Potter Valley Geophysical Investigation Results

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Project name: Potter Valley Water Supply Reliability Studies
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1. Introduction

In support of Sonoma County Water Agency's (Sonoma Water's) Potter Valley Water Supply Reliability Study (Reliability Study), this technical memorandum documents geophysical investigation activities, deviations from the *Field Work Plan for Potter Valley Water Supply Reliability Study* (work plan) (Sonoma Water 2023), findings, and conclusions associated with the geophysical surveys conducted in the Potter Valley, in Mendocino County, California. Jacobs Engineering Group (Jacobs) staff also conducted geophysical investigations to help refine the Potter Valley Groundwater Basin (Basin) hydrogeologic conceptual model.

Geophysical investigation objectives are:

- Improve delineation of the lateral extent and continuity of subsurface materials and hydrogeologic structures
- Improve understanding of Basin depth and geometry

Jacobs addressed these objectives by:

- Reviewing gravity data collected by the US Geological Survey (USGS 2007, 2022a)
- Reviewing existing stratigraphic information from available California Department of Water Resources (DWR) well completion reports
- Conducting additional geophysical surveys

Jacobs reviewed gravity data previously collected by USGS to address the first objective (improve delineation of lateral extent and continuity of subsurface materials and hydrogeologic structures), and to assess whether any additional insights about depth to bedrock could be achieved with a focus on Potter Valley.

Jacobs also reviewed additional geophysical surveys, including drone-based frequency-domain electromagnetic (DBEM) surveys and two-dimensional (2D) electrical resistivity (ER) surveys to gain insight into the distribution of soil texture and help achieve the second objective (improve Basin depth and geometry understanding).

During the weeks of July 17 and November 6, 2023, Jacobs performed the DBEM and ER surveys in two mobilizations. Information from these surveys, along with other available information, is being used to develop a numerical flow model of the Basin. This numerical model is referred to as the Potter Valley Integrated Flow Model (PVIFM) to differentiate it from other models that have been and are being developed to support regional planning efforts.

2. Site Description and Hydrogeologic Setting

Potter Valley is about 8 miles long and up to 2 miles wide and is located approximately 12 miles northeast of Ukiah. It is the northernmost valley in the Russian River drainage basin. Potter Valley is a northwest-trending valley situated in a structural depression formed in bedrock of the Franciscan Complex (DWR 2004).

Previous USGS hydrogeologic modeling efforts indicate that the Basin consists of a thick package of consolidated sediments of up to approximately 1,400 feet that underlies a relatively thin layer of unconsolidated sediments (less than 328 feet), with no apparent structural offsets between these two units (USGS 2022a). The water-bearing formations in Potter Valley are alluvium, terrace deposits, and continental deposits with the alluvium; they are of primary importance with respect to water-bearing and yielding capacity (DWR 2004).

Potter Valley alluvium is approximately 40 to 60 feet thick and consists mainly of silt and clay, which is finer-grained and less permeable than the cobbly gravels along the main course of the Russian River farther downstream (USGS 1965; DWR 2004). Potter Valley terrace deposits are characterized by an abundance of silt and clay, although they may contain local lenses of poorly sorted sand and gravel (DWR 2004). The subsurface thickness of the terrace deposits is not well defined, but they crop out discontinuously along the southeastern and southern parts of Potter Valley (DWR 2004). Similar to the terrace deposits, the thickness of the continental deposits beneath the valley is unknown, but they are discontinuously exposed along the southern and western margins of the valley (DWR 2004). In the northern part of Potter Valley, these deposits are characterized by sandy silt and clay, whereas in the southern part of the valley they are characterized by gravel, friable silty sandstone, mudstone, and concretions (DWR 2004).

3. Geophysical Survey Activities

The DBEM and ER surveys involved assimilating gravity data processed by USGS and DBEM and ER data processed by Jacobs to achieve geophysical investigation objectives. Geophysical surveys are summarized in this section.

3.1 Gravity Survey

Gravity data were collected using LaCoste and Romberg G614 and G17C gravimeters at non-uniformly distributed gravity stations across Potter Valley (Chapman 1966; Chapman and Bishop 1974; USGS 1981; USGS 2007; USGS 2022a). Gravity stations were widely spaced, on average one station per 1.5 square miles, which reduces lateral resolution and generates average estimations of depth-to-basement rocks over large areas (for example, a 1,000-foot by 1,000-foot area) (USGS 2022a). The objective of the gravity survey was to help characterize Basin thicknesses and underlying Basin geometries.

3.2 Drone-based Frequency-domain Electromagnetic Survey

The DBEM survey mapped subsurface geologic and hydrogeologic structures at a Basin scale and identified potential areas for conducting more focused ground-based geophysical investigations. The DBEM survey was conducted using a GSM-90AVU unmanned aerial vehicle, in a very-low frequency (VLF) system manufactured by GEM Systems, Inc., which was attached to an Alta X drone made by FreeFly Systems, Inc. with a 33-foot tow line to minimize electromagnetic interference from the drone platform. DBEM data were collected along two flight paths in the northwest portion of Potter Valley (Figure 1).

3.3 Electrical Resistivity Survey

Prior to starting the ER survey, Jacobs made a site visit to Potter Valley on October 9 and 10, 2023 to evaluate field conditions and site access limitations. The ER survey involved collecting 18,269 linear feet of ER data along 16 transects using a Syscal Pro system manufactured by IRIS Instruments, and 96 electrodes spaced 10 feet apart. The locations of the 16 ER transects were determined based on the DBEM results and input from the Jacobs team and Sonoma Water (Figure 1).

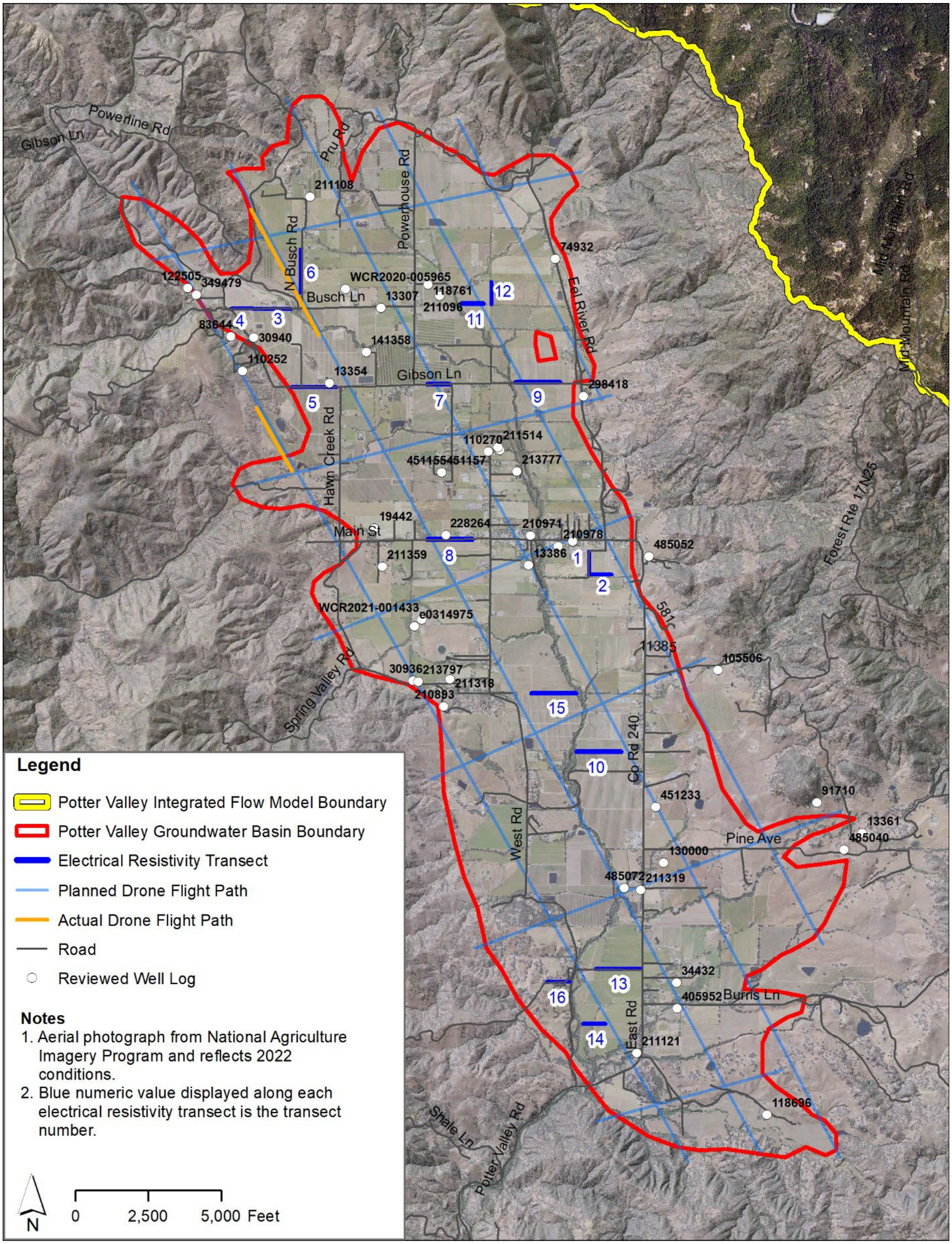

Figure 1. Flight Paths and Electrical Resistivity Transects

4. Deviations from the Work Plan

Per the approved field work plan, the proposed layout of the DBEM survey included collecting five longitudinal transects and six latitudinal transects across Potter Valley (Figure 1). However, the DBEM survey was not completed as planned because of windy conditions, which limited access to landing/takeoff locations and hampered initial attempts at safely flying the drone system above trees and powerlines. As a result, the number of ER transects performed was increased to 16, which improved geophysical data coverage across Potter Valley (Figure 1).

5. Quality Control

Jacobs performed daily quality control (QC) tests to ensure the functionality of DBEM and ER instruments, and completeness of collected measurements. Table 1 presents QC testing requirements and results.

Table 1. Summary of Quality Control Testing

QC Test	Test Method and Requirements	Results
ER Contact Resistance Between Ground and Electrodes	ER contact resistance test was performed before the initiation of data collection at each line to ensure the reading less than 2,000 ohms.	Passed. More than 95% of readings were less than 1,000 ohms. Some exceptions occurred at a few cable electrodes or at areas where transects crossed a road. To lower the contact resistance, electrodes were pushed further into the ground, and water was added around those electrodes.
ER Line Test	Each channel on the ER imaging system was checked for open circuits or voltage overload errors.	Passed. The test was performed before the collection of each ER line.
VLF Sensor Test	Signal strength from VLF stations was detected to be above a threshold of 3 picoteslas to ensure an acceptable signal-to-noise ratio.	Passed. The test was performed when initially setting up the equipment. Two stations were selected that had adequate signal.
Data Completeness	Before demobilization, the field team checked that all instrument files and field notes had been uploaded.	The team confirmed that collected data met quality standards. All collected data and field notes were sent from the field site to the project SharePoint site.
Data Quality	The collected data were initially processed daily to ensure quality.	Data quality for other transects appeared to be good. Additionally, the positioning accuracy of global positioning unit (GPS) measurements were confirmed to be correct.

6. Data Processing

6.1 Gravity Data

USGS used the following standard data-processing steps on all gravity data collected and processed (USGS 2007, 2022a):

- Earth-tide correction, which corrects for tidal effects of the moon and sun
- Instrument drift correction, which compensates for instrument drift
- Latitude correction, which incorporates the variation of the Earth's gravity with latitude
- Free-air correction, which accounts for the variation in gravity due to elevation relative to sea level
- Bouguer correction, which corrects for the attraction of material between the station and sea level
- Curvature correction, which corrects the Bouguer correction for the effect of the Earth's curvature
- Terrain correction, which removes the effect of topography to a radial distance of approximately 100 miles
- Isostatic correction, which removes long-wavelength variations in the gravity field inversely related to topography
- Inverting the gravity data to obtain the thickness of basin deposits beneath Potter Valley

6.2 Drone-based Frequency-domain Electromagnetic Survey Data

The team processed DBEM data using Oasis Montaj software developed by Seequent Inc. using the following steps:

- Apply a median filter to remove outliers and improve signal-to-nose ratio
- Calculate the z-score (normalized electromagnetic responses within ±2 standard deviations from the mean value) as $(x-\mu)/\sigma$ to normalize the electromagnetic measurements, where x is electromagnetic response, μ and σ are the mean and standard deviation of electromagnetic responses
- Grid the normalized electromagnetic data using a minimum-curvature algorithm to generate site maps showing anomalous electromagnetic responses along the surveyed transects

6.3 Electrical Resistivity Survey Data

ER transect data were inverted using Geotomo RES2DINV, version 3.71 software developed by Seequent, Inc. The objective of the inversion was to find a 2D subsurface model that contained an ER structure consistent with expectations regarding the likely distribution of resistivity in the subsurface while providing a set of theoretical measurements that fit the measured data to some pre-described, acceptable level (for example, a change of root-mean-square error from one iteration to the next of less than 1%). A smoothness-constraint inversion was used to produce smooth resistivity images that represent the minimal structure required to satisfy the data while respecting the noise level. Finally, to prepare the output 2D ER models for interpretation, each model cell was tagged with GPS coordinates before all models were plotted in a three-dimensional (3D) viewer. The team can provide a 3D viewer of the ER profiles to Sonoma Water upon request.

7. Geophysical Investigation Findings

Geophysical interpretations involve correlations with existing stratigraphic information from previous investigations and analyses of trends for continuity or discontinuity and for identification and location of hydrogeologic features. This section summarizes geophysical investigation results, organized by objective (Section 1).

7.1 Improve Delineation of Lateral Extent and Continuity of Subsurface Materials and Hydrogeologic Structures

Gravity data previously collected and processed by USGS could not achieve this objective at the local Basin scale due to inherent limitations of the gravity method (for example, insufficient density contrasts between shallow soil types in Potter Valley). Additionally, distinguishing between subtle changes in soil types was not possible using the ER method throughout the depth interval above the bedrock surface because of ambiguities associated with assigning resistivity values to different soil zones. Tables 2 and 3 highlight the overlapping resistivity values of different soil types, rocks, and water. The gravity data did provide information about lateral and vertical distributions of clay versus coarser-grained material or consolidated rock below the ER transects.

Table 2. Resistivity Values for Typical Soil Types

Soil Type	Resistivity (ohm-m)
Alluvium	10 to 800
Sand	60 to 100
Concrete	1 to 10,000
Ash	108 to 1,000,000
Clay	1 to 100

Notes:
ohm-m = ohm-meters
Fresh groundwater resistivity ranges from 10 to 100 ohm-m.
Sources: Keller and Frischknecht 1996; Saad and Mohamad 2012.

Table 3. Resistivity Values for Typical Rocks

Rock Type	Resistivity (ohm-m)
Sandstone	8 to 4,000
Shale	20 to 2,000
Limestone	50 to 4,000
Granite	5,000 to 1,000,000
Gravel	100 to 1,400

Notes:
ohm-m = ohm-meters
Fresh groundwater resistivity ranges from 10 to 100 ohm-m.
Sources: Keller and Frischknecht 1996; Saad and Mohamad 2012.

Using well logs 13354 (near the intersection of Gibson Lane and Hawn Creek Road) and 228264 (along Main Street) (USGS 2022a) (refer to Figure 1 reviewed well completion report locations, which can be provided to Sonoma Water upon request) and documentation about regional geological conditions (USGS 1965, 2007, 2022a; DWR 2004), ER data were calibrated by inspecting resistivity values that most closely represented the clay deposits known to be present based on information from these two nearby well logs, and developing an approximate correlation between soil texture and the resistivity values. Well logs 13354 and 228264 were the only logs that could be reliably used to associate ER readings to soil texture because they were the only available well logs for borings near the ER transects. Lithologic descriptions from these two well logs are summarized in Tables 4 and 5.

Table 4. Lithologic Description from Well Log 13354

Depth (feet bgs)	Lithology
0 to 4	Top Soil
4 to 30	Yellow Clay[a]
30 to 38	Cemented Gravel
38 to 40	Gravel (Water)
40 to 45	Cemented Gravel
45 to 47	Blue clay[b]

Notes:

[a] Driller's report indicates Y Clay, which is assumed to mean "yellow clay."

[b] Driller's report indicates B Clay, which is assumed to mean "blue clay."

Table 5. Lithologic Description from Well Log 228264

Depth (feet bgs)	Lithology
0 to 4	Brown sandy top soil
4 to 6	Clay and gravel
6 to 11	Light brown clay
11 to 24	Blue clay
24 to 33	Tight brown clay
33 to 35	Green clay
35 to 60	Tight brown clay

Figure 2 shows example 2D vertical resistivity profiles (upper image for each transect) along with associated inferred texture profiles (lower image for each transect) for Transects 5 (along Gibson Lane in northwest Potter Valley) and 8 (along Main Street in north-central Potter Valley). Attachment 1 contains all 16 resistivity profiles, which are shown as 2D vertical profiles. The x-axis labels shown in the resistivity profiles indicate the transect number, which can be used to locate the transect in Figure 1. Using the well logs' boring information to correlate resistivity values with lithologic information, the inferred resistivity cutoff value of 77.88 ohm-m was established for the Basin to differentiate between fine-texture materials such as silts and clays (brown color in lower profile sets in Figure 2) versus coarser-texture sands and gravels or consolidated rock (yellow color in lower profiles sets in Figure 2). Based on information shown in Tables 2, 3, 4 and 5, and results of the ER data inversion process, the simplified resistivity-soil scale shown at the bottom of Figure 2 was created to help interpret the ER models across Potter Valley.

Based on ER results and the resistivity and soil scales, the following can be inferred about the general stratigraphy of the valley at the 16 transects shown in Figure 1: the ER models show a pronounced low-resistivity layer in the south-central portion of the valley starting at an approximate depth of 50 to 125 feet below ground surface (bgs) (refer to tops of blue zones in Figure 3). That layer likely represents saturated fine-texture deposits and seems to be consistent with the descriptions of terrace deposits reported for this part of Potter Valley (DWR 2004).

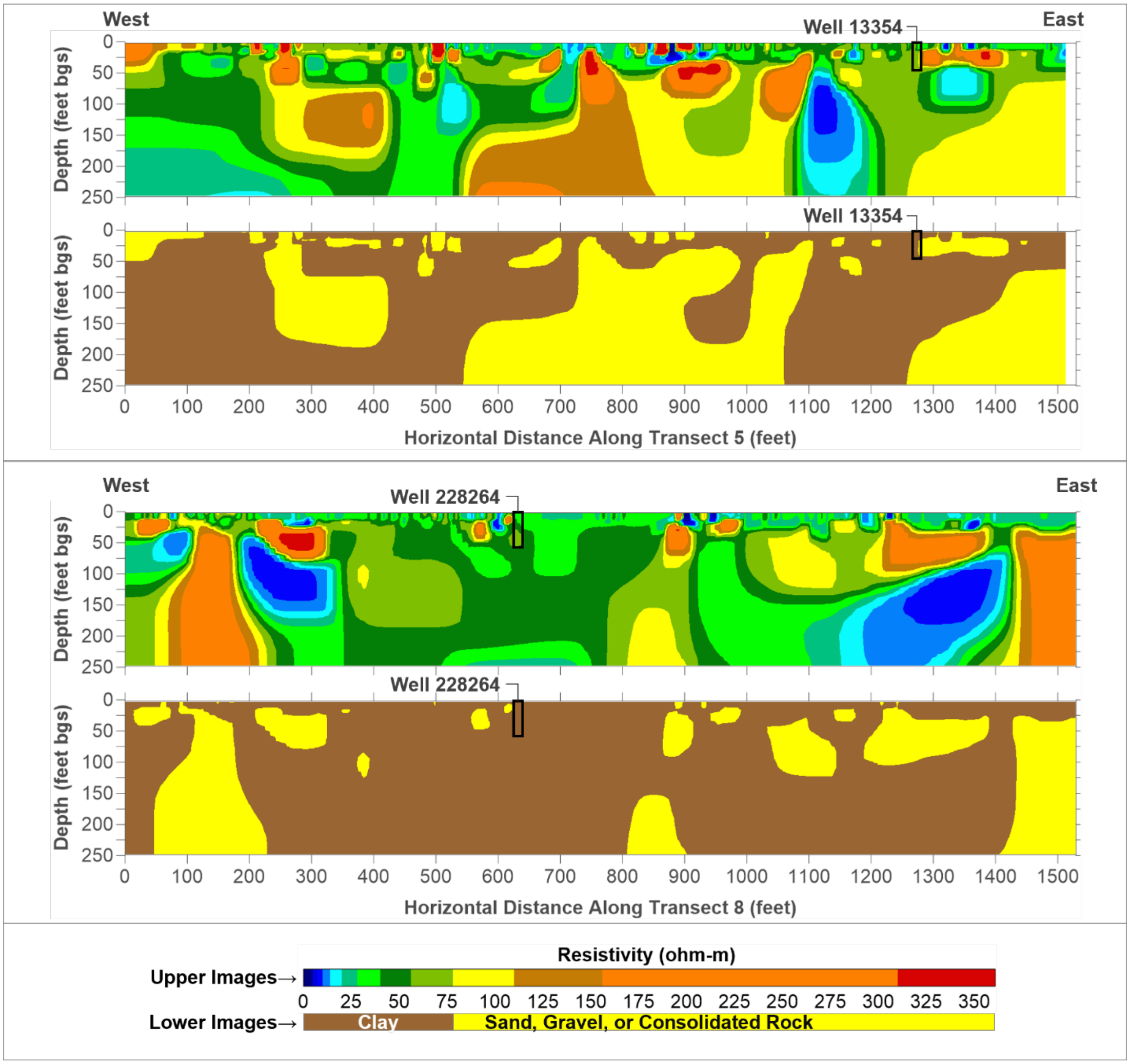

Figure 2. Correlations of Electrical Resistivity Models at Transects 5 and 8 with Clay Soils at Nearby Wells

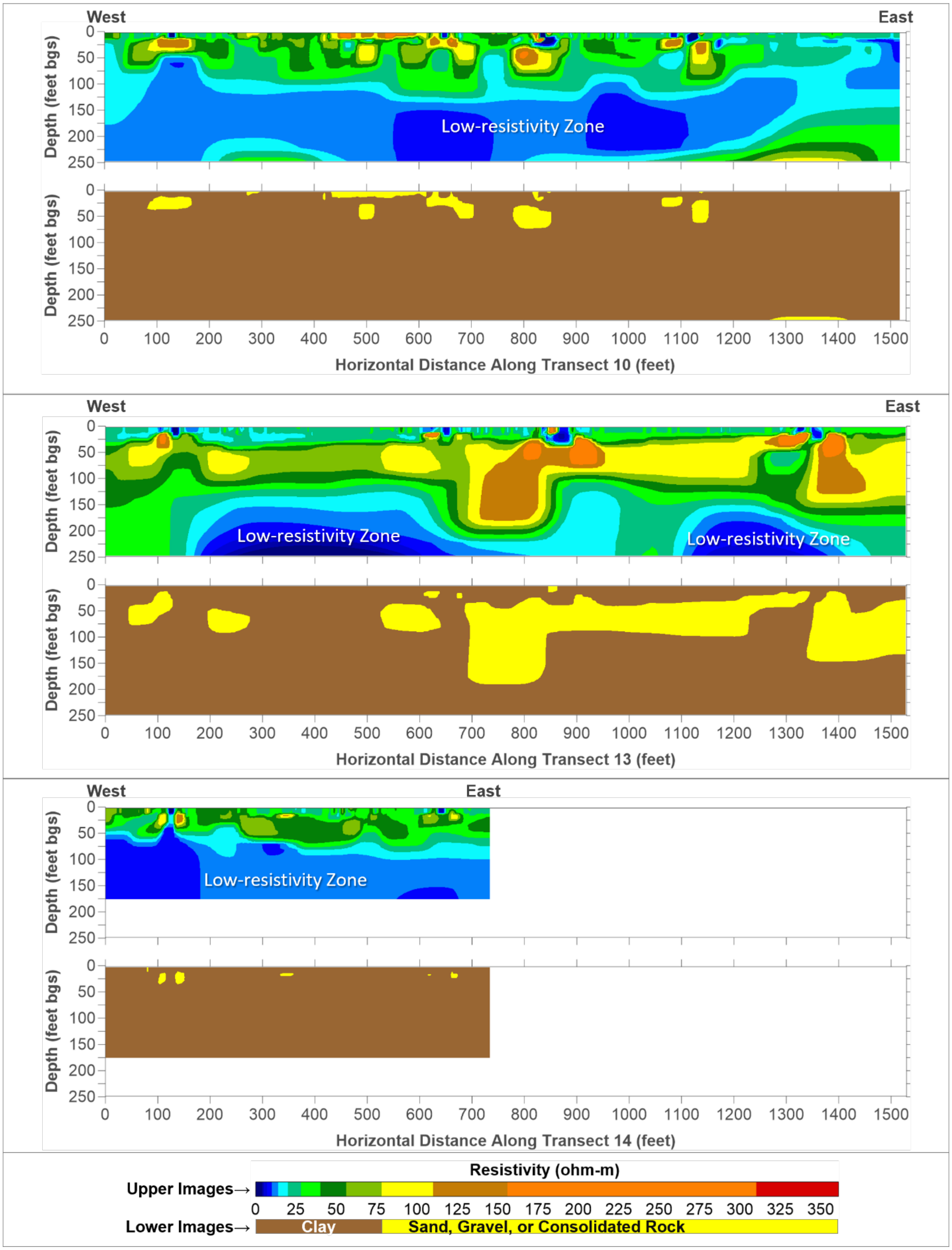

Figure 3. Electrical Resistivity Transects in South-central Potter Valley Showing Low-resistivity Zones

ER models in the northwestern portion of Potter Valley show a greater proportion of higher-resistivity zones, potentially representing coarser deposits or consolidated rock (refer to the greater extent of warmer colors in Figures 4 through 6, as compared to Figure 3). The normalized DBEM data shown in Figure 4 also indicate higher-resistivity responses (that is, higher z-score values greater than zero, which are potentially associated with coarser-grained materials or rocks) extending into the northwestern portion of Potter Valley.

Additionally, the team reviewed hydrologic soil group (HSG) classifications from the Soil Survey Geographic Database (SSURGO) geographic information system datasets to gain insight into general infiltration characteristics. The HSG classifications in the northwestern portion of the valley tend to be HSG A (higher infiltration) and HSG B (moderate infiltration) around Busch Creek near ER Transects 3, 4, and the southern end of ER Transect 6 (Figure 7). Figure 8 shows a 3D view of the ER transects and inferred textures.

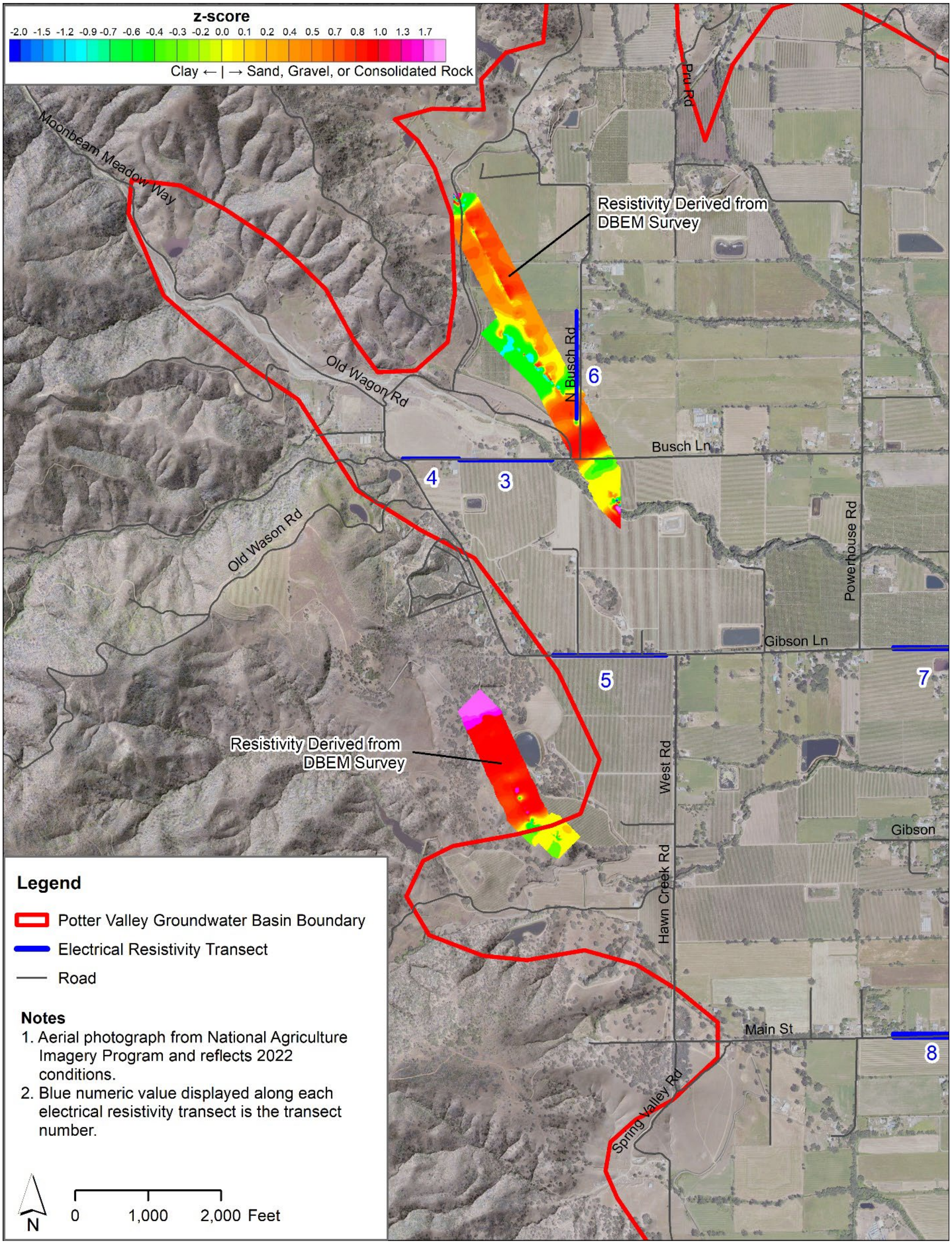

Figure 4. Electrical Resistivity Transects and DBEM Results in Northwestern Potter Valley Showing High-resistivity Zones

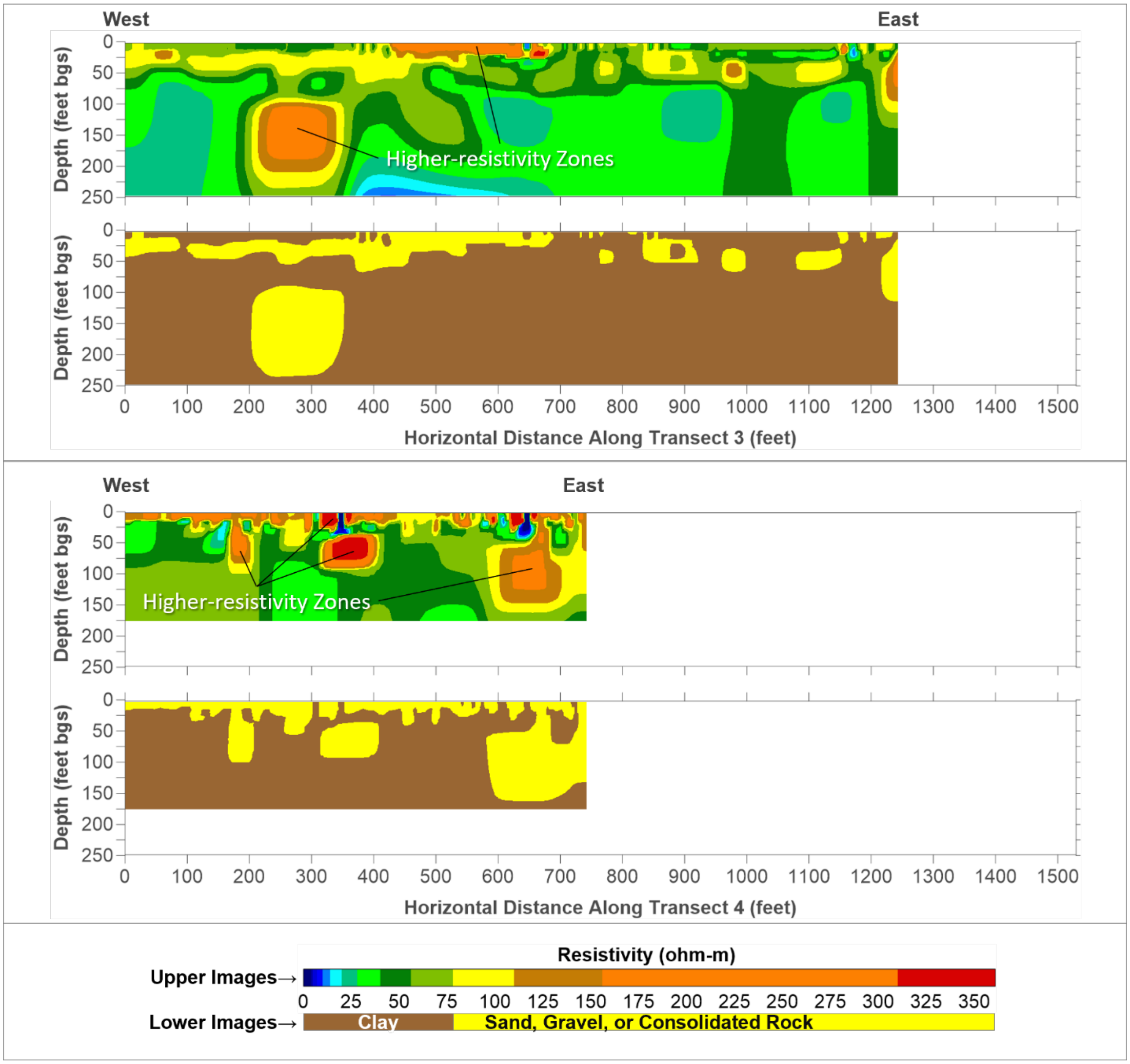

Figure 5. Electrical Resistivity Transects 3 and 4 in Northwest Potter Valley Showing Higher-resistivity Zones

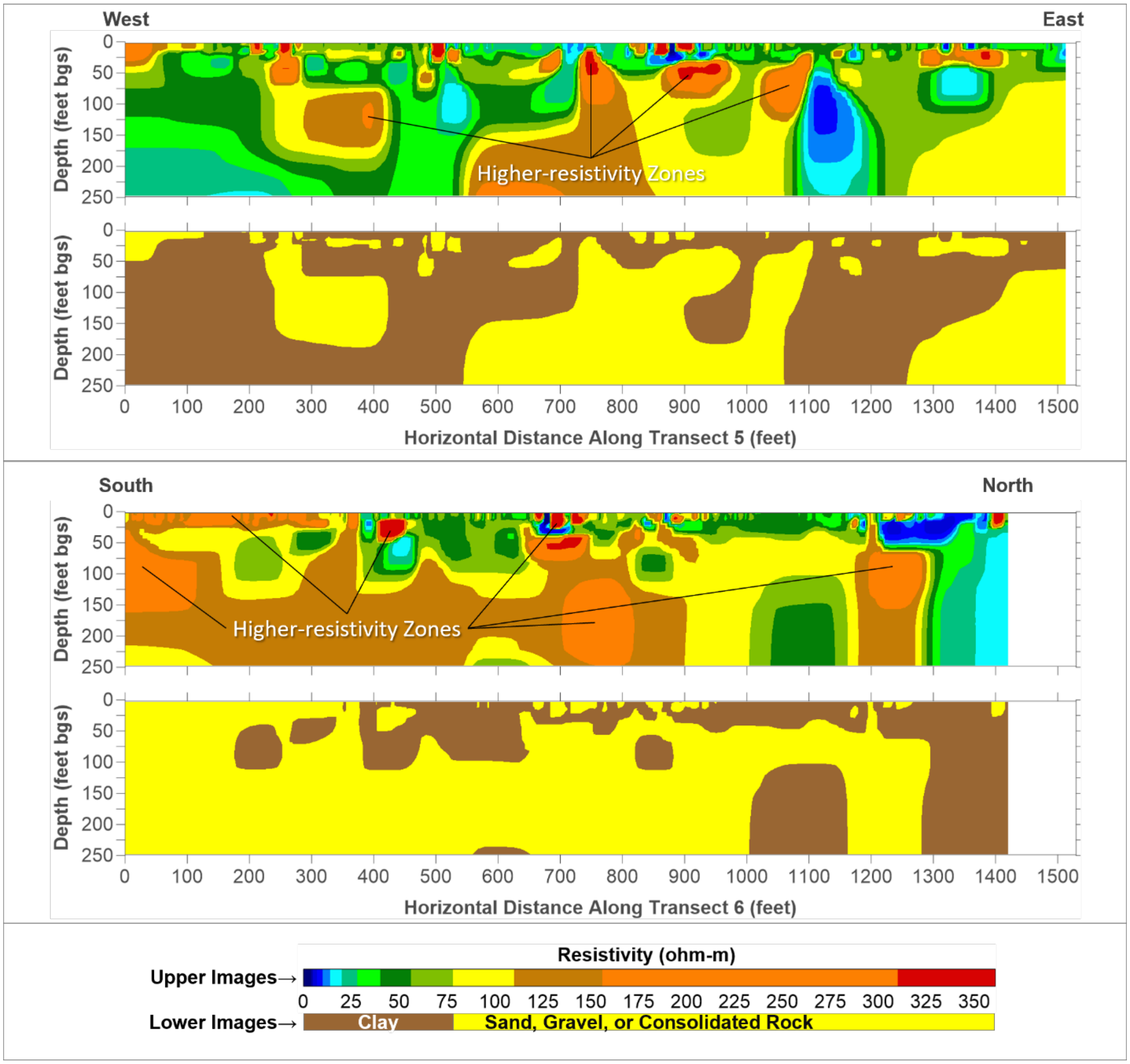

Figure 6. Electrical Resistivity Transects 5 and 6 in Northwest Potter Valley Showing Higher-resistivity Zones

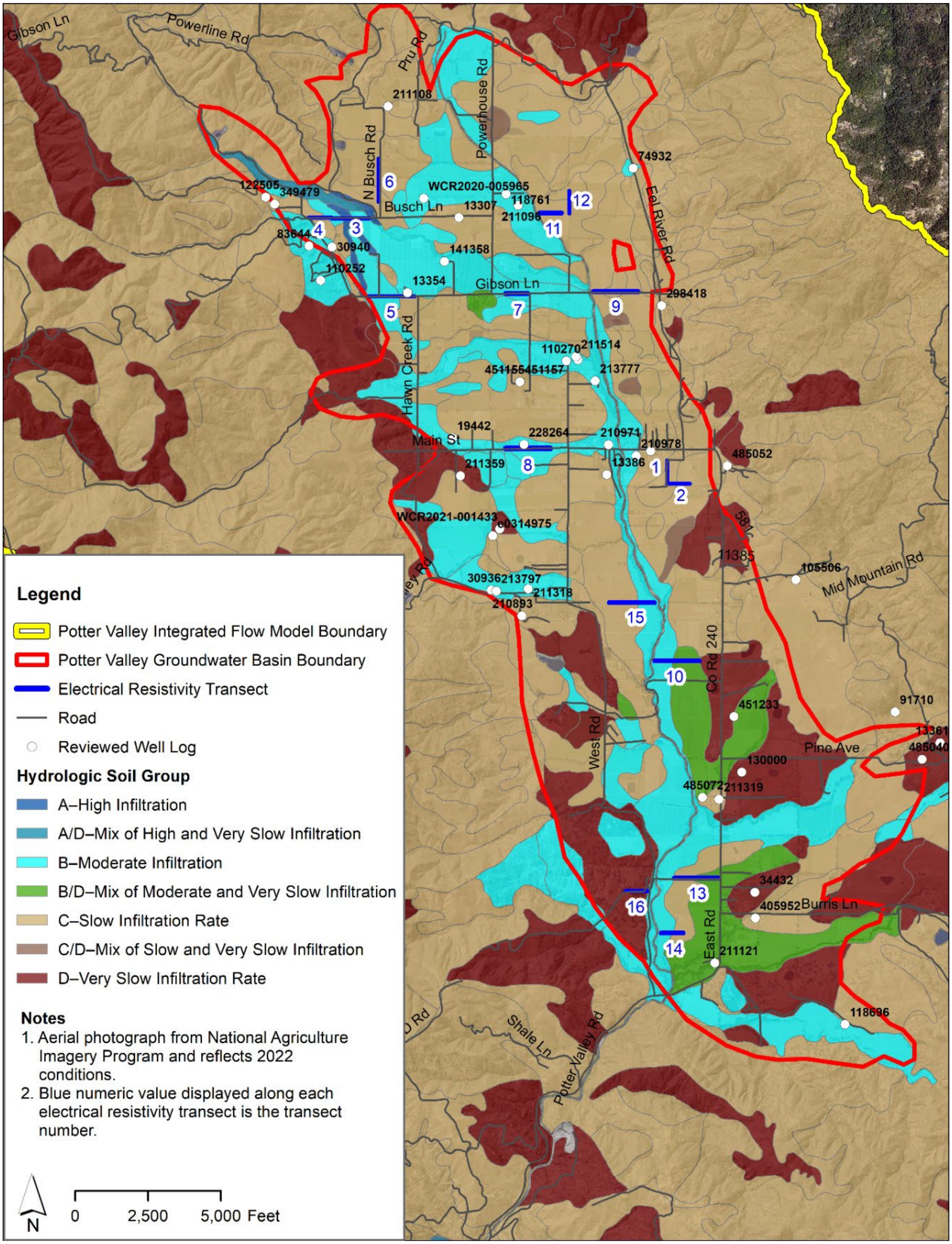

Figure 7. Hydrologic Soils Group

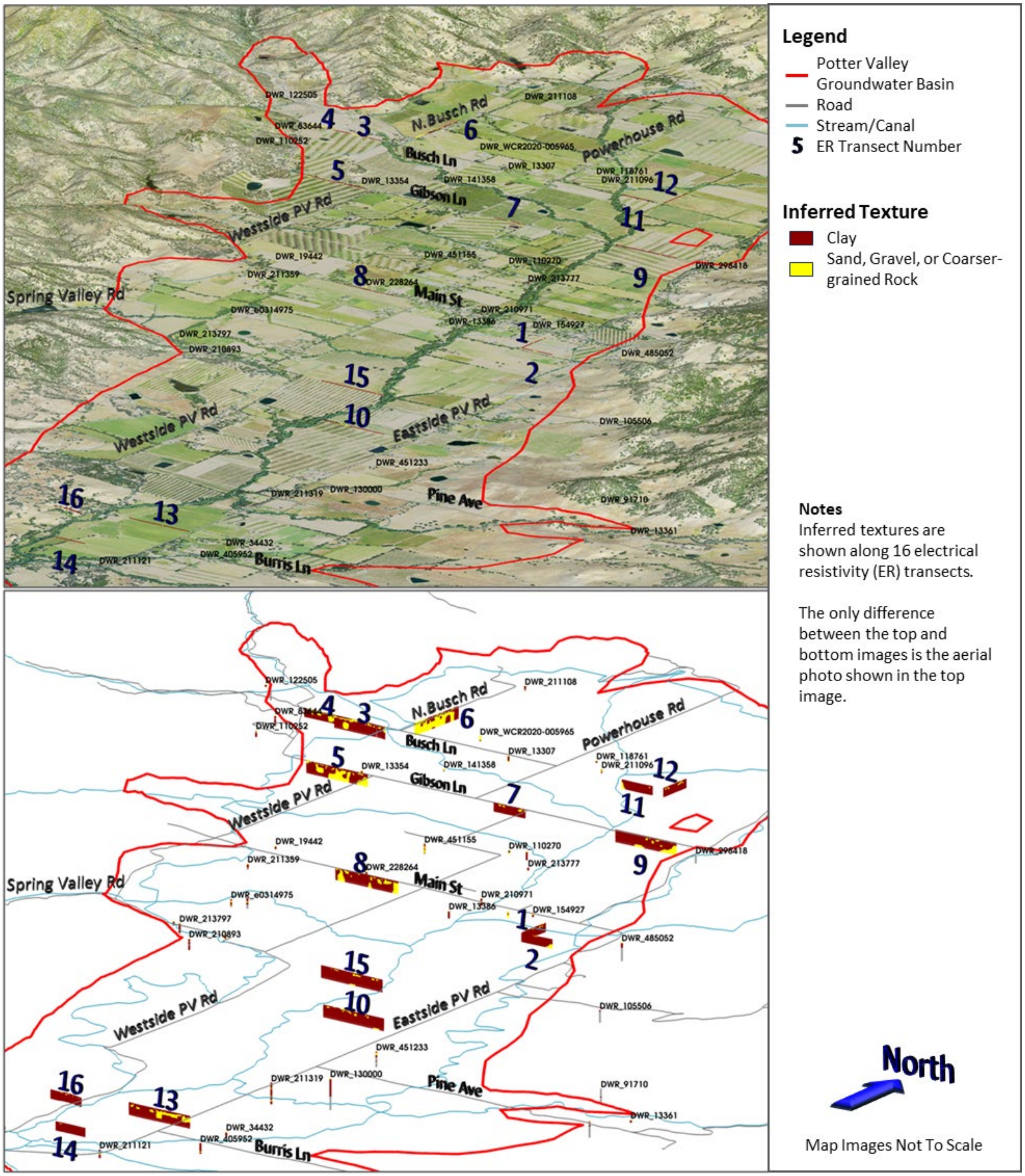

Figure 8. Electrical Resistivity Transect Locations and Results

The DBEM data indicate a low-resistivity (that is, lower z-score values less than zero, which are potentially associated with finer-grained materials) transition zone near the northwestern margin of Potter Valley, which is consistent with descriptions of continental deposits reported for this part of the valley (DWR 2004). These ER and DBEM responses might represent continental deposits reported at the northern part of the valley. The remaining ER models generally show low-resistivity distributions that likely represent fine-texture deposits, which generally could be associated with the alluvium, terrace deposits or continental deposits. Some higher-resistivity anomalies are also shown at scattered locations in the ER models that potentially represent coarser-grained deposits or consolidated rocks.

Because the ER device measures the weighted average ER response over a subsurface volume that extends to about 10 feet bgs, ER models should not be relied upon to delineate depth to water if it is shallower than approximately 10 feet bgs.

7.2 Improve Understanding of Basin Depth and Geometry

USGS estimated Basin depth and geometry below Potter Valley using inversion of gravity data. The inversion was done for grid cells that were 984 feet by 984 feet; therefore, results represented an average thickness of Basin fill for each cell. Thus, variations in Basin fill thickness over distances of less than approximately 1,000 feet were not resolved (USGS 2022a). The inferred Basin thickness model using USGS gravity data is up to a maximum thickness of approximately 1,400 feet beneath Potter Valley. The thickest Basin fill is in the west-southwest portion of Potter Valley (represented by the 100 to 500 meter depth area on Figure 9).

The DBEM and ER methods implemented with recent geophysical survey data were only capable of providing information on subsurface materials to a maximum depth of approximately 250 feet bgs. As shown in Figure 9, previous USGS-estimated depths to basement rock exceeded 246 feet bgs in the west-southwest portion of the Basin. Therefore, the DBEM and ER survey models do not provide more refined estimates of depth to bedrock in the west-southwest portion of the Basin. However, some ER models in the central and eastern portions of the Basin can be used to improve the understanding of Basin depth and geometry.

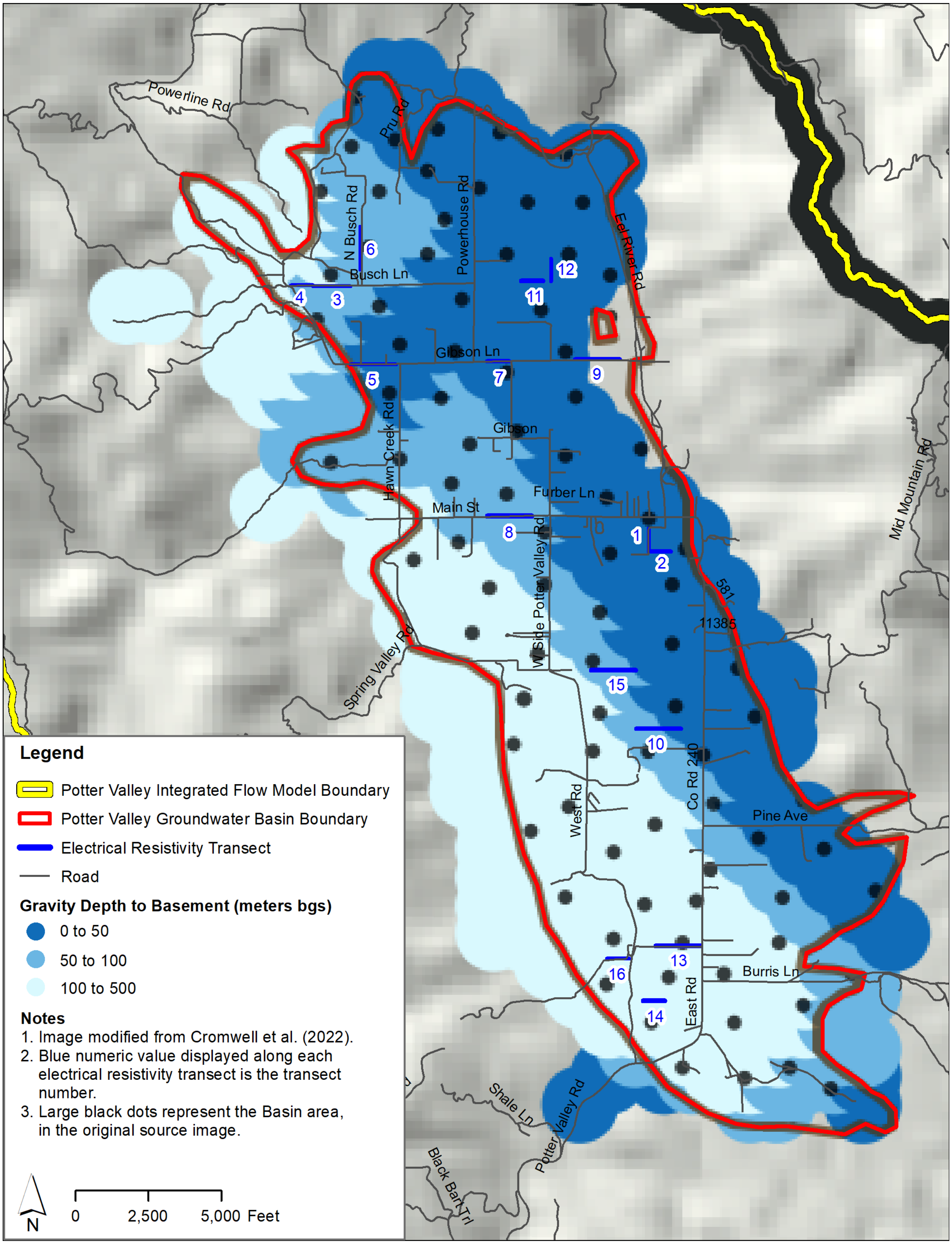

Figure 9. Modeled Depth-to-Basement Based on the US Geological Survey Gravity Data

8. Discussion and Conclusions

8.1 US Geological Survey Gravity Survey

USGS gravity data provide estimates of Basin geometry and depth to bedrock below Potter Valley. However, because the intent of the USGS gravity survey was to provide depth-to-basement rock estimates over a large regional area, it lacks the spatial resolution for more precise estimates in Potter Valley. The top of Model Layer 3 in the preliminary version of the PVIFM already coincides with the estimated top of bedrock from the USGS gravity data, and coincides with a preliminary version of the USGS groundwater-flow model of the Russian River Watershed (USGS 2022a, 2022b). So, no refinements to PVIFM layering have been made based on an independent review of the USGS gravity data.

8.2 Drone-based Frequency-domain Electromagnetic and Electrical Resistivity Surveys

The DBEM and ER methods implemented for recent geophysical surveys provided information about subsurface materials to a maximum depth of approximately 250 feet bgs. As shown in Figure 8, previous USGS estimated depths to basement rock exceeded 246 feet bgs in the west-southwest portion of the Basin. Therefore, the DBEM and ER survey models do not provide more refined estimates of depth to bedrock in the west-southwest portion of the Basin. However, review of the ER models in the central and eastern portions of the Basin indicate some opportunity to refine elevation tops of Model Layer 3 cells representing the bedrock surface. An example of such refinements includes the eastern ends of ER profiles along Transects 2 and 9 (refer to ER transect locations in Figure 1 and individual ER profiles in Attachment 1). These ER models indicate the surface of a higher-resistivity zone that may represent a rising bedrock surface where unconsolidated Basin materials thin in an eastward direction.

Although distinguishing between subtle changes in soil types is generally not possible with the DBEM or ER methods directly, these methods provide information about lateral and vertical distributions of fine- and coarse-texture, or consolidated rocks below the ER transects. Most of the ER models generally show low-resistivity distributions that likely represent fine-texture deposits, which generally could be associated with the alluvium, terrace deposits or continental deposits described by DWR (2004). Some higher-resistivity anomalies were indicated by the ER models at scattered locations; these anomalies likely represent coarser-grained deposits or consolidated rock. In terms of general spatial trends across the Basin, both the DBEM and ER models in the northwestern portion of the valley show a greater proportion of higher-resistivity zones as compared with ER models in the rest of the valley. These higher-resistivity zones likely represent coarser-texture deposits. This is supported by well log WCR2020-005965; this well is located along Busch Lane near ER Transect 6 (refer to Figure 1).

The log indicates:

- Sand and gravel from 0 to 20 feet bgs
- Gravels from 20 to 75 feet bgs
- Gray clay from 75 to 90 feet bgs

According to this well log, there is a higher proportion of gravel to a depth of 75 feet bgs. This area with greater proportions of gravel will inform representation of hydraulic-conductivity values in the PVIFM during its calibration.

9. Recommendations/Next Steps

The northwestern portion of the Basin may offer opportunities for managed aquifer recharge (MAR) strategies, which might improve future water-supply reliability in the Basin. To refine understanding of subsurface conditions in this northwestern area, it would be helpful to drill several boreholes deep enough to delineate the depth-to-bedrock surface and provide descriptions of soil texture throughout the boreholes. Using a sonic drilling technique would provide the opportunity to collect a continuous core and prepare detailed lithologic descriptions for the full well depth. Characterizing the lithology to depths exceeding 400 feet bgs would likely require a rotary drilling technique supplemented by downhole geophysics. This information would help refine the hydrogeologic conceptual model represented in the PVIFM.

Pending results of drilling and testing new monitoring wells that were drilled and constructed in 2024, it may be beneficial to drill and construct a test well(s) several hundred feet deep in the northwestern area to facilitate estimation of transmissivity and groundwater storage over greater depth intervals of the aquifer. Updating transmissivity, hydraulic conductivity, and storage values in the PVIFM would help inform decision-making related to MAR strategies that would rely on aquifer storage and recovery via groundwater wells.

Infiltration testing in selected areas of the Basin would also help inform decision-making related to MAR strategies that rely on surface recharge methods if they are being considered.

Because the ER device measures the weighted average ER response over a subsurface volume that extends to about 10 feet bgs, the ER models should not be used to delineate the depth to water, given that the limited available groundwater-level data indicate the water table is generally within 10 feet bgs. To improve confidence in depth-to-water estimates, it would be helpful to continue identifying landowners with existing wells that will allow groundwater-level measurements to be recorded on an ongoing basis.

Recommendations based on geophysical study are as follows:

- Drill several boreholes deep enough to delineate the depth-to-bedrock surface and provide descriptions of soil texture throughout the boreholes to refine understanding of subsurface conditions in this northwestern area.
- Drill and construct a test well(s) several hundred feet deep in the northwestern area to facilitate estimation of transmissivity and groundwater storage over greater depth intervals of the aquifer.
- Continue identifying landowners with existing wells that will allow groundwater-level measurements to be recorded on an ongoing basis.

10. References

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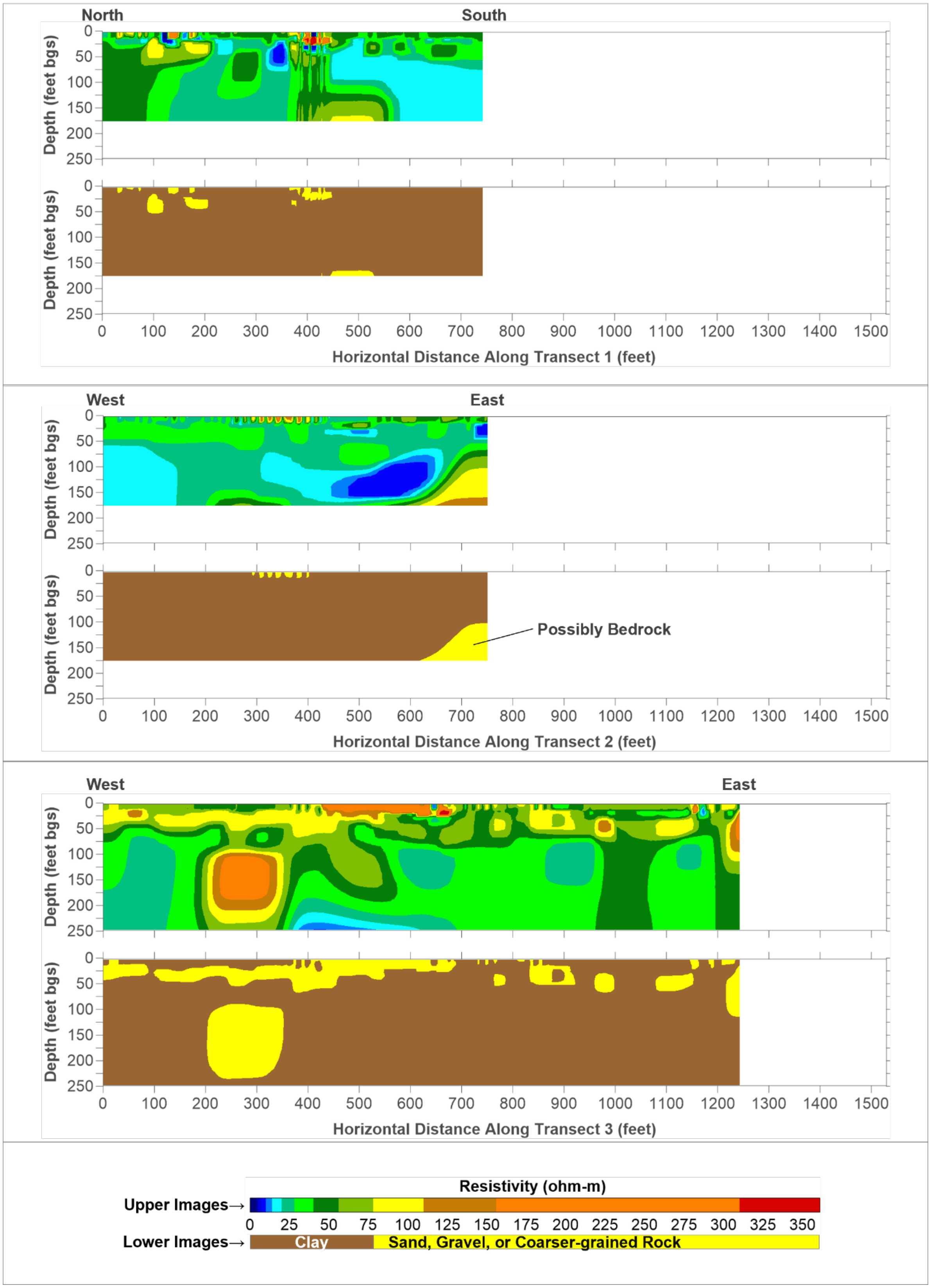
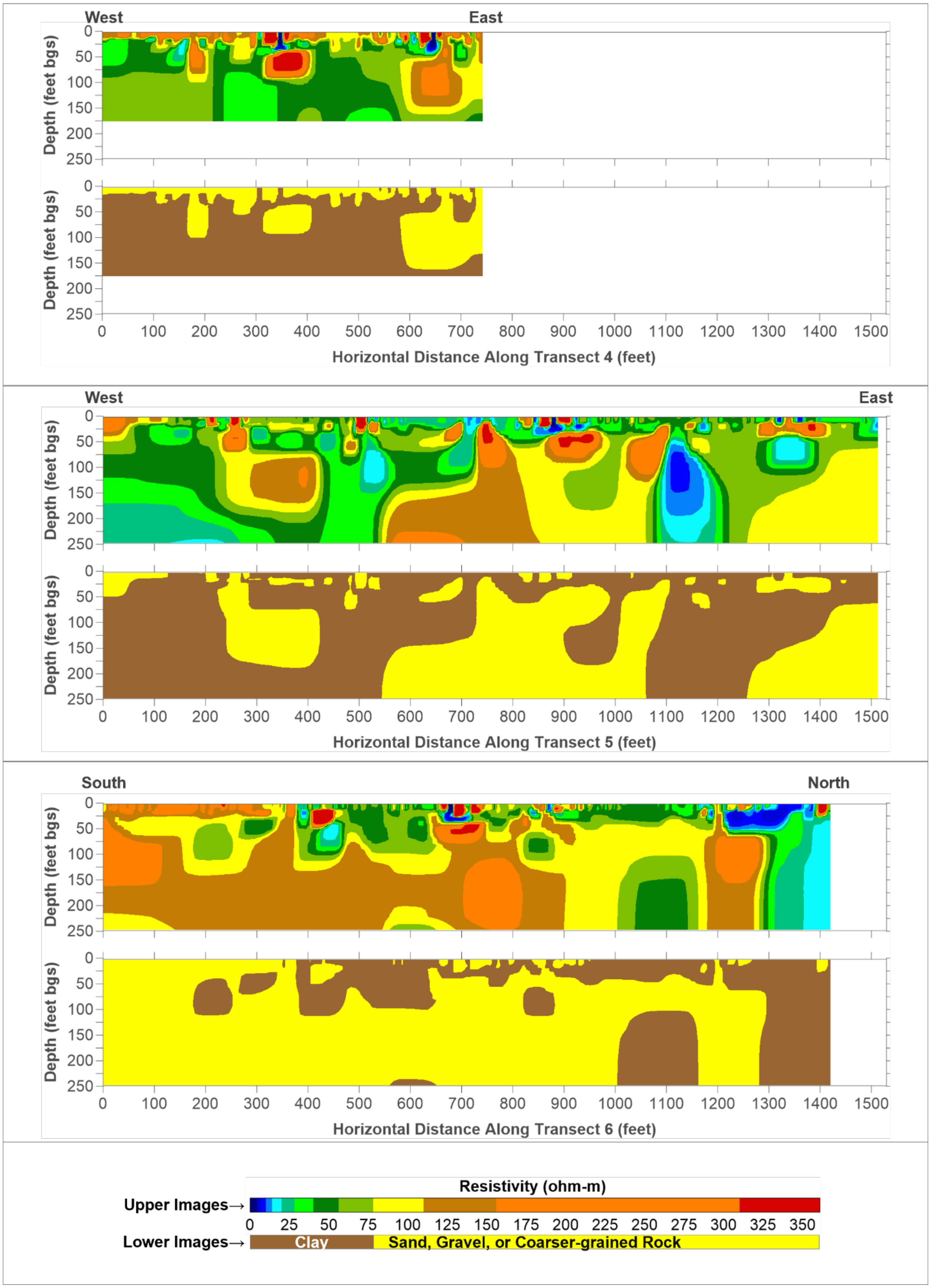
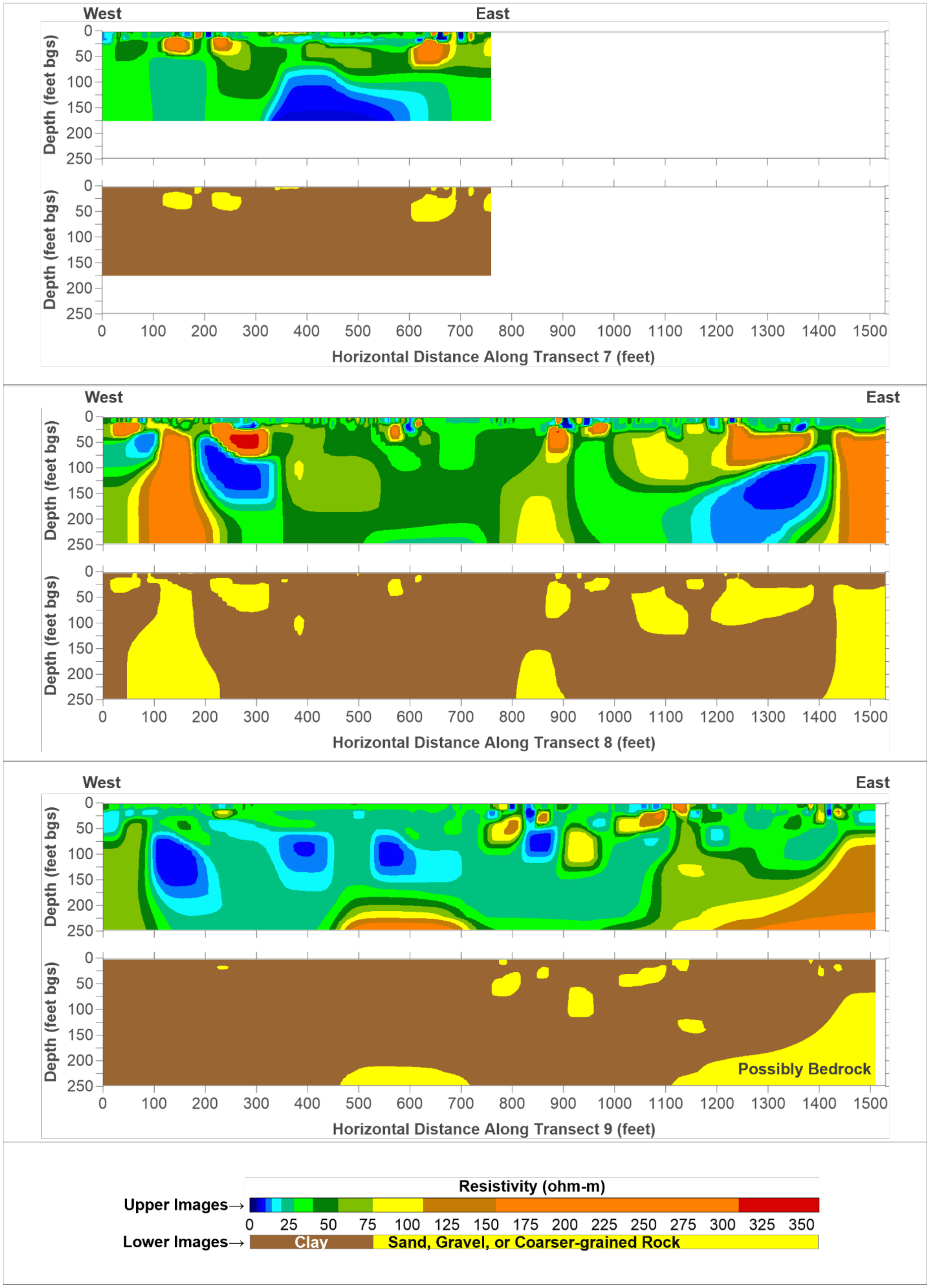
Attachment 1
Electrical Resistivity Profiles Along Transects Shown in Figure 1



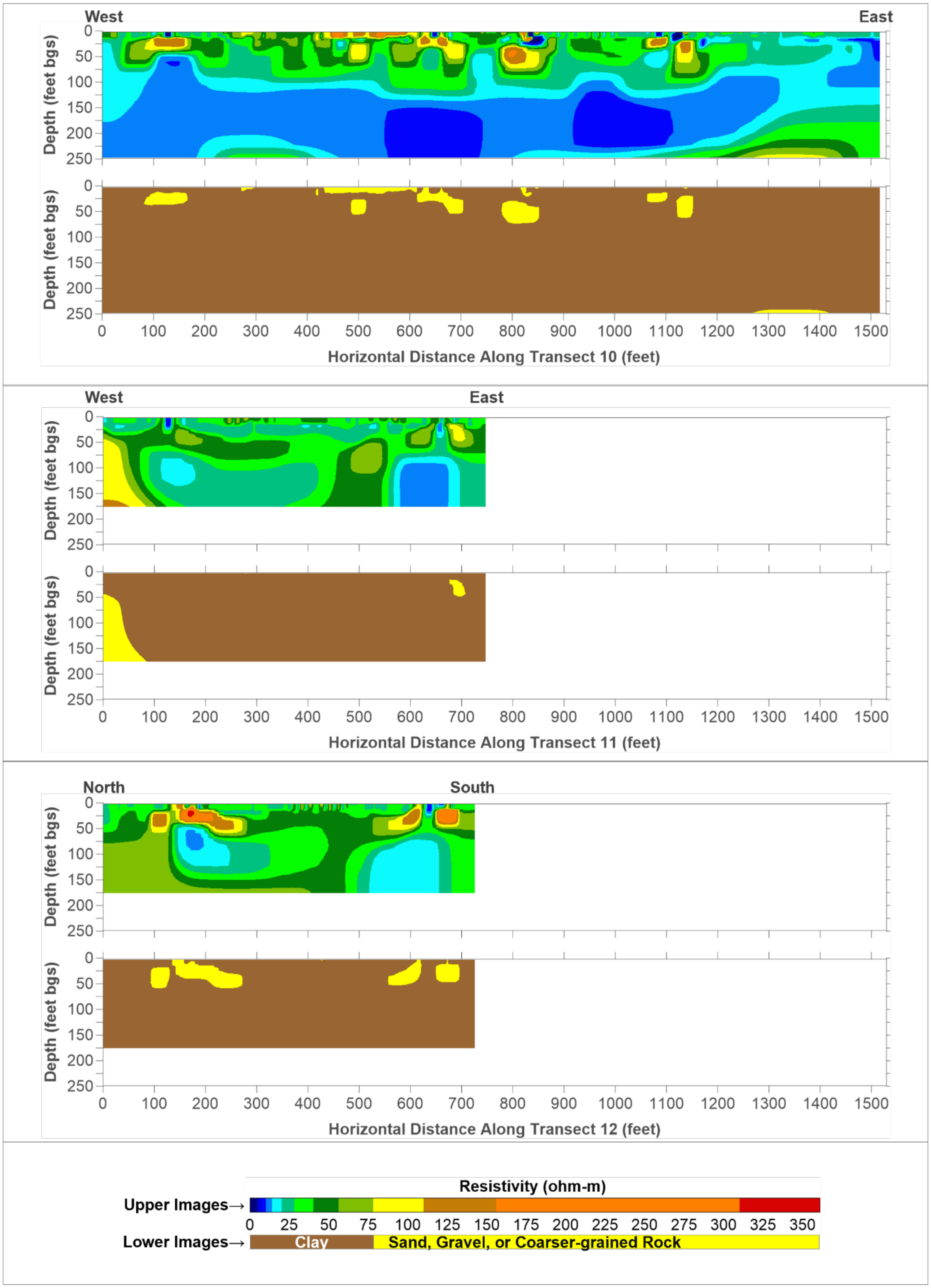
Electrical Resistivity Transects 1, 2, and 3



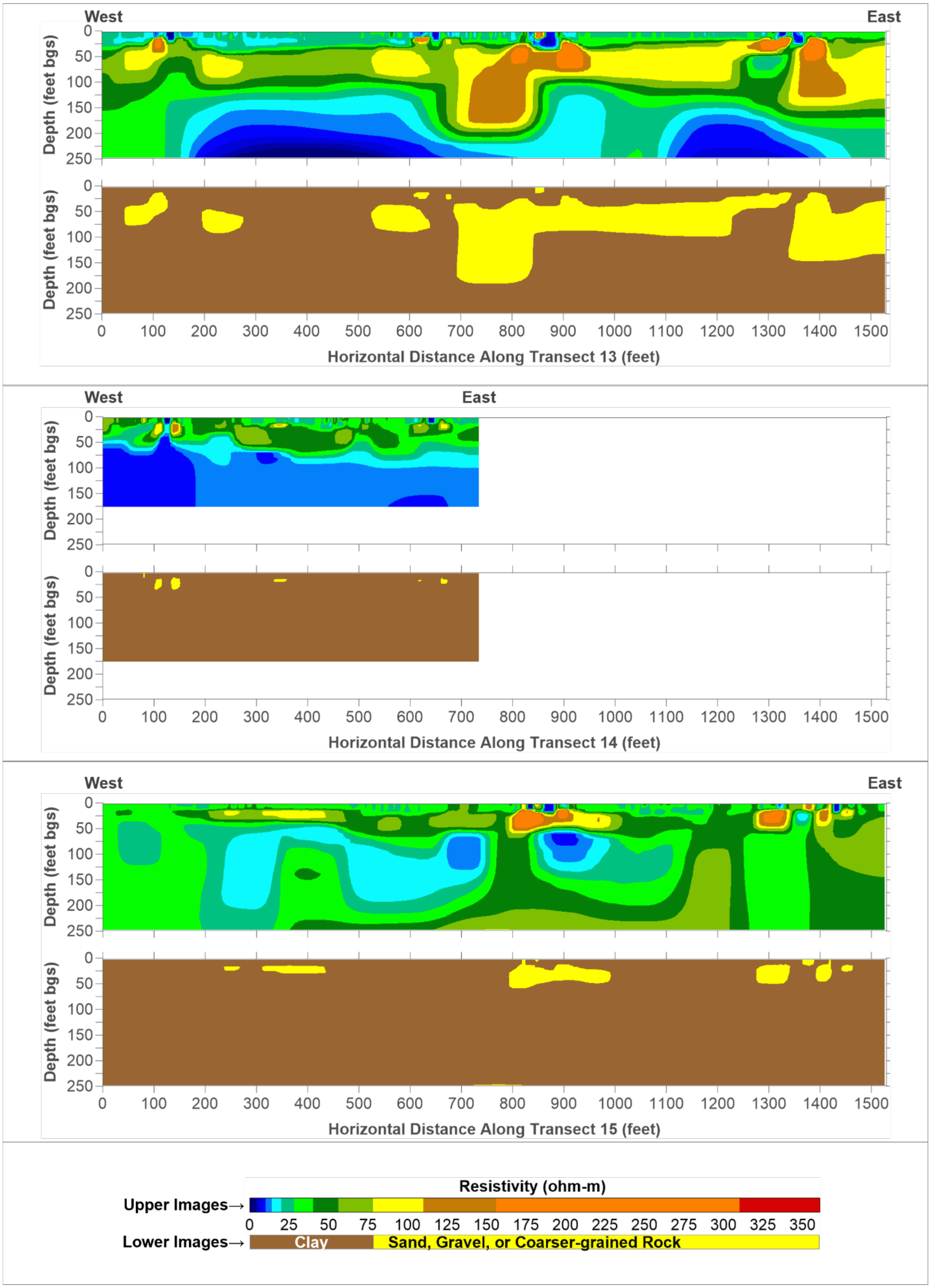
Electrical Resistivity Transects 4, 5, and 6



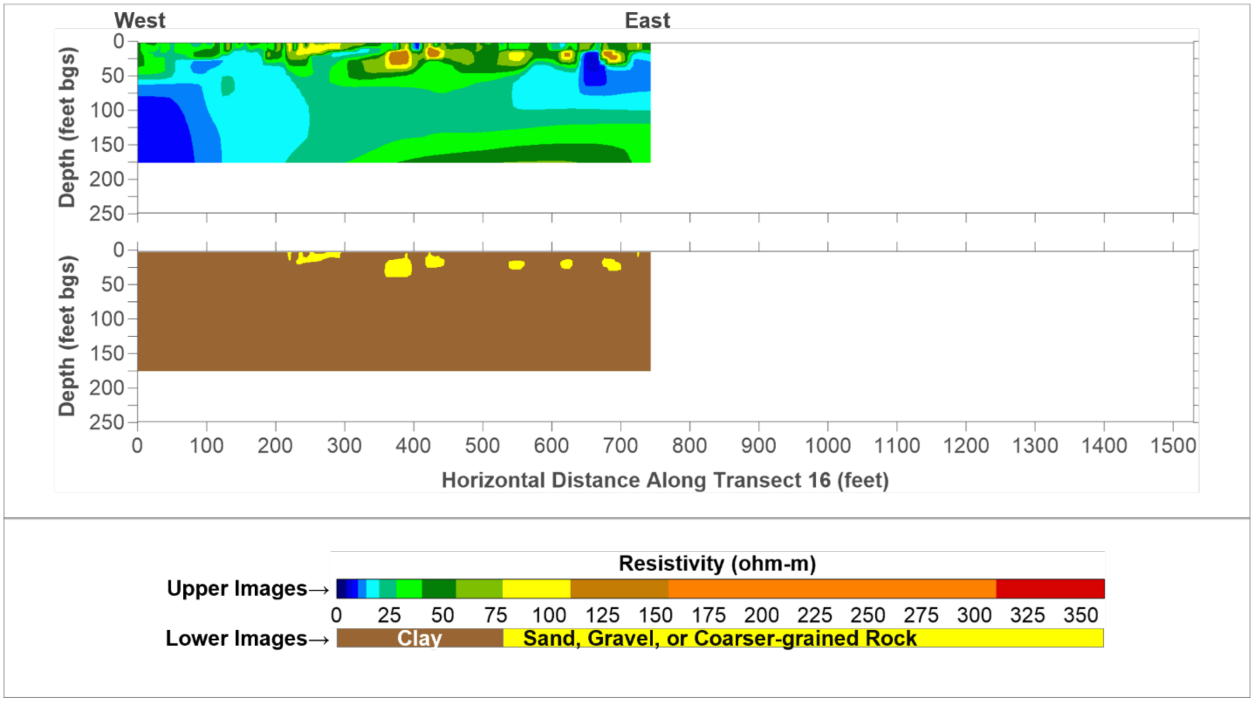
Electrical Resistivity Transects 7, 8, and 9



Electrical Resistivity Transects 10, 11, and 12



Electrical Resistivity Transects 13, 14, and 15



Electrical Resistivity Transect 16