Aquifer Sustainability at the Osceola County Rural Water System H-Series Wellfield

Water Resources Investigation Report 17

The University of Iowa

Iowa Geological Survey

IIHR Hydroscience & Engineering

Aquifer Sustainability at the Osceola County Rural Water System H-Series Wellfield

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EXECUTIVE SUMMARY

The Iowa Geological Survey completed a hydrogeologic investigation of an alluvial aquifer near the Osceola County Rural Water System (OCRWS) H-Series wellfield which is located in Osceola County, Iowa. The initial purpose of the investigation was to evaluate drought resiliency benefits of a temporary low-head dam. Results from the evaluation of the temporary low-head dam would then be used to determine if a permanent structure should be created at the site. However, although still planned for construction, the dam has not been installed due to consistently high flows on the Ocheyedan River during the study period. Results from this investigation provide a background dataset which can be used as a baseline after the dam is implemented. Additionally, a groundwater model was refined and is ready to accept data following implementation of the dam.

Based on data from the on-site production wells and observation wells, the thickness of alluvial deposits beneath the OCRWS H-Series wellfield varies from 25 to 49 feet, and averages approximately 40 feet. The deposits are not uniform or homogeneous and include clay, silt, sand, gravel, cobbles, and boulders. The alluvial aquifer consists of glacial outwash deposits associated with Des Moines Lobe glacial advances. A geophysical investigation was conducted to help evaluate changes in lithology within the wellfield, assist in the assessment of aquifer thickness, gather additional information about aquifer properties, aid in the identification of locations for observation wells, and help with development of the local-scale groundwater flow model.

Groundwater flow in the vicinity of the OCRWS H-Series wellfield is strongly influenced by the Ocheyedan River stage. Groundwater elevations and flow directions fluctuated depending on whether the production wells were actively pumping or idle. Pump tests were conducted in OCRWS production wells H-3 and H-4. Observation wells OB-1 and OB-3 were used to measure drawdowns. Transmissivity values ranged from 59,200 ft^2/day near OB-3 to 146,000 ft^2/day near OB-1. Hydraulic conductivity values were found to range from 1,480 to 1,980 feet/day, with an arithmetic mean of 1,730 feet/day. Storativity values, or specific yield, ranged from 0.0117 near OB-3 to 0.0000001 near OB-1. In addition to the aquifer parameter estimation, the observed drawdown data were also used to help calibrate the groundwater flow model.

The calibrated groundwater flow model was used to simulate the benefits of the proposed, temporary low-head dam. In this severe drought scenario, the temporary dam provides a benefit to all H-Series production wells. The greatest upwelling was shown near well H-4 with a simulated increase of approximately 1.5 feet. Upwelling near wells H-1, H-2, and H-3 was shown to be between half and one foot.

Monthly observations show nitrate concentrations in the Ocheyedan River fluctuated between 2.8 and 24 mg/L during the sampling period. Sampling results also show that nitrate concentrations are low in the piezometers, observation wells, and production wells relative to the river. Significant nitrate reduction from the river sediments was observed consistently throughout the study.

If a decision is made to move forward with a permanent drought resiliency strategy following the monitoring of the temporary low-head dam, consideration should be given to all available strategy

options. For example, a rock riffle structure(s) or an excavated/reconnected cutoff channel system could provide similar benefits to water quantity and quality as a low-head dam. The permanent strategy should assess environmental (biologic, ecosystem) impacts as well as water quantity and quality benefits.

INTRODUCTION

The Iowa Geological Survey completed a hydrogeologic investigation of the alluvial aquifer near the OCRWS H-Series wellfield which is located in Osceola County, Iowa (Figure 1). The initial purpose of the investigation was to evaluate drought resiliency benefits of a temporary low-head dam. Results from the evaluation of the temporary low-head dam would then be used to determine if a permanent structure should be created at the site. However, although still planned for construction, the dam has not been installed due to consistently high flows on the Ocheyedan River during the study period. Results from this investigation provide a background dataset which can be used as a baseline after the dam is implemented. Additionally, a groundwater model was refined and is ready to accept data following implementation of the dam.

The objective of installing a low-head dam near a high capacity wellfield is to increase the surface water storage within the aquifer. During moderate to severe droughts, little, if any precipitation recharge enters an alluvial aquifer. To maintain well capacity and water production, alluvial aquifers must rely on nearby streams, rivers, and other surface water as sources of recharge. Low-head dams provide additional groundwater storage during periods of normal or above normal precipitation by raising the stage of the river. This additional storage is then available to maintain water production during dry periods and droughts.

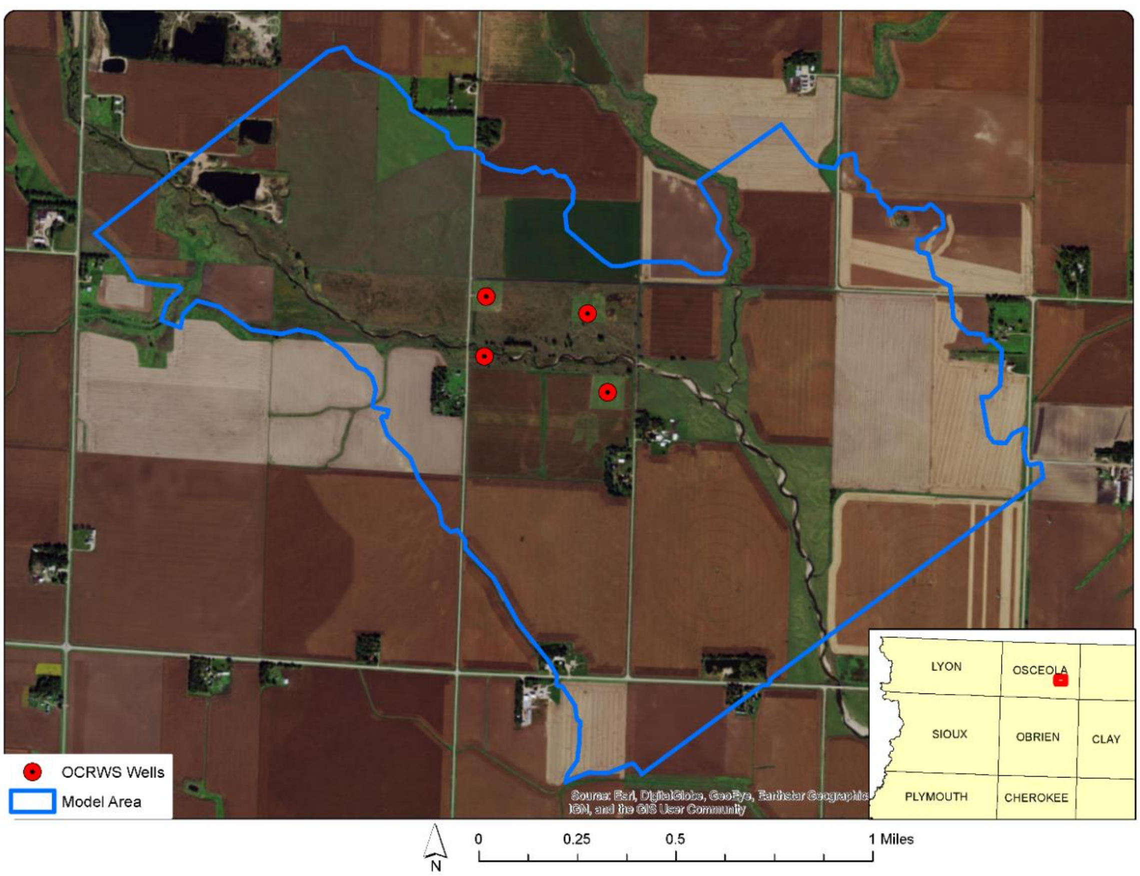

Figure 1. OCRWS H-Series wellfield location and model area.

Monthly water level measurements and water quality samples were collected at the site for approximately one year. In addition, a three-dimensional groundwater flow model was developed to evaluate the groundwater quantity benefits, and to see what, if any, impacts the temporary low-head dam may have on groundwater quality. Previous investigations have been conducted by Leggette Bradshears & Graham, Inc. (LBG) (Oswald and Hume 2007), and the Iowa Geological Survey in 2014 and 2015 (Gannon and Vogelgesang 2014, Gannon and Vogelgesang 2015).

Site Background Information

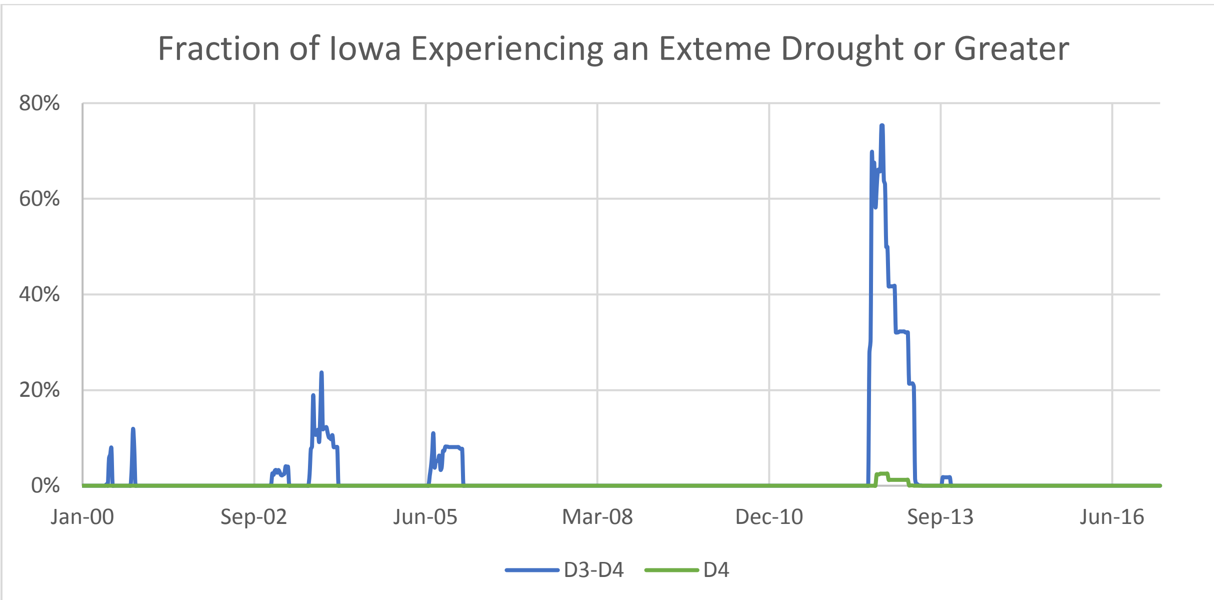

Figure 2. The fraction of Iowa during the last 17 years that experienced an extreme (D3-D4) or exceptional drought (D4) (NDMC).

Iowa experienced a significant statewide drought beginning in the fall of 2011 with dry conditions continuing throughout most of 2012 and 2013. Figure 2 shows the fraction of Iowa during the last 17 years that experienced an extreme (D3-D4) or exceptional drought (D4), as defined by the National Drought Mitigation Center (NDMC). Discharge in many rivers reached historic lows during the widespread drought. The lowest average daily discharge in the Ocheyedan River at Spencer (USGS) was recorded in 2013 at 2.9 cubic feet per second.

Unlike previous droughts, the security risk associated with the 2012-13 drought increased significantly due to sociological and economic changes in water distribution and use. The rapid expansion of rural water systems and the concentration of livestock in animal feeding operations (AFOs) combined to place additional strain on the limited water resources. Unlike the past, when most farms and small rural communities relied on their own wells, regional rural water systems now supply most of the water to individual farms, livestock producers, AFOs, and rural communities. Although Osceola County has a low population, estimated at 6,064 residents (USCB), approximately 335,000 hogs and pigs, and 45,000 cattle and calves were marketed in 2012 (USDA). The increase in water consumption by both urban and rural users in 2012 and 2013 put an enormous strain on water utilities, especially rural water districts.

Field Activities and Data Collection

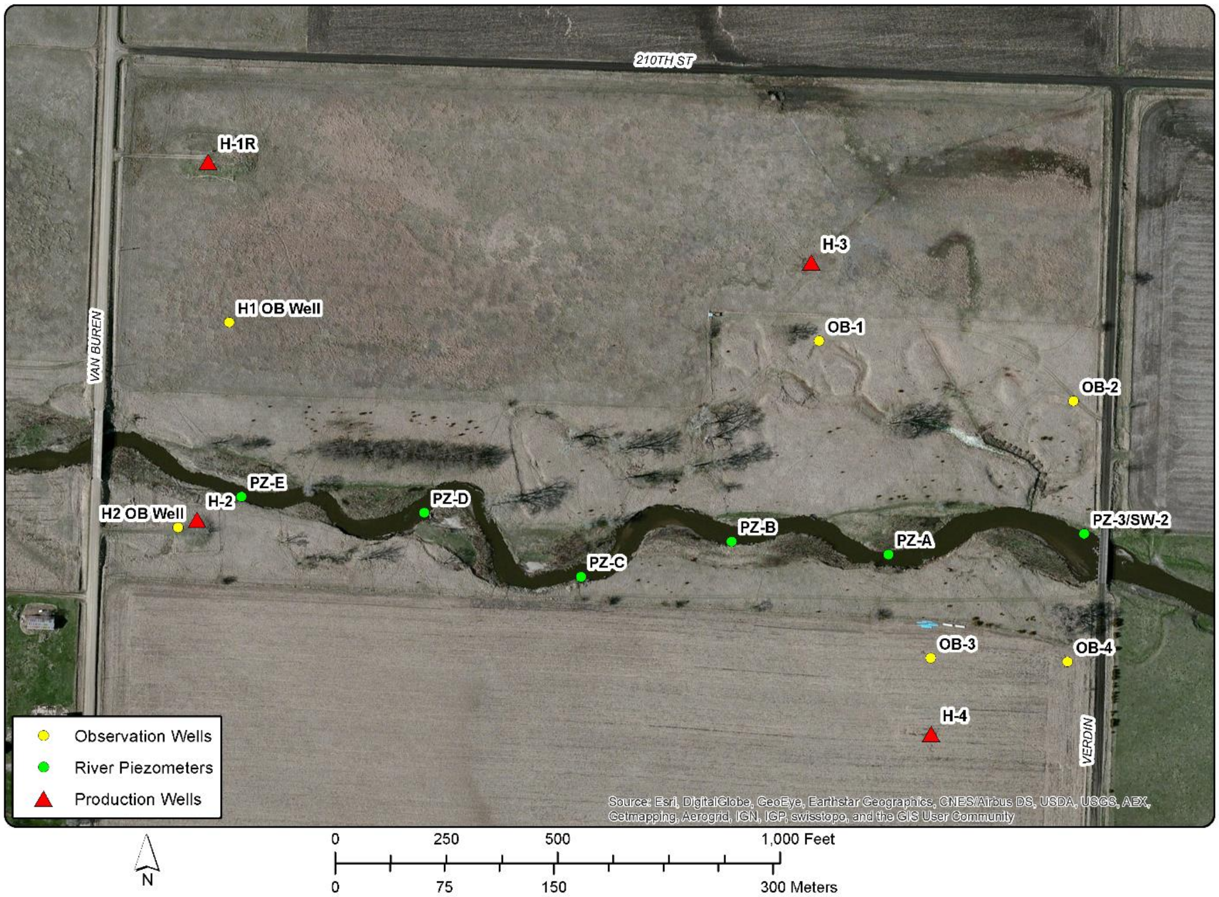

Figure 3. OCRWS H-Series wellfield showing the location of existing observation wells H1 OB Well and H2 OB Well, four new observation wells OB-1, OB-2, OB-3, and OB-4, six new river piezometers PZ-A, PZ-B, PZ-C, PZ-D, PZ-E, and PZ-3, and surface water sample location SW2.

On November 2, 2015, four observation wells (OB-1, OB-2, OB-3, and OB-4) were installed as shown on Figure 3. The wells consisted of 2-inch diameter polyvinyl chloride (PVC) with the lower ten feet screened using 0.010 slot screen. Drilling logs and well construction diagrams are shown in Appendix A. A steel protective casing was also used for each well to complete the installation. The top of the PVC casing elevation for each new observation well and one piezometer (PZ-3-installed near SW2) were surveyed using a David White transit and survey rod. The top of production well H-3 was used as the datum elevation. Existing observation wells (H1 OB Well, H2 OB Well) were also used for this investigation. Five new river piezometers (PZ-A, PZ-B, PZ-C, PZ-D, and PZ-E) were installed in preparation of the low-head dam installation monitoring.

Monthly water levels were measured starting in November of 2015 using an In-Situ electronic water level meter. The monthly water levels and groundwater elevations are shown in Appendix B. Water samples were also collected monthly from each observation well and piezometer location using a peristaltic pump. In addition, water samples were collected in the Ocheyedan River (SW2) and in OCRWS production wells H-1, H-2, H-3, and H-4 (Figure 3). Samples were analyzed for nitrate as nitrogen and chloride. All of the sampling locations are shown in Figure 3.

In addition to the collection of water quality samples, a calibrated local-scale groundwater model was developed to prepare for evaluation of the groundwater quantity benefits, and to see what, if any, impacts the temporary low-head dam may have on groundwater quality. The groundwater flow model referenced a regional model developed by the Iowa Geological Survey in 2015 (Gannon and Vogelgesang 2015).

GEOLOGY

Based on data from the on-site production wells and observation wells (Appendix A), the thickness of alluvial deposits beneath the OCRWS H-Series wellfield varies from 25 to 49 feet, and averages approximately 40 feet. The deposits are not uniform or homogeneous and include clay, silt, sand, gravel, cobbles, and boulders. The alluvial aquifer consists of glacial outwash deposits associated with Des Moines Lobe glacial advances. The upper 2 to 6 feet of the aquifer consists of fine grained sand or silty sand topsoil. Beneath the topsoil is fine to very coarse sand and gravel. The base of the aquifer is underlain by either glacial till or clay-rich alluvium.

Geophysical Survey

A geophysical investigation was conducted to help evaluate changes in lithology within the wellfield, assist in the assessment of aquifer thickness, gather additional information about aquifer properties, aid in the identification of locations for observation wells, and help with development of the local-scale groundwater flow model. Geophysical measurements were collected using an Advanced Geosciences Inc. (AGI) SuperSting R8, 8-channel electrical resistivity (ER) meter.

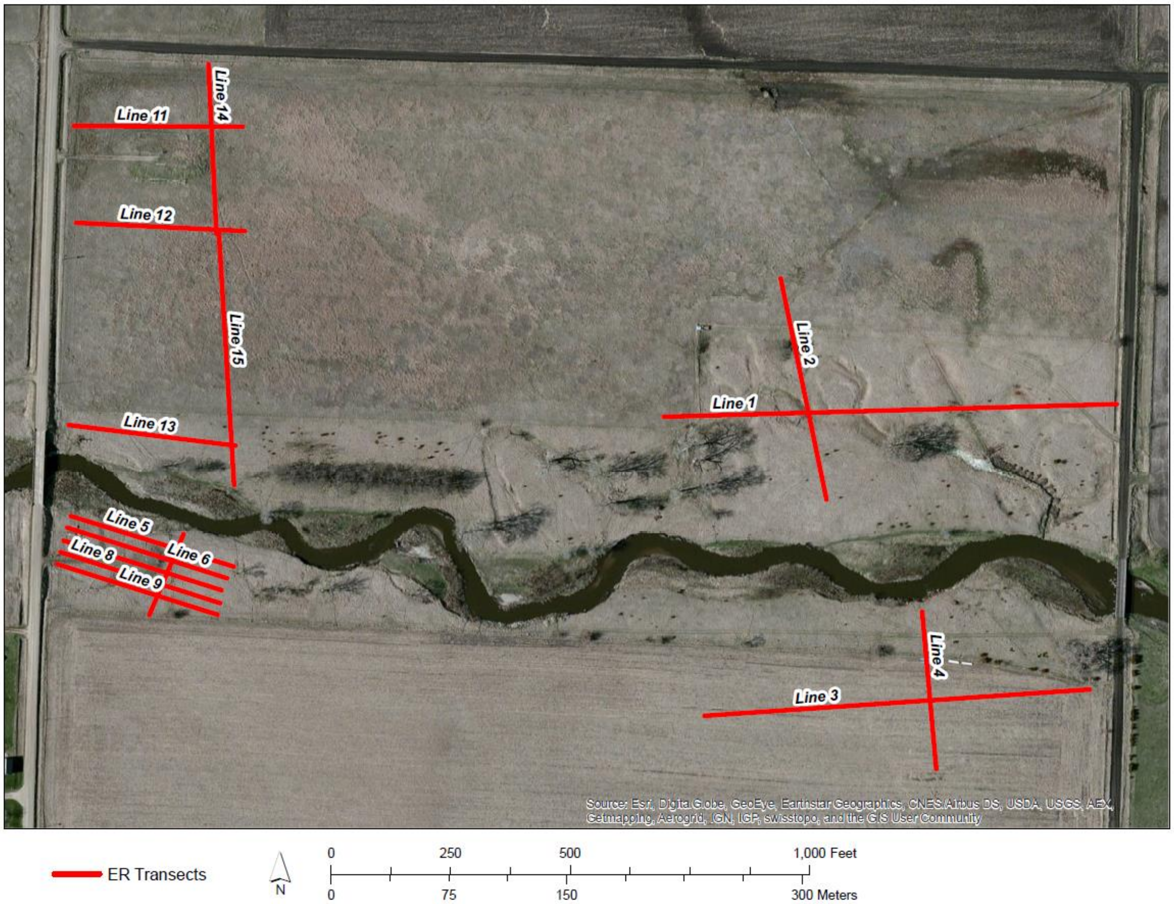

Figure 4. Geophysical survey locations from this investigation (Lines 1-4) and Gannon and Vogelgesang (2015) (Lines 5-15).

Four resistivity lines were completed as part of this study and combined with eleven lines completed as part of a prior investigation (Gannon and Vogelgesang 2015) for a total of fifteen lines (Figure 4). Lines 1 and 2 were gathered parallel and perpendicular to the Ocheyedan River on the northeast portion of the wellfield. Lines 3 and 4 were gathered parallel and perpendicular to the Ocheyedan River on the southeast portion of the wellfield. Existing Lines 5 through 15 were gathered on the western portion of the wellfield and were completed before implementation of production wells H-3 and H-4.

Field measurements were obtained by introducing a direct current into the ground through current electrodes and measuring resulting voltages through potential electrodes. An array of up to 56 electrodes were spaced approximately 20 feet apart, driven approximately one foot into the ground, and connected via electrode cables and a switch box to a central ER meter. A dipole-dipole collection configuration was utilized to better image geologic variability associated with alluvial aquifers. Measure time was set at 3.6 seconds and measurements were stacked (averaged) twice, unless the standard deviation of all channels was less than 2%. In that case, a third measurement was taken and included in the average. To quantify error, overlapping data were collected in areas already covered by normal measurement. Data were processed using AGI EarthImager 2D version 2.4.0 software. A smooth model inversion method was used. The inversion mesh was fine for the near-surface region in each transect and coarsened with depth. Resistivity values below 1 Ohm-m or above 10,000 Ohm-m were removed as these values are typically representative of erroneous data. Inversion was stopped once root-mean-squared (RMS) values were below 6% and L2 norm ratio values were less than 1. Each model was corrected for land surface elevation using LiDAR elevation data.

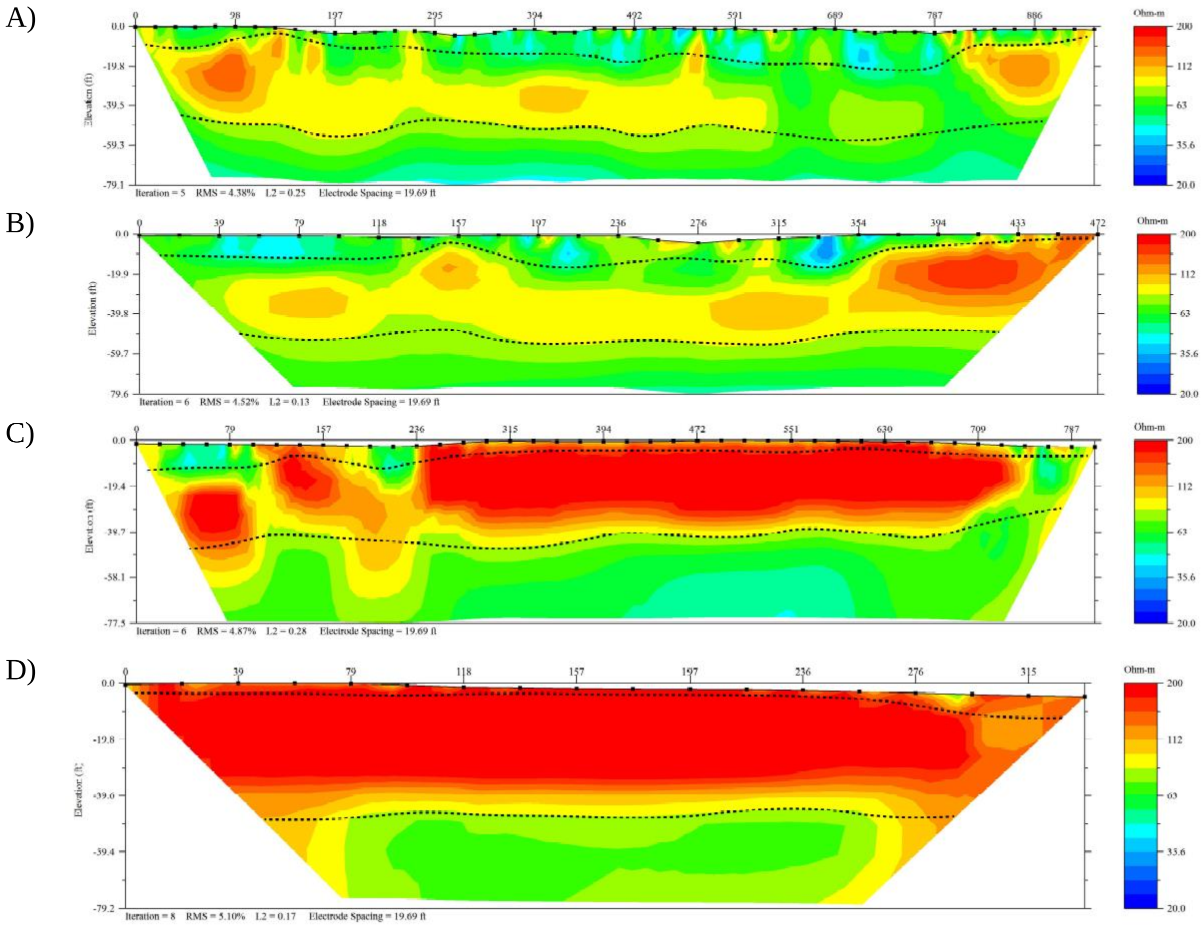

Figure 5. Electrical resistivity models for A) Line 1-west to east B) Line 2-north to south C) Line 3-west to east D) Line 4-north to south. Dashed lines indicate approximate aquifer boundaries.

Final geophysical models for each line are shown in Figure 5 and included in Appendix E. Models provide information on how the subsurface responds to electrical influence. Model results can be indicative of a number of variables including, mineralogy, water saturation, compaction and available pore space, dissolved ions in pore fluid, as well as other geologic, biologic, and chemical factors. Generally, coarse grained material is more resistive to electrical charge than fine grained material. However, interpretation of these data must be in the context of additional site information. Drilling logs from production wells and observation wells were analyzed and used in the interpretation of the geophysical data. The reds and yellows in the models correlate to sand and gravel units identified in neighboring boreholes. Dashed lines in Figure 5 indicate approximate aquifer boundaries and associated groundwater model layer distinctions. Aquifer thicknesses interpreted from the geophysical models show greater variability in some areas. For example, models from Lines 1 and 2 show decreased resistivity values and considerable spatial variability, possibly suggesting this area may have more complex lithology related to alluvial and/or glacial deposits. Understanding aquifer heterogeneity is especially important in alluvial aquifer settings where coarse grained material usually facilities increases in groundwater flow.

HYDROGEOLOGY

Groundwater flow in the vicinity of the OCRWS H-Series wellfield is strongly influenced by the Ocheyedan River stage. Monthly water level data from the observation wells and piezometer can be found in Appendix B. Groundwater elevations and flow directions fluctuated depending on whether the production wells were actively pumping or idle. Our measured evaluations did not factor in the active versus inactive pumping cycles.

Groundwater recharge sources are precipitation, induced recharge from surface water, and seepage from glacial drift and terraces along the valley wall. It is difficult to measure groundwater recharge based on annual precipitation data. Much of the precipitation recharge in Iowa occurs during the spring and fall. The actual amount of groundwater recharge depends on the intensity and distribution of the precipitation events, and when they occur seasonally. The annual rate of precipitation recharge during a moderate to severe drought was calibrated to be approximately 3 inches/year (Gannon, 2012).

Aquifer Test Results

Hydraulic properties are used to define and characterize aquifers and include specific yield or storage, transmissivity, and hydraulic conductivity. The most reliable aquifer properties are those obtained from controlled aquifer pump tests with known pumping rates, pumping duration, accurate well locations, and accurate water level measurements. Pump tests were conducted in OCRWS production wells H-3 and H-4. Observation wells OB-1 and OB-3 were used to measure drawdowns. Table 1 shows the pump test results, which indicate transmissivity values range from 59,200 ft^2/day near OB-3 to 146,000 ft^2/day near OB-1. Storativity values or specific yield range from 0.0117 near OB-3 to 0.0000001 near OB-1. In addition to the aquifer parameter estimation, the observed drawdown data were also used to help calibrate the groundwater flow model. This will be discussed later in the report. The pump test graphs and raw data are given in Appendix D.

Table 1. Aquifer pump test results at the OCRWS H-Series east wellfield.

Pumping Well	Observation Well	Radial Distance to Pumping Well (ft)	Calculated Transmissivity (ft^2/day)	Calculated Hydraulic Conductivity (ft/day)	Calculated Storativity	Observed Drawdown (ft)
H-3	OB-1	200	146,000	1,980	0.0000001	0.737
H-4	OB-3	200	59,200	1,480	0.0117	0.597

Hydraulic conductivity can be calculated by dividing transmissivity by the overall aquifer thickness. Hydraulic conductivity values were found to range from 1,480 to 1,980 feet/day, with an arithmetic mean of 1,730 feet/day. In addition to pump test data collected for this study, pump tests completed for a previous study near production wells H-1 and H-2 were used to analyze aquifer parameters in the western portion of the H-Series wellfield (Gannon and Vogelgesang 2015).

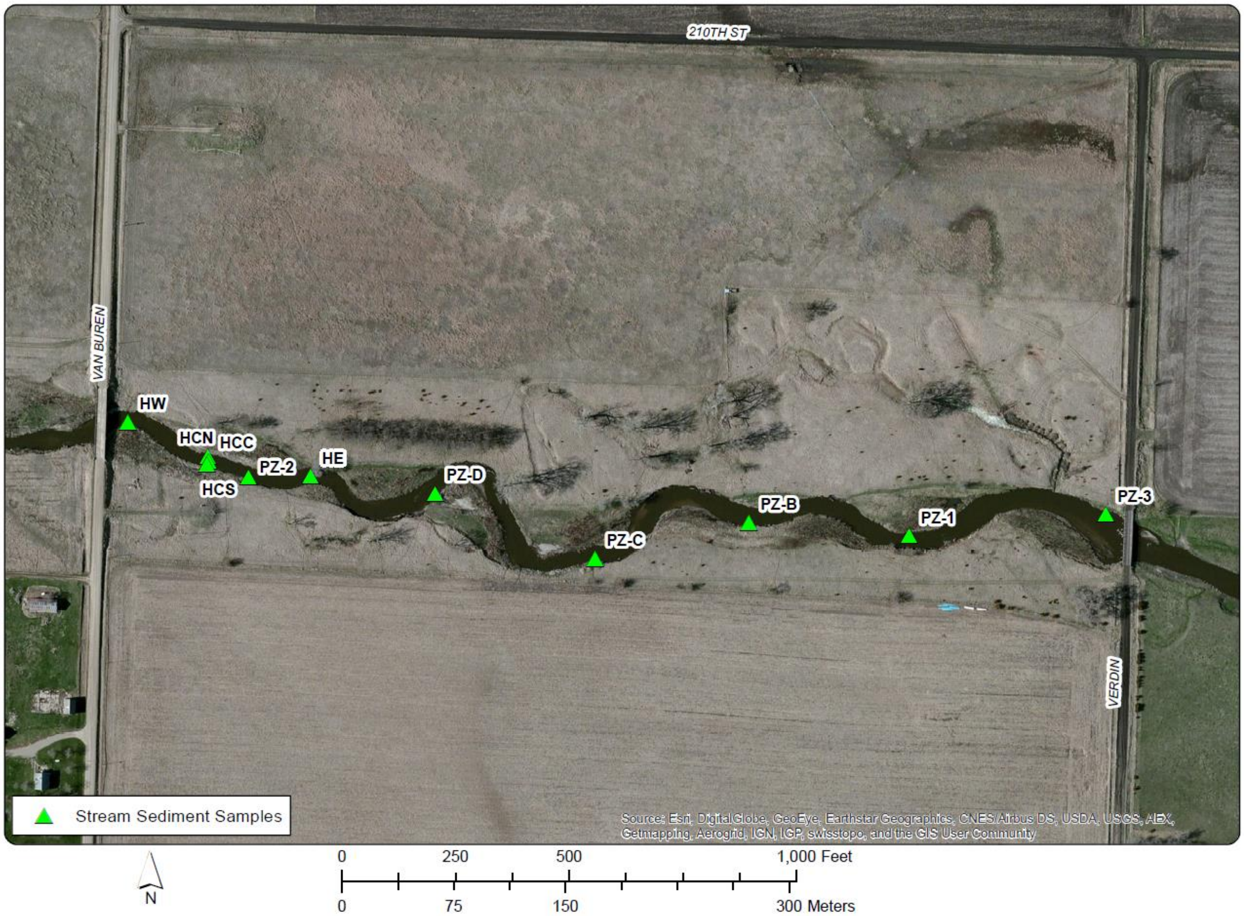

Figure 6. River sediment sampling locations near the OCRWS H-Series wellfield.

Sediment Sampling

Sediment samples were collected from the Ocheyedan River riverbed in locations marked in Figure 6. Constant-head permeability tests were completed for each of the samples to calculate vertical hydraulic conductivity and estimate the spatial variability within the wellfield. The laboratory method used to calculate permeability was taken from the American Society of Testing Materials (ASTM 1967). Results from constant-head permeability tests are shown in Table 2. Relevant results were also extracted from Gannon and Vogelgesang (2015) and are included in the results. Hydraulic conductivity values calculated from the samples range from 0.01315 to 9,725 feet/day.

Table 2. Laboratory permeability results for Ocheyedan River sediment samples.

Sample ID	$H-H_1$	Q (mL/minute)	Length (cm)	Area (cm^2)	K (ft/day)
HW*	66.0	650	15.24	45.58	155.6
HCN*	65.0	690	15.24	45.58	167.7
HCC*	62.0	750	15.24	45.58	191.1
HCS*	103.5	250	15.24	45.58	38.16
HE*	85.5	475	15.24	45.58	87.76
PZ-1*	51.5	0.0429	15.24	45.58	0.01315
PZ-2*	76.0	160	15.24	45.58	33.26
PZ-3*	27.0	820	15.24	45.58	479.7
PZ-B	26.5	700	8	45.34	220.2
PZ-C	1.2	1400	8	45.34	9725
PZ-D	23.5	1120	8	45.34	397.3

**Gannon and Vogelgesang 2015*

GROUNDWATER MODELING

The modeling software Visual MODFLOW Classic Version v.4.6.0.168 (June 2016) was used to simulate the groundwater flow in the alluvial aquifer under severe drought conditions. An original model developed in 2015 (Gannon and Vogelgesang 2015) was referenced in the creation of this OCRWS H-Series wellfield focused model. New on-site test borings and pump test data were utilized as model inputs. A three-layered model was used for the simulation. Borehole logs were obtained from on-site test borings and elevation data were obtained from LiDAR datasets. The model boundary conditions and inputs included the following:

- Layer 1 represented the developed soil zone. The horizontal hydraulic conductivity was assigned a value of 100 feet/day. The vertical hydraulic conductivity value was assigned a value 1/10 the horizontal hydraulic conductivity.
- Layer 2 represented the sand and gravel aquifer. The horizontal hydraulic conductivity was calibrated within the model and ranged from 25 to 1,700 ft. per day. The vertical hydraulic conductivity value was assigned a value 1/10 the horizontal hydraulic conductivity.
- Layer 3 represented a confining silty clay (alluvial clay or glacial till). The horizontal hydraulic conductivity was assigned a value of 0.01 feet/day. The vertical hydraulic conductivity value was assigned a value 1/10 the horizontal hydraulic conductivity.
- The uplands were considered no-flow boundaries. This was represented by de-activating the grids outside the alluvial aquifer boundary. The alluvial aquifer boundary was estimated using geologic maps created by the IGS (Quade, Giglierano et al. 2005), information from a previous study (Gannon and Vogelgesang 2015), and LiDAR elevation data.
- The Ocheyedan River and Dry Run Creek were represented as river boundaries. The surface water gradient was estimated using LiDAR data. Constant-head permeability laboratory tests provided vertical conductivity data for the Ocheyedan River. The model represented baseflow (summer-time) conditions and the stage was kept the same throughout the entire time period for

each simulation.
- General-head boundaries were used for the two sand and gravel pits in the northwest portion of the study area. The general head values were obtained from LiDAR elevation data, then corrected to correlate to river stages for the drought simulation.
- OCRWS production wells were included in the model simulation. Usage was assumed to be constant during the simulation.
- Specific yield values of 0.1 and specific storage values of 0.001 were used in all model layers and assumed to be representative of the aquifer as average values.
- Average annual recharge was set to represent drought conditions (3 inches per year) from Gannon (2016).
- The model domain consisted of 226 rows by 227 columns. The grid size varied from 27 feet to 91 feet.

Calibration Results

The OCRWS H-Series wellfield model was calibrated based on water levels obtained in November 2015. November 2015 was chosen to represent baseline aquifer conditions as increased precipitation following that month influenced river stages, static water levels in observation wells, and aquifer recharge values. Static water levels measured in observation wells OB-1, OB-2, OB-3, and OB-4 in November 2015 were compared to simulated levels. Simulated versus observed water levels for the observation wells after calibration are presented in Figure 7.

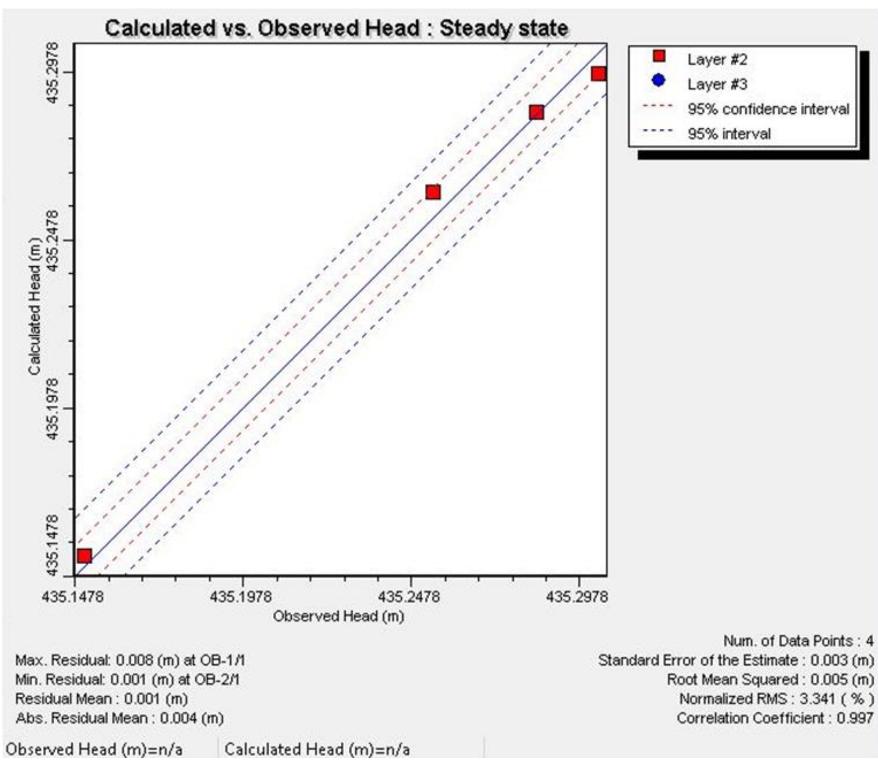

Figure 7. Correlation of simulated versus observed water levels for the November 2015 calibration period.

Calibrated hydraulic conductivity throughout the aquifer ranged from 25 to 1,700 feet/day. Based on model calibration, the area near observation well OB-3 had the highest hydraulic conductivity of 1,700 feet/day. Hydraulic conductivity values in this range are indicative of coarse sand, gravel, and cobbles. Hydraulic conductivity values near observation wells OB-1 and OB-2 were found to be being highly variable. Results from the geophysical investigation suggest this area may have more complex lithology, related to alluvial and/or glacial deposits. Geophysical results near observation wells OB-3 and OB-4 suggest a simpler lithologic package with consistent aquifer thicknesses.

Drought Duration Model Simulation

The calibrated groundwater flow model was used to simulate the benefits of the proposed temporary low-head dam. In this scenario, the dam was placed immediately west of Verdin Avenue and was designed to raise the river stage by three feet from drought stage (1429.4' ASL). A constant elevation of "backed-up" water behind the dam was assumed until the gradient of the Ocheyedan River was greater than the ponded water. The simulation represented a severe two-year drought similar to the 2012 to 2013 drought. The model assumed one foot of water remained in the Ocheyedan River (Gannon and Vogelgesang 2015) and three inches remained in Dry Run Creek. Sand and gravel pits to the northwest of the wellfield were designated as general head boundaries. Water levels in the pits were lowered by the same amount as the Ocheyedan River.

Figure 8 shows simulated groundwater upwelling from the model, which represents increases in the water table elevations during a two-year severe drought following installation of the temporary low-head dam. In this scenario, the temporary dam provides a benefit to all H-Series production wells. The greatest upwelling is near production well H-4, which showed a simulated increase of approximately 1.5 feet. Upwelling near production wells H-1, H-2, and H-3 was shown to be between half and one foot. Groundwater levels should be monitored following implementation of the temporary low-head dam to confirm model results.

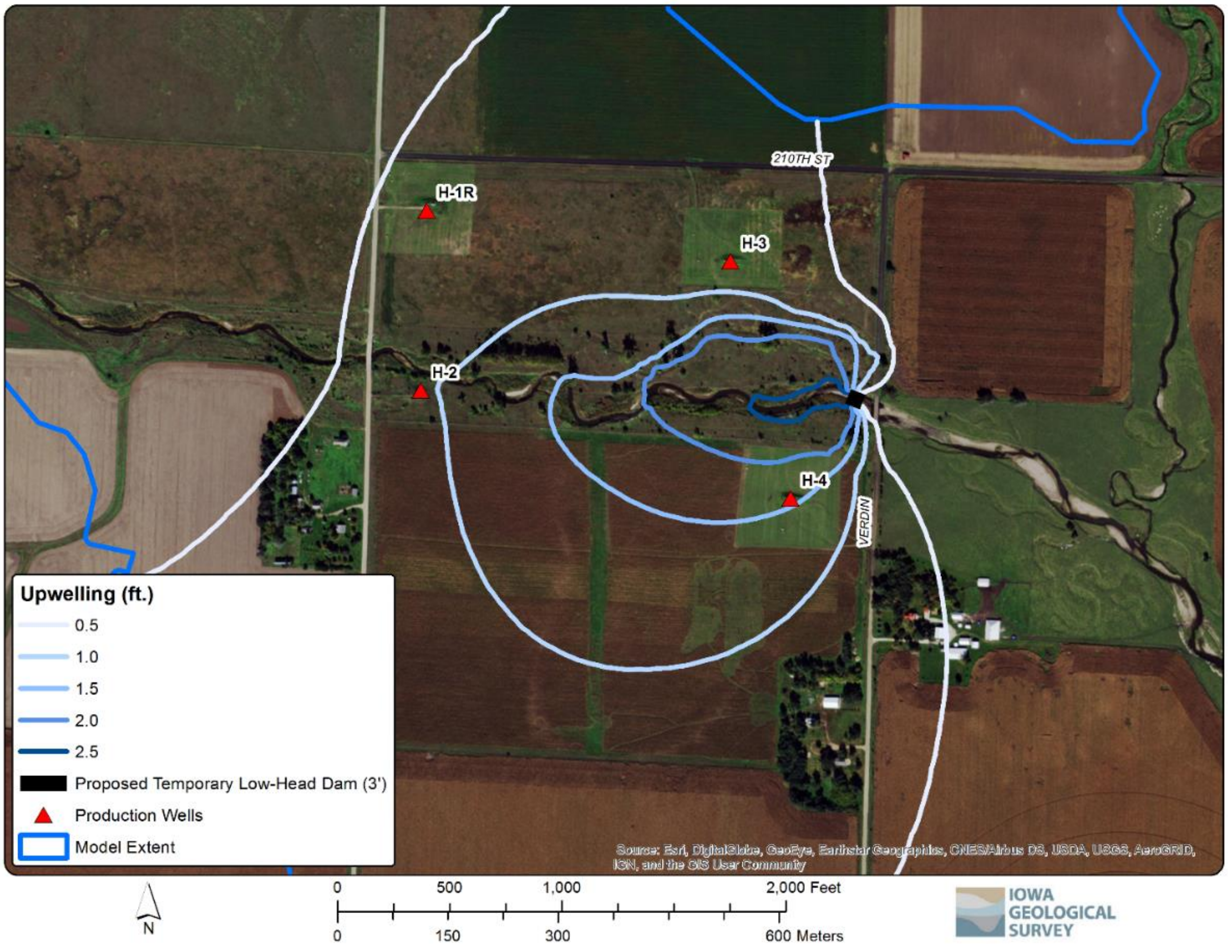

Figure 8. Simulated groundwater upwelling (rise in water table) from the proposed temporary low-head dam under drought conditions.

WATER QUALITY EVALUATION

Water samples were collected monthly from the observation wells (OB-1, OB-2, OB-3, OB-4, H1 OB Well, and H2 OB Well), the production wells (H-1, H-2, H-3, and H-4), one piezometer (PZ-3), and the Ocheyedan River downstream of the wellfield (Figure 3). Water samples were also taken at locations identified as PZ-1 and PZ-2 (Figure 6). However, high flows on the Ocheyedan River eventually displaced those piezometers. Samples were analyzed for nitrate as nitrogen and chloride. Figures 9, 10, and 11 show the nitrate as nitrogen concentrations throughout the 12 month period for the surface water and piezometers, the observation wells, and the production well samples.

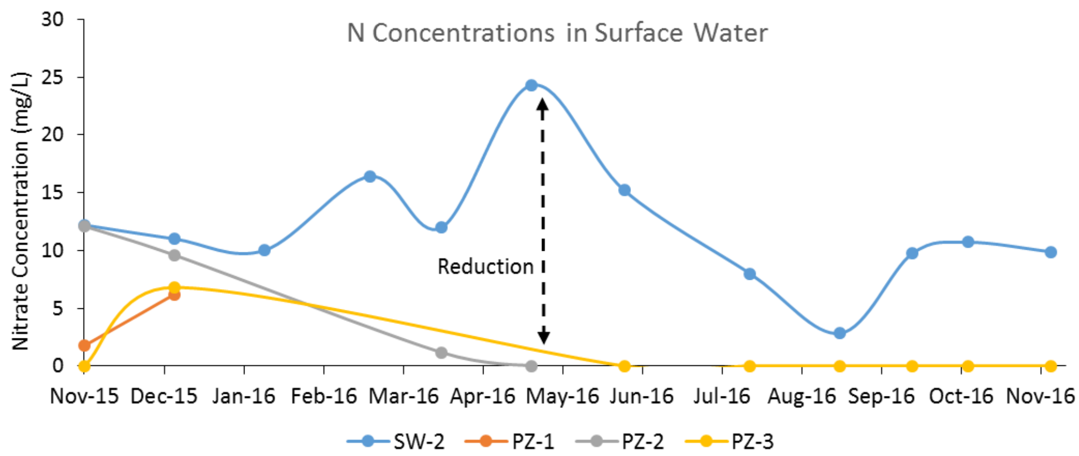

Figure 9. Monthly nitrate as nitrogen concentrations measured in the surface water and piezometer sample locations for November 2015 through November 2016.

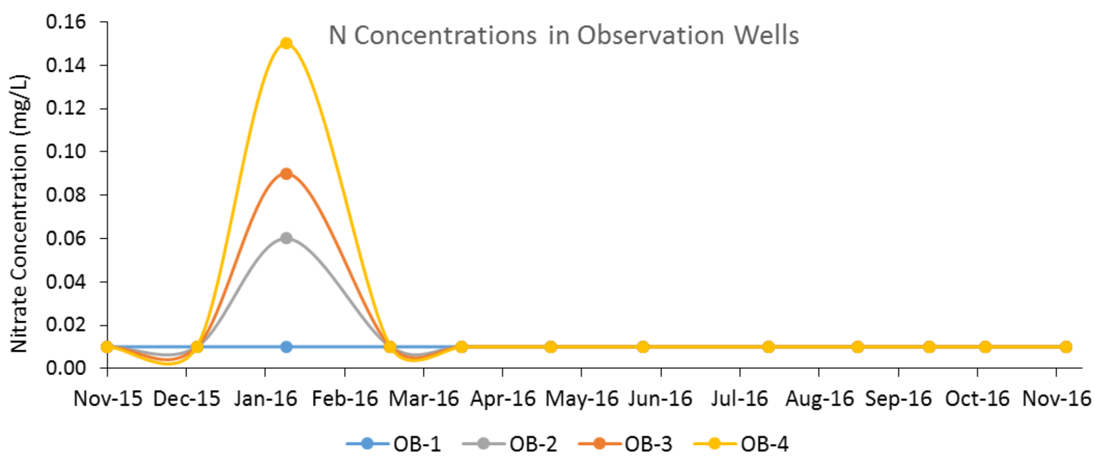

Figure 10. Monthly nitrate as nitrogen concentrations measured in the observation well sample locations for November 2015 through November 2016.

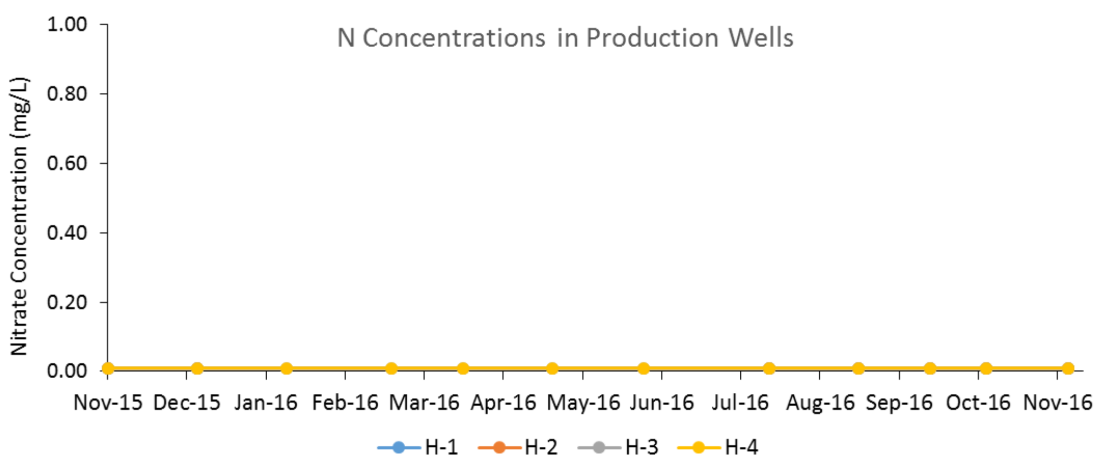

Figure 11. Monthly nitrate as nitrogen concentrations measured in the OCRWS production wells for November 2015 through November 2016.

Monthly observations show nitrate concentrations in the Ocheyedan River fluctuated between 2.8 and 24 mg/L during the sampling period (Figure 9). Sampling observations also show that nitrate concentrations are low in the piezometers, relative to the river. Early samples (November 2015 through May 2016) may be unreliable due to the high flows on the Ocheyedan River causing breakthrough of surface water along well casing and the eventual displacement of piezometers PZ-1 and PZ-2. However, data from PZ-3, which did not get displaced, show major nitrate reductions within the hyporheic zone, a region immediately below the river bottom that facilitates groundwater and surface water interaction. Fine-grained sediments and organic material may be reducing nitrate concentration in this zone. Reduction in the hyporheic zone is likely one of two major mechanisms of reducing nitrate in the aquifer. Precipitation that infiltrates into the aquifer from the prairie surrounding the wellfield is likely a source of low-nitrate groundwater recharge. The prairie does not require nitrate applications and likely filters nitrate runoff from neighboring row-crop fields.

The monthly nitrate as nitrogen concentrations in the Ocheyedan River and observation well OB-3 is shown in Figure 12. Nitrate concentrations observed at OB-3, which is located between the Ocheyedan River and production well H-4 (Figure 3), were under detection limits (<1 or <0.05 mg/L) except for in January 2016 (0.09 mg/L). The percentage of nitrate reduction per month from the Ocheyedan River to OB-3 is shown in Table 3. The nitrate reductions observed at OB-3 likely represent a combination of groundwater induced from the Ocheyedan River (reduction by sediments) and dilution due to precipitation recharge (reduction by prairie grass). While significant nitrate reductions were observed consistently at the site, detailed mechanisms for the reductions were not analyzed as part of this study. Future work analyzing reduction mechanisms (sediment packages, biologic digestion, etc.) may be beneficial to fully understanding the changes in surface water to groundwater nitrate concentrations.

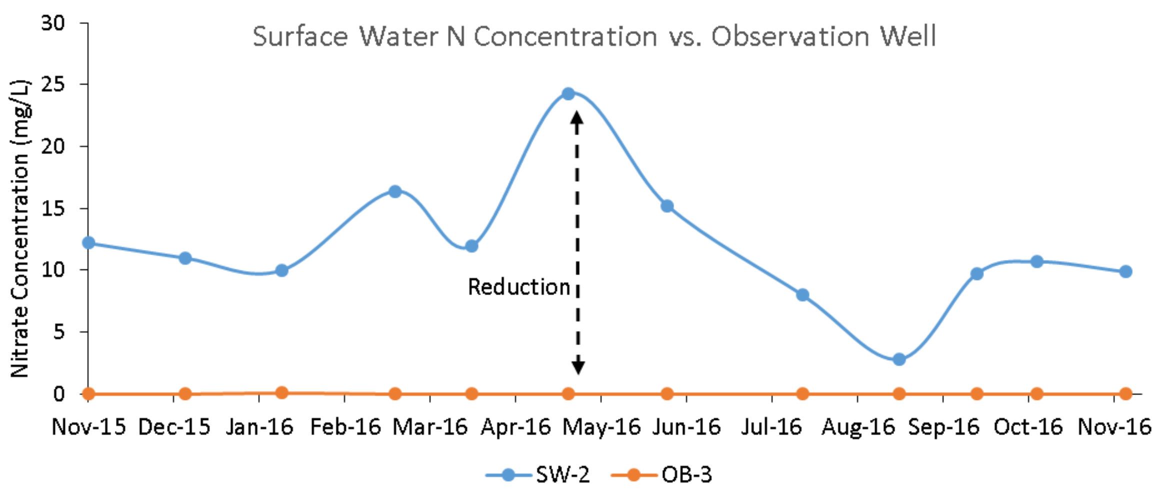

Figure 12. Monthly nitrate as nitrogen concentrations measured in the Ocheyedan River and in the shallow groundwater adjacent to the river (OB-3).

Table 3. Percentage of nitrate reduction as water flows from the Ocheyedan River into the shallow groundwater adjacent to the river (OB-3).

Sampling Date	Nov. 2015	Dec. 2015	Jan. 2016	Feb. 2016	Mar. 2016	Apr. 2016	May 2016	Jul. 2016	Aug. 2016	Sep. 2016	Oct. 2016	Nov. 2016
Nitrate as N in River (ppm)	12.2	11	10	16.4	12	24.3	15.2	7.99	2.83	9.72	10.7	9.89
Nitrate as N in OB3 (ppm)	<1	<1	0.09	<1	<1	<1	<1	<1	<1	<1	<1	<1
Percent Reduction	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Figures 10 and 11 show that the nitrate as nitrogen concentrations in the observation wells and the OCRWS production wells remained consistently low during the sampling period. Nitrate concentrations in the observation wells were below detection limits (<1 or <0.05 mg/L) except for the January 2016 sampling interval, where they ranged from below detection to 0.15 mg/L. While nitrate values were detected in three of the observation wells during January 2016, the concentrations were still very low. Nitrate concentrations for the OCRWS production wells were all below detection limits (<1 or <0.05 mg/L) during the sampling period.

Chloride sampling results are shown in Appendix C. Due to nitrate concentrations being low or below detection limits, chloride concentrations were not useful in our water quality analysis.

CONCLUSIONS

The Iowa Geological Survey completed a hydrogeologic investigation of the alluvial aquifer near the OCRWS H-Series wellfield which is located in Osceola County, Iowa. The initial purpose of the investigation was to evaluate drought resiliency benefits of a temporary low-head dam. Results from the evaluation of the temporary low-head dam would then be used to determine if a permanent structure should be created at the site. However, although still planned for construction, the dam has not been installed due to consistently high flows on the Ocheyedan River during the study period. Results from this investigation provide a background dataset which can be used as a baseline after the dam is implemented.

Major nitrate reductions were observed within the hyporheic zone, a region immediately below the river bottom that facilitates groundwater and surface water interaction. Fine-grained sediments and organic material may be reducing nitrate concentration in this zone. Reduction in the hyporheic zone is likely one of two major mechanisms of reducing nitrate in the aquifer. Precipitation that infiltrates into the aquifer from the prairie surrounding the wellfield is likely an additional source of low-nitrate groundwater recharge.

Additionally, a groundwater model was refined and is ready to accept data following implementation of the dam. The groundwater model was used to simulate potential increases in water table elevations during a severe drought following implementation of a temporary low-head dam.

Recommendations

A similar study is recommended after installation of the temporary low-head dam to quantify its benefits to groundwater quantity and quality. Results from this investigation provide a background dataset which can be used as a baseline after the dam is implemented. The groundwater model for the OCRWS H-

Series wellfield was refined and is ready to accept data following implementation of the dam.

While significant nitrate reductions were observed consistently at the site, specific mechanisms for the reductions were not analyzed as part of this study. Future work analyzing detailed reduction mechanisms (sediment packages, biologic digestion, etc.) may be beneficial to fully understand the changes in surface water to groundwater nitrate concentrations. If a decision is made to move forward with a permanent drought resiliency strategy following the monitoring of the temporary low-head dam, consideration should be given to all available strategy options. For example, a rock riffle structure(s) or an excavated/reconnected cutoff channel system could provide similar benefits to water quantity and quality as a low-head dam. The permanent strategy should assess environmental (biologic, ecosystem) impacts as well as water quantity and quality benefits.

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Appendix A – Drilling Records for New Observation Wells

MONITORING WELL / PIEZOMETER CONSTRUCTION DOCUMENTATION FORM	
Disposal Site Name OCRWD	Permit No.
Well or Piezometer No. #1	
Dates Started Nov. 2, 2015	Date Completed 2015. Nov. 2

A. SURVEYED LOCATIONS AND ELEVATIONS	B. SOIL BORING INFORMATION
Locations (± 0.5 ft.):	Name & address of construction company
Specify corner of site	Rewerts Well Co Inc.
Distance & direction along boundary	742 W. 18th St
Distance & direction from boundary to well	Nevada, IA 50201
Elevations (± 0.01 ft. MSL):	Name of driller Justin Rewerts
Ground Surface	Drilling method HSA
Top of protective casing	Drilling fluid —
Top of well casing	Bore Hole diameter 7½"
Benchmark elevation	Soil sampling method None
Benchmark description	Depth of boring 30'

C. MONITORING WELL INSTALLATION	
Casing material PVC	Placement method Pour in
Length of casing 22.5	Volume 200 lbs
Outside casing diameter 2"	Backfill (if different from seal):
Inside casing diameter	Material
Casing joint type Flush	Placement method
Casing/screen joint type Flush Thread	Volume
Screen material Pvc	Surface seal design:
Screen opening size .010	Material of protective casing:
Screen length 10'	Material of grout between protective casing and well casing:
Depth of Well 30'	Protective cap:
Filter Pack: Uniman 4030	Material 4x4 Steel
Material Silica	Vented?: ☐ Y ☐ N Locking?: ☒ Y ☐ N
Grain Size 4030	Well cap:
Volume	Material
Seal (minimum 3 ft. length above filter pack): Bentonite	Vented?: ☐ Y ☐ N
Material	

D. GROUNDWATER MEASUREMENT (± 0.01 foot below top of inner well casing)	
Water level	Stabilization time
Well development method	
Average depth of frostline	

Attachments: Driller's log. Pipe schedules and grouting schedules. 8 ½ inch x 11 inch map showing locations of all monitoring wells and piezometers.

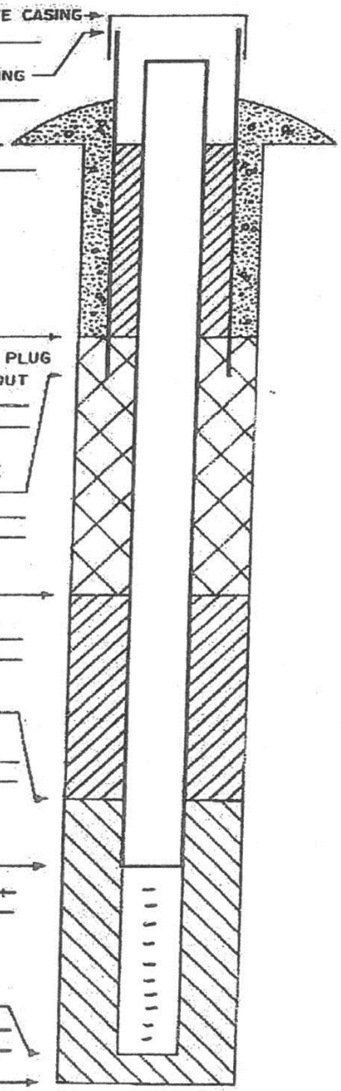
Please mail completed form to: Iowa Department of Natural Resources, Land Quality Bureau, 502 E. 9th St, Des Moines, IA 50319.
Questions? Call or Email: Nina Koger Environmental Engineer Sr., 515-725-8309, nina.koger@dnr.iowa.gov

06/2011 cmz DNR Form 542-1277

ELEVATIONS: ± 0.01 FT. MSL
DEPTHS: ± 0.1 FT. FROM GROUND SERFACE

SPACE TO ATTACH ENTIRE SOIL BORING LOG
(SHOW SCREENED INTERVAL AND FILTER PACK INTERVAL).

OCRWD OB Well #1



TOP OF PROTECTIVE CASING
ELEVATION ________

TOP OF WELL CASING
ELEVATION ________

GROUND SURFACE
ELEVATION ________

TOP OF BACKFILL
BASE OF CONCRETE PLUG
AND BENTONITE GROUT
ELEVATION ________
DEPTH 24"

BASE OF PROTECTIVE
CASING
ELEVATION ________
DEPTH 30"

BASE OF BACKFILL
TOP OF SEAL
ELEVATION ________
DEPTH 13'

TOP OF FILTER PACK
BASE OF SEAL
ELEVATION ________
DEPTH 13'

TOP OF SCREEN
ELEVATION ________
DEPTH 15'

BOTTOM OF SCREEN
ELEVATION ________
DEPTH 25'

BASE OF FILTER PACK
ELEVATION ________
DEPTH 25½'

0 - 2' Topsoil
2 - 6' Sandy Yellow Clay
7 - 25' med. Sand.
25 - 26' Clay

Please mail completed form to: Iowa Department of Natural Resources, Land Quality Bureau, 502 E. 9th St, Des Moines, IA 50319.
Questions? Call or Email: Nina Koger Environmental Engineer Sr., 515-725-8309, nina.koger@dnr.iowa.gov

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MONITORING WELL / PIEZOMETER CONSTRUCTION DOCUMENTATION FORM

Disposal Site Name OCRWD	**Permit No.**
Well or Piezometer No. #2	
Dates Started Nov. 2, 2015	**Date Completed** Nov. 2, 2015

A. SURVEYED LOCATIONS AND ELEVATIONS	B. SOIL BORING INFORMATION
Locations (± 0.5 ft.):	**Name & address of construction company**
Specify corner of site	Rewerts Well Co
Distance & direction along boundary	742 W. 18th St.
Distance & direction from boundary to well	Nevada, IA
Elevations (± 0.01 ft. MSL):	**Name of driller** Justin Rewerts
Ground Surface	**Drilling method** HSA
Top of protective casing	**Drilling fluid**
Top of well casing	**Bore Hole diameter** 7 ½"
Benchmark elevation	**Soil sampling method** —
Benchmark description	**Depth of boring** 25'

C. MONITORING WELL INSTALLATION	
Casing material PVC	**Placement method** Pour
Length of casing 17½'	**Volume** 200 lbs.
Outside casing diameter 2"	**Backfill (if different from seal):**
Inside casing diameter —	**Material**
Casing joint type Flush Thread	**Placement method**
Casing/screen joint type " "	**Volume**
Screen material PVC	**Surface seal design:**
Screen opening size .010	**Material of protective casing:**
Screen length 10'	**Material of grout between protective casing and well casing:**
Depth of Well 25'	**Protective cap:** 4x4
Filter Pack:	**Material** Steel
Material Silica	**Vented?:** ☐ Y ☒ N **Locking?:** ☒ Y ☐ N
Grain Size 4030	**Well cap:**
Volume	**Material**
Seal (minimum 3 ft. length above filter pack): 15'	**Vented?:** ☐ Y ☐ N
Material Bentonite	

D. GROUNDWATER MEASUREMENT (± 0.01 foot below top of inner well casing)	
Water level	**Stabilization time**
Well development method	
Average depth of frostline	

Attachments: Driller's log. Pipe schedules and grouting schedules. 8 ½ inch x 11 inch map showing locations of all monitoring wells and piezometers.

Please mail completed form to: Iowa Department of Natural Resources, Land Quality Bureau, 502 E. 9th St, Des Moines, IA 50319.
Questions? Call or Email: Nina Koger Environmental Engineer Sr., 515-725-8309, nina.koger@dnr.iowa.gov

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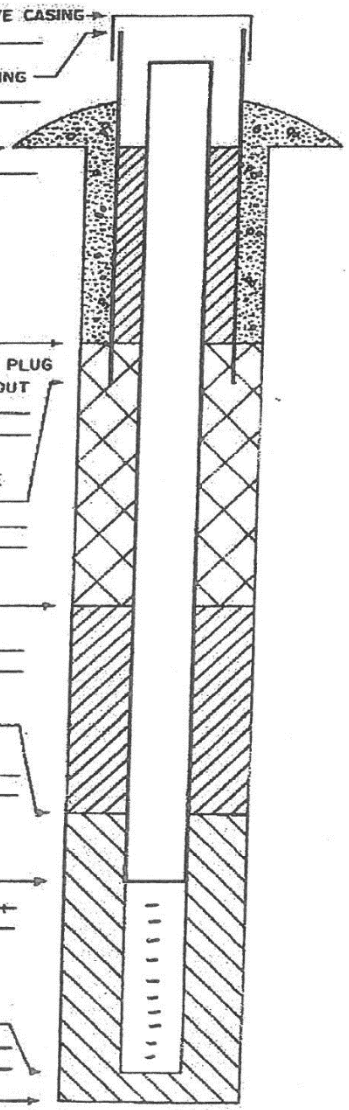
ELEVATIONS: ± 0.01 FT. MSL
DEPTHS: ± 0.1 FT. FROM GROUND SERFACE

SPACE TO ATTACH ENTIRE SOIL BORING LOG
(SHOW SCREENED INTERVAL AND FILTER PACK INTERVAL).

OCRWD OB Well #2



TOP OF PROTECTIVE CASING
ELEVATION ________

TOP OF WELL CASING
ELEVATION ________

GROUND SURFACE
ELEVATION ________

TOP OF BACKFILL
BASE OF CONCRETE PLUG AND BENTONITE GROUT
ELEVATION ________
DEPTH 24"

BASE OF PROTECTIVE CASING
ELEVATION ________
DEPTH 30"

BASE OF BACKFILL
TOP OF SEAL
ELEVATION ________
DEPTH 13'

TOP OF FILTER PACK
BASE OF SEAL
ELEVATION ________
DEPTH 13'

TOP OF SCREEN
ELEVATION ________
DEPTH ~~13~~ 15'

BOTTOM OF SCREEN
ELEVATION ________
DEPTH 25'

BASE OF FILTER PACK
ELEVATION ________
DEPTH 25½'

0-2' Topsoil
2-7' Sandy Clay. Yellow
7-25' med. Sand.
25-26' Clay

Please mail completed form to: Iowa Department of Natural Resources, Land Quality Bureau, 502 E. 9th St, Des Moines, IA 50319.
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DNR Form 542-1277

MONITORING WELL / PIEZOMETER CONSTRUCTION DOCUMENTATION FORM

Disposal Site Name OCRWD	**Permit No.**
Well or Piezometer No. #3	
Dates Started Nov. 2, 2015	**Date Completed** Nov. 2, 2015

A. SURVEYED LOCATIONS AND ELEVATIONS	B. SOIL BORING INFORMATION
Locations (± 0.5 ft.):	**Name & address of construction company**
Specify corner of site	Rewerts Well Co
Distance & direction along boundary	742 W. 18th St.
Distance & direction from boundary to well	Nevada, IA
Elevations (± 0.01 ft. MSL):	**Name of driller** Justin Rewerts
Ground Surface	**Drilling method** HSA
Top of protective casing	**Drilling fluid**
Top of well casing	**Bore Hole diameter** 7 ½"
Benchmark elevation	**Soil sampling method** —
Benchmark description	**Depth of boring** 25'

C. MONITORING WELL INSTALLATION	
Casing material PVC	**Placement method** Pour
Length of casing 17½'	**Volume** 200 lbs.
Outside casing diameter 2"	**Backfill (if different from seal):**
Inside casing diameter –	**Material**
Casing joint type Flush Thread	**Placement method**
Casing/screen joint type " "	**Volume**
Screen material PVC	**Surface seal design:**
Screen opening size .010	**Material of protective casing:**
Screen length 10'	**Material of grout between protective casing and well casing:**
Depth of Well 25'	**Protective cap:** 4×4
Filter Pack:	**Material** Steel
Material Silica	**Vented?:** ☐ Y ☒ N **Locking?:** ☒ Y ☐ N
Grain Size 4030	**Well cap:**
Volume	**Material**
Seal (minimum 3 ft. length above filter pack): 15'	**Vented?:** ☐ Y ☐ N
Material Bentonite	

D. GROUNDWATER MEASUREMENT (± 0.01 foot below top of inner well casing)	
Water level	**Stabilization time**
Well development method	
Average depth of frostline	

Attachments: Driller's log. Pipe schedules and grouting schedules. 8 ½ inch x 11 inch map showing locations of all monitoring wells and piezometers.

Please mail completed form to: Iowa Department of Natural Resources, Land Quality Bureau, 502 E. 9th St, Des Moines, IA 50319.
Questions? Call or Email: Nina Koger Environmental Engineer Sr., 515-725-8309, nina.koger@dnr.iowa.gov

06/2011 cmz DNR Form 542-1277

ELEVATIONS: ± 0.01 FT. MSL
DEPTHS: ± 0.1 FT. FROM GROUND SERFACE

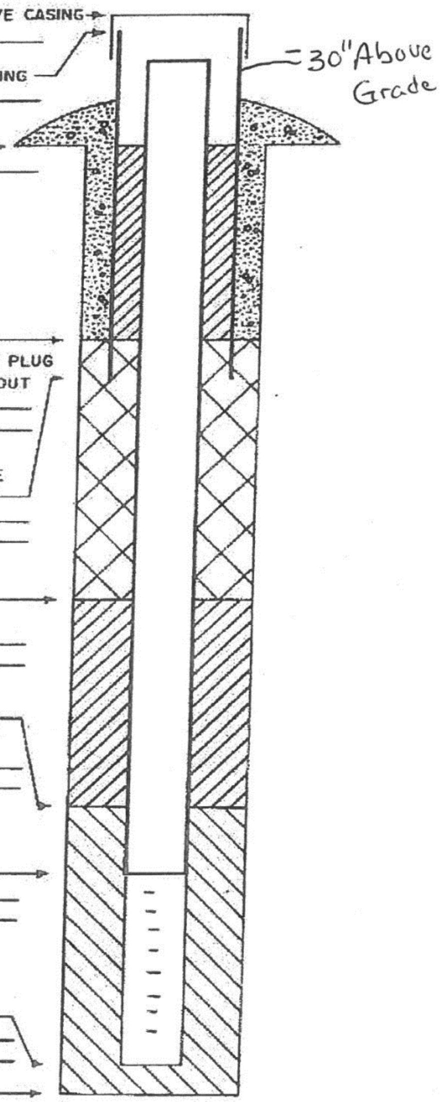
SPACE TO ATTACH ENTIRE SOIL BORING LOG
(SHOW SCREENED INTERVAL AND FILTER PACK INTERVAL).

#1 OCRWD OB Well #3

TOP OF PROTECTIVE CASING
ELEVATION ____

TOP OF WELL CASING
ELEVATION ____

GROUND SURFACE
ELEVATION ____



0 - 2' Topsoil
2 - 7 Sandy Clay - Yellow
7 - 27' med Sand
27' - 31' Clay

TOP OF BACKFILL
BASE OF CONCRETE PLUG
AND BENTONITE GROUT
ELEVATION ____
DEPTH 24"

BASE OF PROTECTIVE
CASING
ELEVATION ____
DEPTH 30"

BASE OF BACKFILL
TOP OF SEAL
ELEVATION ____
DEPTH 18'

TOP OF FILTER PACK
BASE OF SEAL
ELEVATION ____
DEPTH 18'

TOP OF SCREEN
ELEVATION ____
DEPTH 20'

BOTTOM OF SCREEN
ELEVATION ____
DEPTH 30'

BASE OF FILTER PACK
ELEVATION ____
DEPTH 30.5'

Please mail completed form to: Iowa Department of Natural Resources, Land Quality Bureau, 502 E. 9th St, Des Moines, IA 50319.
Questions? Call or Email: Nina Koger Environmental Engineer Sr., 515-725-8309, nina.koger@dnr.iowa.gov

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DNR Form 542-1277

MONITORING WELL / PIEZOMETER CONSTRUCTION DOCUMENTATION FORM

Disposal Site Name OCRWD	**Permit No.**
Well or Piezometer No. #4	
Dates Started Nov. 2, 2015	**Date Completed** Nov. 2, 2015

A. SURVEYED LOCATIONS AND ELEVATIONS	B. SOIL BORING INFORMATION
Locations (± 0.5 ft.):	**Name & address of construction company**
Specify corner of site	Rewerts Well Co
Distance & direction along boundary	742 W. 18th St.
Distance & direction from boundary to well	Nevada, IA
Elevations (± 0.01 ft. MSL):	**Name of driller** Justin Rewerts
Ground Surface	**Drilling method** HSA
Top of protective casing	**Drilling fluid**
Top of well casing	**Bore Hole diameter** 7 1/4"
Benchmark elevation	**Soil sampling method** —
Benchmark description	**Depth of boring** 25'

C. MONITORING WELL INSTALLATION	
Casing material PVC	**Placement method** Pour
Length of casing 17 1/2'	**Volume** 200 lbs.
Outside casing diameter 2"	**Backfill (if different from seal):**
Inside casing diameter –	**Material**
Casing joint type Flush Thread	**Placement method**
Casing/screen joint type " "	**Volume**
Screen material PVC	**Surface seal design:**
Screen opening size .010	**Material of protective casing:**
Screen length 10'	**Material of grout between protective casing and well casing:**
Depth of Well 25'	**Protective cap:** 4×4
Filter Pack:	**Material** Steel
Material Silica	**Vented?:** ☐ Y ☒ N **Locking?:** ☒ Y ☐ N
Grain Size 4030	**Well cap:**
Volume	**Material**
Seal (minimum 3 ft. length above filter pack): 15'	**Vented?:** ☐ Y ☐ N
Material Bentonite	

D. GROUNDWATER MEASUREMENT (± 0.01 foot below top of inner well casing)	
Water level	**Stabilization time**
Well development method	
Average depth of frostline	

Attachments: Driller's log. Pipe schedules and grouting schedules. 8 ½ inch x 11 inch map showing locations of all monitoring wells and piezometers.

Please mail completed form to: Iowa Department of Natural Resources, Land Quality Bureau, 502 E. 9th St, Des Moines, IA 50319.
Questions? Call or Email: Nina Koger Environmental Engineer Sr., 515-725-8309, nina.koger@dnr.iowa.gov

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ELEVATIONS: ± 0.01 FT. MSL
DEPTHS: ± 0.1 FT. FROM GROUND SERFACE

SPACE TO ATTACH ENTIRE SOIL BORING LOG
(SHOW SCREENED INTERVAL AND FILTER PACK INTERVAL).

OCRWD OB Well #4

TOP OF PROTECTIVE CASING
ELEVATION ______

TOP OF WELL CASING
ELEVATION ______

GROUND SURFACE
ELEVATION ______

TOP OF BACKFILL
BASE OF CONCRETE PLUG AND BENTONITE GROUT
ELEVATION ______
DEPTH 24"

BASE OF PROTECTIVE CASING
ELEVATION ______
DEPTH 30"

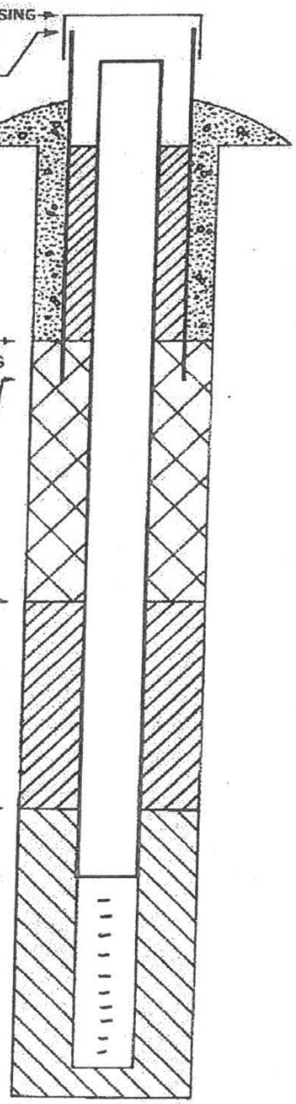
BASE OF BACKFILL
TOP OF SEAL
ELEVATION ______
DEPTH 13'

TOP OF FILTER PACK
BASE OF SEAL
ELEVATION ______
DEPTH 13'

TOP OF SCREEN
ELEVATION ______
DEPTH 15'

BOTTOM OF SCREEN
ELEVATION ______
DEPTH 25'

BASE OF FILTER PACK
ELEVATION ______
DEPTH 25½'



0-2 · Topsoil
2-7' Sandy Clay · Yellow
7-25' , Sand
25-26' Clay

Please mail completed form to: Iowa Department of Natural Resources, Land Quality Bureau, 502 E. 9th St, Des Moines, IA 50319.
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Appendix B – Monthly Water Level Measurements in On-Site Observation Wells

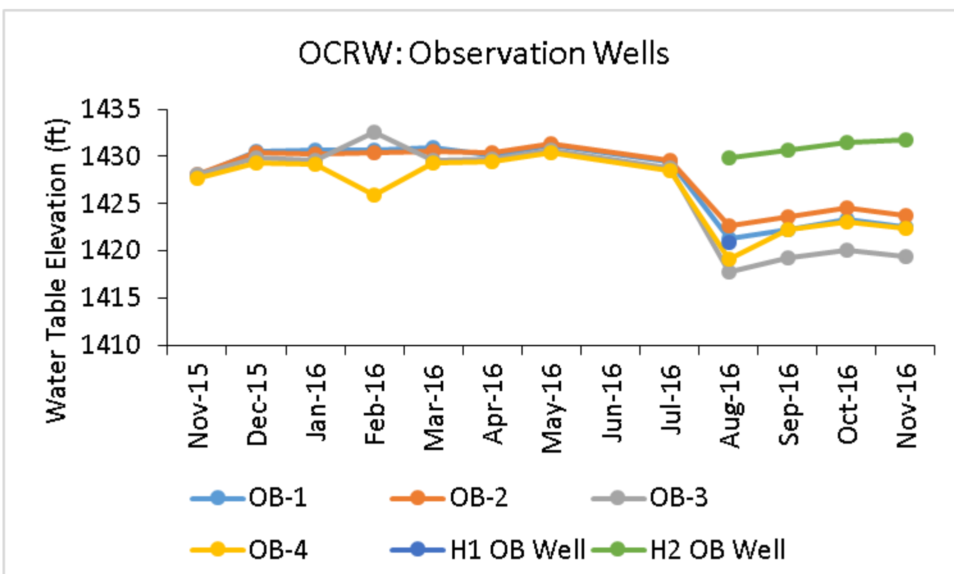
Static Water Table Levels* (ft)													
Well Name	Nov-15	Dec-15	Jan-16	Feb-16	Mar-16	Apr-16	May-16	Jun-16	Jul-16	Aug-16	Sep-16	Oct-16	Nov-16
PZ-3	3.10	1.88					0.55		2.05	3.19	2.35	0.87	2.55
OB-1	9.85	7.30	7.14	7.20	6.97	7.66	6.66		8.45	10.03	9.02	8.01	8.81
OB-2	8.74	6.45	6.52	6.40	6.32	6.40	5.44		7.27	8.67	7.69	6.81	7.57
OB-3	12.73	11.00	11.31	8.27	11.24	11.21	10.23		12.14	13.58	12.09	11.25	11.98
OB-4	9.77	8.09	8.24	11.44	8.14	8.01	7.05		8.86	12.20	9.05	8.27	8.91
SW-2 (Downstream Surface) at PZ-3	3.10	1.88					0.55		2.05	3.19	2.35	0.87	2.55
H1 OB Well										10.45			
H2 OB Well										15.20	14.45	13.58	13.34

*Depth from top of metal casing

**SW: Surface water to top of metal casing

Water Table Elevations* (ft)													
Well Name	Nov-15	Dec-15	Jan-16	Feb-16	Mar-16	Apr-16	May-16	Jun-16	Jul-16	Aug-16	Sep-16	Oct-16	Nov-16
PZ-3	1428.23	1429.45	1431.33	1431.33	1431.33	1431.33	1430.78		1429.28	1428.14	1428.98	1430.46	1428.78
OB-1	1428.00	1430.55	1430.71	1430.65	1430.88	1430.19	1431.19		1429.40	1421.30	1422.31	1423.32	1422.52
OB-2	1428.10	1430.39	1430.32	1430.44	1430.52	1430.44	1431.40		1429.57	1422.66	1423.64	1424.52	1423.76
OB-3	1428.16	1429.89	1429.58	1432.62	1429.65	1429.68	1430.66		1428.75	1417.75	1419.24	1420.08	1419.35
OB-4	1427.66	1429.34	1429.19	1425.99	1429.29	1429.42	1430.38		1428.57	1419.13	1422.28	1423.06	1422.42
SW-2 (Downstream Surface) at PZ-3	1428.23	1429.45					1430.78		1429.28	1428.14	1428.98	1430.46	1428.78
H1 OB Well										1420.88			
H2 OB Well										1429.90	1430.65	1431.52	1431.76

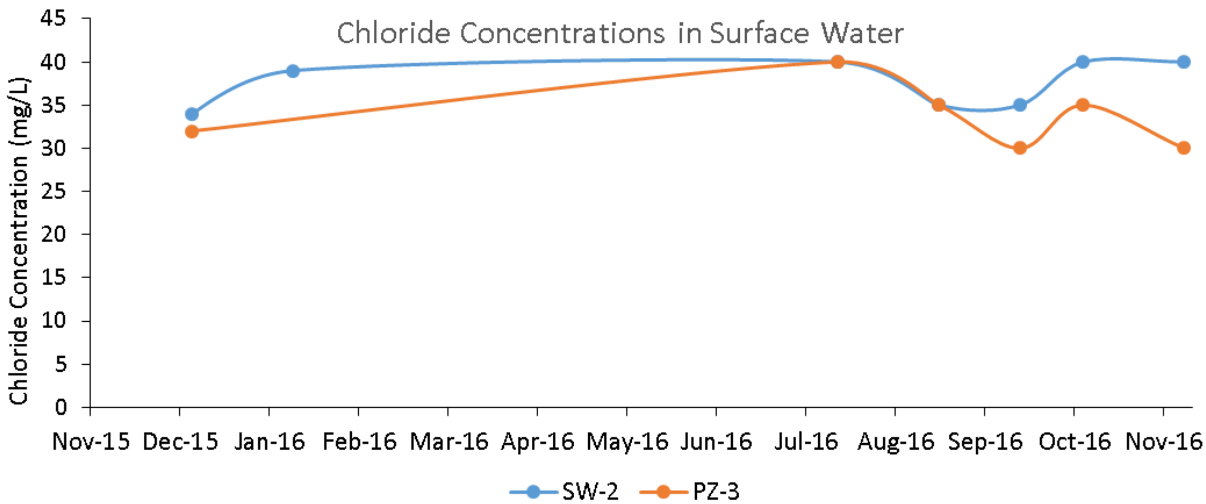
*Based on 2016 Survey



Appendix C – Chloride Sampling Results

	Chloride Concentration (mg/L)									
	Nov-15	Dec-15	Jan-16	Feb-16	Mar-16	Apr-16	Jun-16	Jul-16	Aug-16	Sep-16
H-1	NS	22	NS	NS	NS	NS	NS	30	NS	NS
H-2	NS	30	NS	NS	NS	NS	NS	40	NS	NS
H-3	NS	16	24	NS	NS	NS	NS	30	25	25
H-4	NS	25	24	NS	NS	NS	NS	35	30	25
OB-1	NS	14	17	NS	NS	NS	NS	20	20	25
OB-2	NS	15	20	NS	NS	NS	NS	35	20	30
OB-3	NS	22	25	NS	NS	NS	NS	30	25	25
OB-4	NS	18	23	NS	NS	NS	NS	25	30	30
PZ-1	NS	32	NS	NS	NS	NS	NS	NS	NS	NS
PZ-2	NS	32	NS	NS	NS	NS	NS	NS	NS	NS
PZ-3	NS	35	NS	NS	NS	NS	NS	40	35	30
SW2	NS	34	39	NS	NS	NS	NS	40	35	35

NS=No Sample, insufficient sample volume or frozen



Appendix D – Aquifer Pump Tests

IOWA GEOLOGICAL SURVEY		**Pumping Test - Water Level Data** Page 1 of 2
		Project: OCRW
		Number:
		Client:
Location: May City	Pumping Test: Well 3	Pumping Well: Well 3
Test Conducted by:	Test Date: 1/5/2016	Discharge Rate: 400 [U.S. gal/min]
Observation Well: OB 1	Static Water Level [ft]: 7.29	Radial Distance to PW [ft]: 200

	Time [min]	Water Level [ft]	Drawdown [ft]
1	0	7.289	0.00
2	15	7.90	0.611
3	30	7.967	0.678
4	45	7.988	0.699
5	60	7.999	0.71
6	75	7.993	0.704
7	90	7.993	0.704
8	105	7.995	0.706
9	120	7.992	0.703
10	135	7.995	0.706
11	150	7.998	0.709
12	165	7.997	0.708
13	180	7.993	0.704
14	195	7.997	0.708
15	210	7.994	0.705
16	225	8.00	0.711
17	240	7.996	0.707
18	255	7.996	0.707
19	270	7.996	0.707
20	285	7.998	0.709
21	300	7.998	0.709
22	315	8.00	0.711
23	330	8.006	0.717
24	345	8.00	0.711
25	360	8.002	0.713
26	375	8.006	0.717
27	390	8.004	0.715
28	405	8.005	0.716
29	420	8.006	0.717
30	435	8.012	0.723
31	450	8.016	0.727
32	465	8.013	0.724
33	480	8.012	0.723
34	495	8.009	0.72
35	510	8.01	0.721
36	525	8.011	0.722
37	540	8.008	0.719
38	555	8.011	0.722
39	570	8.01	0.721
40	585	8.01	0.721
41	600	8.015	0.726
42	615	8.011	0.722
43	630	8.014	0.725
44	645	8.013	0.724
45	660	8.011	0.722
46	675	8.015	0.726
47	690	8.013	0.724
48	705	8.012	0.723
49	720	8.014	0.725
50	735	8.013	0.724
51	750	8.013	0.724
52	765	8.013	0.724
53	780	8.015	0.726

IOWA GEOLOGICAL SURVEY

Pumping Test - Water Level Data

Project: OCRW

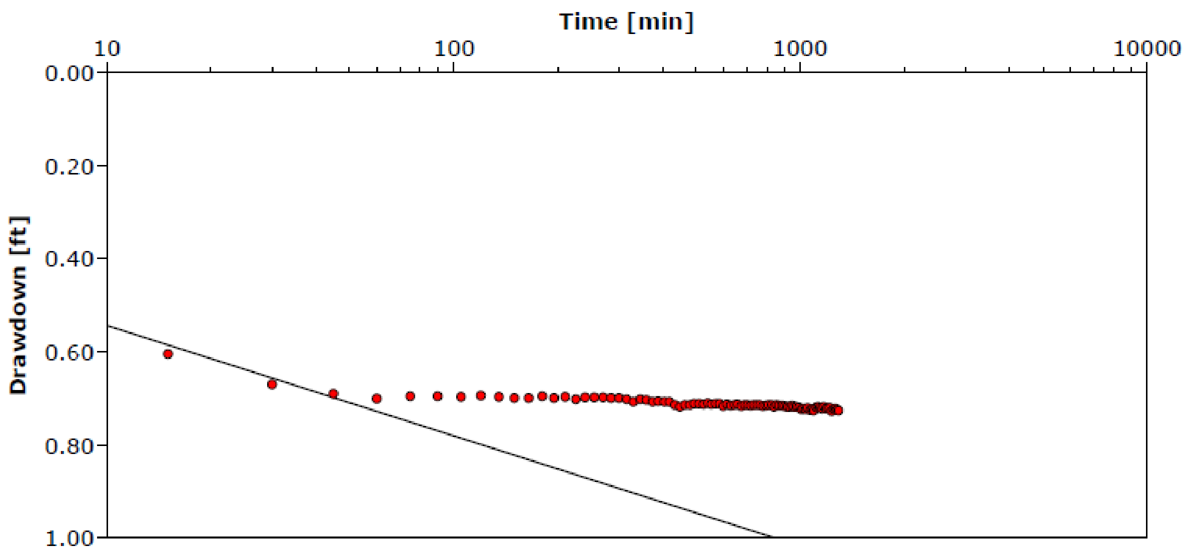
Number:

Client:

	Time [min]	Water Level [ft]	Drawdown [ft]
54	795	8.014	0.725
55	810	8.013	0.724
56	825	8.013	0.724
57	840	8.016	0.727
58	855	8.012	0.723
59	870	8.014	0.725
60	885	8.014	0.725
61	900	8.015	0.726
62	915	8.016	0.727
63	930	8.017	0.728
64	945	8.014	0.725
65	960	8.017	0.728
66	975	8.017	0.728
67	990	8.018	0.729
68	1005	8.022	0.733
69	1020	8.02	0.731
70	1035	8.022	0.733
71	1050	8.019	0.73
72	1065	8.023	0.734
73	1080	8.022	0.733
74	1095	8.025	0.736
75	1110	8.018	0.729
76	1125	8.016	0.727
77	1140	8.018	0.729
78	1155	8.02	0.731
79	1170	8.017	0.728
80	1185	8.021	0.732
81	1200	8.019	0.73
82	1215	8.019	0.73
83	1230	8.026	0.737
84	1245	8.022	0.733
85	1260	8.021	0.732
86	1275	8.023	0.734
87	1290	8.025	0.736

IOWA GEOLOGICAL SURVEY	**Pumping Test Analysis Report**
	Project: OCRW
	Number:
	Client:

Location: May City	Pumping Test: Well 3	Pumping Well: Well 3
Test Conducted by:		Test Date: 1/5/2016
Analysis Performed by:	New analysis 1	Analysis Date: 1/5/2016
Aquifer Thickness: 30.00 ft	Discharge Rate: 400 [U.S. gal/min]	



Calculation using COOPER & JACOB

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Storage coefficient	Radial Distance to PW [ft]	
OB 1	5.94×10^{4}	1.98×10^{3}	1.18×10^{-4}	200.0	

IOWA GEOLOGICAL SURVEY	**Pumping Test - Water Level Data**	Page 1 of 2
	Project: OCRW	
	Number:	
	Client:	

Location: May City	Pumping Test: Well 3	Pumping Well: Well 4
Test Conducted by:	Test Date: 1/5/2016	Discharge Rate: 400 [U.S. gal/min]
Observation Well: OB 3	Static Water Level [ft]: 10.93	Radial Distance to PW [ft]: 200

	Time [min]	Water Level [ft]	Drawdown [ft]
1	0	10.928	0.00
2	15	11.168	0.24
3	30	11.189	0.261
4	45	11.187	0.259
5	60	11.221	0.293
6	75	11.239	0.311
7	90	11.25	0.322
8	105	11.267	0.339
9	120	11.271	0.343
10	135	11.283	0.355
11	150	11.288	0.36
12	165	11.292	0.364
13	180	11.303	0.375
14	195	11.307	0.379
15	210	11.314	0.386
16	225	11.319	0.391
17	240	11.324	0.396
18	255	11.332	0.404
19	270	11.342	0.414
20	285	11.349	0.421
21	300	11.35	0.422
22	315	11.351	0.423
23	330	11.363	0.435
24	345	11.359	0.431
25	360	11.368	0.44
26	375	11.37	0.442
27	390	11.377	0.449
28	405	11.38	0.452
29	420	11.383	0.455
30	435	11.39	0.462
31	450	11.391	0.463
32	465	11.398	0.47
33	480	11.397	0.469
34	495	11.402	0.474
35	510	11.404	0.476
36	525	11.407	0.479
37	540	11.414	0.486
38	555	11.413	0.485
39	570	11.419	0.491
40	585	11.42	0.492
41	600	11.422	0.494
42	615	11.429	0.501
43	630	11.427	0.499
44	645	11.432	0.504
45	660	11.435	0.507
46	675	11.437	0.509
47	690	11.436	0.508
48	705	11.437	0.509
49	720	11.445	0.517
50	735	11.442	0.514
51	750	11.447	0.519
52	765	11.446	0.518
53	780	11.448	0.52

IOWA GEOLOGICAL SURVEY

Pumping Test - Water Level Data

Project: OCRW

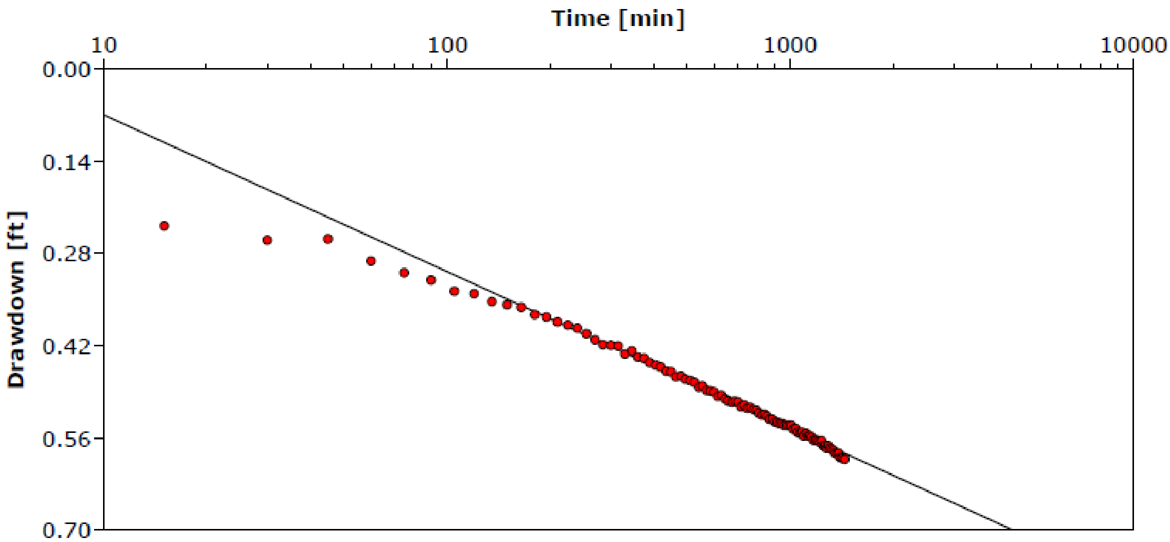
Number:

Client:

	Time [min]	Water Level [ft]	Drawdown [ft]
54	795	11.449	0.521
55	810	11.454	0.526
56	825	11.457	0.529
57	840	11.456	0.528
58	855	11.459	0.531
59	870	11.464	0.536
60	885	11.464	0.536
61	900	11.467	0.539
62	915	11.468	0.54
63	930	11.47	0.542
64	945	11.47	0.542
65	960	11.473	0.545
66	975	11.473	0.545
67	990	11.473	0.545
68	1005	11.473	0.545
69	1020	11.479	0.551
70	1035	11.478	0.55
71	1050	11.483	0.555
72	1065	11.485	0.557
73	1080	11.483	0.555
74	1095	11.489	0.561
75	1110	11.485	0.557
76	1125	11.489	0.561
77	1140	11.489	0.561
78	1155	11.491	0.563
79	1170	11.496	0.568
80	1185	11.496	0.568
81	1200	11.497	0.569
82	1215	11.499	0.571
83	1230	11.497	0.569
84	1245	11.504	0.576
85	1260	11.504	0.576
86	1275	11.508	0.58
87	1290	11.504	0.576
88	1305	11.508	0.58
89	1320	11.51	0.582
90	1335	11.512	0.584
91	1350	11.516	0.588
92	1365	11.517	0.589
93	1380	11.516	0.588
94	1395	11.522	0.594
95	1410	11.523	0.595
96	1425	11.523	0.595
97	1440	11.525	0.597

IOWA GEOLOGICAL SURVEY	Pumping Test Analysis Report
	Project: OCRW
	Number:
	Client:

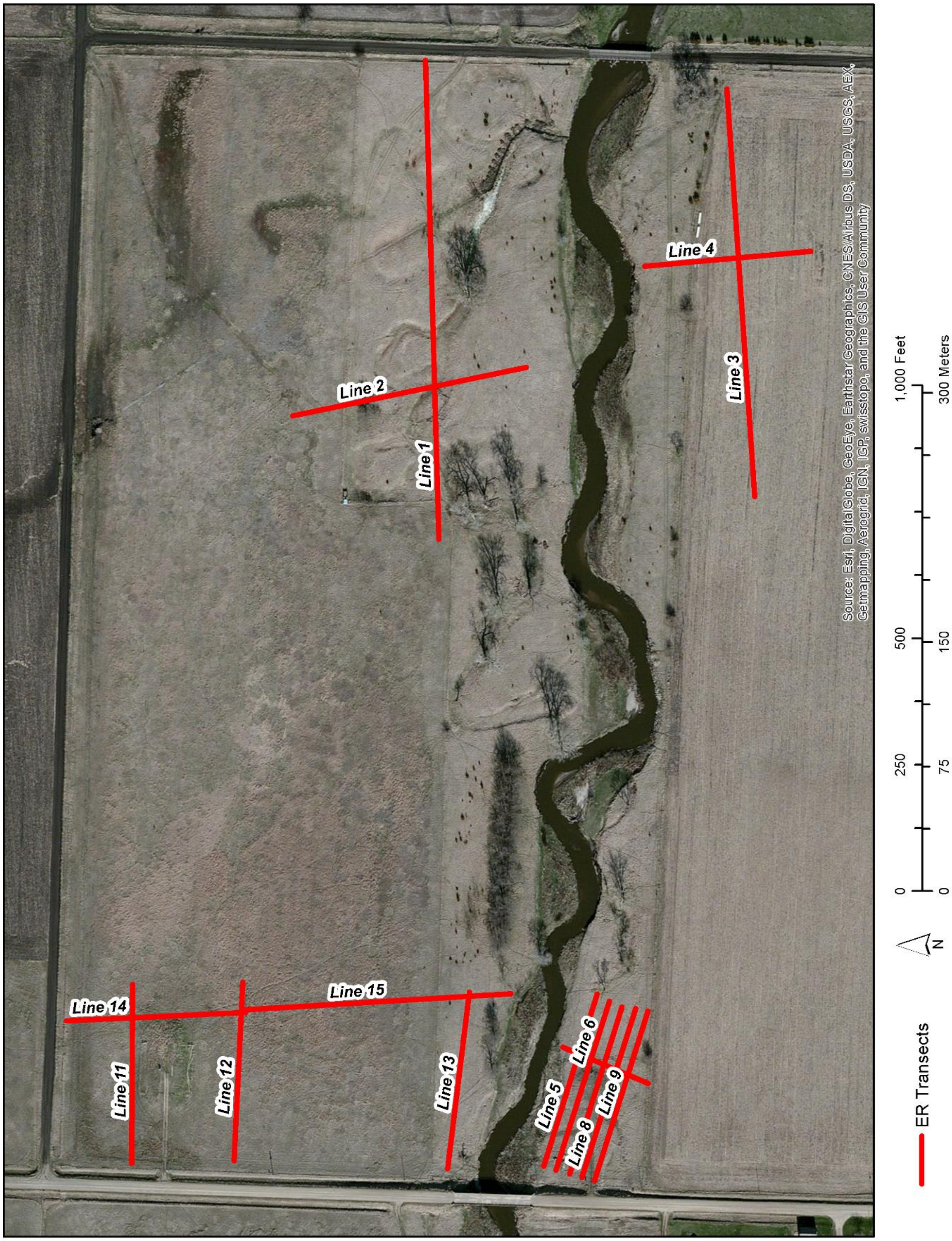
Location: May City	Pumping Test: Well 3	Pumping Well: Well 4
Test Conducted by:		Test Date: 1/5/2016
Analysis Performed by:	New analysis 1	Analysis Date: 1/5/2016
Aquifer Thickness: 40.00 ft	Discharge Rate: 400 [U.S. gal/min]	

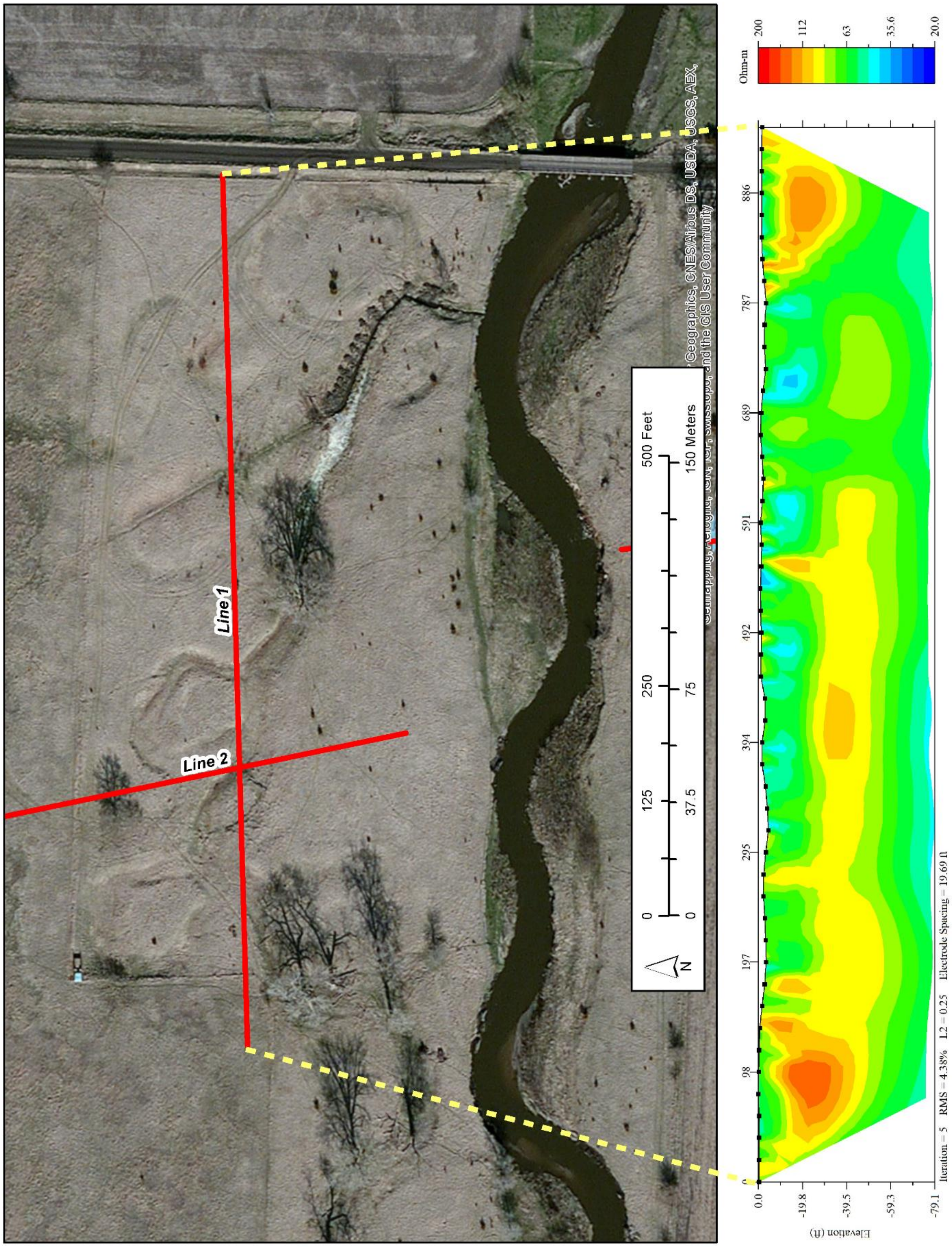


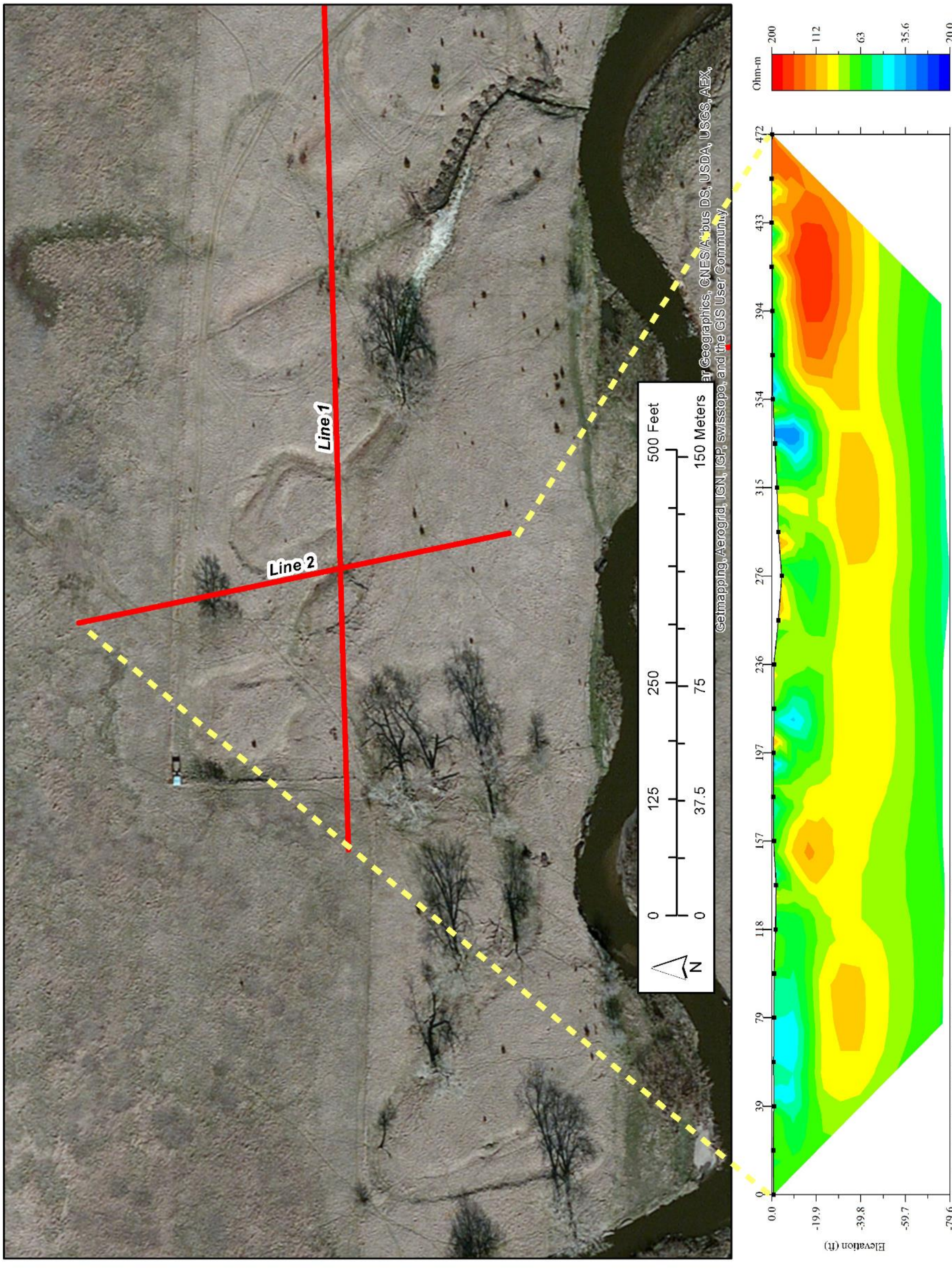
Calculation using COOPER & JACOB

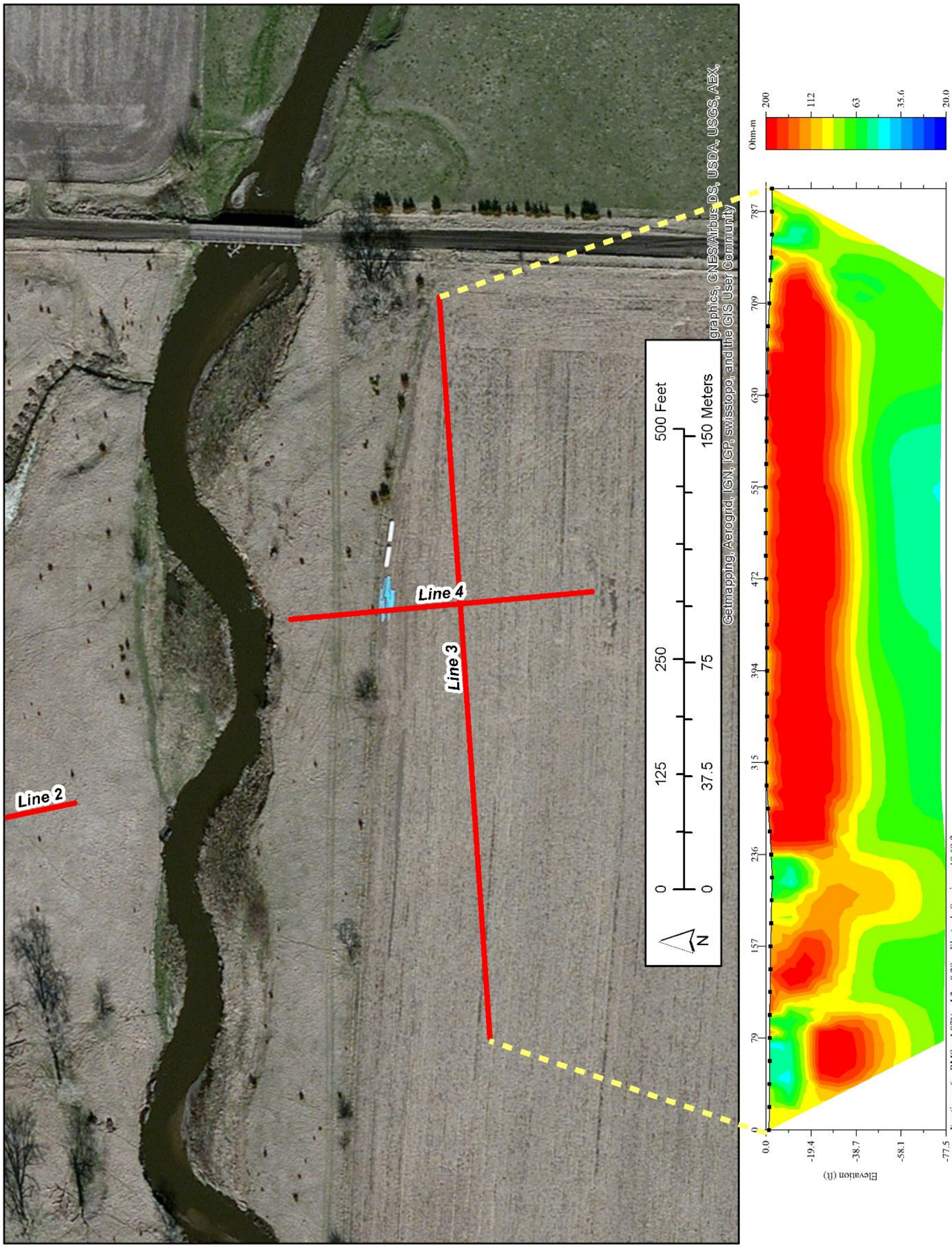
Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Storage coefficient	Radial Distance to PW [ft]	
OB 3	5.92×10^4	1.48×10^3	1.17×10^{-2}	200.0	

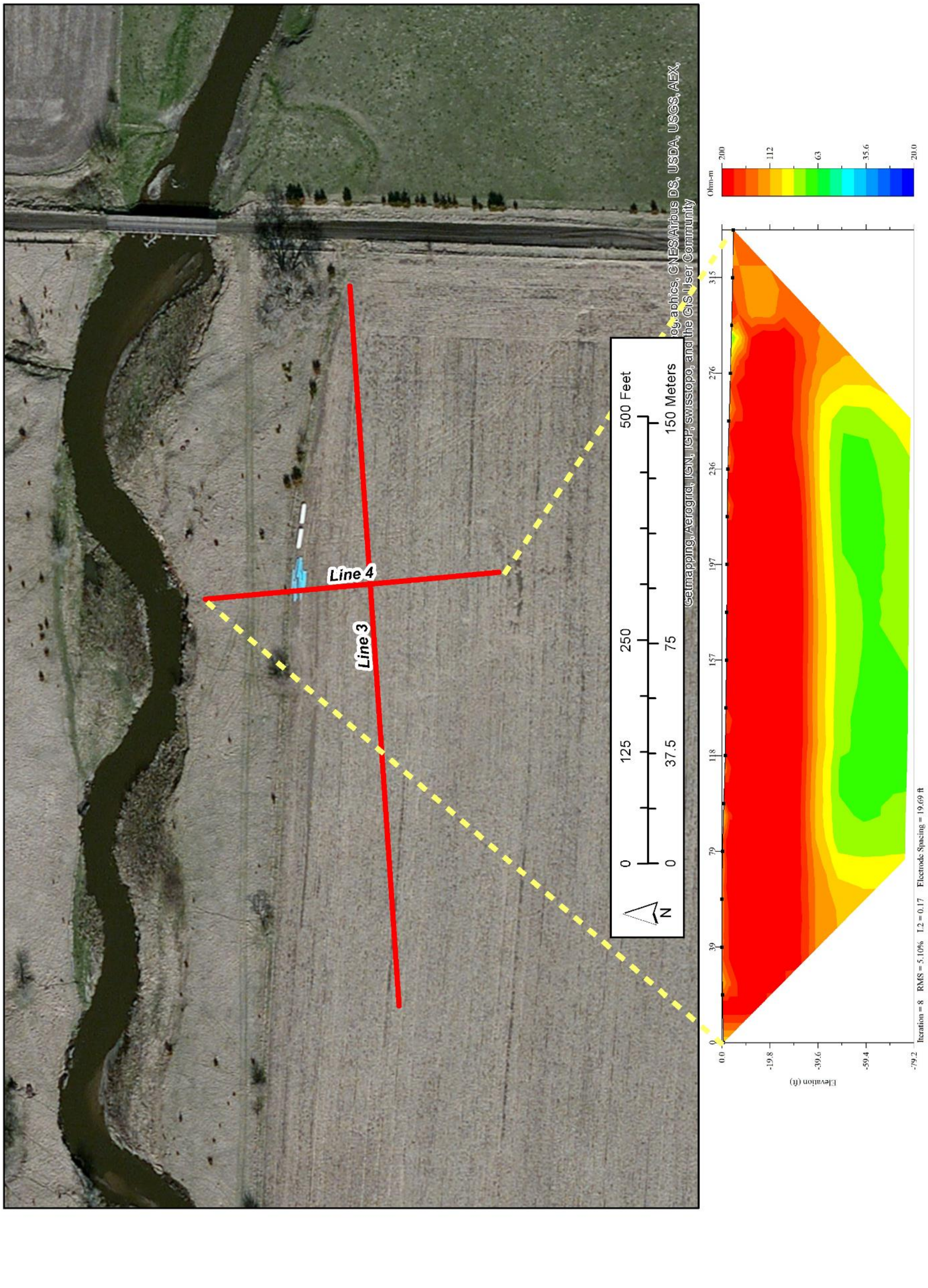
Appendix E – Electrical Resistivity Geophysical Survey Results



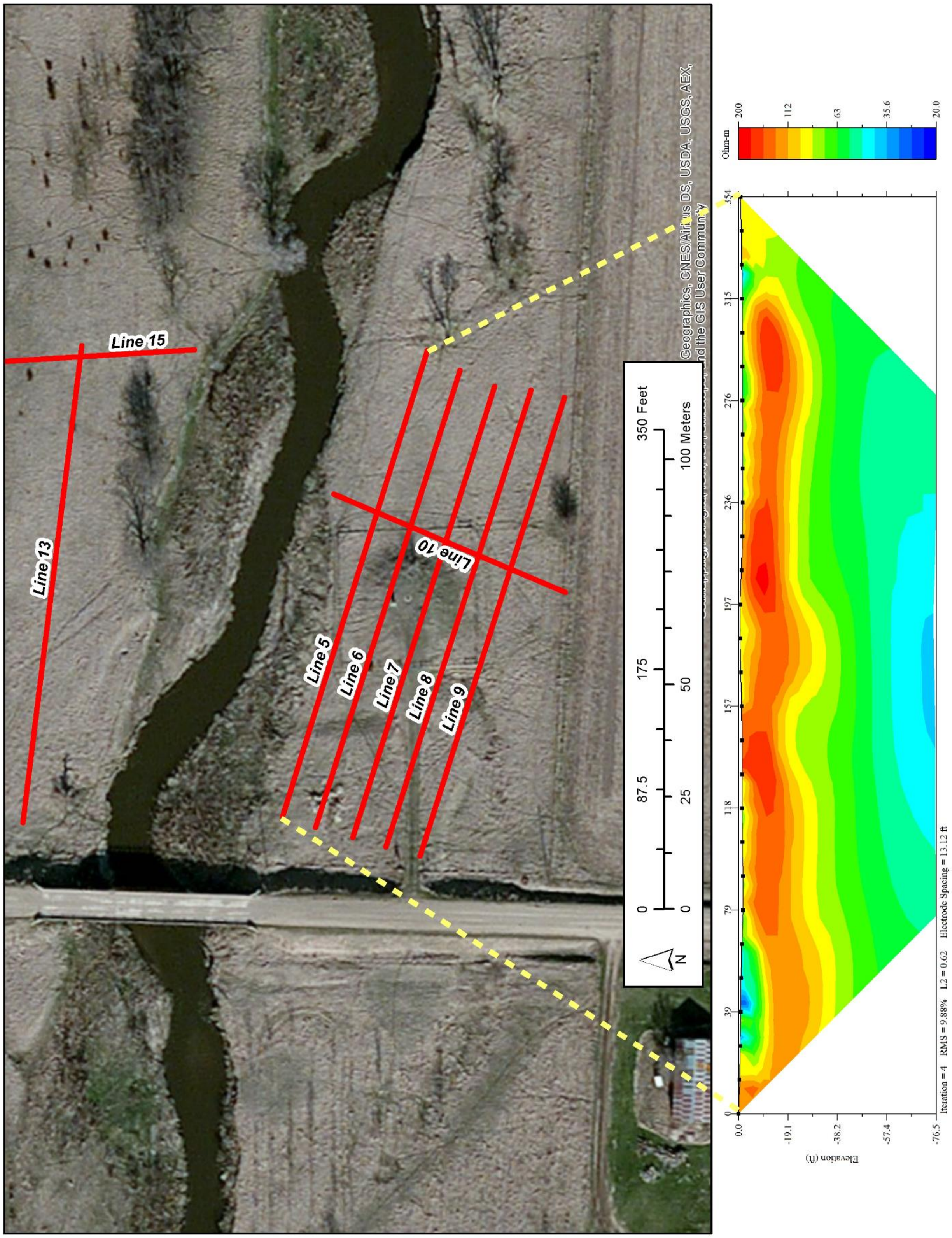

Line 1
Line 2
0
125
250
500 Feet
0
37.5
75
150 Meters
N
Ohm-m
200
112
63
35.6
20.0
Elevation (ft)
0.0
-19.8
-39.5
-59.3
-79.1
98
197
295
394
492
591
689
787
886
Iteration = 5 RMS = 4.38% L2 = 0.25 Electrode Spacing = 19.69 ft


Line 1
Line 2
0
125
250
500 Feet
0
37.5
75
150 Meters
N
Ohm-m
200
112
63
35.6
20.0
Elevation (ft)
Iteration = 6 RMS = 4.52% L2 = 0.13 Electrode Spacing = 19.69 ft

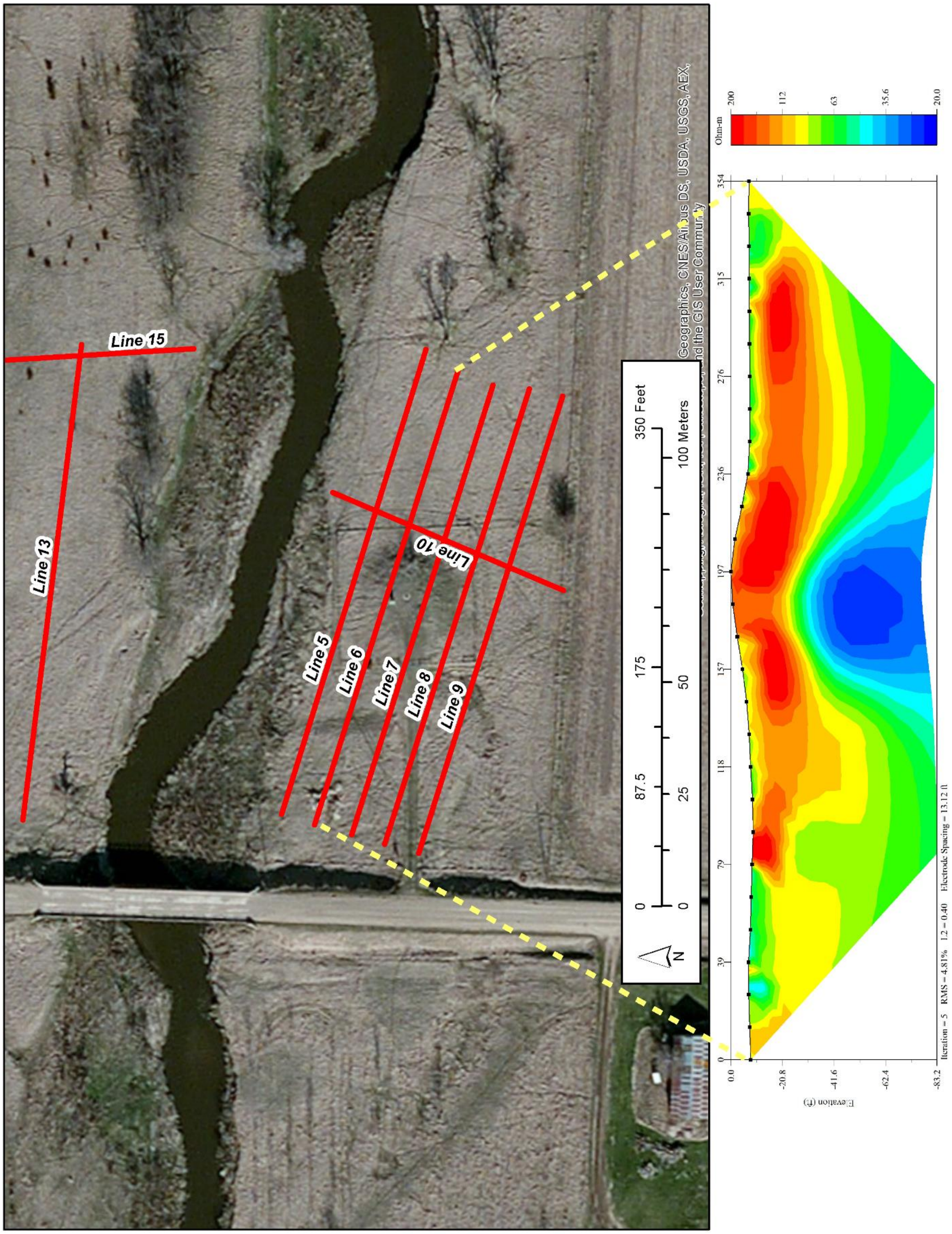

Line 2
Line 3
Line 4
0 125 250 500 Feet
0 37.5 75 150 Meters
N
graphics, CNES/Airbus DS, USDA, USGS, AEX,
Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community
Ohm-m
200
112
63
35.6
20.0
0 79 157 236 315 394 472 551 630 709 787
0.0 -19.4 -38.7 -58.1 -77.5
Elevation (ft)
Iteration = 6 RMS = 4.87% L2 = 0.28 Electrode Spacing = 19.69 ft



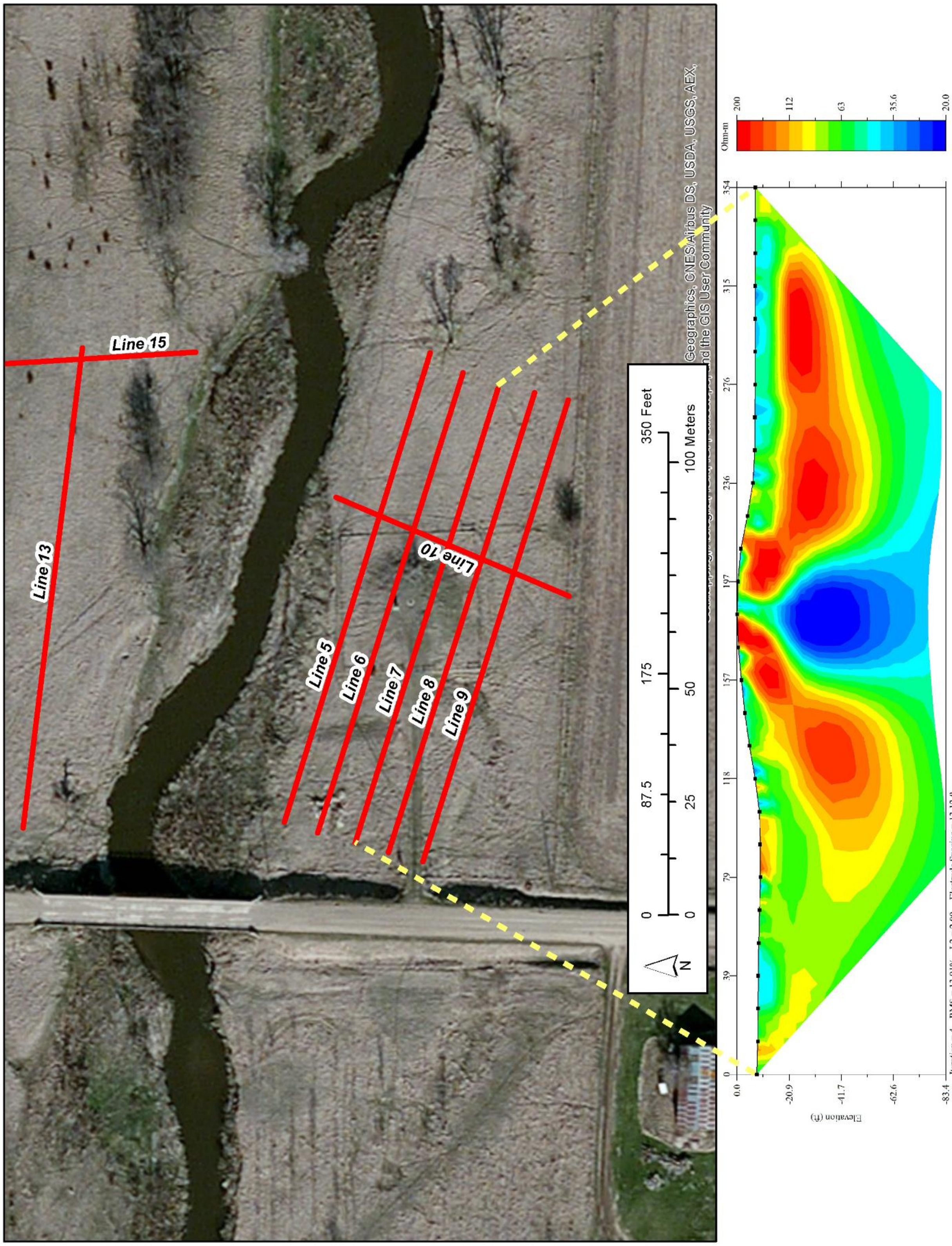
Line 4
Line 3
0 125 250 500 Feet
0 37.5 75 150 Meters
N
Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community
Ohm-m
200 112 63 35.6 20.0
0 39 79 118 157 197 236 276 315
0.0 -19.8 -39.6 -59.4 -79.2
Elevation (ft)
Iteration = 8 RMS = 5.10% L2 = 0.17 Electrode Spacing = 19.69 ft

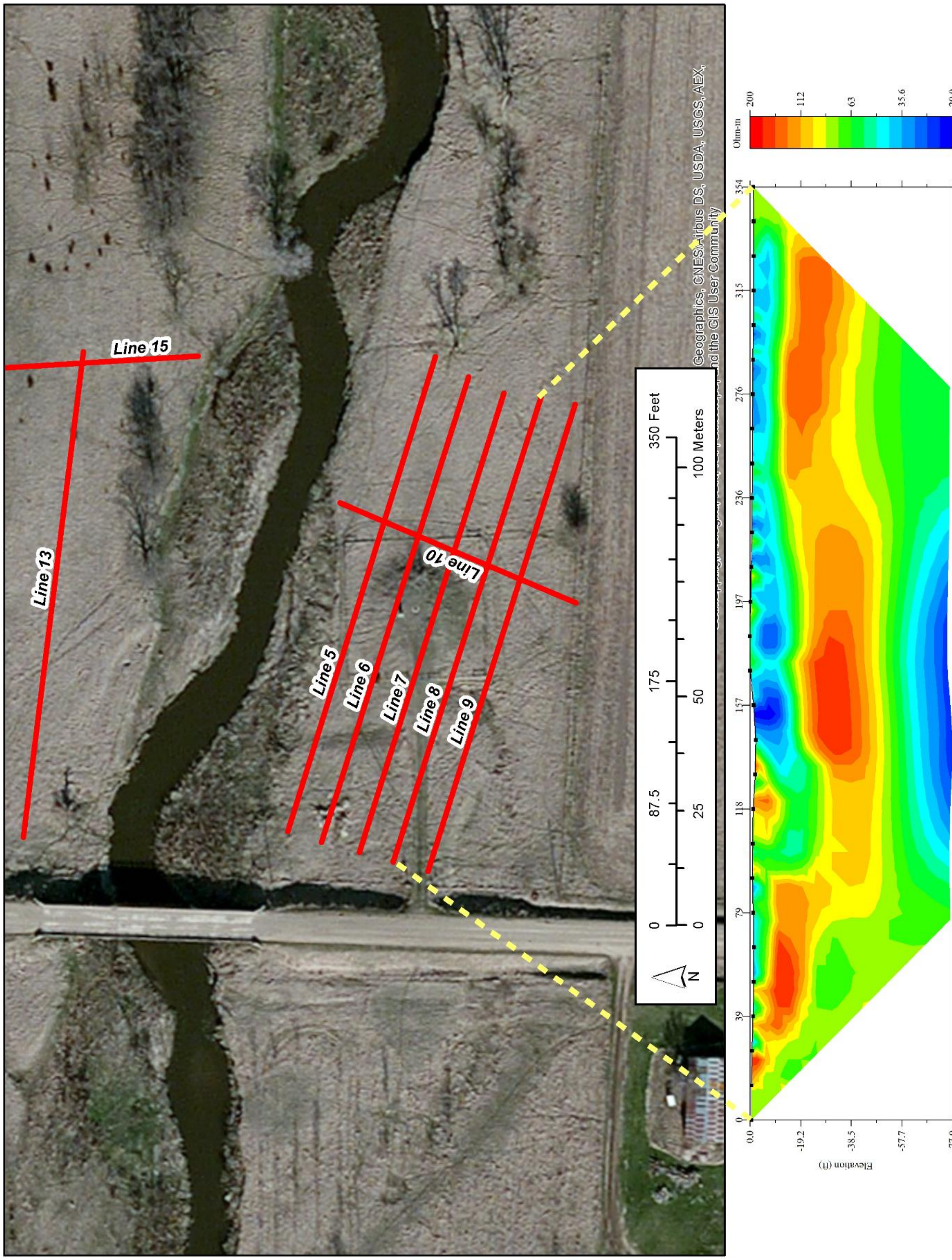


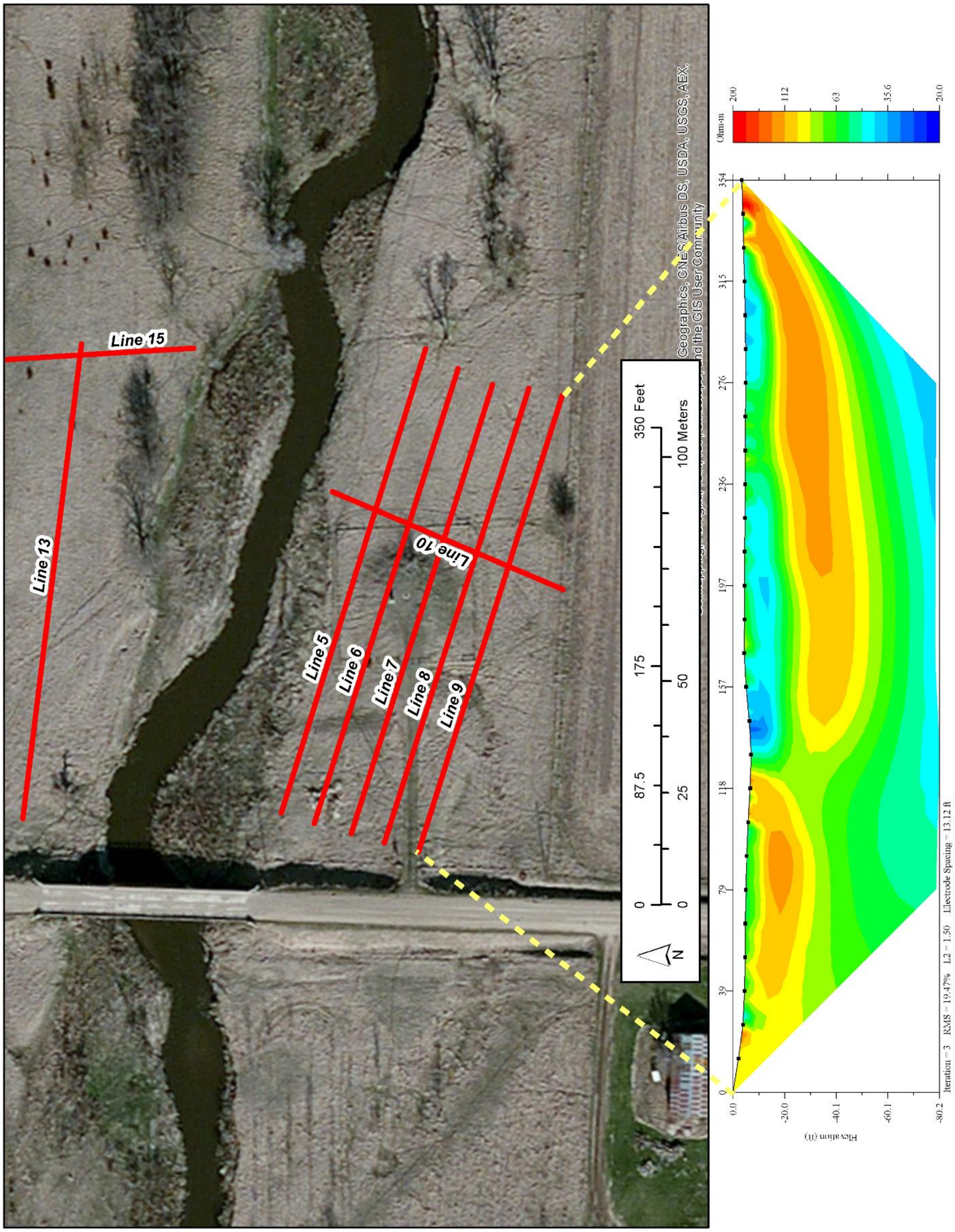
Line 15
Line 13
Line 10
Line 5
Line 6
Line 7
Line 8
Line 9
0
87.5
175
350 Feet
0
25
50
100 Meters
N
Ohm-m
200
112
63
35.6
20.0
Elevation (ft)
Iteration = 4 RMS = 9.88% L2 = 0.62 Electrode Spacing = 13.12 ft

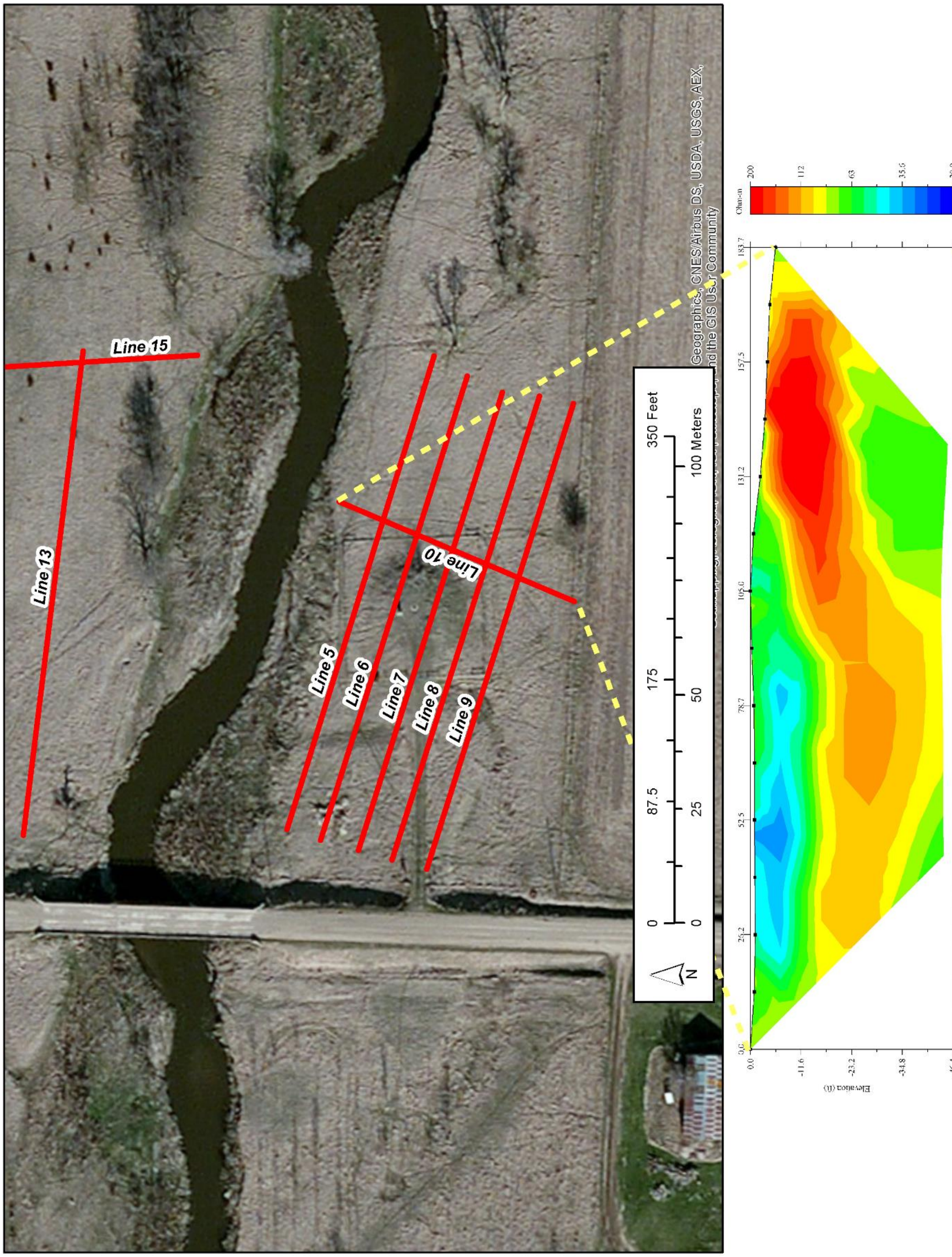


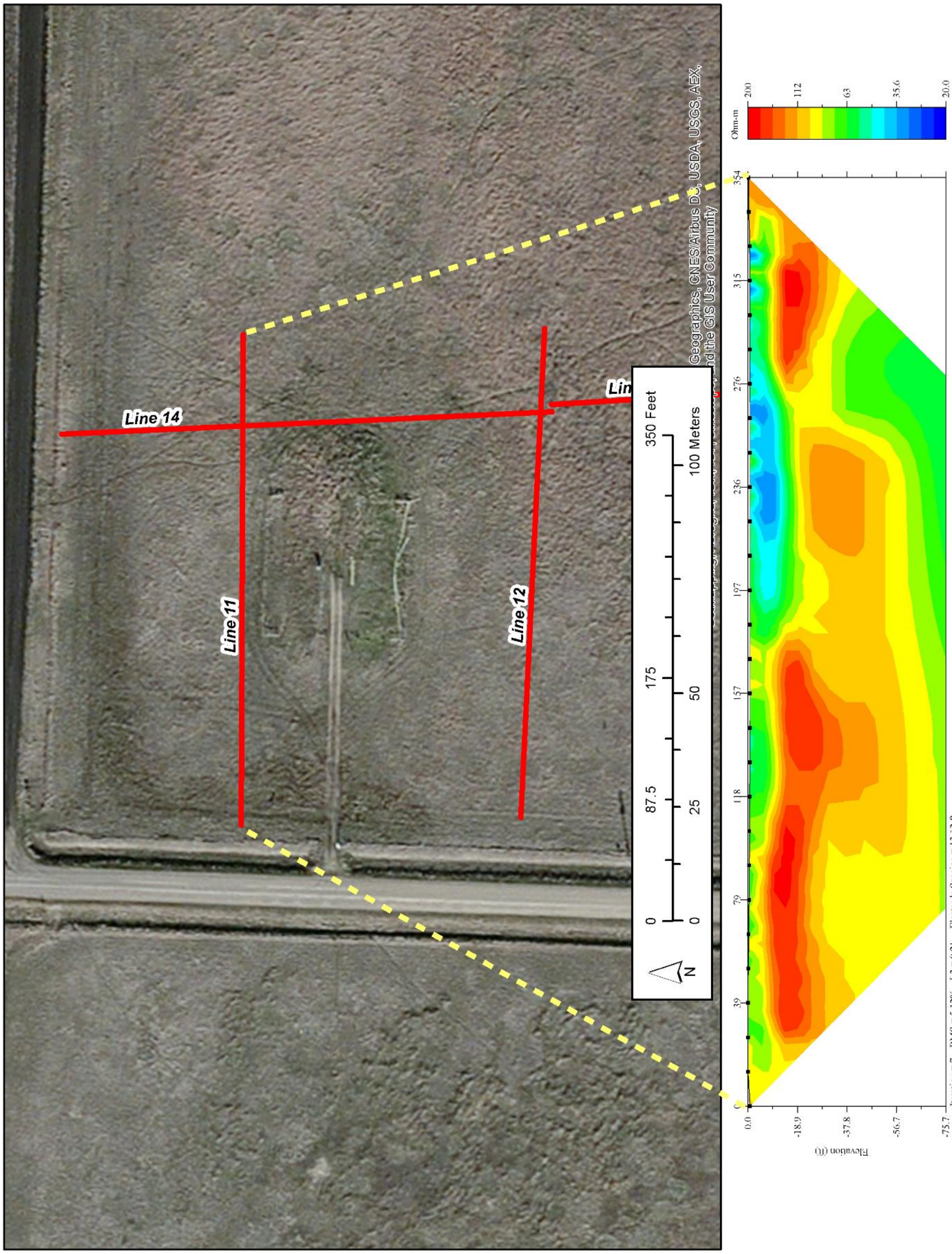
Line 15
Line 13
Line 5
Line 6
Line 7
Line 8
Line 9
Line 10
0
87.5
175
350 Feet
0
25
50
100 Meters
N
Ohm-m
200
112
63
35.6
20.0
Elevation (ft)
Iteration = 5 RMS = 4.81% L2 = 0.40 Electrode Spacing = 13.12 ft

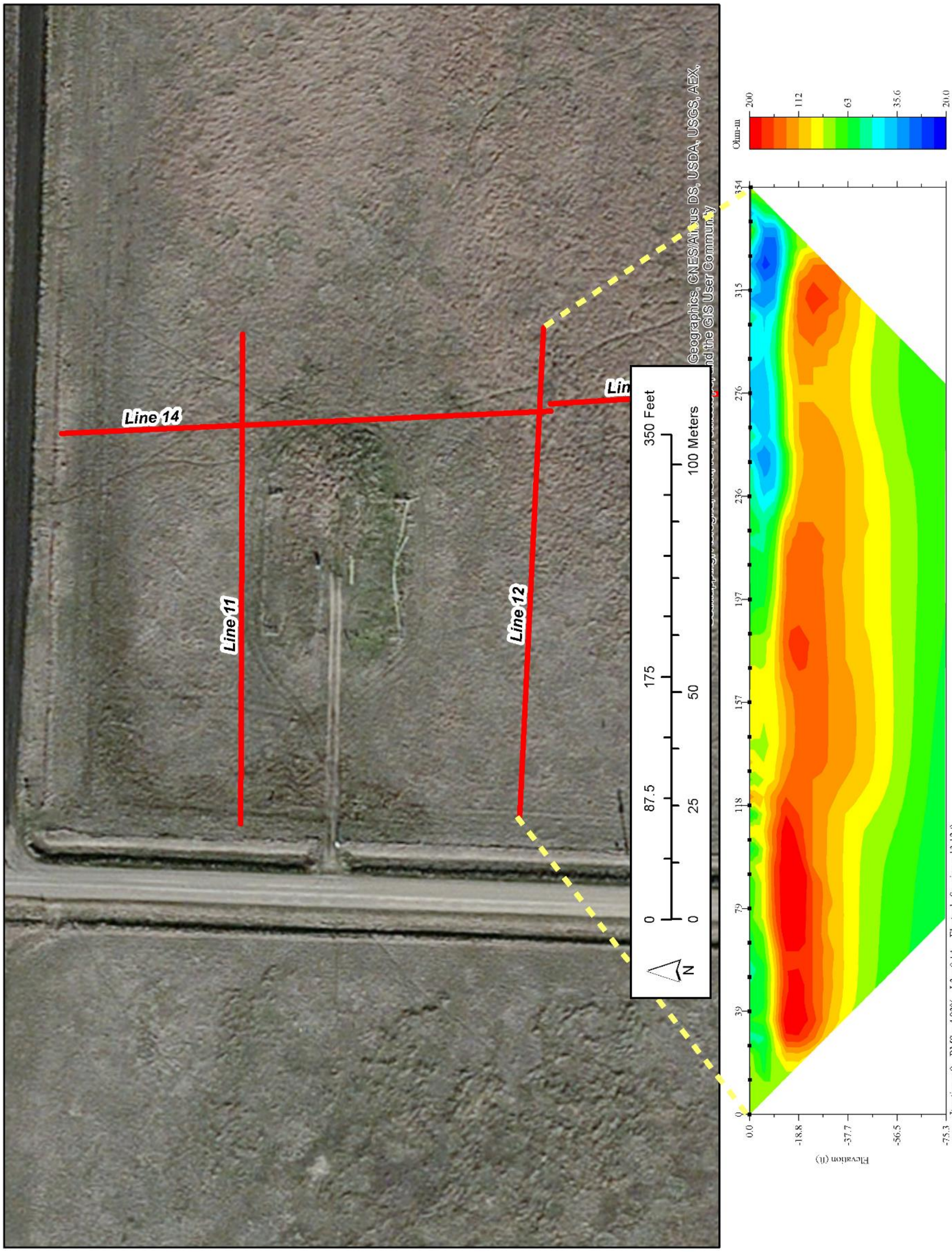

Line 15
Line 13
Line 5
Line 6
Line 7
Line 8
Line 9
Line 10
0
87.5
175
350 Feet
0
25
50
100 Meters
N
Ohm-m
200
112
63
35.6
20.0
Iteration = 4 RMS = 13.91% L2 = 2.00 Electrode Spacing = 13.12 ft
Elevation (ft)


Line 15
Line 13
Line 5
Line 6
Line 7
Line 8
Line 9
Line 10
0
87.5
175
350 Feet
0
25
50
100 Meters
N
Ohm-m
200
112
63
35.6
20.0
Elevation (ft)
0.0
-19.2
-38.5
-57.7
-77.0
0
39
79
118
157
197
236
276
315
354
Iteration = 8 RMS = 3.90% L2 = 0.19 Electrode Spacing = 13.12 ft

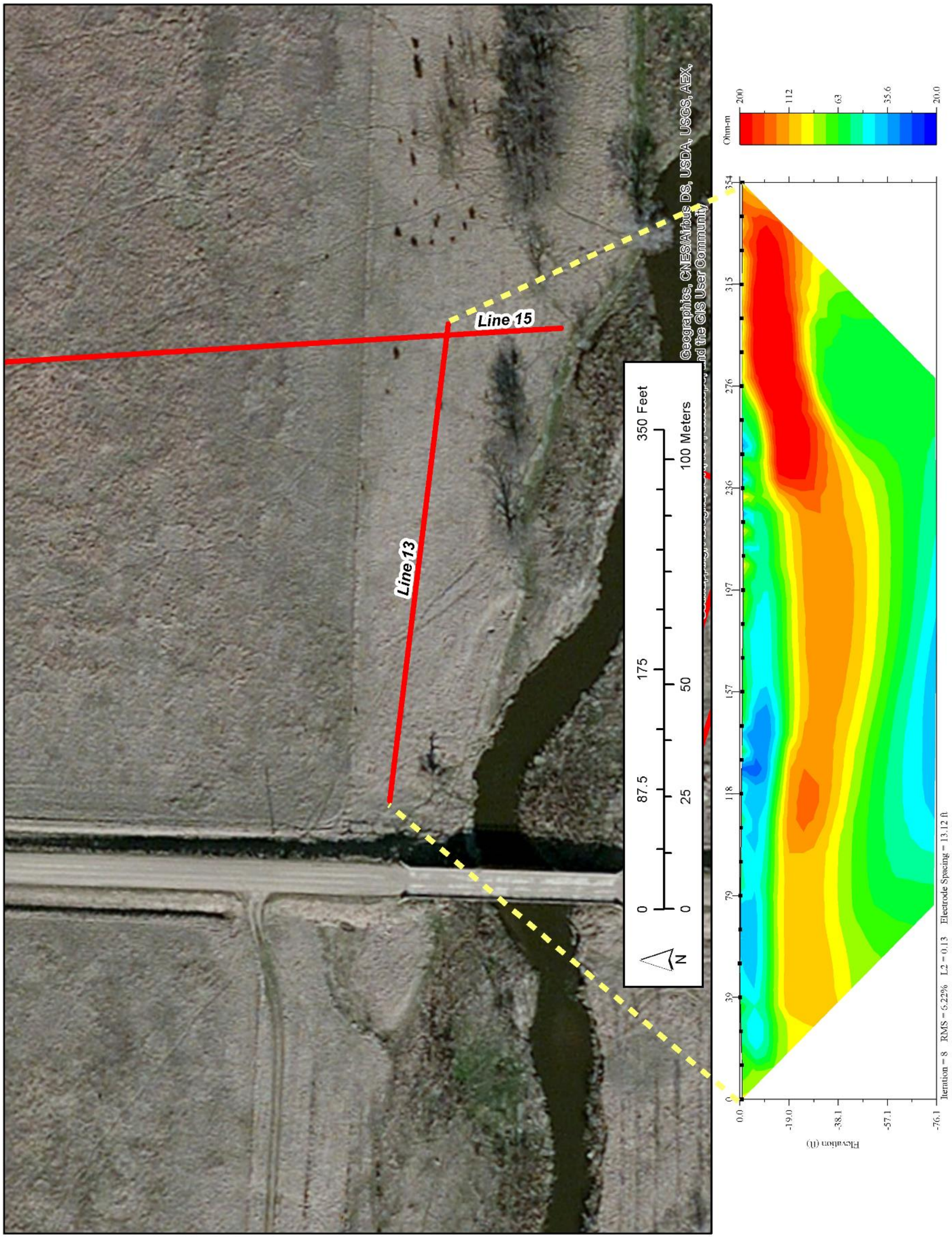

Line 15
Line 13
Line 5
Line 6
Line 7
Line 8
Line 9
Line 10
0 87.5 175 350 Feet
0 25 50 100 Meters
N
Geographics, CNES/Airbus DS, USDA, USGS, AEX,
and the GIS User Community
Ohm-m
200
112
63
35.6
20.0
0 39 79 118 157 197 236 276 315 354
Elevation (ft)
0.0
-20.0
-40.1
-60.1
-80.2
Iteration = 3 RMS = 19.47% L2 = 1.50 Electrode Spacing = 13.12 ft


Line 15
Line 13
Line 10
Line 5
Line 6
Line 7
Line 8
Line 9
N
0
87.5
175
350 Feet
0
25
50
100 Meters
Ohm-m

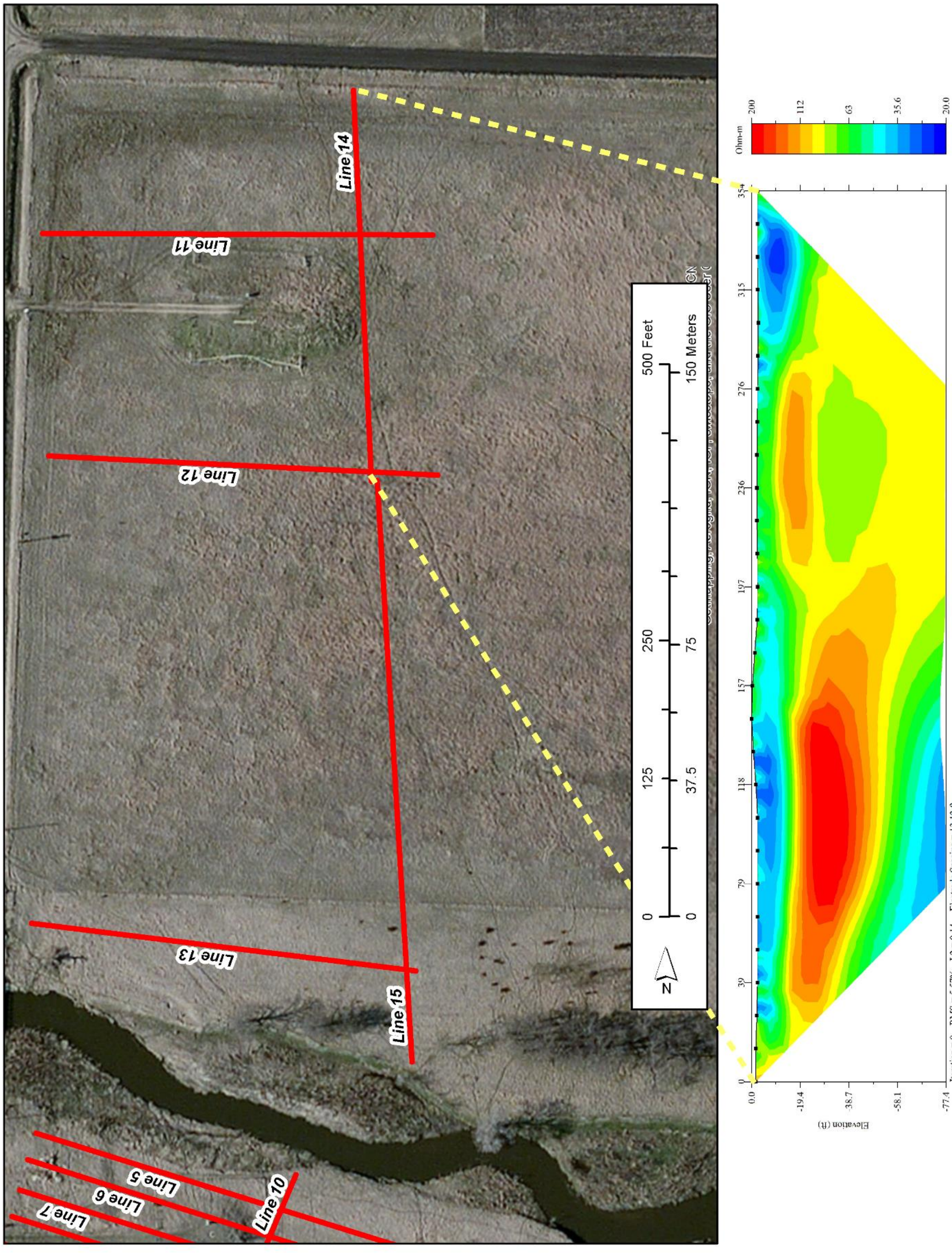

Line 14
Line 11
Line 12
Lin
350 Feet
175
87.5
0
100 Meters
50
25
0
N
Geographics, CNES/Airbus DS, USDA, USGS, AEX,
and the GIS User Community
Ohm-m
200
112
63
35.6
20.0
0
39
79
118
157
197
236
276
315
354
0.0
-18.9
-37.8
-56.7
-75.7
Elevation (ft)
Iteration = 7 RMS = 5.12% L2 = 0.21 Electrode Spacing = 13.12 ft



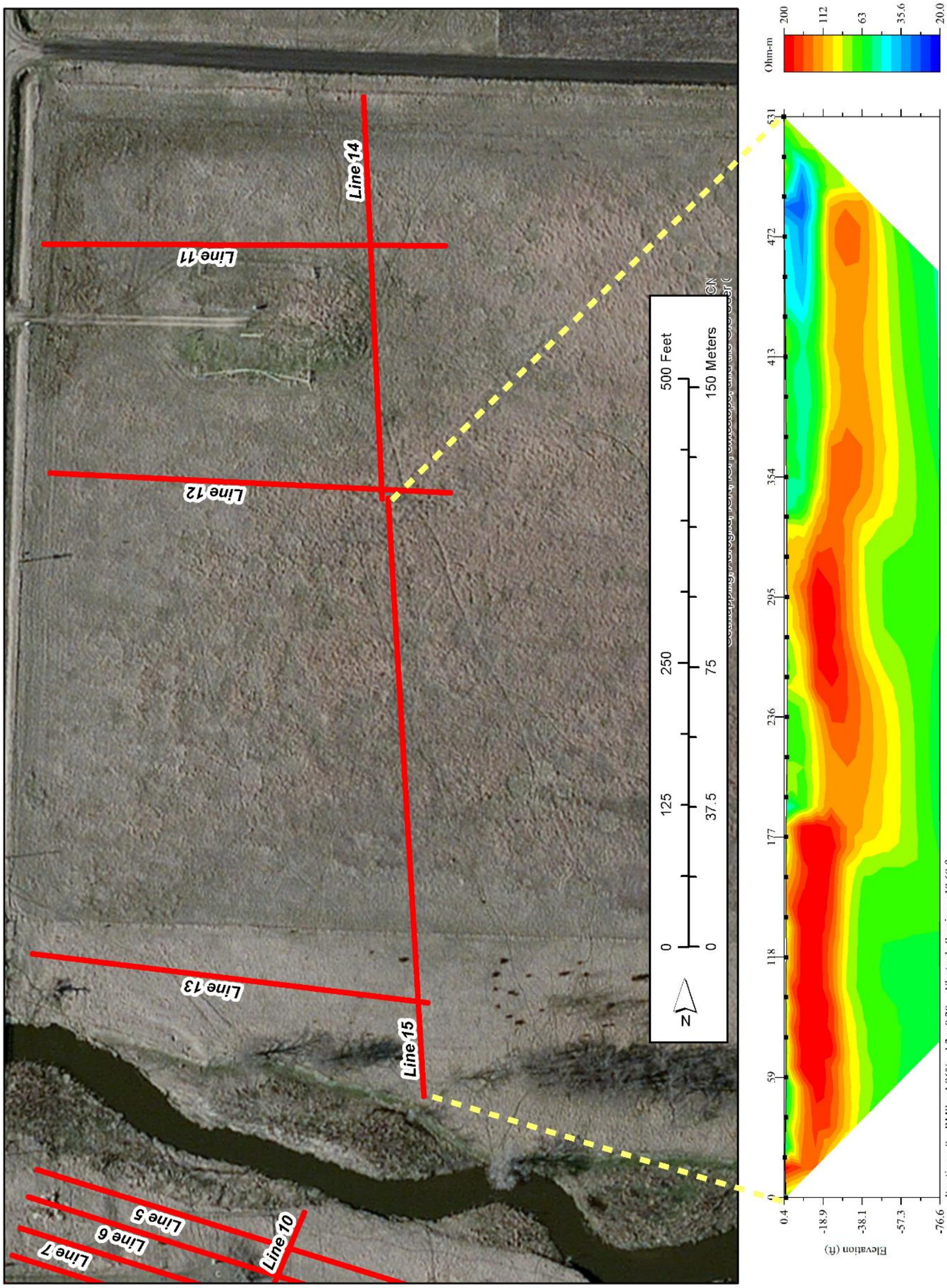
Line 14
Line 11
Line 12
0
87.5
175
350 Feet
0
25
50
100 Meters
N
Ohm-m
200
112
63
35.6
20.0
Elevation (ft)
0.0
-18.8
-37.7
-56.5
-75.3
0
39
79
118
157
197
236
276
315
354
Iteration = 8 RMS = 4.82% L2 = 0.14 Electrode Spacing = 13.12 ft



Line 15
Line 13
0
87.5
175
350 Feet
0
25
50
100 Meters
N
Geographics, CNES/Airbus DS, USDA, USGS, AEX,
and the GIS User Community
Ohm-m
200
112
63
35.6
20.0
0
39
79
118
157
197
236
276
315
354
0.0
-19.0
-38.1
-57.1
-76.1
Elevation (ft)
Iteration = 8 RMS = 5.22% L2 = 0.13 Electrode Spacing = 13.12 ft



Line 14
Line 11
Line 12
Line 13
Line 15
Line 5
Line 6
Line 7
Line 10
0 125 250 500 Feet
0 37.5 75 150 Meters
N
Ohm-m
200
112
63
35.6
20.0
0 39 79 118 157 197 236 276 315 354
0.0 -19.4 -38.7 -58.1 -77.4
Elevation (ft)
Iteration = 8 RMS = 5.57% L2 = 0.14 Electrode Spacing = 13.12 ft


Line 5
Line 6
Line 7
Line 10
Line 11
Line 12
Line 13
Line 14
Line 15
0 125 250 500 Feet
0 37.5 75 150 Meters
N
Ohm-m
200
112
63
35.6
20.0
Elevation (ft)
0.4
-18.9
-38.1
-57.3
-76.6
0 59 118 177 236 295 354 413 472 531
Iteration = 8 RMS = 4.96% L2 = 0.20 Electrode Spacing = 19.69 ft