5
68.5 - 69.6
69.6 - 70.9
70.9 - 72.7
Ground water inflow
to pond: strong
SD0077 Shallow sediment temperature
and relative surface water elevations,
June 13, 2002
100
0
100
Feet


100.00
99.15
Approximate ground water flow direction
98.89
98.89
Pipestone Creek
Pond surface water temperature: 75.6 F
No data
52.6 - 58.7
58.7 - 62.1
62.1 - 64.3
64.3 - 66
66 - 67.3
67.3 - 68.5
68.5 - 69.6
69.6 - 70.9
70.9 - 72.7
Ground water inflow to pond: strong
Base: 1 meter digital orthoquad (DOQ) 2002 Farm Service Administration
SD99033 Shallow sediment temperature and relative surface water elevations August 27, 2001.
100
0
100
Feet

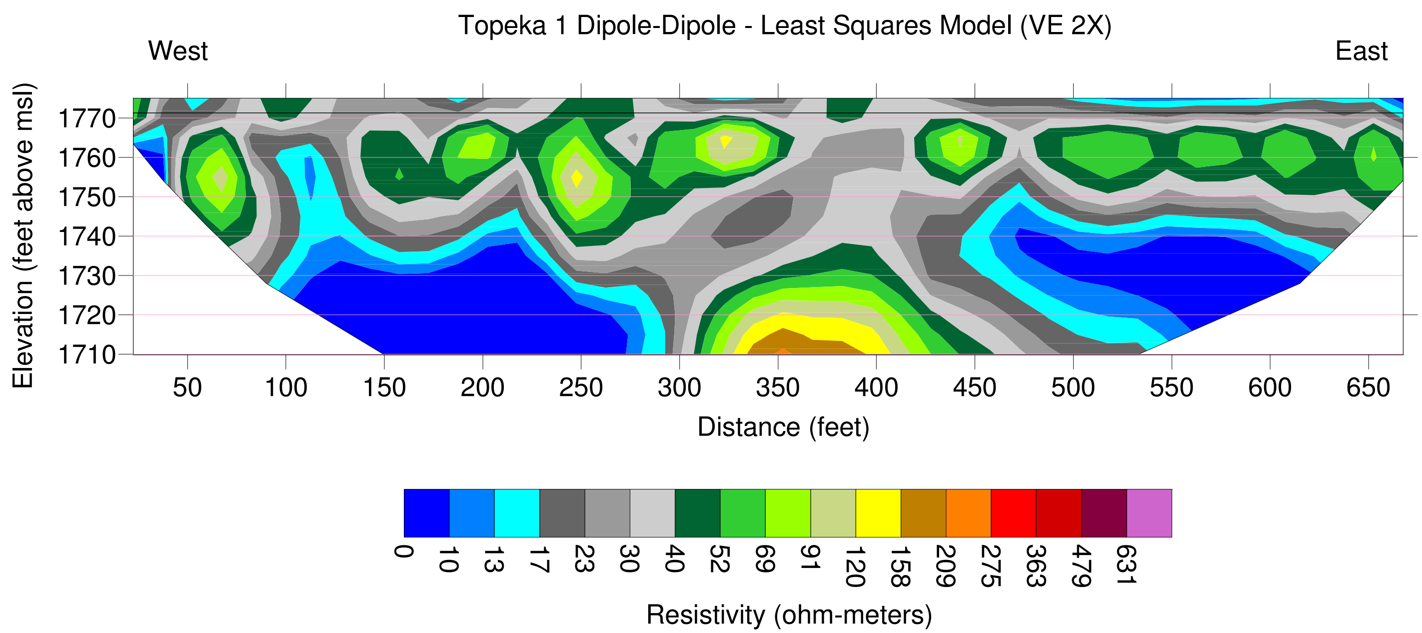
Appendix B – Surface Resistivity Images

Electrical Resistivity Imaging Method

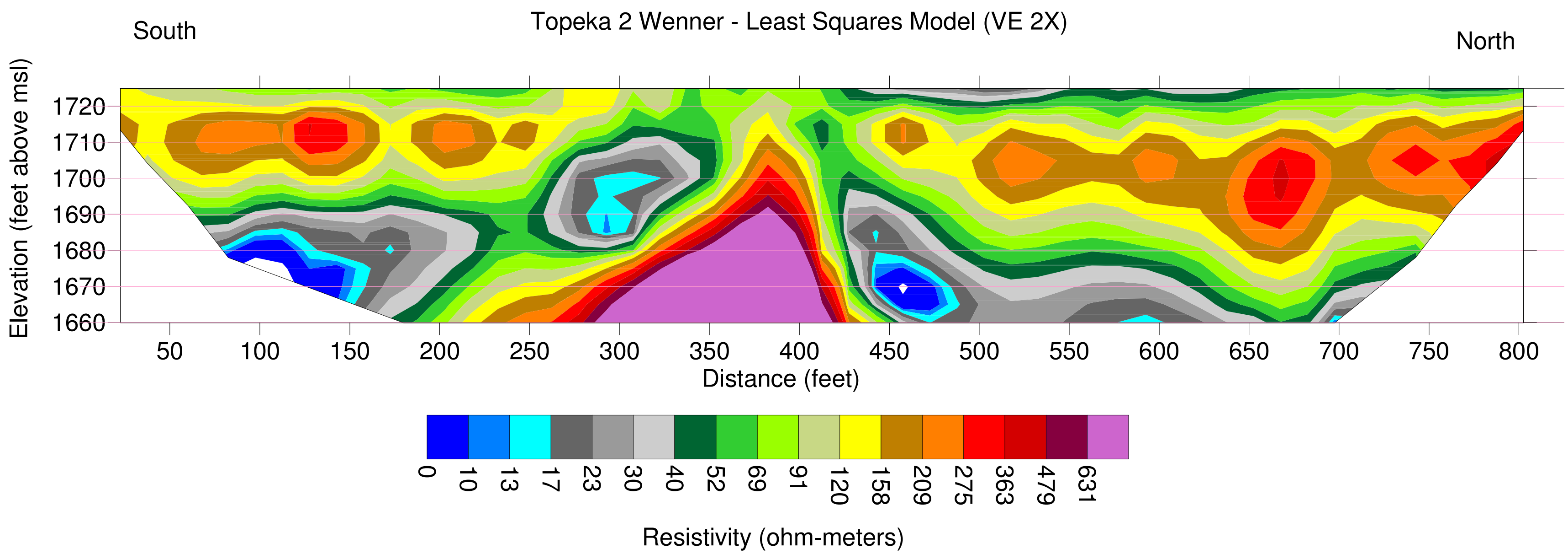
The resistivity imaging method used standard arrays developed as sounding techniques and modified them to create two-dimensional resistivity profiles. A line of 56 electrodes was placed at equal 10- to15-foot intervals (usually 15 feet) along the desired profile. Four electrodes were used at one time. Two injected current into the ground and two read the electrical potential between them. The resistivity meter and switch box automatically read many combinations of current and potential electrodes from short offsets to long offsets starting at one side of the electrode spread and moving toward the opposite end. The short offsets analyzed the shallow earth, and the longer offsets penetrated more deeply. The resistivity data were collected with a Sting R1 Resistivity Meter in conjunction with the Swift automatic multi-electrode system and a 12-volt deep cycle marine battery.

Different patterns of current and potential electrodes can be used for different purposes. We typically used either the dipole-dipole or the Wenner-Schlumberger array. The dipole-dipole array gives good horizontal resolution, but may have a poor signal to noise ratio (S/N) because the potential electrodes are outside of the current electrodes. The Wenner-Schlumberger array is more directed for vertical resolution, but may have poorer horizontal resolution. This method has greater S/N than the dipole-dipole method because the potential electrodes are placed between the two current electrodes. For the depths of interest on this project, the dipole-dipole method seemed to yield the best results.

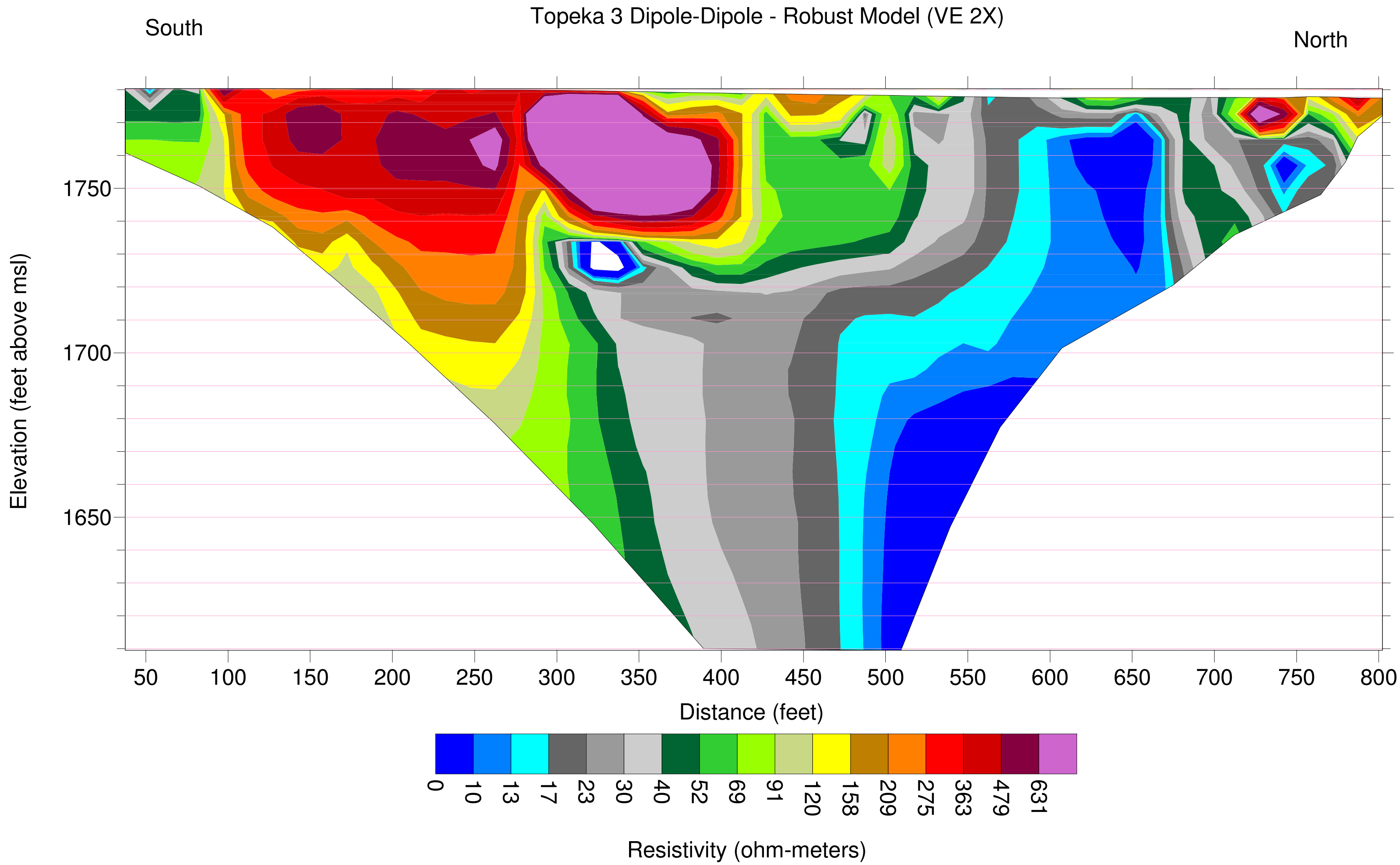
The resistivity field data comprise resistance measurements between various electrodes and related geometry information. An apparent resistivity value is calculated, which depends only on the resistance measurements and the array geometry. These data are plotted as a pseudosection, which is a plot of the apparent resistivity values based on the geometry of the electrodes. Each apparent resistivity value is plotted midway between the set of electrodes used in making the measurement. The pseudo depth of each point is plotted at the median depth of investigation for the particular array; a data inversion is done to help with the interpretation. The inversion produces a plot that shows a resistivity value for each horizontal and vertical node. This resistivity inversion section is then used to interpret subsurface lithology. These data were inverted with RES2DINV, a commercially available program. Programming steps include removing bad data points, setting up appropriate horizontal and vertical filters, selecting the inversion method, and then interpreting the data.



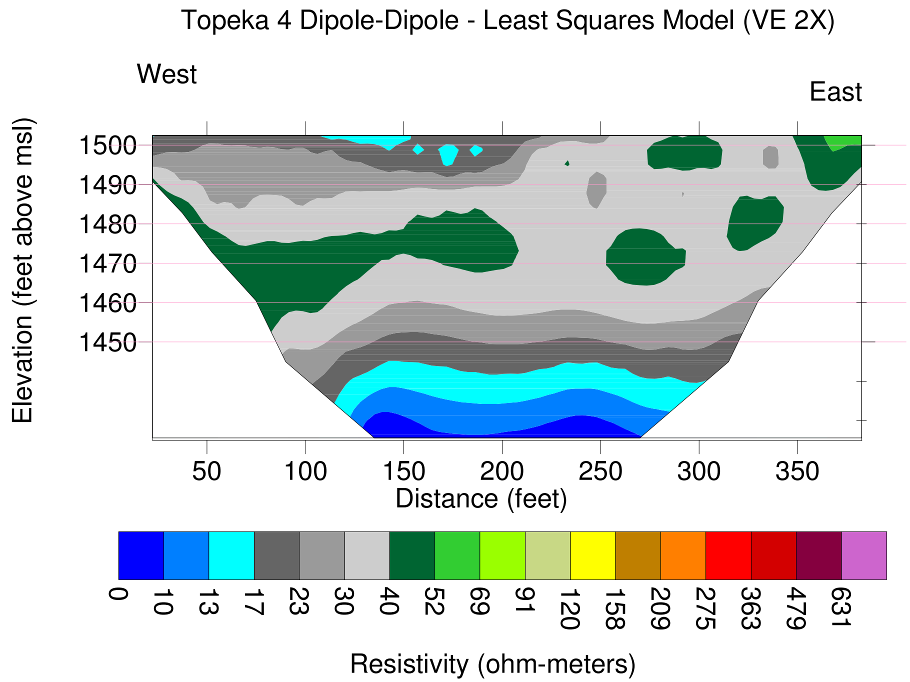
Topeka 1 Dipole-Dipole - Least Squares Model (VE 2X)
West
East
Elevation (feet above msl)
1770
1760
1750
1740
1730
1720
1710
50
100
150
200
250
300
350
400
450
500
550
600
650
Distance (feet)
0
10
13
17
23
30
40
52
69
91
120
158
209
275
363
479
631
Resistivity (ohm-meters)

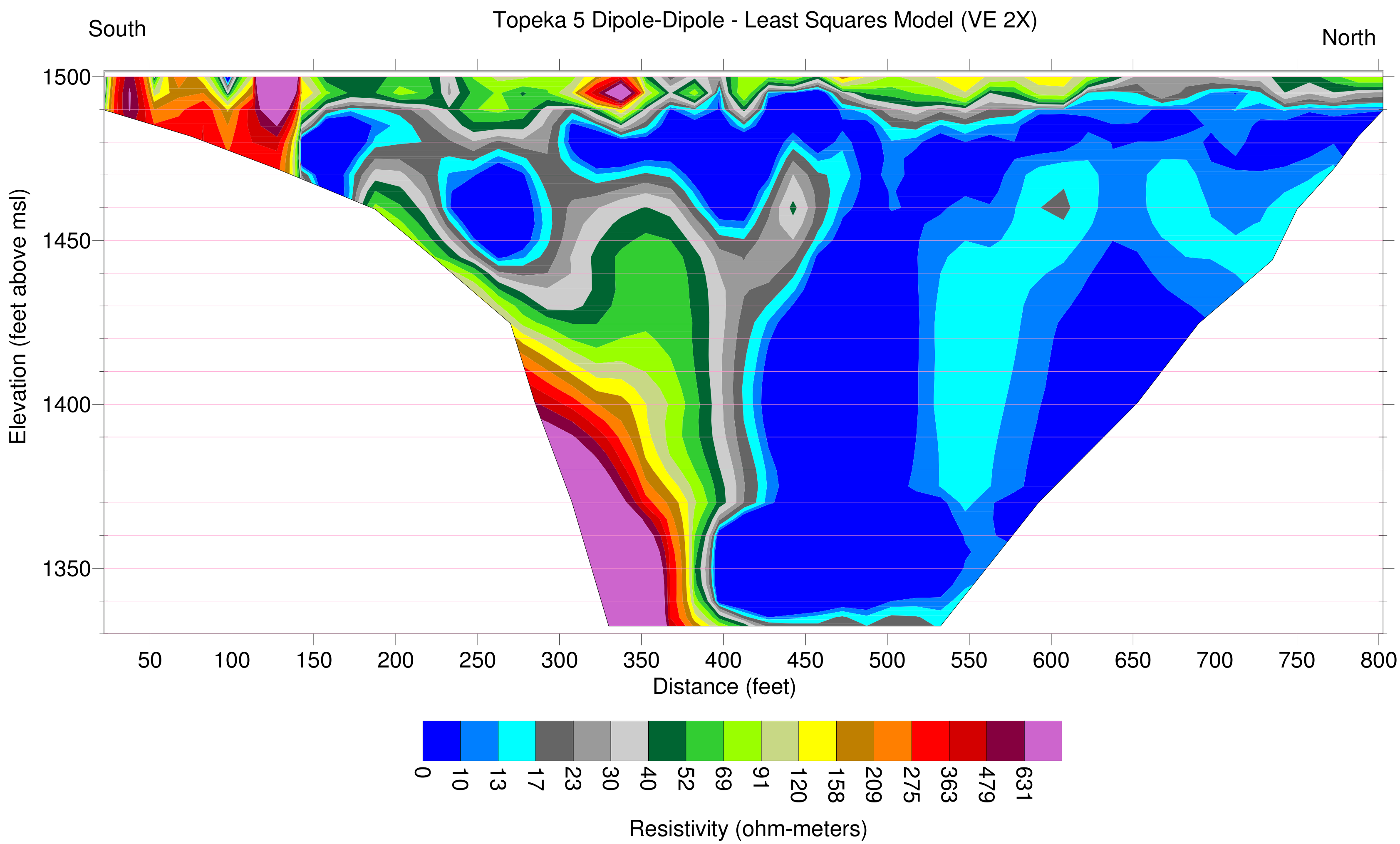


Topeka 2 Wenner - Least Squares Model (VE 2X)
South
North
Elevation (feet above msl)
1720
1710
1700
1690
1680
1670
1660
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
Distance (feet)
0
10
13
17
23
30
40
52
69
91
120
158
209
275
363
479
631
Resistivity (ohm-meters)

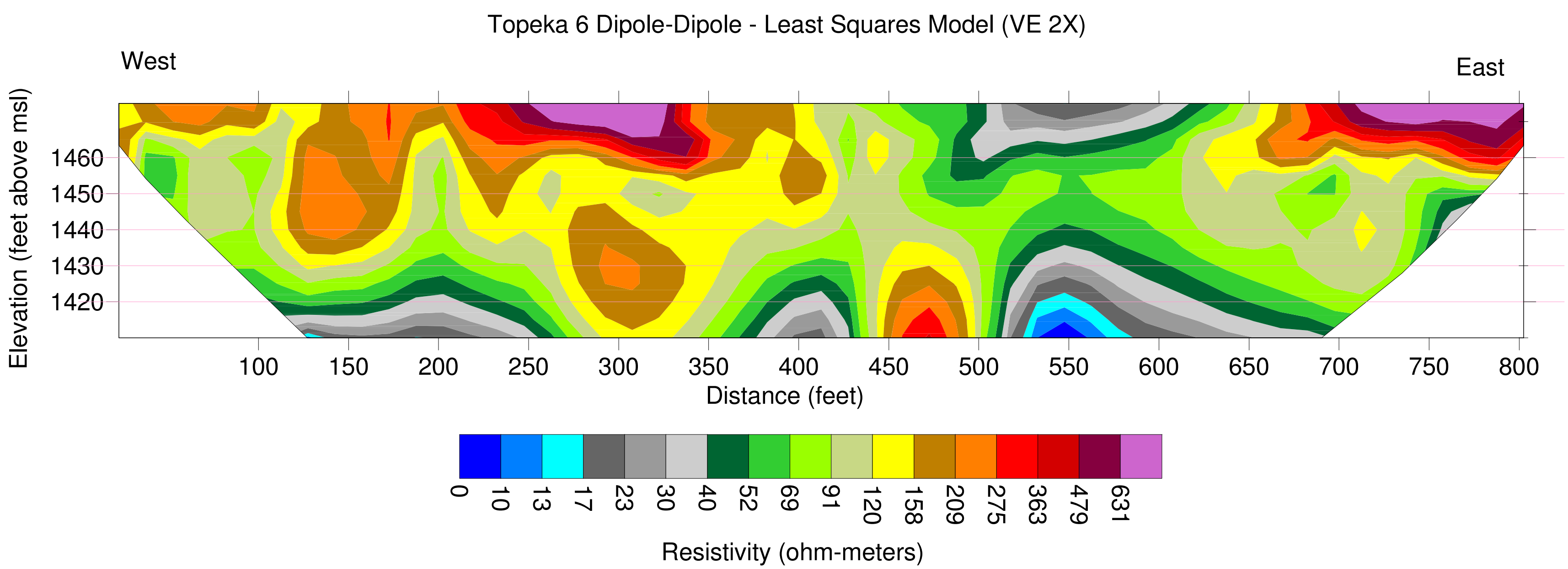


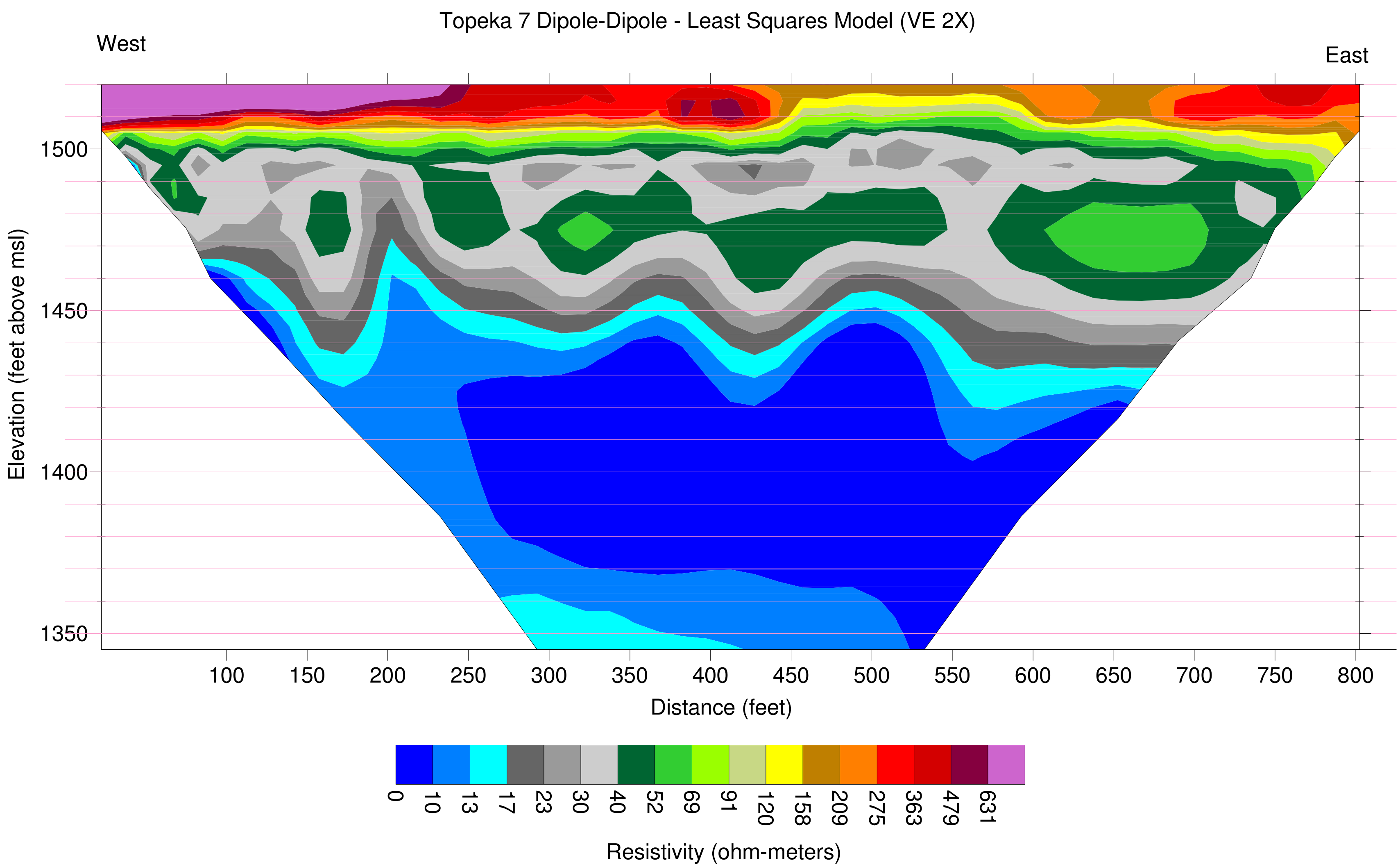
Topeka 3 Dipole-Dipole - Robust Model (VE 2X)
South
North
1750
1700
1650
Elevation (feet above msl)
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
Distance (feet)
0
10
13
17
23
30
40
52
69
91
120
158
209
275
363
479
631
Resistivity (ohm-meters)

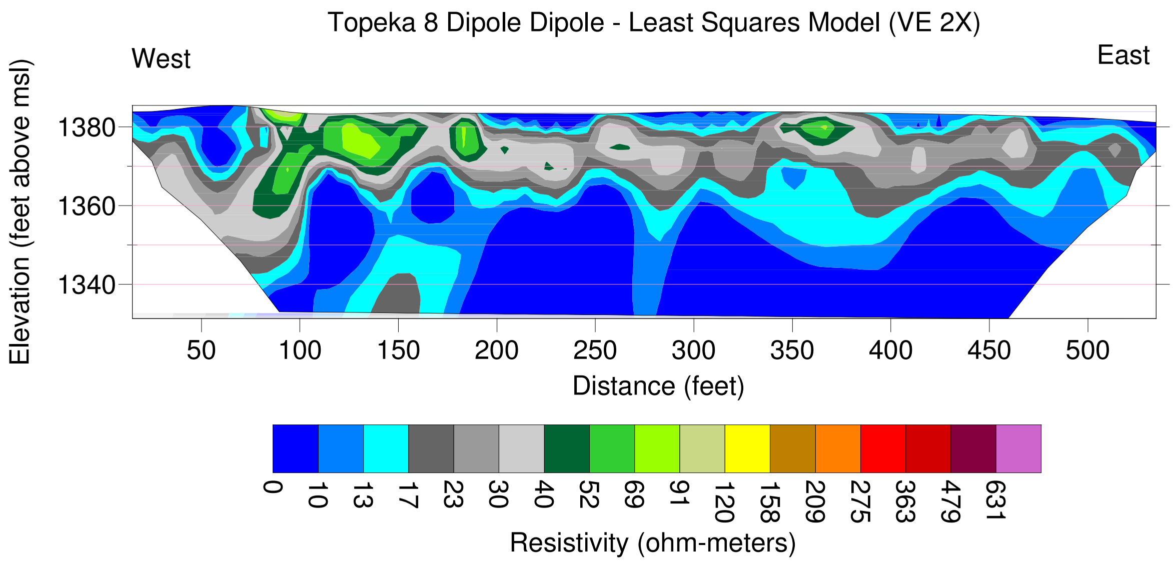

Topeka 4 Dipole-Dipole - Least Squares Model (VE 2X)
West
East
Elevation (feet above msl)
1500
1490
1480
1470
1460
1450
50
100
150
200
250
300
350
Distance (feet)
0
10
13
17
23
30
40
52
69
91
120
158
209
275
363
479
631
Resistivity (ohm-meters)



Topeka 5 Dipole-Dipole - Least Squares Model (VE 2X)
South
North
1500
1450
1400
1350
Elevation (feet above msl)
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
Distance (feet)
0
10
13
17
23
30
40
52
69
91
120
158
209
275
363
479
631
Resistivity (ohm-meters)

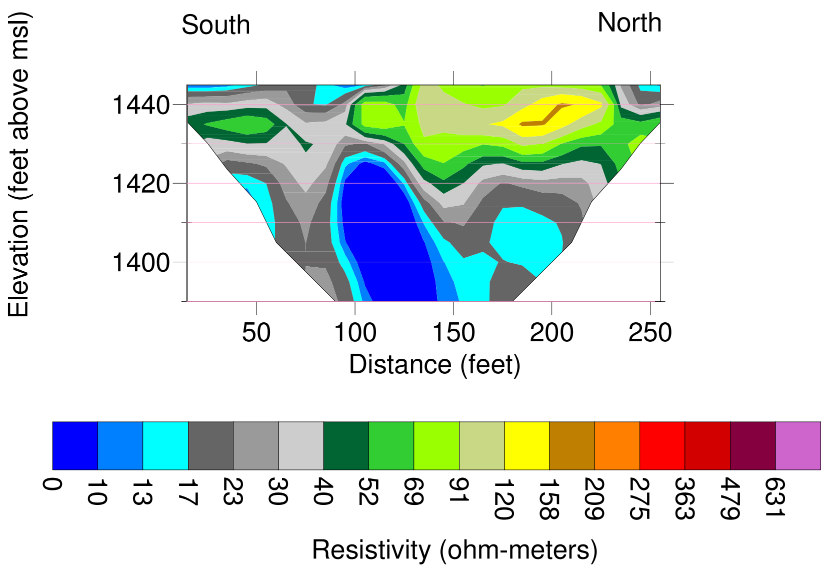

Topeka 6 Dipole-Dipole - Least Squares Model (VE 2X)
West
East
Elevation (feet above msl)
1460
1450
1440
1430
1420
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
Distance (feet)
0
10
13
17
23
30
40
52
69
91
120
158
209
275
363
479
631
Resistivity (ohm-meters)

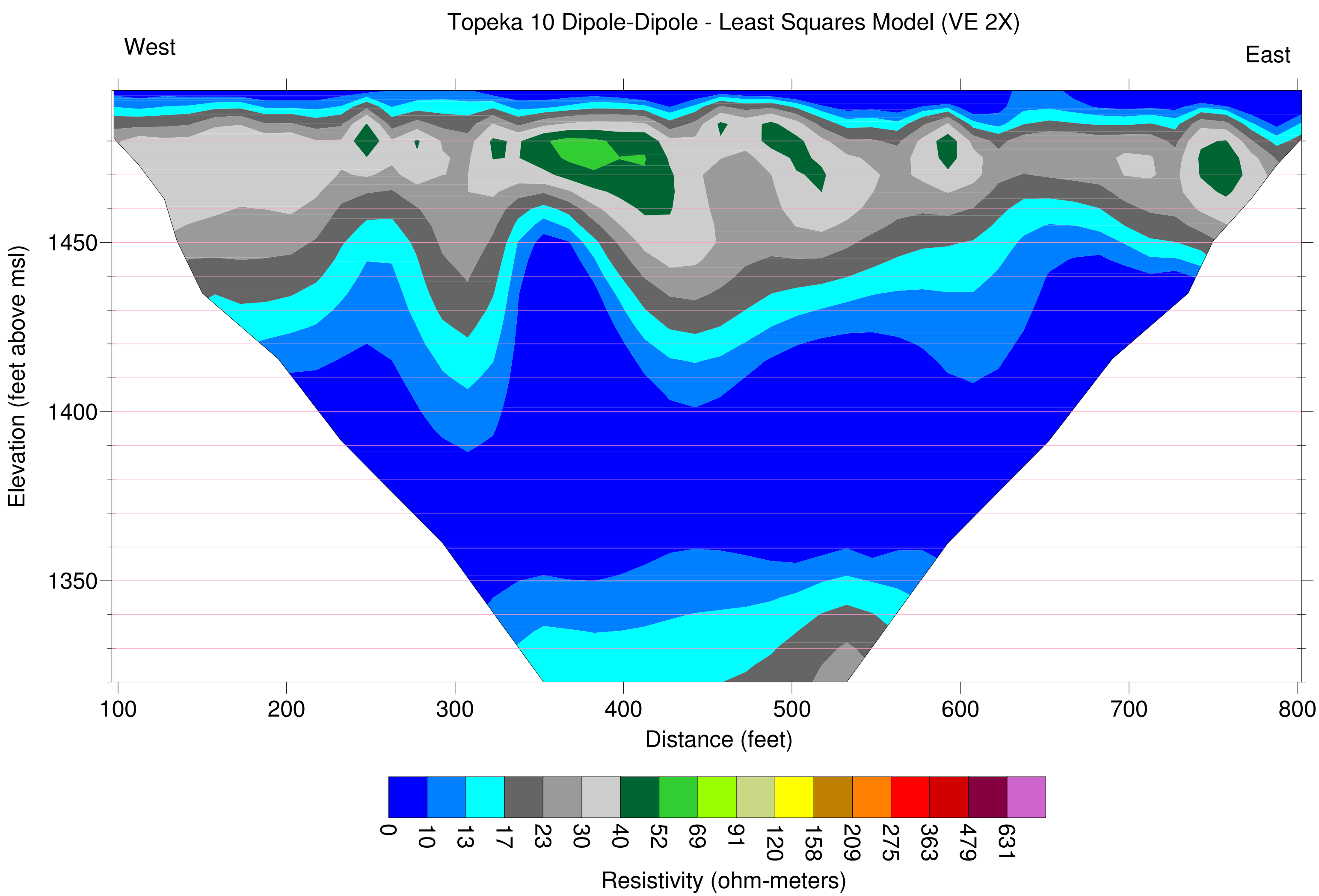

Topeka 7 Dipole-Dipole - Least Squares Model (VE 2X)
West
East
1500
1450
1400
1350
Elevation (feet above msl)
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
Distance (feet)
0
10
13
17
23
30
40
52
69
91
120
158
209
275
363
479
631
Resistivity (ohm-meters)

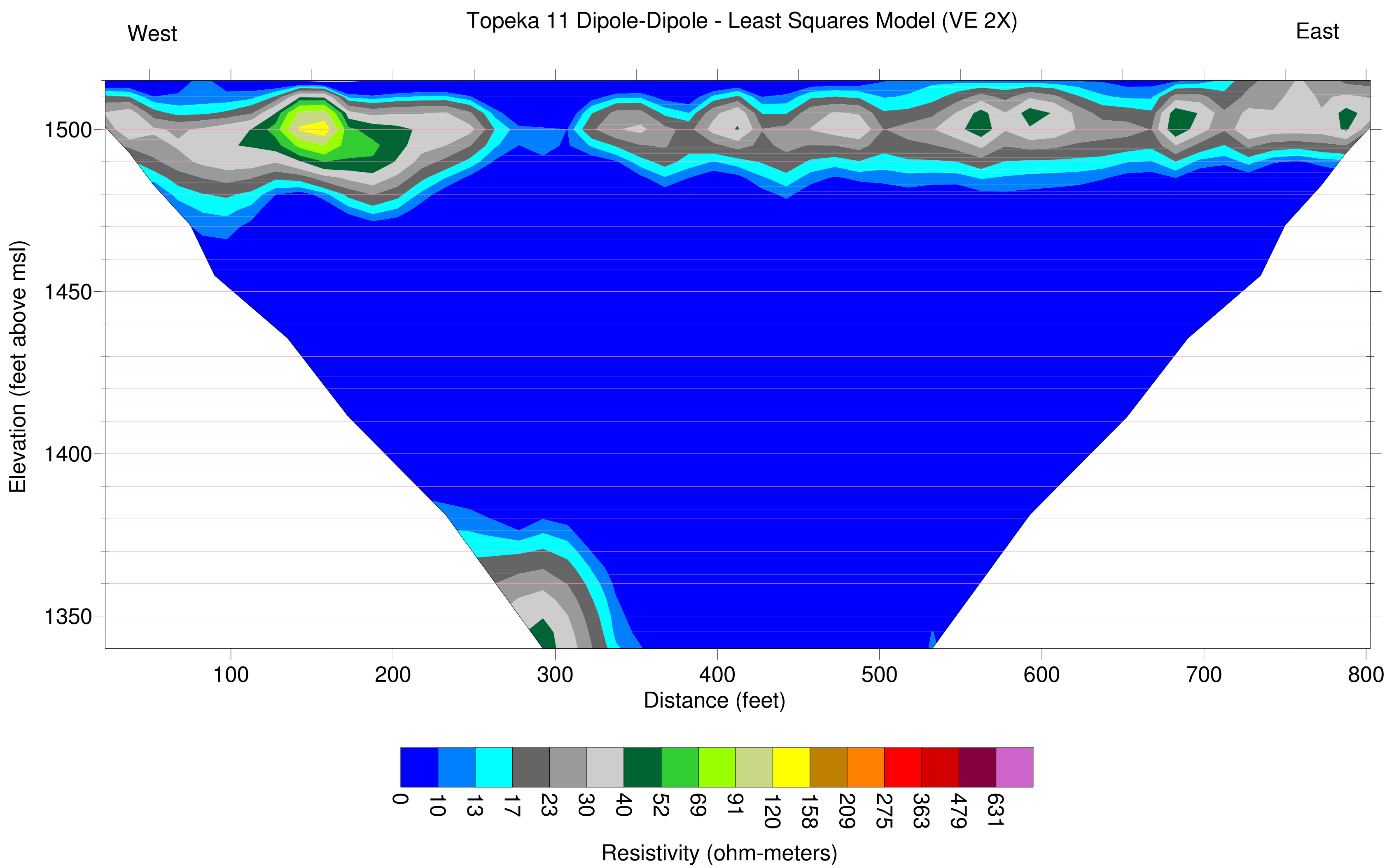


Topeka 8 Dipole Dipole - Least Squares Model (VE 2X)
West
East
Elevation (feet above msl)
1380
1360
1340
50
100
150
200
250
300
350
400
450
500
Distance (feet)
0
10
13
17
23
30
40
52
69
91
120
158
209
275
363
479
631
Resistivity (ohm-meters)

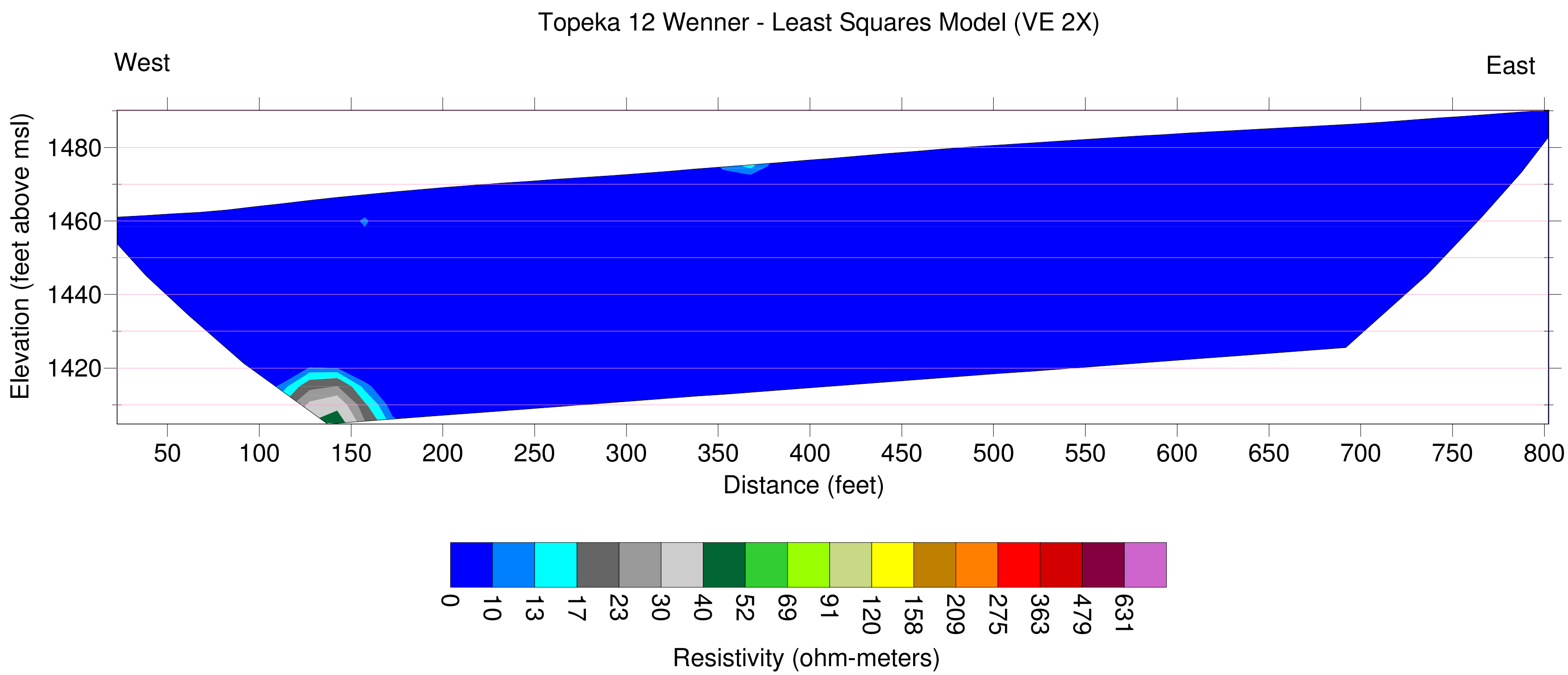
Topeka 9B Dipole-Dipole - Least Squares Model (VE 2X)



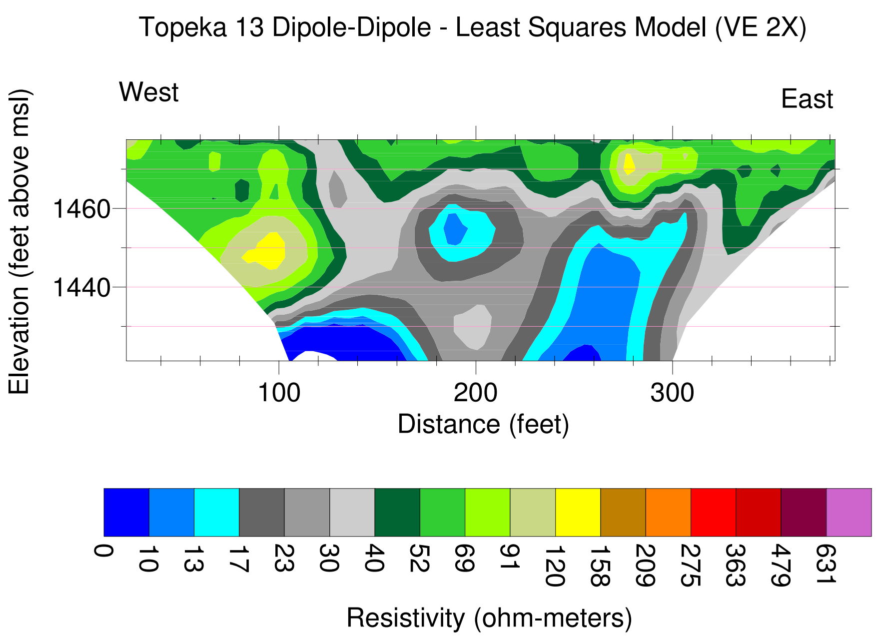

Topeka 10 Dipole-Dipole - Least Squares Model (VE 2X)
West
East
Elevation (feet above msl)
1450
1400
1350
100
200
300
400
500
600
700
800
Distance (feet)
0
10
13
17
23
30
40
52
69
91
120
158
209
275
363
479
631
Resistivity (ohm-meters)



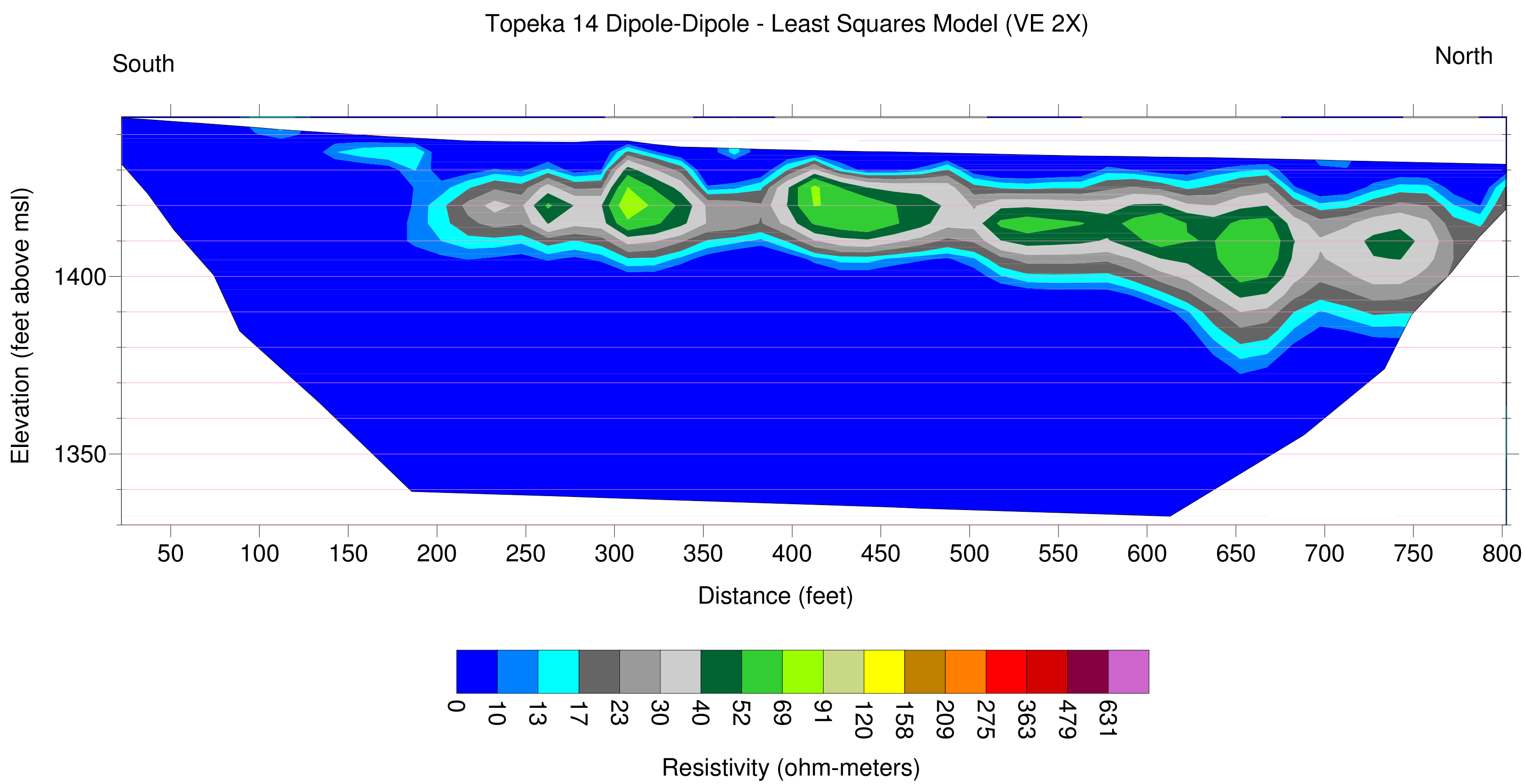
Topeka 11 Dipole-Dipole - Least Squares Model (VE 2X)
West
East
Elevation (feet above msl)
1500
1450
1400
1350
100
200
300
400
500
600
700
800
Distance (feet)
0
10
13
17
23
30
40
52
69
91
120
158
209
275
363
479
631
Resistivity (ohm-meters)



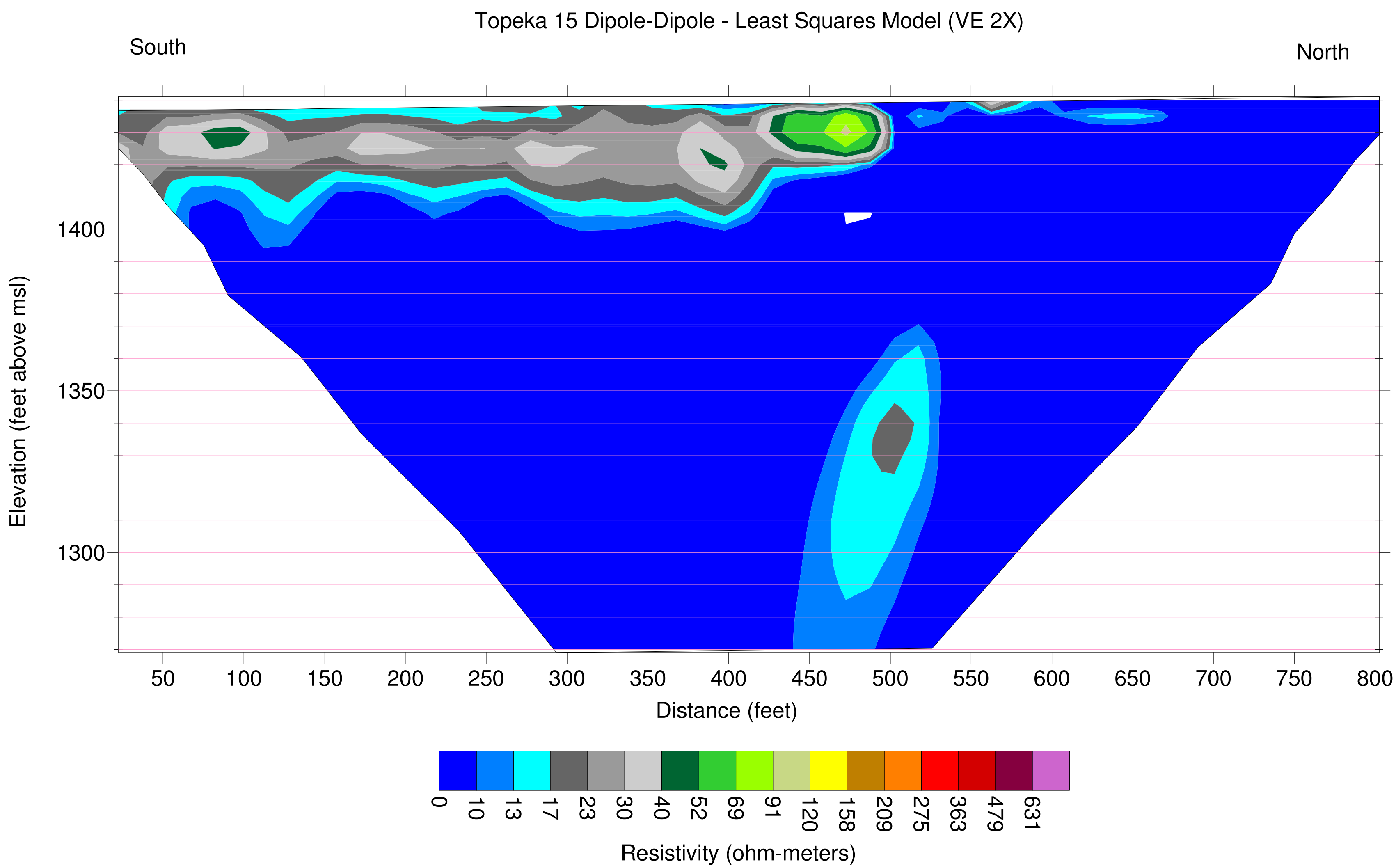
Topeka 12 Wenner - Least Squares Model (VE 2X)
West
East
1480
1460
1440
1420
Elevation (feet above msl)
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
Distance (feet)
0
10
13
17
23
30
40
52
69
91
120
158
209
275
363
479
631
Resistivity (ohm-meters)



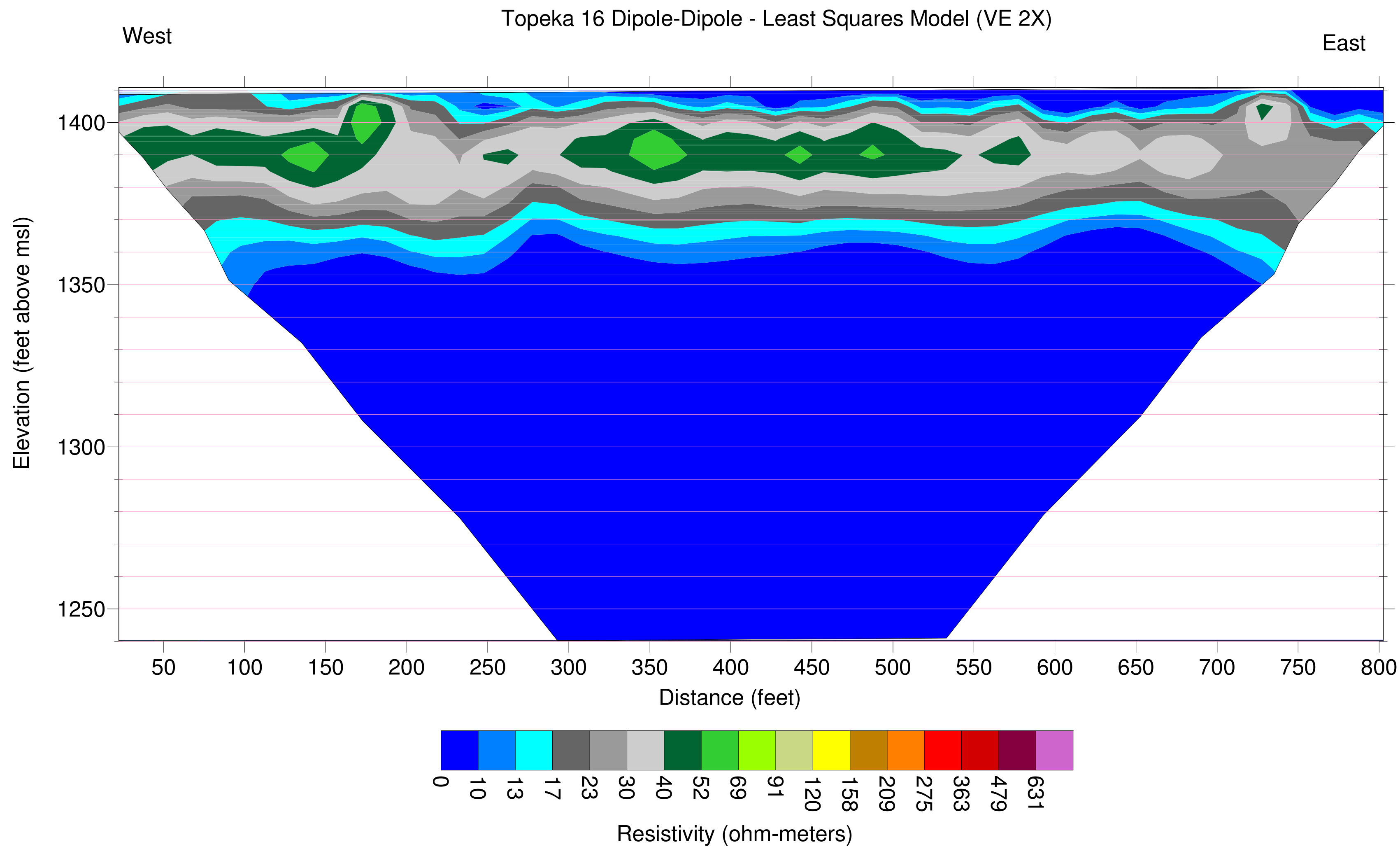
Topeka 13 Dipole-Dipole - Least Squares Model (VE 2X)
West
East
Elevation (feet above msl)
1460
1440
100
200
300
Distance (feet)
0
10
13
17
23
30
40
52
69
91
120
158
209
275
363
479
631
Resistivity (ohm-meters)



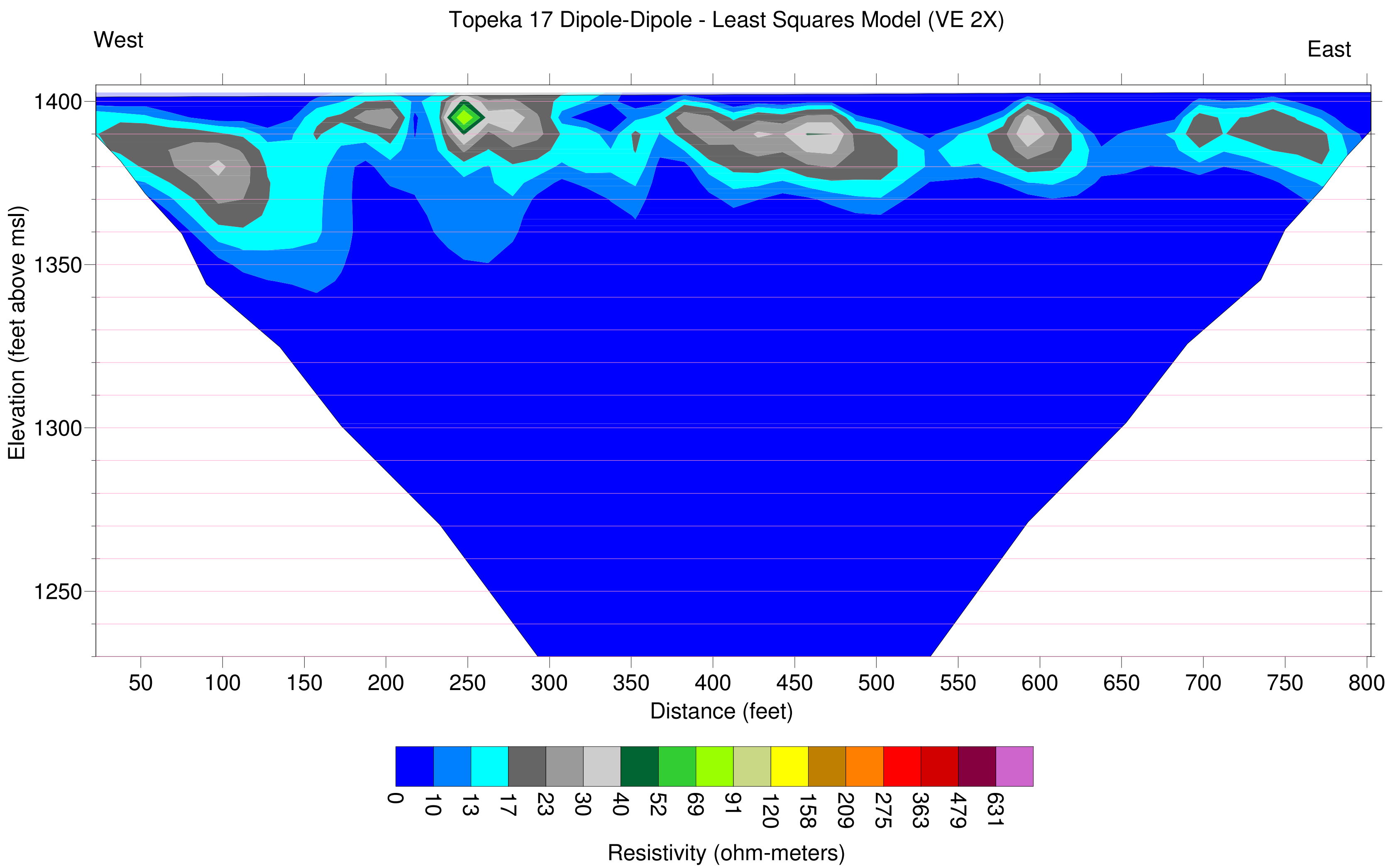
Topeka 14 Dipole-Dipole - Least Squares Model (VE 2X)
South
North
1400
1350
Elevation (feet above msl)
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
Distance (feet)
0
10
13
17
23
30
40
52
69
91
120
158
209
275
363
479
631
Resistivity (ohm-meters)



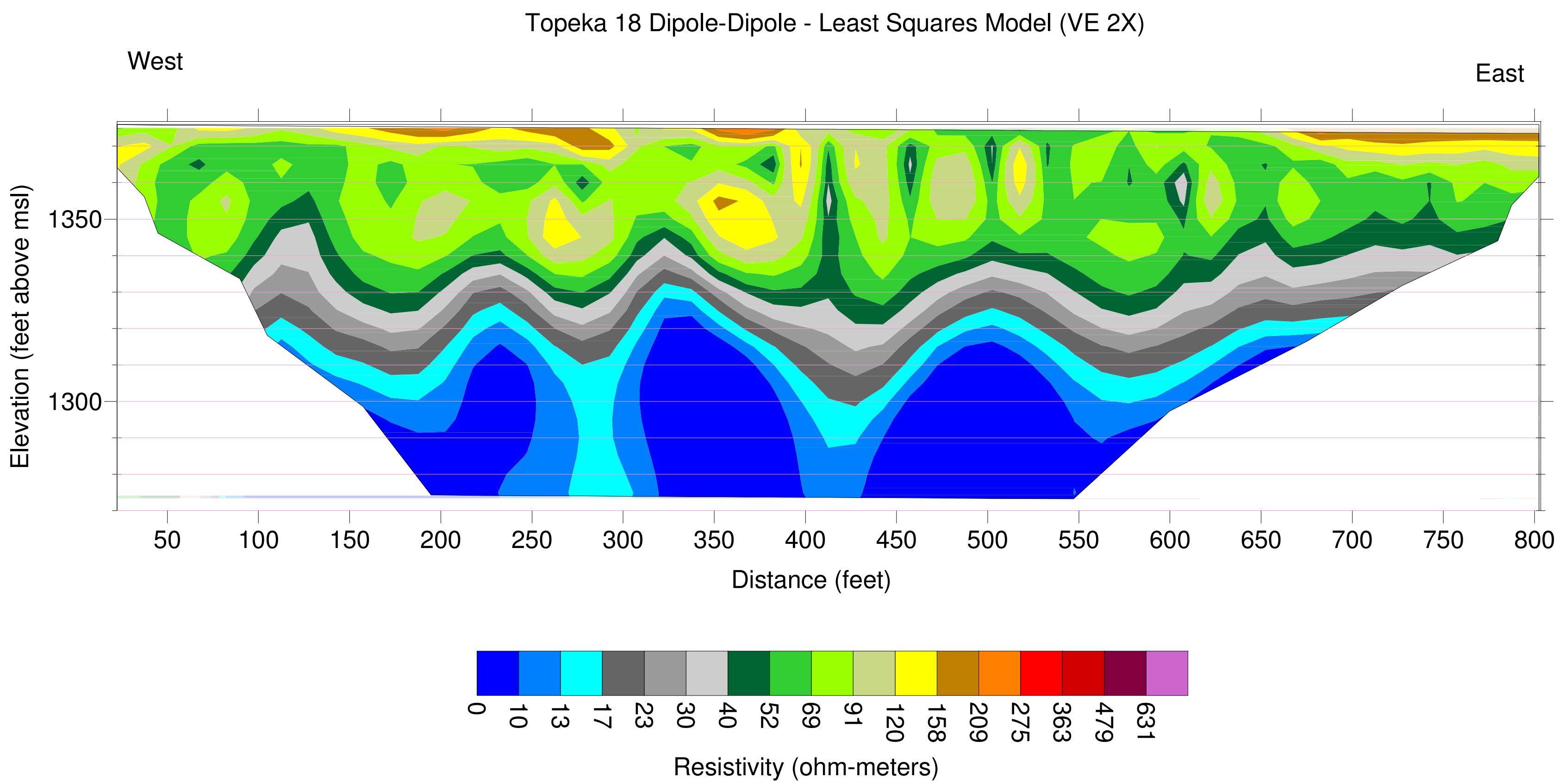
Topeka 15 Dipole-Dipole - Least Squares Model (VE 2X)
South
North
Elevation (feet above msl)
1400
1350
1300
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
Distance (feet)
0
10
13
17
23
30
40
52
69
91
120
158
209
275
363
479
631
Resistivity (ohm-meters)

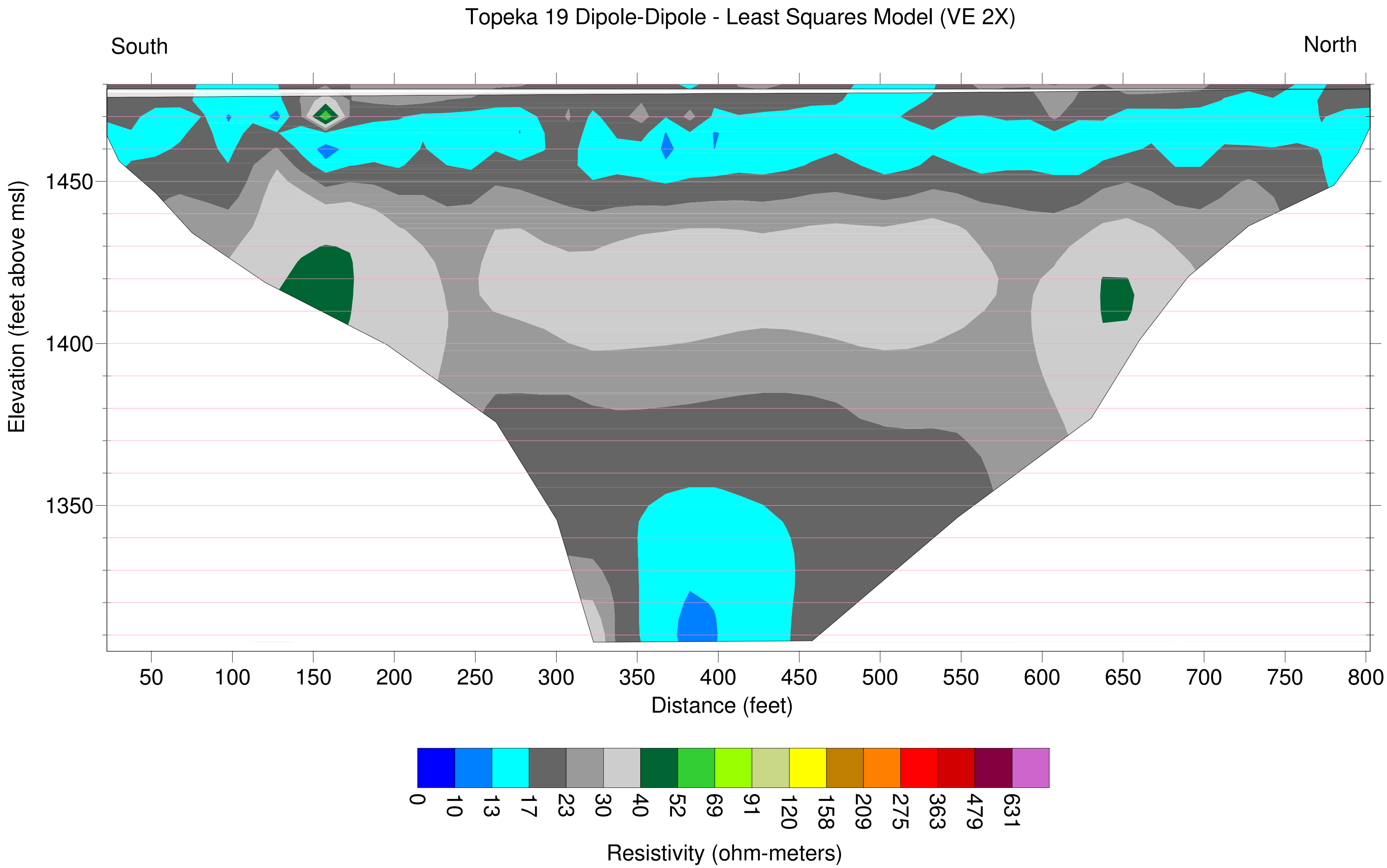


Topeka 16 Dipole-Dipole - Least Squares Model (VE 2X)
West
East
Elevation (feet above msl)
1400
1350
1300
1250
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
Distance (feet)
0
10
13
17
23
30
40
52
69
91
120
158
209
275
363
479
631
Resistivity (ohm-meters)

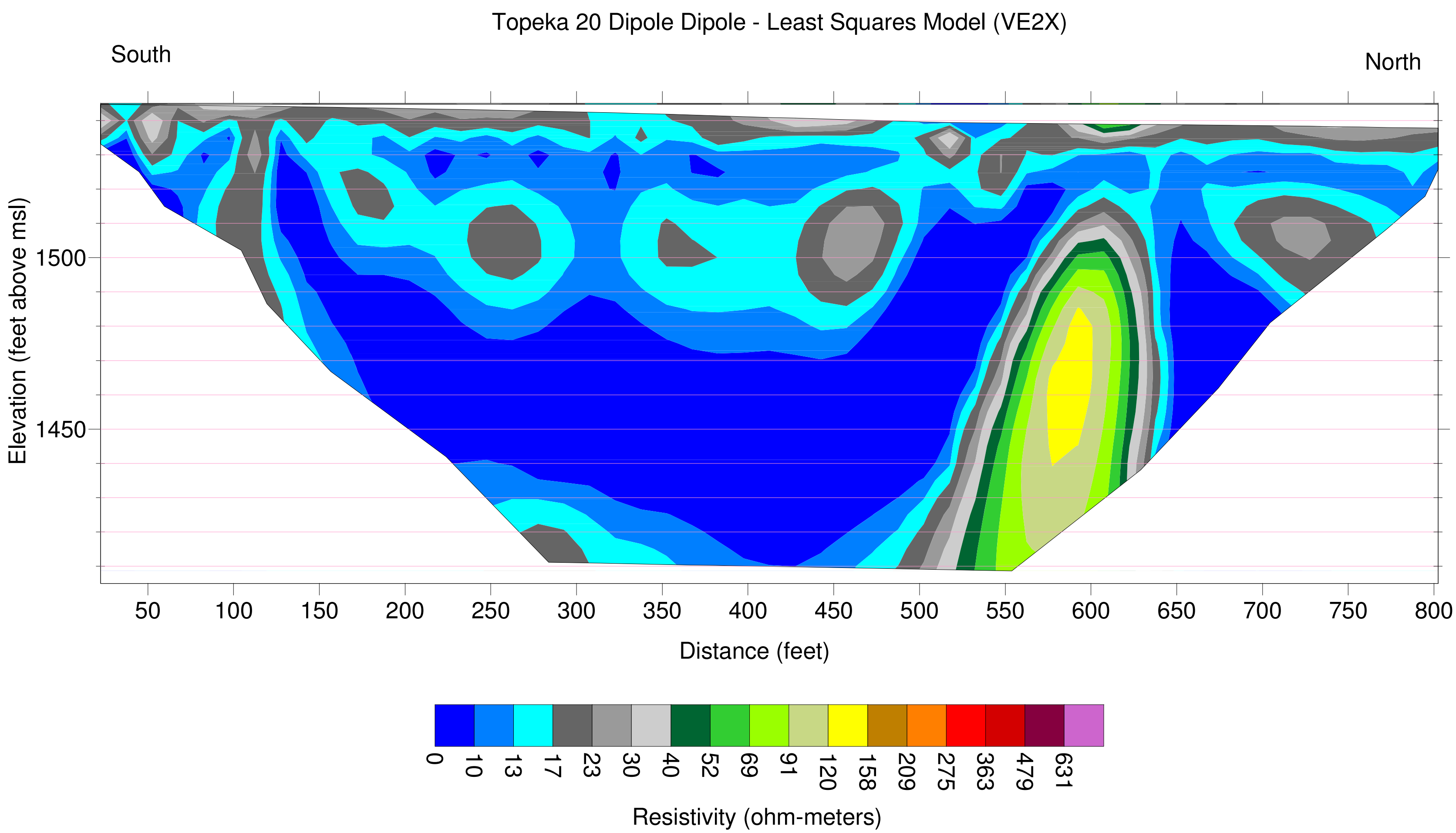


Topeka 17 Dipole-Dipole - Least Squares Model (VE 2X)
West
East
1400
1350
1300
1250
Elevation (feet above msl)
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
Distance (feet)
0
10
13
17
23
30
40
52
69
91
120
158
209
275
363
479
631
Resistivity (ohm-meters)

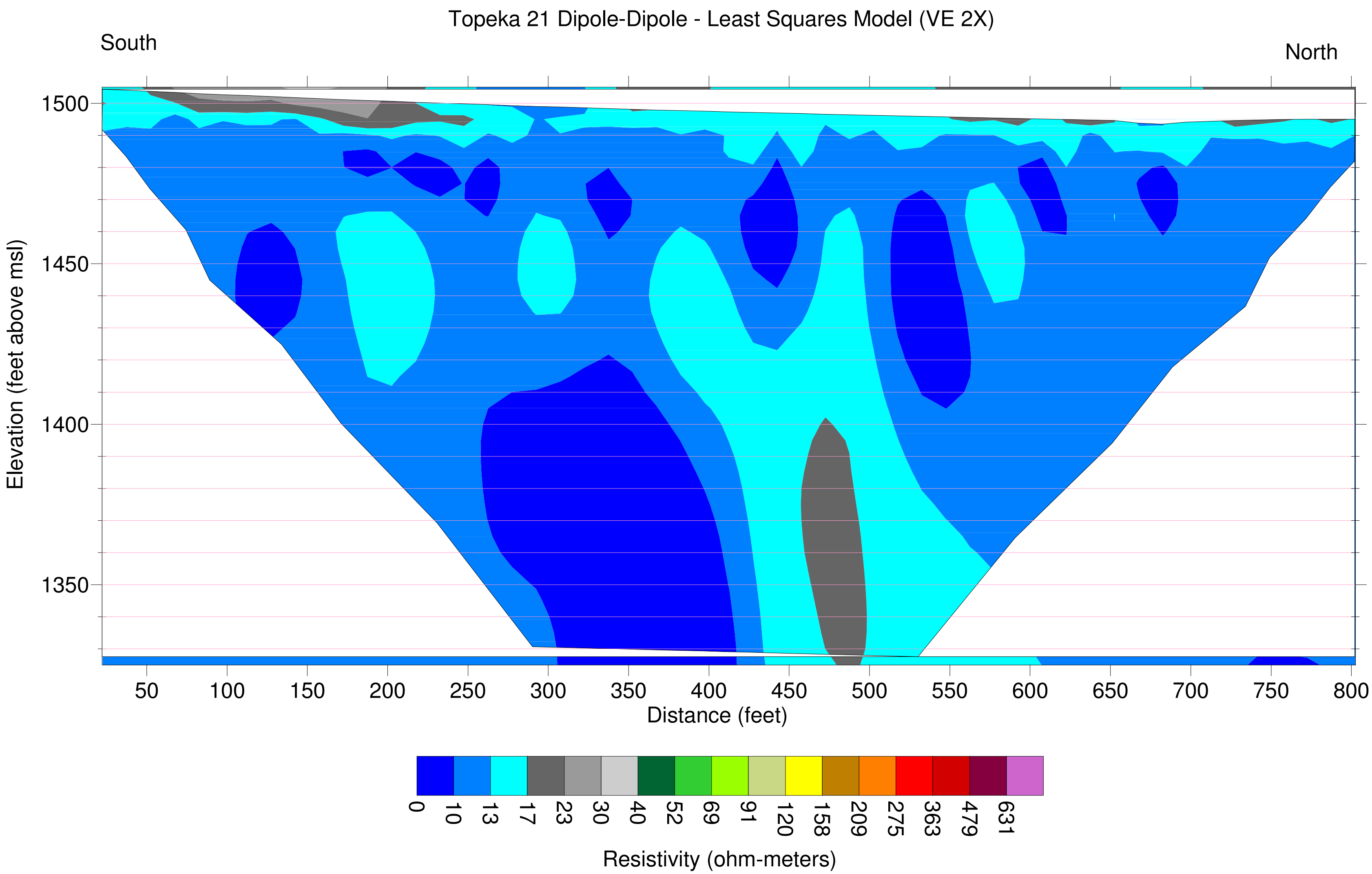

Topeka 18 Dipole-Dipole - Least Squares Model (VE 2X)
West
East
Elevation (feet above msl)
1350
1300
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
Distance (feet)
0
10
13
17
23
30
40
52
69
91
120
158
209
275
363
479
631
Resistivity (ohm-meters)

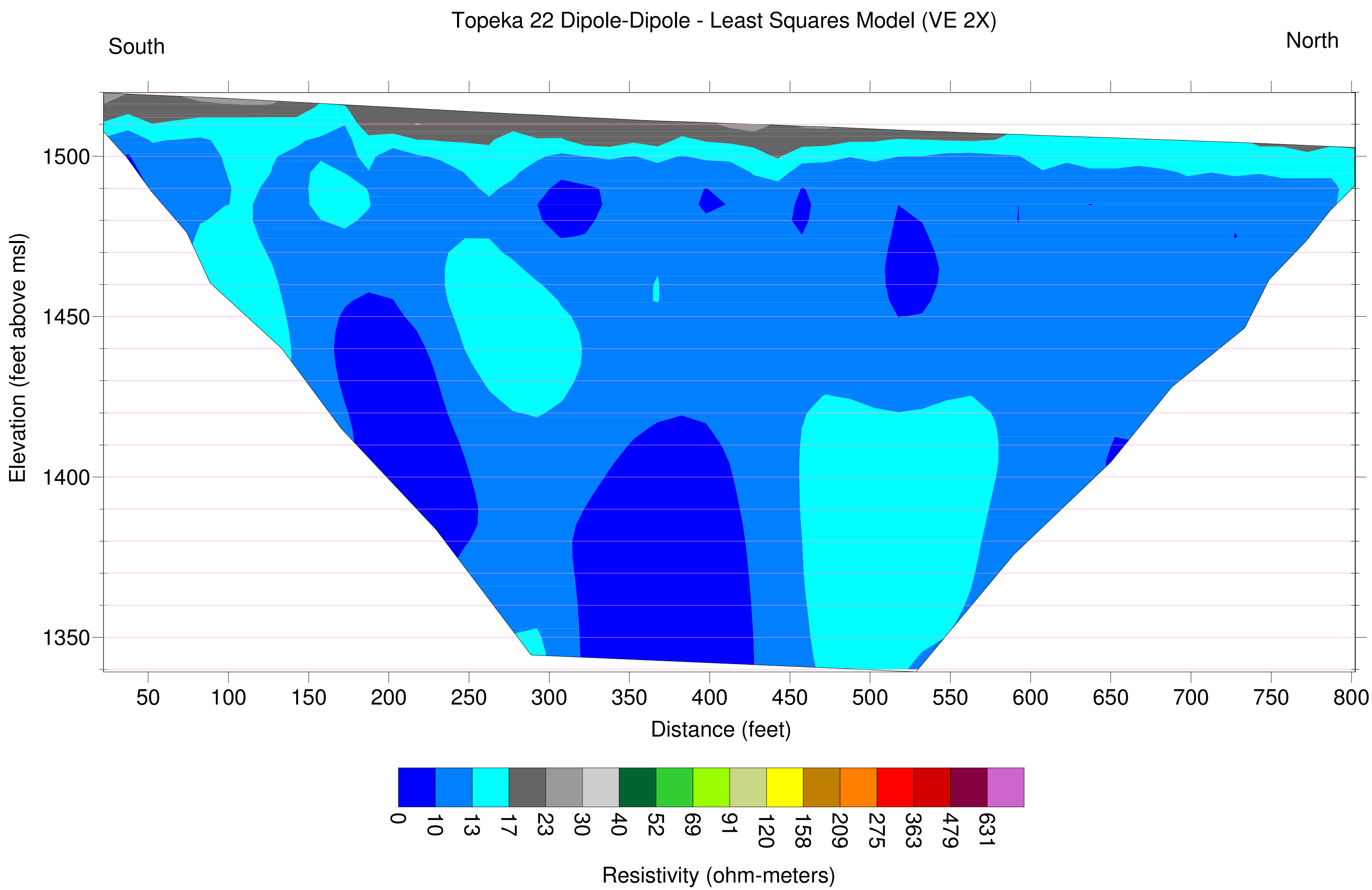


Topeka 19 Dipole-Dipole - Least Squares Model (VE 2X)
South
North
Elevation (feet above msl)
1450
1400
1350
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
Distance (feet)
0
10
13
17
23
30
40
52
69
91
120
158
209
275
363
479
631
Resistivity (ohm-meters)



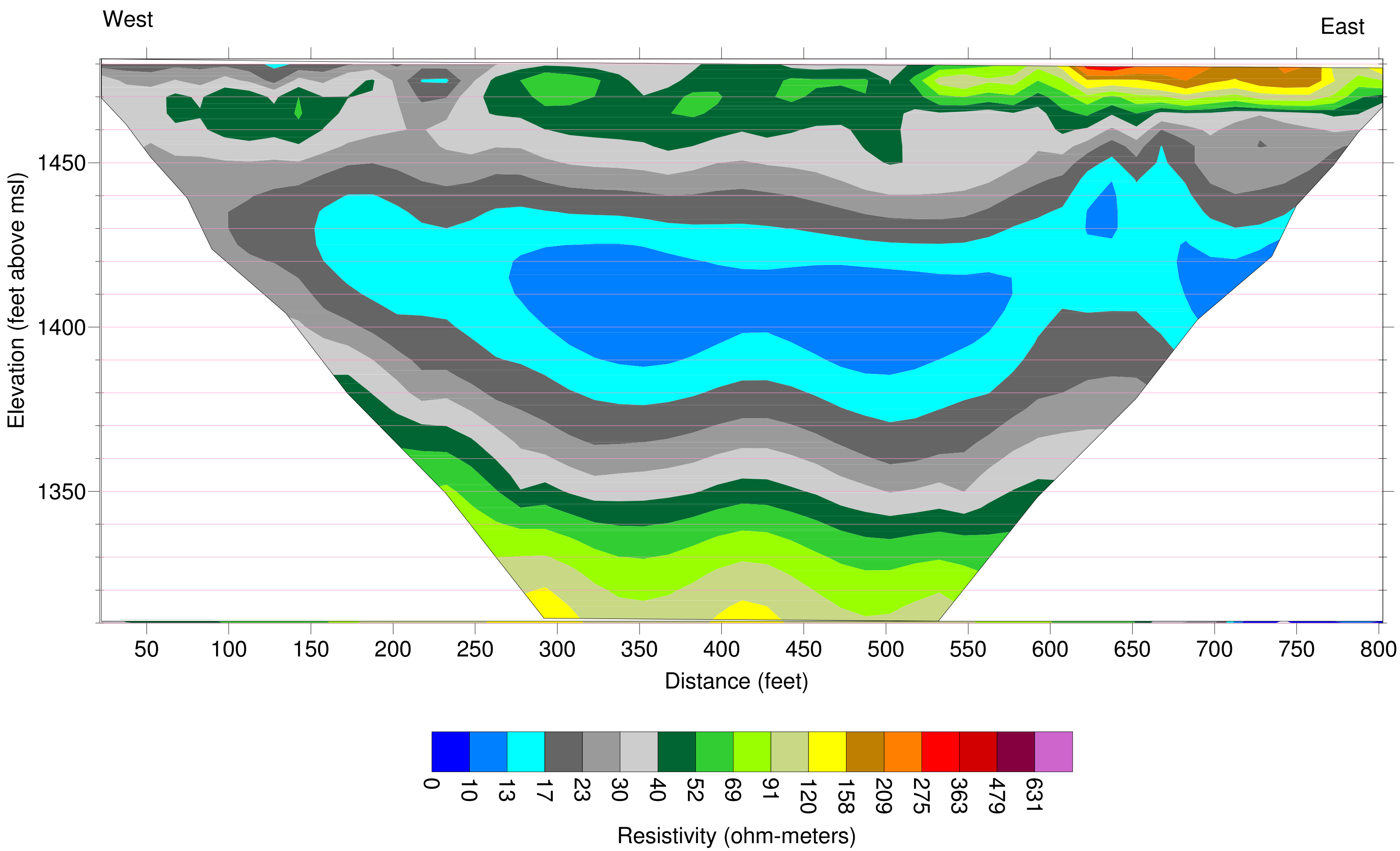
Topeka 20 Dipole Dipole - Least Squares Model (VE2X)
South
North
Elevation (feet above msl)
1500
1450
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
Distance (feet)
0
10
13
17
23
30
40
52
69
91
120
158
209
275
363
479
631
Resistivity (ohm-meters)

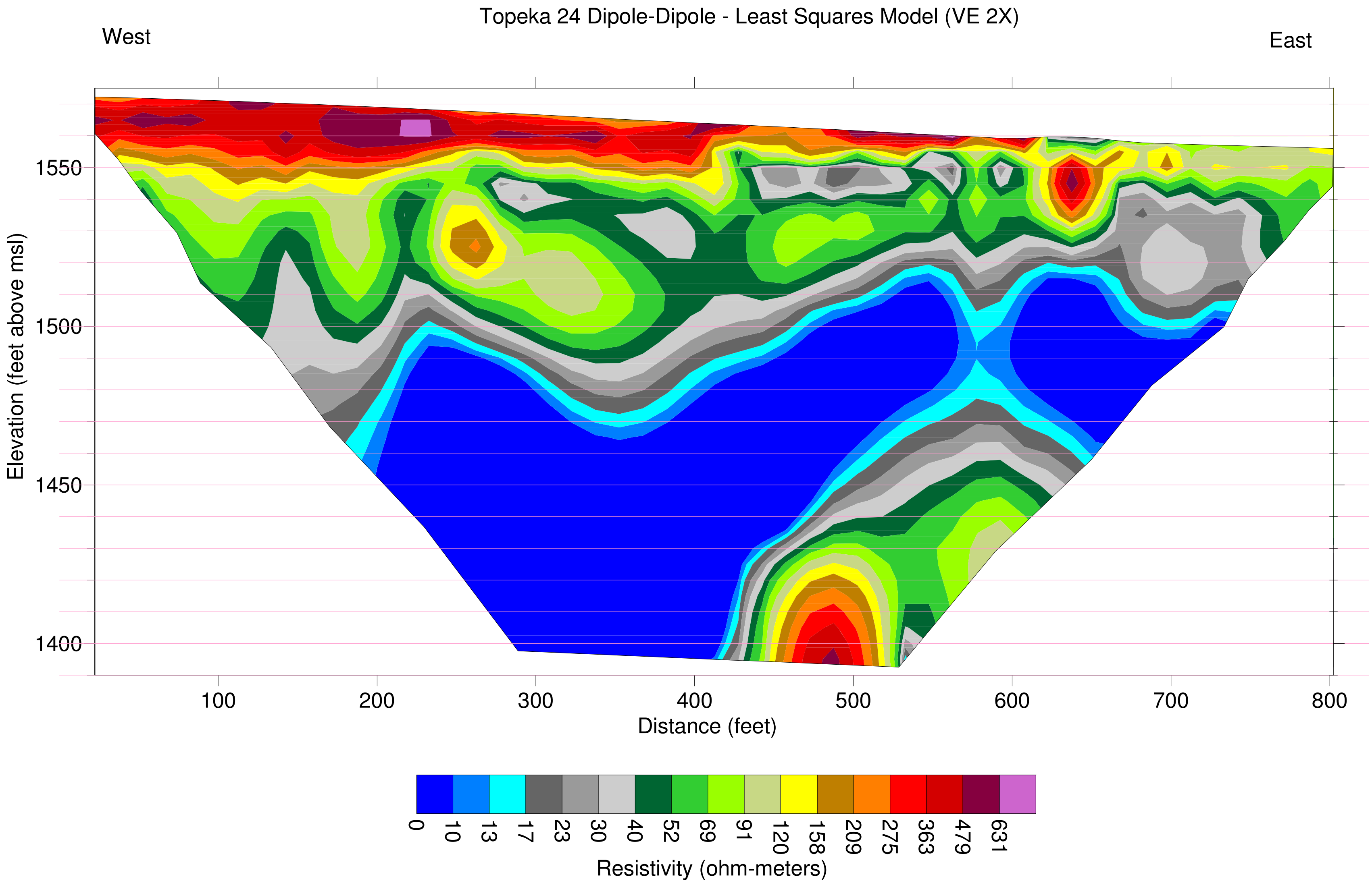

Topeka 21 Dipole-Dipole - Least Squares Model (VE 2X)
South
North
Elevation (feet above msl)
1500
1450
1400
1350
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
Distance (feet)
0
10
13
17
23
30
40
52
69
91
120
158
209
275
363
479
631
Resistivity (ohm-meters)



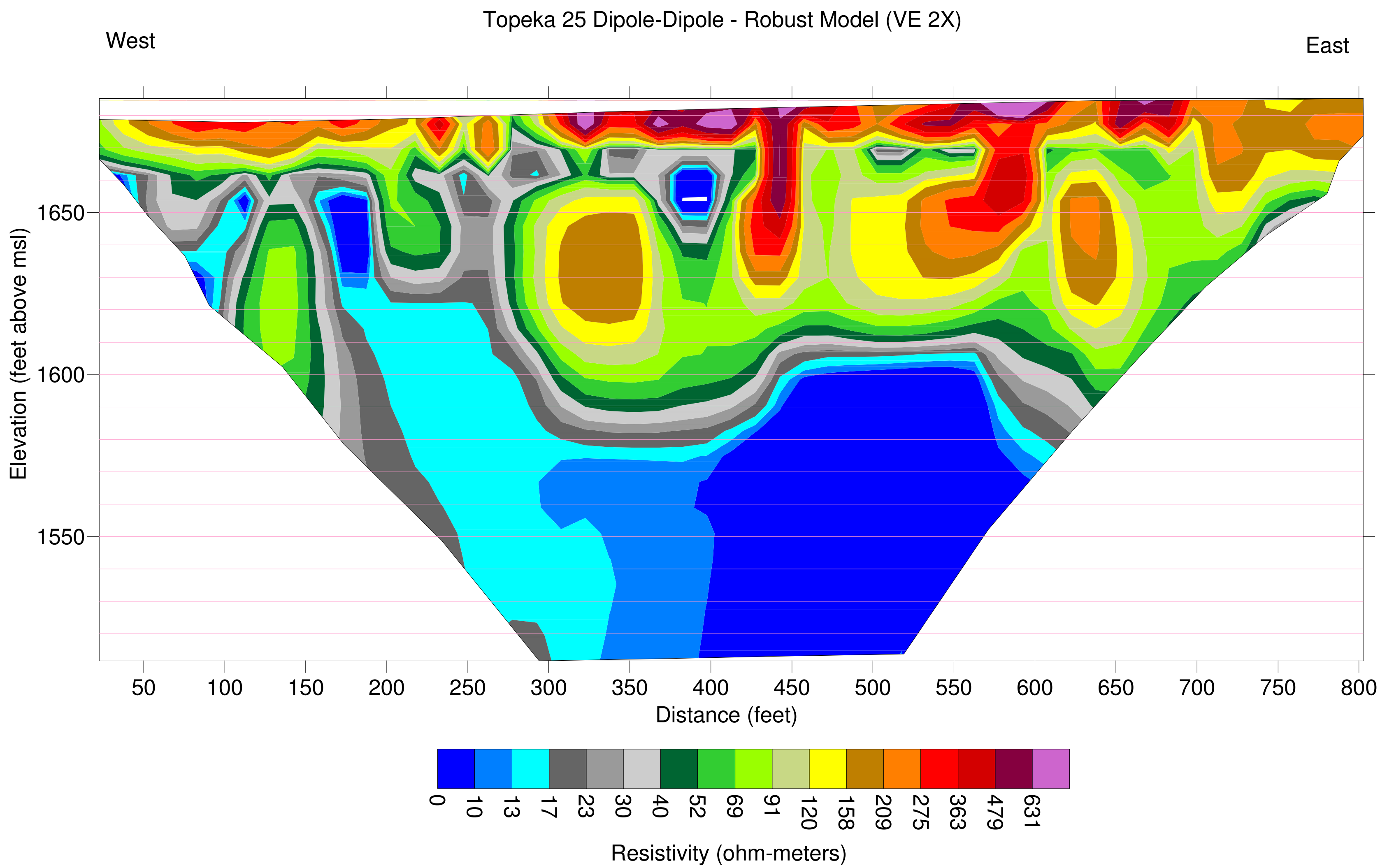
Topeka 22 Dipole-Dipole - Least Squares Model (VE 2X)
South
North
Elevation (feet above msl)
1500
1450
1400
1350
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
Distance (feet)
0
10
13
17
23
30
40
52
69
91
120
158
209
275
363
479
631
Resistivity (ohm-meters)

Topeka 23 Dipole-Dipole - Least Squares Model (VE 2X)

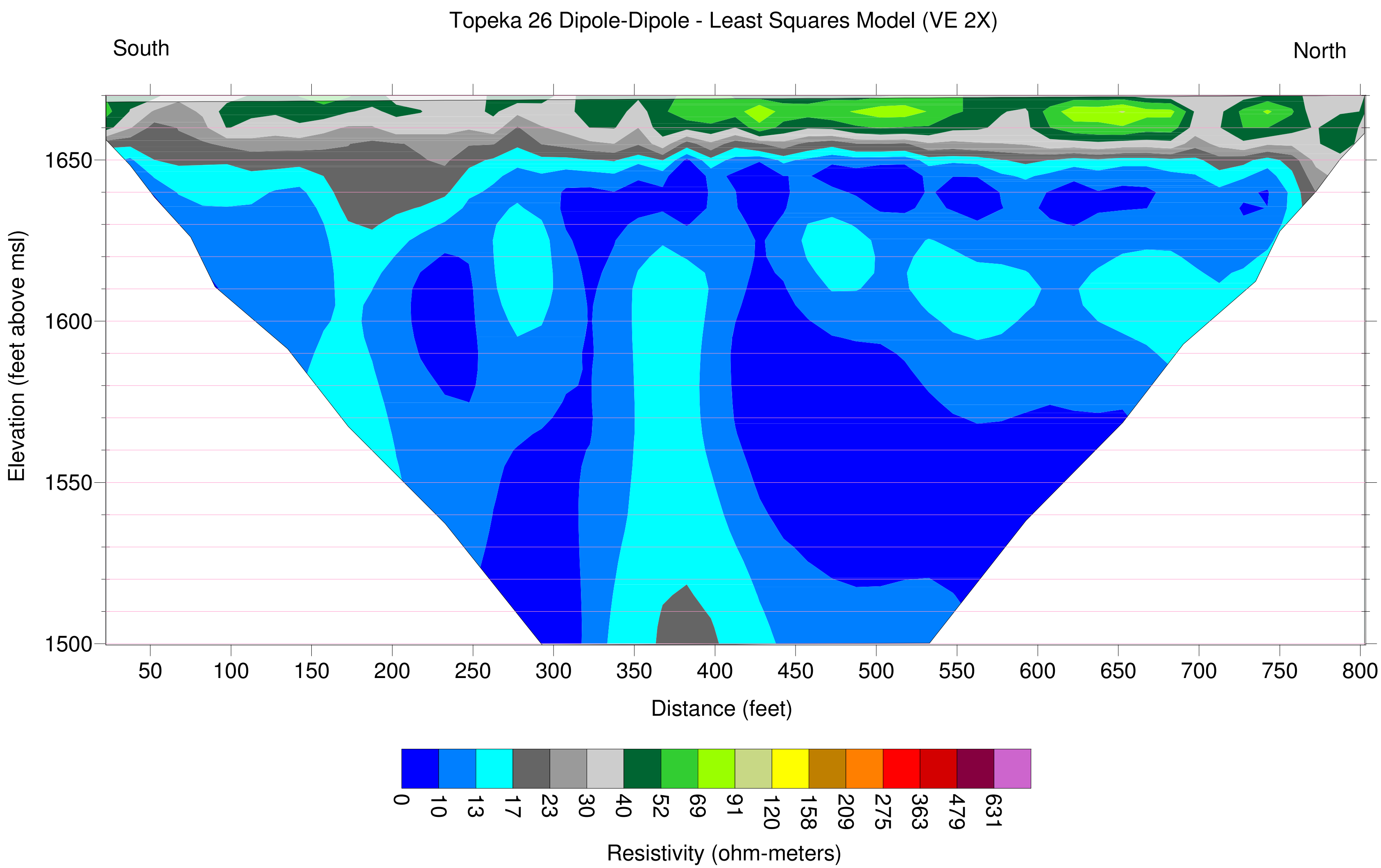




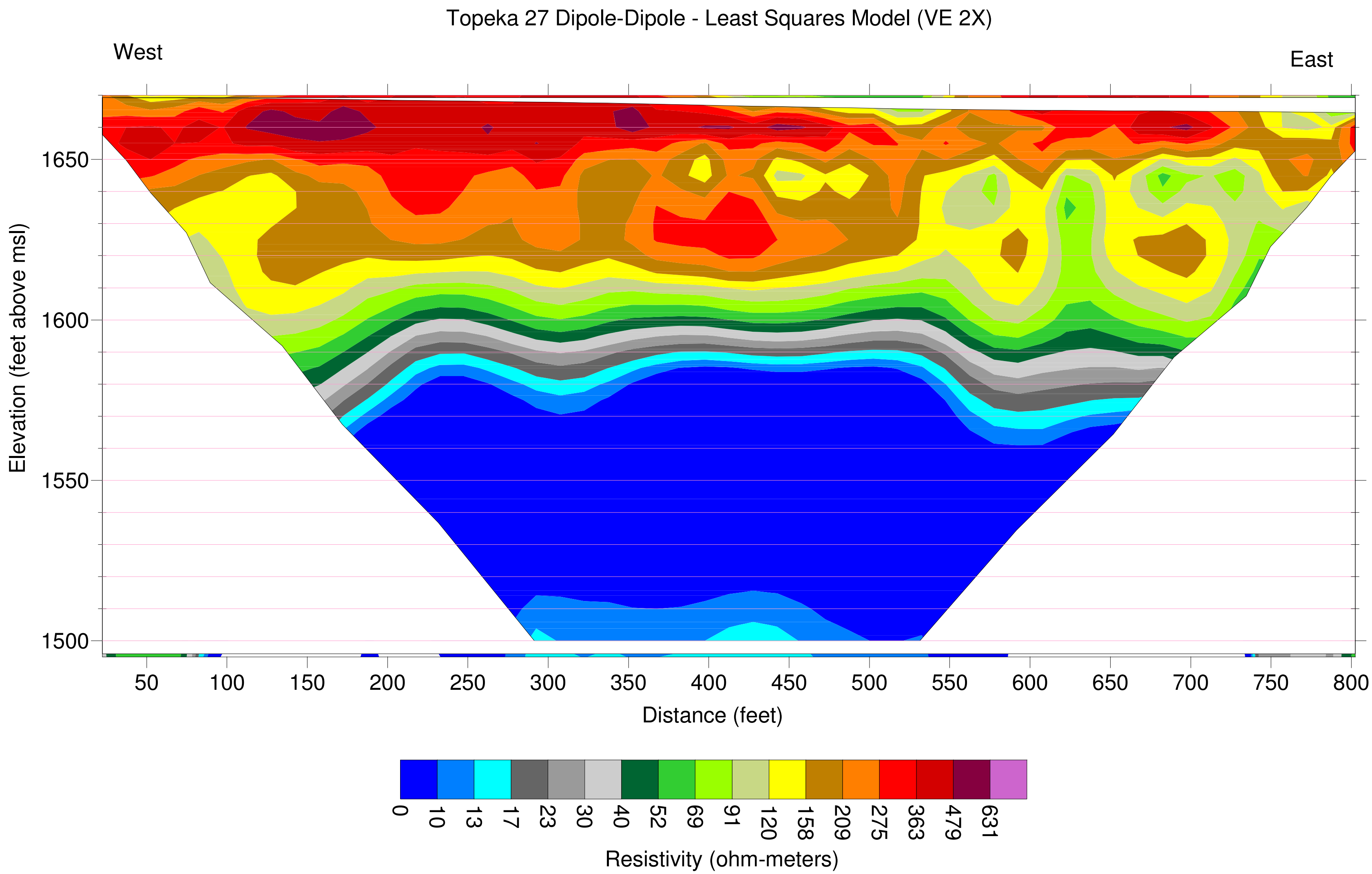
Topeka 24 Dipole-Dipole - Least Squares Model (VE 2X)
West
East
Elevation (feet above msl)
1550
1500
1450
1400
100
200
300
400
500
600
700
800
Distance (feet)
0
10
13
17
23
30
40
52
69
91
120
158
209
275
363
479
631
Resistivity (ohm-meters)



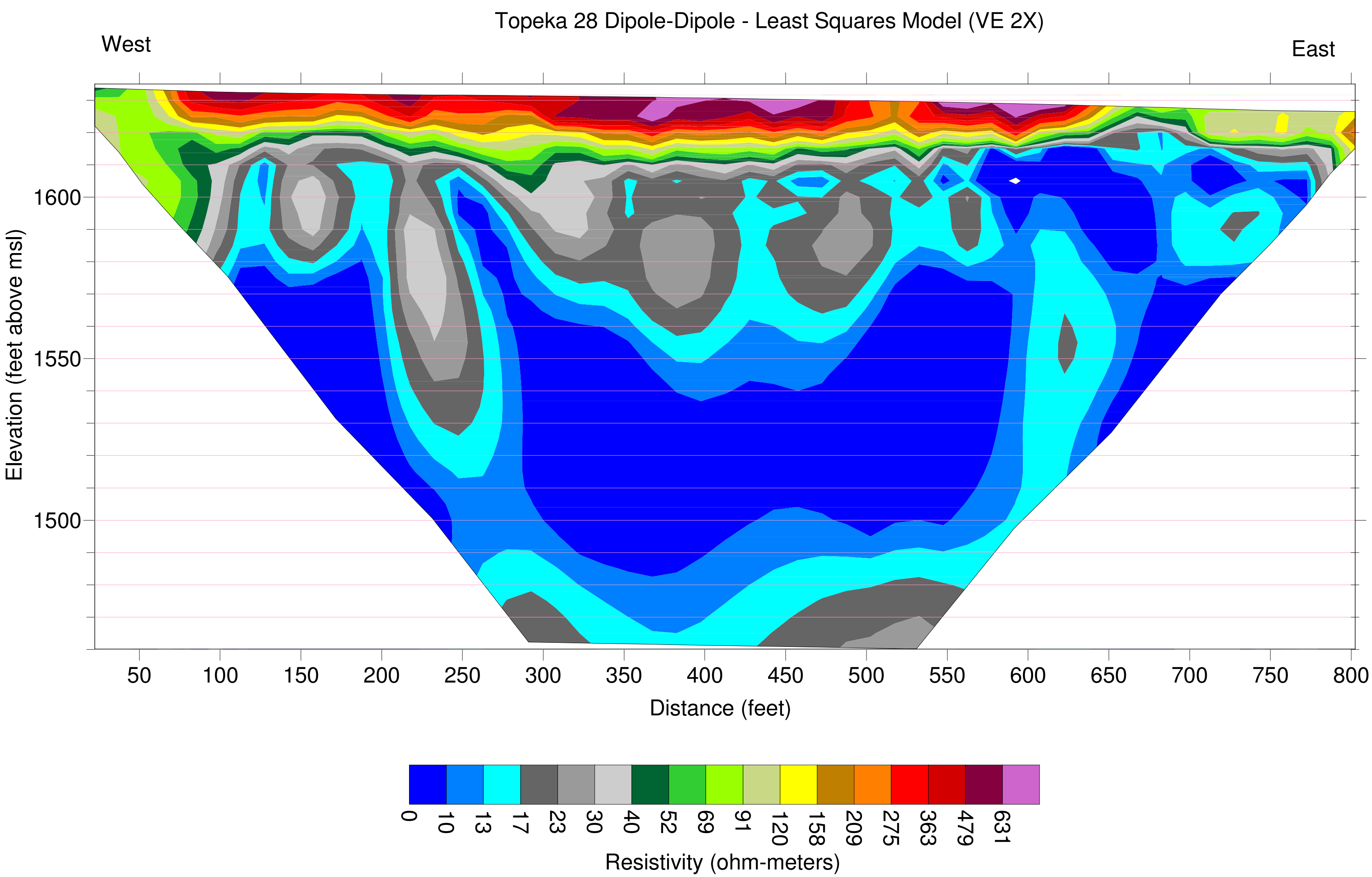
Topeka 25 Dipole-Dipole - Robust Model (VE 2X)
West
East
Elevation (feet above msl)
1650
1600
1550
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
Distance (feet)
0
10
13
17
23
30
40
52
69
91
120
158
209
275
363
479
631
Resistivity (ohm-meters)



Topeka 26 Dipole-Dipole - Least Squares Model (VE 2X)
South
North
Elevation (feet above msl)
1650
1600
1550
1500
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
Distance (feet)
0
10
13
17
23
30
40
52
69
91
120
158
209
275
363
479
631
Resistivity (ohm-meters)

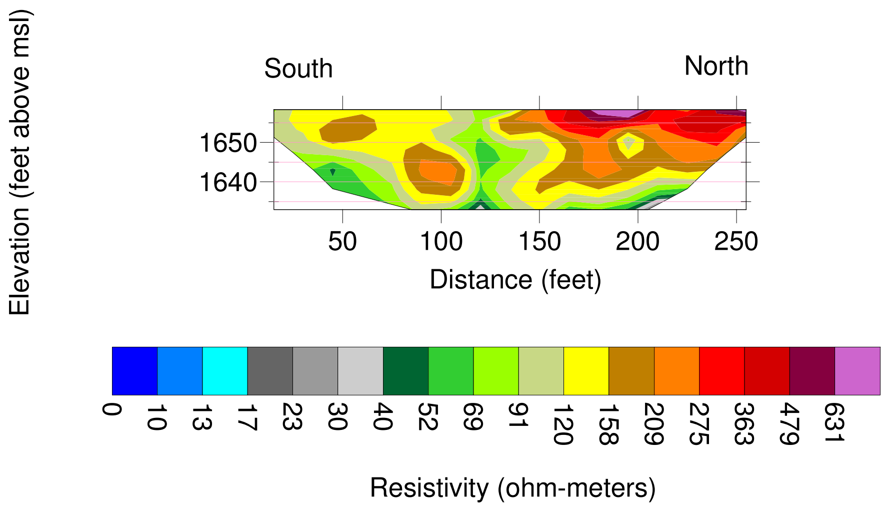


Topeka 27 Dipole-Dipole - Least Squares Model (VE 2X)
West
East
Elevation (feet above msl)
1650
1600
1550
1500
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
Distance (feet)
0
10
13
17
23
30
40
52
69
91
120
158
209
275
363
479
631
Resistivity (ohm-meters)

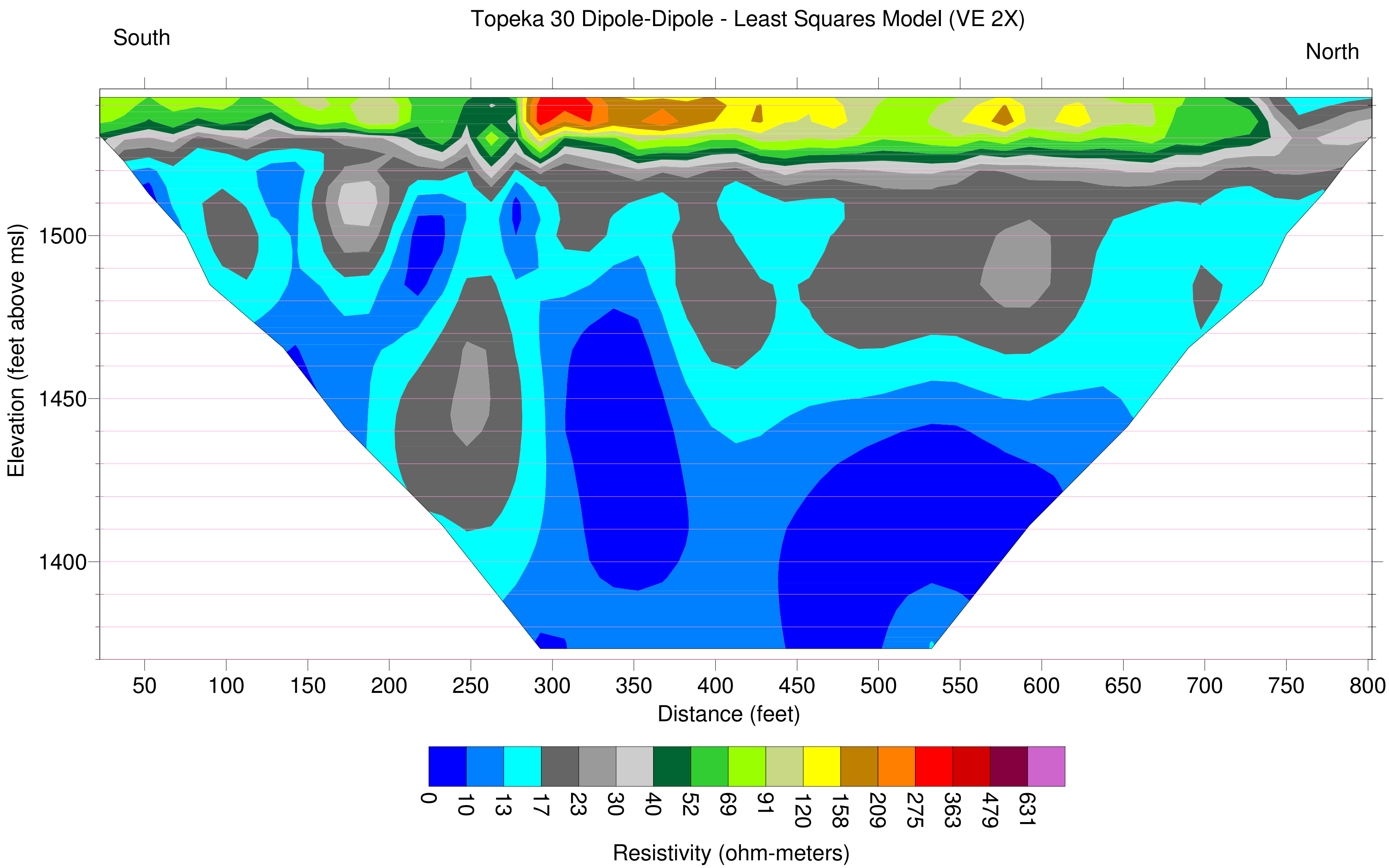


Topeka 28 Dipole-Dipole - Least Squares Model (VE 2X)
West
East
Elevation (feet above msl)
1600
1550
1500
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
Distance (feet)
0
10
13
17
23
30
40
52
69
91
120
158
209
275
363
479
631
Resistivity (ohm-meters)

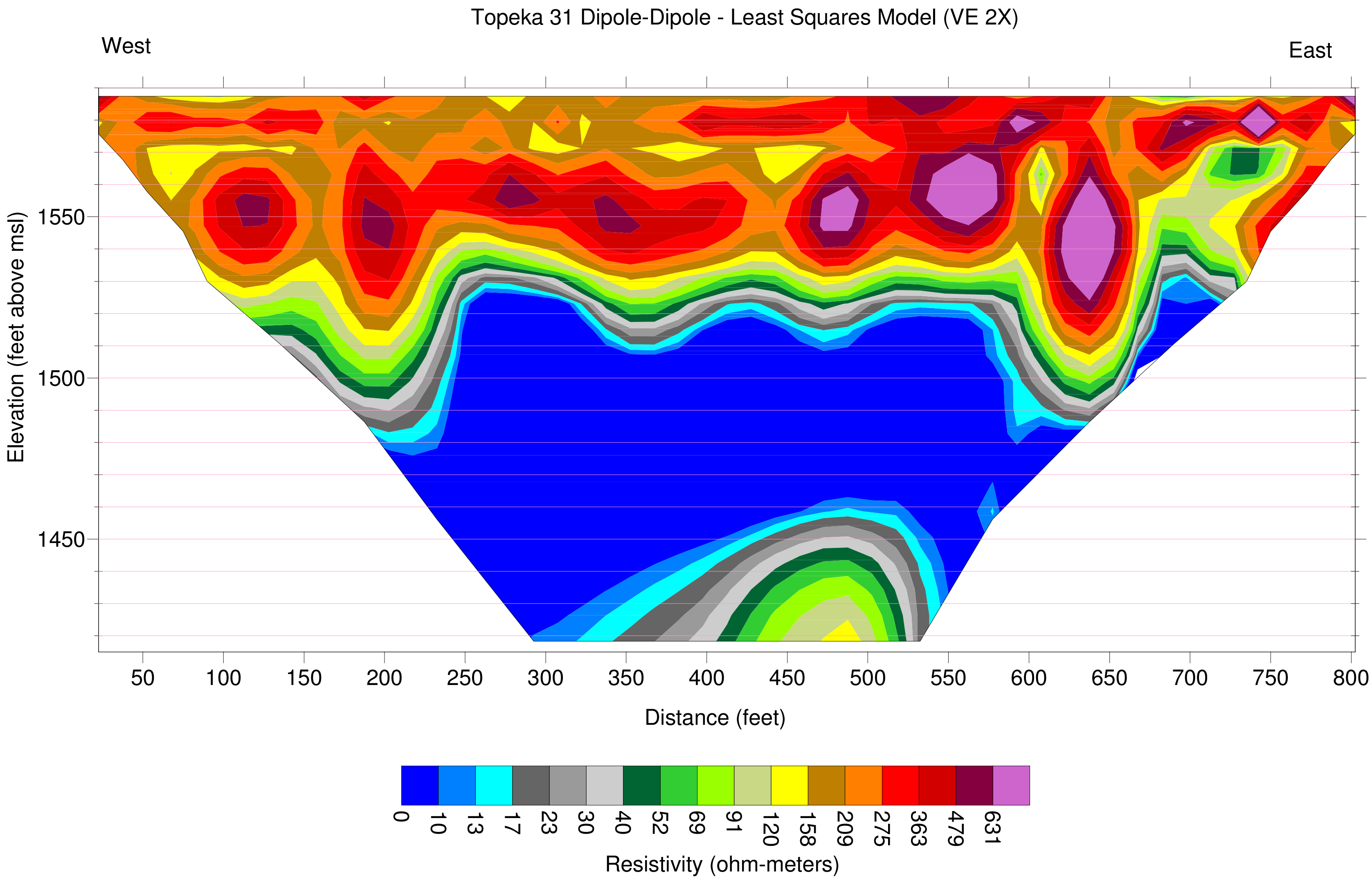
Topeka 29B Dipole-Dipole - Least Squares Model (VE 2X)

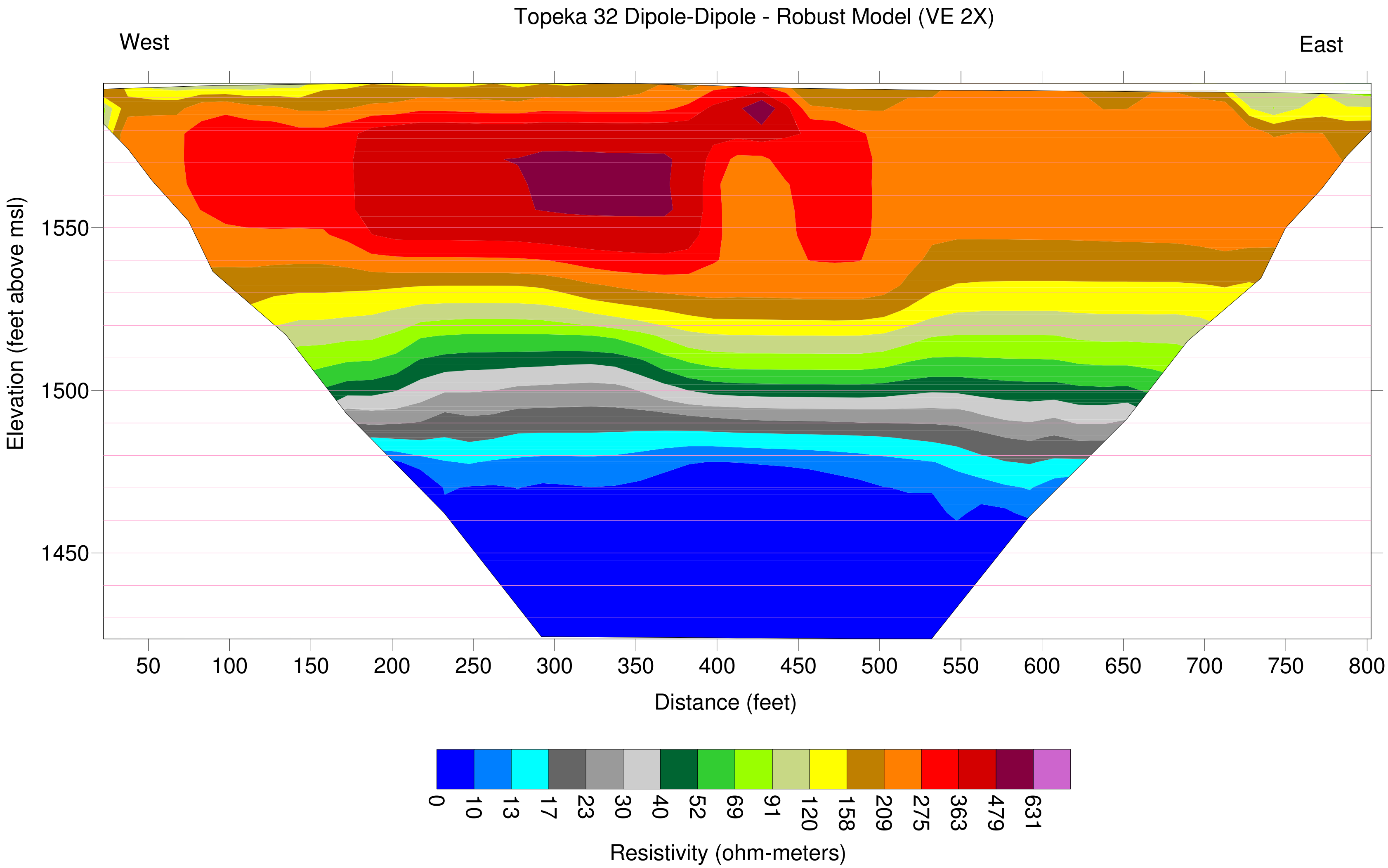


NOTE: Data is noisy. Deep data has been removed and ignored.

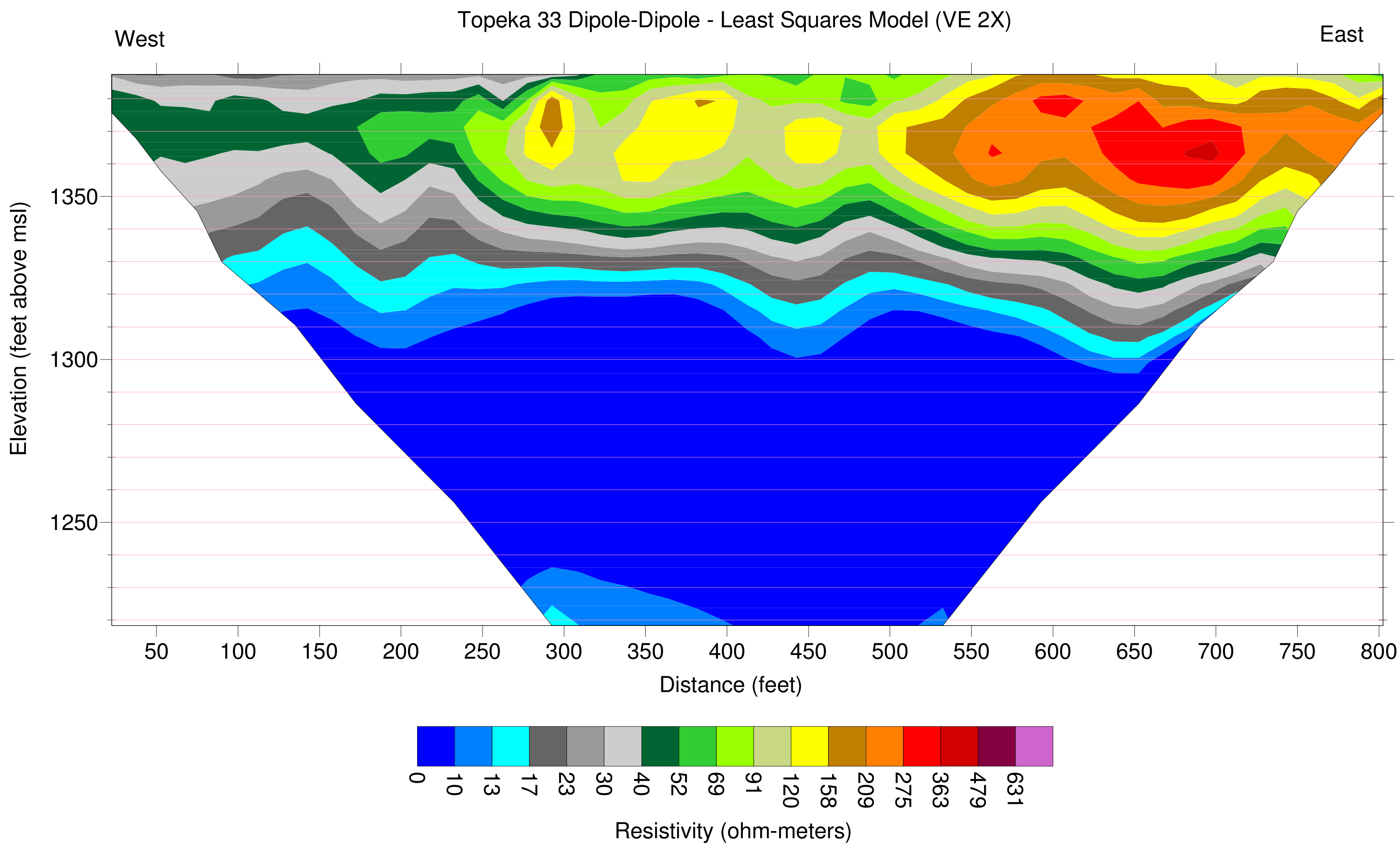


Topeka 30 Dipole-Dipole - Least Squares Model (VE 2X)
South
North
Elevation (feet above msl)
1500
1450
1400
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
Distance (feet)
0
10
13
17
23
30
40
52
69
91
120
158
209
275
363
479
631
Resistivity (ohm-meters)

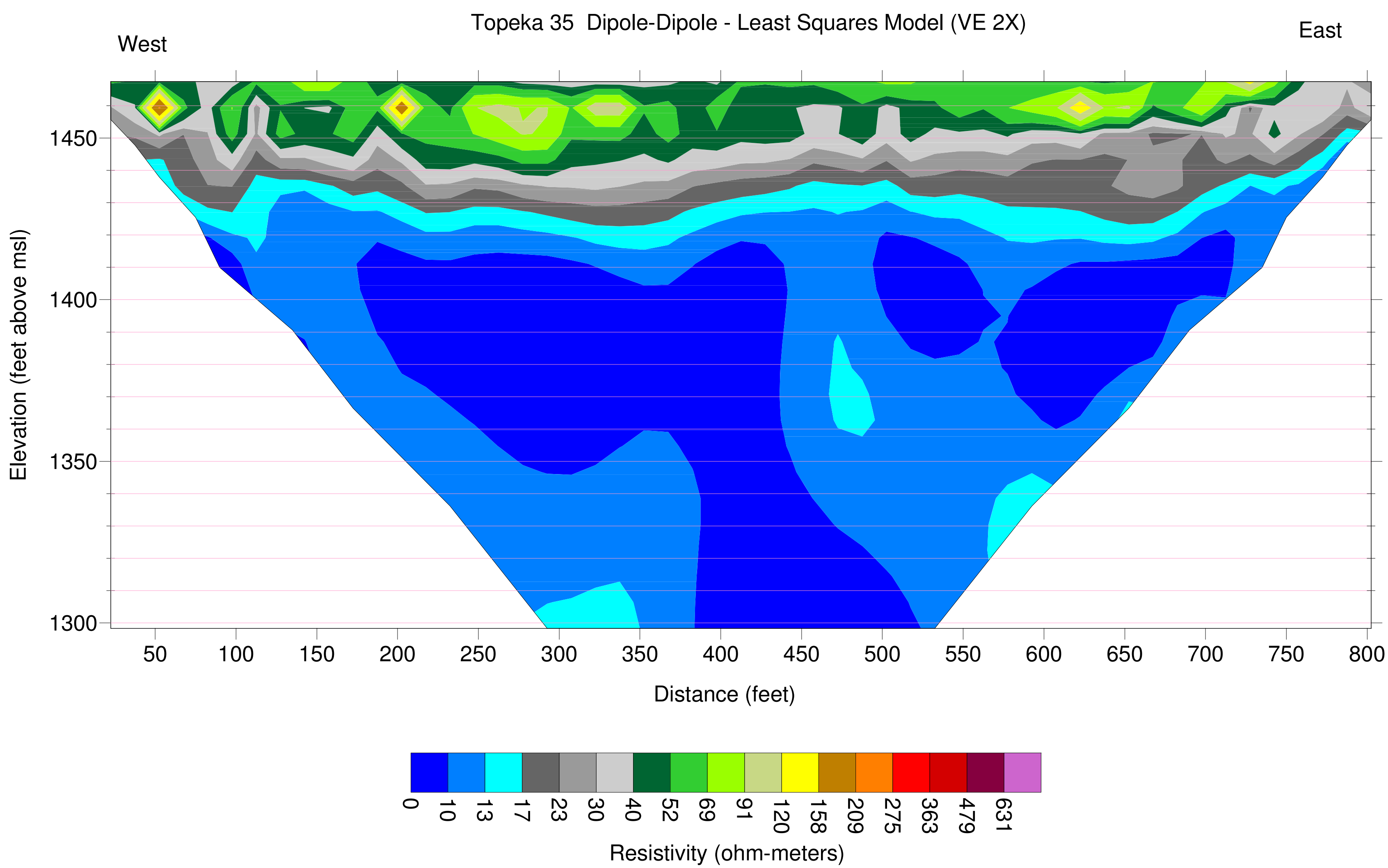

Topeka 31 Dipole-Dipole - Least Squares Model (VE 2X)
West
East
Elevation (feet above msl)
1550
1500
1450
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
Distance (feet)
0
10
13
17
23
30
40
52
69
91
120
158
209
275
363
479
631
Resistivity (ohm-meters)



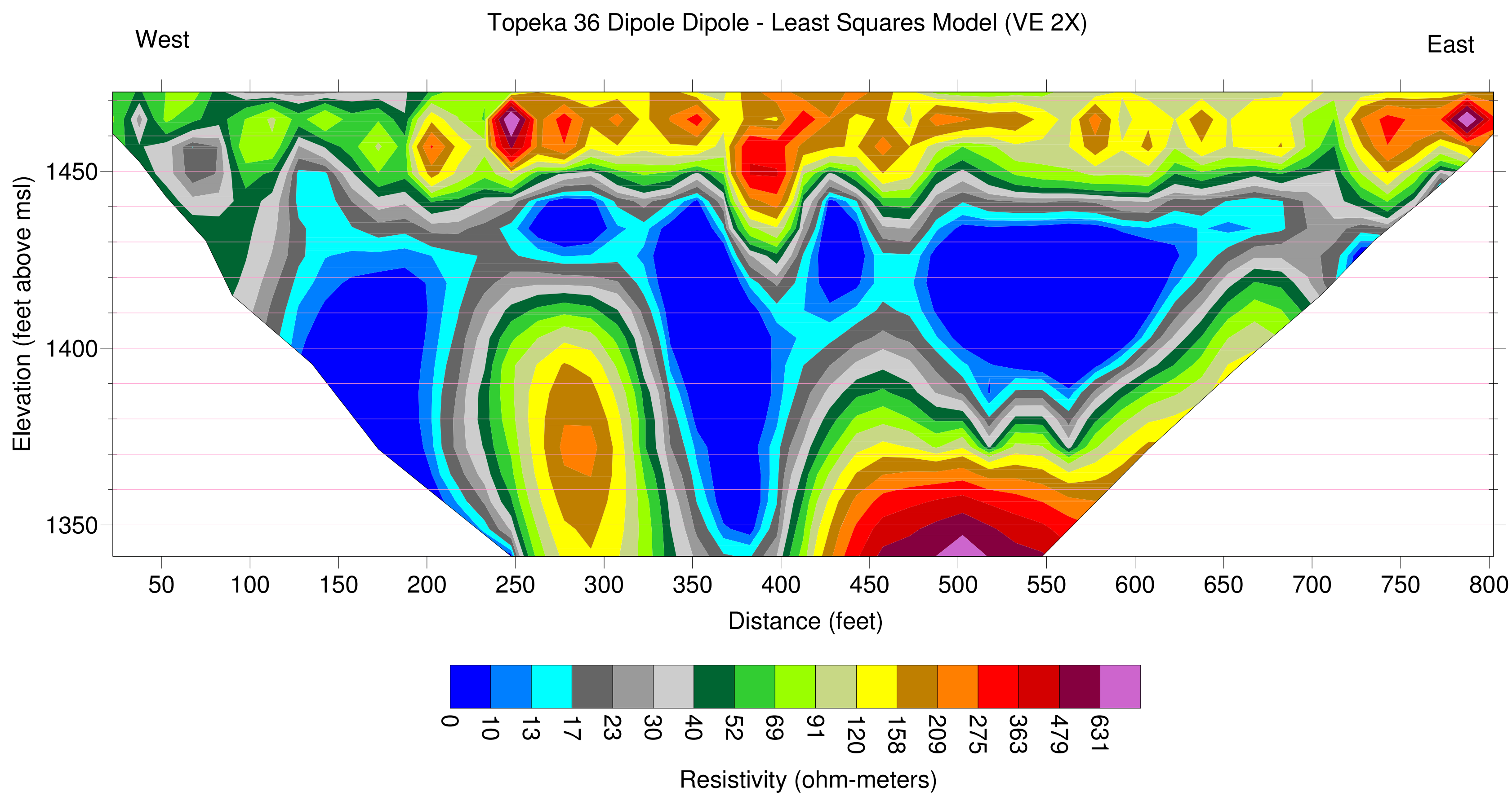
Topeka 32 Dipole-Dipole - Robust Model (VE 2X)
West
East
Elevation (feet above msl)
1550
1500
1450
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
Distance (feet)
0
10
13
17
23
30
40
52
69
91
120
158
209
275
363
479
631
Resistivity (ohm-meters)



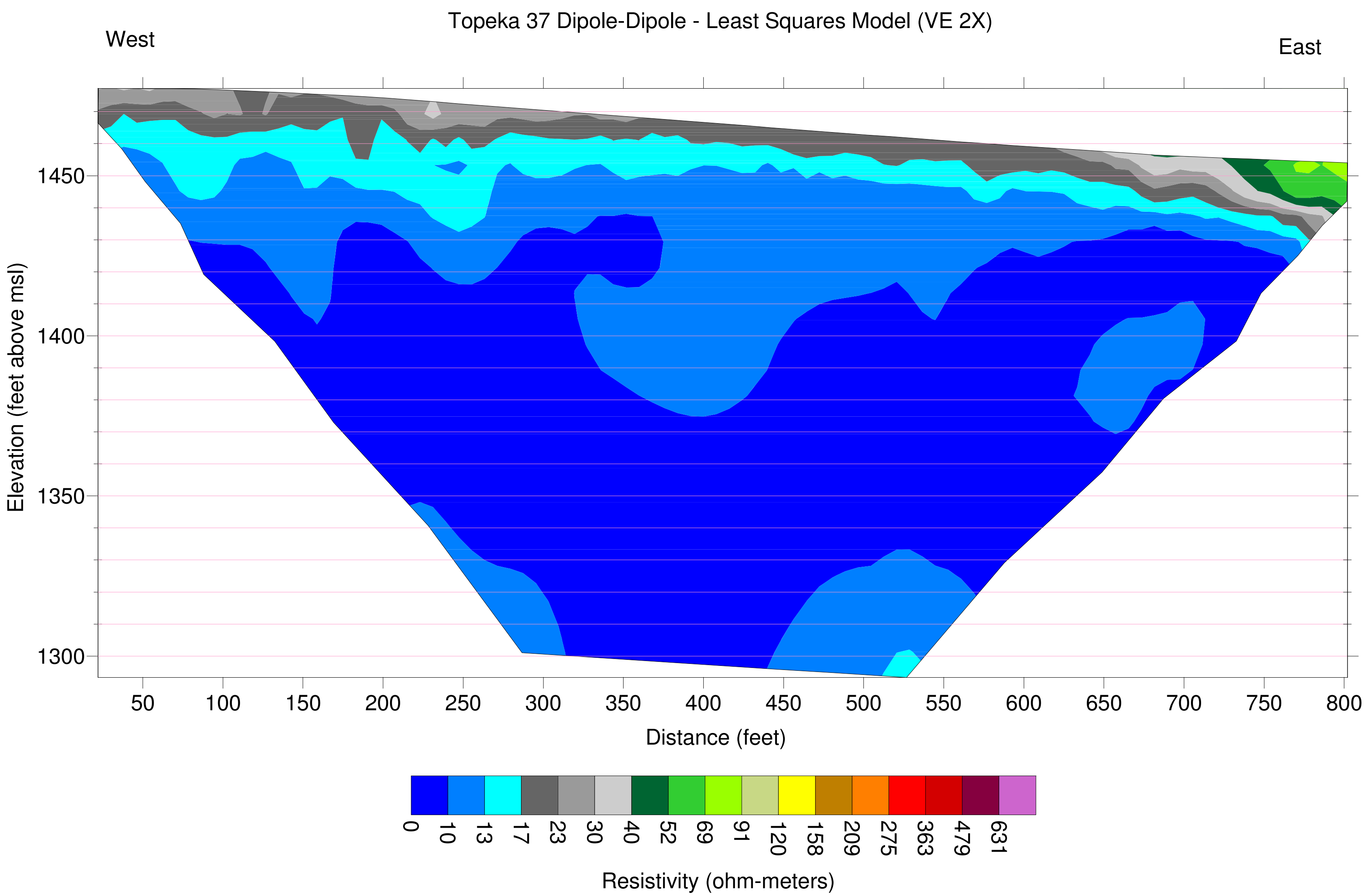
Topeka 33 Dipole-Dipole - Least Squares Model (VE 2X)
West
East
Elevation (feet above msl)
1350
1300
1250
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
Distance (feet)
0
10
13
17
23
30
40
52
69
91
120
158
209
275
363
479
631
Resistivity (ohm-meters)



Topeka 35 Dipole-Dipole - Least Squares Model (VE 2X)
West
East
1450
1400
1350
1300
Elevation (feet above msl)
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
Distance (feet)
0
10
13
17
23
30
40
52
69
91
120
158
209
275
363
479
631
Resistivity (ohm-meters)

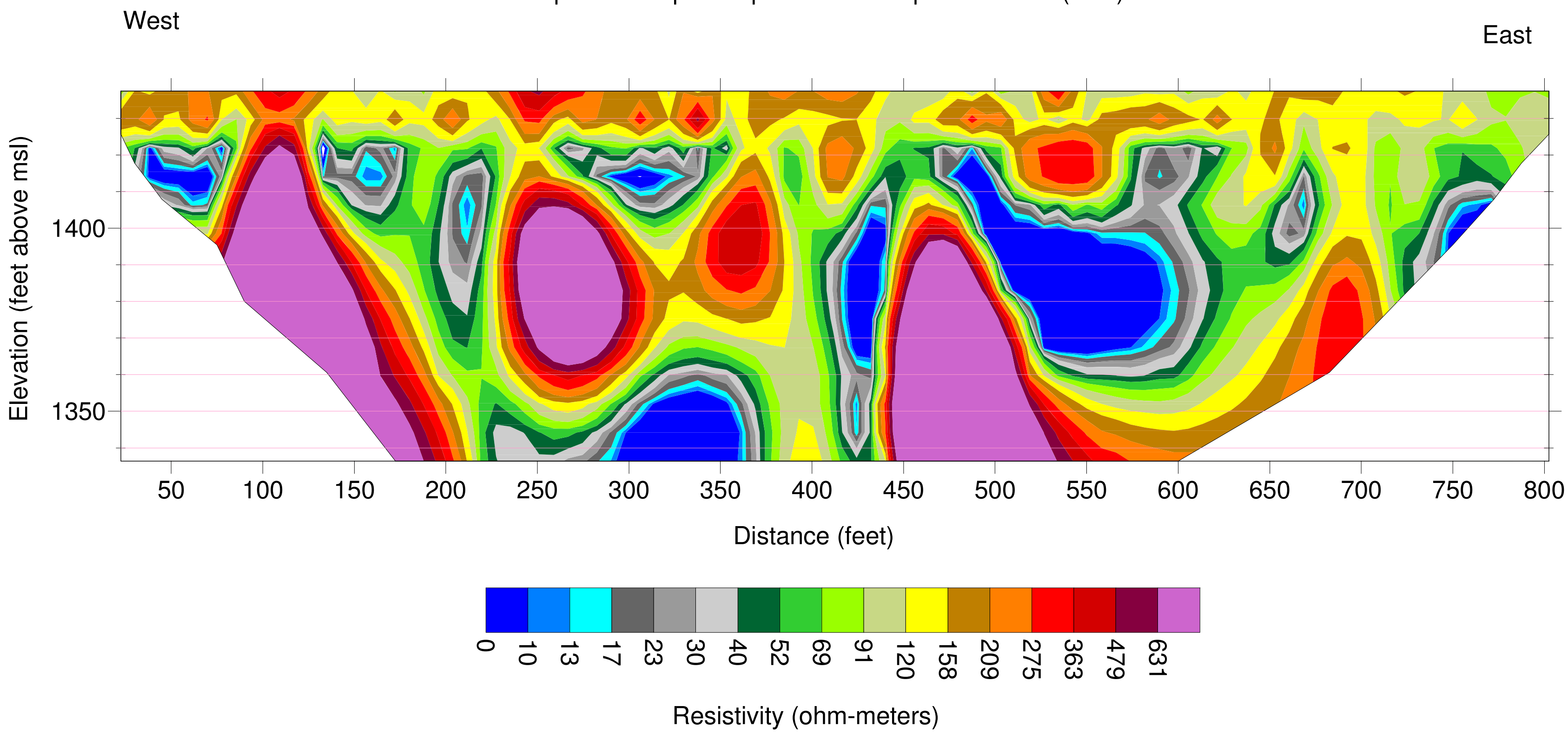


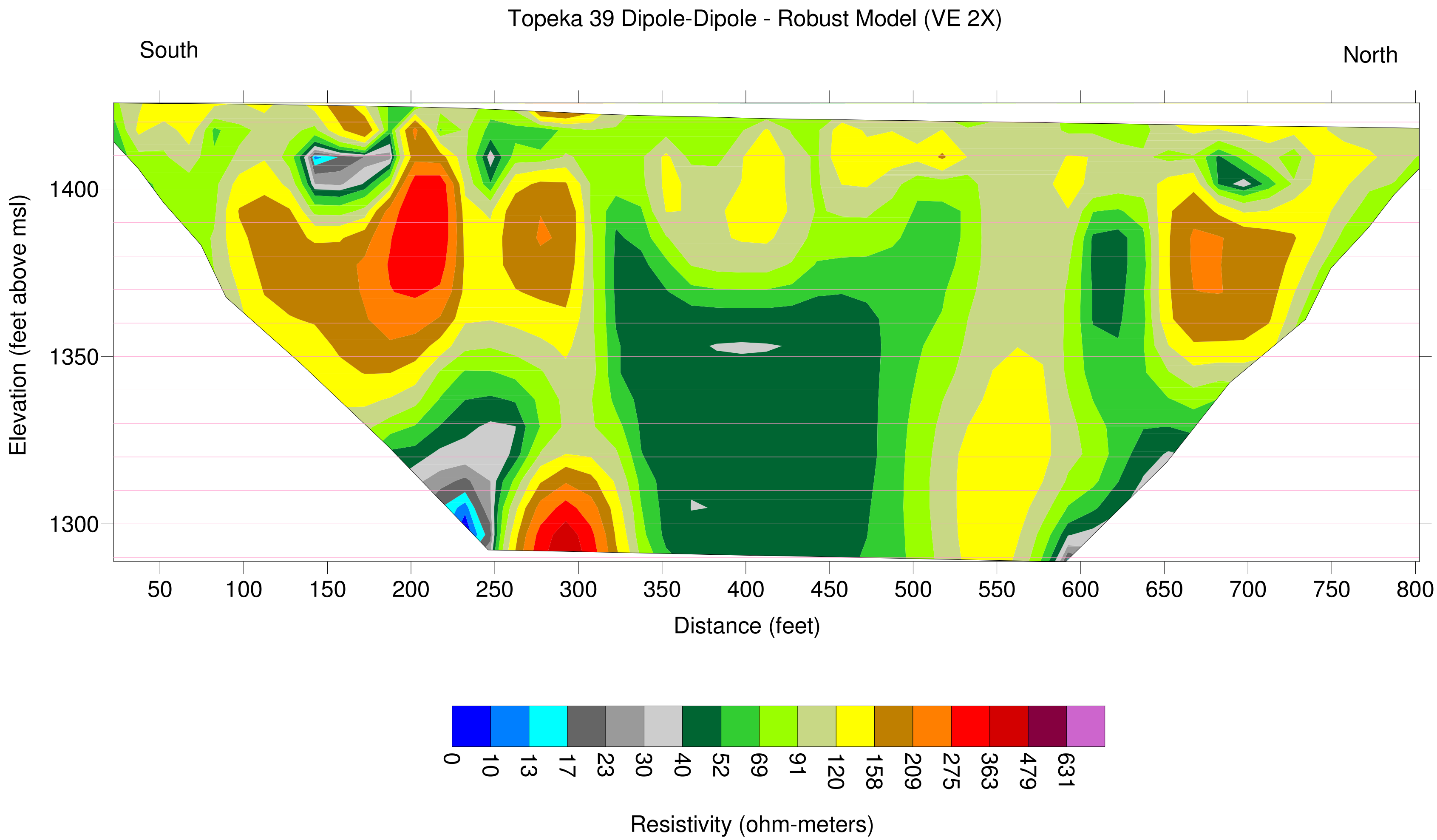
High resistivity section in deeper horizons is questionable. The data was noisy.



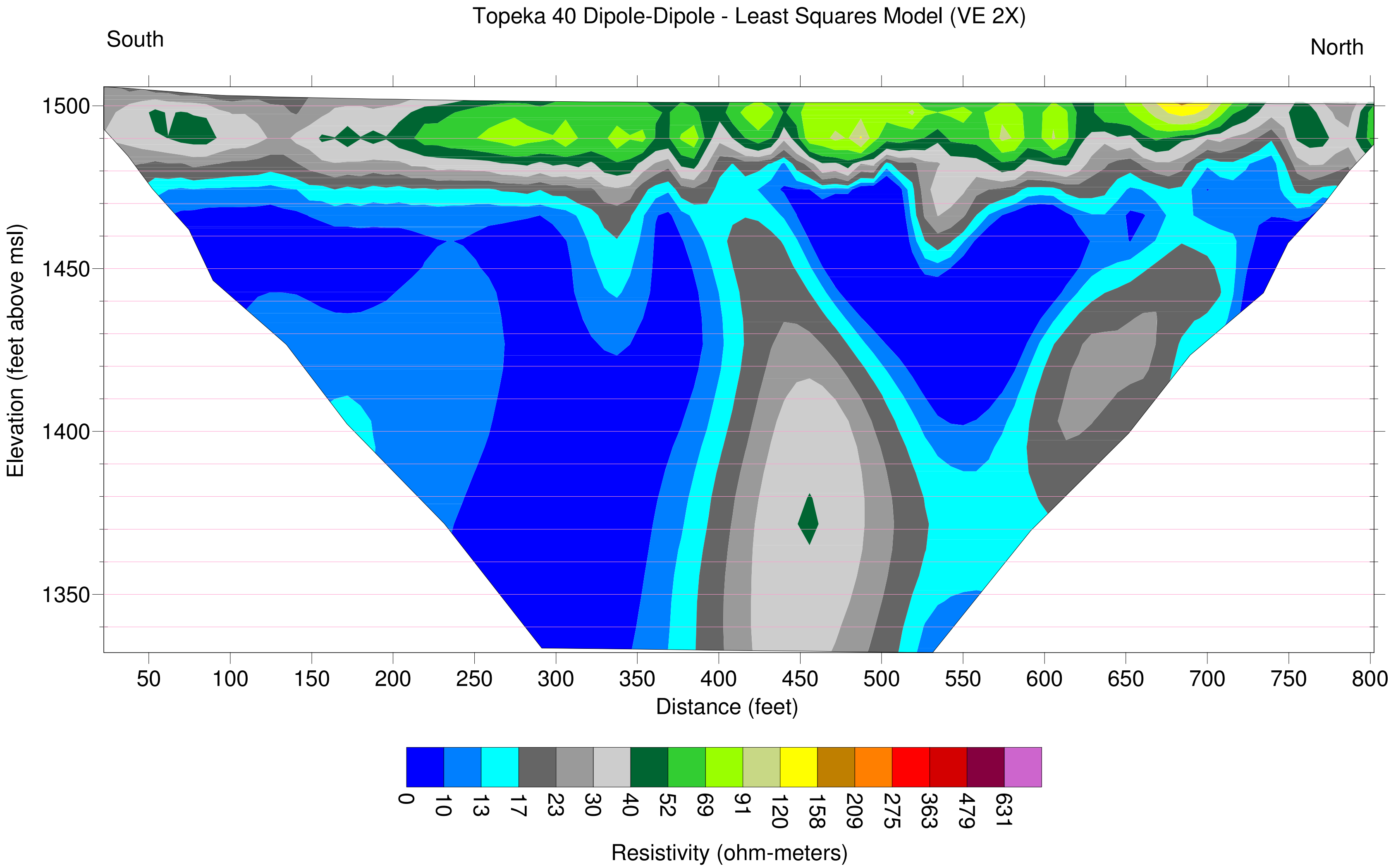
Topeka 37 Dipole-Dipole - Least Squares Model (VE 2X)
West
East
1450
1400
1350
1300
Elevation (feet above msl)
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
Distance (feet)
0
10
13
17
23
30
40
52
69
91
120
158
209
275
363
479
631
Resistivity (ohm-meters)

Topeka 38 Dipole-Dipole - Least Squares Model (2VE)

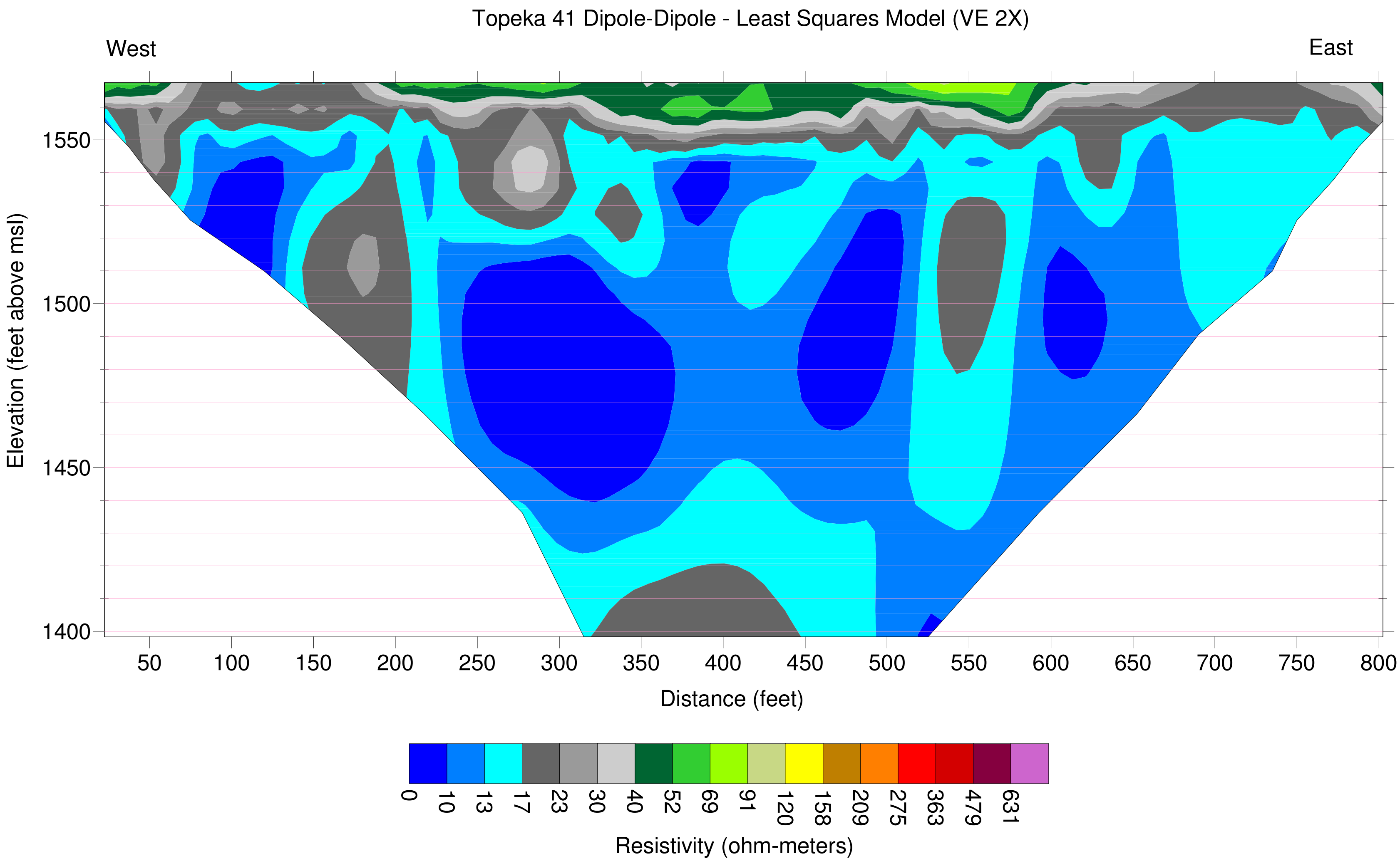




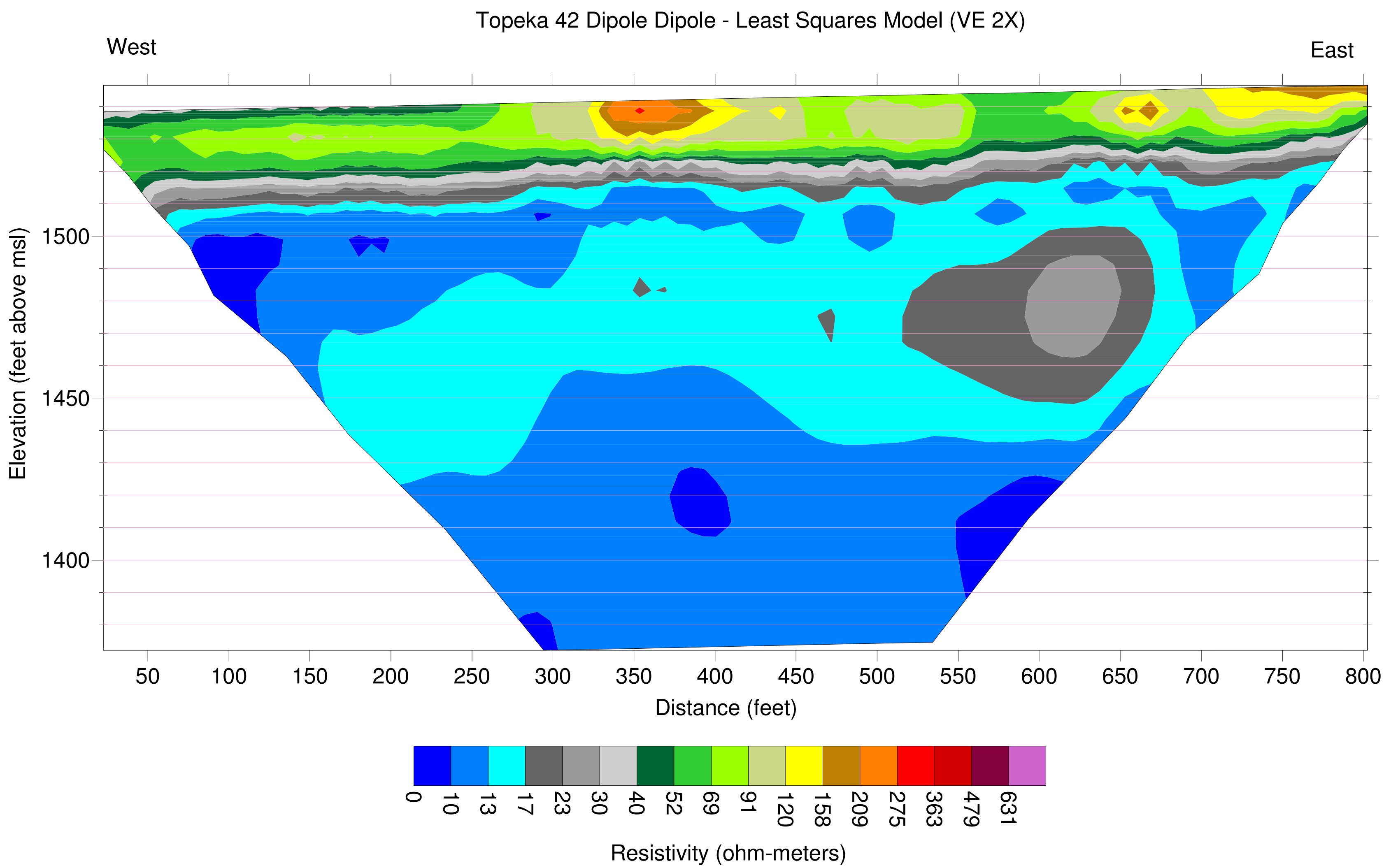
Topeka 39 Dipole-Dipole - Robust Model (VE 2X)
South
North
Elevation (feet above msl)
1400
1350
1300
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
Distance (feet)
0
10
13
17
23
30
40
52
69
91
120
158
209
275
363
479
631
Resistivity (ohm-meters)



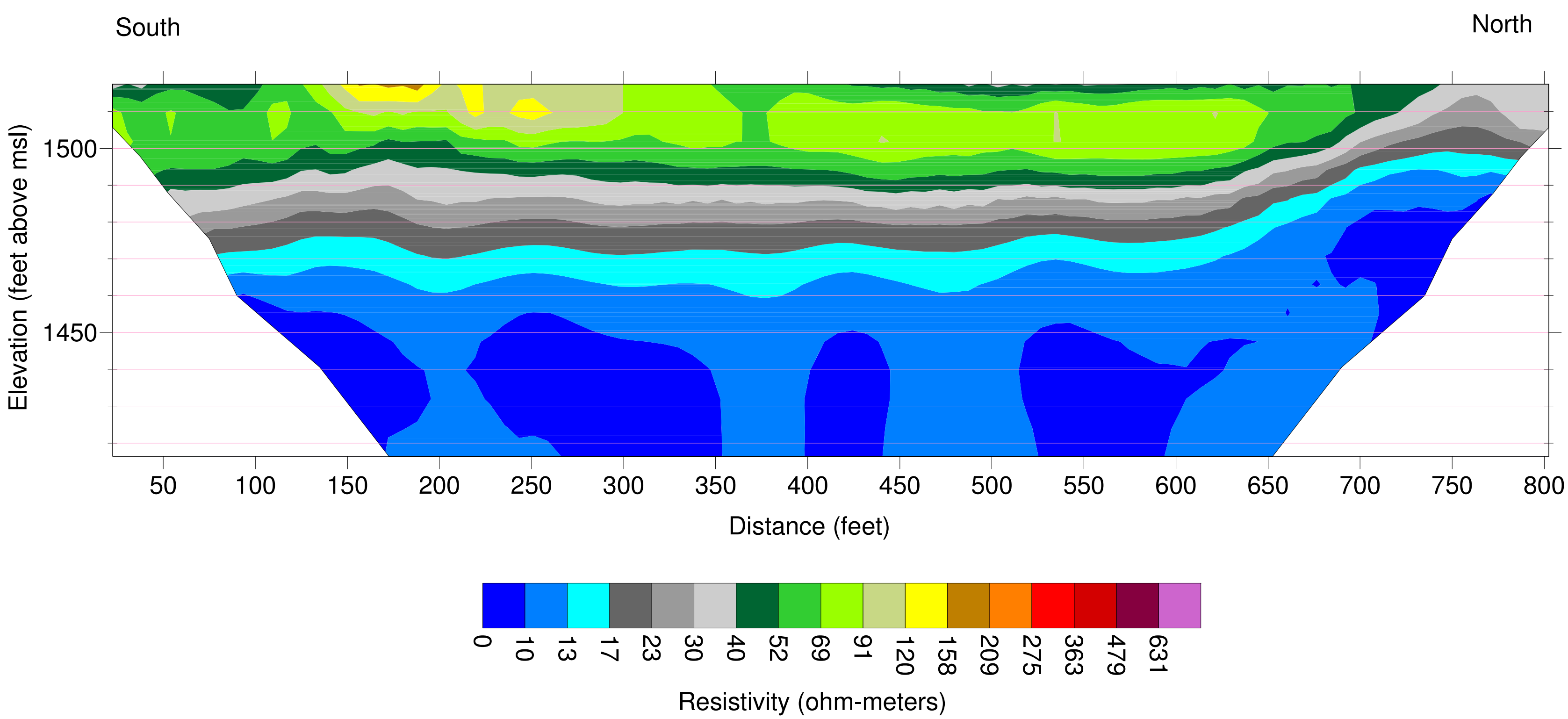
Topeka 40 Dipole-Dipole - Least Squares Model (VE 2X)
South
North
Elevation (feet above msl)
1500
1450
1400
1350
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
Distance (feet)
0
10
13
17
23
30
40
52
69
91
120
158
209
275
363
479
631
Resistivity (ohm-meters)

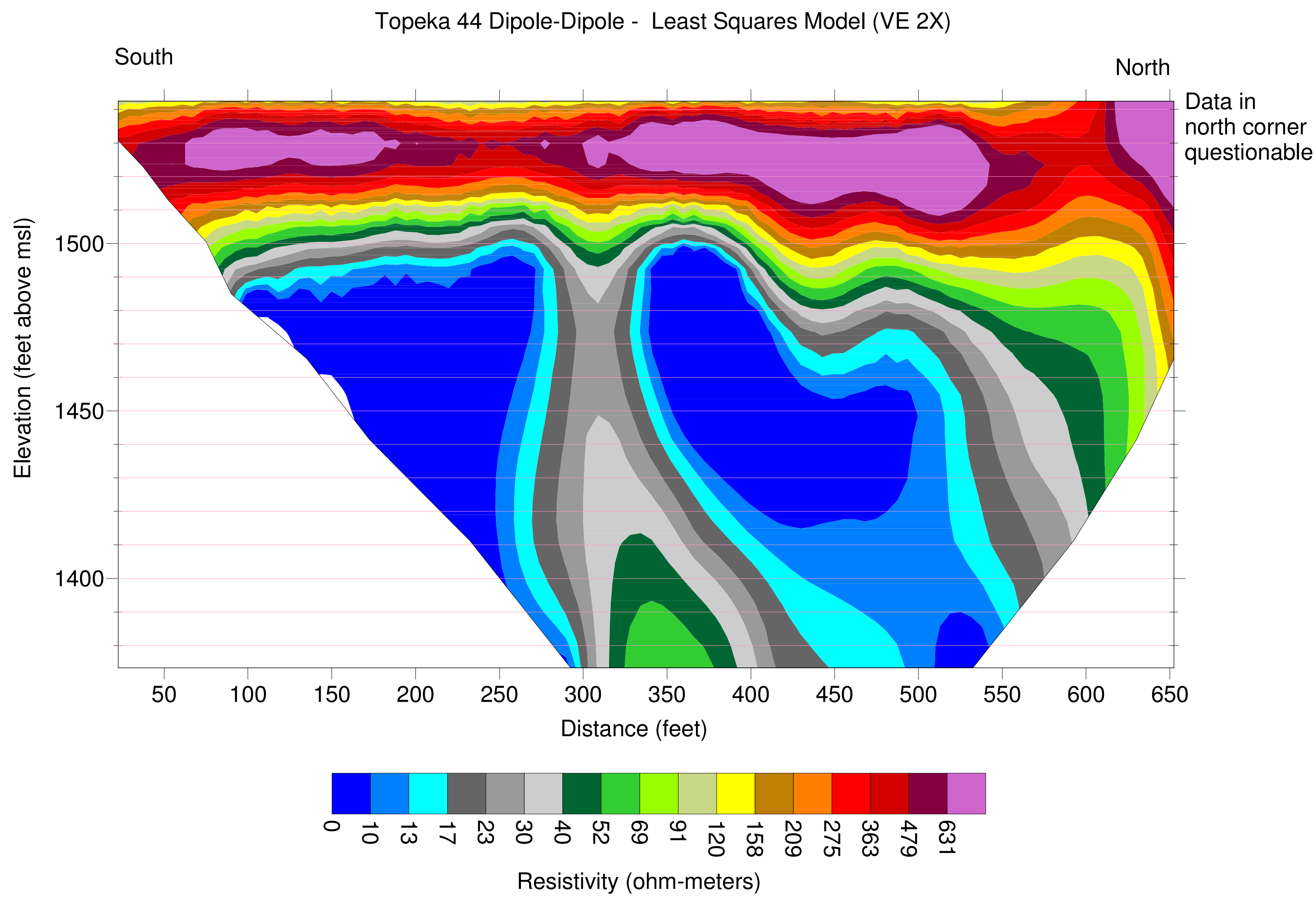


Topeka 41 Dipole-Dipole - Least Squares Model (VE 2X)
West
East
1550
1500
1450
1400
Elevation (feet above msl)
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
Distance (feet)
0
10
13
17
23
30
40
52
69
91
120
158
209
275
363
479
631
Resistivity (ohm-meters)

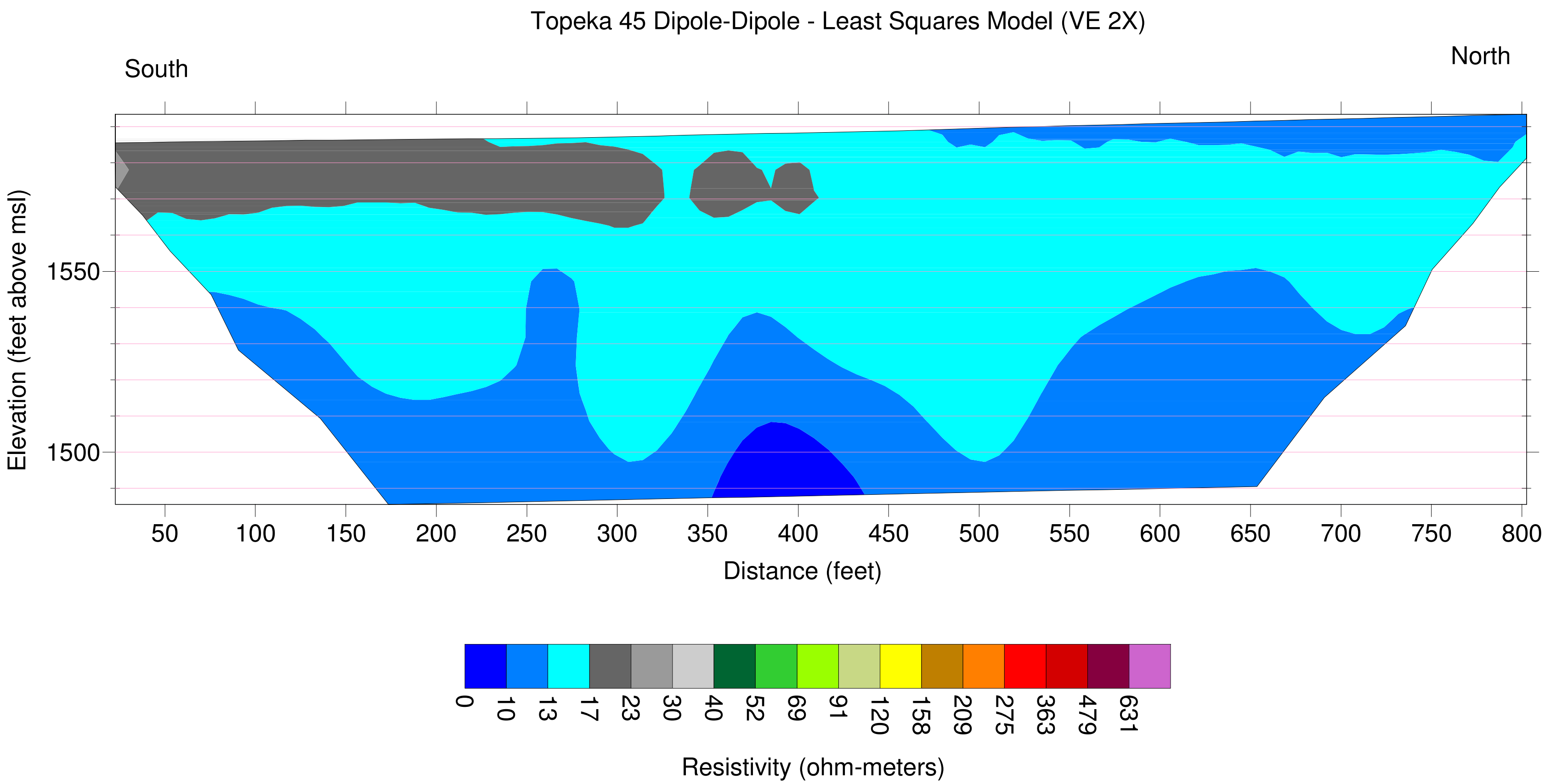

Topeka 42 Dipole Dipole - Least Squares Model (VE 2X)
West
East
Elevation (feet above msl)
1500
1450
1400
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
Distance (feet)
0
10
13
17
23
30
40
52
69
91
120
158
209
275
363
479
631
Resistivity (ohm-meters)

Topeka 43 Dipole-Dipole - Least Squares Model (VE 2X)



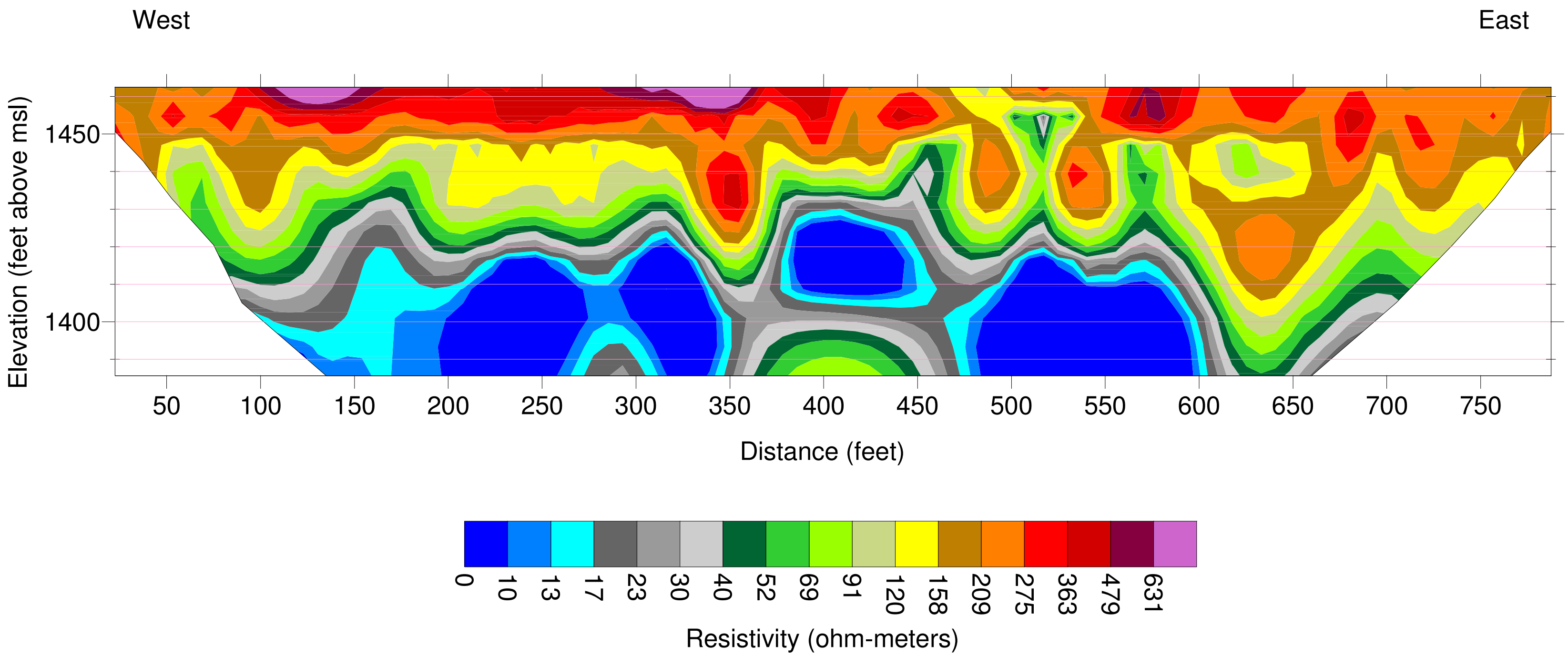


Topeka 44 Dipole-Dipole - Least Squares Model (VE 2X)
South
North
Data in north corner questionable
Elevation (feet above msl)
1500
1450
1400
50
100
150
200
250
300
350
400
450
500
550
600
650
Distance (feet)
0
10
13
17
23
30
40
52
69
91
120
158
209
275
363
479
631
Resistivity (ohm-meters)



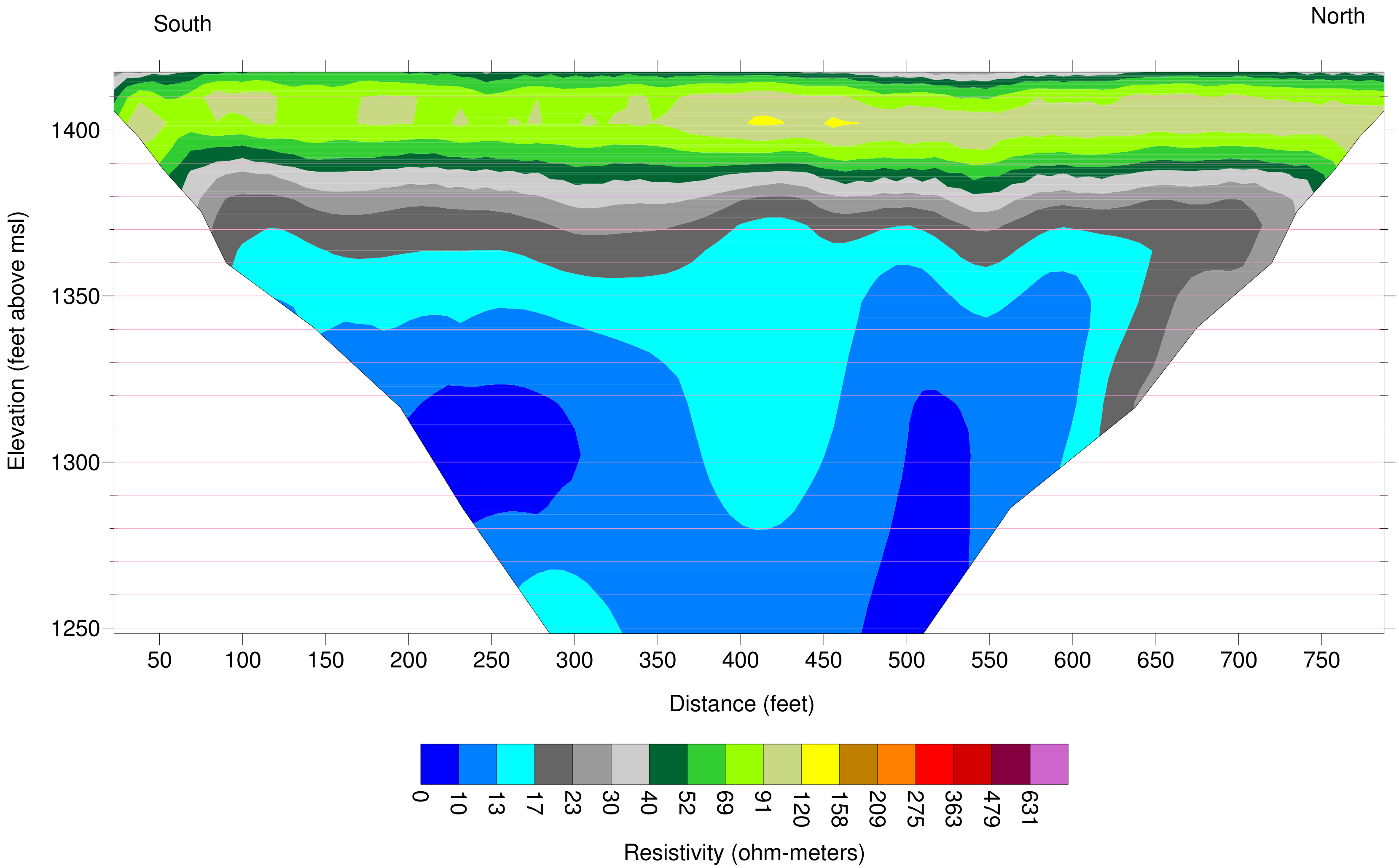
Topeka 45 Dipole-Dipole - Least Squares Model (VE 2X)
South
North
Elevation (feet above msl)
1550
1500
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
Distance (feet)
0
10
13
17
23
30
40
52
69
91
120
158
209
275
363
479
631
Resistivity (ohm-meters)

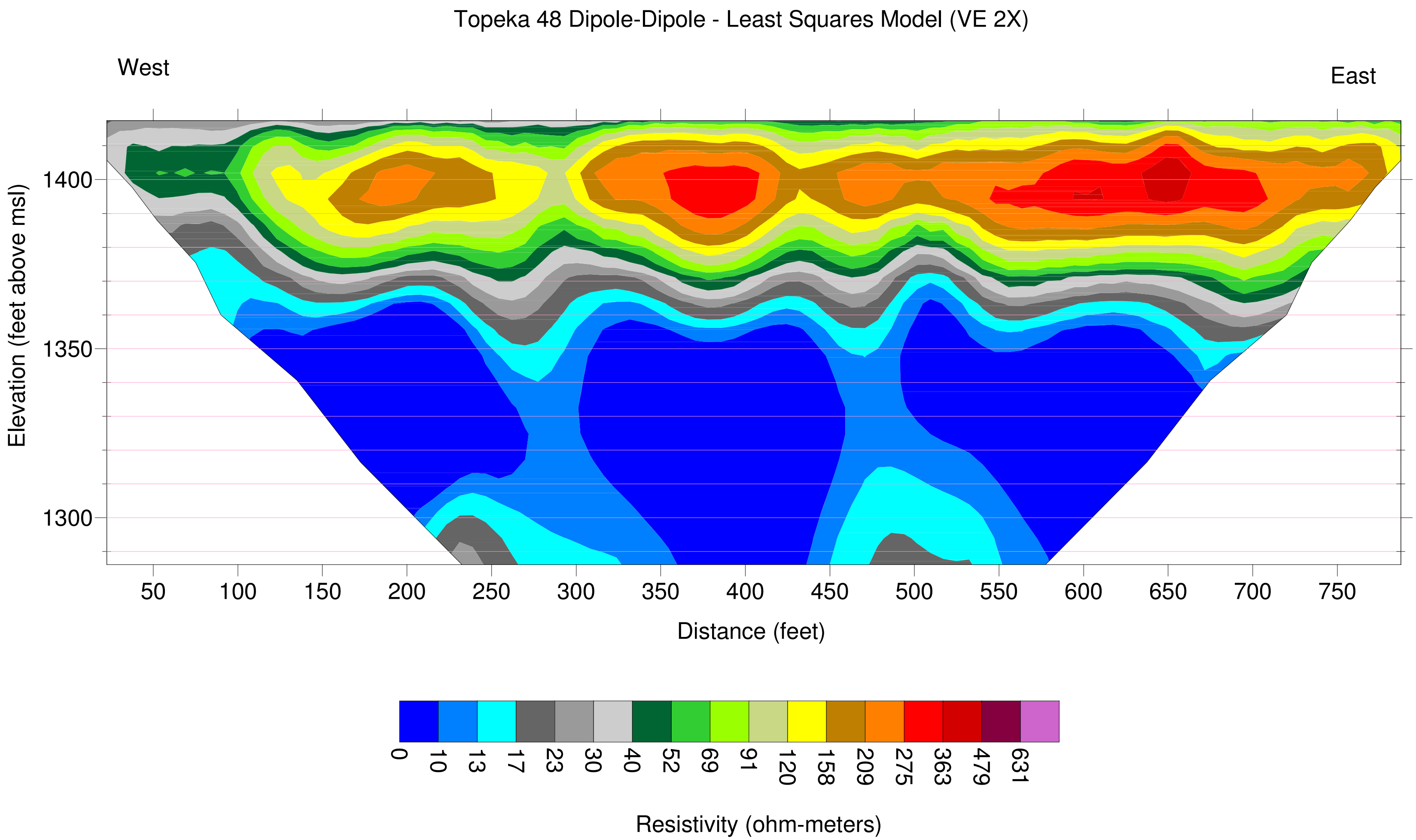
Topeka 46 Dipole-Dipole - Least Squares Model (VE 2X)



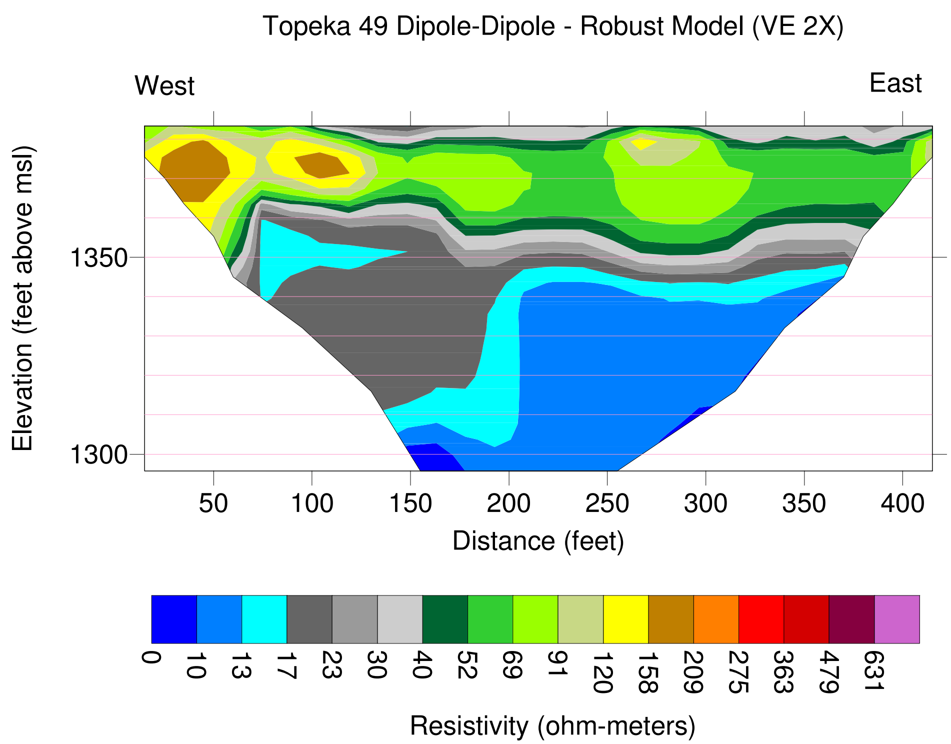
(11.9% error)

Topeka 47 Dipole-Dipole - Least Squares Model (VE 2X)



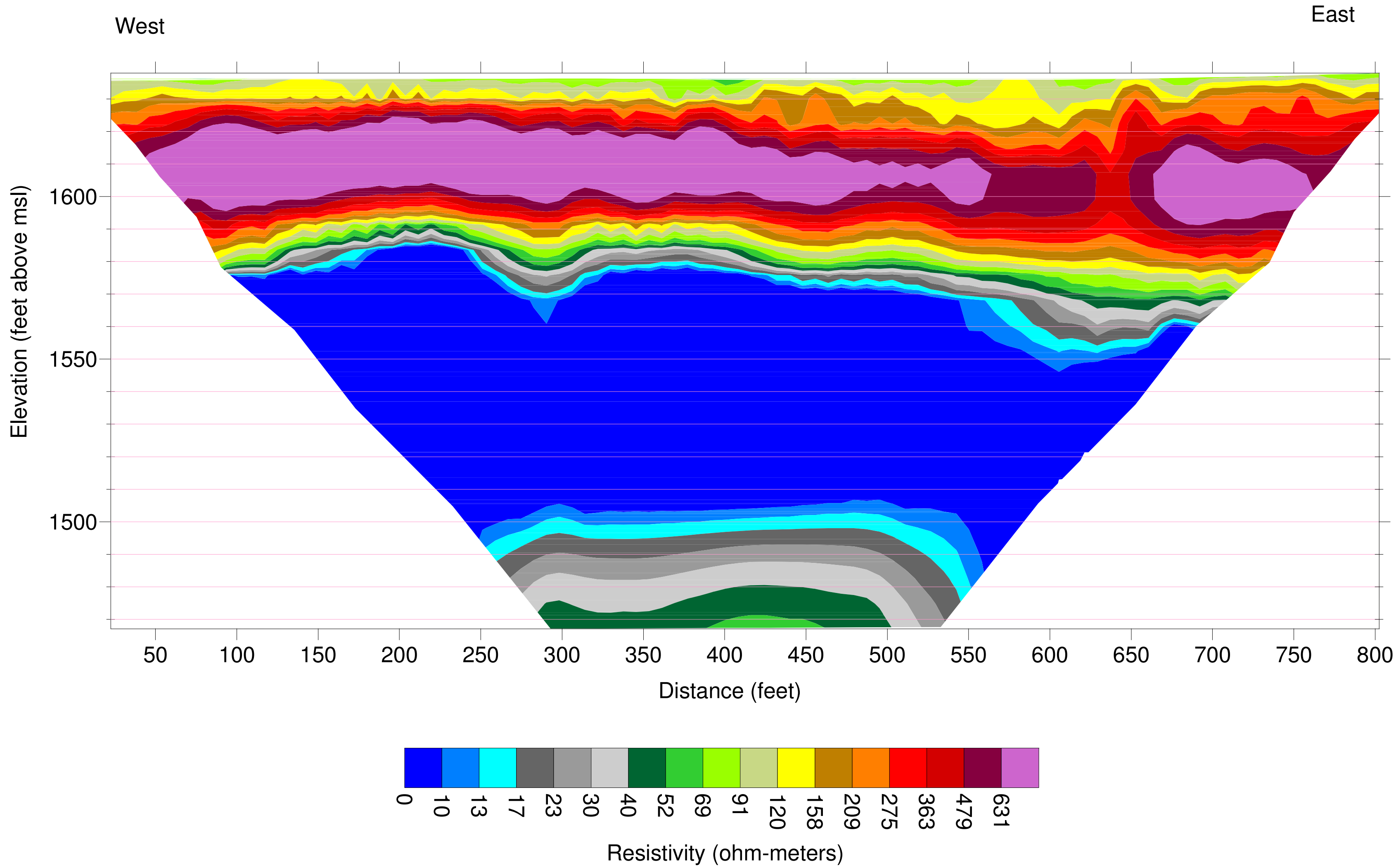


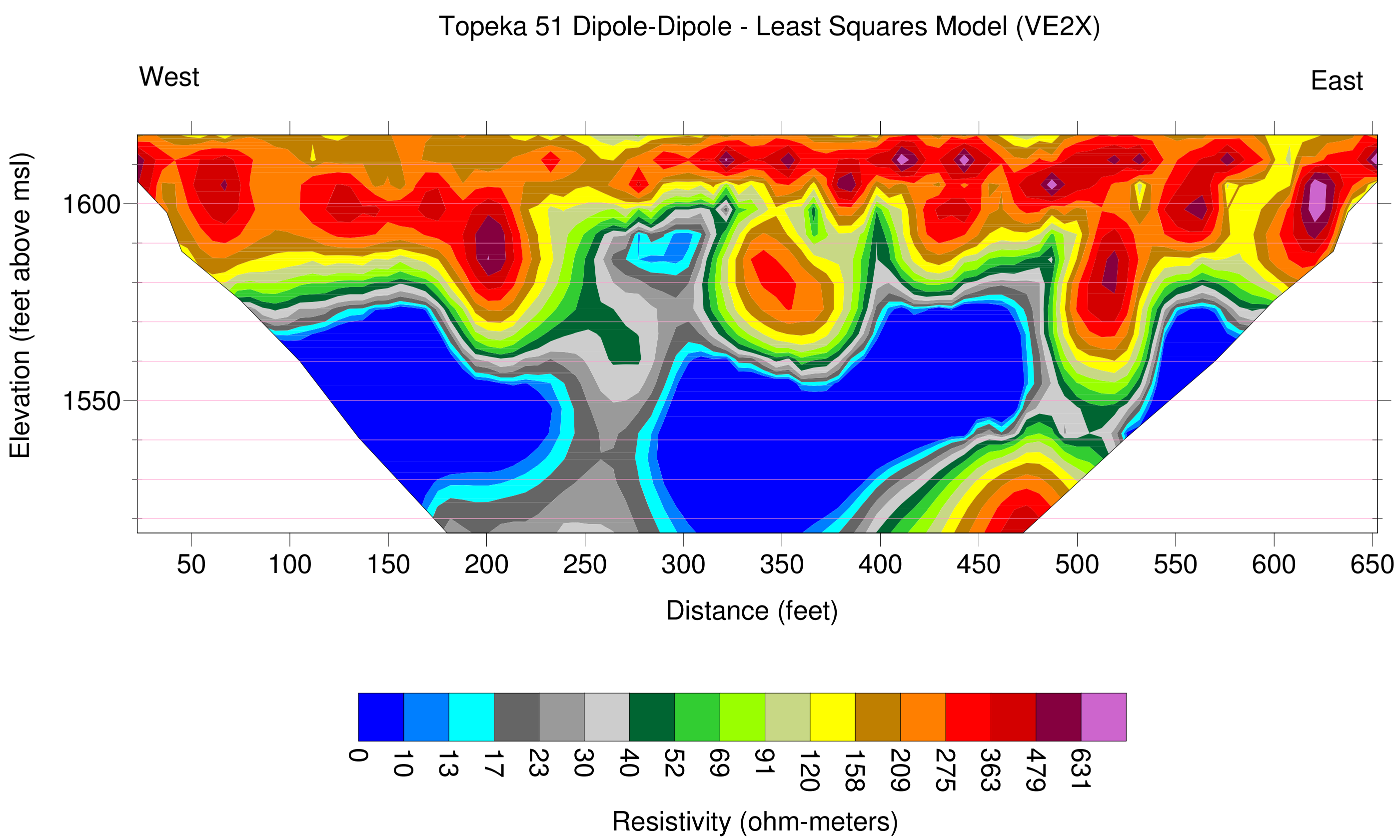
Topeka 48 Dipole-Dipole - Least Squares Model (VE 2X)
West
East
Elevation (feet above msl)
1400
1350
1300
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
Distance (feet)
0
10
13
17
23
30
40
52
69
91
120
158
209
275
363
479
631
Resistivity (ohm-meters)



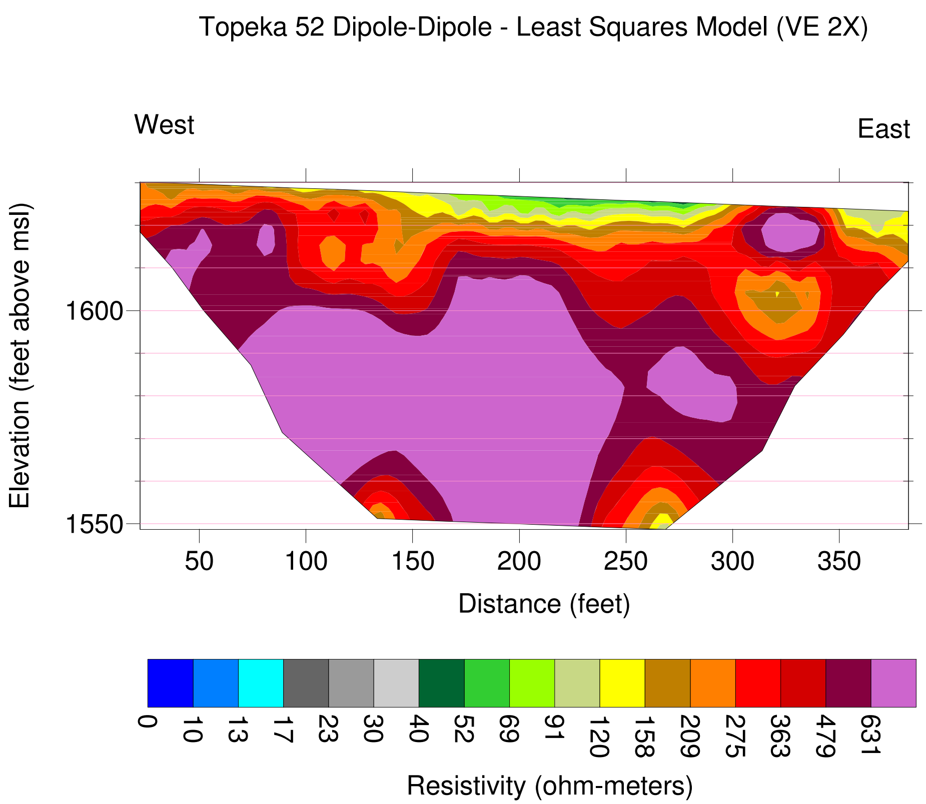
Topeka 49 Dipole-Dipole - Robust Model (VE 2X)
West
East
Elevation (feet above msl)
1350
1300
50
100
150
200
250
300
350
400
Distance (feet)
0
10
13
17
23
30
40
52
69
91
120
158
209
275
363
479
631
Resistivity (ohm-meters)

Topeka 50 Dipole-Dipole - Least Squares Model (VE 2X)

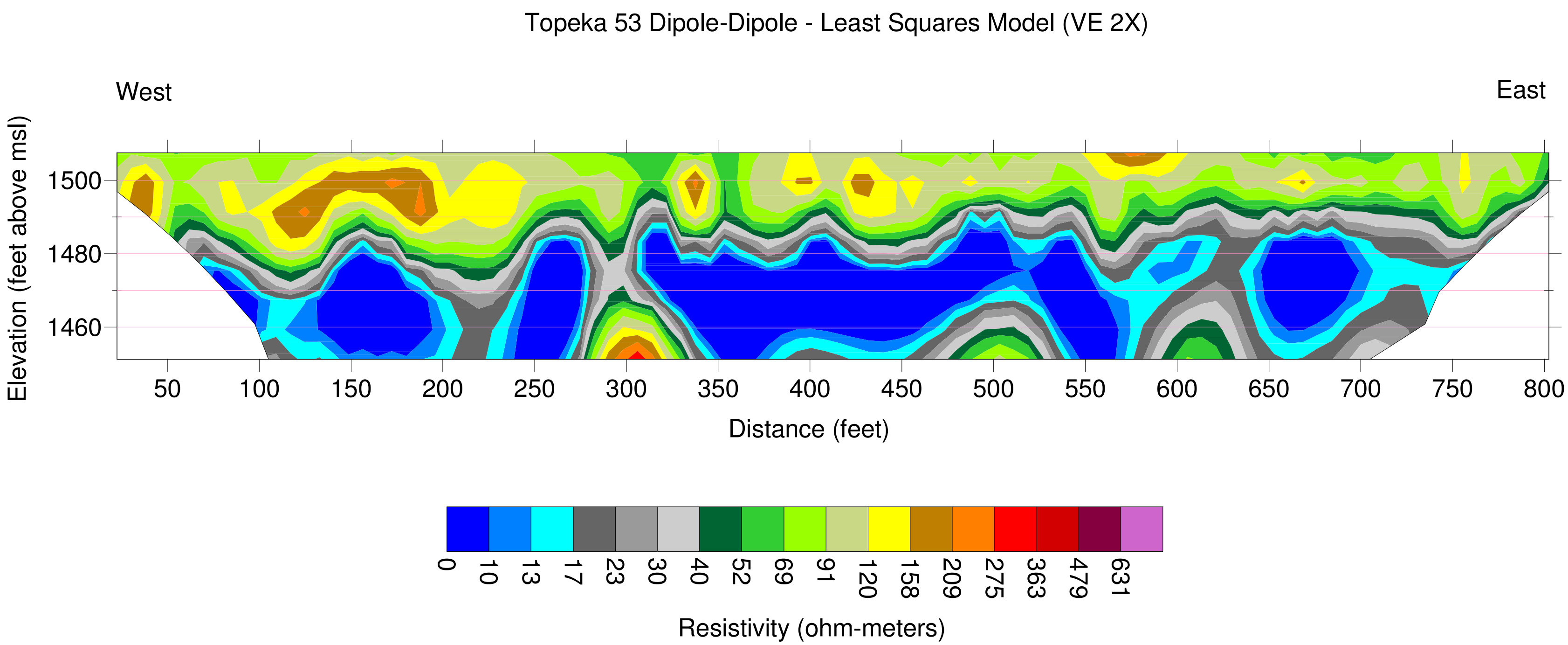




Topeka 51 Dipole-Dipole - Least Squares Model (VE2X)
West
East
Elevation (feet above msl)
1600
1550
50
100
150
200
250
300
350
400
450
500
550
600
650
Distance (feet)
0
10
13
17
23
30
40
52
69
91
120
158
209
275
363
479
631
Resistivity (ohm-meters)

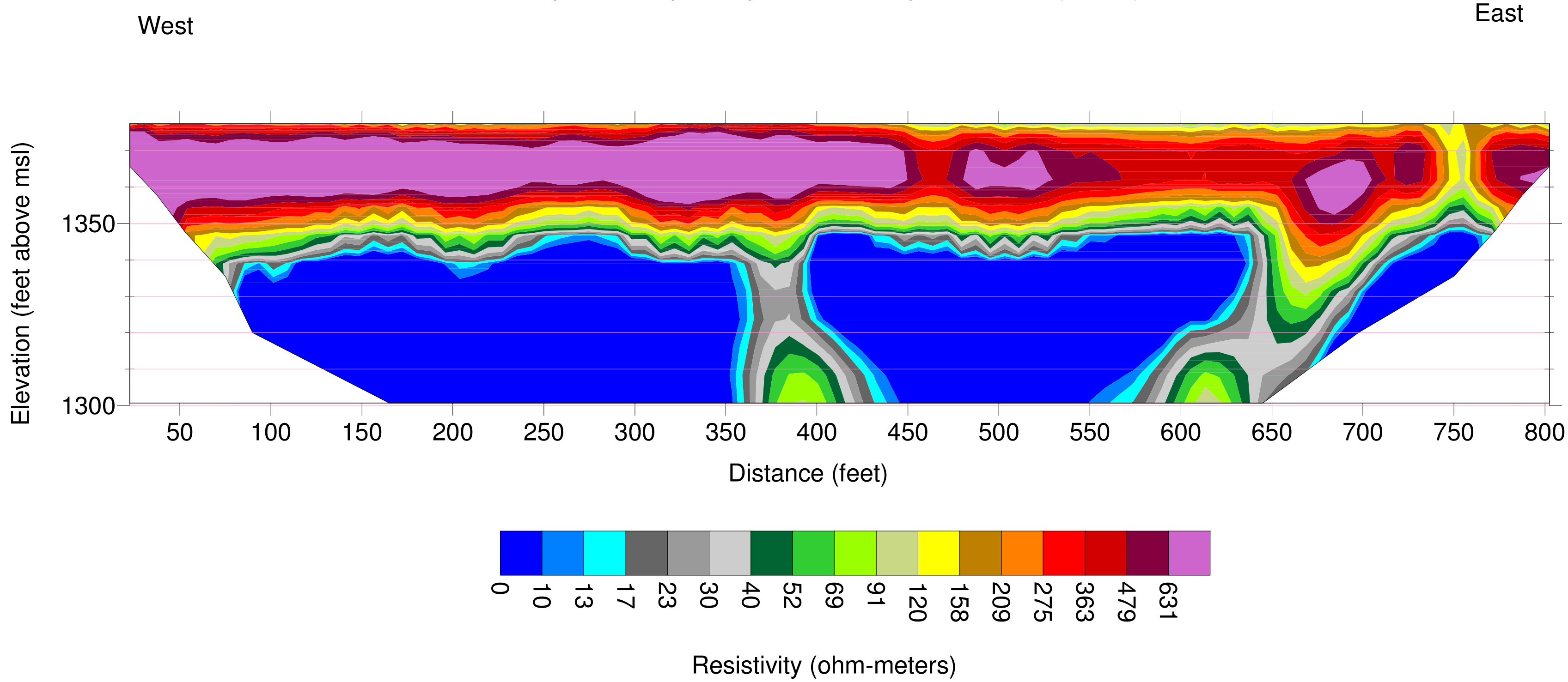


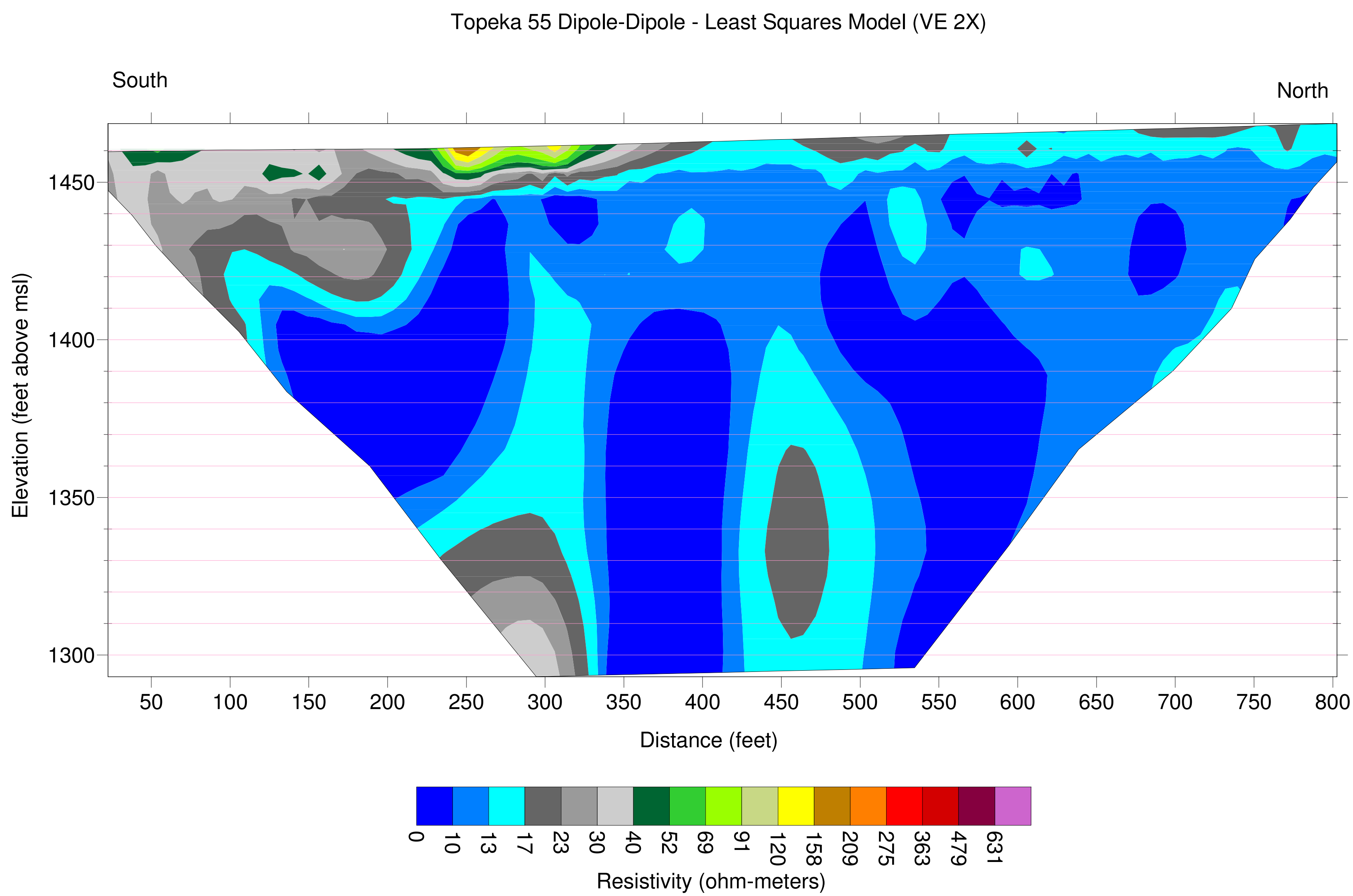
Topeka 52 Dipole-Dipole - Least Squares Model (VE 2X)
West
East
Elevation (feet above msl)
1600
1550
50
100
150
200
250
300
350
Distance (feet)
0
10
13
17
23
30
40
52
69
91
120
158
209
275
363
479
631
Resistivity (ohm-meters)

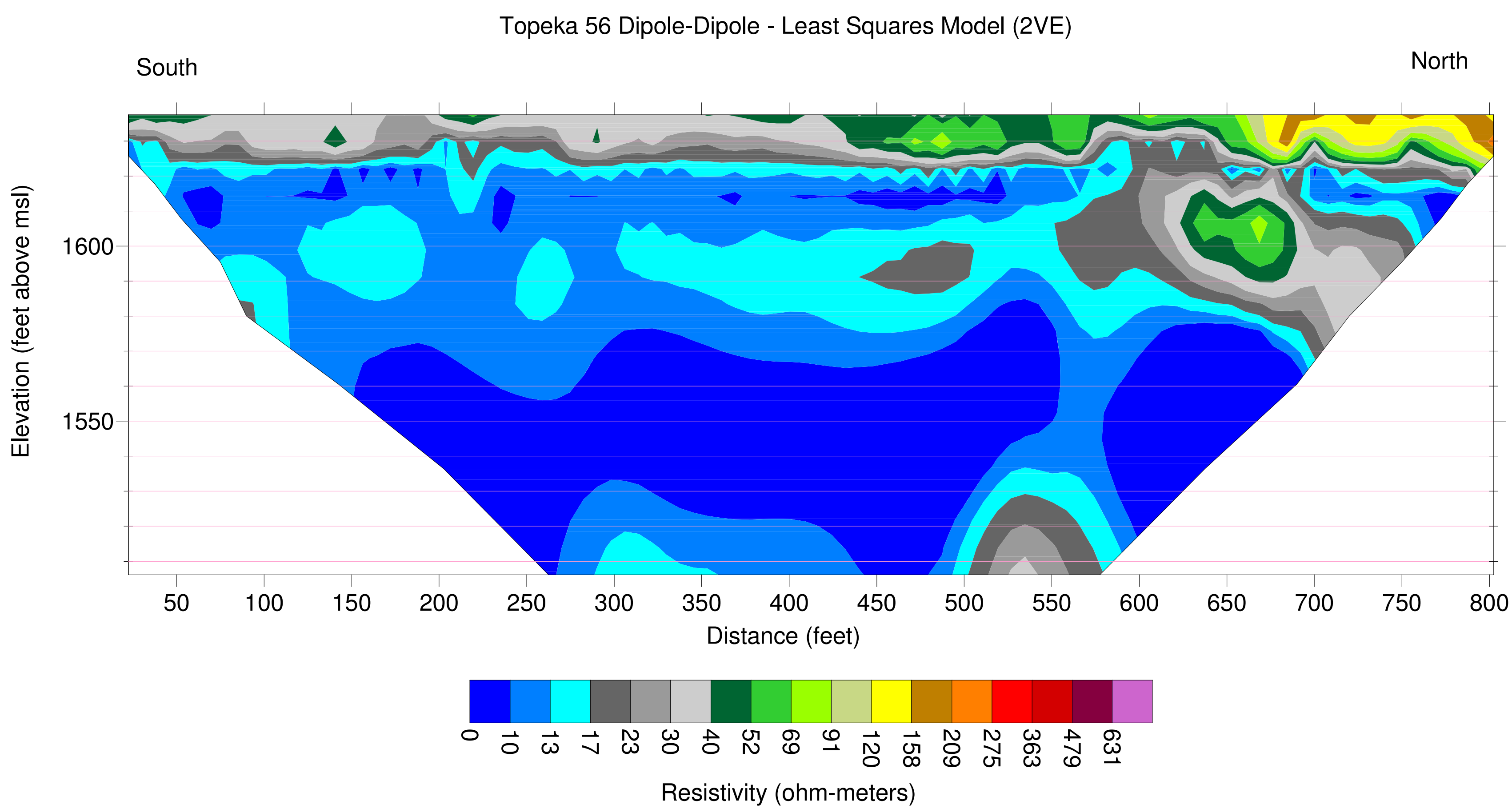


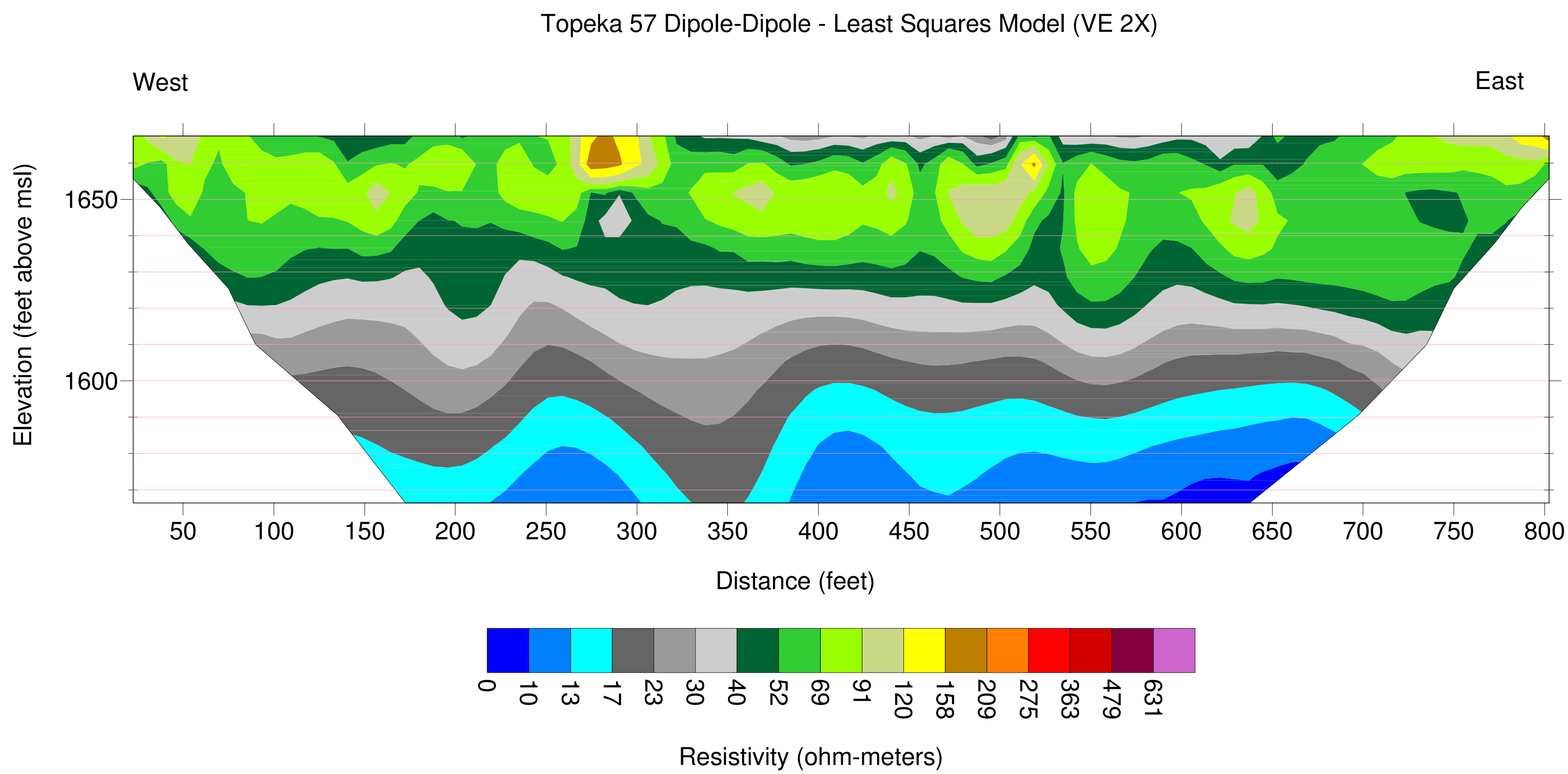
Topeka 53 Dipole-Dipole - Least Squares Model (VE 2X)
West
East
Elevation (feet above msl)
1500
1480
1460
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
Distance (feet)
0
10
13
17
23
30
40
52
69
91
120
158
209
275
363
479
631
Resistivity (ohm-meters)

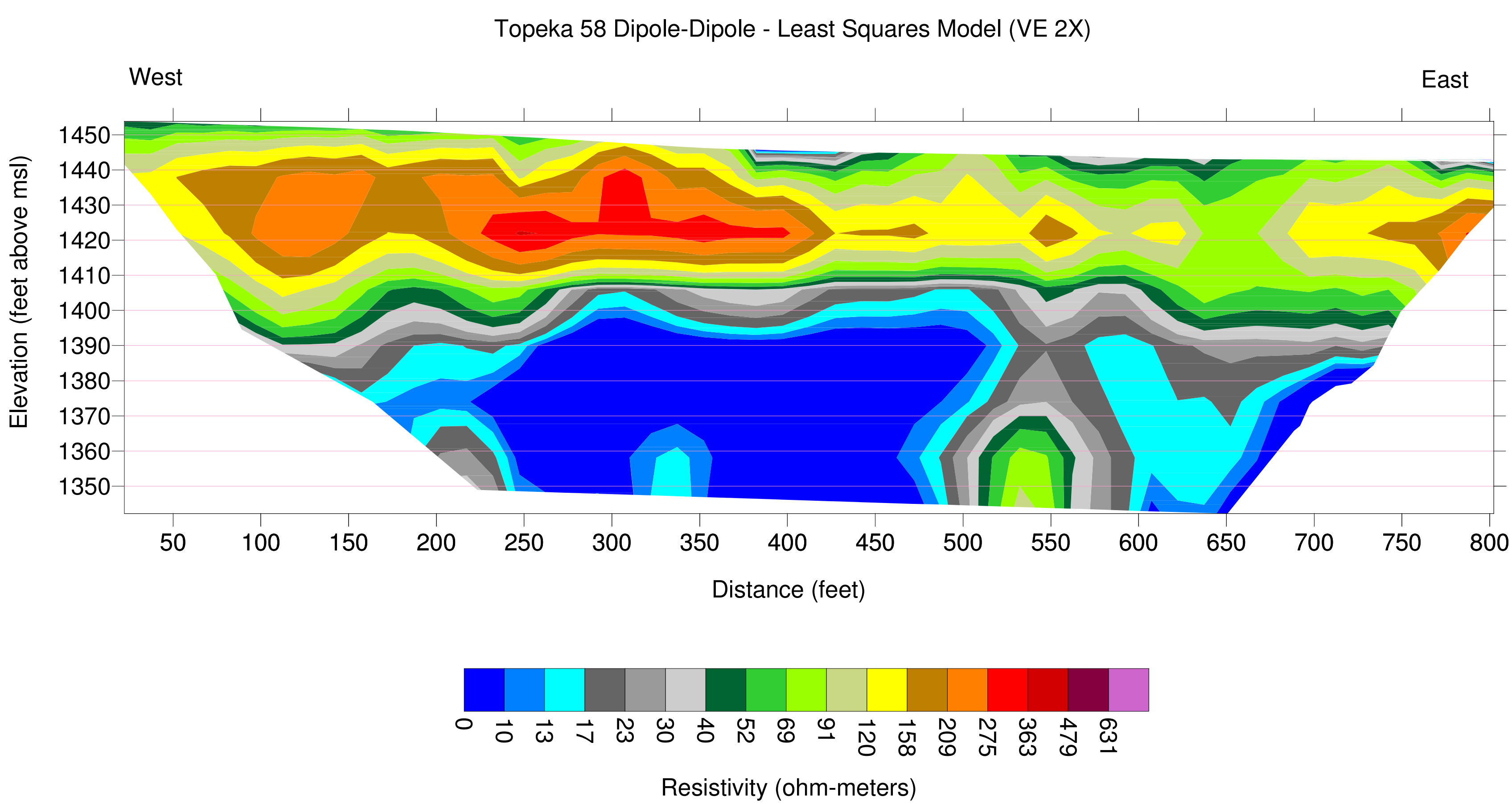
Topeka 54 Dipole Dipole - Least Squares Model (VE 2X)

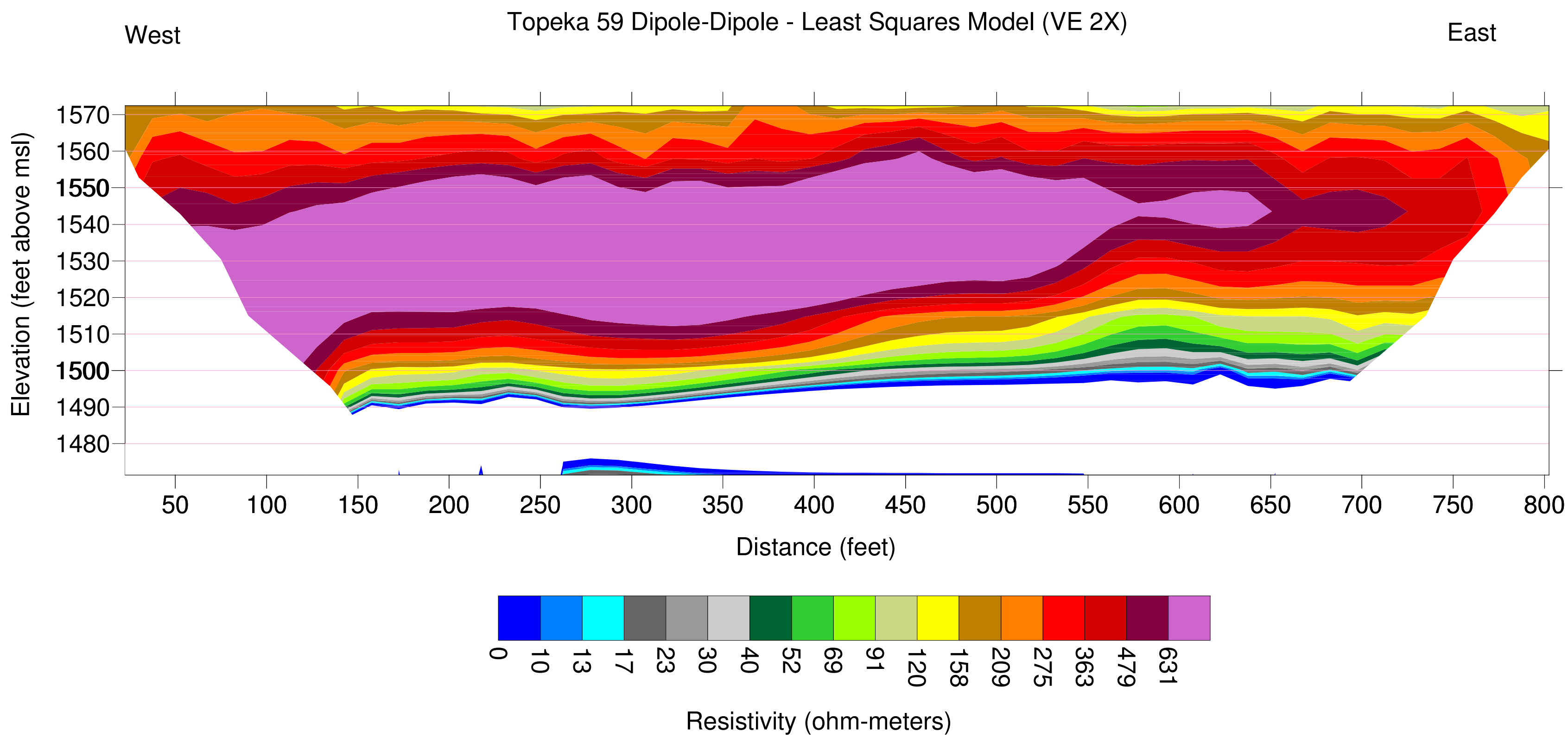



Topeka 55 Dipole-Dipole - Least Squares Model (VE 2X)
South
North
Elevation (feet above msl)
1450
1400
1350
1300
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
Distance (feet)
0
10
13
17
23
30
40
52
69
91
120
158
209
275
363
479
631
Resistivity (ohm-meters)

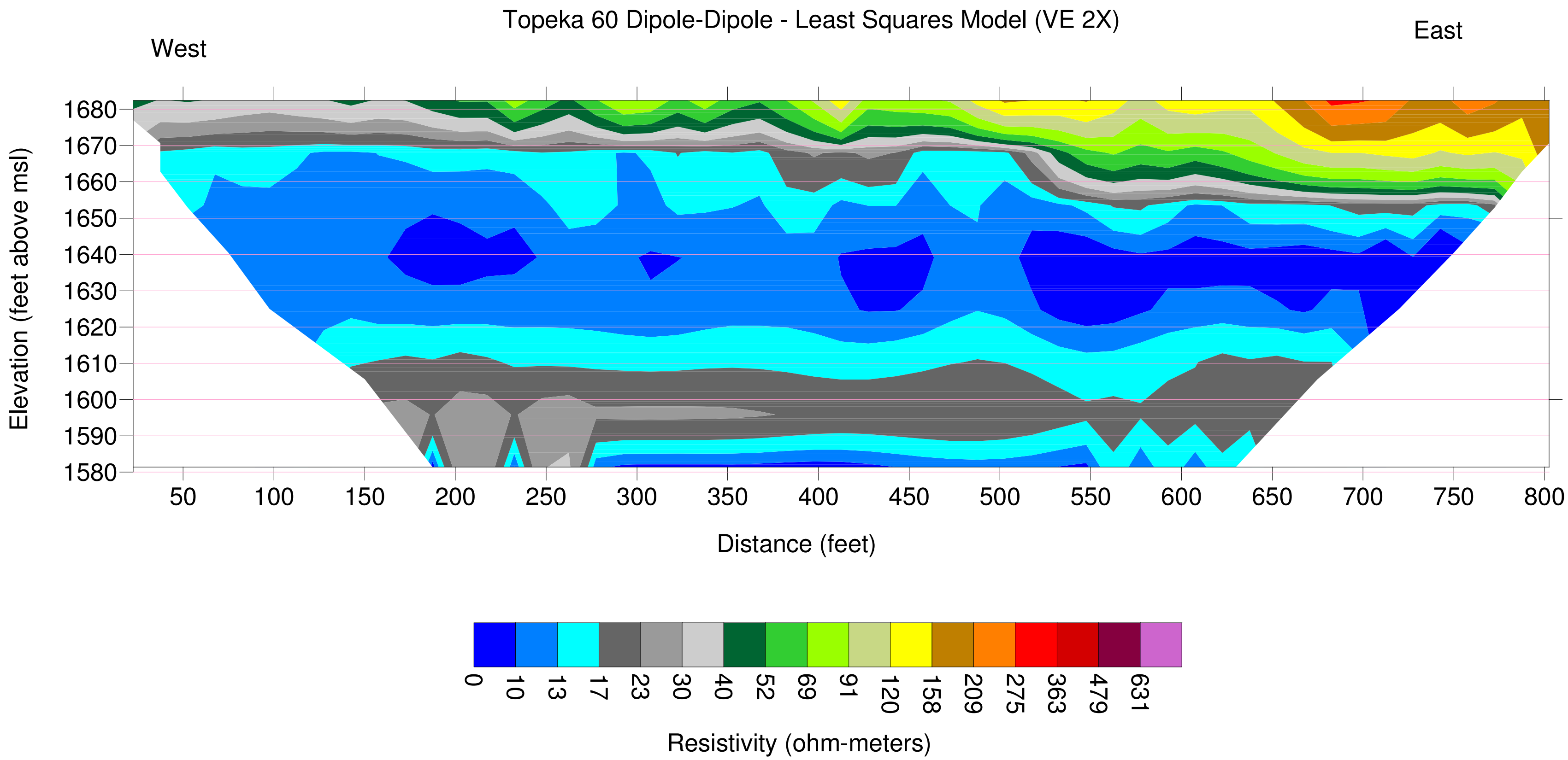

Topeka 56 Dipole-Dipole - Least Squares Model (2VE)
South
North
Elevation (feet above msl)
1600
1550
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
Distance (feet)
0
10
13
17
23
30
40
52
69
91
120
158
209
275
363
479
631
Resistivity (ohm-meters)


Topeka 57 Dipole-Dipole - Least Squares Model (VE 2X)
West
East
Elevation (feet above msl)
1650
1600
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
Distance (feet)
0
10
13
17
23
30
40
52
69
91
120
158
209
275
363
479
631
Resistivity (ohm-meters)


Topeka 58 Dipole-Dipole - Least Squares Model (VE 2X)
West
East
Elevation (feet above msl)
1450
1440
1430
1420
1410
1400
1390
1380
1370
1360
1350
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
Distance (feet)
0
10
13
17
23
30
40
52
69
91
120
158
209
275
363
479
631
Resistivity (ohm-meters)



Topeka 59 Dipole-Dipole - Least Squares Model (VE 2X)
West
East
Elevation (feet above msl)
1570
1560
1550
1540
1530
1520
1510
1500
1490
1480
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
Distance (feet)
0
10
13
17
23
30
40
52
69
91
120
158
209
275
363
479
631
Resistivity (ohm-meters)



Topeka 60 Dipole-Dipole - Least Squares Model (VE 2X)
West
East
Elevation (feet above msl)
1680
1670
1660
1650
1640
1630
1620
1610
1600
1590
1580
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
Distance (feet)
0
10
13
17
23
30
40
52
69
91
120
158
209
275
363
479
631
Resistivity (ohm-meters)

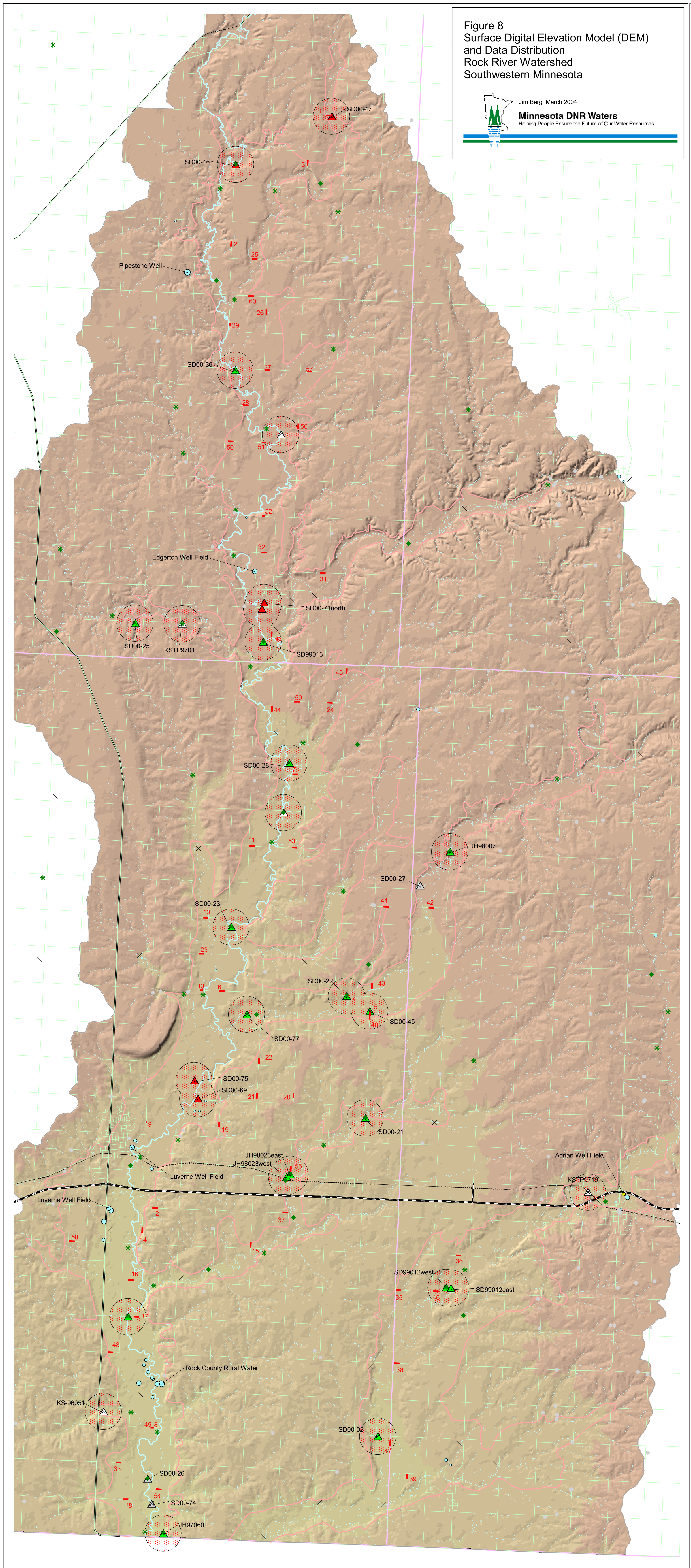


Figure 8
Surface Digital Elevation Model (DEM) and Data Distribution
Rock River Watershed
Southwestern Minnesota

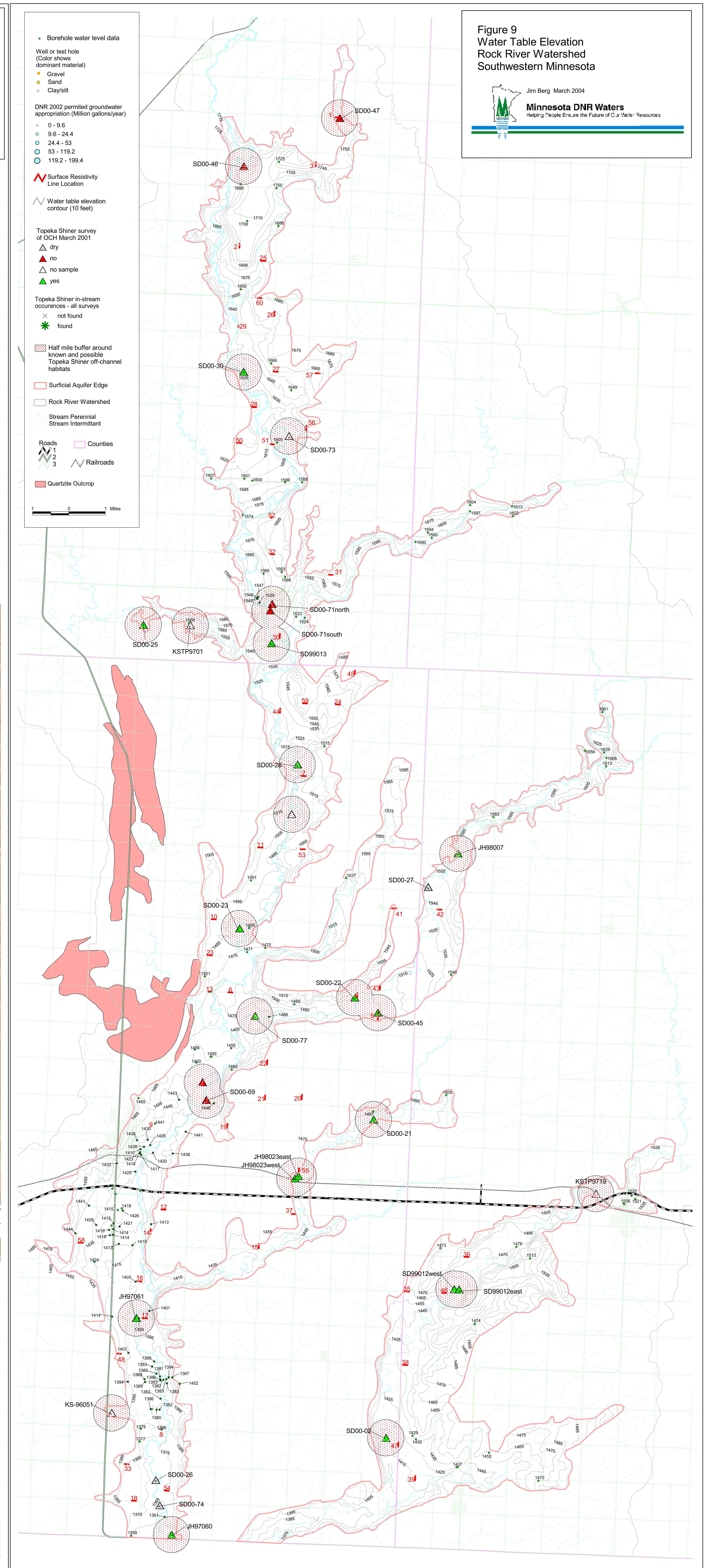


Figure 9
Water Table Elevation
Rock River Watershed
Southwestern Minnesota

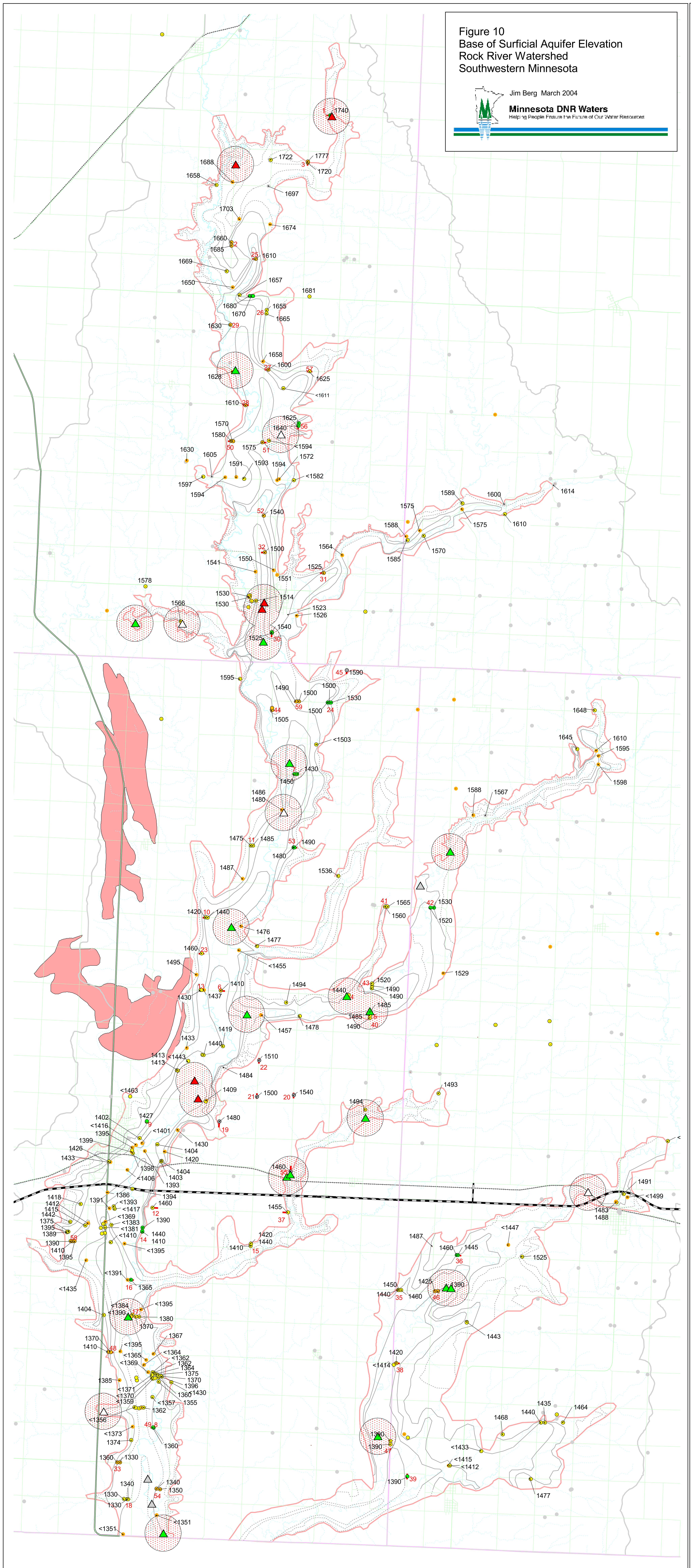


Figure 10
Base of Surficial Aquifer Elevation
Rock River Watershed
Southwestern Minnesota
Jim Berg March 2004
Minnesota DNR Waters
Helping People Ensure the Future of Our Water Resources

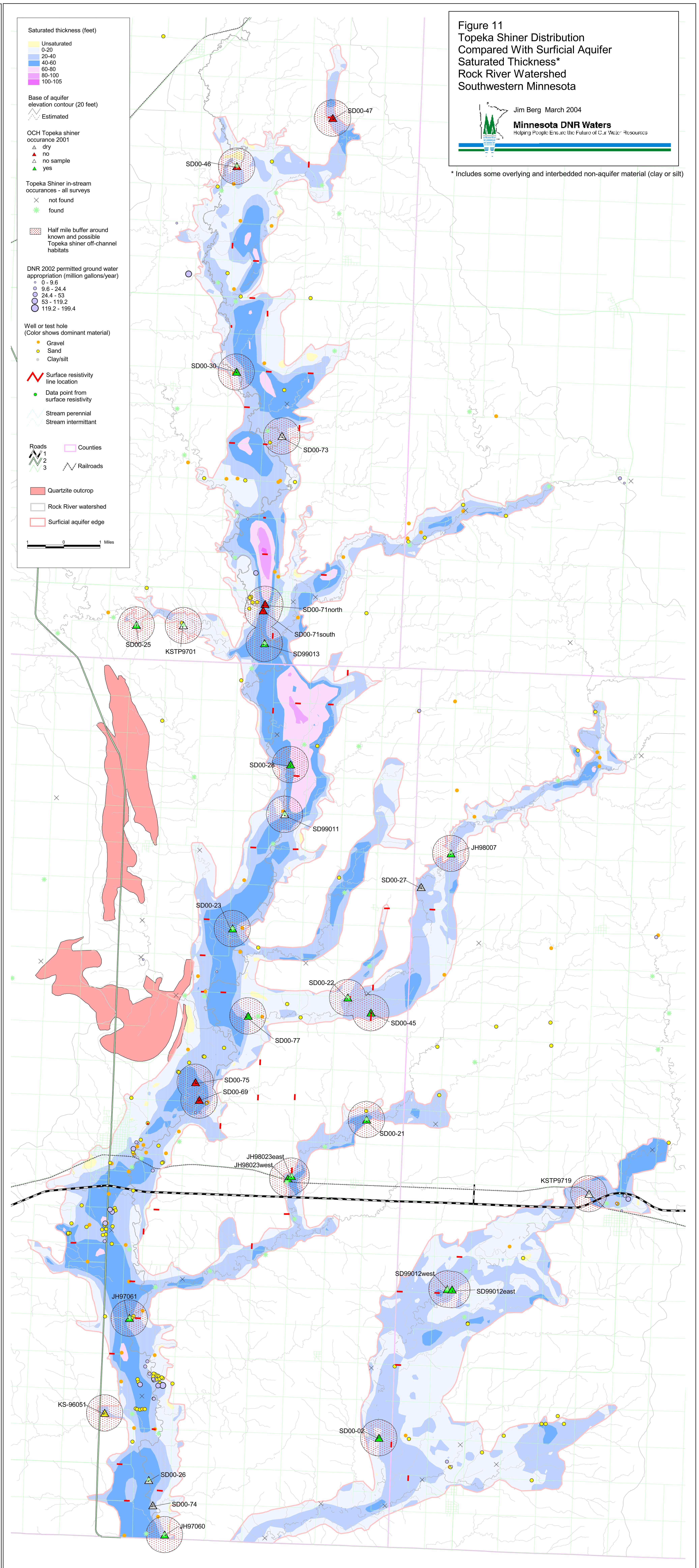


Figure 11
Topeka Shiner Distribution
Compared With Surficial Aquifer
Saturated Thickness*
Rock River Watershed
Southwestern Minnesota
Jim Berg March 2004
Minnesota DNR Waters
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* Includes some overlying and interbedded non-aquifer material (clay or silt)
Saturated thickness (feet)
Unsaturated
0-20
20-40
40-60
60-80
80-100
100-105
Base of aquifer elevation contour (20 feet)
Estimated
OCH Topeka shiner occurance 2001
dry
no
no sample
yes
Topeka Shiner in-stream occurances - all surveys
not found
found
Half mile buffer around known and possible Topeka shiner off-channel habitats
DNR 2002 permitted ground water appropriation (million gallons/year)
0 - 9.6
9.6 - 24.4
24.4 - 53
53 - 119.2
119.2 - 199.4
Well or test hole (Color shows dominant material)
Gravel
Sand
Clay/silt
Surface resistivity line location
Data point from surface resistivity
Stream perennial
Stream intermittant
Roads
1
2
3
Counties
Railroads
Quartzite outcrop
Rock River watershed
Surficial aquifer edge
1 0 1 Miles