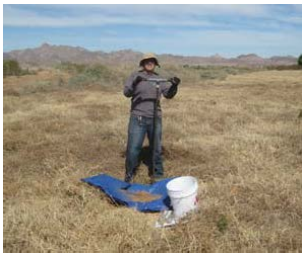
Lower Colorado River Multi-Species Conservation Program

Balancing Resource Use and Conservation

Soil and Groundwater Salinity Conditions for Lower Colorado River Multi-Species Conservation Program Habitat Creation Sites – 2014



February 2018

Work conducted under LCR MSCP Work Task E34

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Lower Colorado River Multi-Species Conservation Program

Soil and Groundwater Salinity Conditions for Lower Colorado River Multi-Species Conservation Program Habitat Creation Sites – 2014

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February 2018

Grabau, M., J. Banuelos, and L. Hovland. 2018. Soil and Groundwater Salinity Conditions for Lower Colorado River Multi-Species Conservation Program Habitat Creation Sites – 2014. Submitted to the Bureau of Reclamation, Boulder City, Nevada, by GeoSystems Analysis, Inc., Tucson, Arizona, under contract No. R10AP30003.

ACRONYMS AND ABBREVIATIONS

ANCOVA	analysis of covariance
ASTM	American Society for Testing and Materials International
BLCA	Beal Lake Conservation Area
Cibola NWR Unit #1	Cibola National Wildlife Refuge Unit #1 Conservation Area
CSTPA	Council on Soil Testing and Plant Analysis
CVCA	Cibola Valley Conservation Area
df	degrees of freedom
dS/m	decisiemen(s) per meter
EC	electrical conductivity
ESP	exchangeable sodium percentage
ft	feet/foot
GSA	GeoSystems Analysis, Inc.
IPCA	Imperial Ponds Conservation Area
LCR	lower Colorado River
LCR MSCP	Lower Colorado River Multi-Species Conservation Program
m	meter(s)
mg/L	milligram(s) per liter
n	number of samples
Nature Trail	Cibola National Wildlife Refuge Unit #1 Conservation Area Nature Trail
NRCS	Natural Resources Conservation Service
pH	scale of acidity from 0 to 14
PVER	Palo Verde Ecological Reserve
R^2	correlation coefficient
Reclamation	Bureau of Reclamation

Symbols

≥	greater than or equal to
%	percent

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EXECUTIVE SUMMARY

Through implementation of the Lower Colorado River Multi-Species Conservation Program (LCR MSCP), the Bureau of Reclamation will be establishing and managing at least 7,260 acres of riparian and honey mesquite (*Prosopis glandulosa*) communities within the historic lower Colorado River flood plain. Management of the Colorado River during the 20th century has increased flood plain salinity, including some areas planned for riparian restoration, above the tolerances of native Fremont cottonwood-Goodding's willow (*Populus fremontii-Salix gooddingii*) forests, which are a key component of the LCR MSCP. Long-term success of the program's conservation areas will require maintenance of salinity levels to support target vegetation species. For sites with salinized soils, active management may be required.

GeoSystems Analysis, Inc. (GSA) conducted a literature review and characterized and modeled soil and groundwater salinity at three riparian habitat creation areas on the lower Colorado River: the Beal Lake Conservation Area (BLCA), the Palo Verde Ecological Reserve (PVER), and the Cibola National Wildlife Refuge Unit #1 Conservation Area (Cibola NWR Unit #1). Based on the literature review and modeling, factors controlling soil and groundwater salinity at these sites include:

- *Soil texture*: Coarser (i.e., sandier) soil textures increase percolation rates and retain less of the dissolved salts introduced with irrigation. Sandy soils also limit capillary rise (upward movement of groundwater and dissolved salts into the root zone).

- *Depth to groundwater*: Increased depth to groundwater decreases the evapotranspiration of groundwater and contribution of dissolved salts to the vegetation root zone.

- *Irrigation water salinity*: Higher irrigation water salinity inputs more dissolved salts into the root zone and increases the annual applied water volume required to maintain target soil salinity.

- *Groundwater flow rates*: Higher groundwater flow rates more efficiently remove percolated irrigation water and leached soil salts away from the site.

In addition to controlling salinity conditions, soil texture and groundwater depth affect plant-available water for native riparian species. Many of the target plant species are phreatophytes, meaning that they require shallow groundwater or abundant soil moisture to meet evapotranspiration demand. Sandier soils and increased depth to groundwater reduce water availability and increase irrigation demand. Additionally, sandier soils typically result in higher infiltration rates, decreasing irrigation efficiency and increasing the required annual irrigation volume.

GSA installed a monitoring network at the three LCR MSCP conservation areas and collected data between May 2010 and July 2012. Existing piezometers were instrumented to monitor for groundwater levels (elevation and depth to water); slug tests were conducted to determine aquifer hydraulic conductivity; and soil samples were collected at 2-foot intervals to 6 feet below ground surface and analyzed for soil texture and salinity. Additionally, a vegetation health assessment was completed for Crane Roost on Cibola NWR Unit #1. Site conditions observed during this study are summarized as follows:

Conservation area	Soil texture[1]	Depth to groundwater[2]	Groundwater salinity[3]	Irrigation water salinity[4]	Groundwater flow rates[5]	Mean composite soil salinity[6]
BLCA	Coarse, average 92% sand	Shallow, 2–8 feet	Intermediate, average 1.8–3.5 dS/m	Intermediate, 1.2–2.4 dS/m	Intermediate, 0.0011– 0.0023 m/day	Intermediate, 4.5 dS/m, 2.8 dS/m
PVER	Coarse, average 84% sand	Deep, 10–20 feet	Low, average 1.2–1.7 dS/m	Low, 0.6–1.0 dS/m	High, 0.066–0.084 m/day	Low, 1.7 dS/m, 1.3 dS/m
Cibola NWR Unit #1	Fine, average 34% sand	Intermediate, 4–9 feet	High, average 2.4–4.7 dS/m	Low, average 1.0–1.6 dS/m	Low, 0.0003–0.0016 m/day	High, 15.0 dS/m, 12.5 dS/m

[1] Average composite across each conservation area.
[2] Range over the duration of the monitoring period, excluding mounding after irrigation.
[3] Range of the mean groundwater electrical conductivity value, by observation point, over the duration of the monitoring period measured in decisiemens per meter (dS/m).
[4] Range of all observed values.
[5] Range of all observed values, as calculated by GSA (2013a), measured in meters per day.
[6] 2010 and 2012 mean soil electrical conductivity based on data in this report.

The combination of factors listed above at the PVER resulted in very low soil salinity. Only 1 out of 123 soil samples exceeded the estimated 8 decisiemens per meter (dS/m) salinity tolerance for native vegetation. Over the range of soil texture and salinity observed, higher percent sand was correlated with lower soil salinity. A vegetation health analysis was not conducted at this site because all riparian trees in the observation area were in good health.

Soil salinity at the BLCA varied based on irrigation frequency, with irrigation at least once per month resulting in lower soil electrical conductivity (average of 1.4 to 2.2 dS/m) than fields irrigated twice per year (8.2 to 8.9 dS/m) or not at all (31.1 dS/m). A higher percent sand was correlated with a lower soil electrical conductivity for a subset of fields within the site, dependent on irrigation frequency.

Soil salinity at Cibola NWR Unit #1 was much higher than the other two sites likely due to finer-textured soils compared to the other sites. Soil salinity at Crane Roost increased with distance from the irrigation source, indicating enhanced leaching where more water is applied. Vegetation survey results for

Crane Roost indicated that vegetation survival and growth was limited when salinity thresholds were exceeded, with different depth intervals differentially affecting surveyed species; in other words, excessive soil salinity for a given depth interval did not always preclude growth when other depth intervals were less saline. Compared to PVER Phase 04, which was planted at the same time, Fremont cottonwood and Goodding's willow growth rates were reduced by approximately two-thirds due to more saline soils at Crane Roost.

Based on results of this study and long-term goals for the LCR MSCP, the following could be considered:

1. Perform initial soil texture and salinity investigations at conservation areas where riparian revegetation is planned or underway but soil salinity data are currently insufficient. These conservation areas likely include PVER Phase 01[1] and PVER Phases 04–08, areas of Cibola NWR Unit #1, and the entirety of the Cibola Valley and Pretty Water Conservation Areas.

2. Continue periodic soil salinity sampling on a reduced frequency (e.g., once every 3 to 5 years) at areas where current salinity levels are acceptable. These areas include most fields at the BLCA and PVER Phases 02 and 03. The status of salinity at other conservation areas is uncertain (see 1 above).

3. Continue annual soil sampling at Cibola NWR Unit #1, where current salinity levels approach or exceed 8 dS/m, and at other conservation areas if irrigation and drainage management might be altered.

4. Conduct soil salinity sampling at permanent vegetation monitoring plots at all LCR MSCP conservation areas to increase understanding of the interaction between vegetation success and soil salinity.

5. Conduct demonstration projects to determine if irrigation rates modeled for this project achieve predicted results (e.g., does an increase in annual irrigation result in reduced soil salinity at Crane Roost? Does a decrease in annual irrigation at the PVER maintain acceptable soil salinity?). These demonstrations will verify model results and allow improvements in model structure and parameterization as needed.

6. Continue groundwater level and salinity monitoring to detect changes that might negatively impact vegetation or result in increased irrigation demand.

[1] The PVER phases are written as PVER1, PVER2, etc., on the figures in this report.

7. Expand groundwater level, flow, and salinity monitoring to encompass other habitat creation sites. These observations will help determine the availability of groundwater to support vegetation, the ability of the aquifer to remove leached salts from each site, and the potential contributions of dissolved salts in the groundwater to the root zone.

1.0 INTRODUCTION

At least 7,260 acres of riparian and honey mesquite (*Prosopis glandulosa*) (hereafter mesquite) habitat creation are to be developed under the Lower Colorado River Multi-Species Conservation Program (LCR MSCP) (Bureau of Reclamation [Reclamation] 2012). LCR MSCP habitat creation is being implemented primarily within the historic flood plain, which is now disconnected as a result of river regulation, and the flood plain is no longer subject to periodic overbank flows. Disconnection impairs the natural, cyclic flushing of soil and groundwater salinity that occurs following overbank flow events (Jolly 1996; Poff et al. 1997). Thus, dams on the Colorado River, which regulate flows and evapoconcentrate salts in reservoirs, and extensive agriculture have led to increased salinity on the LCR flood plain (Busch and Smith 1995; Nagler et al. 2005).

Vegetation salinity tolerance varies considerably among different plant species and within a single species (GeoSystems Analysis, Inc. [GSA] 2011a). For the purposes of discussion in this report, the salinity tolerance, as saturated paste extract soil electrical conductivity (EC), above which mortality is expected, follow GSA (2011a):

- 8 decisiemens per meter (dS/m): Fremont cottonwood (*Populus fremontii*) (hereafter cottonwood), Goodding's willow (*Salix gooddingii*), and coyote willow (*Salix exigua*)

- 11 dS/m: Mesquite and *Baccharis* spp. (e.g., seep willow and desert broom)

- Greater than 50 dS/m: *Atriplex* spp. (quailbush and various saltbushes)

Salinity conditions on the LCR flood plain have limited the success of revegetation efforts in some cases, with results ranging from extremely poor establishment (e.g., Ducks Unlimited restoration site, now known as the Imperial Ponds Conservation Area (IPCA) (Raulston 2003) to apparent limits on growth rates and survival at the Cibola National Wildlife Refuge. Thus, maintenance of salinity below threshold values for planted riparian vegetation species is a necessity for LCR MSCP success.

Soil salinity typically affects vegetation by reducing soil water availability (GSA 2011a); osmotic potential exhibited by saline soil water provides resistance to water uptake on top of soil matric potential (soil "suction"). Sodic soils have a disproportionately higher concentration of sodium salts. Soils are considered sodic if the sodium adsorption rate (the ratio of sodium ions to calcium and magnesium ions) is ≥ 13 (Natural Resources Conservation Service [NRCS] 1997) or the exchangeable sodium percentage (ESP) (ration of exchangeable sodium to total cation exchange capacity) is greater than 15%. These soils can negatively affect vegetation through toxicity, nutrient deficiency, and soil dispersion (GSA 2011a).

In addition to having low salinity tolerance, riparian vegetation species rely on readily available water from soil moisture and/or shallow groundwater (Lite and Stromberg 2005; Snyder and Williams 2000). Regulation of the Colorado River has decreased seasonal flow variability and disconnected the flood plain by preventing overbank flows (Briggs and Cornelius 1998) and thus eliminated the contribution of riverflows to surface soil moisture. Therefore, irrigation will be required where groundwater is too deep to support vegetation (Hartwell et al. 2010). Irrigation in arid regions with shallow groundwater often exacerbates salinity accumulation (Raulston 2003; GSA 2011a), further complicating irrigation and soil salinity management of LCR MSCP habitat creation sites.

Sources of salts in restoration site soils include applied irrigation water and groundwater. Irrigation water contains dissolved salts, which are introduced into the soil matrix. Irrigation water can either evaporate, transpire (taken up and evaporated by plants), or percolate through the rooting zone and into groundwater. Evaporation and transpiration remove water from the soil but leave dissolved salts behind. Irrigation in excess of evapotranspirative demand (evaporation and transpiration combined) results in percolation and flushing of soil salts below the rooting zone and into the aquifer. Salts can either be removed from the site via groundwater flow or returned to the rooting zone via capillary rise. The rate of groundwater flow is determined by the gradient (slope of groundwater) and the hydraulic conductivity (flow capacity, controlled by the soil composition and structure) of the aquifer matrix.

Groundwater also contains dissolved salts. The concentration of dissolved salts in groundwater is a result of (1) the salinity of incoming (upgradient) groundwater, (2) the salinity of incoming (percolating) irrigation water, and (3) capillary rise, evapoconcentration, and subsequent leaching of groundwater salts. The contribution of groundwater to soil salinity is determined by the depth of groundwater and the soil texture and structure (finer-grained soils typically increase the amount of capillary rise). Thus, soil salinity levels are determined by the following interrelated factors:

1. Incoming water salinity concentration (groundwater and irrigation)
2. The ratio of irrigation to evapotranspirative demand
3. The rate of groundwater flow
4. The amount of capillary rise

When appropriate, in preparation for planting, LCR MSCP conservation areas are cleared of existing vegetation, planted with a cover crop of alfalfa (*Medicago sativa*) or Bermuda grass (*Cynodon datctylon*), and irrigated to leach soil salts and provide additional soil conditioning (Reclamation 2007). Soil salinity assessments are typically conducted prior to site planting. Thereafter, a 3- to 5-year sampling frequency has been suggested for sites where salinity is stable (Reclamation 2006). For sites where soil salinity has not stabilized, annual

monitoring has been recommended (Reclamation 2007). However, data have not been consistently collected at the suggested time intervals. Groundwater salinity monitoring is not currently included in conservation area monitoring.

Through Grant R10AP30003: *Groundwater and Soil Salinity Monitoring Network in Support of Long-term Irrigation and Salt Management of MSCP Restoration Areas*, GSA assisted Reclamation in analyzing soil and groundwater salinity, evaluating impacts on vegetation, and identifying potential mitigation measures to promote long-term success of restoration at LCR MSCP habitat creation sites. This project was comprised of five tasks:

- Task 1: Review of Existing Data and Salinity Status Report
    - GSA retrieved and reviewed historic data of the LCR and compiled information on soil and groundwater salinity and sodicity problems and mitigation strategies.
- Task 2: Install a Soil and Groundwater Monitoring System Network
    - GSA conducted year 1 soil sampling in May – June 2010 and installed piezometers at three MSCP habitat creation sites between December 2010 and February 2011.
- Task 3: Soil and Groundwater Quality/Elevation Monitoring
    - GSA monitored groundwater elevations and salinity at the habitat creation sites between approximately January 2011 and July 2013 and conducted year 3 soil sampling in February 2012.
- Task 4: Develop a Water Salinity and Budget Model
    - GSA calibrated a pre-existing salinity model to the three LCR MSCP habitat creation sites using soil attributes, aquifer characteristics, and groundwater elevation data collected for tasks 2 and 3.
- Task 5: Analyze Irrigation Management Strategies
    - Using the results of tasks 1–4, GSA modeled site-specific irrigation alternatives to estimate the amount of irrigation required to maintain acceptable soil salinity at the habitat creation sites.

The literature review was presented in GSA (2011a); a well installation and preliminary monitoring data report was provided to Reclamation (GSA 2011b);

model development and calibration was documented in GSA (2013a); and irrigation management strategies were detailed in GSA (2013b). With delivery of this report, GSA has completed all tasks. This report provides the following:

- Historic LCR MSCP habitat creation site soil salinity data
- Methods and results for characterization of soil and groundwater conditions at the Beal Lake Conservation Area (BLCA), the Palo Verde Ecological Reserve (PVER), and the Cibola National Wildlife Refuge Unit #1 Conservation Area (Cibola NWR Unit #1) between 2010 and 2013
- Methods and results for vegetation condition assessments at Crane Roost on Cibola NWR Unit #1 and integration with soil salinity results.

Project site descriptions are provided in section 2.0; detailed methods are provided in section 3.0, with supplemental information provided in references; results are provided in section 4.0; and conclusions and recommendations are provided in sections 5.0 and 6.0, respectively.

2.0 PROJECT SITES

Intensive site investigations were conducted for three LCR MSCP riparian habitat creation areas between Needles, California, and Cibola, Arizona (figure 1): the BLCA, PVER, and Cibola NWR Unit #1. Background information available for these sites is provided below. Site history, construction/revegetation, and management information is summarized from various LCR MSCP reports. Existing soil texture data were obtained from the NRCS (data available at http://websoilsurvey.nrcs.usda.gov), and soil salinity data were summarized from LCR MSCP reports and other tabular data provided to GSA by Reclamation.

2.1 Beal Lake Conservation Area

The BLCA was constructed on material excavated during dredging of Beal Lake, which began in 2001. The site was leveled and subdivided into 30 fields (figure 2), and 1 alfalfa valve (a capped pipe outlet used as a surface irrigation point source) was placed in the corner of each field to allow for independent surface irrigation. After preparation, the site was planted in two phases between 2003 and 2005 (Reclamation 2008). Vegetation types observed at each field in April 2010 included both honey and screwbean mesquite (*Prosopis pubescens*), cottonwood, riparian, mixed riparian, and saltcedar (*Tamarix* spp.) (table 1). Irrigation frequencies, prescribed by Reclamation to maximize water availability

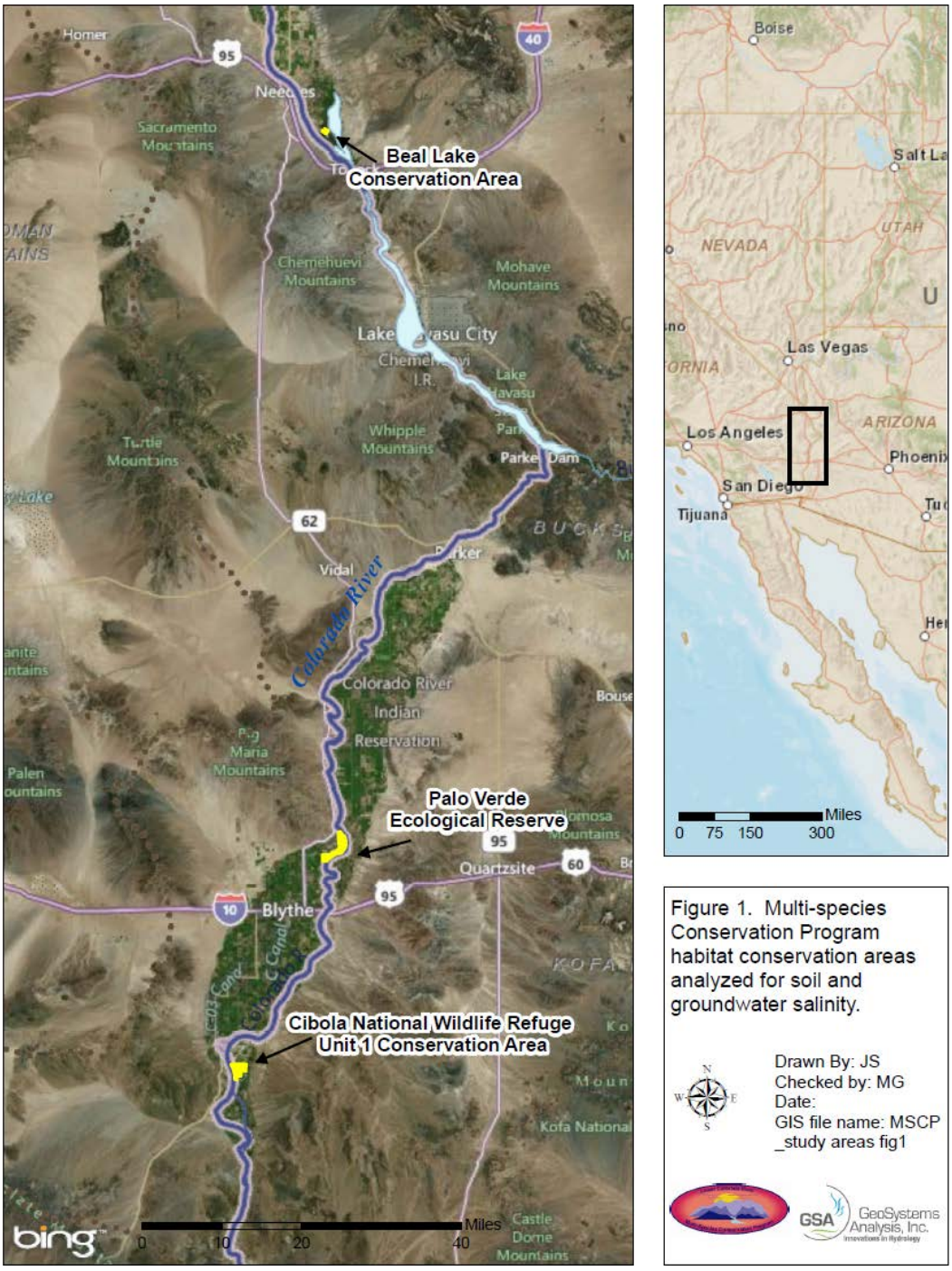

Figure 1.—LCR MSCP conservation areas analyzed for soil and groundwater salinity.

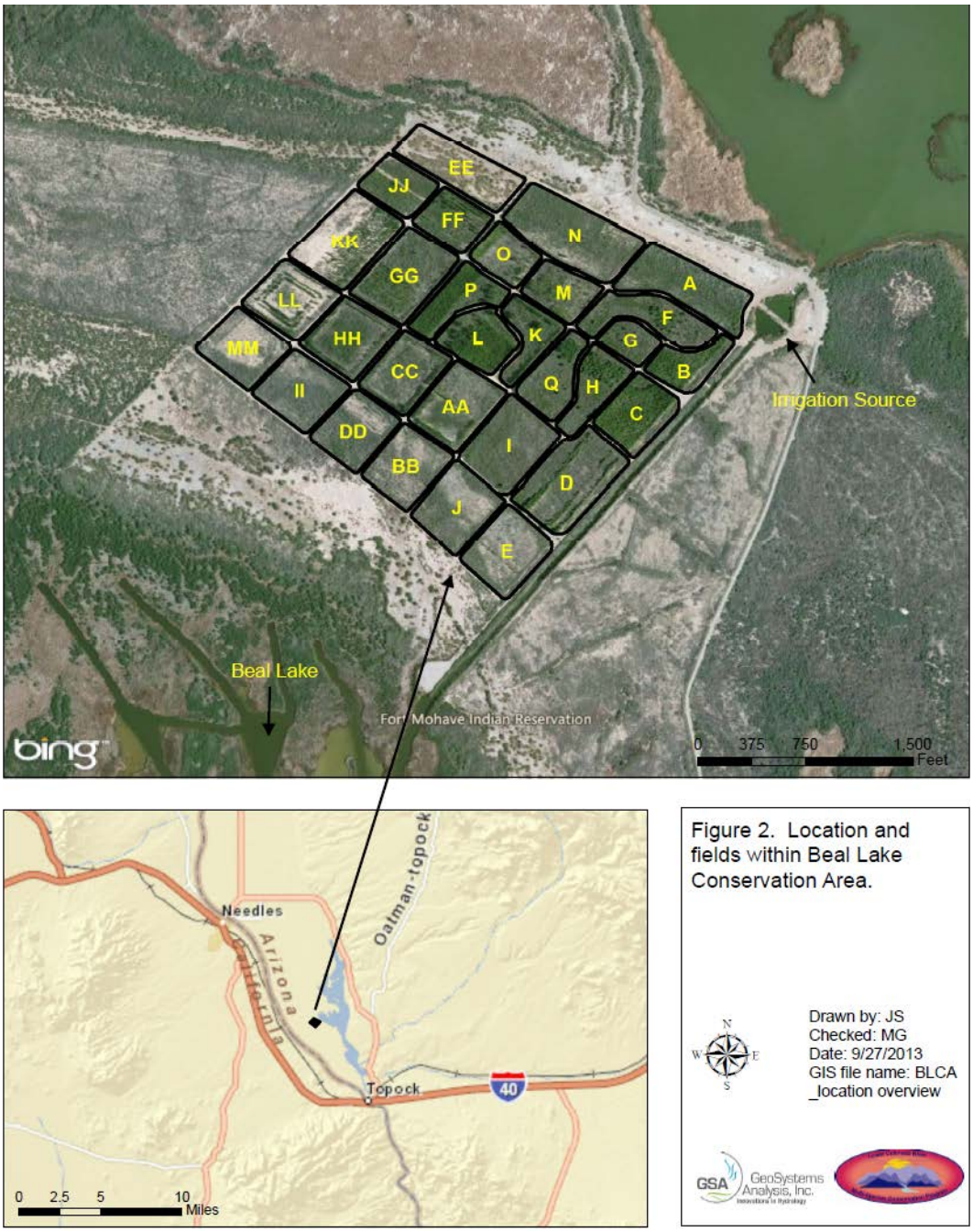

Figure 2.—Location and fields within the BLCA.

Table 1.—BLCA summary information

Field	Area (acres)	Dominant overstory vegetation	Irrigation frequency
A	5.1	Mixed mesquite	Twice per year
B	2.4	Cottonwood and mixed mesquite	Once per month
C	3.6	Cottonwood and mixed mesquite	Once per month
D	5.4	Mixed riparian	Once per month
E	3.9	Mixed mesquite	Twice per year
F	4.1	Mixed riparian	Once per month
G	1	Mixed riparian	Once per month
H	2.7	Mixed riparian	Twice per month
I	4.3	Mixed riparian	Once per month
J	3.6	Mixed mesquite	Twice per year
K	2.5	Mixed riparian	Once per week
L	4.2	Mixed riparian	Once per week
M	2.6	Mixed riparian	Once per month
N	6.2	Mixed mesquite	Twice per year
O	2.5	Mixed riparian	Once per month
P	2.6	Mixed riparian	Once per week
Q	2.9	Mixed riparian	Twice per month
AA	3.9	Mixed riparian	Once per month
BB	3.1	Mixed mesquite	Twice per year
CC	3.6	Mixed riparian	Once per month
DD	3.3	Mixed mesquite	Twice per year
EE	4.7	Saltcedar	None
FF	2.5	Mixed riparian	Twice per month
GG	4.4	Mixed riparian	Once per month
HH	4	Mixed riparian	Once per month
II	3.7	Mixed mesquite	Twice per year
JJ	2.5	Riparian/saltcedar/mesquite	Twice per month
KK	4.4	Mixed riparian	Once per month
LL	3.6	Mixed riparian	Once per month
MM	3.6	Mixed mesquite	Twice per year

in fields planted with riparian trees, have been implemented for several years and continued through 2012. Generally, fields in the center were irrigated most intensively, and some outer fields were irrigated only twice per year or not at all, as in Field EE (table 1).

Soil survey data indicate the entire site is composed of Lagunita sand (figure 3). Previous surveys conducted by Reclamation indicate primarily a sand soil texture with a small component of loamy sand, sandy loam, and silt loam.

2.2 Palo Verde Ecological Reserve

The PVER encompasses approximately 1,352 acres on the California side of the Colorado River north of Blythe, California (see figure 1). It is comprised entirely of land being converted from agricultural use to native riparian habitat types. The area is subdivided into sites, with the site number corresponding to the sequence of planting (figure 4). For this project, analysis was conducted for PVER Phases 02 and 03, encompassing approximately 80 and 87 acres, respectively. PVER Phase 02 was planted in 2007, and PVER Phase 03 was planted in 2008 and 2009. Irrigation of both sites is conducted by border irrigation, whereby 10 “checks” (segments of each site are bordered by earthen berms to allow independent irrigation) in each site are irrigated using slide gates placed in the irrigation lateral canal (checks are shown on figures 5 and 6).

PVER Phase 02 checks were planted with a section of coyote willow through the center, bordered by Goodding’s willow on the east and west (Reclamation 2009). The southern portions of PVER Phase 02 were planted with various vegetation types. The three easternmost checks were used for a research project on Salicaceae species genetics and were planted with more widely spaced cottonwood and coyote willow. The three western checks of PVER Phase 03 were planted with mesquite, and the remaining seven were planted with mixed riparian vegetation (Reclamation 2010).

The soil types estimated by NRCS soil surveys for PVER Phase 02 are shown on figure 5. The western side of PVER Phase 02 is composed primarily of sandy loam, whereas textures are finer grained to the east and southeast, transitioning to silt loam and clay soil classifications. NRCS soil survey data for PVER Phase 03 are shown on figure 6. The western side of PVER Phase 03 is composed of primarily sandy loam and loam soil texture classifications. The eastern portion of PVER Phase 03 is a mix of clay, clay loam, loam, and loamy sand soil texture classifications.

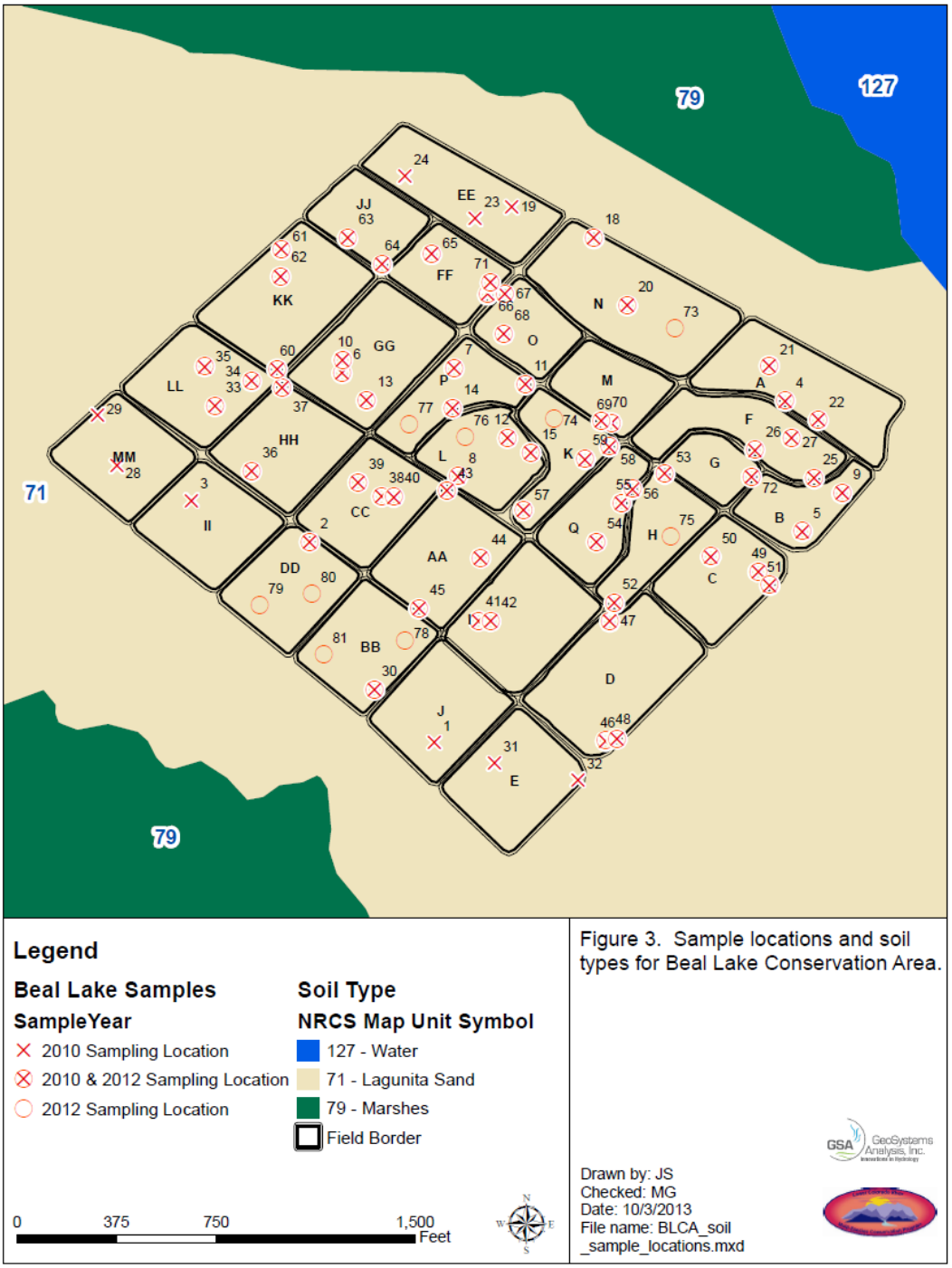

Figure 3.—Sample locations and soil types at the BLCA.

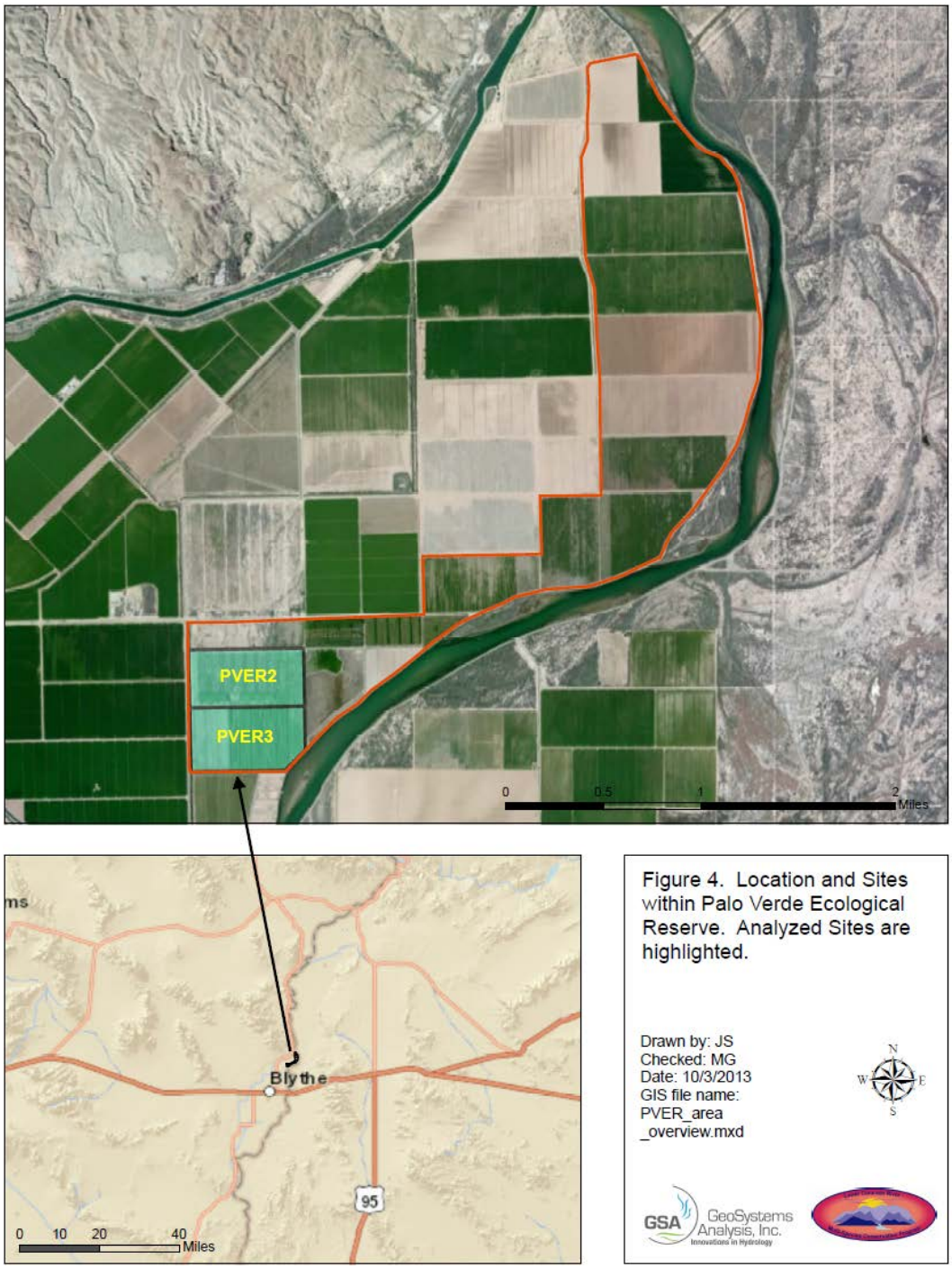

Figure 4.—Location and sites within the PVER.
Analyzed sites are highlighted.

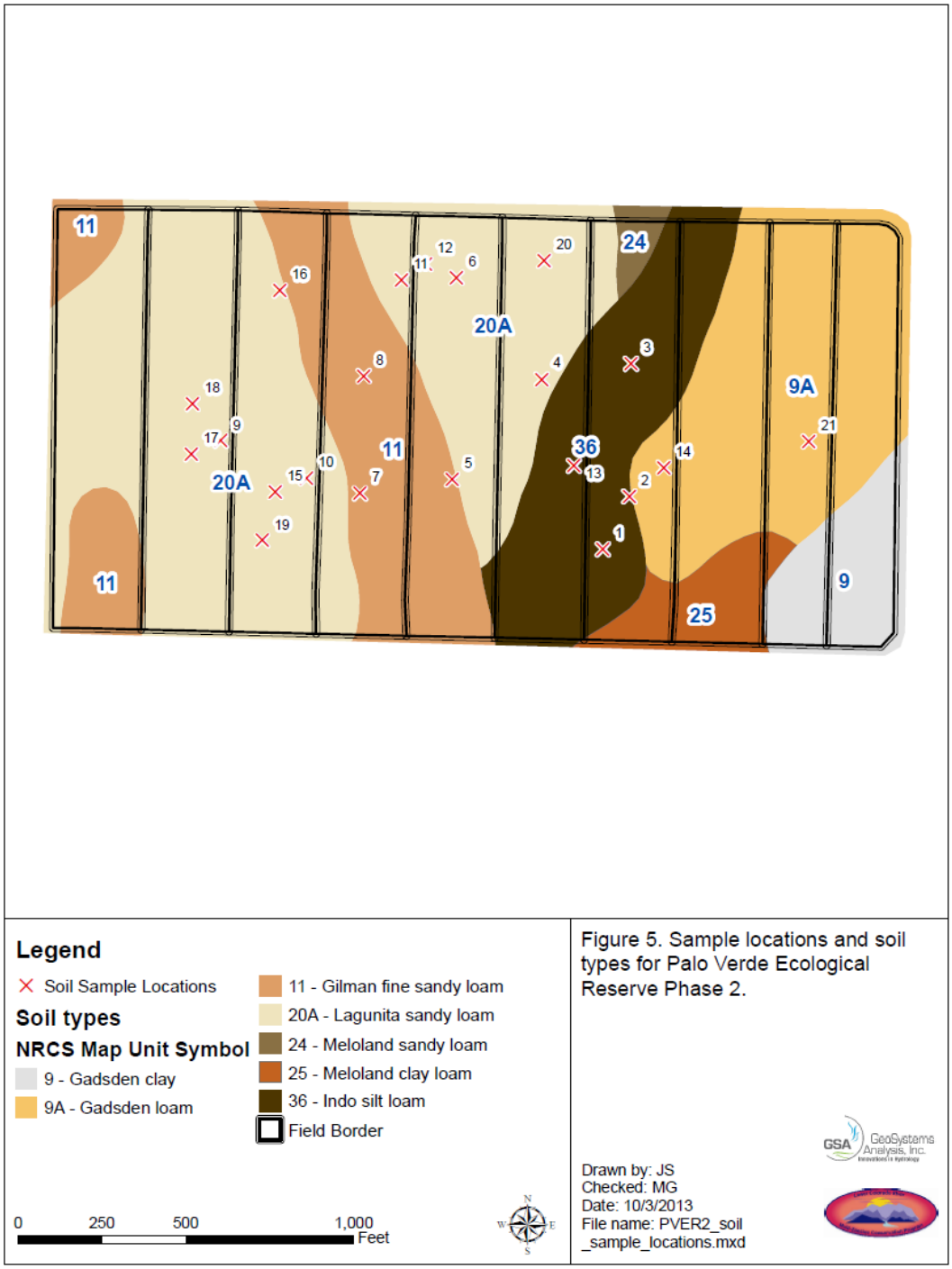

Figure 5.—Sample locations and soil types at PVER Phase 02.

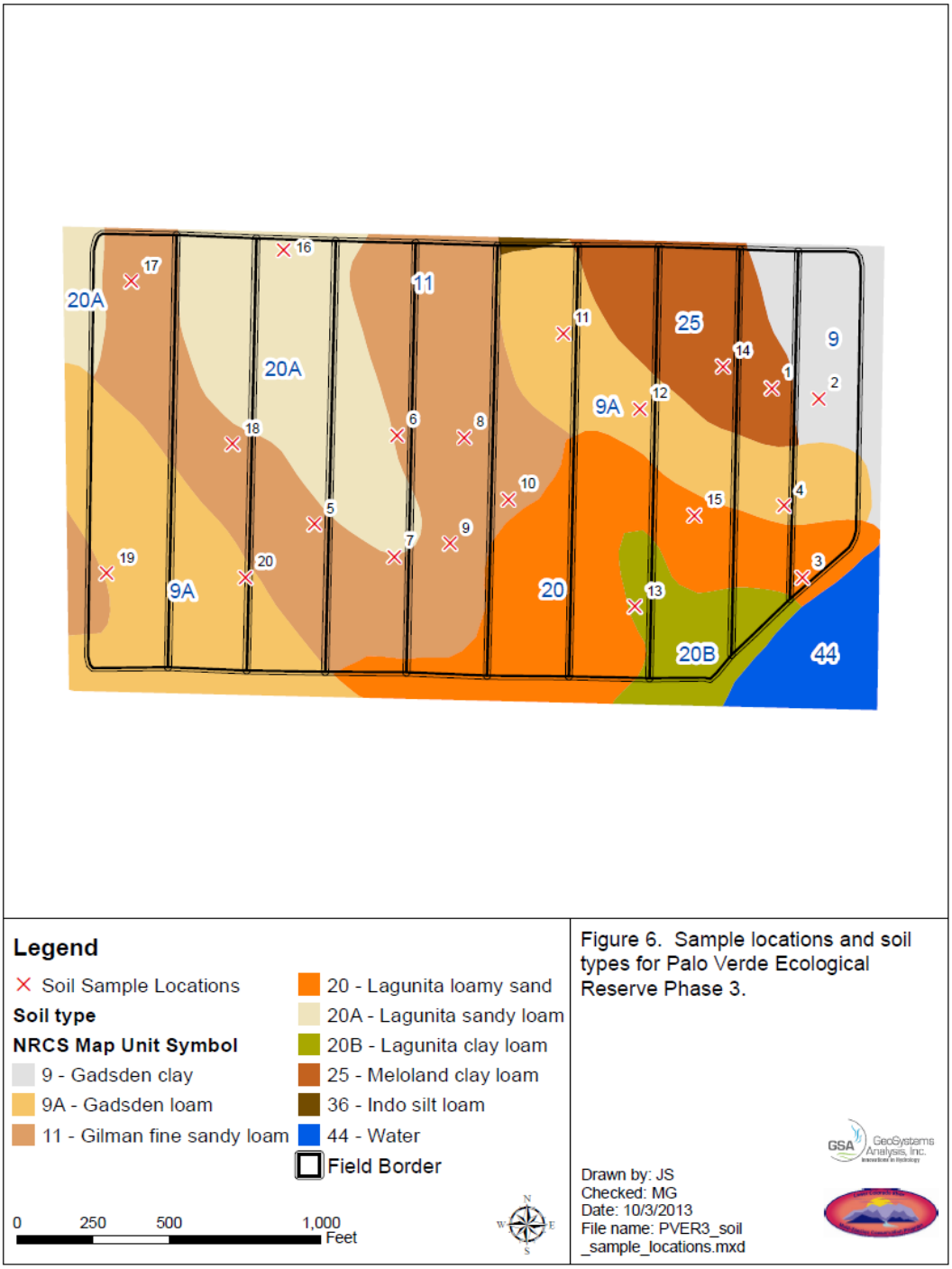

Figure 6.—Sample locations and soil types at PVER Phase 03.

2.3 Cibola National Wildlife Refuge Unit #1 Conservation Area

Cibola NWR Unit #1 encompasses an area of approximately 950 acres on the northwest corner of the Cibola National Wildlife Refuge (see figure 1); Cibola NWR Unit #1 is divided into several management units (see figure 7). These units include former agricultural fields and previously undeveloped land (Hippy Fire, Baseline 90, North 160, and Crane Roost). This project includes the analysis of Crane Roost and two former agricultural areas (Cibola National Wildlife Refuge Unit #1 Conservation Area Nature Trail [Nature Trail] and Mass Transplanting). A third agricultural field conversion (Seed Feasibility Study) was also analyzed for groundwater conditions but not for soil salinity. Site descriptions for the PVER and Cibola NWR Unit #1 are summarized in table 2.

Table 2.–PVER and Cibola NWR Unit #1 summary information

Area	Site	Site area (acres)	Dominant overstory vegetation	Irrigation frequency
PVER	PVER Phase 02	78	Areas of cottonwood, Goodding's willow, coyote willow, intermixed riparian, and mesquite	Approximately twice per month
	PVER Phase 03	84	Zonal intermixed riparian	
Cibola NWR Unit #1	Nature Trail	36	Distinct riparian	Approximately twice per month
	Mass Transplanting	20	Dense riparian	
	Crane Roost	140	Distinct riparian	

The Nature Trail and Mass Transplanting fields were previously under agricultural irrigation for decades, with the Nature Trail developed and planted in 1999 and Mass Transplanting planted in 2005. The northern field of Crane Roost began receiving irrigation in 2005 and was planted with native vegetation that same year. The three southern fields at Crane Roost were irrigated beginning in 2007 and were planted in 2009. Drainage improvements at Crane Roost (e.g., drainage ditch debris removal and deepening) have also occurred as part of the ongoing development of this site. As of 2009, the Hippy Fire, Baseline 90, and North 160 sites were not planted and were not included for analysis in this project. However, preparation and/or planting were underway at Hippy Fire and

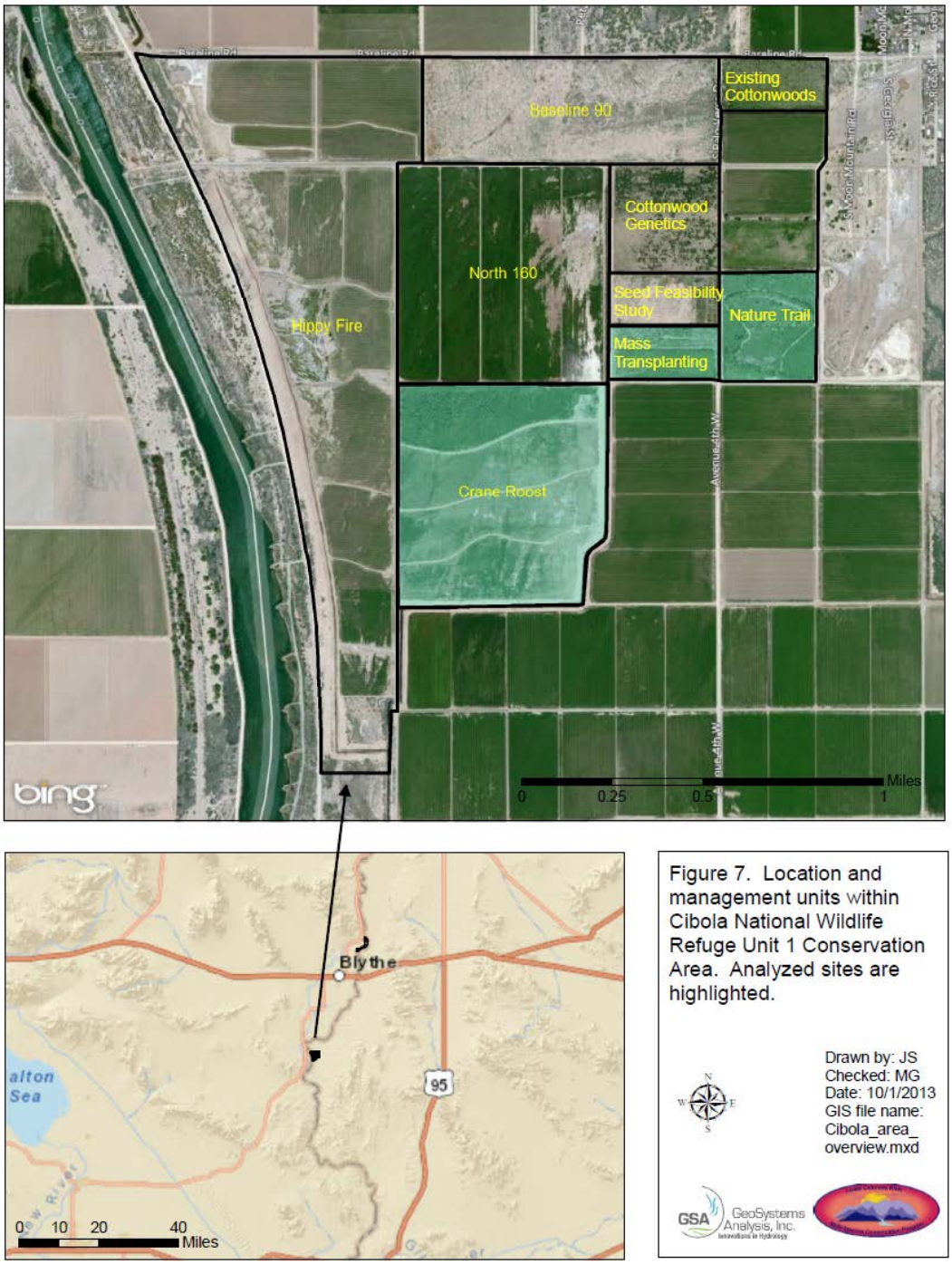

Figure 7.—Location and management units within Cibola NWR Unit #1.
Analyzed sites are highlighted.

North 160 prior to project completion. Based on historic satellite images, soil conditioning (i.e., removal of existing vegetation, planting and maintenance of a grass cover crop, and salt leaching/irrigation) at the Hippy Fire site began in 2005. The site was planted in spring 2013. Clearing of the North 160 site began in 2009, and irrigation to leach soil salts began in approximately September 2010.

Planted areas are irrigated through a network of canals with gates at each field unit. Two irrigation gates are used to irrigate the Nature Trail, one is used to irrigate Mass Transplanting, and four are used to irrigate Crane Roost (one gate per field). Irrigation at Cibola NWR Unit #1 typically occurs once or twice per month for each plot during the growing season.

NRCS soil survey data for the northeastern portion of Cibola NWR Unit #1 (i.e., Nature Trail and Mass Transplanting) are shown on figure 8. Silt loam is the dominant soil texture classification for this portion, and the northern portion of the Nature Trail was identified as strongly saline (figure 8). NRCS soil survey data for Crane Roost indicate a soil textural classification of highly saline silt loam (figure 9).

3.0 METHODS

As part of this study, GSA conducted an integrated assessment of soil and groundwater conditions at the LCR MSCP conservation areas. First, historic soil salinity data were compiled for all LCR MSCP conservation areas as available (section 3.1). Based on available background information, soil and groundwater monitoring plans were developed to characterize the BLCA, PVER Phase 02, PVER Phase 03, and planted portions of Cibola NWR Unit #1. Soil texture and groundwater depth conditions at these three sites cover the range of those anticipated at LCR MSCP conservation areas. Development of soil sampling plans was detailed in GSA (2010a). A review of the soil sampling plan, along with detailed sample collection and testing procedures, is provided in section 3.2. The groundwater monitoring plan and preliminary monitoring results were provided in GSA (2011b). A review of the monitoring plan for groundwater levels (i.e., depth and elevation) and groundwater quality is provided in section 3.3.

3.1 Historic Soil Salinity Data

To provide baseline data and determine the historic extent of salinity issues at LCR MSCP habitat creation sites, Reclamation and contractors were contacted. Available data are summarized in table 3. It was anticipated that spatially explicit data would allow for further analysis of historic salinity values. However, due to inconsistent or unspecified soil collection intervals, lack of documentation of sample collection locations, and a paucity of data for sites monitored for this

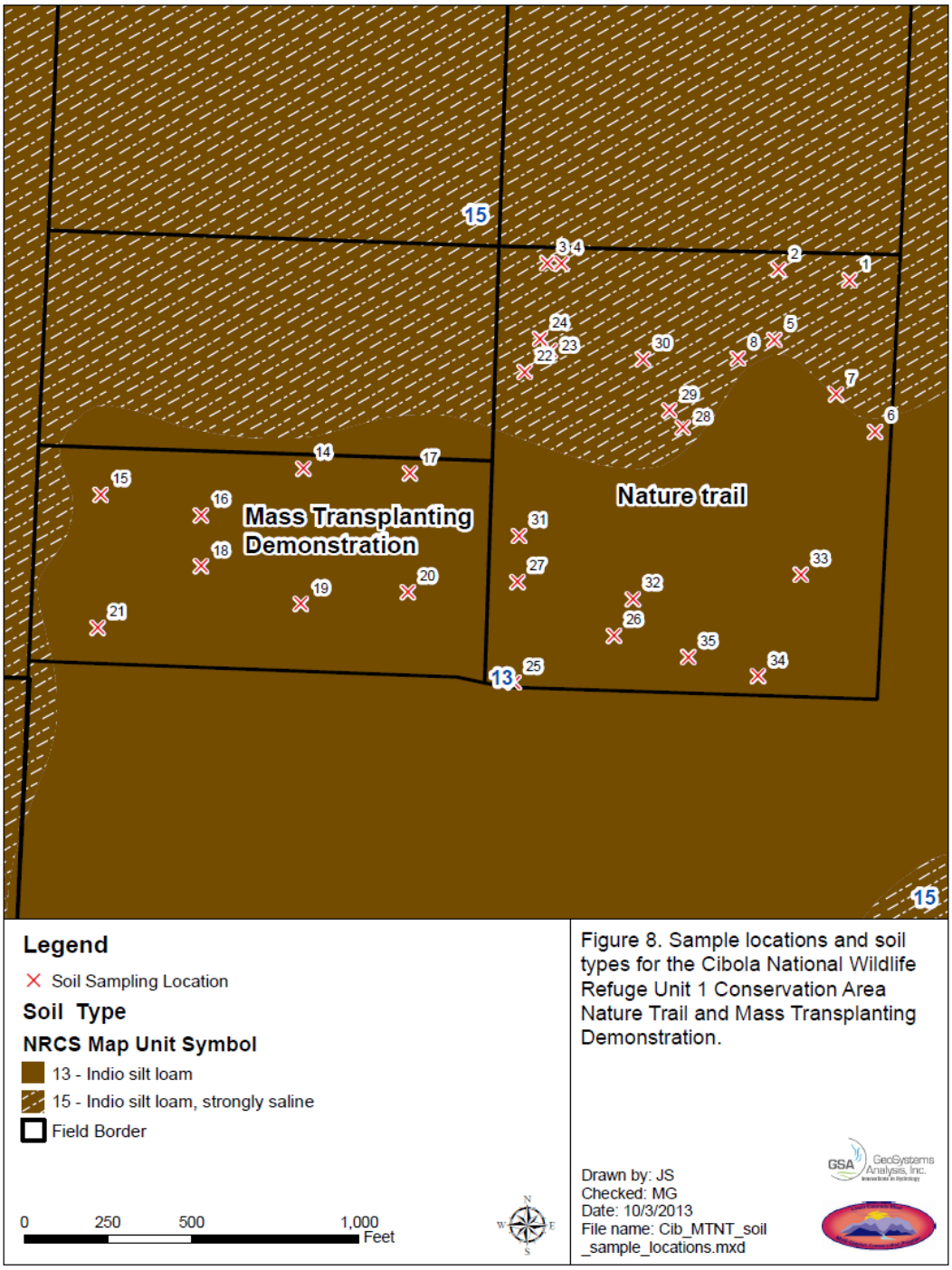

Figure 8.—Sample locations and soil types at the Nature Trail and Mass Transplanting.

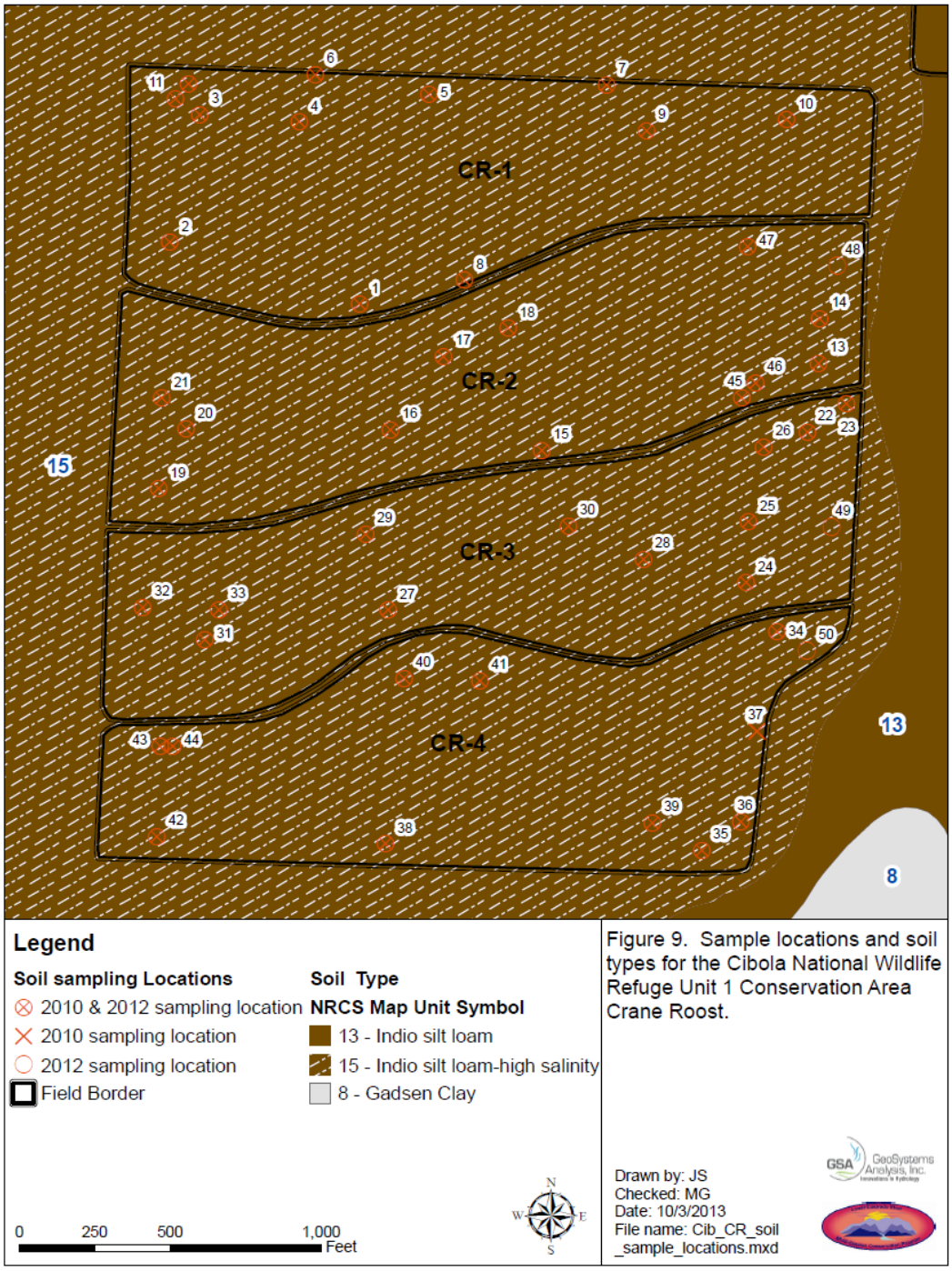

Figure 9.—Sample locations and soil types at Crane Roost.

Table 3.—Historic soil salinity results from LCR MSCP project sites

Area	Site	Sampling date	Data source
BLCA		December 2002	Reclamation 2005[1]
		September 2003	Reclamation 2005[1]
		October 2004	2005soilsamples.pdf[2]
		March 2006	2006soilsamples.pdf[2]
Cibola NWR Unit #1	Crane Roost	March 2009	CRAIN ROOST.pdf[2]
	Seed Feasibility Study (Research 3)	2006–2007	GSA 2008[1]
Cibola Valley Conservation Area (CVCA)	CVCA1	May 2009	CVCA Phase 1 Soil and Tissue 5-26-09.pdf[2]
	CVCA2	May 2009	CVCA Phase 2 Soil and Tissue 5-26-09.pdf[2]
Hart Mine Marsh		October 2006	Hautzinger, Kundargi, and Donnelly (2007[1])
IPCA		February 2010	Imperial Soils.xls[2]
PVER	PVER Phase 01	March 2008	31208 PVER Phase 1.pdf[2]
	PVER Phase 02	March 2008	31208 PVER phase 2.pdf[2]
	PVER Phase 03	February 2008	PVER phase 3.pdf[2]
	PVER Phase 04	April 2009	PVER phase 4 Soil Report.pdf[2]
	PVER Phase 05	January 2010	PVER phase 5 NO-1.pdf, PVER phase 5 SO-1.pdf[2]

[1] Complete data available in the reference.
[2] Data provided in attachment 1. (*Note*: Raw data sheets for the attachments listed in this report are available from the LCR MSCP Office in Boulder City, Nevada; phone: 702-293-8577). For more information about the program, visit the LCR MSCP Web site at https://www.lcrmscp.gov/).

project, extensive analysis of historic data was not possible. Additionally, laboratory soil salinity testing methods were inconsistent. Methods for determination of soil EC were not always presented. Some laboratories have approximated saturated paste extract soil EC by doubling 1:1 soil:water solution extract EC (GSA 2008), which does not necessarily represent the true saturated paste extract soil EC (Rhoades et al. 1999; Shaw 1999) that is determined by testing the salinity of vacuum-extracted water collected from soil at saturation (U.S. Salinity Laboratory 1954).

Because of the constraints discussed above, analysis of historical soil salinity data was limited. Previously collected soil EC data were summarized by site and subsite, as possible, for initial observations of the extent of soil salinity issues at LCR MSCP habitat creation sites. Values presented in tables are presented as they were reported in the references. Composite soil salinity values were

calculated as the depth interval-weighted for samples at a given sampling location and date. Composite samples provide one value for each location and represent the average value for the sample location.

3.2 Soil Monitoring

Soils were sampled at the BLCA, PVER, and Cibola NWR Unit #1 for analysis of soil texture, soil salinity (soil EC), and soil geochemical parameters (section 3.2.1). Soil geochemical parameters include those relevant to salinity, sodicity, and nutrient availability. Site-specific sampling schematics, detailed in section 3.2.1, were developed to account for site layouts and presence of areas where salinity-related plant stress was apparent. Soil sampling and analysis methods, common to all sites, are detailed in section 3.2.3; data analysis methods are described in section 3.5.

3.2.1 Sampling Design Considerations

Variability in irrigation layouts, planting schematics, and vegetation success indicated the need for site-specific sampling plans. While designing sample locations and frequency for each site, considerations were made for vegetation types, distance from irrigation sources, and irrigation regimes as discussed below.

3.2.1.1 Vegetation Types

Many sites monitored for this project contained significant sections comprised of mixed mesquite or other vegetation besides cottonwood and willow (*Salix* spp.). The primary objective of the sampling plan was the investigation of salinity conditions within, and the effects specific to, cottonwood-willow species (riparian trees). Thus, sample density was higher in areas comprised primarily of cottonwood-willow communities. Where vegetation planted across a site varied (in the PVER and portions of Cibola NWR Unit #1), stratified random sampling was conducted to ensure that sampling occurred in all of the vegetation types present.

3.2.1.2 Distance from Irrigation Source

Where possible, sample locations were stratified within a field to allow for evaluation of the effect of distance from the irrigation source on soil salinity. Applied water depth for each irrigation event varied based on distance from the irrigation source (i.e., less water and therefore reduced percolation will occur with increasing distance from the irrigation source). In the case of Crane Roost, vegetation was planted in blocks based on distance from the irrigation source. Therefore, blocking by vegetation type also resulted in blocking by distance from the irrigation source. However, for other fields at the BLCA, the PVER, and

Cibola NWR Unit #1vegetation type does not vary with distance from the irrigation source, and blocks were created by dividing the field with increasing distance from the irrigation source.

3.2.1.3 Irrigation Regime

At the BLCA, fields were irrigated on a prescribed frequency ranging from once per week during the growing season to never. To observe the effects of irrigation frequency on soil salinity, sampling was stratified by irrigation regime. Variable irrigation frequencies were not imposed at other project sites.

3.2.2 Sampling Schematics

The conditions above were considered on a site-by-site basis for each restoration site, and site-specific sampling designs are as described below.

3.2.2.1 Beal Lake Conservation Area

Due to the small size and large number of individual fields at the BLCA, GSA prioritized the soil sample regime to maximize the number of soil samples collected from fields containing a significant portion of cottonwood and willow trees. However, additional samples were collected so that all fields were sampled to maximize spatial coverage and the number of samples for each irrigation regime (see figure 3). Twenty-one of the fields were identified as having a significant component of mixed riparian trees, whereas the remaining eight fields were composed primarily of mixed mesquite (honey and screwbean mesquite), with some components of arrowweed (*Pluchea sericea*), saltcedar, and various shrubs.

As a rule of thumb for the 2010 sampling design, three locations were sampled from fields containing greater than 50% visually estimated cover of riparian trees; two locations were sampled from fields with between 1 and 50% visually estimated cover of riparian trees; and one location was sampled from fields with no riparian cover. Finally, at least two locations were sampled from each corner field (Fields A, E, EE, and MM; see figure 3). Two locations each were sampled from Fields E and MM, and three locations were sampled from Fields AA and EE due to their large size and to allow statistical comparison of Field EE, the one field that did not receive irrigation prior to 2010, with other fields.

Within each field, sampling locations were chosen randomly based on a 50-foot (ft) grid. Each grid point was assigned a number, and a random number generator (www.random.org) was used to select points for the desired number of sample locations. In total, 70 locations were sampled at the BLCA during 2010, resulting in 210 soil salinity tests (3 per sampling location) and 21 soil texture and nutrient analyses (table 4).

Table 4.—Soil sampling summaries by conservation area for May – June, 2010 and February 2012

Site	Area (acres)	Number of:	Soil EC/ gravimetric water content		Visual-manual texture		Hydrometer texture	Macro- and micro-nutrients	
			2010	2012	2010	2012	2010[1]	2010	2012
BLCA	107	Locations	70	70	70	9	7	7	7
		Samples[2]	210	207	210	27	21	21	21
PVER	127	Locations	41	41	41	0	4	4	4
		Samples	123	123	123	0	12	12	12
Cibola NWR Unit #1	197	Locations	77	80	77	3	10	10	8
		Samples	230	240	230	9	30	30	24
Total	**431**	Locations	188	191	193	12	21	21	19
		Samples	563	570	578	36	63	63	57

[1] No hydrometer analysis was completed in 2012.
[2] Three sample depth intervals per location unless capillary fringe was encountered prior to 6 ft below ground surface.

Soil material was excavated from field EE during winter 2011–12, and the field was replanted with coyote willow prior to February 2012. Four additional fields (Fields E, II, J, and MM) were also cleared of vegetation at this time. Due to changes in management and/or incorporation into other research projects, these fields were not resampled during 2012. The nine locations sampled in these fields during 2010 were reassigned to other fields with a paucity of data during 2010 (table 5). Thus, soils were sampled at 70 locations again in 2012. However, saturated soils were encountered at three locations prior to reaching 4 ft below ground surface, resulting in only two samples for those locations— one location in Field AA and both locations in Field I. Thus, a total of 207 samples were analyzed for EC in 2012.

3.2.2.2 Palo Verde Ecological Reserve

Sampling at PVER Phases 02 and 03 for this project is summarized in table 6. At PVER Phase 02, two random sample locations were selected along the centerline of each check with 50-ft spacing. For the Goodding's willow portion of each irrigation check, a sample location was randomly selected on one side. A coin flipper was used to select which side (east or west) the sample would be collected on, and the north-south location of the sample was randomly selected along the centerline of the vegetation type, again on 50-ft spacing. One sampling location

Table 5.—BLCA soil sampling summary by field for May – June 2010 and February 2012

	Soil EC/ gravimetric water content[1]		Visual-manual texture[1]		Hydrometer texture[1]	Nutrients and geochemistry[1]	
Field	**2010**	**2012**	**2010**	**2012**	**2010[2]**	**2010**	**2012**
A	3/9	3/9	3/9	0/0	1/3	1/3	0/0
B	2/6	2/6	2/6	0/0	0/0	0/0	0/0
C	3/9	3/9	3/9	0/0	1/3	1/3	1/3
D	3/9	3/9	3/9	0/0	0/0	0/0	0/0
E	2/6	0/0	2/6	0/0	1/3	1/3	0/0
F	3/9	3/9	3/9	0/0	0/0	0/0	1/3
G	1/3	1/3	1/3	0/0	0/0	0/0	0/0
H	2/6	3/9	2/6	1/3	0/0	0/0	0/0
I	2/6	2/4	2/6	0/0	0/0	0/0	0/0
J	1/3	0/0	1/3	1/3	0/0	0/0	0/0
K	3/9	4/12	3/9	0/0	0/0	0/0	0/0
L	3/9	4/12	3/9	1/3	0/0	0/0	1/3
M	2/6	2/6	2/6	0/0	0/0	0/0	0/0
N	2/6	3/9	2/6	1/3	0/0	0/0	0/0
O	2/6	2/6	2/6	0/0	0/0	0/0	0/0
P	3/9	4/12	3/9	1/3	0/0	0/0	0/0
Q	3/9	3/9	3/9	0/0	1/3	1/3	1/3
AA	3/9	3/8	3/9	0/0	0/0	0/0	0/0
BB	1/3	3/9	1/3	2/6	0/0	0/0	1/3
CC	3/9	3/9	3/9	0/0	0/0	0/0	0/0
DD	1/3	3/9	1/3	2/6	1/3	1/3	1/3
EE	3/9	0/0	3/9	0/0	1/3	1/3	0/0
FF	3/9	3/9	3/9	0/0	0/0	0/0	0/0
GG	3/9	3/9	3/9	0/0	0/0	0/0	0/0
HH	2/6	2/6	2/6	0/0	0/0	0/0	0/0
II	1/3	0/0	1/3	0/0	0/0	0/0	0/0
JJ	2/6	2/6	2/6	0/0	0/0	0/0	0/0
KK	3/9	3/9	3/9	0/0	0/0	0/0	0/0
LL	3/9	3/9	3/9	0/0	0/0	0/0	1/3
MM	2/6	0/0	2/6	0/0	1/3	1/3	1/3

[1] Indicates the number of sample locations/number of samples.
[2] No hydrometer analysis was completed in 2012.

Table 6.—PVER and Cibola NWR Unit #1 soil sampling summary for May – June 2010 and February 2012

Area	Site	Site area (acres)	Soil EC/ gravimetric water content[1]		Visual-manual texture[1]		Hydrometer texture[1]	Nutrients and geochemistry[1]	
			2010	2012	2010	2012	2010[2]	2010	2012
PVER	PVER Phase 02	43	21/63	21/63	21/63	0/0	2/6	2/6	2/6
	PVER Phase 03	84	20/60	20/60	20/60	0/0	2/6	2/6	2/6
Cibola NWR Unit #1	Nature Trail	36	22/65	22/66	22/65	0/0	2/6	2/6	1/3
	Mass Transplanting	20	8/24	8/24	8/24	0/0	1/3	1/3	1/3
	Crane Roost	140	47/141	50/150	47/141	3/9	7/21	7/21	6/18

[1] Indicates the number of sample locations/number of samples.
[2] No hydrometer analysis was completed in 2012.

was randomly selected for two areas of cottonwood on the southern end of PVER Phase 02 to provide maximal spatial coverage of sampling. A total of 21 locations were sampled from PVER Phase 02 (63 samples).

In PVER Phase 03, stratified random sampling was conducted within each check. The checks were halved based on distance from the irrigation source, and a point was randomly selected within each half per a 50-ft grid. Thus, 20 locations were sampled from PVER Phase 03 (60 samples).

3.2.2.3 Cibola National Wildlife Refuge Unit #1 Conservation Area

A sampling summary for Cibola NWR Unit #1 is provided in table 6. The Nature Trail was designed as a park, constructed with distinct vegetation types and several subfields hydraulically connected by pipes beneath walking paths. The total area of the site is approximately 36 acres. The Nature Trail is irrigated from two irrigation turnouts on the western edge of the site. Sampling was randomized within subfields (areas delineated by the walking path) and further subdivided based on vegetation type. Higher priority for sampling was given to riparian tree areas. Twenty-two locations were sampled at the Nature Trail in both 2010 and 2012 (see figure 8).

Mass Transplanting consists of two subfields, planted during 2005 (southern half) or 2006 (northern half), with a total acreage of approximately 20 acres. The southern half consists of densely planted riparian trees (primarily cottonwood at spacing of 4–6 ft). The northern half consists of a sparser stand of riparian trees. The field is irrigated from a turnout on the east edge of the field. For design, the

field was split into planting years (i.e., the southern half [2005] and the northern half [2006]). Each subfield was then quartered into blocks with increasing distance from the irrigation source (east to west). One sampling location was randomly selected per block along a transect bisecting each subfield (see figure 8). This design resulted in a total of 8 sampling locations in Mass Transplanting.

Crane Roost, southwest of Mass Transplanting, includes four independently irrigated non-rectangular fields covering approximately 140 acres. The northernmost field (CR-1) was planted prior to 2009 with significant portions of mesquite and lesser components of cottonwood and willow. The southern three fields (CR-2, CR-3, and CR-4, from north to south) were planted during 2009 with sections of coyote willow and Goodding's willow and lesser amounts of cottonwood and mesquite.

Each field was blocked based on vegetation types. Within each block, a minimum of three samples were collected for all blocks containing some portion of cottonwood or willow. Larger sections of Goodding's willow in the southern three fields were sampled at a minimum of four locations. All sample locations were selected randomly within each block on a 50-ft grid. The resulting sampling layout is shown on figures 9 and 10. This design resulted in a total of 47 sampling locations in Crane Roost for 2010. Three additional sampling locations were added to Crane Roost for 2012 to allow three sample locations in each field within the mesquite vegetation area.

3.2.3 Soil Sampling and Analysis Methods

A hand-operated soil auger was used to collect soil samples for EC testing. Soil was collected at 2-ft intervals to a maximum of 6 ft below ground surface, for a maximum of three soil samples per sampling location. Each 2-ft interval was homogenized and subsampled for testing. The capillary fringe (saturated soil) was sometimes reached at the BLCA and Cibola NWR Unit #1 at less than 6 ft below ground surface. When saturated soil was encountered, augering was terminated, and soil excavated to that point was homogenized and subsampled. The actual sampling depth interval was recorded.

Samples were triple-bagged in labeled freezer bags to maintain soil moisture until testing. Upon return to the GSA laboratory, "wet" samples were weighed and then oven dried. Gravimetric water content was determined using ASTM D 2216 methods. "Dry" samples were tested for EC using the 1:1 soil/water method, following Rhoades (1986). To estimate saturated paste extract EC, the 1:1 EC result was multiplied by three, following US Salinity Laboratory (1954).

Sample particle size fractions (percent sand, silt, and clay) were estimated using hydrometer-calibrated visual-manual methods. One person estimated particle size

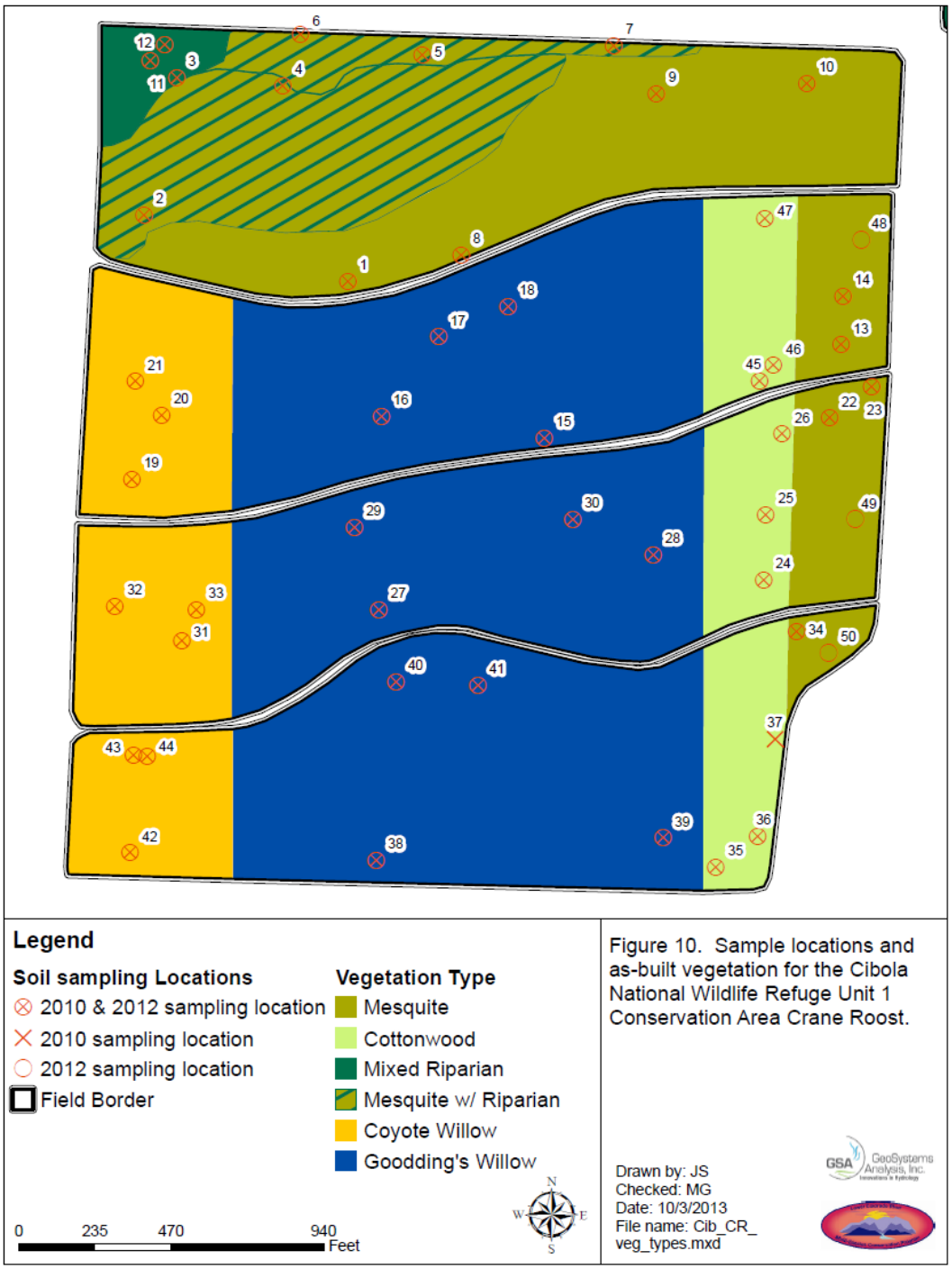

Figure 10.—Sample locations and as-built vegetation at Crane Roost.

fractions using visual-manual methods (ASTM D 2488-09a). A subset of samples obtained during 2010 (63 of 578) was analyzed for particle size fractions via a hydrometer (ASTM D 422) at the GSA laboratory. Regression equations were determined for the hydrometer-estimated particle size fractions versus manual estimations to obtain correction parameters, which were then applied to all soil samples. A subset of samples (i.e., 53 of the 578 samples for 2010 and 57 of the 570 samples for 2012), which were selected to represent the range of encountered soil textures, were submitted to IAS Laboratories (Phoenix, Arizona) for analysis of geochemical parameters and fertility (table 7).

Table 7.—Soil fertility and geochemical analysis methods

Parameter	Analytical method
1:1 pH	American Society of Agronomy, Inc., and Soil Science Society of America, Inc. (ASA/SSA) 1982 Methods of Soil Analysis Part 2, 12-2
Soluble salt EC	ASA/SSA 1982 Methods of Soil Analysis, Part 2, 10-3.3
Available calcium, potassium, sodium, and magnesium	Council on Soil Testing and Plant Analysis (CSTPA) 1974
Nitrate-nitrogen	Carter 1993 Method 7.3.3
Phosphate	CSTPA, 1974
Boron	Walsh and Beaton 1973
Sulfate-sulfur	Carter 1993 Method 9.2
ESP	U.S. Salinity Laboratory 1954

3.3 Groundwater Monitoring

Groundwater monitoring methods were detailed in GSA (2011b) and are reviewed briefly below.

3.3.1 Schematics and Installation Methods

For each of the three monitoring sites, a grid of piezometers was established (PVER) or expanded (BLCA and Cibola NWR Unit #1) in 2010 and 2011. Piezometers were instrumented with either a Rugged LevelTroll 100 or AquaTroll 200 sensor and data logger system (In-Situ, Inc., Fort Collins, Colorado) for automated measurement of groundwater depth. Both systems include a pressure transducer, which measures the absolute pressure at the sensor location and a thermistor to measure water temperature. The gage pressure at the

sensor was determined by correcting for atmospheric pressure, measured at one piezometer per restoration site using a barometric pressure sensor (BaroTroll 100, In-Situ, Inc.). The gage pressure was then converted to a depth of water by dividing by the density of water. In addition to the measurements of pressure and temperature, the AquaTroll 200 sensor measures and records EC of groundwater within the piezometer. This sensor was placed in a subset of piezometers (i.e., two per conservation area) for automated measurement of EC. All data loggers were programmed to record groundwater elevation and EC at 4-hour intervals.

At the BLCA, transects of piezometers were previously installed by Reclamation along the northeast and southeast edges of the site. A subset of these piezometers was instrumented as part of this study. To enhance this network, five additional piezometers were installed within the BLCA using driven piezometer points and hand-augered casing advancement methods. Additionally, one driven piezometer point (PZ4BL) was installed southwest of the BLCA between Beal Lake and the Colorado River main stem. Because this piezometer is outside the boundaries of the BLCA, the groundwater elevation at this location provided background data to observe seasonal groundwater elevation changes without the influence of BLCA irrigation. Installations were completed between December 2010 and February 2011. The resulting monitoring schematic for the BLCA is provided on figure 11. In January 2012, five Reclamation piezometers were destroyed during excavation for the marsh on the northeast side of the BLCA — EE-3, NN-1, NN-2, NN-3, and NN-6. On February 29, 2012, the Rugged Level Troll previously installed in NN-1 was recovered and moved to piezometer A.

No piezometers were previously installed at the PVER. During December 2010, seven piezometers were installed on the perimeter of the monitoring area, and one was installed near the center. All piezometers were installed using a hollow-stem auger. The resulting monitoring schematic for the PVER is provided on figure 12.

At Cibola NWR Unit #1, 10 driven piezometer points were established for previous projects (GSA 2010a) but provided coverage for only the Seed Feasibility Study field. One piezometer was located north of Crane Roost (installed by an unknown party) and was used for monitoring during field visits. Eleven additional driven piezometer points and hand-augered casing advancement piezometers were installed between December 2010 and February 2011. The resulting monitoring schematic for Cibola NWR Unit #1 is provided on figure 13.

3.3.2 Monitoring

Groundwater elevations were recorded using electronic sensors as detailed above, and piezometers instrumented with AquaTroll 200s were also monitored for EC data on the programmed 4-hour interval. Data were downloaded from all monitored piezometers on approximately a quarterly basis (table 8). Upon arrival at each piezometer, groundwater depth was measured using an electronic sounder (Solinst Model 101 Water Level Meter, Georgetown, Ontario, Canada). The date,

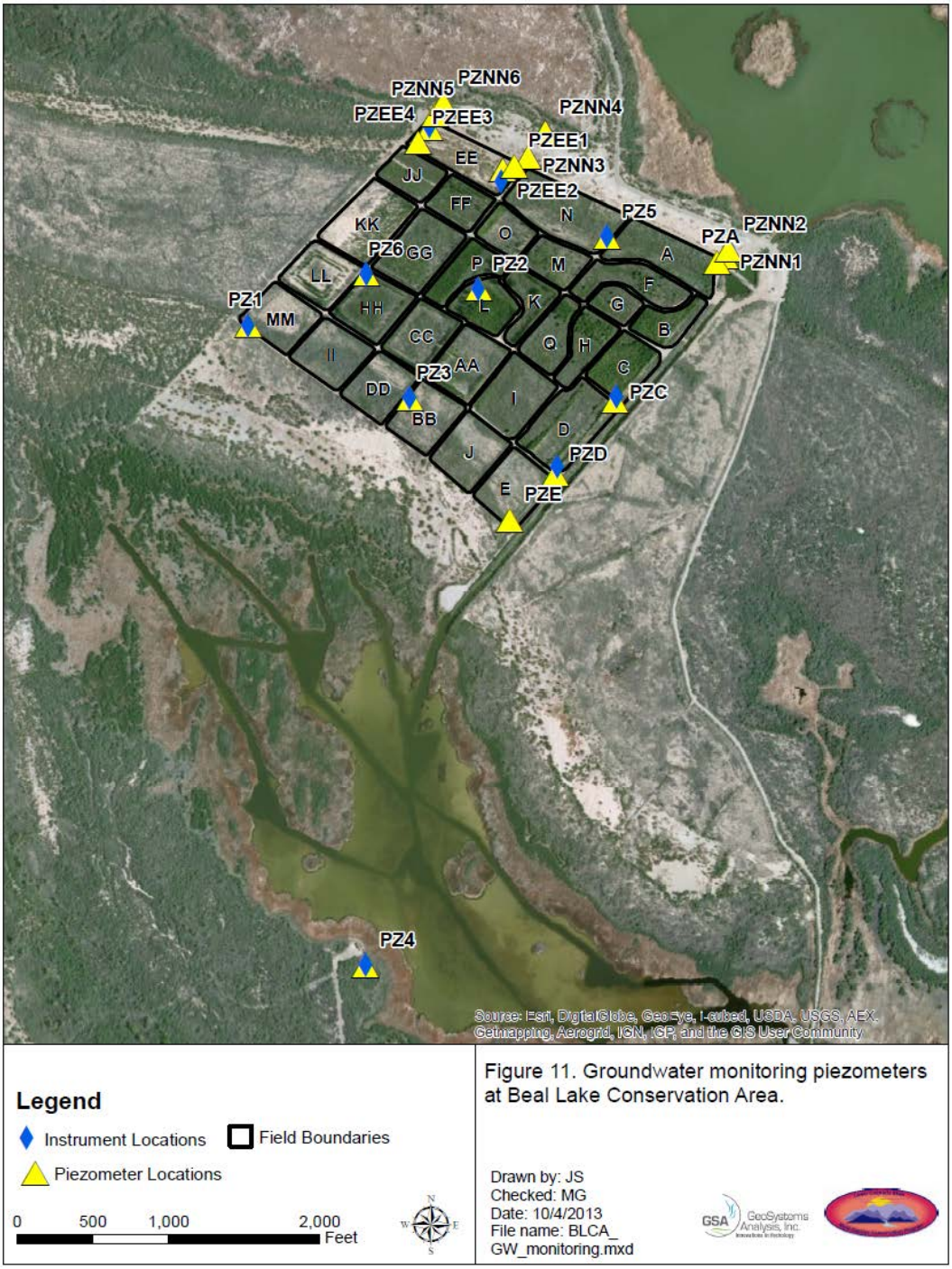

Figure 11.—Groundwater monitoring piezometers at the BLCA.

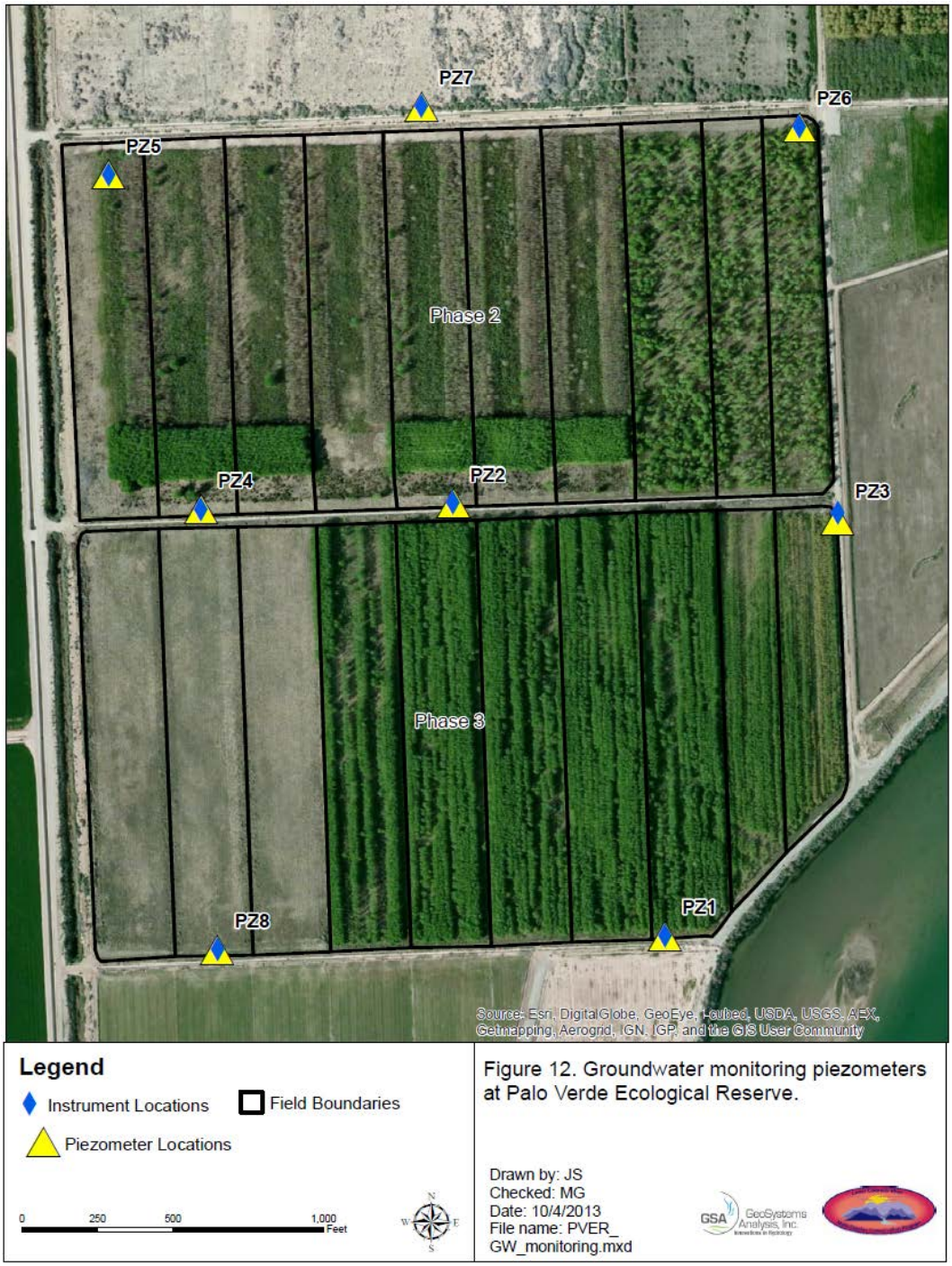

Figure 12.—Groundwater monitoring piezometers at the PVER.

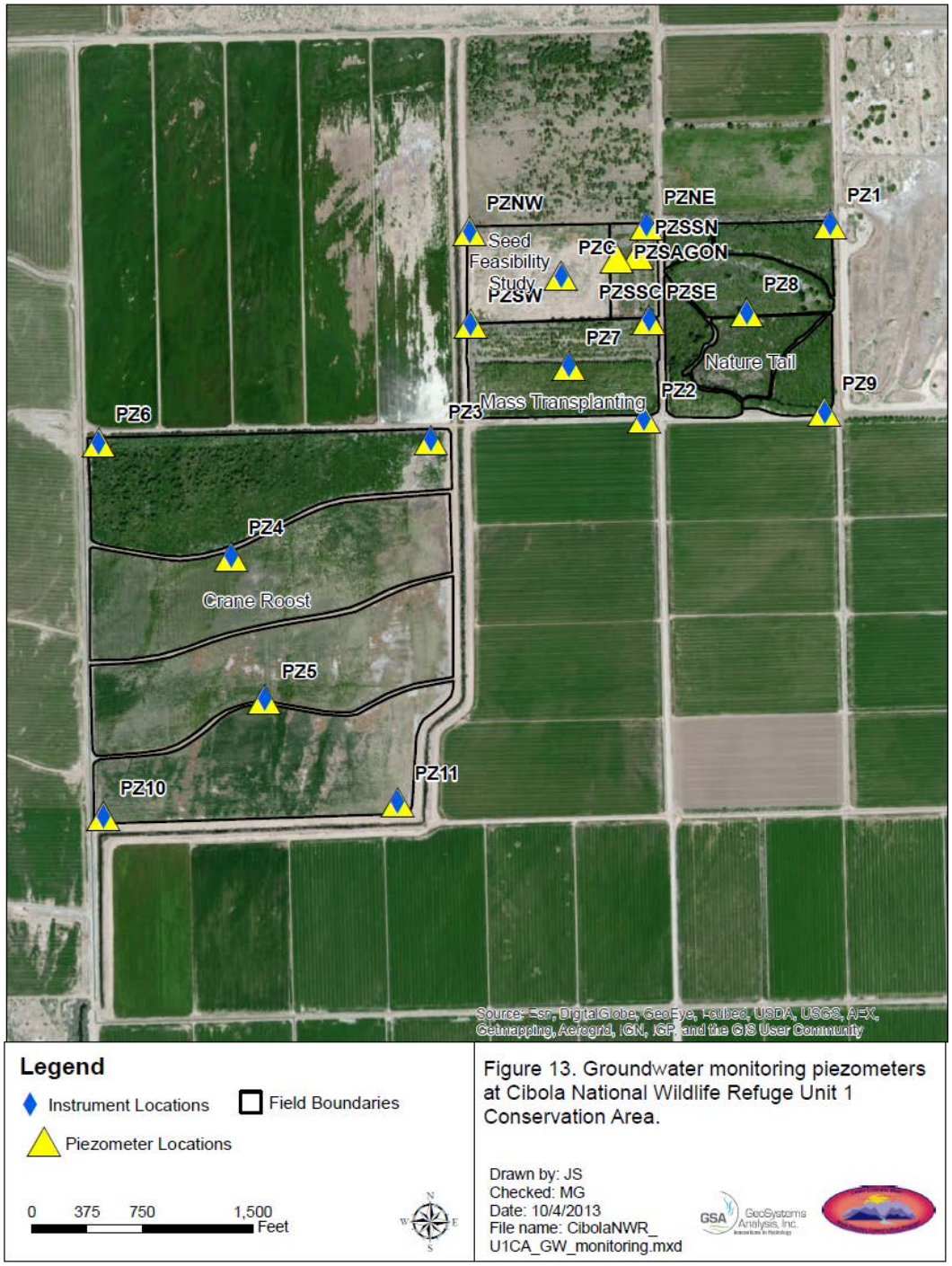

Figure 13.—Groundwater monitoring piezometers at Cibola NWR Unit #1.

Table 8.—Groundwater level and EC data collection schedule

Site	Sampling date	Number of groundwater EC sample locations
BLCA	2/9/2011	13
	5/20/2011	18
	9/1/2011	17
	11/29/11 – 11/30/11	17
	2/28/12 – 2/29/12	13
	4/30/2012	12
	7/24/2012	13
PVER	2/10/2011	8
	5/19/2011	8
	8/31/2011	8
	11/30/2011	8
	2/22/12 – 2/23/12	8
	5/1/2012	8
	7/24/12 – 7/25/12	8
Cibola NWR Unit #1	2/10/2011	13
	5/18/2011 – 5/19/2011	20
	8/30/2011 – 8/31/2011	20
	12/1/2011	20
	2/22/2012 – 2/23/2012	19
	5/1/2012 – 5/2/2012	20
	7/25/2012 – 7/26/2012	20

time, and distance to groundwater from the top of the well casing was recorded in field books and on data sheets. The depth and elevation to groundwater was then determined by subtracting the distance to groundwater from the well casing from the height of the well casing above the ground surface and the elevation of the top of the well casing, respectively. These measurements were used to determine the elevation of the pressure transducer and to correct for any stretching of the suspension cord. Data were downloaded from each logger using the data logger utility and reviewed in the field to confirm remaining battery life and to monitor for malfunctioning equipment. Groundwater depths at non-instrumented wells were manually determined using the electronic sounder.

Groundwater samples were obtained for all instrumented and non-instrumented piezometers during each field visit. Each piezometer was bailed for a minimum of three well volumes. EC was determined for the final bailed sample using a field EC meter (HYDAC Digital Conductivity/Temperature/pH Tester, On-Site

Instruments LLC, Lewis Center, Ohio). Adjacent surface waters (e.g., irrigation supply canals or sumps, drainage ditches, and flooded fields), when present and accessible, were also analyzed for EC using the field EC meter.

To supplement field EC measurements and correlate groundwater EC to total dissolved solids, groundwater samples were collected during the July 24–26, 2012, groundwater monitoring field visit and analyzed for the constituents listed in table 9. BLCA samples were obtained from two piezometers (PZ1BL and PZ2BL) and adjacent to the irrigation pump on July 24, 2012. PVER samples were obtained from two piezometers (PZ3PVER and PZ4PVER) and from the irrigation ditch north of PVER Phase 02. Cibola NWR Unit #1 samples were obtained for three piezometers (PZ6C, PZ7C, and PZ11C) and from the irrigation canal west of Crane Roost.

Table 9.—Groundwater laboratory analysis constituents and analysis methods

Category/method	Analytes
Inductively coupled plasma total metals—E200.7	Calcium, magnesium, potassium, and sodium
Anions by ion chromatography—E300	Chloride, fluoride, nitrogen (nitrate), and sulfate
Alkalinity—SM3320B	Bicarbonate, carbonate, hydroxide, and total alkalinity
EC—SM2510 B	Conductivity
Total dissolved solids (residue, filterable)—SM2540C	Total dissolved solids

3.4 Vegetation Monitoring

It was initially anticipated that vegetation data collected annually by LCR MSCP contractors (i.e., LCR MSCP Work Task F1: Habitat Monitoring at Conservation Areas) would be used to correlate vegetation success with salinity levels. However, the spatial coverage of existing vegetation plots did not sufficiently overlap with established soil monitoring locations.

For the BLCA, high heterogeneity among fields precluded generalization correlation of tree condition with salinity monitoring results. At PVER Phases 02 and 03, stress of riparian vegetation was not observed, and soil and groundwater salinity was lower than published salinity tolerances for all samples collected during this study (section 4.2.2). Therefore, PVER Phases 02 and 03 did not offer a good opportunity to correlate vegetation success with soil salinity and was omitted from analysis. Despite these limitations and lack of funding to complete a detailed vegetation analysis for the project, a preliminary assessment of the

effects of soil and groundwater salinity was needed to guide long-term recommendations. The variability in salinity and apparent vegetation stress across the monitoring sites was reviewed, and it was determined that the southern three fields of Crane Roost provided a good opportunity to obtain initial information. High soil salinity variability was observed at the site (section 4.2.2.), and all trees in this area were planted in the same season (spring 2009), which allowed for direct comparison of growth and survival rates. Vegetation was surveyed based on the salinity sampling grid as described below.

3.4.1 Crane Roost Vegetation Monitoring Methods

Vegetation at Crane Roost was surveyed on May 29–30, 2012. A measuring tape was anchored at the 2012 soil sampling locations, and every tree and shrub present within the assigned radius was measured for height, diameter at breast height, and condition index. The monitored radius was determined based on the observed tree density. A minimum 1-meter (m) (3.3 ft) radius was observed. If less than 10 live trees fell within that radius, the radius was increased in 1-m intervals to a maximum of 10 m (32.8 ft). Condition was assigned as good, fair, poor, or dead. Trees were assumed dead if no leaves or green stems were observed. Canopy closure was determined using a spherical densiometer. The number of sky and canopy hits was recorded for each cardinal direction, and the average was used to determine canopy closure, following Reclamation vegetation monitoring methods. The effects of salinity on tree density, height, and total canopy closure were assessed as described in section 4.0.

3.5 Data Analysis

Soil EC, texture, and geochemical data were compiled in Microsoft Excel. Data were summarized by depth interval (e.g., 0–2 ft below ground surface, 2–4 ft below ground surface, and 4–6 ft below ground surface) as well as composite for a given location (e.g., 0–6 ft below ground surface). Summary statistics were obtained using Excel and JMP V9 (SAS Institute, Cary, North Carolina). A graphical presentation of the results was completed using Excel. Spatial analysis and interpolations of salinity and texture results were completed using ArcGIS 10.1 (Esri, Redlands, California). While salinity distribution at most sites was approximately normal, a log-10 conversion was needed for Crane Roost to improve normality and reduce skew observed in statistical model results. Analysis of covariance (ANCOVA) models were constructed in JMP to determine the effects of soil texture (with percent sand as a continuous variable) and depth interval (categorical variable) on resultant soil salinity. Depending on site-specific sampling layouts, additional effects were included in the ANCOVAs as follows:

- *BLCA*: Irrigation frequency (categorical)
- *PVER*: Distance from irrigation source (i.e., north half or south half of the field) (categorical)
- *Mass Transplanting*: Distance from irrigation source (i.e., east or west half of the field) (categorical)
- *Crane Roost*: Field within Crane Roost (categorical), distance from irrigation source, as grouped by as-built vegetation species (categorical)

Effect tests were obtained for independent variables, and Student's t-tests on least-squares means were used to determine significant differences among categorical variables. The alpha level for all tests was 0.05. Soil moisture comparison was not an objective of the study, so gravimetric water content data were not analyzed in detail. Results were tabularized in Microsoft Excel for inclusion in the attachments. (*Note*: Raw data sheets for the attachments listed in this report are available from the LCR MSCP Office in Boulder City, Nevada; phone: 702-293-8577). For more information about the program, visit the LCR MSCP Web site at https://www.lcrmscp.gov/.

Groundwater elevation, EC, and chemistry data collected during the study were compiled in Microsoft Excel. Summary charts were developed for groundwater depth, groundwater elevation, and field EC data. Annual geometric means of groundwater EC for each piezometer were interpolated in ArcGIS to determine spatial trends. Additional groundwater chemistry data (laboratory data for parameters in table 9) were summarized in Microsoft Excel.

For Crane Roost, data were summarized to determine live tree density and height by species and condition category. Correlations between soil salinity and canopy closure, tree density, and tree height were performed in JMP. Correlations were plotted in Excel for graphical presentation.

4.0 RESULTS

Available historic soil salinity data (collected prior to the current study) for all LCR MSCP conservation areas are presented in section 4.1. Results for soil samples collected at the BLCA, PVER, and Cibola NWR Unit #1 for this project are presented in section 4.2. Groundwater monitoring (groundwater level and quality) data collected at the BLCA, PVER, and Cibola NWR Unit #1 for this project are presented in section 4.3. Results for vegetation monitoring conducted at Crane Roost are presented in section 4.4.

4.1 Historic Soil Salinity Summary

Soil salinity results from previous projects on the LCR are compiled in table 10. At the BLCA, soil salinity ranged from below to much above native species salinity tolerances for each sampling event. The average soil salinity ranged between 1 and 10 dS/m, depending on the selection of fields sampled. For example, the October 2004 sampling event included a greater number of samples from Field EE, which had higher salinity values and skewed averages higher. For the 2002 and 2003 sampling events, average soil salinity for the BLCA was below the cottonwood and willow riparian tree tolerance (8 dS/m), but average soil salinity was greater than 8 dS/m in the 2004 event.

Table 10.—Historic soil EC data summary for LCR MSCP conservation areas
(n = number of samples; $\bar{x}$ = mean; s = standard deviation)

Area	Site	Sample date	n	Soil EC (dS/m)			
				$\bar{x}$	Maximum	Minimum	s
BLCA	N/A	December 2002	18	3.77	18.95	1.17	4.31
	N/A	September 2003	14	1.25	2.18	0.75	0.50
	N/A	October 2004	28	9.42	47.00	0.53	15.62
PVER	PVER Phase 01	March 2008	2	1.07	1.34	0.80	N/A
	PVER Phase 02	March 2008	5	0.70	1.00	0.31	0.26
	PVER Phase 03	February 2008	34	0.56	1.51	0.16	0.38
	PVER Phase 04	February 2008	40	0.85	1.69	0.43	0.30
	PVER Phase 05	January 2010	55	1.03	1.90	0.43	0.38
Cibola NWR Unit #1	Crane Roost	October 2004	32	15.10	115.00	0.72	22.96
	Seed Feasibility Study	July 2006	24	3.63	16.80	1.30	3.52
	Seed Feasibility Study	November – December 2007	36	6.89	23.33	1.77	4.98
Cibola Valley Conservation Area (CVCA)	CVCA1	May 2009	3	0.99	1.26	0.64	0.32
	CVCA2	May 2009	3	0.99	1.26	0.64	0.32
IPCA	N/A	February 2010	13	20.95	47.57	4.80	11.05
Hart Mine Marsh	N/A	October 2006	10	101.89	246.00	19.59	71.29

As for the BLCA, historic soil EC values at Cibola NWR Unit #1 have ranged from less than 1 dS/m to much above native riparian tree tolerances. Some soil EC results at Crane Roost have exceeded 100 dS/m, and average soil salinity at this site in 2004 was greater than cottonwood-willow tolerances. At the Cibola NWR Unit #1 Seed Feasibility Study site, soil salinity was frequently above cottonwood-willow tolerances in both 2006 and 2007, with 2007 average composite soil salinity (6.89 dS/m) approaching thresholds for mature tree mortality.

Soil salinity at the PVER and the Cibola Valley Conservation Area (CVCA) was consistently low in the 2008 to 2010 sampling events. No soil EC results at these sites exceeded riparian tree tolerances. Conversely, soil EC at the IPCA and Hart Mine Marsh was quite high during the single sampling events at each of those areas (2010 and 2006, respectively). The mean soil EC for both conservation areas was higher than the salinity tolerance of native riparian species. At Hart Mine Marsh, even the minimum value is more than double the salinity tolerance of native riparian vegetation.

4.2 Soil Monitoring

Soil texture, salinity, nutrient, and geochemistry results are presented in the following subsections. Soil water content data are provided in attachment 2.

4.2.1 Soil Texture

Hydrometer-calibrated soil particle size fractions for all sites are presented in table 11. Soils at the BLCA are dominated by sand, with mean values over 90% of the particle size fraction for all depth intervals. However, at depths greater than 2 ft, greater percentages of silt and clay are encountered on the northern and southwest edges of the site (Fields BB, EE, J, and N; figure 14).

At both PVER sites, sand also comprised the majority of the soil particle fraction, with values slightly lower than for the BLCA (figures 15 and 16). On the eastern portion of PVER Phase 02, the 0–6 ft composite is approximately 80% sand. This area of relatively finer-grained soils corresponds to NRCS soils maps (see figure 5). Similarly, relatively finer-grained soils were encountered on the east-central and southwest portions of PVER Phase 03, corresponding to loam, clay loam, and clay soil textures also predicted by the NRCS soil maps (see figure 6).

Soils samples from the eastern portion of Cibola NWR Unit #1 (Mass Transplanting and Nature Trail) averaged less than 20% sand between 0–2 ft below ground surface. Samples taken at 2–4 and 4–6 ft below ground

Table 11.—Hydrometer-calibrated soil texture
(n = number of samples; $\bar{x}$ = mean; s = standard deviation)

Conservation area	Site	Sampling depth	n	% sand $\bar{x}$	% sand s	% sand max.	% sand min.	% silt $\bar{x}$	% silt s	% silt max.	% silt min.	% clay $\bar{x}$	% clay s	% clay max.	% clay min.
BLCA		0–2 ft	79	93	3	96	81	4	2	13	1	3	1	8	2
		2–4 ft	79	92	8	96	53	4	5	32	2	3	2	15	2
		> 4 feet	79	91	13	97	39	5	9	39	1	4	4	25	2
		Composite	79	92	7	96	59	5	5	28	2	4	2	15	2
PVER	PVER Phase 02	0–2 ft	21	84	4	89	75	12	4	20	7	4	0	5	4
		2–4 ft	21	85	6	90	72	11	6	23	7	4	1	7	4
		4–6 ft	21	86	6	90	68	10	5	26	7	4	1	6	4
		Composite	21	85	5	89	72	11	5	23	7	4	0	5	4
	PVER Phase 03	0–2 ft	20	82	6	87	69	13	5	25	9	5	1	7	4
		2–4 ft	20	83	7	89	69	13	6	23	7	5	1	8	4
		4–6 ft	20	86	6	89	70	10	5	25	7	4	1	7	4
		Composite	20	84	5	88	71	12	4	22	8	5	1	7	4
Cibola NWR Unit #1	Nature Trail	0–2 ft	21	15	4	21	12	49	12	64	24	35	14	65	18
		2–4 ft	22	26	14	57	9	46	9	59	28	28	12	61	14
		4–6 ft	22	34	14	63	15	45	10	57	26	21	6	34	11
		Composite	21	25	8	43	15	47	6	55	36	28	8	49	19
	Mass Transplanting	0–2 ft	8	18	3	24	15	57	5	63	50	25	4	34	22
		2–4 ft	8	37	22	57	12	40	12	59	29	23	13	41	14
		4–6 ft	8	56	8	64	45	30	5	37	25	14	3	18	11
		Composite	8	37	9	46	24	42	4	48	37	21	5	31	16
	Crane Roost	0–2 ft	50	33	13	60	15	48	11	64	28	19	4	30	11
		2–4 ft	50	39	16	63	15	42	11	64	26	19	8	41	11
		4–6 ft	50	39	18	63	12	41	11	60	26	20	9	45	11
		Composite	50	37	10	62	19	44	7	55	27	19	4	31	11

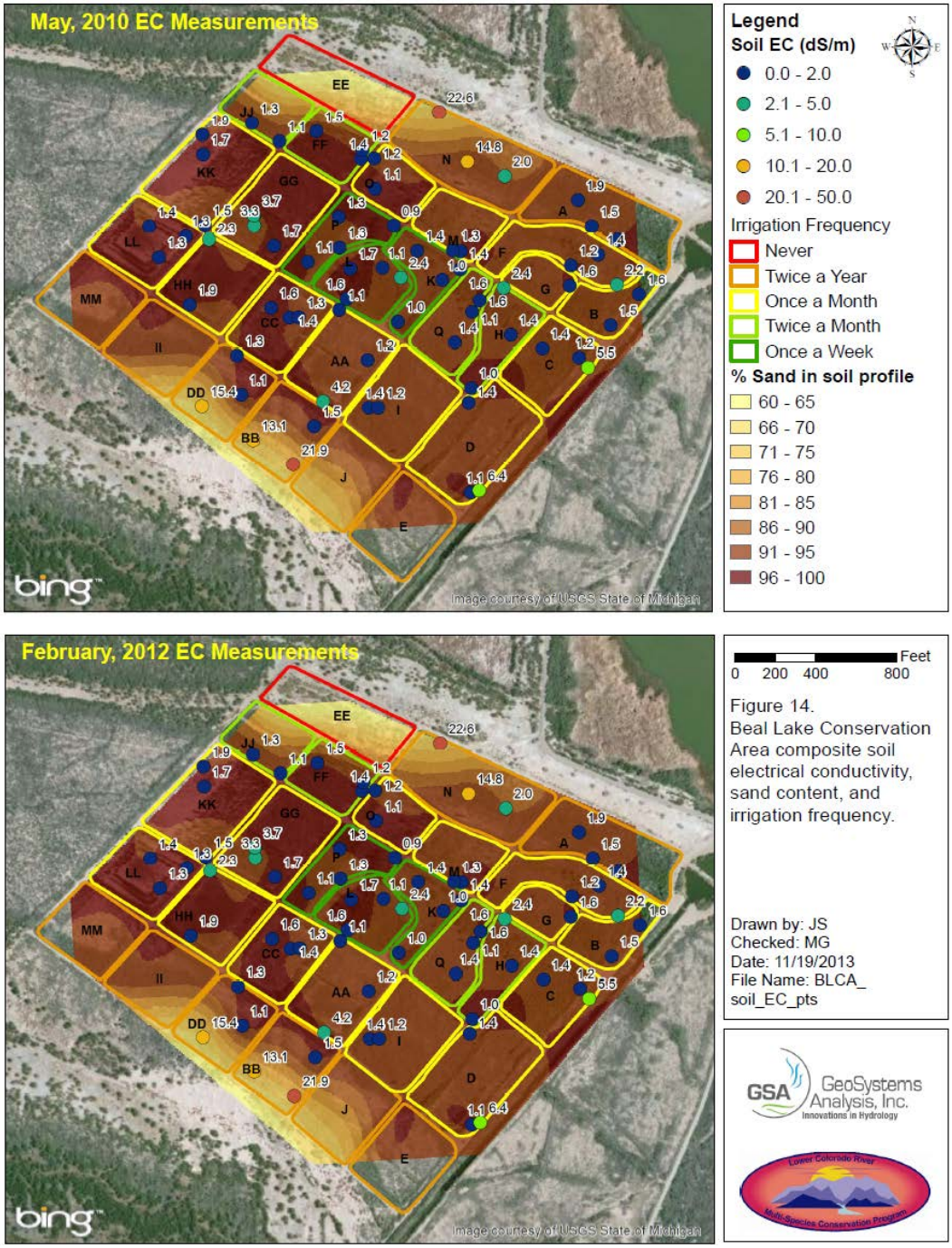

Figure 14.—BLCA composite soil EC, sand content, and irrigation frequency.

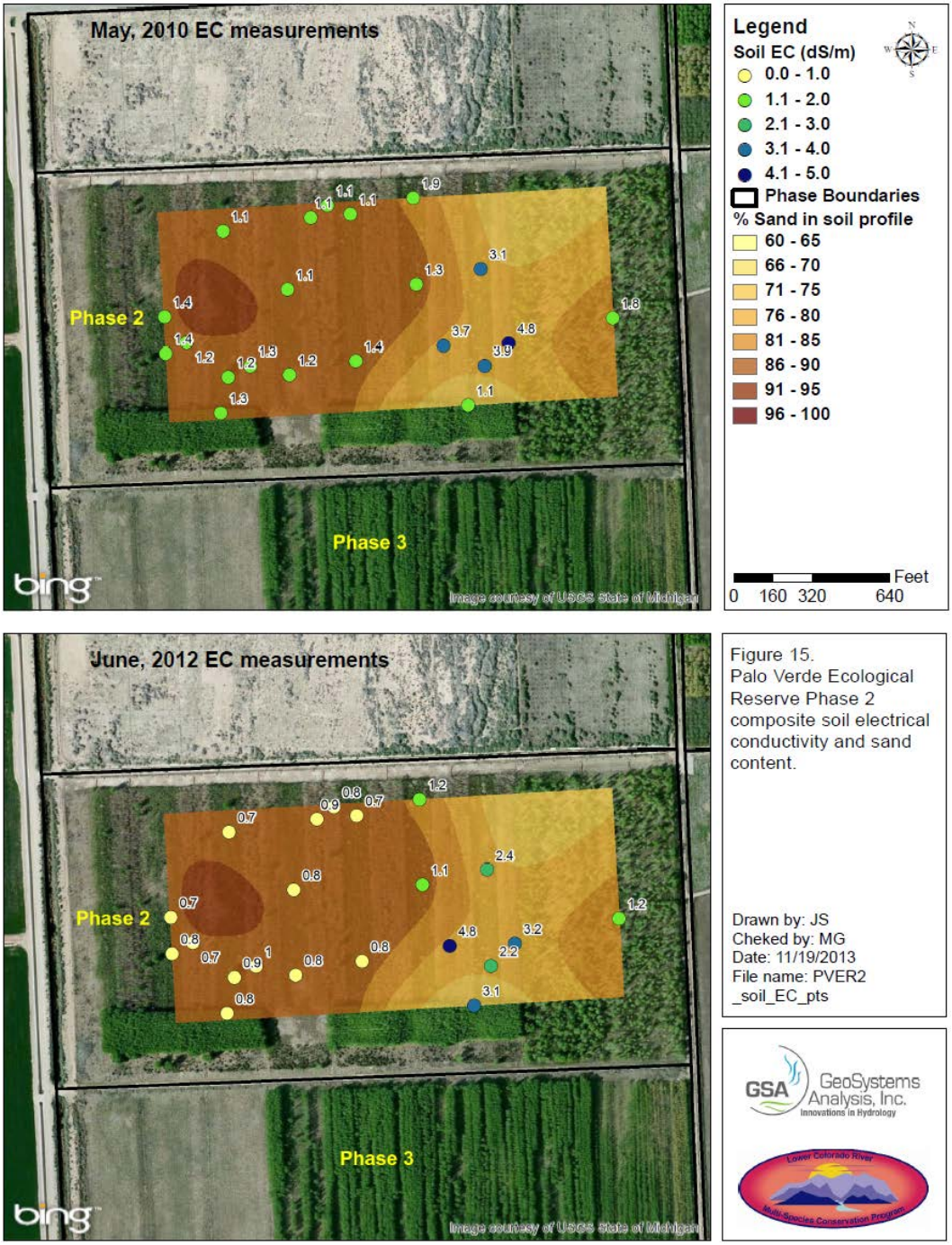

Figure 15.—PVER Phase 02 composite soil EC and sand content.

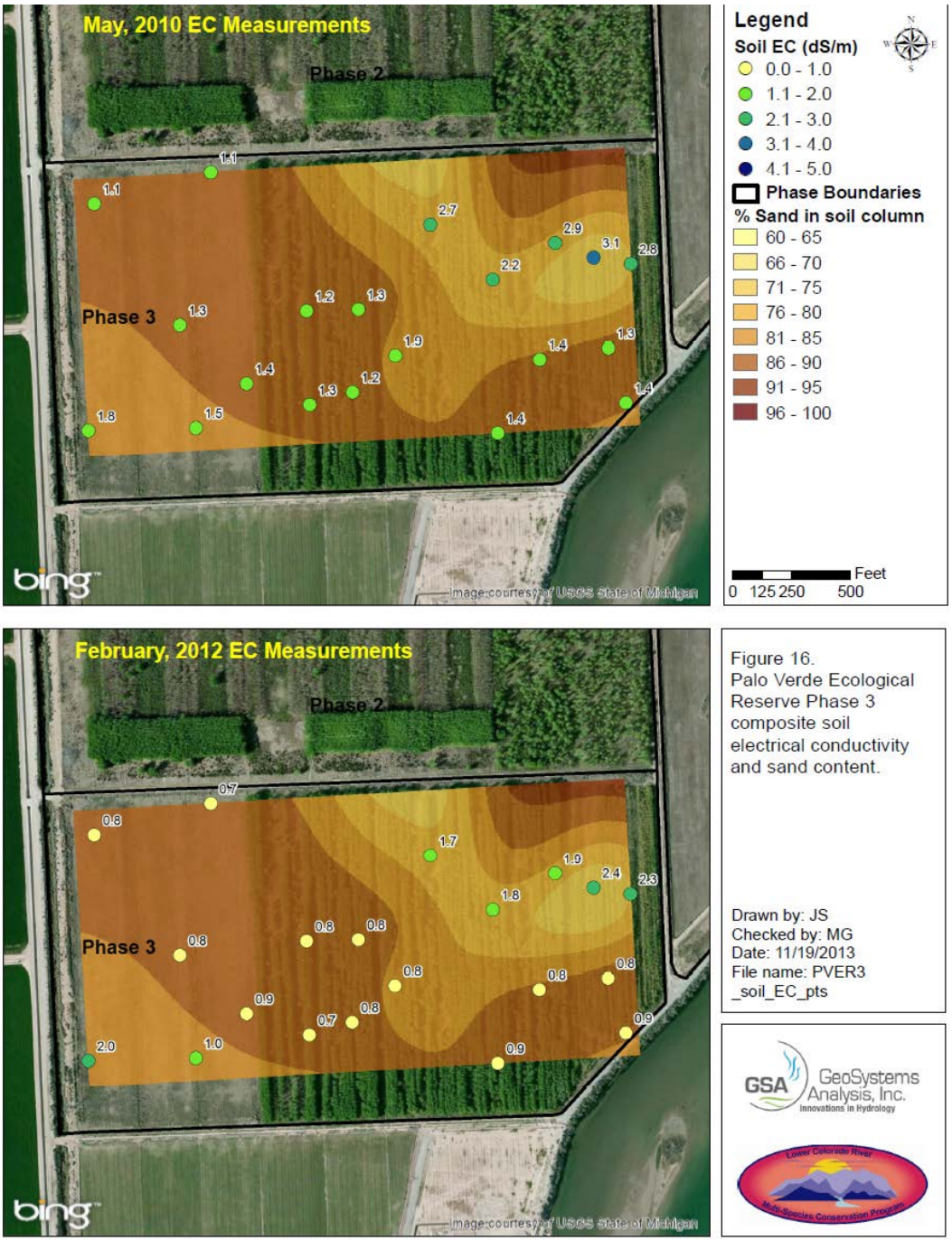

Figure 16.—PVER Phase 03 composite soil EC and sand content.

surface had a higher percentage of sand. Mass Transplanting averaged 37 and 56% sand, respectively, and the Nature Trail averaged 26 and 34%, respectively. Conversely, average percent sand at Crane Roost was relatively uniform with depth, averaging 33% for 0–2 ft below ground surface and 39% for samples collected at both 2–4 and 4–6 ft below ground surface. No consistent spatial trends were observed for composite soil texture at Cibola NWR Unit #1 (figures 17 and 18).

4.2.2 Soil Salinity

Soil EC results by depth for 2010 and 2012 are provided in table 12. Composite soil salinity is presented graphically on figure 19, and statistical comparisons of composite EC are shown in table 13. Spatial distribution of composite soil salinity is shown on figures 14–18.

Soils at the PVER had the lowest EC of the three sites in 2010: PVER Phase 02 composite soil EC averaged 1.8 dS/m and PVER Phase 03 composite soil EC averaged 1.7 dS/m. Mean composite soil EC at the BLCA was 4.5 dS/m. The Cibola NWR Unit #1 composite EC was highest of the three sites, with a mean of 11.7 dS/m at Mass Transplanting, 7.4 dS/m at the Nature Trail, and 17.9 dS/m at Crane Roost.

In 2012, the PVER maintained the lowest composite soil EC, Cibola NWR Unit #1 maintained the highest, and the BLCA maintained its position between the two. Composite soil EC decreased from 2010 to 2012 for the BLCA fields irrigated at least twice per month, both PVER sites, and Crane Roost. Soil EC at other sites did not change between sampling events. Below, each site is discussed in further detail.

4.2.2.1 Beal Lake Conservation Area

Soil analysis results for the PVER indicate that irrigation frequency is inversely correlated with soil EC, with irrigation less than once per month resulting in increased soil salinity (figure 19). This relationship is due in part to the distribution of soil textures at the site. Fields with less frequent irrigation are generally located in finer-textured soils (see figure 14), and soil EC was inversely correlated with percent sand (i.e., higher percent sand resulted in lower soil salinity, table 14). When corrected for percent sand via ANCOVA analysis, increasing irrigation frequency resulted in decreased soil EC for 2010 results but not for 2012 (table 14). ANCOVA results for the interaction of sand and irrigation frequency are provided in table 15. The interaction shows that percent sand was inversely correlated with soil composite soil EC (i.e., a higher percent sand resulted in lower salinity) only for irrigation frequency of twice per year and once per week.

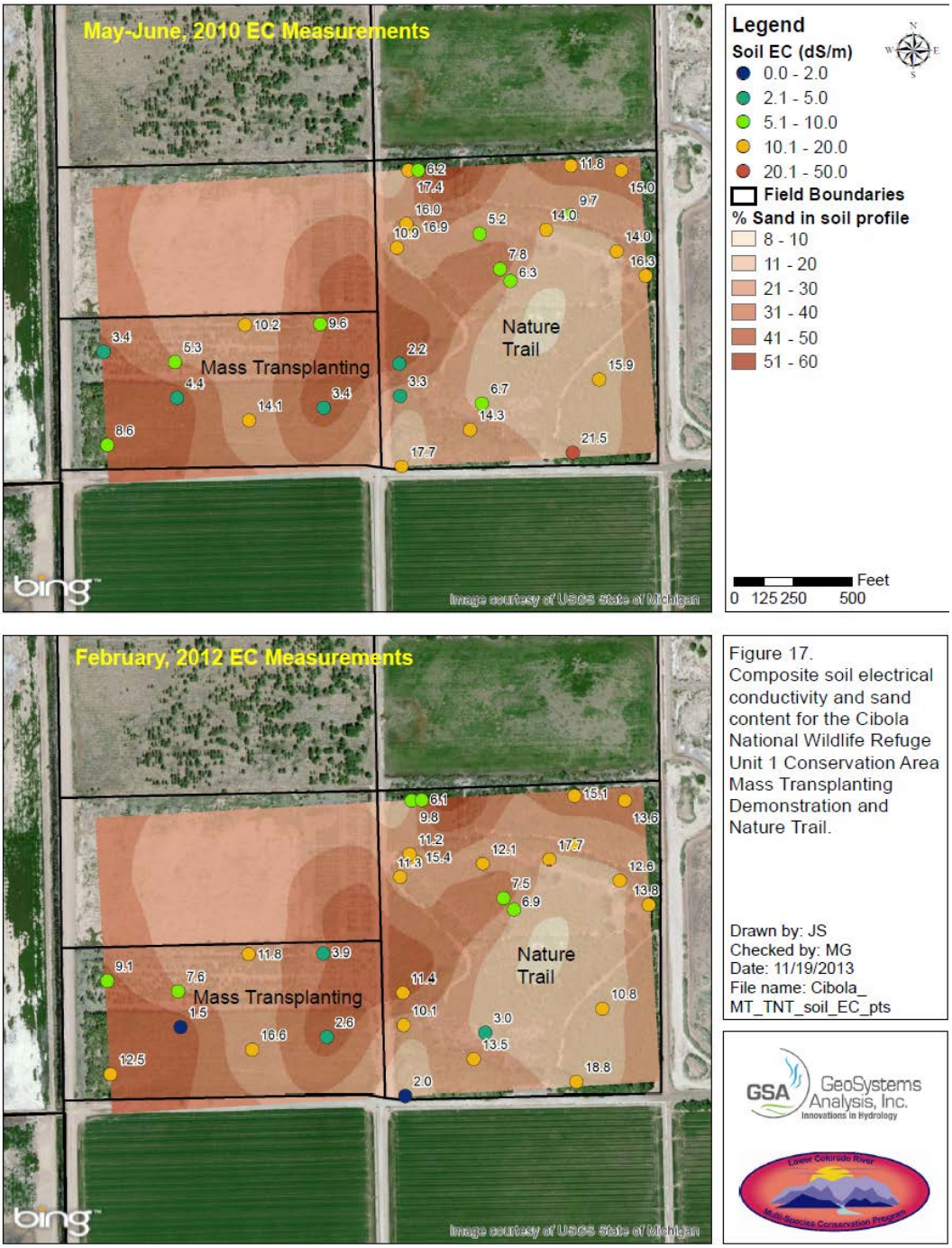

Figure 17.
Composite soil electrical conductivity and sand content for the Cibola National Wildlife Refuge Unit 1 Conservation Area Mass Transplanting Demonstration and Nature Trail.

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Date: 11/19/2013
File name: Cibola_ MT_TNT_soil_EC_pts

Figure 17.—Composite soil EC and sand content for and Mass Transplanting and the Nature Trail.

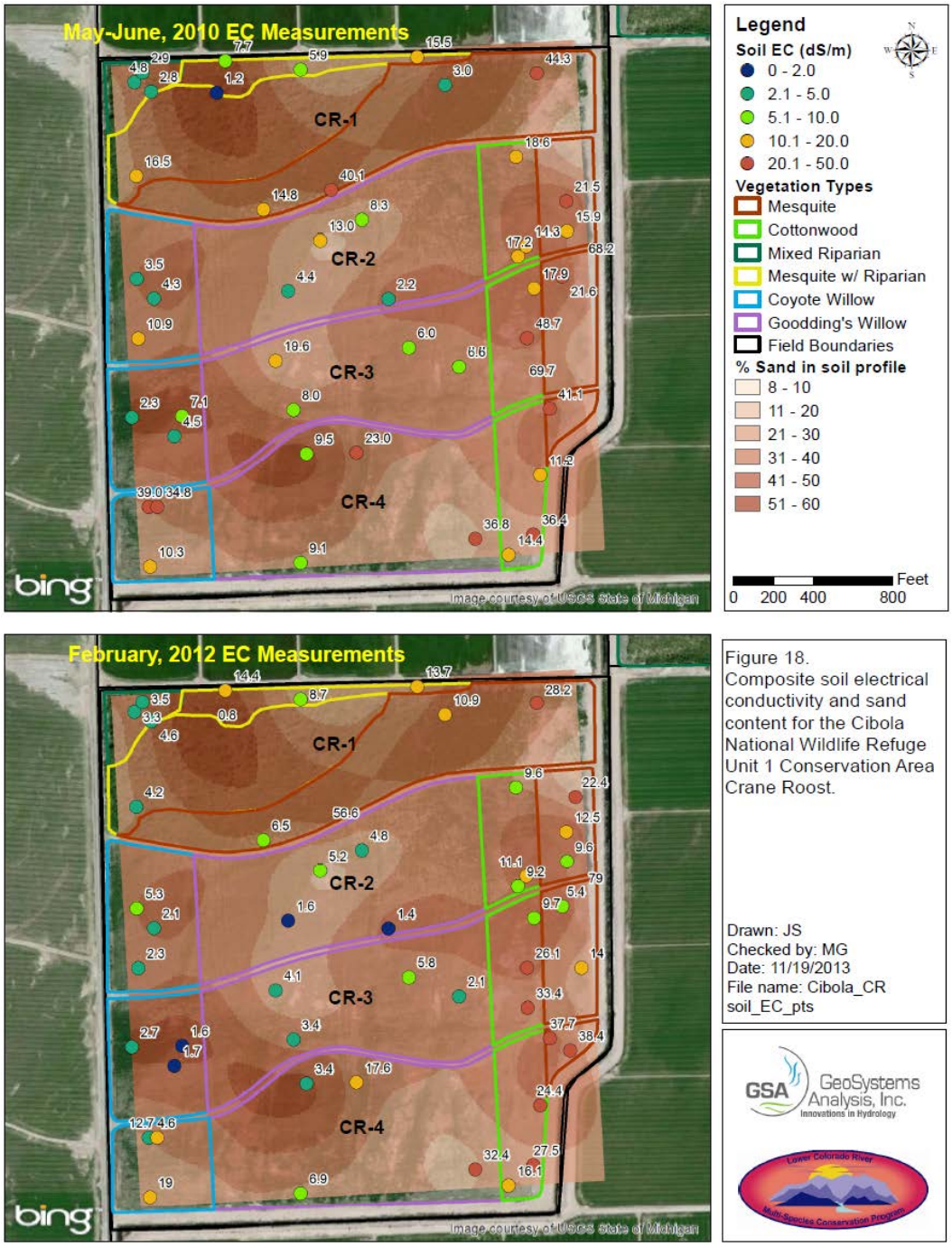

Figure 18.—Composite soil EC and sand content for Crane Roost.

Table 12.—EC data for May – June 2010 and February 2012
(n = number of samples; $\bar{x}$ = mean; s = standard deviation)

Conservation area	Site	Sampling depth	Saturated paste extract soil EC (dS/m)										p-value[1]
			2010					2012					
			n	$\bar{x}$	s	Max.	Min.	n	$\bar{x}$	s	Max.	Min.	
BLCA		0–2 ft	70	5.0	11.0	66.2	1.0	70	2.1	2.7	14.5	0.6	0.071
		2–4 ft	70	5.3	10.4	47.6	1.4	70	3.5	6.9	34.7	0.7	0.686
		> 4 ft	70	3.3	3.7	19.8	1.6	67	2.7	2.9	20.0	1.1	0.774
		Composite	70	4.5	8.0	41.5	1.5	70	2.8	4.4	22.6	0.9	0.189
PVER	PVER Phase 02	0–2 ft	21	1.7	0.4	2.9	1.2	21	1.2	0.3	1.8	0.9	< 0.0001
		2–4 ft	21	1.5	0.8	3.1	0.9	21	1.4	1.4	6.5	0.6	0.708
		4–6 ft	21	2.1	2.3	8.9	0.8	21	1.6	1.7	6.2	0.6	0.126
		Composite	21	1.8	1.1	4.8	1.0	21	1.4	1.1	4.8	0.7	0.035
	PVER Phase 03	0–2 ft	20	1.9	0.6	3.4	1.4	20	1.2	0.4	2.1	0.7	< 0.0001
		2–4 ft	20	1.8	1.0	4.2	0.9	20	1.2	0.7	2.7	0.6	< 0.0001
		4–6 ft	20	1.5	0.7	3.7	0.8	20	1.1	0.7	2.9	0.5	0.025
		Composite	20	1.7	0.7	3.1	1.1	20	1.2	0.6	2.4	0.7	< 0.0001
Cibola NWR Unit #1	Nature Trail	0–2 ft	21	11.0	8.6	36.7	3.0	22	8.1	5.8	26.6	1.4	0.134
		2-4 ft	22	13.6	8.3	34.0	2.0	22	14.7	6.6	28.0	2.0	0.598
		4–6 ft	22	12.0	9.4	42.3	1.6	22	12.4	9.6	36.6	1.9	0.758
		Composite	21	11.7	5.3	21.5	2.2	22	11.5	4.4	18.8	2.0	0.689
	Mass Transplanting	0–2 ft	8	5.0	2.1	8.7	3.1	8	5.2	4.4	12.3	1.9	0.917
		2–4 ft	8	10.8	7.2	22.9	2.8	8	11.8	7.9	20.8	1.0	0.709
		4–6 ft	8	6.3	4.4	14.8	2.5	8	8.1	6.9	18.2	1.3	0.157
		Composite	8	7.4	3.9	14.1	3.4	8	8.2	5.3	16.5	1.5	0.560
	Crane Roost	0–2 ft	47	20.4	28.3	142.8	1.1	50	15.2	26.9	158.0	1.0	0.012
		2–4 ft	47	14.5	17.7	74.1	1.2	50	11.5	14.1	56.9	0.7	0.065
		4–6 ft	47	18.7	12.4	47.0	1.3	50	14.2	11.6	60.9	0.8	< 0.001
		Composite	47	17.9	16.8	69.7	1.2	50	13.6	15.3	79.0	0.8	0.002

[1] The probability of no change between sampling dates based on matched pairs t-tests.

Irrigation frequency differentially affected EC at depth, as shown by the significant interaction between irrigation frequency and depth (table 16). For 2010 results, no irrigation (never, Field EE) resulted in the highest soil salinity at 0–2 and 2–4 ft depth intervals even when corrected for a lower percent sand (table 17). Irrigation twice per year resulted in higher soil EC for the 0–2 and 2–4 ft depth intervals than irrigation more frequently in both 2010 and 2012 (tables 16 and 17). For soils greater than 4 ft below ground surface and irrigated at least twice per year (i.e., excluding Field EE, which was not receiving irrigation in 2010), irrigation frequency did not affect soil EC. This result indicates that groundwater EC likely controls soil EC at this depth (where the capillary fringe was often encountered).

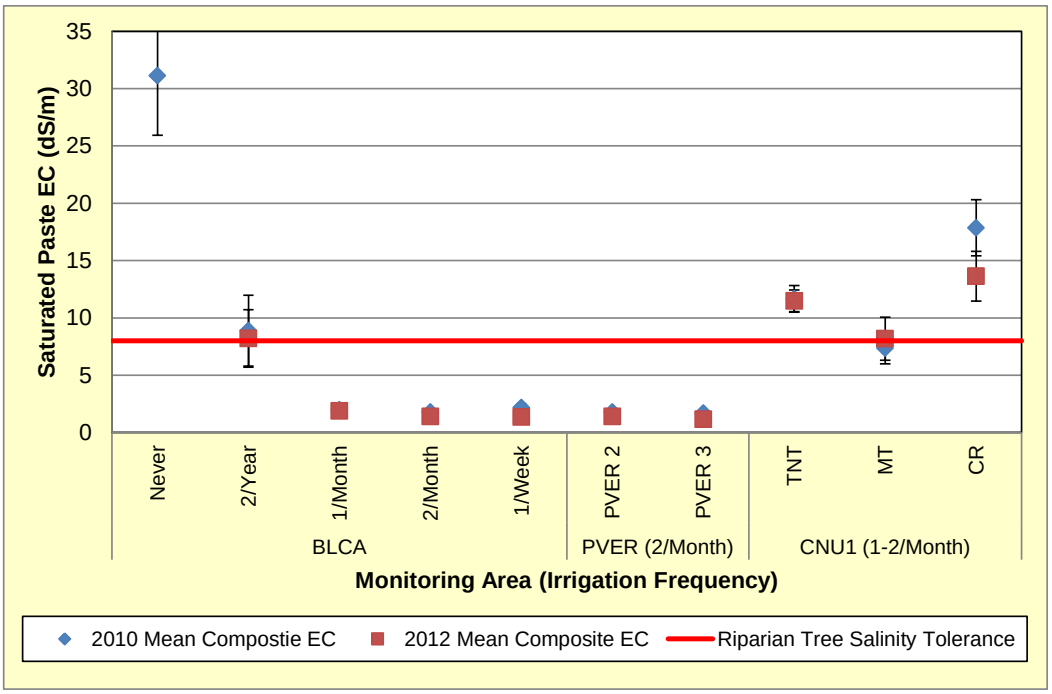

Figure 19.—Composite soil EC summary for 2010 and 2012 sampling.
Error bars show one standard error.

For 2010 results, significant interactions were observed between irrigation frequency, depth, and percent sand (table 16). Results for this interaction (table 18) indicate that higher percent sand results in lower EC at all depth intervals only for an irrigation frequency of twice per year. For 2012 results, a significant interaction was observed between irrigation frequency and percent sand (table 16). As for 2010, a higher percent sand was correlated with a lower EC for fields irrigated twice per year (table 19).

Table 13.—Composite soil EC means and significant differences

Conservation area	Irrigation frequency or site	2010 means and significant differences[1]	2012 means and significant differences[1]	P-value[2]
BLCA	Never	31.1 A	N/A	N/A
	Twice per year	8.9 CD	8.2 BC	0.71
	Once per month	2 E	1.9 DE	0.91
	Twice per month	1.8 DE	1.4 CDE	0.03
	Once per week	2.2 DE	1.4 DE	0.01
PVER	PVER Phase 02	1.8 E	1.4 DE	0.035
	PVER Phase 03	1.7 E	1.2 E	< 0.0001
Cibola NWR Unit #1	Nature Trail	11.7 C	11.5 AB	0.689
	Mass Transplanting	7.4 CDE	8.2 ABCD	0.56
	Crane Roost	17.9 B	13.6 A	0.002

[1] Letters indicate significant differences among sites for the given year, p = 0.05, Student's t-test.
[2] Indicates the probability of no change between sampling years for a given site, p = 0.05, matched pairs t-tests.

Table 14.—ANCOVA results for composite soil EC versus irrigation frequency and percent sand at the BLCA

Results	2010 EC (dS/m)	2012 EC (dS/m)
Summary of fit		
R^{2*}	0.95	0.83
Degrees of freedom	69	69
p-value	< 0.0001	< 0.0001
Main effects	**p-value**	**p-value**
Irrigation frequency	< 0.0001	0.10
% sand	0.0034	0.15
Irrigation frequency * % sand	< 0.0001	0.02
Least-squares means and significant differences		
Irrigation frequency		
Never	25.3 A	N/A
Twice per year	5.6 B	3.5
Once per month	2.4 C	1.9
Twice per month	1.8 C	1.4
Once per week	3.1 C	1.5

* Correlation coefficient.

Table 15.—ANCOVA results for the interaction of irrigation frequency and percent sand for May 2010 and February 2012 soil composite EC at the BLCA

Irrigation frequency	May 2010				February 2012			
	F*	df^	P-value	R^{2}^^	F	df	P-value	R^2
Never	0.04	2	0.88	0.03	N/A			
Twice per year	521	12	< 0.0001	0.98	39	11	< 0.0001	0.80
Once per month	3.5	35	0.07	0.09	0.02	35	0.89	< 0.01
Twice per month	2.2	8	0.18	0.24	0.05	9	0.83	< 0.01
Once per week	14.6	7	0.0065	0.68	1.96	11	0.19	0.16

* F-value.
^ Degrees of freedom.
^^ Correlation coefficient.

Table 16.—ANCOVA results for soil EC by depth versus irrigation frequency and percent sand at the BLCA

Results	2010 EC (dS/m)	2012 EC (dS/m)
Summary of fit		
R^{2*}	0.84	0.72
Degrees of freedom	209	206
p-value	< 0.0001	< 0.0001
Main effects	**p-value**	**p-value**
Irrigation frequency	< 0.0001	0.0023
Depth	< 0.0001	0.55
% sand	0.0006	0.08
Interactions		
Irrigation frequency * depth	< 0.0001	0.56
Irrigation frequency * % sand	< 0.0001	0.03
Depth * % sand	< 0.0001	0.82
Irrigation frequency * depth * % sand	< 0.0001	0.63
Least-squares means and significant differences		
Irrigation frequency		
Never	33.7	N/A
Twice per year	7.4	4.3 A
Once per month	2.3	2.2. B
Twice per month	1.8	1.4 B
Once per week	2.3	1.6 B
Depth		
0–2 ft	4.3	2.0 A
2–4 ft	16.9	2.8 A
> 4 ft	7.3	2.3 A

* Correlation coefficient.

Table 17.—ANCOVA results for the interaction of soil EC versus depth and irrigation frequency at the BLCA for May 2010

Irrigation frequency, depth	EC (dS/m)
Never, 0–2 ft	4.6 BCDE
Twice per year, 0–2 ft	10.7 BC
Once per month, 0–2 ft	2.5 E
Twice per month, 0–2 ft	1.5 E
Once per week, 0–2 ft	2.5 E
Never, 2–4 ft	70.1 A
Twice per year, 2–4 ft	8.1 BCD
Once per month, 2–4 ft	2.2 E
Twice per month, 2–4 ft	2.0 E
Once per week, 2–4 ft	2.3 CDE
Never, > 4 ft	26.4 B
Twice per year, > 4 ft	3.6 E
Once per month, > 4 ft	2.5 E
Twice per month, > 4 ft	2.0 DE
Once per week, > 4 ft	2.1 DE

Table 18.—ANCOVA results for the interaction of irrigation frequency, depth, and percent sand for May 2010 soil EC at the BLCA

		May 2010			
Irrigation frequency	Depth	F*	df^	p-value	R^{2}^^
Never	0–2 ft	0.57	2	0.59	0.36
	2–4 ft	50.2	2	0.09	0.98
	> 4 ft	10.0	2	0.20	0.91
Twice per year	0–2 ft	20.9	12	0.0008	0.66
	2–4 ft	19.3	12	0.0011	0.64
	> 4 ft	78.8	12	< 0.0001	0.88
Once per month	0–2 ft	4.4	35	0.04	0.11
	2–4 ft	0.66	35	0.42	0.02
	> 4 ft	2.3	35	0.14	0.06
Twice per month	0–2 ft	4.7	8	0.07	0.40
	2–4 ft	0.07	8	0.80	0.01
	> 4 ft	0.43	8	0.53	0.06
Once per week	0–2 ft	28.3	8	0.0011	0.80
	2–4 ft	5.7	8	0.048	0.45
	> 4 ft	0.04	8	0.86	0.01

* F-value.
^ Degrees of freedom).
^^ Correlation coefficient.

Table 19.—ANCOVA results for the interaction of irrigation frequency and percent sand for February 2012 soil EC at the BLCA

Irrigation frequency	Correlation results*			
	F**	df^	p-value	R^{2}^^
Twice per year	12.7	35	0.0011	0.27
Once per month	0.009	104	0.92	< 0.0001
Twice per month	0.2	29	0.65	0.007
Once per week	5.4	35	0.03	0.14

* Results indicate correlation of soil EC with percent sand for the given irrigation frequency.
** F-value.
^ Degrees of freedom).
^^ Correlation coefficient.

4.2.2.2 Palo Verde Ecological Reserve

Composite soil EC at both PVER Phases 02 and 03 decreased from 2010 to 2012 (see table 12). For PVER Phase 02, the reduction occurred only in the 0–2 ft depth interval, whereas EC at PVER Phase 03 reduced at all three depth intervals. Composite soil EC did not differ between PVER Phases 02 and 03 for either sampling period (see table 13). Soil EC remained much below native riparian tree tolerances for both fields. The depth interval did not affect soil EC in either sampling period (table 20).

Soil EC was inversely correlated with percent sand (tables 20, 21, and 22) and observed in the spatial variability of the sand particle size fraction and composite EC (see figures 15 and 16). The significant interaction between percent sand and site during 2012 (table 21) was due to a difference in slope of regression between sites; a higher percent sand resulted in lower soil EC for both PVER Phases 02 and 03 (table 22). Higher salinity and finer-grained soils were observed in the areas the NRCS soil classifications predicted to be silt loam, loam, clay loam, and clay soils (see figures 5 and 6).

Soil salinity was unaffected by field location (north or south half of the site, closer to and further from the irrigation source, respectively; table 20). This result indicates that soil EC was not affected by the amount of applied irrigation water, assuming that the northern portion of each site receives more irrigation than the southern portion.

Table 20.—ANCOVA results for soil EC with depth versus site, field location, and percent sand at the PVER

Results	2010 EC (dS/m)	2012 EC (dS/m)
Summary of fit		
R^{2*}	0.49	0.64
Degrees of freedom	119	119
p-value	< 0.0001	< 0.0001
Main effects	**p-value**	**p-value**
Site and field location	0.38	0.02
Depth	0.40	0.26
% sand	0.0004	< 0.0001
Interactions		
Site and field location * depth	0.55	0.51
Site and field location * % sand	0.61	0.06
Depth * % sand	0.66	0.20
Site and field location * depth * % sand	0.66	0.43
Least-squares means and significant differences		
Site and field location		
PVER Phase 02 North	1.9 A	1.4 AB
PVER Phase 02 South	2.0 A	1.7 A
PVER Phase 03 North	1.6 A	1.2 B
PVER Phase 03 South	1.6 A	1.0 B
2010 depth		
0–2 ft	1.8 A	1.6 A
2–4 ft	1.6 A	1.2 A
4–6 ft	2.0 A	1.1 A

* Correlation coefficient.

Table 21.—ANCOVA results for composite soil EC versus site and percent sand at the PVER

Results	2010 EC (dS/m)	2012 EC (dS/m)
Summary of fit		
R^{2*}	0.59	0.75
Degrees of freedom	39	39
p-value	< 0.0001	< 0.0001
Main effects	**p-value**	**p-value**
Site	0.17	0.005
% sand	< 0.0001	< 0.0001
Site * % sand	0.60	0.03
Least-squares means and significant differences		
Site		
PVER Phase 02	1.9 A	1.5 A
PVER Phase 03	1.6 A	1.1 B

* Correlation coefficient.

Table 22.—ANCOVA results for the interaction of site and percent sand for February 2012 soil EC at the PVER

Site	Correlation results*			
	F**	df^	p-value	R^{2}^^
PVER Phase 02	74.3	19	< 0.0001	0.70
PVER Phase 03	171.3	19	< 0.0001	0.90

* Results indicate a correlation of soil EC with percent sand for the given site.
** F-value.
^ Degrees of freedom.
^^ Correlation coefficient.

4.2.2.3 Cibola National Wildlife Refuge Unit #1 Conservation Area

In 2010, composite soil EC at Cibola NWR Unit #1 was higher at Crane Roost than the Nature Trail and Mass Transplanting. Composite soil EC was not significantly different between the Nature Trail and Mass Transplanting. Composite soil EC did was not statistically different between any of the Cibola NWR Unit #1 sites in 2012 (see table 13). Soil EC did not decrease between 2010 and 2012 for any depth interval at the Nature Trail or Mass Transplanting but decreased for all depth intervals at Crane Roost (see table 12).

Conversely to the BLCA and PVER, neither composite EC nor EC by depth was correlated with percent sand (i.e., higher sand content did not result in lower soil EC [tables 23 and 24]). Soil EC at Cibola NWR Unit #1 did not differ among depth intervals (table 24).

Table 23.—ANCOVA results for composite soil EC versus site and percent sand at Cibola NWR Unit #1

Results	2010 EC (dS/m)	2012 EC (dS/m)
Summary of fit		
R^{2*}	0.13	0.05
Degrees of freedom	75	78
p-value	0.08	0.60
Main effects	**p-value**	**p-value**
Site	0.04	0.55
% sand	0.18	0.38
Site * % sand	0.97	0.78
Means and significant differences		
Site		
Crane Roost	19.1 A	14.3 A
Nature Trail	9.2 B	11.3 A
Mass Transplanting	8.2 AB	9.4 A

* Correlation coefficient.

Table 24.—ANCOVA results for soil EC by depth versus site and percent sand at Cibola NWR Unit #1

Results	2010 EC (dS/m)	2012 EC (dS/m)
Summary of fit		
R^{2*}	0.21	0.11
Degrees of freedom	229	238
p-value	< 0.0001	0.06
Main effects	**p-value**	**p-value**
Site	0.17	0.62
Depth	0.90	0.54
% sand	0.21	0.15
Interactions		
Site * depth	0.92	0.75
Site * % sand	0.85	0.91
Depth * % sand	0.93	0.76
Site * depth * % sand	0.70	0.78
Least-squares means and significant differences		
Site		
Crane Roost	18.7 A	14.1 A
Nature Trail	6.3 A	8.6 A
Mass Transplanting	13.6 A	9.1 A
Depth		
0–2 ft	9.4 A	2.0 A
2–4 ft	13.6 A	13.5 A
> 4 ft	15.6 A	16.2 A

* Correlation coefficient.

ANCOVA results for the Nature Trail are provided in table 25. At this site, a higher sand fraction predicted a lower soil EC in 2010, but this relationship was not observed for 2012 data. Soil EC was not significantly affected by depth interval.

ANCOVA results for Mass Transplanting are provided in table 26. Higher percent sand did not result in a lower soil EC for either year. Field location did not affect soil EC; east locations closer to the irrigation source and presumably receiving more irrigation did not have a lower EC than the western locations further from the irrigation source. Soil EC did not differ among depth intervals.

Table 25.—ANCOVA results for soil EC by depth versus percent sand at the Nature Trail

Results	2010 EC (dS/m)	2012 EC (dS/m)
Summary of fit		
R^{2*}	0.17	0.16
Degrees of freedom	64	64
P-value	0.048	0.059
Main effects	**p-value**	**p-value**
Depth	0.14	0.09
% sand	0.016	0.18
Interactions		
Depth * % sand	0.54	0.28
Means and significant differences		
Depth		
0–2 ft	2.4 A	2.7 B
2–4 ft	13.9 A	14.6 A
> 4 ft	14.2 A	13.8 A

* Correlation coefficient.

Table 26.—ANCOVA results for soil EC versus field location, depth, and percent sand at Mass Transplanting

Results	2010 EC (dS/m)	2012 EC (dS/m)
Summary of fit		
R^{2*}	0.85	0.61
Degrees of freedom	23	24
p-value	0.002	0.19
Main effects	**p-value**	**p-value**
Field location	0.71	0.81
Depth	0.64	0.28
% sand	0.81	0.07
Interactions		
Field location * depth	0.93	0.99
Field location * % sand	0.62	0.72
Depth * % sand	0.13	0.53
Field location * depth * % sand	0.92	0.99
Least-squares means and significant differences		
Field location		
East	14.3 A	6.7 A
West	11.8 A	10.1 A
Depth		
0–2 ft	15.3 A	-9.3 A
2–4 ft	9.8 A	10.8 A
> 4 ft	14.0 A	23.6 A

* Correlation coefficient.

ANCOVA results for composite soil EC at all Crane Roost fields are provided in table 27. A higher percent sand was correlated with lower soil EC in 2010 but not in 2012. No significant differences were observed among fields in 2010. In 2012, EC in CR-2 was lower than that of CR-4, but no other significant differences were observed.

Table 27.—ANCOVA results for composite soil EC versus field and percent sand at Crane Roost

Results	2010 EC (dS/m)	2012 EC (dS/m)
Summary of fit		
R^{2*}	0.30	0.23
Degrees of freedom	46	49
p-value	0.04	0.11
Main effects	**p-value**	**p-value**
Field	0.13	0.18
% sand	0.04	0.07
Interactions		
Field * % sand	0.34	0.66
Least-squares means and significant differences		
Field		
CR-1	9.0 A	8.5 AB
CR-2	9.0 A	5.4 B
CR-3	16.5 A	7.9 AB
CR-4	19.2 A	14.3 A

* Correlation coefficient.

ANCOVA results for CR-2 through CR-4, which were subject to stratified sampling based on vegetation types, are provided in table 28. For these three fields, a higher percent sand was correlated with a lower soil EC. For both sampling periods, soil EC was lower for the 0–2 and 2–4 ft depth intervals than for the 4–6 ft depth interval.

The sampling location in the field, denoted by vegetation effect in the ANCOVA, significantly affected soil EC for both sampling periods (table 28). Sample locations closer to the irrigation source (coyote willow and Goodding's willow vegetation areas) had a lower EC than sample locations further from the irrigation source (cottonwood and mesquite) for CR-2 and CR-3 in both years. In CR-4, this trend was also observed in 2012. However, in 2010, soil EC did not vary among areas planted with coyote willow, Goodding's willow, or cottonwood although mesquite areas did have the highest soil EC in 2010 (table 29).

Table 28.—ANCOVA results for soil EC by depth versus field, vegetation type, and percent sand at CR-2 through CR-4

Results	2010 EC (dS/m)	2012 EC (dS/m)
Summary of fit		
R^{2*}	0.76	0.76
Degrees of freedom	104	113
p-value	< 0.0001	< 0.0001
Main effects	**p-value**	**p-value**
Field	< 0.0001	< 0.0001
Vegetation	< 0.0001	< 0.0001
Depth	0.003	0.0026
% sand	< 0.0001	< 0.0001
Interactions		
Field * vegetation	0.0003	0.0722
Field * depth	0.839	0.6924
Vegetation * depth	0.093	0.7003
Field * vegetation * depth	0.548	0.8916
Least-squares means and significant differences		
Field		
CR-2	8.6	4.9 C
CR-3	16.0	7.3 B
CR-4	19.6	14.9 A
Vegetation		
Coyote willow	9.1	4.0 B
Goodding's willow	7.0	3.7 B
Cottonwood	21.0	15.4 A
Mesquite	31.8	18.7 A
Depth		
0–2 ft	12.0 B	6.5 B
2–4 ft	11.5 B	7.2 B
4–6 ft	19.7 A	11.5 A

* Correlation coefficient.

Table 29.—ANCOVA results for the interaction of soil EC versus field and vegetation type at CR-2 through CR-4 in May – June 2010

Field, vegetation	2010 EC (dS/m)	2012 EC (dS/m)
CR-2, coyote willow	4.7 DE	2.8 D
CR-2, Goodding's willow	3.3 E	1.9 D
CR-2, cottonwood	15.5 C	8.9 C
CR-2, mesquite	22.2 ABC	12.6 BC
CR-3, coyote willow	6.5 D	3.0 D
CR-3, Goodding's willow	7.8 D	3.0 D
CR-3, cottonwood	40.9 A	20.0 AB
CR-3, mesquite	31.8 AB	15.8 BC
CR-4, coyote willow	16.9 BC	7.9 C
CR-4, Goodding's willow	13.1 C	10.0 C
CR-4, cottonwood	14.5 C	20 AB
CR-4, mesquite	46.1 A	50.1 A

4.2.3 Soil Geochemistry

Soil geochemical testing results are provided in tables 30 and 31. Mean soil EC for these samples was generally lower than other data collected for this project primarily because only a subset of samples was sent for analyses. Sodic soils were observed at a subset of sampling locations at the BLCA and Cibola NWR Unit #1 in both 2010 and 2012.

4.3 Groundwater Monitoring

Groundwater elevation and groundwater depth summaries are presented by site in section 4.3.1. All data are provided in tabular form in attachment 4. Groundwater chemistry results are detailed in section 4.3.2; field groundwater EC data measurements are provided in attachment 5; and laboratory data are provided in attachment 6.

4.3.1 Groundwater Depth and Groundwater Elevation

4.3.1.1 Beal Lake Conservation Area

Groundwater depth data at the BLCA for the 2011 to 2013 calendar years are provided on figures 20–22. When irrigation was not applied (approximately

Table 30.—May – June 2010 soil geochemistry results
(n = number of samples; $\bar{x}$ = mean; s = standard deviation)

Conservation area	Site	Depth	n	EC $\bar{x}$	EC s	EC max.	EC min.	pH $\bar{x}$	pH s	pH max.	pH min.	ESP $\bar{x}$	ESP s	ESP max.	ESP min.
BLCA		0–2 ft	7	2.0	2.9	8.6	0.5	8.7	8.7	9.2	8.0	4.3	3.9	12.4	1.3
		2–4 ft	7	2.6	4.7	13.2	0.1	8.8	0.1	9.0	8.6	6.7	10.0	29.3	1.3
		4–6 ft	7	1.3	1.3	4.2	0.7	8.7	0.4	9.0	8.0	3.9	0.9	5.6	2.9
		Composite	7	2.0	3.0	8.7	0.4	8.7	0.2	9.0	8.3	5.0	4.8	15.8	2.2
PVER	PVER Phase 02	0–2 ft	2	0.7	0.1	0.8	0.6	8.2	0.1	8.2	8.1	1.7	0.4	1.9	1.4
		2–4 ft	2	0.6	0.0	0.6	0.6	8.5	0.0	8.5	8.5	1.4	0.0	1.4	1.4
		4-6 ft	2	0.5	0.1	0.6	0.4	8.9	0.0	8.9	8.9	1.3	0.3	1.5	1.1
		Composite	2	0.6	0.1	0.7	0.5	8.5	0.0	8.5	8.5	1.5	0.2	1.6	1.3
	PVER Phase 03	0–2 ft	2	0.6	0.0	0.6	0.6	8.5	0.1	8.5	8.4	1.3	0.1	1.4	1.2
		2–4 ft	2	0.6	0.3	0.8	0.4	8.6	0.3	8.8	8.4	1.4	0.4	1.7	1.1
		4–6 ft	2	0.5	0.1	0.5	0.4	8.7	0.1	8.8	8.6	1.4	0.5	1.7	1.0
		Composite	2	0.4	0.3	0.6	0.2	8.6	0.2	8.7	8.5	1.4	0.3	1.5	1.2
Cibola NWR Unit #1	Nature Trail	0–2 ft	2	2.3	1.3	3.2	1.4	8.0	0.4	8.3	7.7	2.8	0.7	3.3	2.3
		2–4 ft	2	3.0	2.3	4.6	1.4	7.9	0.1	8.0	7.8	6.5	1.6	7.6	5.4
		4–6 ft	2	5.3	4.9	8.8	1.8	8.1	0.2	8.2	7.9	8.0	6.9	12.8	3.1
		Composite	2	3.5	0.5	3.9	3.2	8.0	0.0	8.0	8.0	5.8	2.6	7.6	3.9
	Mass Transplanting	0–2 ft	1	3.6	N/A	N/A	N/A	7.7	N/A	N/A	N/A	4.2	N/A	N/A	N/A
		2–4 ft	1	3.8	N/A	N/A	N/A	8.3	N/A	N/A	N/A	6.4	N/A	N/A	N/A
		4–6 ft	1	4.8	N/A	N/A	N/A	8.4	N/A	N/A	N/A	8.8	N/A	N/A	N/A
		Composite	1	4.1	N/A	N/A	N/A	8.1	N/A	N/A	N/A	6.5	N/A	N/A	N/A
	Crane Roost	0–2 ft	7	3.5	2.0	6.2	1.0	8.2	0.2	8.4	8.0	3.7	1.7	5.8	1.4
		2–4 ft	7	3.4	1.6	5.8	0.8	8.2	0.2	8.6	7.9	4.3	1.8	6.9	1.4
		4–6 ft	7	5.4	2.3	9.2	2.2	8.3	0.3	8.7	7.9	8.7	4.1	14.2	3.9
		Composite	7	4.1	1.4	5.3	1.3	8.2	0.1	8.4	8.1	5.6	1.9	7.7	2.2

Table 31.—February 2012 soil geochemistry results
(n = number of samples; $\bar{x}$ = mean; s = standard deviation)

Conservation area	Site	Depth	n	EC $\bar{x}$	EC s	EC max.	EC min.	pH $\bar{x}$	pH s	pH max.	pH min.	ESP $\bar{x}$	ESP s	ESP max.	ESP min.
BLCA		0–2 ft	8	1.3	1.3	4.2	0.6	8.8	0.3	9.1	8.4	3.0	0.9	4.7	2.3
		2–4 ft	8	2.2	3.9	11.0	0.6	8.9	0.2	9.2	8.5	7.1	10.6	31.1	2.5
		> 4 ft	8	2.9	5.2	14.6	0.8	8.8	0.2	9.1	8.6	7.3	7.1	22.9	3.2
		Composite	8	2.0	3.1	9.0	0.7	8.8	0.2	9.1	8.6	5.6	5.9	18.9	2.6
PVER	PVER Phase 02	0–2 ft	2	0.7	0.1	0.8	0.6	8.3	0.0	8.3	8.3	2.3	0.1	2.3	2.2
		2–4 ft	2	0.6	0.0	0.6	0.6	8.7	0.1	8.7	8.6	1.6	0.3	1.8	1.4
		4–6 ft	2	0.5	0.1	0.6	0.4	8.8	0.1	8.8	8.7	2.1	0.1	2.1	2.0
		Composite	2	0.6	0.1	0.7	0.5	8.6	0.0	8.6	8.5	2.0	0.0	2.0	1.9
	PVER Phase 03	0–2 ft	2	0.6	0.0	0.6	0.6	8.4	0.0	8.4	8.4	1.8	0.0	1.8	1.8
		2–4 ft	2	0.5	0.1	0.6	0.4	8.1	0.7	8.6	7.6	1.8	0.3	2.0	1.6
		4–6 ft	2	0.5	0.1	0.6	0.4	8.8	0.1	8.8	8.7	2.2	0.6	2.6	1.7
		Composite	2	0.5	0.0	0.5	0.5	8.4	0.3	8.6	8.2	1.9	0.3	2.1	1.7
Cibola NWR Unit #1	Nature Trail	0–2 ft	1	2.2	N/A	N/A	N/A	8.1	N/A	N/A	N/A	4.0	N/A	N/A	N/A
		2–4 ft	1	10.8	N/A	N/A	N/A	7.7	N/A	N/A	N/A	14.7	N/A	N/A	N/A
		4–6 ft	1	12.4	N/A	N/A	N/A	8.1	N/A	N/A	N/A	16.2	N/A	N/A	N/A
		Composite	1	8.5	N/A	N/A	N/A	8.0	N/A	N/A	N/A	11.6	N/A	N/A	N/A
	Mass Transplanting	0–2 ft	1	1.8	N/A	N/A	N/A	8.1	N/A	N/A	N/A	2.7	N/A	N/A	N/A
		2–4 ft	1	5.4	N/A	N/A	N/A	8.2	N/A	N/A	N/A	10.2	N/A	N/A	N/A
		4–6 ft	1	6.4	N/A	N/A	N/A	8.3	N/A	N/A	N/A	11.1	N/A	N/A	N/A
		Composite	1	4.5	N/A	N/A	N/A	8.2	N/A	N/A	N/A	8.0	N/A	N/A	N/A
	Crane Roost	0–2 ft	6	3.3	2.8	7.6	1.2	8.2	0.2	8.5	7.9	4.0	3.9	11.6	1.5
		2–4 ft	6	3.5	3.6	8.8	1.0	8.2	0.2	8.4	8.0	6.0	5.4	14.3	1.5
		4–6 ft	6	3.8	1.5	5.4	1.2	8.3	0.3	8.8	7.9	7.5	5.4	14.7	2.6
		Composite	6	3.5	2.5	7.3	1.1	8.2	0.1	8.3	8.1	5.8	4.7	13.2	1.9

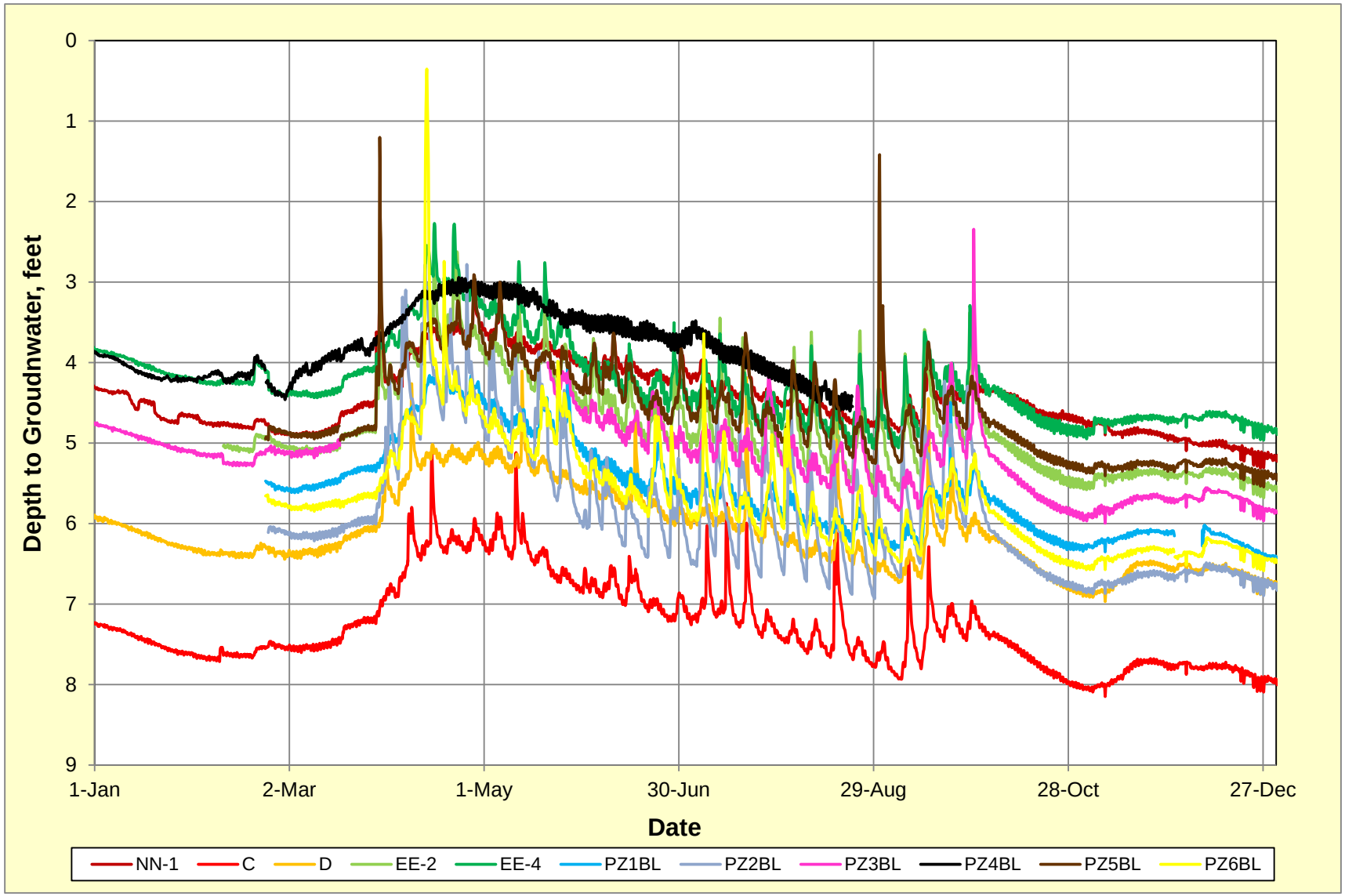

Figure 20.—Depth to groundwater data for the BLCA during 2011.

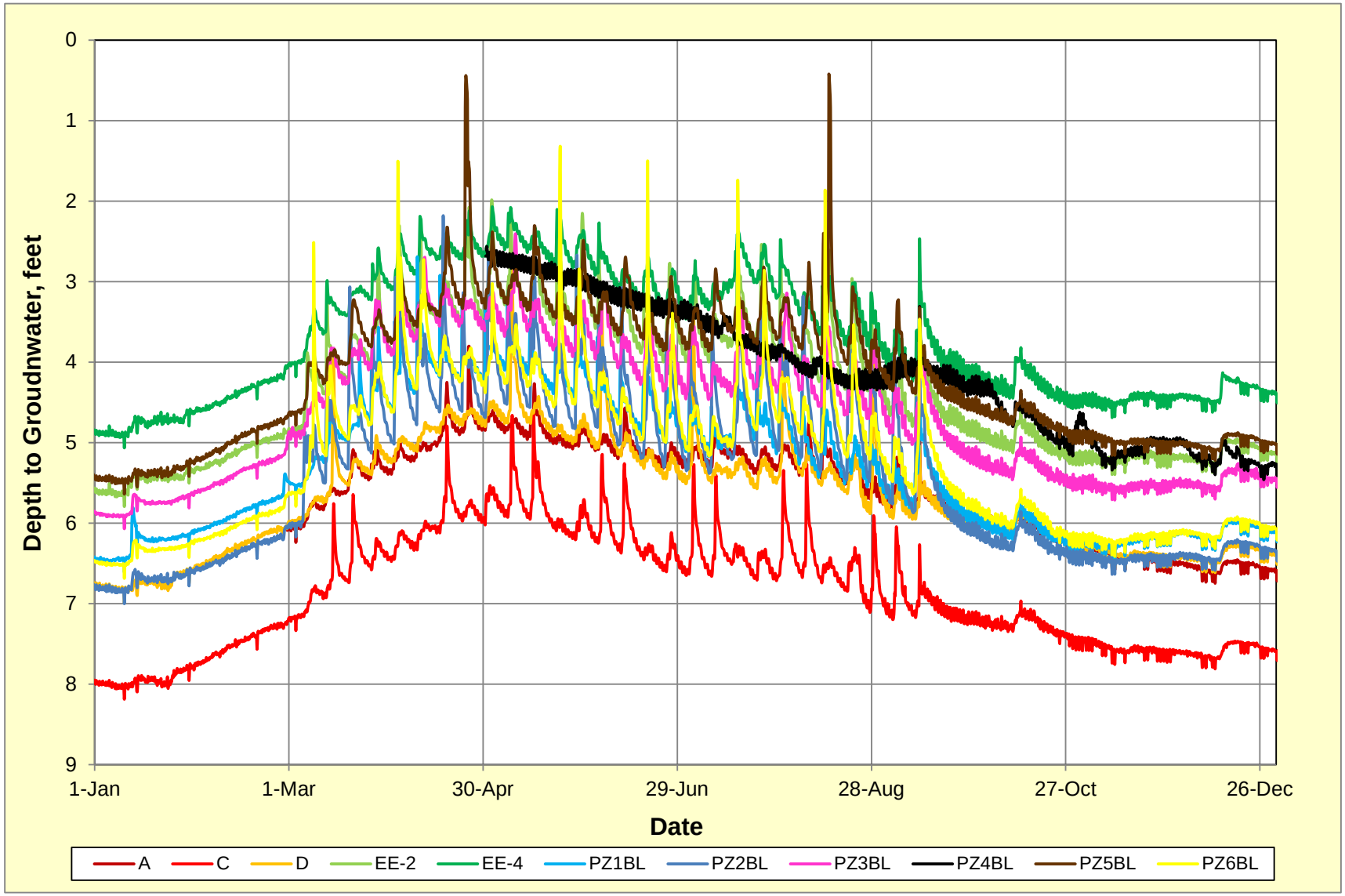

Figure 21.—Depth to groundwater data for the BLCA during 2012.

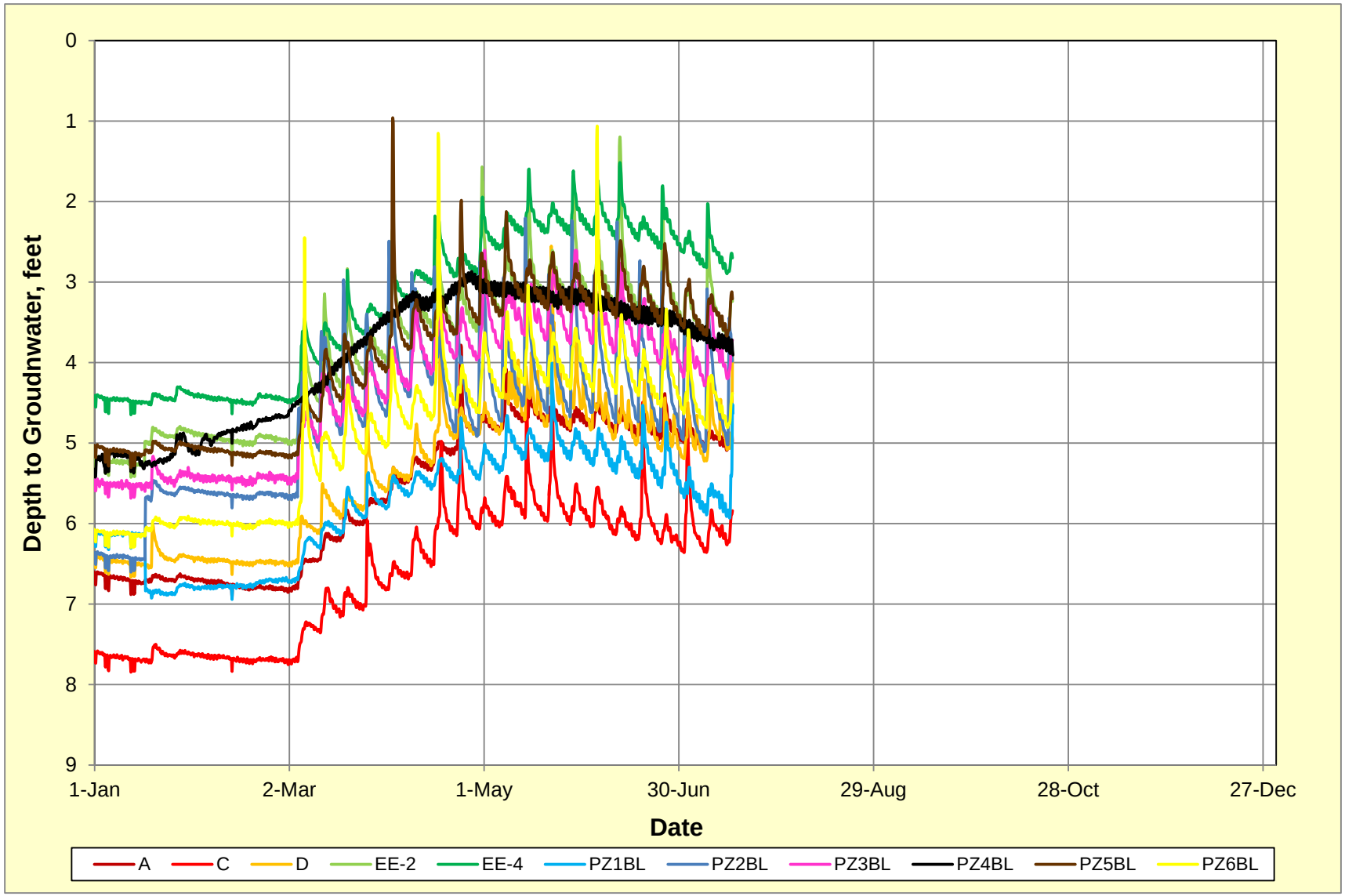

Figure 22.—Depth to groundwater data for the BLCA during 2013.

October through February), the groundwater levels at the BLCA ranged from 4 to 8 ft below ground surface. The groundwater gradient was minimal, so the range of groundwater depth was primarily due to placement of piezometers (e.g., depth to groundwater was less at locations within fields compared to tops of berms adjacent to fields). During the irrigation season, the background (i.e., non-irrigation time) groundwater depth ranged from 2 to 8 feet. During 2011, groundwater elevations decreased during January and February, increased during March and April, and then slowly declined during the remainder of the year. This trend is likely due to managed elevations of surrounding surface water (i.e., Topock Marsh, Beal Lake, and the Colorado River main stem). During 2012, groundwater elevations increased between January and April, and then slowly decreased for the remainder of the year, approximately returning to initial levels. During 2013, the groundwater elevation between January 1 and March 1 remained approximately constant and then increased through mid-May. Data through mid-July 2013 indicated that groundwater was following a mid-summer decreasing trend similar to previous years.

Rapid groundwater elevation increases were observed during and immediately after irrigation events, indicating that irrigation water is reaching the water table. Fields irrigated more frequently are thus experiencing more frequent leaching of soils and episodic shallower groundwater. Changes in groundwater elevation at the BLCA over the week of July 10, 2011, are shown on figure 23. According to irrigation contractor records, the irrigation schedule was as follows: July 11—L, K; July 12—P, JJ, FF, Q; July 13—LL, July 14, H, C; July 15–17—none. Prior to irrigation onset, the gradient indicates a groundwater flow direction of west-northwest, with the highest groundwater elevations at Topock Marsh and the Beal Lake ditch. The groundwater elevation under irrigated fields quickly increases during the irrigation event, resulting in a change of gradient direction and transient groundwater flow away from the irrigated field. After irrigation stops, mounded groundwater disperses over approximately a 1-day period and the groundwater gradient returns to pre-irrigation conditions.

4.3.1.2 Palo Verde Ecological Reserve

Groundwater depth data at the PVER for the 2011 to 2013 calendar years are provided on figures 24– 26. In the non-irrigated season (i.e., December through January), the groundwater depth at the PVER ranged between 12 and 20 ft. During the irrigation season, the maximum groundwater depth between irrigation events ranged from 11 to 19 ft.

Groundwater elevation increased rapidly during and immediately after irrigation events in sandy areas of the field, indicating extensive percolation. Groundwater elevation increased up to 7 ft compared to pre-irrigation levels. In the finer-grained areas and areas toward the south end of the monitoring area (i.e., further

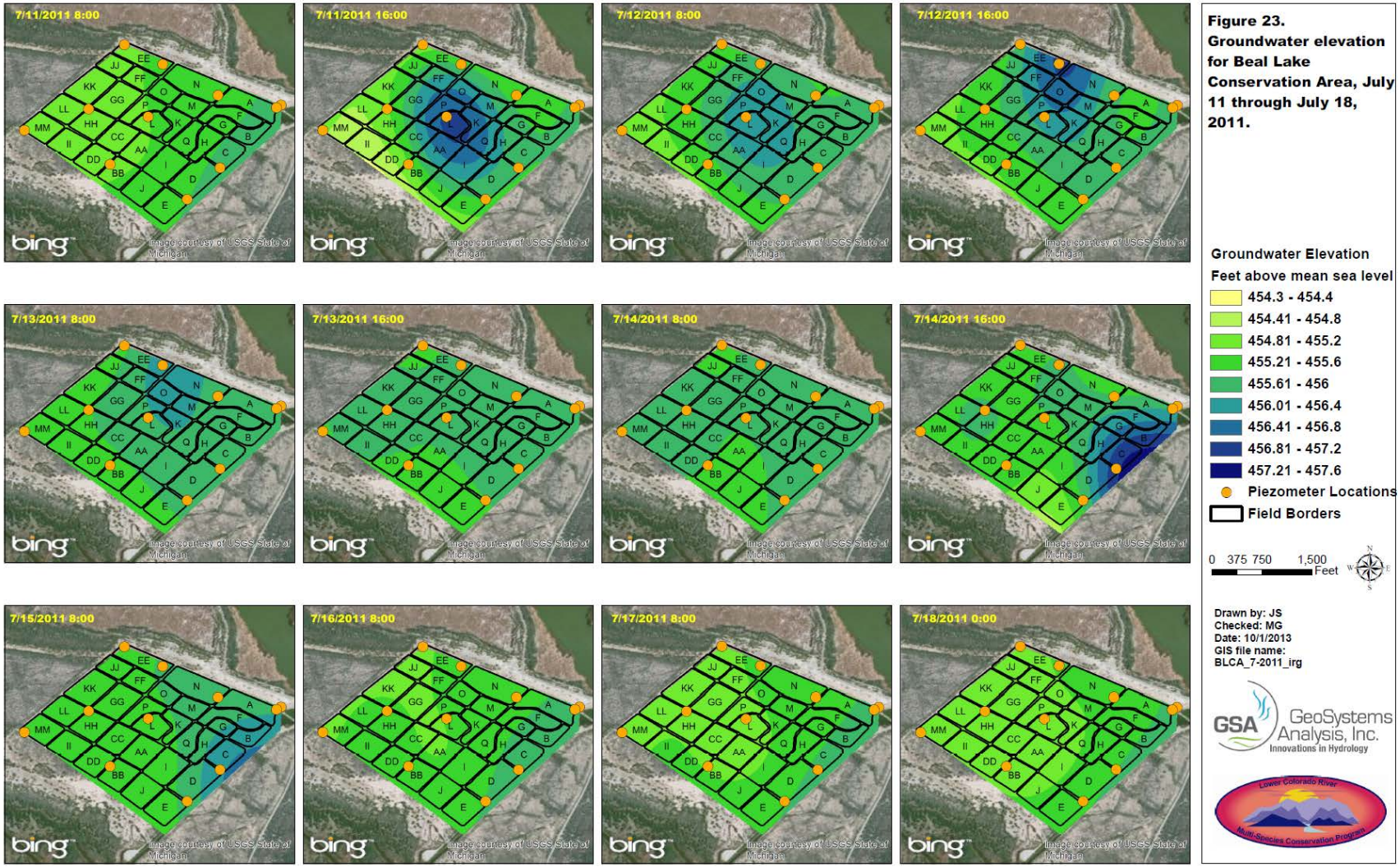

Figure 23.—Groundwater elevation for the BLCA, July 11–18, 2011.

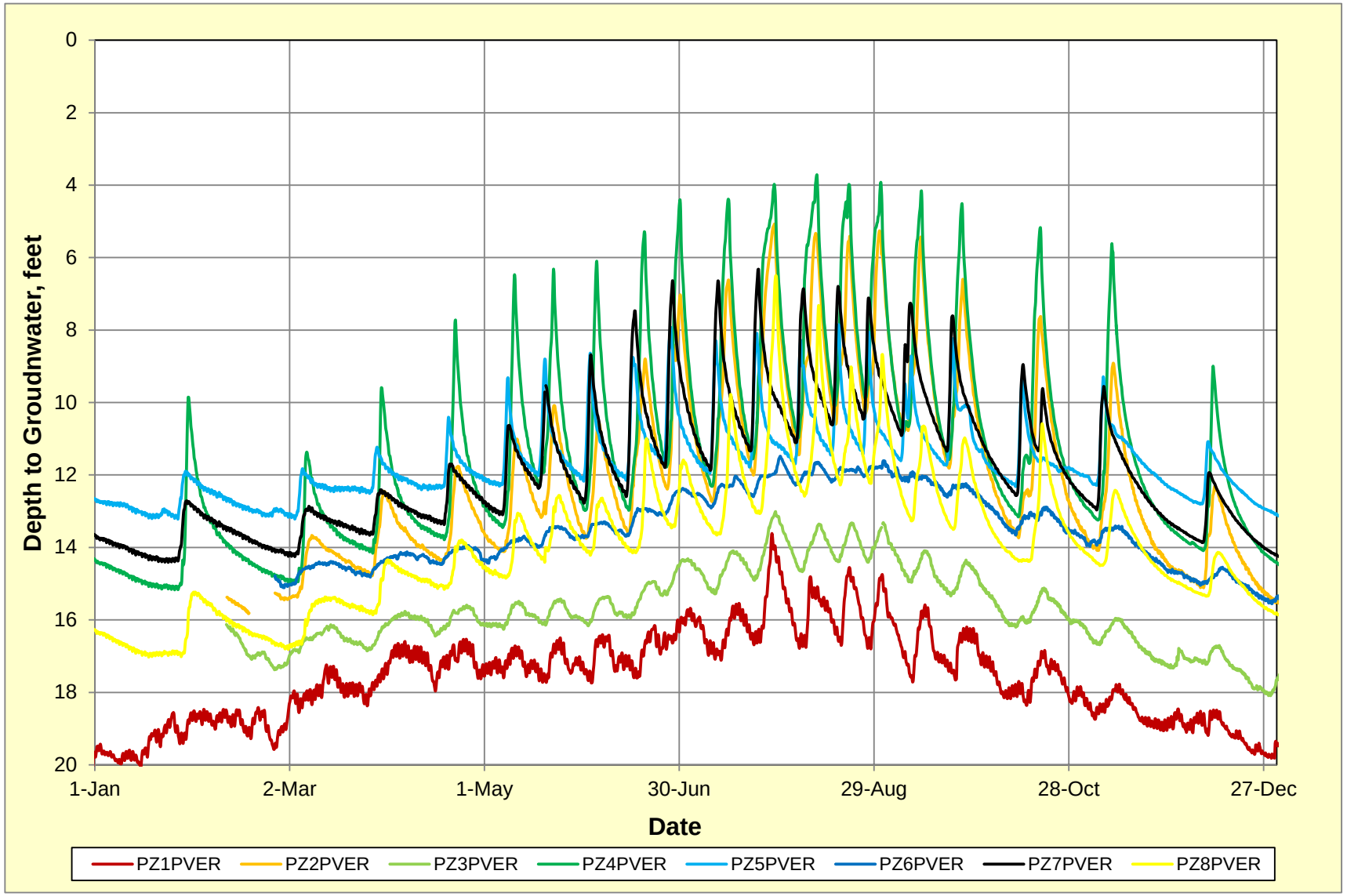

Figure 24.—Depth to groundwater data for the PVER during 2011.

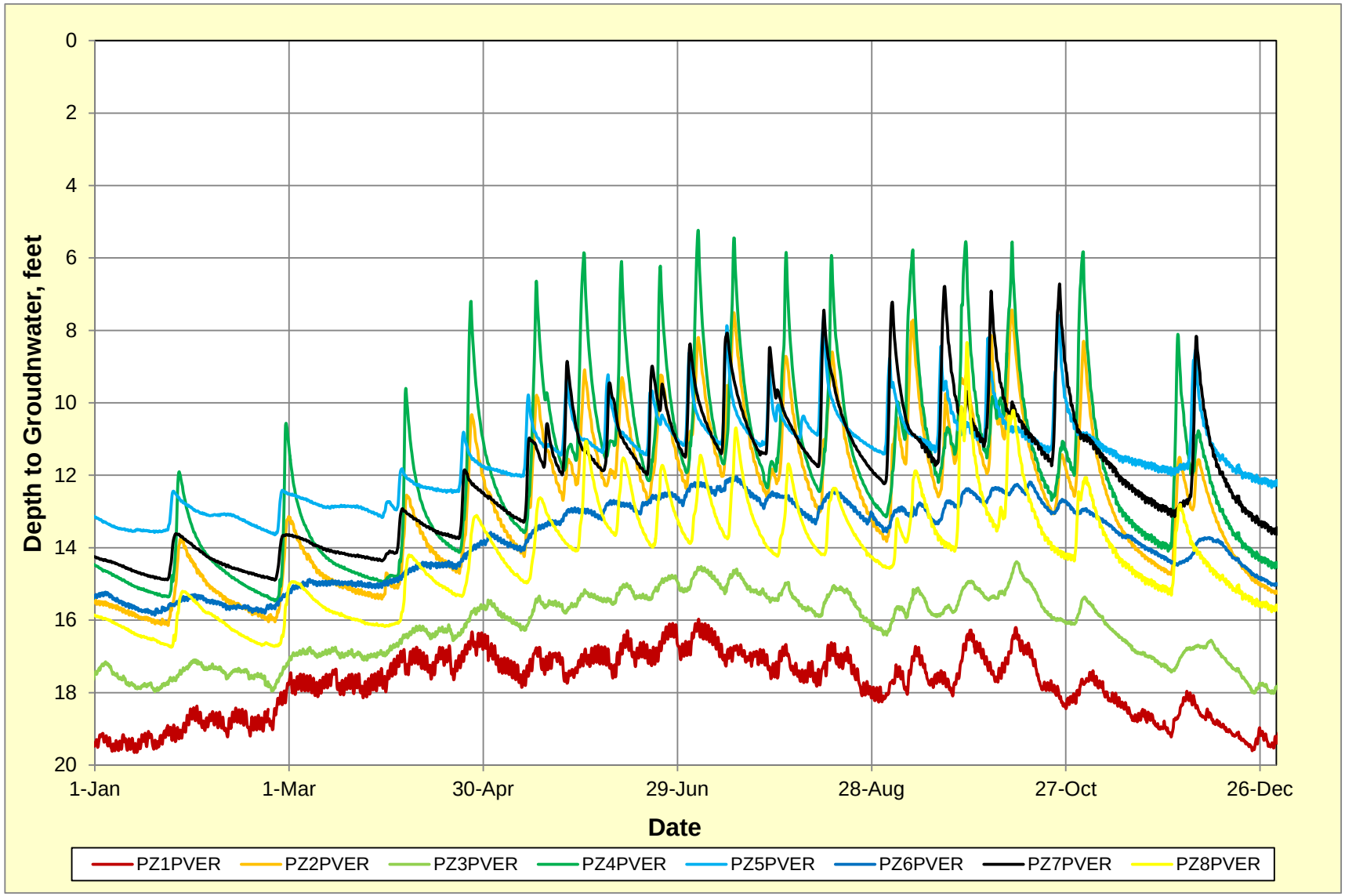

Figure 25.—Depth to groundwater data for the PVER during 2012.

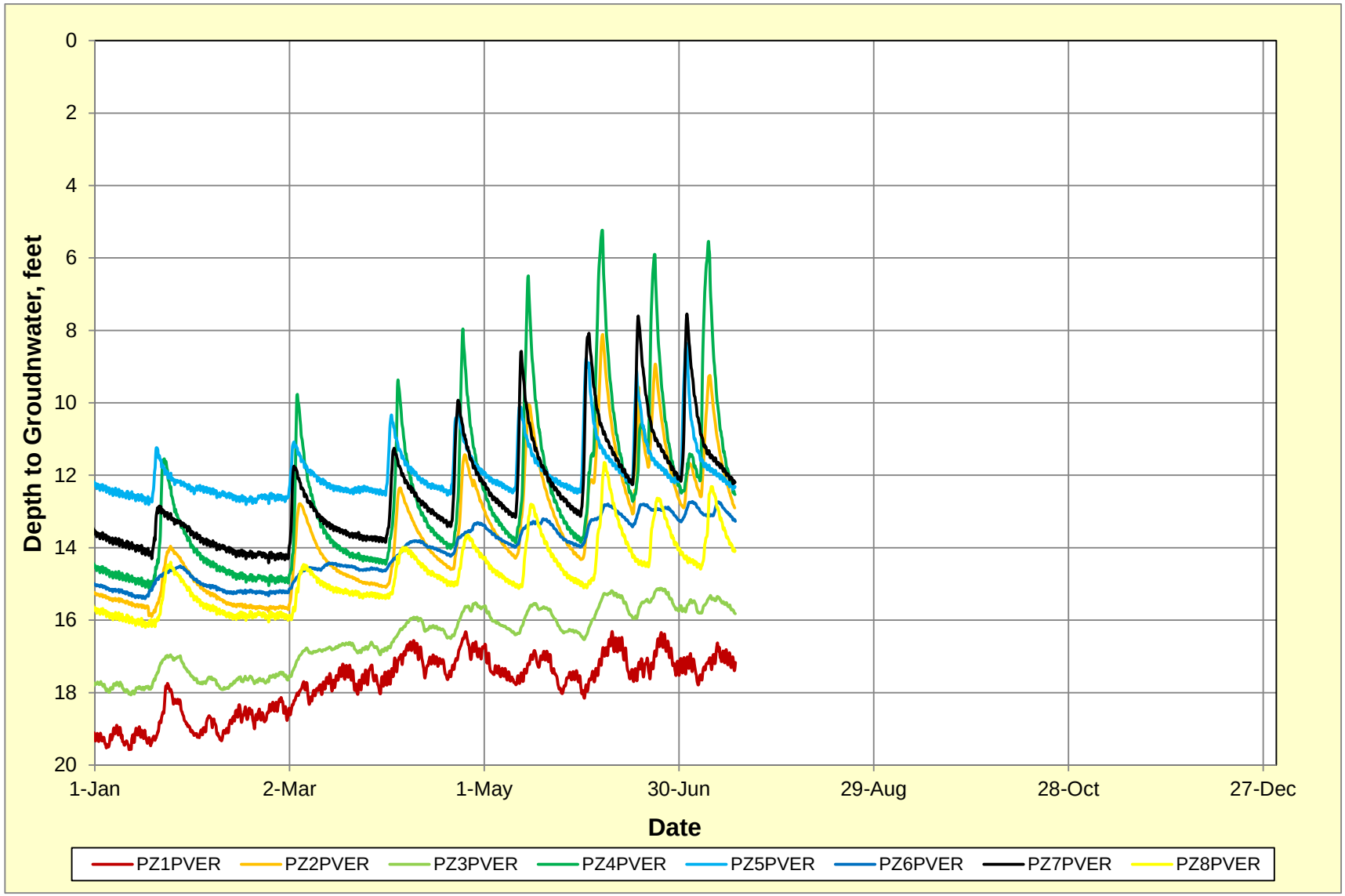

Figure 26.—Depth to groundwater data for the PVER during 2013.

from the irrigation source), less groundwater mounding was observed. This is likely due to a combination of less irrigation application and less water reaching the water table because of lower soil hydraulic conductivity in these areas.

Changes in groundwater elevation at the PVER during and after an irrigation event between September 20 and September 27, 2011, are shown on figure 27. Based on the groundwater elevation data, PVER Phases 02 and 03 were irrigated in succession during this period. Prior to irrigation, a general northwest to southeast gradient was present, indicating flow of groundwater through the site toward the Colorado River main stem. As irrigation was initiated at PVER Phase 02, the groundwater elevation on the north and northwest portion of the site increased quickly, indicating percolation and mounding of irrigation water. As for the BLCA, this groundwater mounding results in transient changes to groundwater flow direction away from irrigated portions of the site. After irrigation stopped, this groundwater mound began to dissipate. A second groundwater mound formed in the northwest section of PVER Phase 03 when irrigation was initiated at this phase. As noted for depth to groundwater results, little percolation was observed on the eastern and southern portions of the field likely due to less percolation in those areas. Over a period of 7 days, the groundwater mound dissipates and the groundwater gradient returns to initial levels.

4.3.1.3 Cibola National Wildlife Refuge Unit #1 Conservation Area

Groundwater depth data for the Cibola NWR Unit #1 Seed Feasibility Study, Mass Transplanting, and the Nature Trail for the 2011 to 2013 calendar years are provided on figures 28–30. Groundwater depth data for Crane Roost for the 2011 to 2013 calendar years are provided on figures 31–33.

In the non-irrigated season (approximately November through February), the groundwater depth at the Seed Feasibility Study, Mass Transplanting, and the Nature Trail ranged between 7 and 9 ft, with the exception of PZ1C, PZ8C, and PZ9C, where groundwater was shallower. During the irrigation season, groundwater depth changes were erratic. Clear percolation events were observed due to irrigation at each site; erratic groundwater depths between irrigation events is likely due to percolation from irrigation of surrounding fields. In general, groundwater was deeper during the non-irrigation season and shallower during the irrigation season. PZ1C, PZ8C, and PZ9C followed the opposite trend, whereby groundwater was shallower during the non-irrigation season. Shallow groundwater at these locations was likely supported by percolation from the adjacent Danner Lake, which was flooded during the winter for migratory waterfowl. During February 2013, a rapid decrease in groundwater elevation was observed at these wells, corresponding to the draining of Danner Lake.

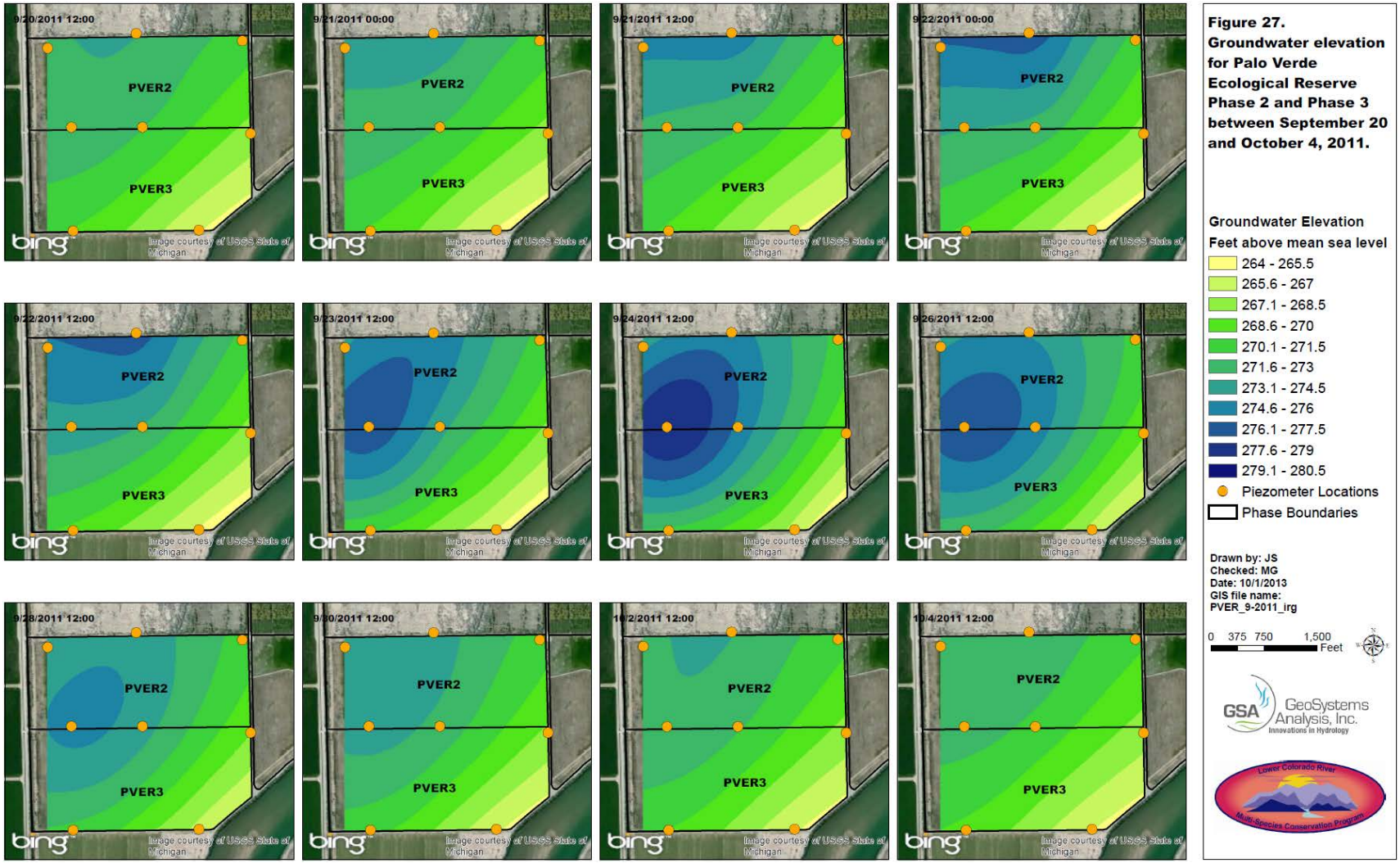

Figure 27.—Groundwater elevation for PVER Phases 02 and 03 between September 20 and October 4, 2011.

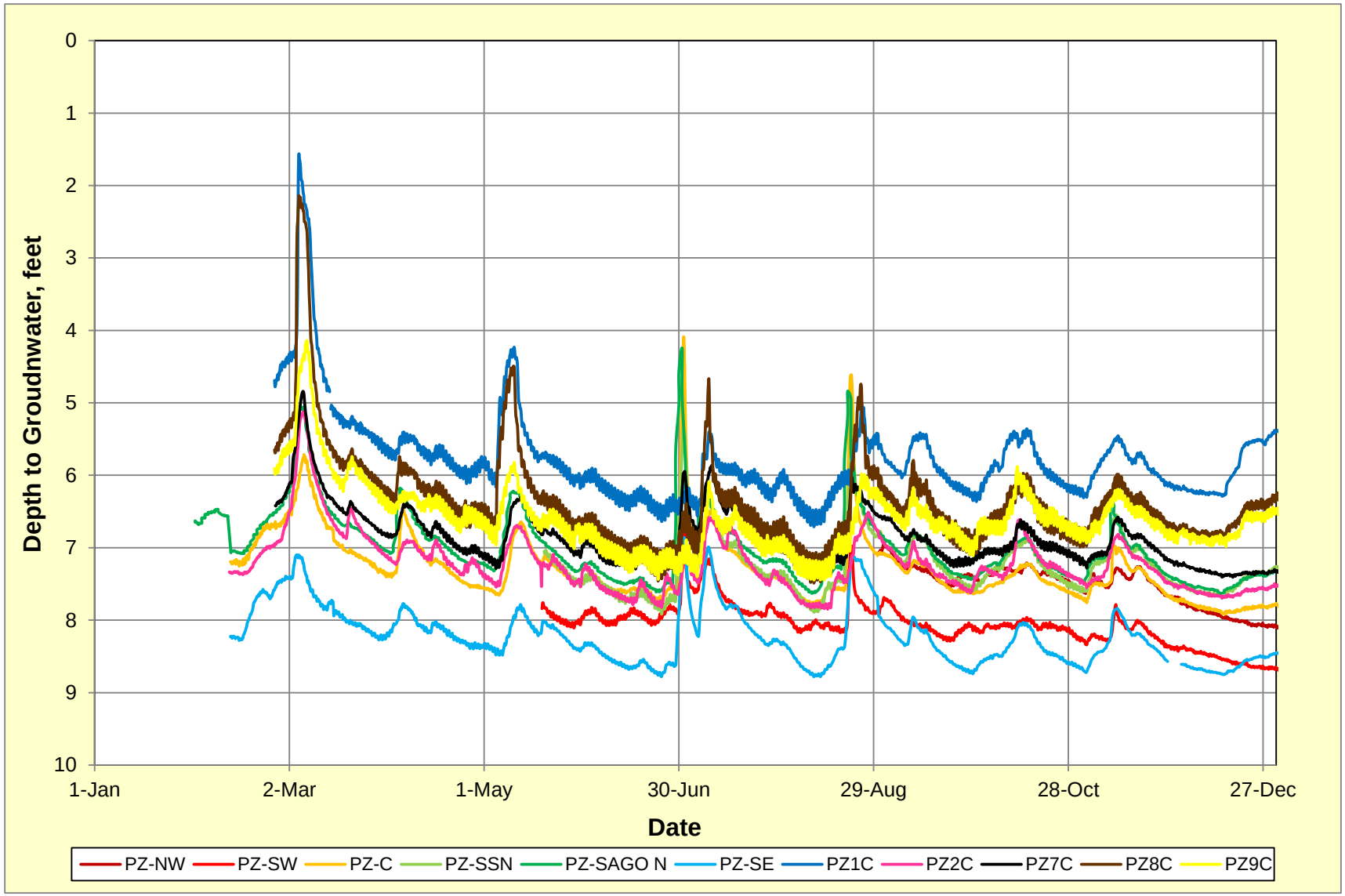

Figure 28.—Depth to groundwater data for the Seed Feasibility Study, Mass Transplanting, and the Nature Trail during 2011.

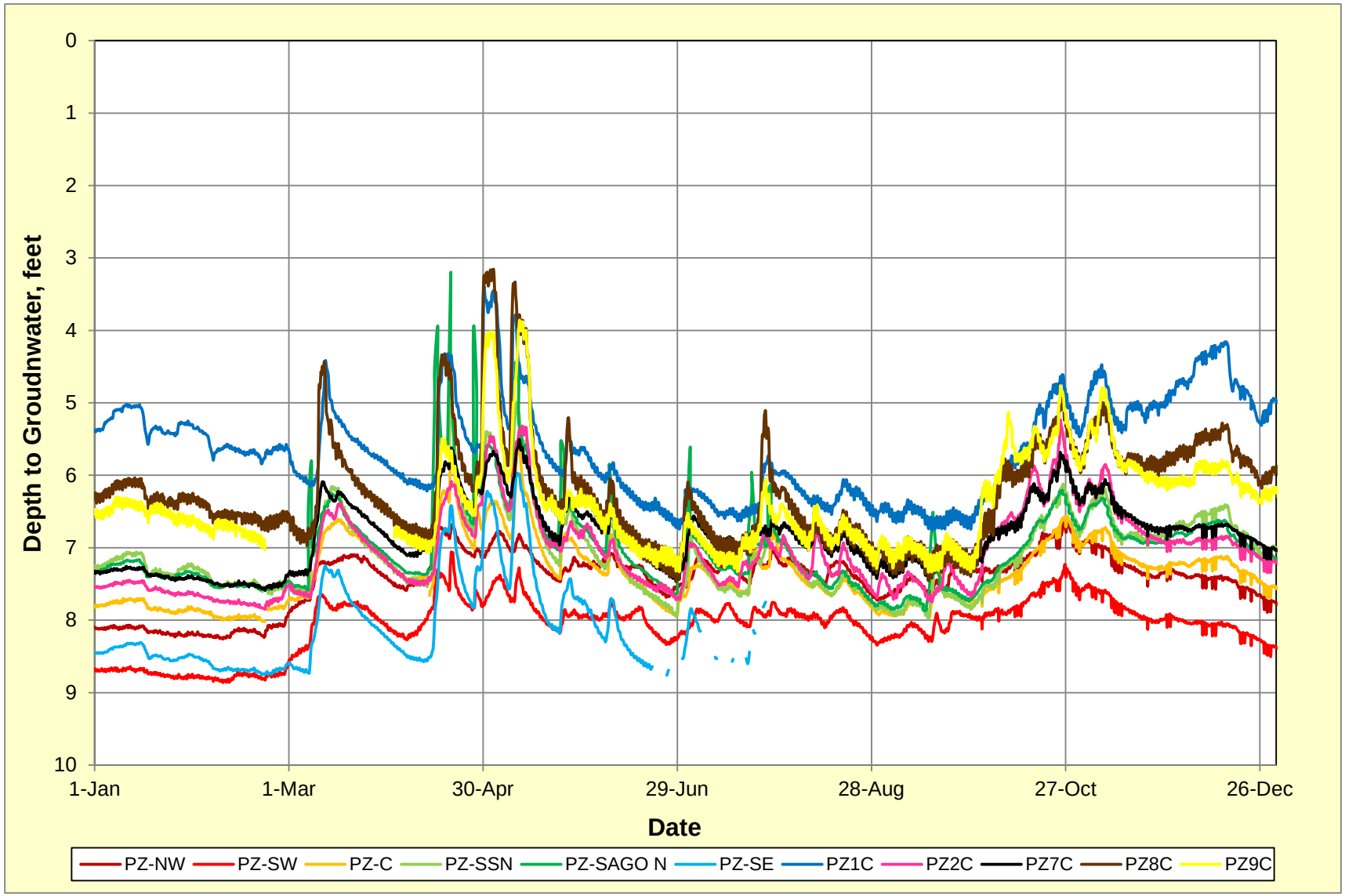

Figure 29.—Depth to groundwater data for the Seed Feasibility Study, Mass Transplanting, and the Nature Trail during 2012.

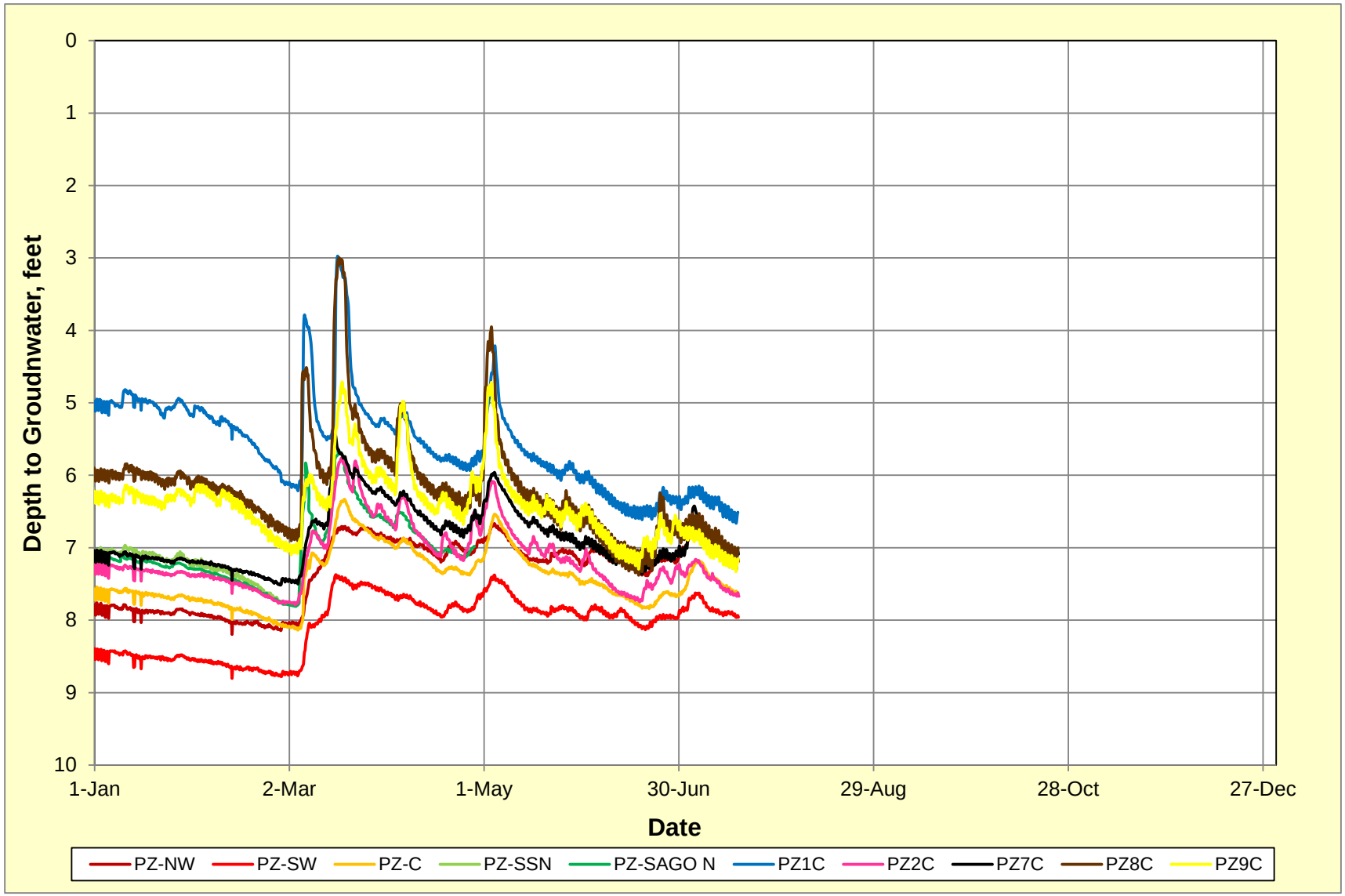

Figure 30.—Depth to groundwater data for the Seed Feasibility Study, Mass Transplanting, and the Nature Trail during 2013.

Figure 31.—Depth to groundwater data for Crane Roost during 2011.

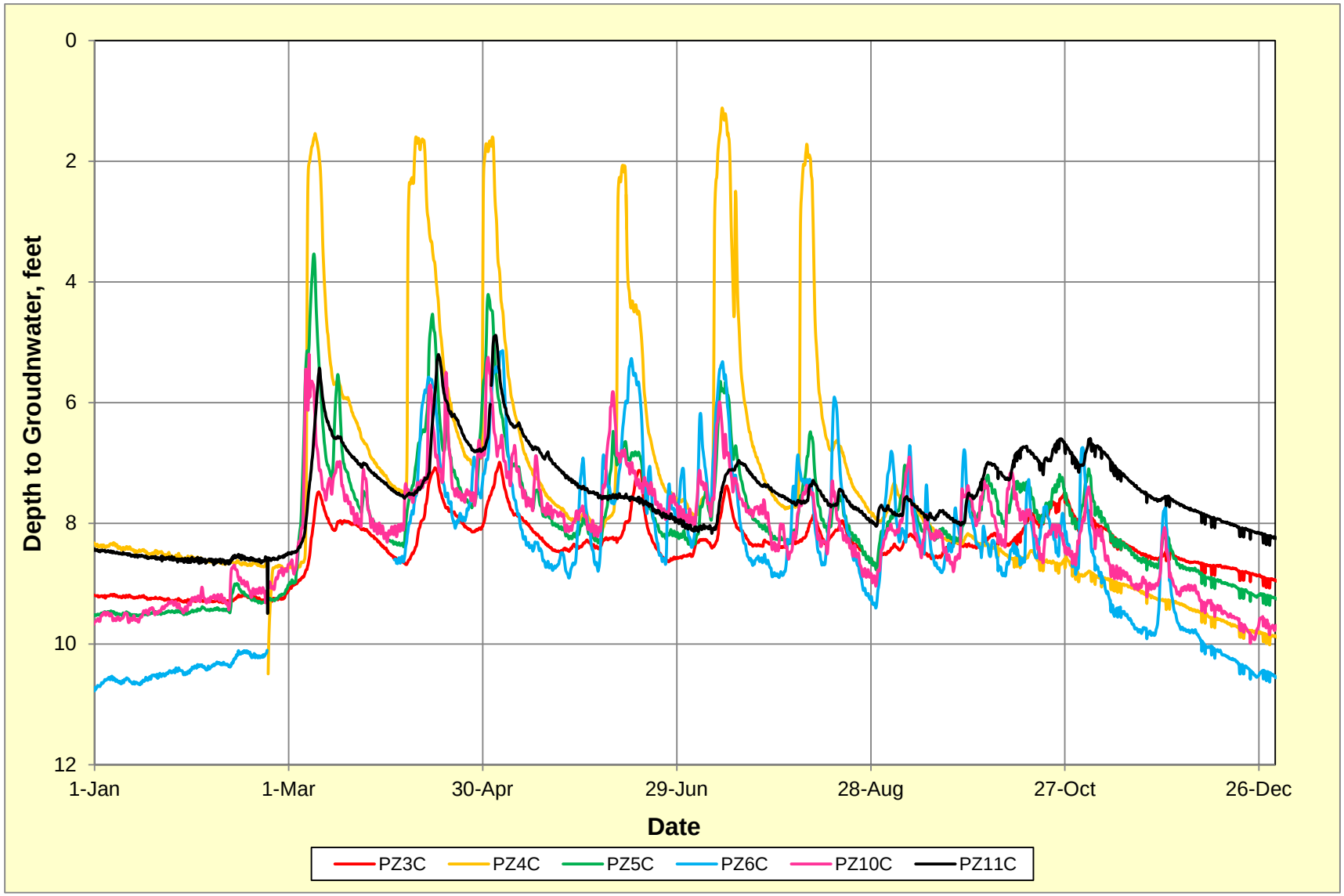

Figure 32.—Depth to groundwater data for Crane Roost during 2012.

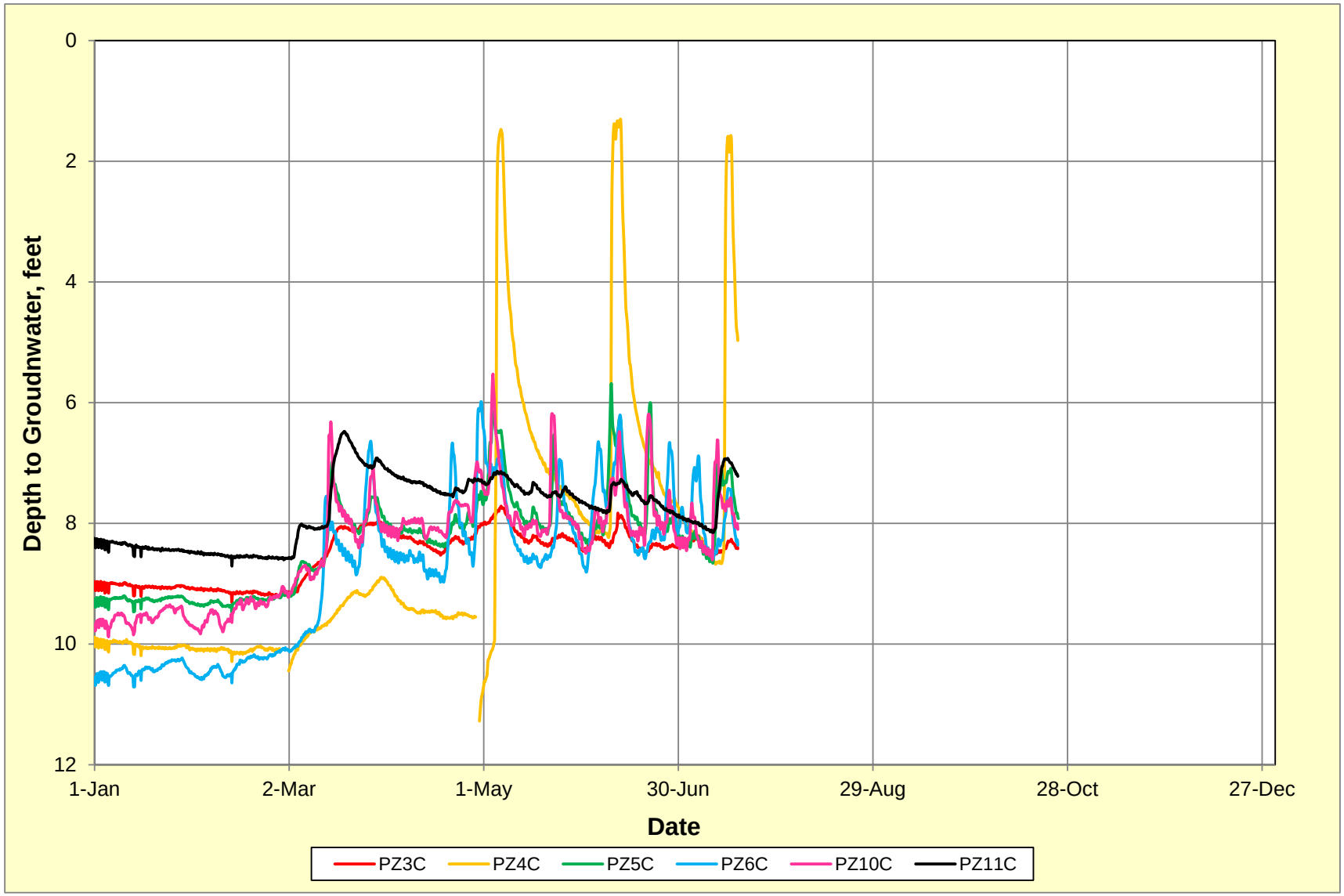

Figure 33.—Depth to groundwater data for Crane Roost during 2013.

Similarly to other management units at Cibola NWR Unit #1, the groundwater depth at Crane Roost was greater during the non-irrigation season, and erratic groundwater depths were observed between clear percolation events. In the non-irrigated season, groundwater depths ranged between 8 and 11 ft. Data for PZ4C indicate extensive mounding of groundwater at this location. The much more clayey soil texture observed throughout the soil and shallow aquifer at this location and corresponding low hydraulic conductivity likely reduces the rate at which mounding dissipates.

The height of groundwater mounding at Cibola NWR Unit #1 was similar to the BLCA and lower than the PVER (with the exception of PZ4C). However, relatively infrequent groundwater elevation increases were observed compared to both the BLCA and PVER, indicating less percolation and salt leaching.

The change in groundwater elevation at the Nature Trail during and after irrigation on July 7, 2011, is shown on figure 34. Prior to irrigation, a general northwest to southeast gradient was present, indicating flow of groundwater through to the southeast. During irrigation, mounding was apparent on the north and northwest portions of the Nature Trail near the irrigation source. During irrigation, the gradient within the site remained generally from northwest to southeast but increased in magnitude, which indicates an increased rate of groundwater flow to the southeast. Over a period of approximately 2 weeks, the groundwater mound dissipated and the groundwater gradient returned to pre-irrigation conditions.

The change in groundwater elevations at Crane Roost during and after irrigation on May 7, 2011, is shown on figure 35. Prior to irrigation, a general northwest to southeast gradient was present, indicating flow of groundwater through the site toward Arnett Ditch on the eastern and southern edges of Crane Roost. As irrigation was initiated, mounding occurred primarily on the west side of the site nearer the irrigation source. Similarly to the Nature Trail, the gradient and flow direction remained approximately the same (to the southeast) but increased in magnitude. Over a period of 12 days, the groundwater mound dissipated and groundwater elevations and gradient approximated pre-irrigation conditions.

4.3.2 Groundwater Chemistry

Chemistry data for groundwater are summarized in table 32. The ratio of total dissolved solids (milligrams per liter [mg/L]) to groundwater EC (dS/m) ranged from 560:1 to 660:1, with an average of 628:1 for the BLCA, 600:1 for the PVER, and 614:1 for Cibola NWR Unit #1.

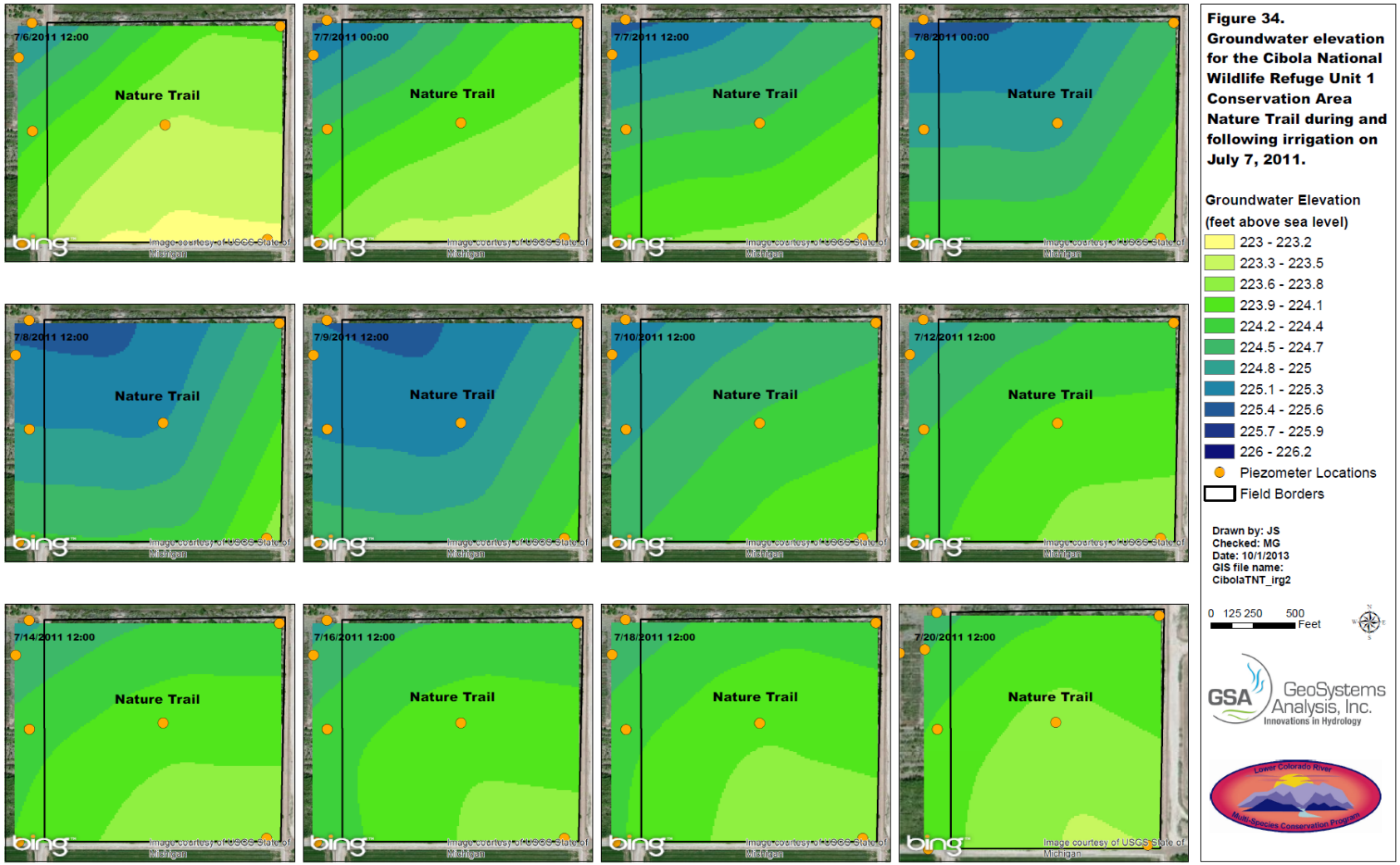

Figure 34.—Groundwater elevation for the Nature Trail during and following irrigation on July 7, 2011.

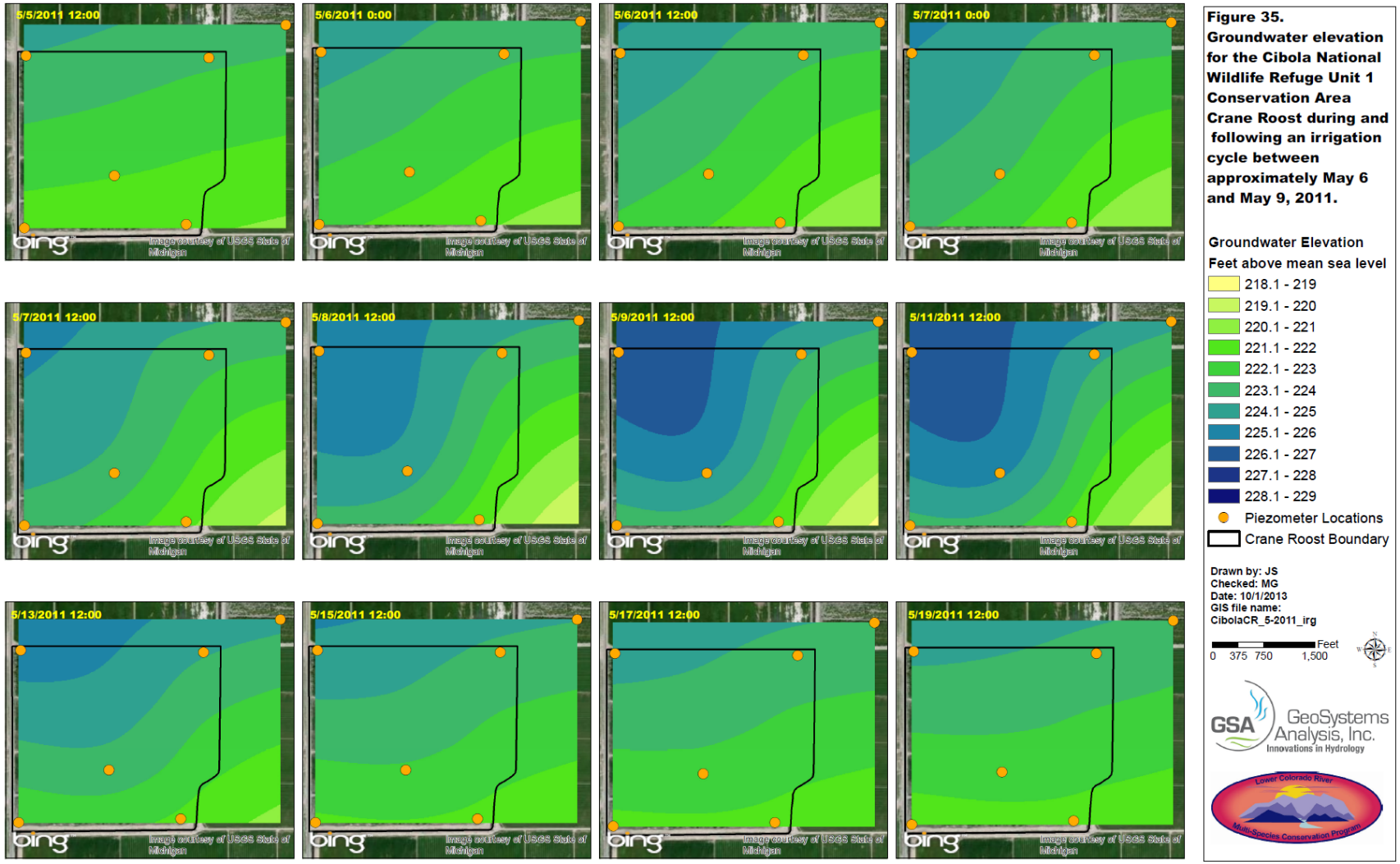

Figure 35.—Groundwater elevations for Crane Roost during and following an irrigation cycle between approximately May 6 and May 9, 2011.

Table 32.—Groundwater and irrigation water chemistry results for July 24–26, 2012

Category	Analyte	BLCA			PVER			Cibola NWR Unit #1			
		PZ1BL	PZ2BL	Irrigation	PZ3PVER	PZ4PVER	Irrigation	PZ6C	PZ7C	PZ11C	Irrigation
Inductively coupled plasma total metals (mg/L)	Calcium	320	450	93	810	270	160	370	1,200	850	200
	Magnesium	170	120	37	180	65	29	89	210	610	45
	Potassium	22	23	8.8	15	8.9	5.5	11	15	20	8.7
	Sodium	510	280	120	170	110	78	1,300	280	3,900	100
Anions by ion chromatography (mg/L)	Chloride	1,100	570	80	150	97	110	1,100	210	4,900	81
	Fluoride	0.75	1.1	ND	ND	ND	ND	ND	0.56	ND	ND
	Nitrogen, nitrate	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Sulfate	2,500	1500	220	400	290	300	1,100	580	5,200	11
Alkalinity (mg/L)	Bicarbonate	390	630	130	650	380	170	560	410	--	150
	Carbonate	ND	ND	ND	ND	ND	ND	ND	ND	--	ND
	Hydroxide	ND	ND	ND	ND	ND	ND	ND	ND	--	ND
	Total alkalinity	390	630	130	650	380	170	560	410	--	150
EC (dS/m)	Conductivity	4.7	3.6	0.96	2.5	1.6	1.3	7.2	2.8	27	1.0
Total dissolved solids (mg/L)	Total dissolved solids	3,100	2,200	590	1,400	960	830	4,300	1,700	16,000	660

Groundwater EC data are summarized by conservation area on figure 36. Points indicate geometric means, and error bars show the range of observed values. Overall, groundwater EC was lowest at the PVER, highest at Cibola NWR Unit #1, and intermediate at the BLCA. The range of groundwater EC observed at both the BLCA and Cibola NWR Unit #1 increased during the project period. Individual piezometer data are described in additional detail by conservation area below.

4.3.2.1 Beal Lake Conservation Area

Groundwater EC sampling results for the BLCA are shown on figure 37 and provided in table 33. Seasonal trends in groundwater EC were not apparent, and the range of groundwater EC was between 1 and 5 dS/m. However, increases in groundwater EC were observed for a subset of piezometers near the beginning of 2011. The EC at piezometer PZ6BL approached 10 dS/m in July 2012. Annual averages of groundwater EC are shown on figure 38. Groundwater at piezometer A remained lowest, and was similar to the irrigation water EC (see below). Groundwater EC measured in the rest of the piezometers onsite was greater than irrigation water EC, and the mean EC for each sampling event was between 1.8 and 3.5 dS/m.

Salinity data for surrounding surface water at the site (i.e., Topock Marsh, Beal Lake, the marsh created northeast of the site, and Field EE) are provided in table 34. For the newly created marsh, water EC decreased between July 2012 and January 2013 and then increased again for July 2013. Irrigation water (Topock Marsh at the BLCA pump) salinity ranged between 2.4 and 1.2, with the salinity likely controlled by the management of Topock Marsh. Beal Lake water salinity was greater than that of Topock Marsh.

Field EC measurements at PZ2BL were consistently lower than that at PZ5BL. Automated groundwater EC results are presented for the BLCA on figure 39. Rapid changes in groundwater EC were observed, particularly for PZ5BL, during percolation (irrigation) events. Increases in EC during irrigation were likely due to flushing of accumulated soil salts into the groundwater. During the non-irrigation season, groundwater EC at PZ2BL stabilized between 2 and 4 dS/m, and groundwater EC at PZ5BL was between 4 and 6 dS/m. Manual soil EC sampling measurements at PZ2BL and PZ5BL, also shown on figure 39, were generally close to automated EC measurements. Manual sampling was sufficient to observe seasonal trends in PZ2BL groundwater EC for the entire monitoring period. Manual sampling did not detect the seasonal increase in groundwater EC at PZ5BL during summer 2011. The time of sampling greatly affected manual EC measurements. This method of periodic point sampling did not help detect as much variation in groundwater EC as did the automated monitoring.

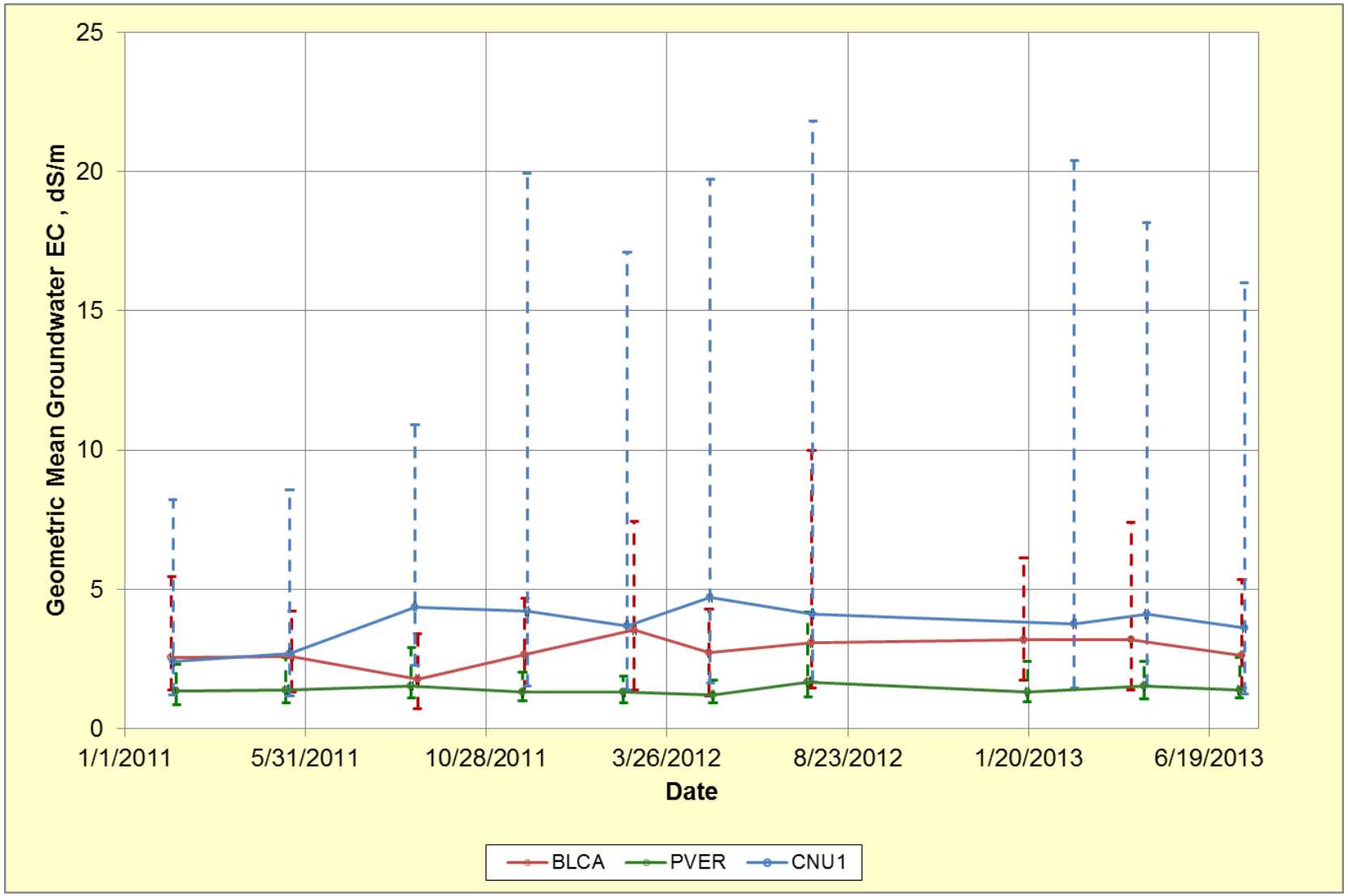

Figure 36.—Summary groundwater EC results for the BLCA, PVER, and Cibola NWR Unit #1.
Error bars show the range of observed values.

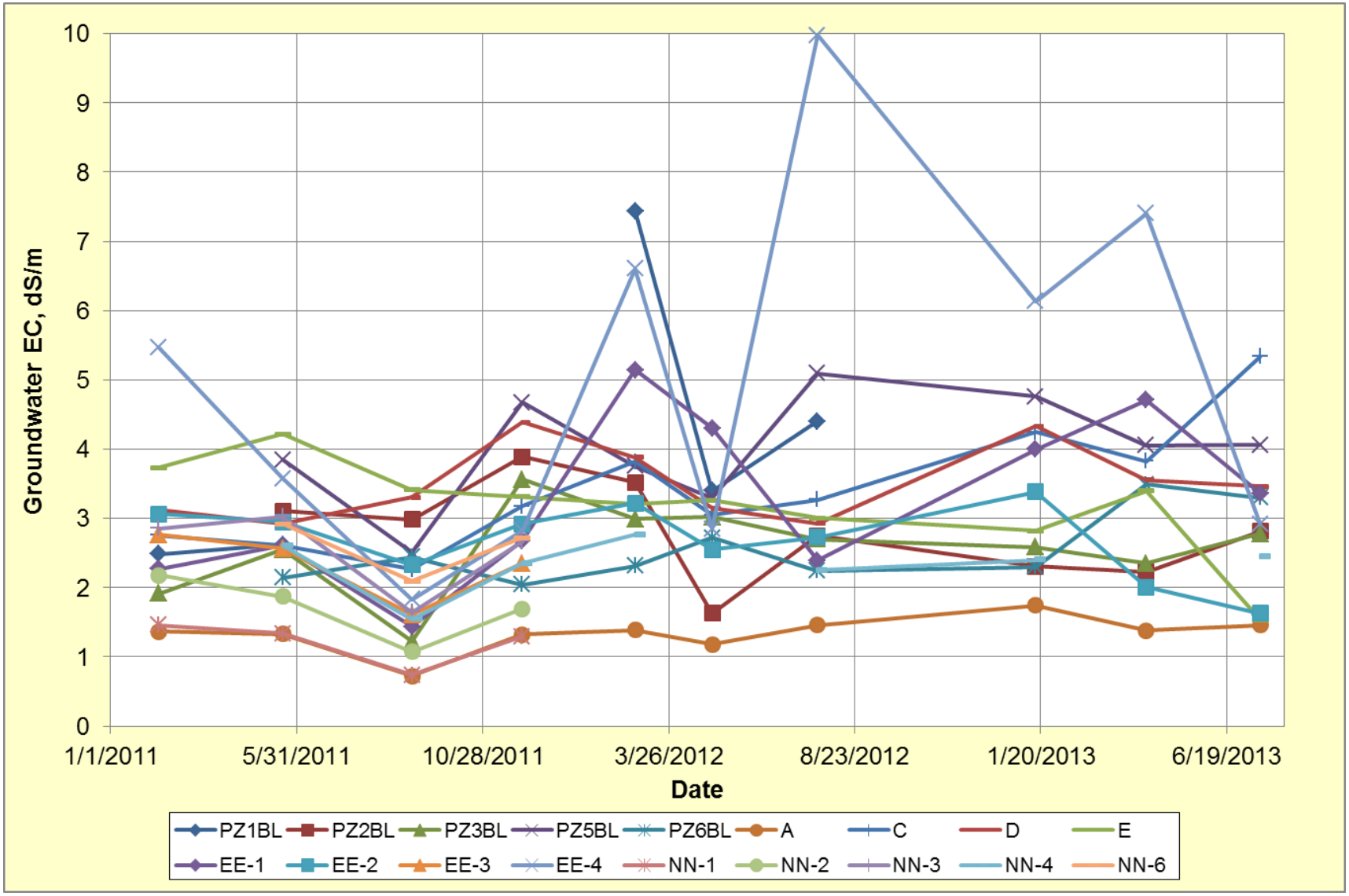

Figure 37.—Groundwater EC results for the BLCA.

Table 33.—Groundwater EC field testing results for the BLCA

Piezometer	EC (dS/m)									
	2/9/2011	5/20/2011	9/1/2011	11/29/11–11/30/11	2/28/12–2/29/12	4/30/2012	7/24/2012	1/16/2013	4/15/2013	7/16/2013
PZ1BL	2.5	2.6	–	–	7.4	3.4	4.4	–	–	1.6
PZ2BL	–	3.1	3.0	3.9	3.5	1.6	2.7	2.3	2.2	2.8
PZ3BL	1.9	2.5	1.2	3.6	3.0	3.0	2.7	2.6	2.3	2.8
PZ5BL	–	3.9	2.5	4.7	3.8	3.3	5.1	4.8	4.1	4.1
PZ6BL	–	2.1	2.4	2.0	2.3	2.7	2.2	2.3	3.5	3.3
A	1.4	1.3	0.7	1.3	1.4	1.2	1.5	1.7	1.4	1.5
C	2.8	2.6	2.3	3.2	3.8	3.0	3.3	4.2	3.8	5.3
D	3.1	2.9	3.3	4.4	3.9	3.1	2.9	4.3	3.6	3.5
E	3.7	4.2	3.4	3.3	3.2	3.3	3.0	2.8	3.4	1.5
EE-1	2.3	2.6	1.4	2.7	5.1	4.3	2.4	4.0	4.7	3.4
EE-2	3.1	3.0	2.3	2.9	3.2	2.6	2.7	3.4	2.0	1.6
EE-3	2.8	2.6	1.6	2.4	–	–	–	–	–	–
EE-4	5.5	3.6	1.8	2.8	6.6	2.8	10.0	6.1	7.4	2.9
NN-1	1.5	1.3	0.7	1.3	–	–	–	–	–	–
NN-2	2.2	1.9	1.1	1.7	–	–	–	–	–	–
NN-3	2.9	3.0	1.6	2.7	–	–	–	–	–	–
NN-4	–	2.6	1.5	2.4	2.8	–	2.3	2.4	–	2.5
NN-6	–	2.9	2.1	2.7	–	–	–	–	–	–
Geometric mean	2.6	2.6	1.8	2.7	3.5	2.7	3.1	3.2	3.2	2.6
PZ4BL	15.9	–	2.3	23.4	3.8	2.5	2.6	9.7	2.9	2.6

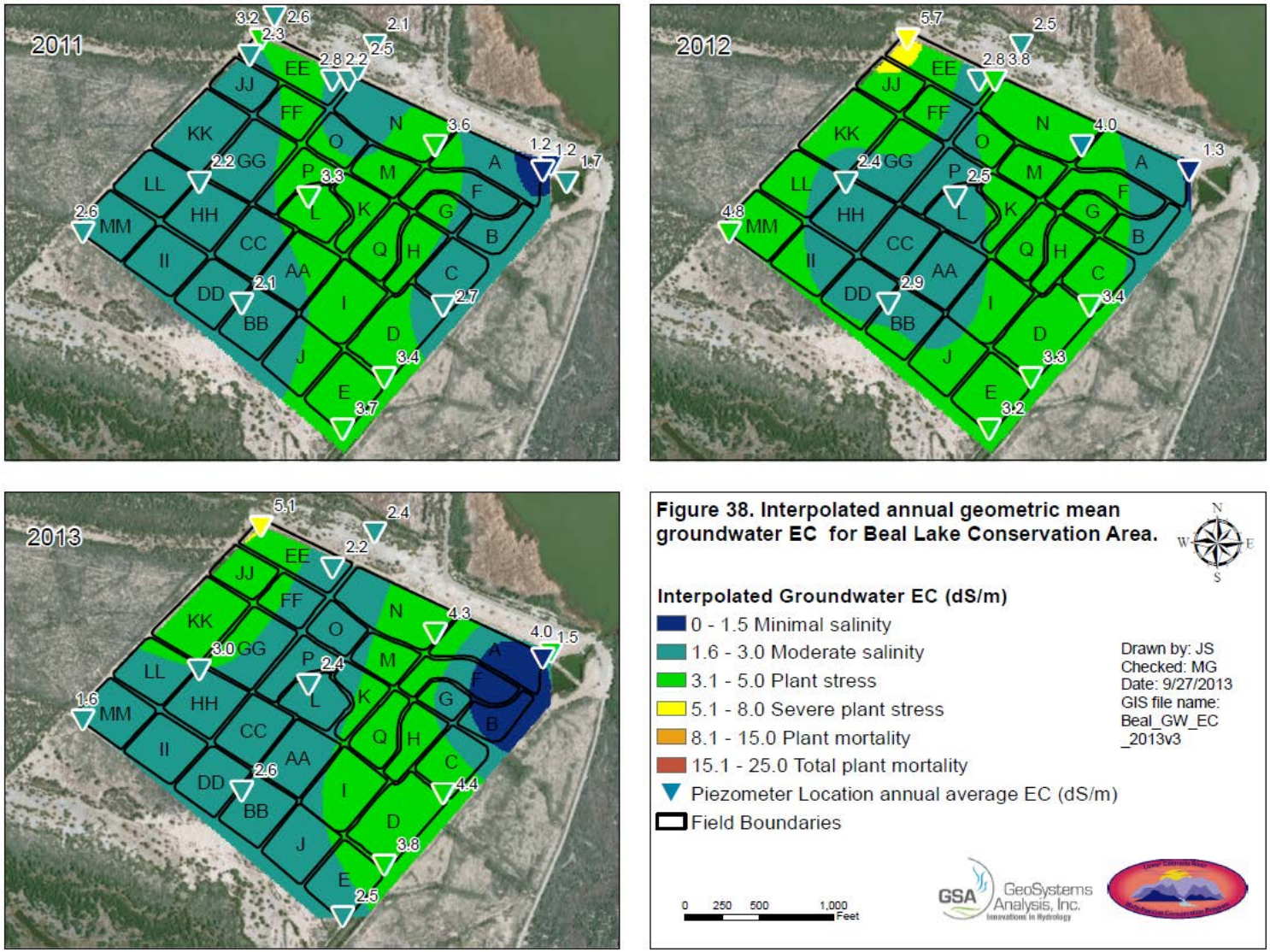

Figure 38.—Interpolated annual geometric mean groundwater EC for the BLCA.

Table 34.—Irrigation and surface water EC results for the BLCA

Date	EC (dS/m)			
	Irrigation	Beal Lake	Created marsh	Willow swale (Field EE)
2/9/2011	2.4	–	–	–
5/20/2011	2.0	–	–	–
11/29/11–11/30/11	2.0	3.4	–	–
2/28/12–2/29/12	1.9	4.8	4.9	2.9
4/30/2012	1.2	–	4.3	4.3
7/24/2012	–	–	7.5	–
1/16/2013	1.8	–	1.7	–
4/15/2013	1.4	–	1.4	–
7/16/2013	1.3	–	3.2	2.1

4.3.2.2 Palo Verde Ecological Reserve

Groundwater EC sampling results for the PVER are shown on figure 40 and provided in table 35. No seasonal trends were apparent. Groundwater EC averaged between 1.2 and 1.7 dS/m across the sites and was consistently below 2.5 dS/m for all piezometers except PZ6PVER, which was as high as 4.2 dS/m. Salinity data for irrigation water and drainage water (collected from the drain on the west side of PVER Phases 02 and 03) are provided in table 36. Irrigation water EC was at or below 1.0 dS/m for every sampling event, and drainage ditch water EC was at or below 2.0 dS/m.

Annual average groundwater EC values are interpolated on figure 41. Groundwater EC was typically lowest on the northwest portion of the monitored area and higher on the northeast. Compared to the BLCA and Cibola NWR Unit #1, groundwater EC was lower at the PVER, with less variation between piezometer locations.

Automated groundwater EC data for the PVER are presented on figure 42. As for manual sampling results, groundwater EC was generally higher at PZ6PVER than at PZ2PVER. Automated groundwater EC readings often increased concomitantly with increased groundwater elevation, indicating the flushing of soil salts into groundwater. Early in 2011, automated EC readings at PZ2PVER often doubled in response to irrigation. Following July 2011, EC at this piezometer rarely exceeded 1.5 dS/m. At PZ6PVER, automated groundwater EC

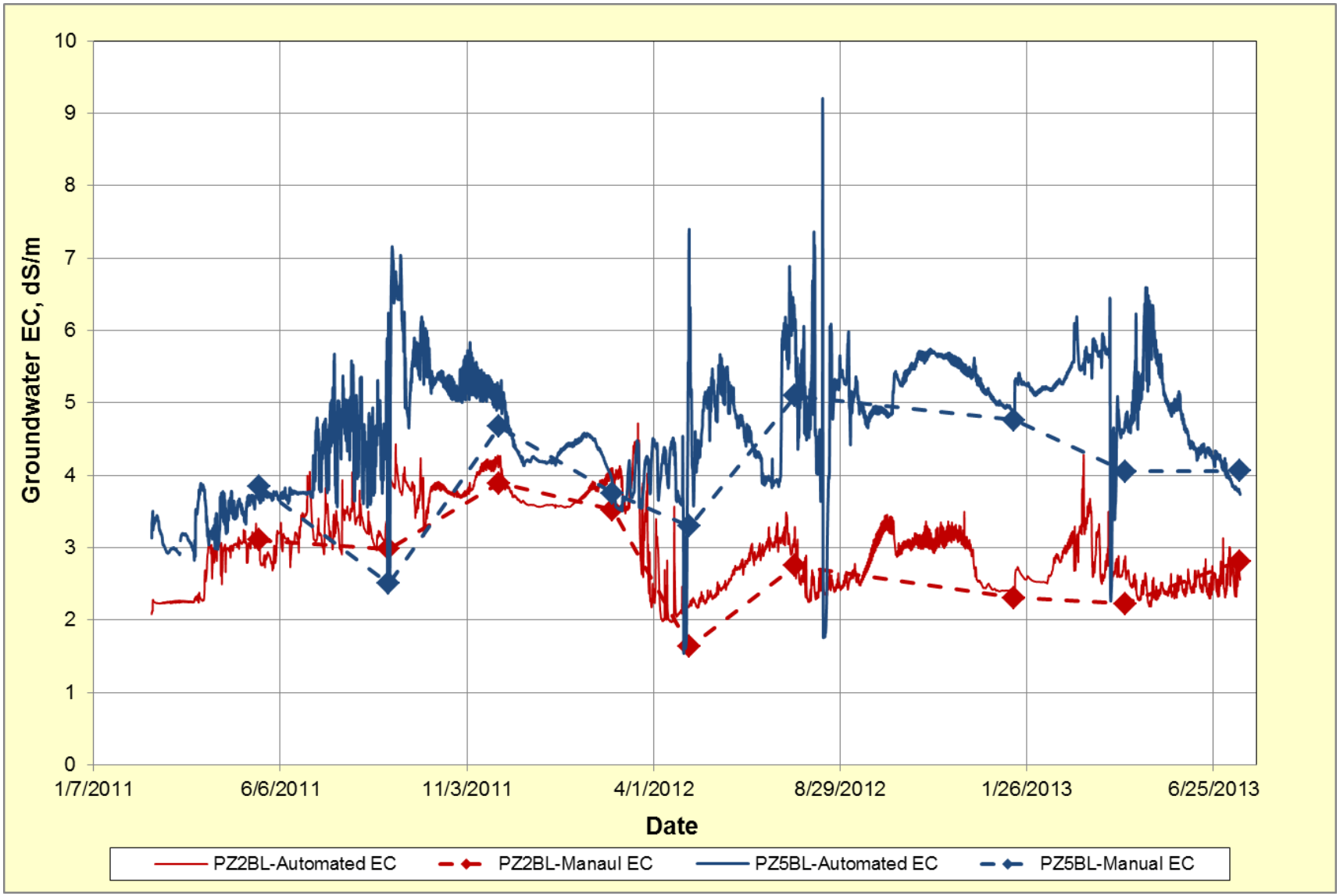

Figure 39.—Automated and manual groundwater EC results for the BLCA.

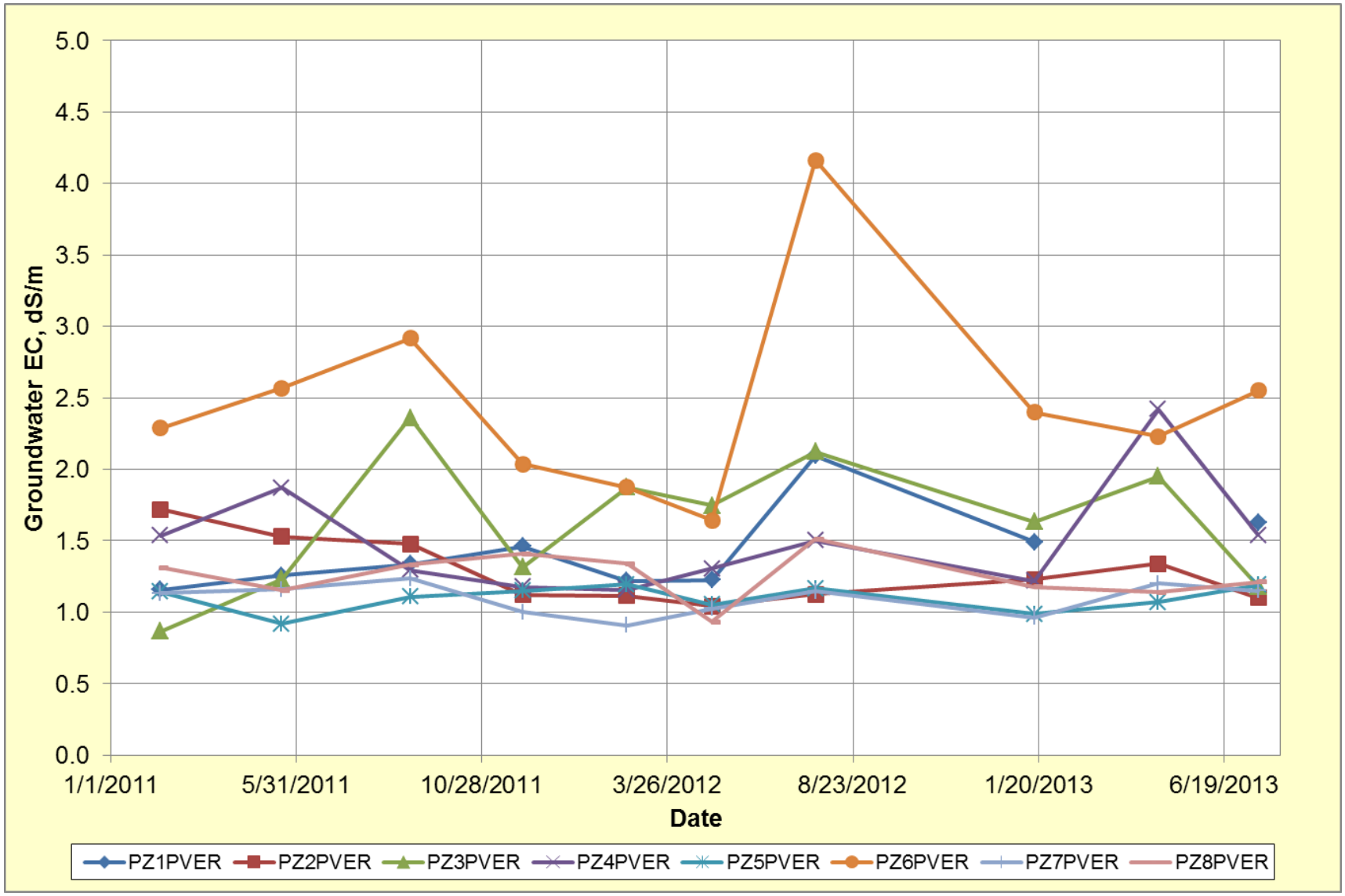

Figure 40.—Groundwater EC results for the PVER.

Table 35.—Groundwater EC field testing results for the PVER

Piezometer	EC (dS/m)									
	2/10/2011	5/19/2011	8/31/2011	11/30/2011	2/22/2012	5/1/2012	7/24/2012	1/17/2013	4/27/2013	7/17/2013
PZ1PVER	1.2	1.3	1.3	1.5	1.2	1.2	2.1	1.5	–	1.6
PZ2PVER	1.7	1.5	1.5	1.1	1.1	1.0	1.1	1.2	1.3	1.1
PZ3PVER	0.9	1.2	2.4	1.3	1.9	1.7	2.1	1.6	2.0	1.2
PZ4PVER	1.5	1.9	1.3	1.2	1.2	1.3	1.5	1.2	2.4	1.5
PZ5PVER	1.1	0.9	1.1	1.1	1.2	1.1	1.2	1.0	1.1	1.2
PZ6PVER	2.3	2.6	2.9	2.0	1.9	1.6	4.2	2.4	2.2	2.6
PZ7PVER	1.1	1.2	1.2	1.0	0.9	1.0	1.1	1.0	1.2	1.2
PZ8PVER	1.3	1.2	1.3	1.4	1.3	0.9	1.5	1.2	1.1	1.2
Geometric mean	1.3	1.4	1.5	1.3	1.3	1.2	1.7	1.3	1.5	1.4

Table 36.—Irrigation and drainage ditch water EC results for the PVER

Date	EC (dS/m)	
	Irrigation	Drainage ditch
5/19/2011	0.6	2.0
8/31/2011	1.0	–
2/22/12–2/23/12	1.0	–
4/27/2013	0.9	1.8
7/17/2013	1.0	1.7

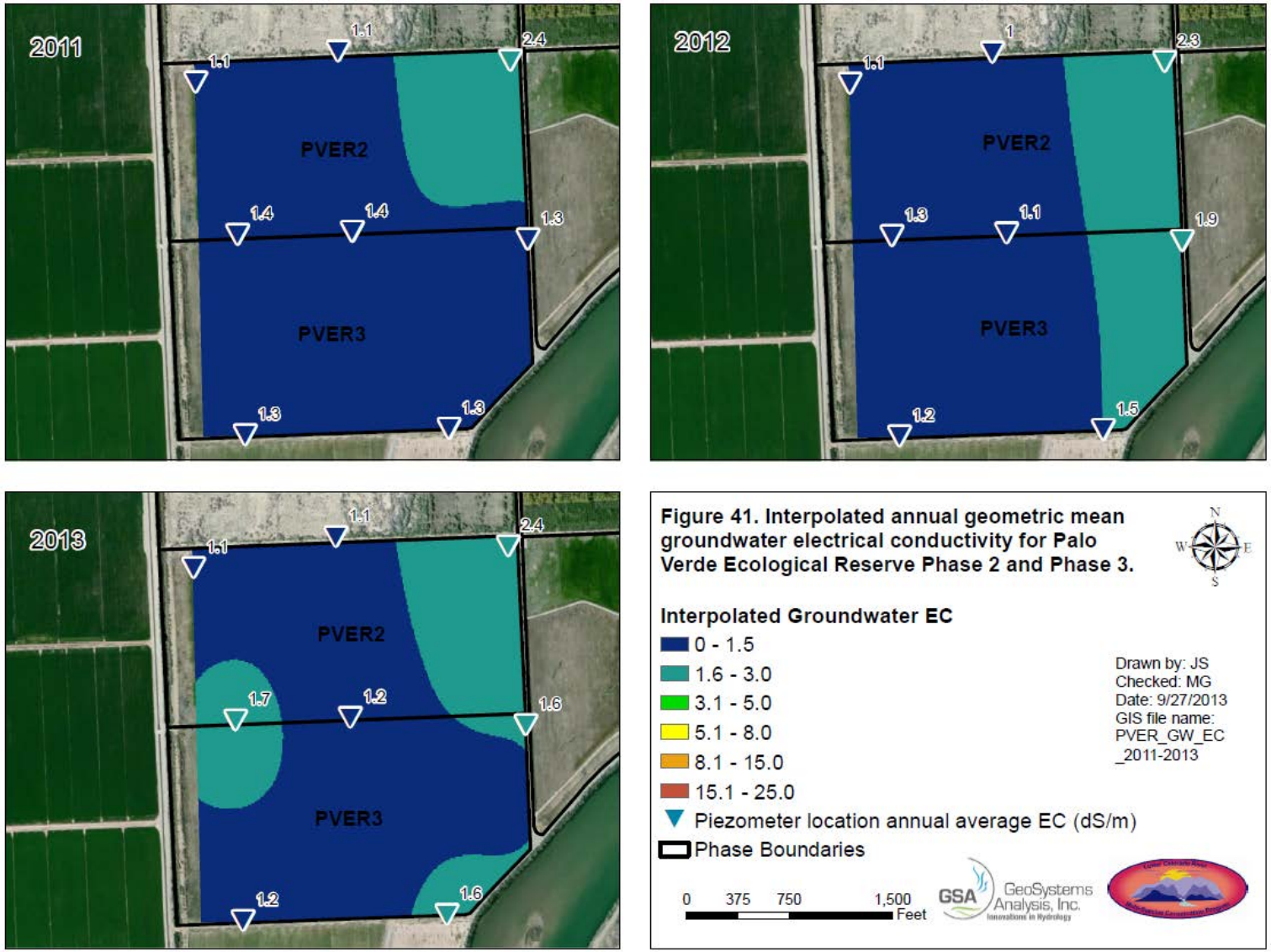

Figure 41.—Interpolated annual geometric mean groundwater EC for PVER Phases 02 and 03.

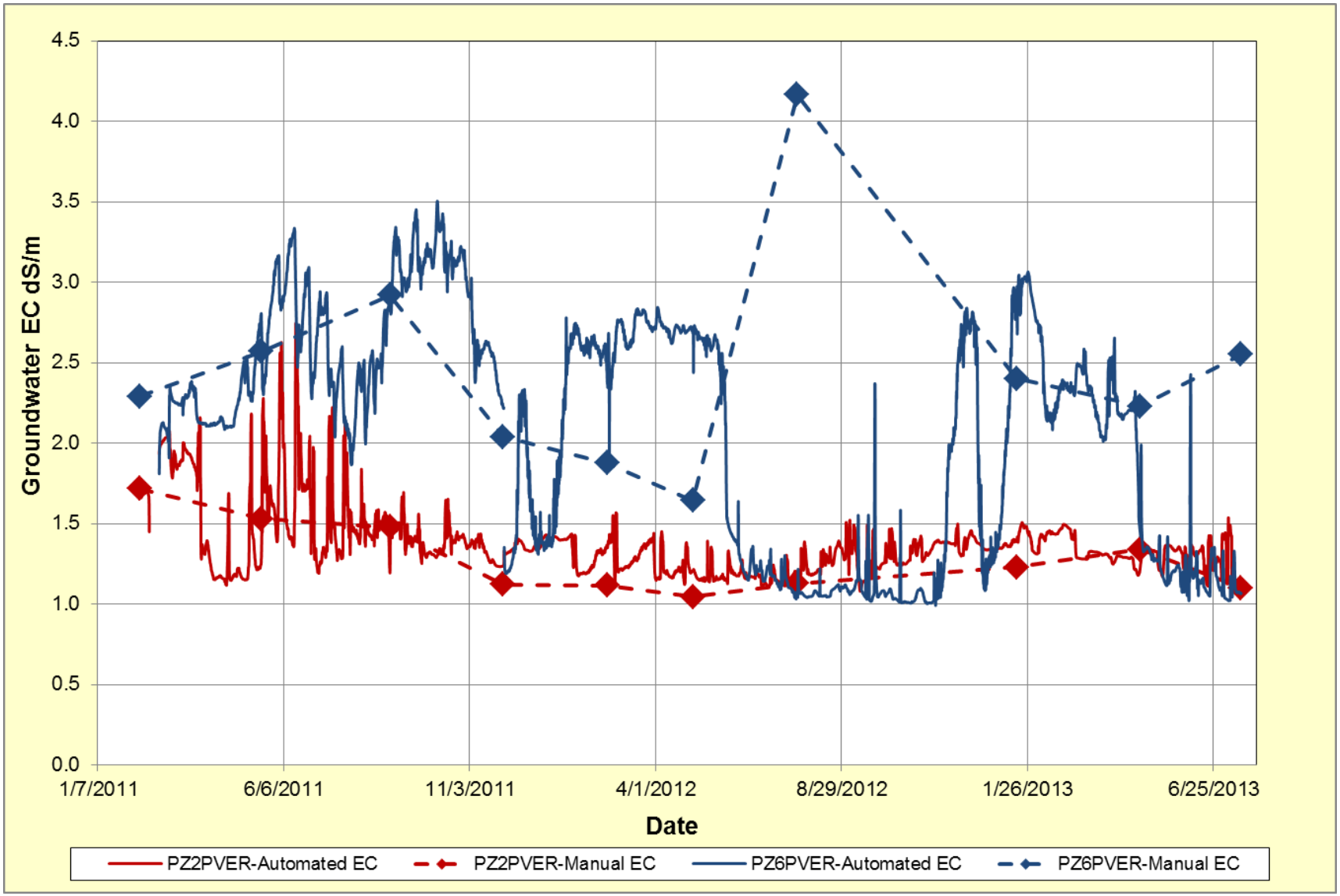

Figure 42.—Automated and manual groundwater EC results for the PVER.

measurements during 2011 were usually greater than 2 dS/m. During 2012 and 2013, the groundwater EC at this location declined to less than 2.5 dS/m during the middle of the irrigation season (May through October 2012 and April 2013). Manual groundwater EC sampling results, also shown on figure 42, generally agreed with automated data readings. The exception was in July 2012, when the manual EC measurement was nearly four times that of the sensor reading. As for the BLCA, automated EC monitoring allowed detection of rapid changes in groundwater EC compared to periodic manual sampling.

4.3.2.3 Cibola National Wildlife Refuge Unit #1 Conservation Area

Groundwater EC field data for Cibola NWR Unit #1 are provided in table 37. Average groundwater EC at the site varied between 2.4 and 4.7 dS/m. Groundwater EC sampling results for the eastern portion of the Cibola NWR Unit #1 monitoring area (i.e., the Seed Feasibility Study, Mass Transplanting, and the Nature Trail) are shown on figure 43. No seasonal trends were apparent. Annual average values are interpolated on figure 44. Salinity for the southeast corner of the Nature Trail (PZ9C) greatly increased in 2012. EC remained higher than initial levels in 2013 but decreased compared to 2012.

Groundwater EC for the western portion of Crane Roost are shown on figure 45. Average annual values are shown on figure 46. Beginning in late 2011 and corresponding to the initiation of irrigation at the North 160 site, groundwater EC increased, particularly on the southeast portion of Crane Roost. Salinity at PZ11C and PZ4C remained elevated into early 2013, whereas salinity at PVCPIEZO approximately returned to 2011 levels by April 2013.

Salinity data for irrigation water, Arnett Ditch water, and irrigation water on the surface of the North 160 site are presented in table 38. Irrigation water salinity was intermediate between the PVER and BLCA, averaging 1.2 dS/m. Arnett Ditch EC was much greater (up to four times) than that of the drainage ditch at the PVER, with a mean of 6.8 dS/m over the monitoring period.

Automated groundwater EC data for Crane Roost are presented on figure 47. Automated groundwater EC readings for PZ3C increased steadily during 2011 from approximately 4 dS/m to over 12 dS/m. During 2012 and 2013, groundwater EC at this location was generally between 10 and 14 dS/m. Between January 2011 and early March 2012, groundwater EC at PZ5C was between 3 and 10 dS/m except for immediately after three irrigation events. Thereafter, groundwater EC at PZ5C stabilized between approximately 5 and 7 dS/m. As for the other sites, manual EC sampling results for these piezometers (also on figure 47) were similar to automated results and showed similar seasonal trends. However, these point measurements did not detect short-term variability or detect the minimum or maximum groundwater EC value for the monitoring period.

Table 37.—Groundwater EC field testing results for Cibola NWR Unit #1

Piezometer	EC (dS/m)									
	2/10/2011	5/18/2011–5/19/2011	8/30/2011–8/31/2011	12/1/2011	2/22/2012–2/23/2012	5/1/2012–5/2/2012	7/25/2012–7/26/2012	2/27/2013	4/28/2013	7/18/2013
PZ1C	–	8.3	4.4	1.5	1.6	5.6	2.1	2.9	4.3	1.7
PZ2C	2.6	3.1	4.3	2.9	2.5	2.6	2.6	2.0	2.6	3.9
PZ3C	–	8.6	10.9	10.8	7.9	8.6	9.8	7.5	12.8	8.4
PZ4C	–	2.3	2.3	19.9	11.6	7.2	12.2	17.5	2.9	13.7
PZ5C	8.2	3.0	5.9	7.9	5.9	2.9	5.6	5.8	7.0	6.8
PZ6C	4.3	5.9	7.1	7.2	–	6.2	6.6	5.8	9.1	8.0
PZ7C	–	1.2	3.3	2.1	2.0	2.9	2.0	1.9	2.2	2.1
PZ8C	–	5.3	6.0	3.2	3.5	5.7	5.5	3.2	4.2	3.2
PZ9C	–	5.3	3.5	2.1	–	14.5	12.4	8.4	13.2	1.3
PZ10C	–	2.5	5.7	6.1	3.8	6.3	2.4	2.1	2.4	2.6
PZ11C	–	4.0	2.4	17.6	17.0	19.7	21.8	20.4	18.2	16.0
PZ-NW	3.0	–	–	3.0	2.4	2.5	2.8	3.1	2.9	2.9
PZ-SW	3.1	2.8	4.1	6.4	3.2	6.3	4.0	3.3	3.8	4.0
PZ-NE	1.2	1.3	2.6	1.9	1.5	3.2	2.5	2.0	3.3	2.3
PZ-SE	1.3	1.2	2.3	2.7	3.3	4.1	2.2	1.5	1.5	1.6
PZ-C	2.2	2.2	4.4	4.0	3.2	2.9	2.8	2.8	3.4	3.1
PZ-SSC	2.2	2.4	4.1	2.6	1.4	1.6	1.7	1.8	1.8	2.0
PZ-SSN	1.7	1.2	7.4	3.0	2.1	3.3	2.8	2.8	3.4	3.3
PZ-SAGO N	1.6	1.4	5.3	3.7	4.3	3.2	3.8	–	3.4	3.7
PZ-SAGO S	2.1	1.6	5.5	3.3	2.4	–	–	–	3.6	3.2
PVCPIEZO	2.6	2.5	3.7	–	17.1	5.4	3.9	–	4.1	3.3
Geometric mean	2.4	2.7	4.4	4.2	3.7	4.7	4.1	3.8	4.1	3.6

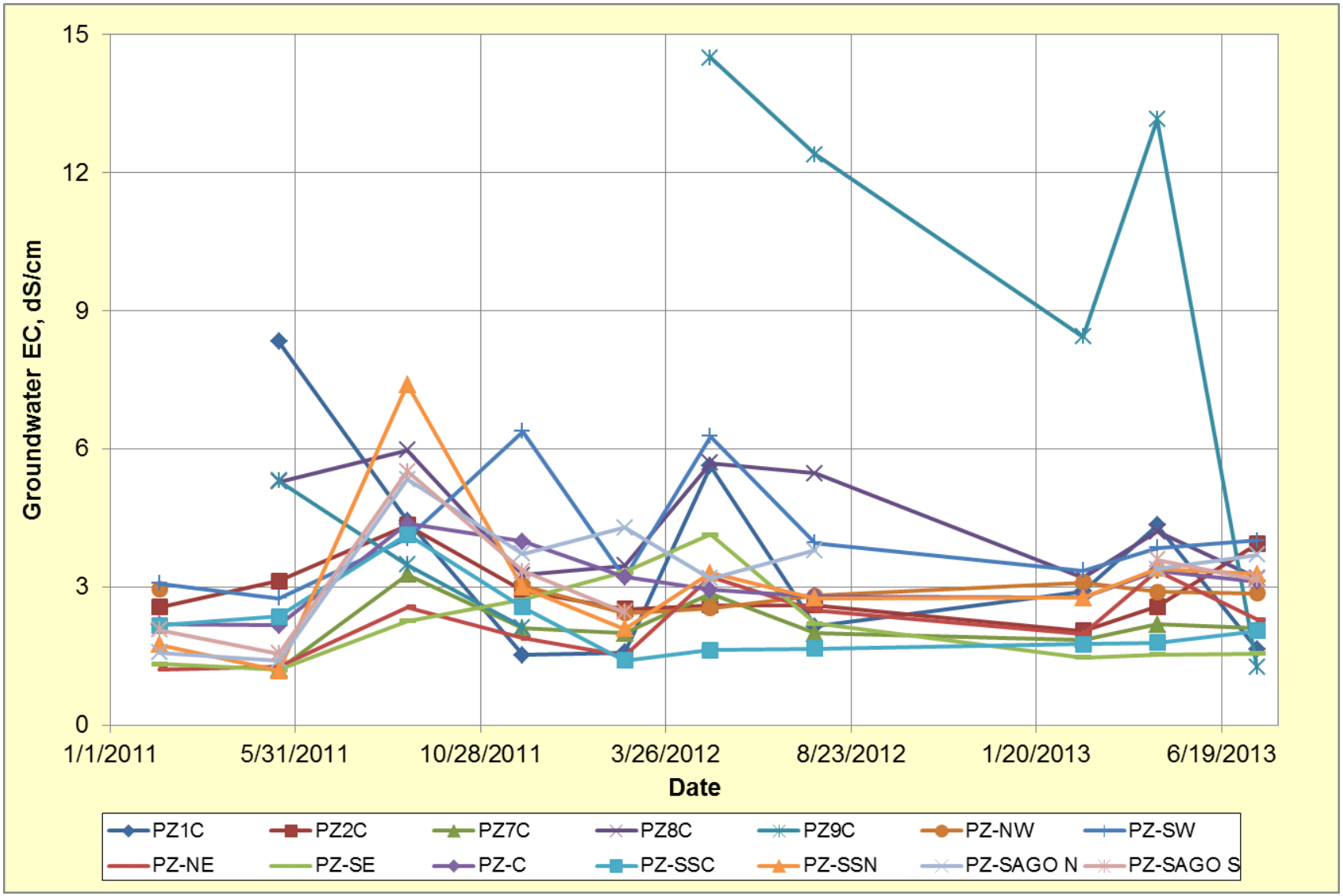

Figure 43.—Groundwater EC results for the Seed Feasibility Study, Mass Transplanting, and the Nature Trail.

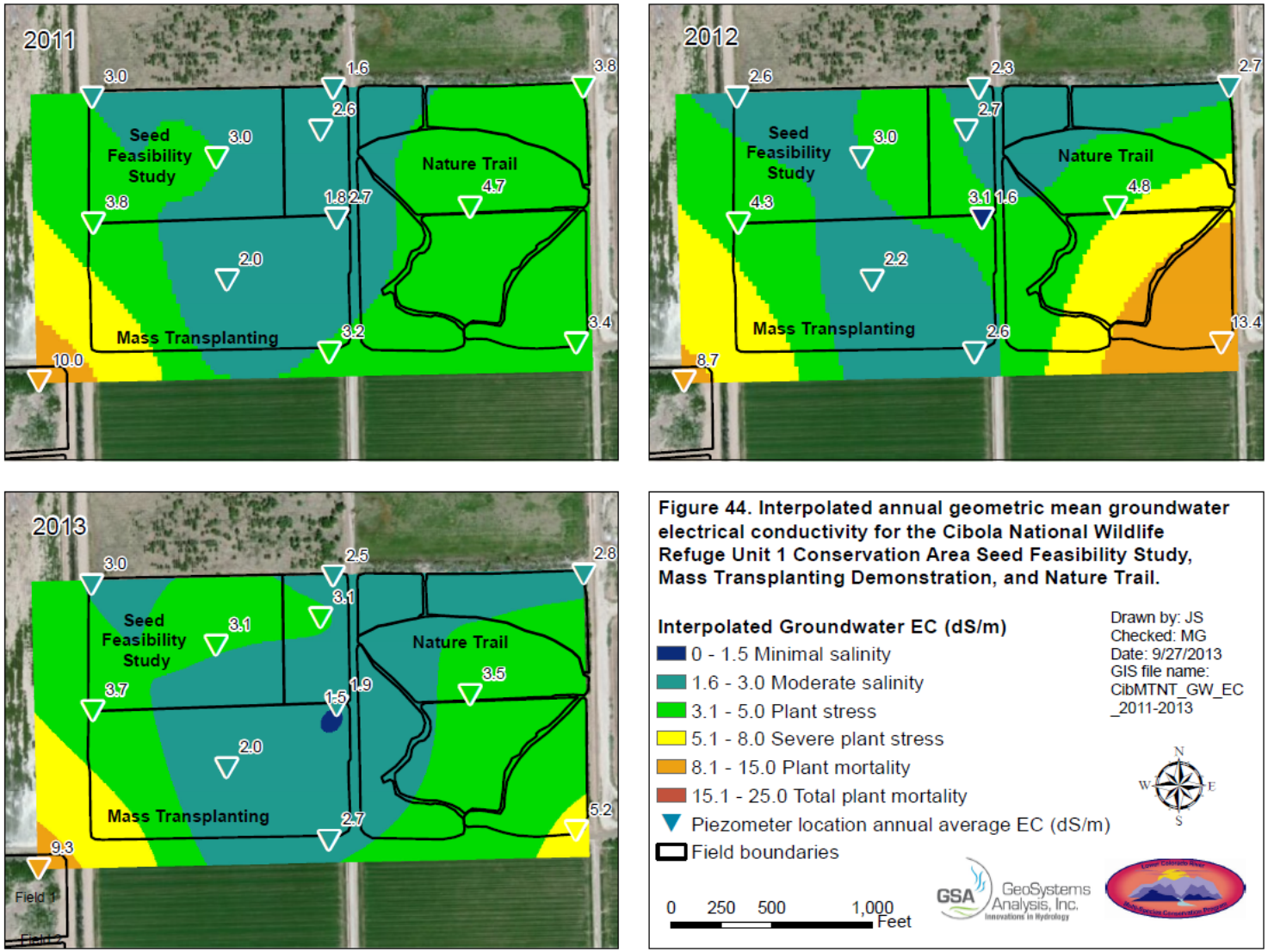

Figure 44.—Interpolated annual geometric mean groundwater EC for the Seed Feasibility Study, Mass Transplanting, and the Nature Trail.

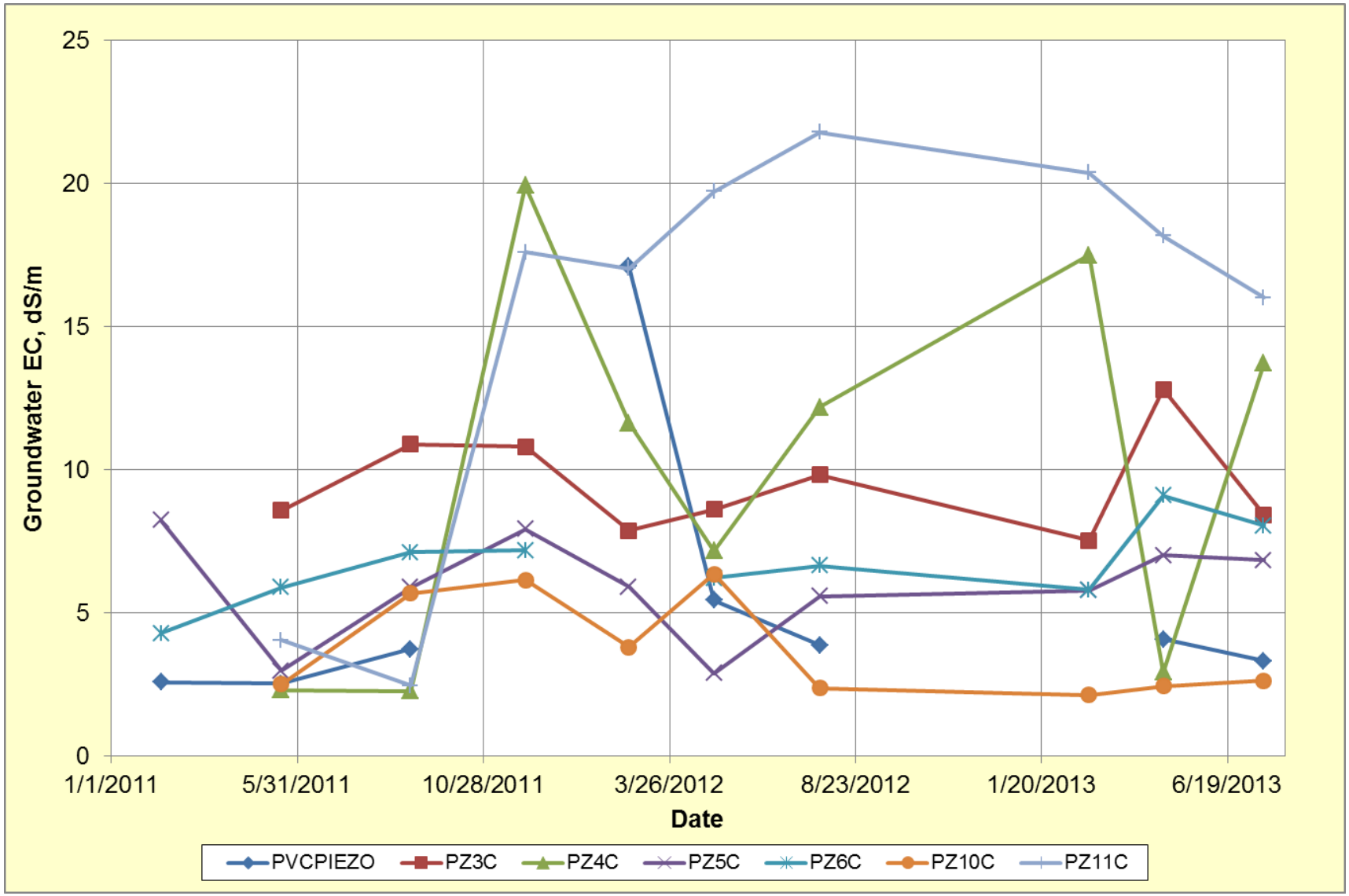

Figure 45.—Groundwater EC results for Crane Roost.

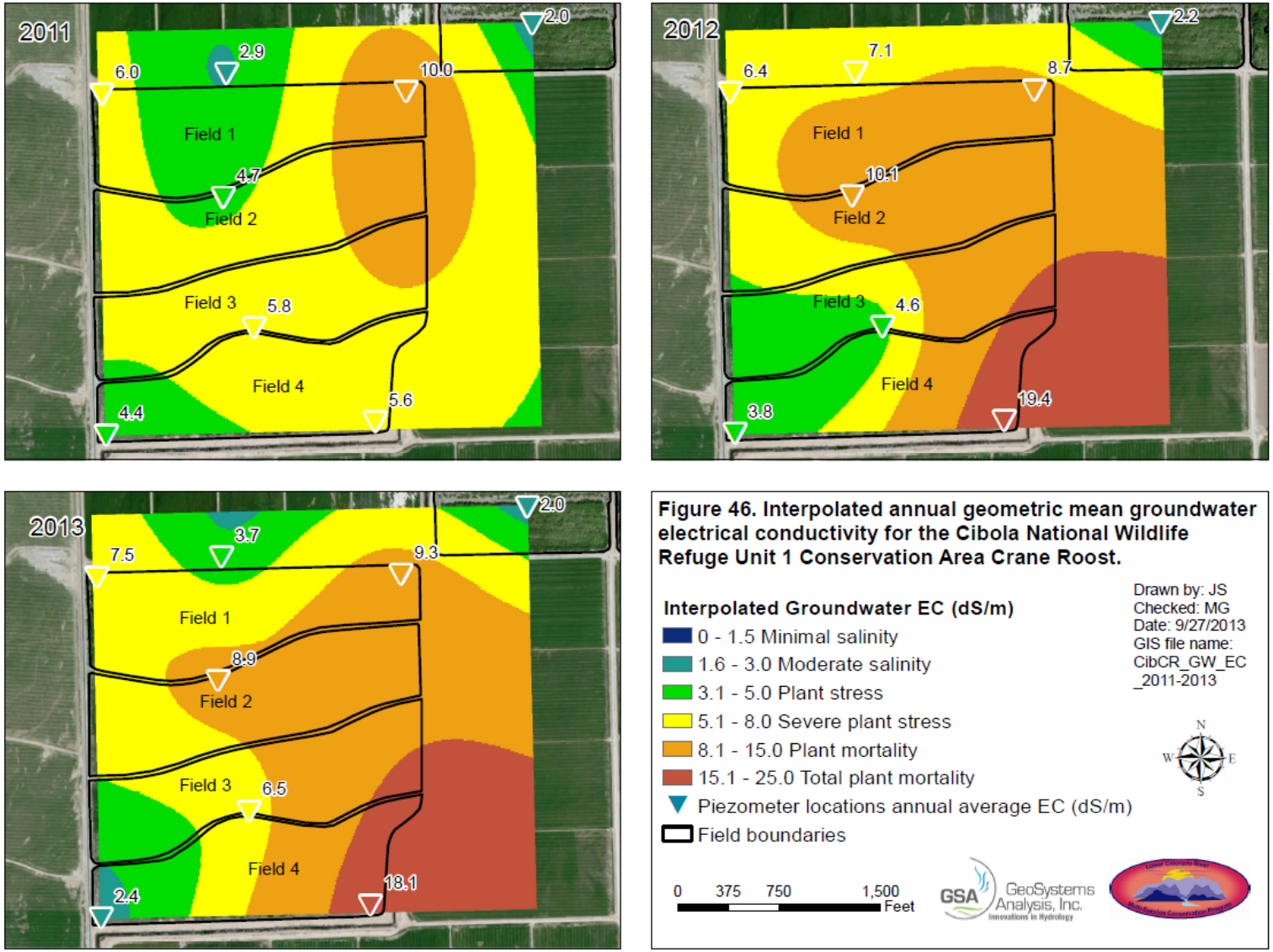

Figure 46.—Interpolated annual geometric mean groundwater EC for Crane Roost.

Table 38.—Irrigation, drainage ditch, and surface irrigation water EC results for Cibola NWR Unit #1

Date	EC (dS/m)		
	Irrigation	Arnett Ditch	North 160 surface water
5/18/2011–5/19/2011	1.6	4.9	12.2
8/30/2011–8/31/2011	1.6	–	2.2
2/22/2012–2/23/2012	1.0	–	–
5/1/2012–5/2/2012	1.0	–	1.4
7/25/2012–7/26/2012	1.0	–	–
2/27/2013	1.1	8.4	–
4/28/2013	1.1	6.1	–
7/18/2013	1.1	7.9	–

During 2011, Crane Roost groundwater EC responded to irrigation events. For example, EC increased greatly during the July 2011 event at both PZ3C and PZ5C. During 2012 and 2013, EC at PZ5C responded to irrigation events in March 2012, May 2013, and June, 2013. EC at PZ3C, particularly in 2012, responded to groundwater elevation increases that were not explained by Crane Roost irrigation. These short-term increases in groundwater elevation and EC are likely explained by irrigation and leaching of the North 160 site, immediately north and upgradient of Crane Roost.

4.4 Vegetation Monitoring

Vegetation monitoring results for Crane Roost are presented in section 4.4.1. All data are presented in attachment 7.

4.4.1 Crane Roost

For four points (CR15, CR16, CR17, and CR18) at Crane Roost, the vegetation type was not Goodding's willow as predicted based on the as-built schematics. Vegetation at point CR15 was dominated by cottonwood, and vegetation at CR16 was dominated by coyote willow. These points were analyzed for the observed vegetation types. Vegetation near CR17 and CR18 was a mix of cottonwood and

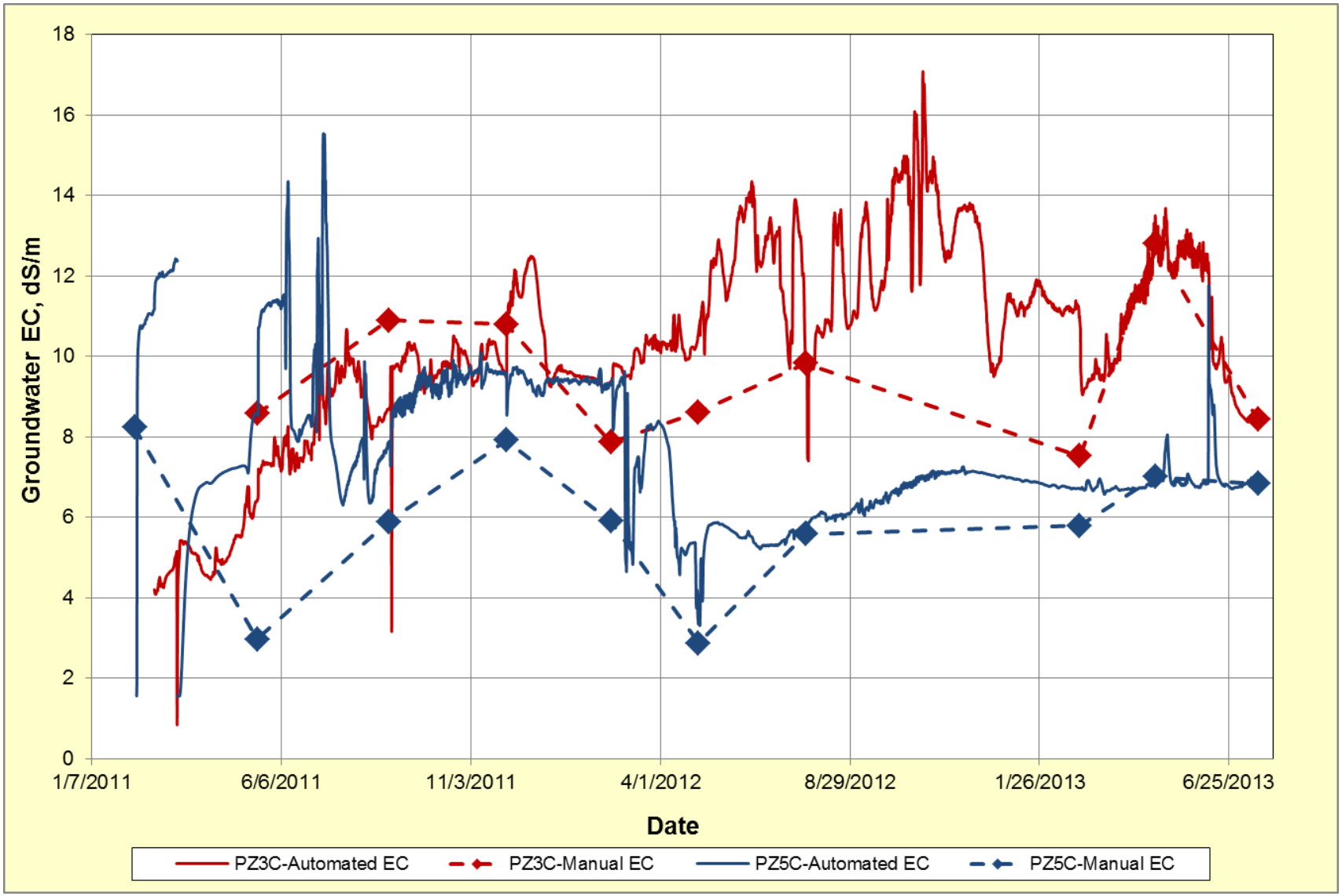

Figure 47.—Automated and manual groundwater EC results for Crane Roost.

and Goodding's willow. Therefore, it was uncertain which species was planted and at what density. Thus, these points were omitted from analyses to prevent including biased tree density results. Summary information for all monitoring points, excluding CR17 and CR18, is provided in table 39. Additional results are presented below by species. The detection of dead trees was uncertain (dead, fallen trees were often difficult to locate due to the abundance of herbaceous cover), and thus, this category is not discussed within this section. Dead tree data are provided in attachment 7.

4.4.1.1 Cottonwood

Cottonwood vegetation monitoring results for Crane Roost are summarized in table 40. Correlation between key results and 0–6 ft composite soil EC are shown on figures 48 and 49. Correlation statistics by depth interval are provided in table 41, and scatterplots are provided in attachment 7. Canopy closure at cottonwood sampling locations varied between 0 and 97% (table 39) and was not significantly correlated with soil EC for any depth interval. Tree density ranged from 0 to 1,610 trees per acre. Tree density was not correlated with 0–2, 2–4, or 0–6 ft composite soil salinity, but was inversely correlated with 4–6 ft soil EC (i.e., higher soil salinity resulted in decreased density of trees). The average height for good condition trees ranged between 2.7 and 8.3 m but was not correlated with soil EC for any depth interval. These relationships indicate that soil salinity at depth likely decreased the establishment and survival rates of trees but did not affect the growth rate of surviving trees over the range of soil salinities observed.

4.4.1.2 Goodding's Willow

Goodding's willow vegetation monitoring results for Crane Roost are summarized in table 42. Correlation between key results and 0-6 ft composite soil EC are shown on figures 50 and 51. Correlation statistics by depth interval are provided in table 41, and scatterplots are provided in attachment 7. Canopy closure at Goodding's willow sampling locations varied between 0 and 95% (see table 39), and was not correlated with soil EC for any depth interval. Good condition tree density ranged from 0 to 1,718 trees per acre, and was not correlated with soil EC for any depth interval. However, an EC of over 10 dS/m for any depth interval resulted in a good condition tree density less than 200 trees per acre. The average height for good condition trees ranged between 1.6 and 4.6 m, but was not correlated with soil EC for any depth interval.

Table 39.—Vegetation monitoring results for Crane Roost, May 29–30, 2012

Location	Planted species	Soil EC (dS/m)				Canopy closure (%)	Herbaceous cover depth (centimeters)	Monitoring radius (m)	Total live trees
		0–2 ft	2–4 ft	4–6 ft	0–6 ft				
CR15	Cottonwood	2.1	1.3	0.9	1.4	33	30	3	9
CR24		49.8	24.4	25.9	33.4	0	45	10	0
CR25		33.8	22.5	21.9	26.1	1	20	4	3
CR26		16.0	6.0	7.1	9.7	97	20	2	5
CR35		20.5	15.5	12.1	16.1	20	20	3	17
CR36		17.7	43.5	21.3	27.5	12	40	3	6
CR37		37.5	22.3	13.3	24.4	31	0	3	4
CR45		16.3	4.2	6.9	9.2	3	20	3	10
CR46		4.6	14.1	14.6	11.1	3	25	3	9
CR47		4.5	3.7	20.6	9.6	3	30	5	1
CR27	Goodding's willow	1.6	3.3	5.2	3.3	88	25	4	16
CR28		2.5	1.7	2.0	2.1	95	45	3	14
CR29		1.8	3.4	7.1	4.1	55	0	3	12
CR30		5.6	3.2	8.6	5.8	2	40	3	12
CR38		9.6	5.3	5.7	6.9	1	0	8	8
CR39		12.7	50.3	34.2	32.4	10	40	4	9
CR40		2.4	1.5	6.4	3.4	0	30	6	15
CR41		27.9	9.1	15.7	17.6	0	2	6	1
CR16	Coyote willow	1.7	1.5	1.5	1.6	20	25	2	32
CR19		1.6	1.7	3.7	2.3	28	0	1	16
CR20		1.8	1.8	2.8	2.1	45	50	1	13
CR21		2.5	2.3	11.0	5.3	95	25	1	11
CR31		1.8	1.6	1.7	1.7	39	45	2	24
CR32		1.4	1.8	4.9	2.7	97	25	1	14
CR33		1.7	1.4	1.7	1.6	20	0	1	22
CR42		18.1	22.2	16.7	19.0	0	35	10	6
CR43		3.6	3.6	6.7	4.6	0	45	10	5
CR44		6.4	15.8	15.9	12.7	3	0	6	21
CR13	Mesquite	8.0	5.0	15.8	9.6	0	40	5	2
CR14		18.3	4.9	14.1	12.5	17	40	5	2
CR22		4.0	1.9	10.2	5.4	0	50	5	1
CR23		158.0	56.9	22.2	79.0	0	40	10	0
CR34		68.1	22.2	22.7	37.7	20	20	6	1
CR48		9.0	15.3	42.8	22.4	3	0	5	1
CR49		9.3	14.9	17.8	14.0	3	10	5	1
CR50		66.7	22.2	26.3	38.4	0	40	6	1

Table 40.—Cottonwood monitoring results for Crane Roost, May 29–30, 2012

Location	Good condition				Fair condition				Poor condition			
	Count	Average height (m)	Total height (m)	Density (trees/acre)	Count	Average height (m)	Total height (m)	Density (trees/acre)	Count	Average height (m)	Total height (m)	Density, (trees/acre)
CR15	9	2.7	24.3	1,288	0	N/A	0.0	0	0	N/A	0.0	0
CR24	0	N/A	0.0	0	0	N/A	0.0	0	0	N/A	0.0	0
CR25	2	2.7	5.4	161	0	N/A	0.0	0	1	1.4	1.4	81
CR26	5	8.3	41.5	1,610	0	N/A	0.0	0	0	N/A	0.0	0
CR35	7	2.7	18.7	1,002	8	2.4	19.1	1,145	2	1.3	2.6	286
CR36	3	2.2	6.5	429	2	2.0	4.0	286	1	1.7	1.7	143
CR37	2	5.8	11.5	286	1	5.0	5.0	143	1	1.8	1.8	143
CR45	1	3.0	3.0	143	8	3.5	28.2	1,145	1	1.9	1.9	143
CR46	2	3.0	6.0	286	2	3.5	7.0	286	5	2.0	10.0	716
CR47	0	N/A	0.0	0	0	N/A	0.0	0	1	2.5	2.5	52

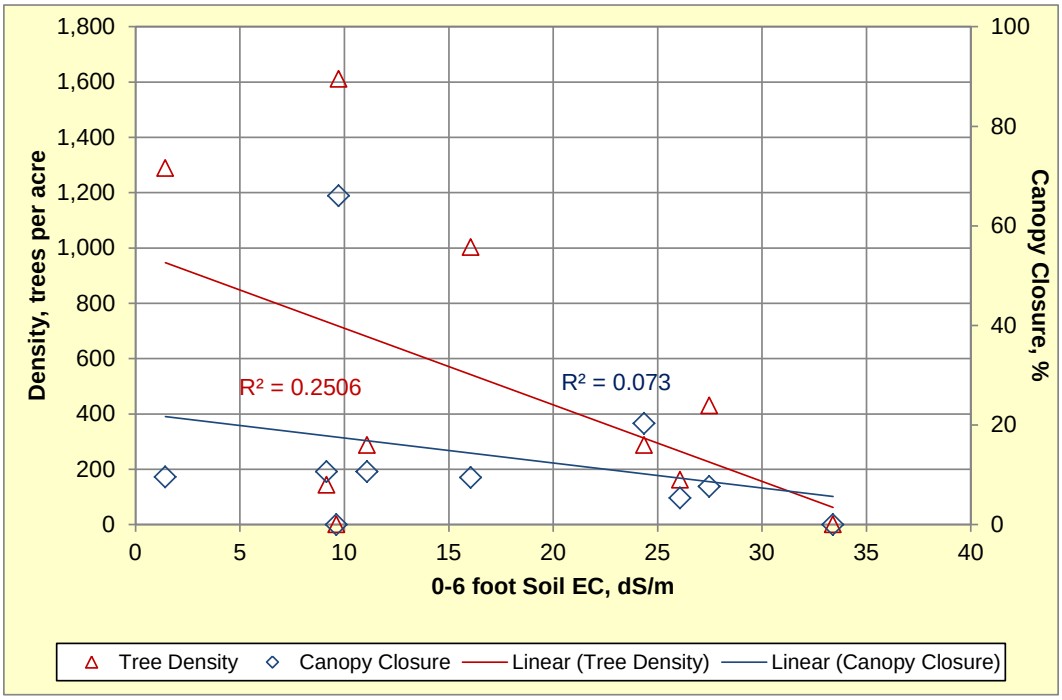

Figure 48.—Cottonwood tree density (p = 0.14) and canopy closure (p = 0.45) versus soil EC at Crane Roost.

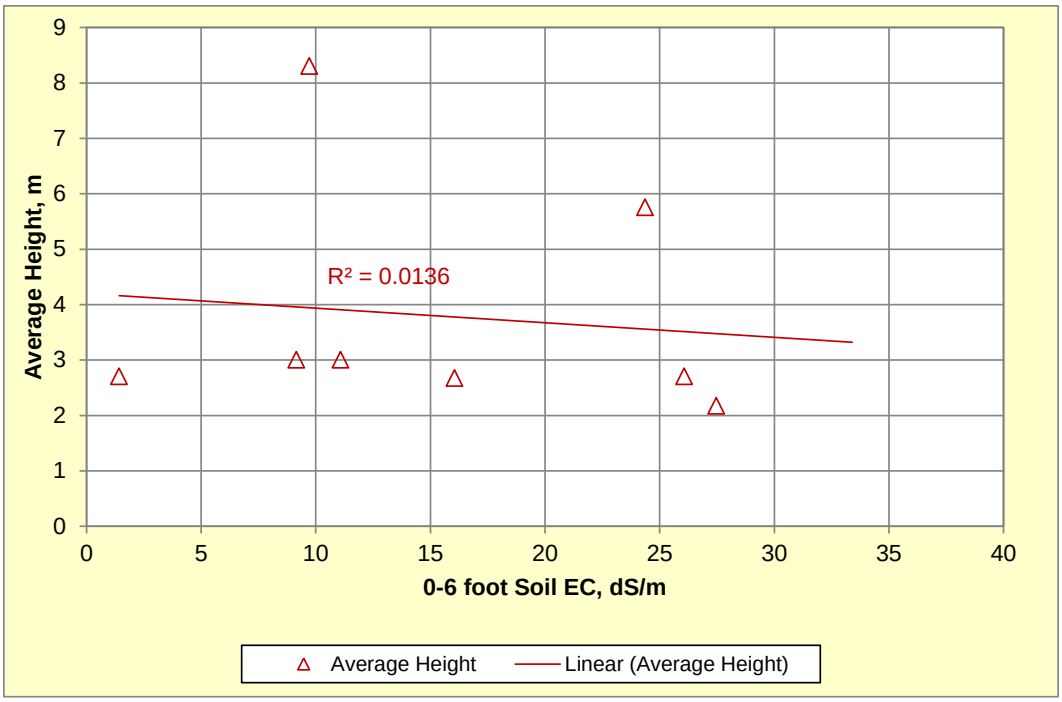

Figure 49.—Cottonwood average height (p = 0.78) versus soil EC at Crane Roost.

Table 41.—Correlation analysis[1] summary for good condition trees at Crane Roost, May 2012

Species	Effect	Result[1]														
		Density (trees/acre)					Canopy closure (%)					Average height (m)				
		df	R^2	F(p)	m	b	df	R^2	F(p)	m	b	df	R^2	F(p)	m	b
Cottonwood	0–2 ft EC	9	0.13	1.2(0.31)	-13.1	786	9	0.01	0.1 (0.79)	-0.12	16	7	0.05	0.3(0.61)	0.04	0.1
	2–4 ft EC	9	0.11	1.0 (0.36)	-14.4	748	9	0.06	0.5(0.50)	-0.36	10	7	0.08	0.5(0.50)	-0.04	4.5
	4–6 ft EC	9	**0.50**	**7.9(0.02)**	**-50.5**	**1,250**	9	0.22	2.3(0.17)	-1.13	30	7	0.09	0.6(0.48)	-0.09	4.8
	0–6 ft EC	9	0.25	2.7(0.14)	-27.7	986	9	0.07	0.6(0.45)	-0.50	22	7	0.01	0.1(0.78)	-0.03	4.2
Goodding's willow	0–2 ft EC	7	0.40	4.0(0.09)	-51.9	1,187	7	0.28	2.3(0.18)	-2.44	51	6	0.15	0.9(0.40)	-0.10	3.4
	2–4 ft EC	7	0.17	1.2(0.31)	-18.2	949	7	0.07	0.5(0.52)	-0.67	38	6	0.03	0.7(0.73)	-0.01	2.9
	4–6 ft EC	7	0.25	2.0(0.21)	-35.4	1,146	7	0.18	1.3(0.30)	-1.68	49	6	0.08	0.4(0.53)	-0.03	3.2
	0–6 ft EC	7	0.31	2.7(0.15)	-39.4	1,143	7	0.18	1.4(0.29)	-1.70	47	6	0.06	0.3(0.61)	-0.03	3.1
Coyote willow	0–2 ft EC	9	0.16	1.5(0.26)	-690	10,044	9	0.21	2.1(0.19)	-3.14	47	8	0.05	0.3(0.58)	0.09	1.2
	2–4 ft EC	9	0.19	1.9(0.21)	-534	10,109	9	0.25	2.6(0.14)	-2.41	47	8	0.01	0.04(0.85)	0.01	1.4
	4–6 ft EC	9	0.21	2.1(0.18)	-701	11,905	9	0.04	0.4(0.57)	-1.26	43	8	0.27	2.5(0.16)	0.07	1.0
	0–6 ft EC	9	0.20	2.1(0.19)	-693	10,957	9	0.17	1.6(0.24)	-2.50	48	8	0.09	0.7(0.43)	0.06	1.2
Mesquite	**0–2 ft EC**	7	**0.56**	**7.8(0.03)**	**-0.49**	75	7	0.05	0.3(0.59)	-0.03	4	6	0.06	0.3(0.58)	-0.001	2.2
	2–4 ft EC	7	**0.66**	**11.9(0.01)**	**-1.6**	83	7	0.10	0.7(0.45)	-0.10	4	6	**0.57**	**6.7(0.048)**	**-0.01**	**2.3**
	4–6 ft EC	7	0.11	0.7(0.43)	-1.1	78	7	0.06	0.4(0.56)	-0.14	5	6	0.52	5.5(0.07)	-0.01	2.4
	0–6 ft EC	7	**0.63**	**10.3(0.02)**	**-1.1**	85	7	0.08	0.5(0.51)	-0.07	4	6	0-29	2.0(0.22)	-0.01	2.3

[1] Indicates degrees of freedom (df), correlation coefficient (R^2), F-value (F), p-value (p) and coefficients for the predictive equation Y = mX + B, where Y is the result, m is the slope, and B is the y-intercept. Bold effects and results indicate significant correlation at p = 0.05.

Table 42.—Goodding's willow monitoring results for Crane Roost, May 29–30, 2012

Location	Good condition				Fair condition				Poor condition			
	Count	Average height (m)	Total height (m)	Density (trees/acre)	Count	Average height (m)	Total height (m)	Density, (trees/acre)	Count	Average Height (m)	Total Height (m)	Density (trees/acre)
CR27	15	4.6	69.7	1,208	1	2.4	2.4	81	0	N/A	0.0	0
CR28	12	4.6	55.0	1,718	2	2.5	4.9	286	0	N/A	0.0	0
CR29	10	2.6	25.5	1,431	2	2.3	4.5	286	0	N/A	0.0	0
CR30	10	2.1	20.6	1,431	2	1.6	3.1	286	0	N/A	0.0	0
CR38	4	2.3	9.1	81	4	1.7	6.6	81	0	N/A	0.0	0
CR39	2	2.5	4.9	161	7	1.5	10.4	564	0	N/A	0.0	0
CR40	4	1.6	6.2	143	10	1.4	13.5	358	1	1.4	1.4	36
CR41	0	N/A	0.0	0	1	1.8	1.8	36	0	N/A	0.0	0

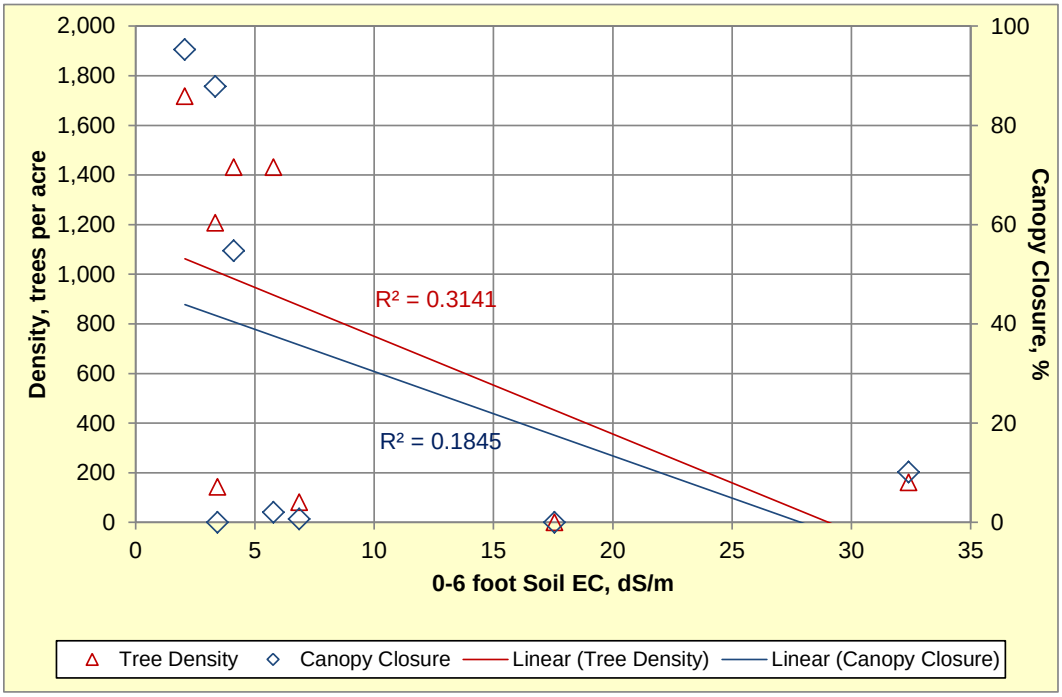

Figure 50.—Goodding's willow tree density (p = 0.15) and canopy closure (p = 0.29) versus soil EC at Crane Roost.

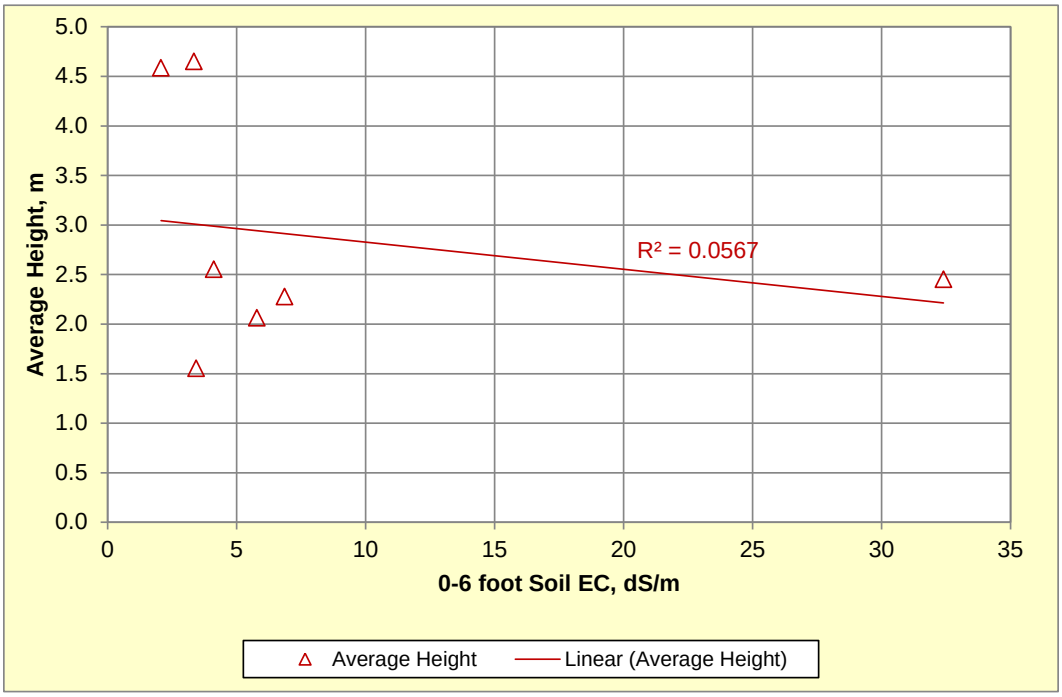

Figure 51.—Goodding's willow average height (p = 0.61) versus soil EC at Crane Roost.

4.4.1.3 Coyote Willow

Coyote willow vegetation monitoring results for Crane Roost are summarized in table 43. Correlation between key results and 0–6 ft composite soil EC are shown on figures 52–53. Correlation statistics by depth interval are provided in table 41, and scatterplots are provided in attachment 7. Canopy closure at coyote willow sampling locations varied between 0 and 97% (see table 39) and was not correlated with soil EC for any depth interval. Density of good condition trees ranged from 0 to 28,339 per acre (higher than other species due to vegetative propagation of stems from coyote willow roots following planting) and was not correlated with soil EC for any depth interval. The average height for good condition trees ranged between 0.7 and 2.6 m and was not correlated with soil EC for any depth interval.

4.4.1.4 Mesquite

Mesquite vegetation monitoring results for Crane Roost are summarized in table 44. All trees were classified to be in good condition (i.e., no fair or poor condition trees were observed). Correlations between key results and 0–6 ft composite soil EC are shown on figures 54 and 55. Correlation statistics by depth interval are provided in table 41, and scatterplots are provided in attachment 7. Canopy closure at mesquite sampling locations varied between 0 and 20% (see table 39) due to a lower density of trees, ranging from 0 to 103 per acre. Tree density was inversely correlated with 0–2, 2–4, and 0–6 ft composite soil EC (a greater salinity was correlated with lower tree density) but was not correlated with 4–6 ft EC. The average height for good condition trees ranged between 2.0 and 2.4 m and was inversely correlated with 2–4 ft soil EC. Average height was not significantly correlated with other depth intervals. These results indicate that a greater 0–4 ft soil EC negatively impacted mesquite at the site primarily by reducing the tree establishment and survival rates.

5.0 CONCLUSIONS

5.1 Beal Lake Conservation Area

Composite soil salinity for all BLCA fields irrigated at least once per month was below native tree thresholds of 8 dS/m for both sampling years (54 locations in 2010 and 58 in 2012). Soil salinity in fields irrigated twice per year exceeded 8 dS/m for 4 of 13 sampling locations in 2010 and 5 of 12 sampling locations in 2012. All three sampling locations in Field EE (never irrigated) during 2010 had a composite soil EC of over 10 dS/m. Salinity modeling results predicted that an applied water depth of approximately 2 m would maintain acceptable soil salinity at BLCA fields (GSA 2013b). This generally agrees with monitoring results; based on irrigation contractor records, it was estimated that fields irrigated once per month received a mean applied water of 3.2 m per year (ranging from 1.6 to

Table 43.—Coyote willow monitoring results for Crane Roost, May 29–30, 2012

Location	Good condition				Fair condition				Poor Condition			
	Count	Average height (m)	Total height (m)	Density, (trees/acre)	Count	Average height (m)	Total height (m)	Density, (trees/acre)	Count	Average height (m)	Total height (m)	Density, (trees/acre)
CR16	15	1.4	20.3	4,831	16	1.2	18.7	5,153	1	0.3	0.3	322
CR19	2	0.7	1.3	2,576	14	1.7	23.4	18,034	0	N/A	0.0	0
CR20	3	1.1	3.2	3,864	9	1.6	14.2	11,593	1	0.4	0.4	1,288
CR21	6	2.6	15.8	7,729	4	1.0	3.8	5,153	1	0.6	0.6	1,288
CR31	22	1.0	21.2	7,085	2	0.3	0.6	644	0	N/A	0.0	0
CR32	13	2.0	26.3	16,746	1	0.4	0.4	1,288	0	N/A	0.0	0
CR33	22	0.7	15.6	28,339	0	N/A	0.0	0	0	N/A	0.0	0
CR42	0	N/A	0.0	0	2	1.4	2.8	26	4	0.7	2.7	52
CR43	2	2.1	4.1	26	3	1.6	4.8	39	0	N/A	0.0	0
CR44	16	1.4	22.3	573	5	1.0	4.9	179	0	N/A	0.0	0

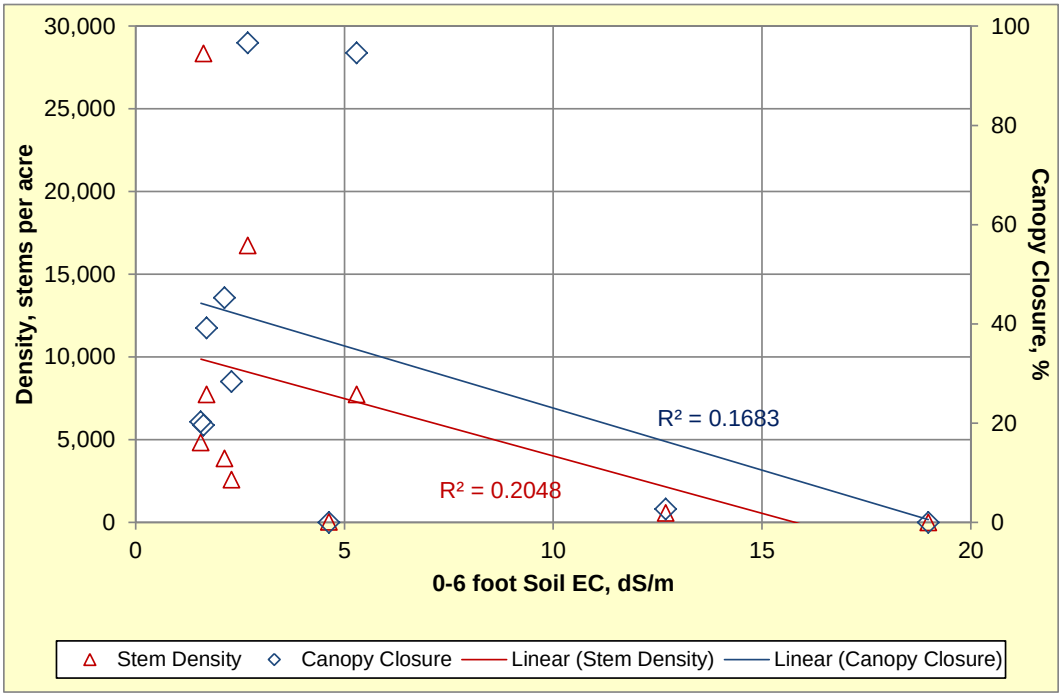

Figure 52.—Coyote willow tree density (p = 0.19) and canopy closure (p = 0.24) versus soil EC at Crane Roost.

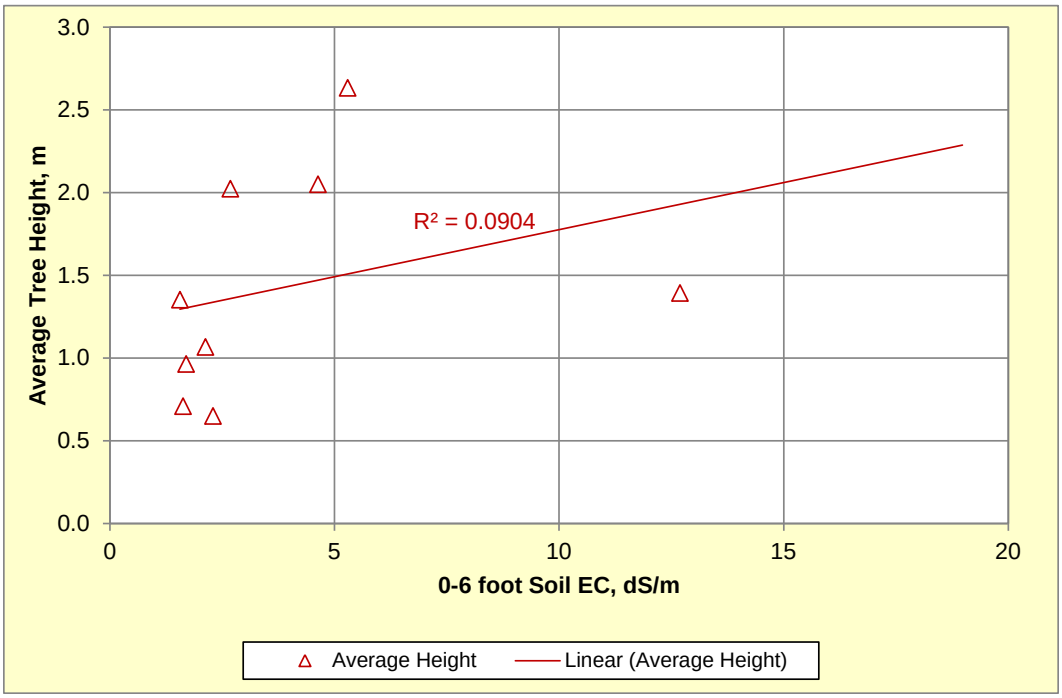

Figure 53.—Coyote willow average height (p = 0.43) versus soil EC at Crane Roost.

Table 44.—Mesquite monitoring results for Crane Roost, May 29–30, 2012

Location	Good condition			
	Count	Average height (m)	Total height (m)	Density (trees/acre)
CR13	2	2.2	4.4	103
CR14	2	2.3	4.5	103
CR22	1	2.4	2.4	52
CR23	0	N/A	0.0	0
CR34	1	2.1	2.1	36
CR48	1	2.0	2.0	52
CR49	1	2.0	2.0	52
CR50	1	2.1	2.1	36

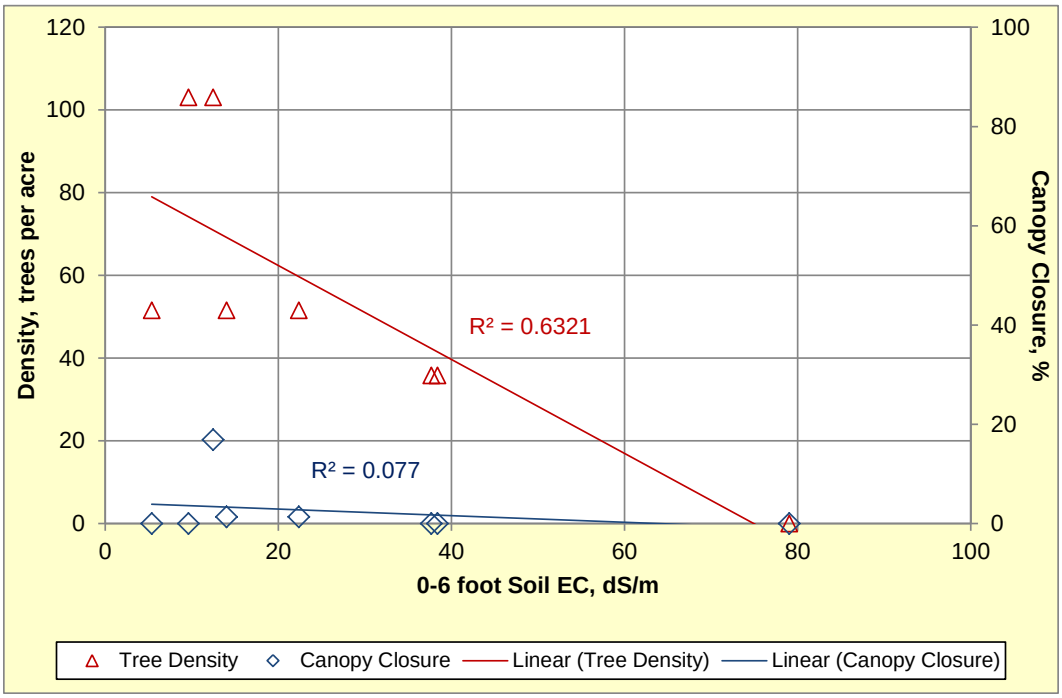

Figure 54.—Mesquite tree density (p = 0.02) and canopy closure (p = 0.51) versus soil EC at Crane Roost.

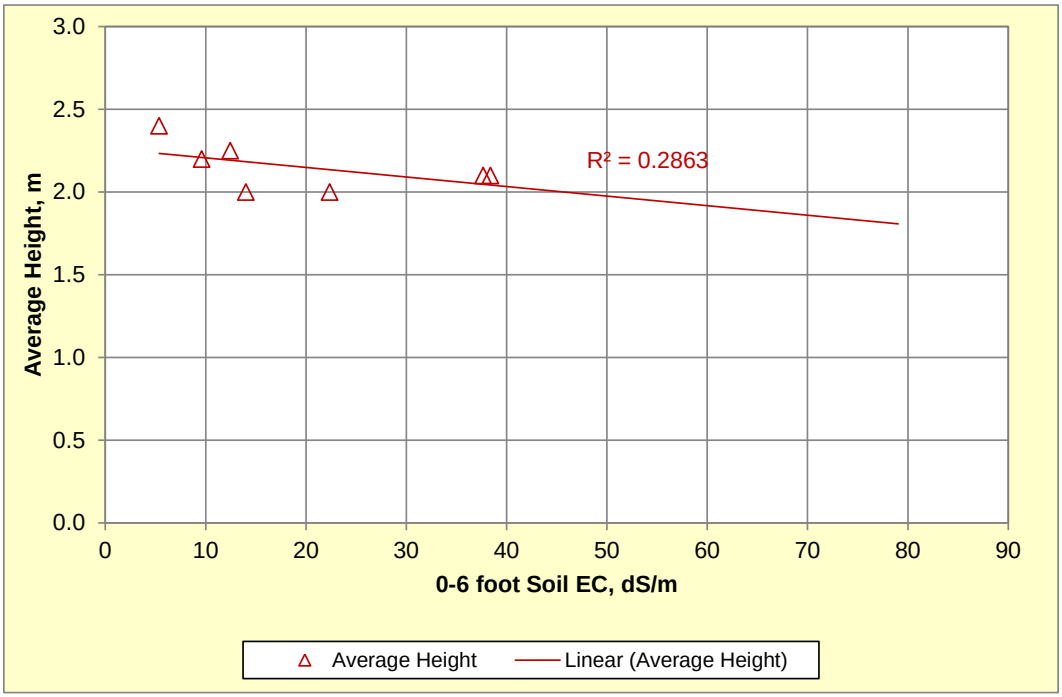

Figure 55.—Mesquite average height (p = 0.22) versus soil EC at Crane Roost.

9.3 m (GSA 2013a). It is anticipated that infrequent (i.e., once per month) irrigation would likely maintain acceptable soil and groundwater salinity levels in all fields.

5.2 Palo Verde Ecological Reserve

Groundwater EC at the PVER was always below native riparian tree thresholds and, with the exception of 1 sample in 2010 (out of a 246 total samples for both years combined), soil salinity was as well. Sandy soil textures, high irrigation rates, and deep groundwater relative to other sites appear to provide sufficient removal of salts from the root zone. Additionally, high groundwater flow rates (GSA 2013a) provide a mechanism for salts to be removed from the site. Salinity modeling results indicate that soil salinity would remain below native species tolerance thresholds indefinitely even if the PVER was not irrigated (GSA 2013b). However, riparian vegetation at the PVER will be dependent on soil moisture from frequent irrigation. When mounding from irrigation is absent, the depth to groundwater is greater than thresholds for use by native vegetation (Lite and Stromberg 2005), and sandy soils at the site do not maintain high soil moisture between irrigation events (GSA 2014).

5.3 Cibola National Wildlife Refuge Unit #1 Conservation Area

Soil salinity was much higher at Cibola NWR Unit #1, with average composite EC values near or exceeding cottonwood-willow salinity tolerances in both 2010 and 2012. Forty-nine of 76 composite soil EC values at Cibola NWR Unit #1 exceeded 8 dS/m in 2010, and 46 of 79 exceeded 8 dS/m in 2012. Groundwater EC on the eastern portion of Cibola NWR Unit #1 (the Seed Feasibility Study, Mass Transplanting, and the Nature Trail) was below native riparian tree thresholds with the exception of one piezometer (PZ9C) on the southeast corner of the Nature Trail adjacent to Danner Lake. Groundwater EC at Crane Roost often exceeded native tree thresholds. Leaching of salts at this site via irrigation has been occurring for less time relative to the other Cibola NWR Unit #1 sites, and soil salinity decreased between 2010 and 2012 (66% of composite EC samples exceeded 8 dS/m in 2010 compared to 52% in 2012). However, the long-term equilibrium soil salinity for this site is uncertain.

High soil and groundwater salinity at Cibola NWR Unit #1 compared to the other conservation areas is likely due to the combination of fine-grained soil textures, intermediate depth to groundwater, reduced irrigation rates, lower groundwater flow rates, and greater inflowing groundwater EC. Salinity modeling results indicate that increasing irrigation rates to greater than 2.6 m of applied water per year would reduce soil EC to acceptable levels at all Cibola NWR Unit #1 sites (GSA 2013b). However, the effects of leaching high salt loads into adjacent groundwater must be considered—leaching of the North 160 site upgradient of Crane Roost appeared to result in increasing groundwater EC at Crane Roost, and it is likely that the addition of water into Danner Lake increased groundwater EC under portions of the Nature Trail. These observations highlight the need for integrated management of LCR MSCP conservation areas to ensure that favorable management of one site does not adversely affect surrounding areas.

For Crane Roost, soil salinity effects on vegetation were uncertain. Despite soil salinity in excess of published salinity tolerance, all planted species have shown some level of success at this site. Higher cottonwood tree density (establishment rate) was correlated with lower 4–6 ft soil salinity. Other relationships were not significant. Goodding's willow results were not correlated with soil salinity, but a threshold (non-linear) response was observed at approximately 10 dS/m, indicating that this value severely limited Goodding's willow success at the site. Similarly, no significant linear correlations were observed for coyote willow, but tree density showed a threshold response for 0–2 and 2–4 ft soil EC—values above approximately 3 dS/m resulted in less than 600 stems per acre. The response of coyote willow to 4–6 ft soil EC was unclear. In one case, a 4–6 ft soil EC of greater than 10 dS/m supported over 7,500 stems per acre.

Although tree height was typically not correlated with soil EC at this site, it is apparent that soil conditions are limiting vegetation growth. For comparison, at PVER Phase 04, also planted in 2009 with a mix of cottonwoods, Goodding's willows, and coyote willows (Reclamation 2013), average heights for cottonwoods and Goodding's willows during fall 2012 surveys were 11.7 and 8.7 m, respectively (Parametrix, Inc. 2014). Overall average cottonwood height at Crane Roost was 1.9 m, and the average Goodding's willow height was 2.8 m. Crane Roost growth rates for these species have been less than one-third of those observed at the PVER. The lack of significant correlations with soil EC is likely due to the narrow scope of monitoring; expanding the analysis of EC effects on riparian vegetation to include other LCR MSCP habitat creation sites would likely enhance the understanding of vegetation-salinity effects.

The correlation of mesquite establishment (tree density and height of tree per unit area) at Crane Roost was correlated with 0–2 and 2–4 ft soil EC with a correlation coefficient (R^2) between 0.56 and 0.98. These much-improved correlations compared to cottonwood-willow results are likely due to the higher tolerance of mesquite to salinity (i.e., trees were sampled across the range of acceptable levels). Such relationships would likely be observed with a wider range of sampling for cottonwood-willow habitat types.

5.4 LCR MSCP Soil and Groundwater Salinity Factors

Historic salinity data and analysis during the course of this project indicate the presence of variable salinity that, in many areas, poses potential limitations to riparian revegetation. Several interacting factors affect soil and groundwater salinity as detailed in table 45. Many factors that are beneficial in terms of salinity management are detrimental to soil moisture management and irrigation efficiency.

In addition to available reference information (GSA 2011a) and modeling results for LCR MSCP conservation areas (GSA 2013a, 2013b), results for a pilot irrigation and soil moisture monitoring project at PVER Phase 02 (GSA 2014) showed that finer-textured soils on the eastern portion of the site, while having higher soil salinity (see figure 15), also support increased soil moisture and higher irrigation efficiency compared to sandier soils on the western portion of the site. Fine-grained soil textures at the Cibola NWR Unit #1 Seed Feasibility Study field supported higher soil moisture levels even with lower irrigation application (GSA 2010b). These soils also had very low infiltration rates (GSA 2008), which would promote high irrigation efficiency. However, fine-textured soils at the Seed Feasibility Study soils were also more saline (see table 10) than those at PVER Phase 02 (see table 12).

Table 45.—Factors controlling soil and groundwater salinity at LCR MSCP conservation areas

Factor	Measure	Benefits	Detrimental	Limitations
Soil type	Percent sand	Higher percent sand results in increased percolation, lower retention of salts, less capillary rise, and groundwater evapoconcentration.	Poorer irrigation distribution, less plant-available water, and nutrient poor.	Generally site conditions that are not managed. Management control likely limited to site selection.
	Percent fines	Higher percent fines results in increased irrigation efficiency, plant-available water, and nutrients.	Poorer salt leaching, greater capillary rise, and groundwater evapoconcentration.	
Groundwater	Depth	Greater depth to groundwater results in less evapo-concentration of dissolved salts.	Less root-available water, and more irrigation required.	Controlled by regional groundwater depth, evapotranspiration rates, and percolation (mounding).
	Flow rate	Higher flow rates result in more efficient removal of salts from the site.	Less mounding of groundwater after irrigation (less groundwater availability).	Governed by groundwater elevation gradient and aquifer hydraulic conductivity.
	Incoming salinity	Low-salinity incoming water can reduce groundwater salinity at the site.	High incoming salinity can cause direct phytotoxicity or contribute to soil salinity.	Governed by adjacent site conditions and management as well as communication of groundwater with the Colorado River main stem.
Irrigation	Applied water	More applied water increases leaching and plant-available water.	Excessive irrigation can increase groundwater elevation and groundwater salinity evapoconcentration and can also waterlog soils.	Limited by the availability of water (water rights) and the transmissivity of the soil and aquifer (i.e., how quickly water leaves the system).
	Salinity	Lower irrigation water salinity decreases the leaching fraction (ratio of applied water to evapotranspiration) required to maintain favorable salinity.	Higher irrigation water salinity increases the required leaching fraction.	Generally increases from upstream to downstream with the exception of the BLCA, which uses Topock Marsh for irrigation water.

Shallower groundwater provides water in support of riparian vegetation evapotranspirative demand but also contributes dissolved salts to the root zone (GSA 2011a). Salinity modeling (GSA 2013a, 2013b) and sampling results provided in this report for the PVER (sandy soils and deep groundwater) and the BLCA (sandy soils and shallow groundwater) demonstrate this effect. Due to shallow groundwater at the BLCA, more irrigation must be applied to leach soil salts originating from groundwater.

Irrigation in areas with shallow groundwater causes soil salinization if aquifer transmissivity is insufficient to allow groundwater mounds to quickly dissipate (GSA 2011a). For this study, the effects of different irrigation rates could only be directly observed at the BLCA. Mounded groundwater at this conservation area quickly dissipates, so increasing irrigation rates is not problematic. Because the PVER is also sandy (see table 11) with higher aquifer transmissivity (GSA 2011b), this site is also receptive to high irrigation rates. Salinity modeling results (GSA 2013b) predicted that higher irrigation volumes at Cibola NWR Unit #1 could also be dissipated into the aquifer. If higher irrigation rates are implemented, monitoring would be required to confirm that groundwater elevation would not increase sufficiently to exacerbate salinity, as aquifer transmissivity is low for some locations at Crane Roost (GSA 2011b).

6.0 DISCUSSION

Previous results indicate that wide ranges of soil salinity have been present at LCR MSCP conservation areas. Salinity in excess of native tree tolerance has limited restoration success at some sites. Results from this study confirm that soil salinity continues to vary among and within the BLCA, PVER, and Cibola NWR Unit #1 due to factors such as soil texture and volume of applied irrigation. Continued soil salinity monitoring will allow the LCR MSCP to track changes in this potential limitation to vegetation success. Groundwater salinity data have not previously been collected for the LCR MSCP. Groundwater monitoring results from this study indicate a large salinity source for at least one LCR MSCP conservation area (Cibola NWR Unit #1). Continued and expanded monitoring of groundwater salinity could determine the extent of groundwater salinity problems at other LCR MSCP areas and assist in identifying trends in groundwater salinity and related impacts on soil salinity and riparian vegetation.

For sites with currently acceptable soil salinity, occasional testing could be performed to monitor for trends that could indicate potential long-term soil salinity accumulation. For this trend monitoring, a 3- to 5-year monitoring frequency is likely sufficient, as suggested by Reclamation (2006). For sites such as Cibola NWR Unit #1, where the soil salinity is often above native tree thresholds and has not stabilized, annual monitoring is recommended as

suggested in Reclamation (2007). A demonstration study could be implemented to determine if increased irrigation improves Cibola NWR Unit #1 soil salinity conditions as predicted by GSA (2013b).

Modeling activities conducted as a separate task for this project (GSA 2013a, 2013b) provided estimates of anticipated soil and groundwater salinity for variable irrigation application depths. If these management situations are implemented, pre- and post-management conditions should be assessed to determine if soil salinity responds as anticipated. Additionally, if irrigation management is altered, increased frequency (e.g., annually) of soil salinity monitoring should be implemented until a new soil salinity equilibrium is reached. Thereafter, monitoring frequency could be reduced to once every 3 years.

Continuation of automated groundwater elevation monitoring will allow Reclamation to monitor the amount of percolation at the BLCA, PVER, CVCA, and Cibola NWR Unit #1, which indicates leaching of soil salts. In addition, groundwater depth and elevation monitoring can be used to detect changes in groundwater depth that might negatively impact vegetation. These changes could include a decline of groundwater elevations below the rooting depth of phreatophyte cottonwood-willow vegetation or waterlogging of soils due to increased groundwater elevation.

Groundwater quality monitoring in conjunction with soil salinity monitoring should continue, as increased groundwater salinity can indicate inputs of salts to restoration sites from adjacent fields. Saline groundwater can negatively impact vegetation directly (i.e., phytotoxicity) or indirectly by contributing additional salts to the root zone through capillary rise and evapotranspiration. The monitoring frequency for groundwater salinity should be driven by observed salinity conditions (i.e., sites with marginal soil and groundwater salinity should be monitored more frequently). Additionally, greater monitoring frequency should be implemented if irrigation management strategies or adjacent drainage or irrigation management is altered. While manual groundwater EC monitoring does allow determination of long-term trends, automated groundwater EC measurements should be collected at a subset of piezometers. These data enhance the ability to detect rapid changes in groundwater salinity and correlate with irrigation management of each site and adjacent areas.

Expansion of the soil and groundwater salinity monitoring network to encompass all LCR MSCP conservation areas should continue as part of long-term LCR MSCP monitoring and the Adaptive Management Program. Some level of soil salinity monitoring is typically implemented prior to planting. However, followup data have been lacking. Groundwater has typically not been monitored at LCR MSCP conservation areas with the exception of the BLCA. Monitoring groundwater levels provides information on the availability of groundwater to satisfy a portion of riparian evapotranspirative demand and the potential contributions of capillary rise to soil salinity.

Based on results of this study, the effects of soil salinity on planted vegetation are unclear. Riparian vegetation at Cibola NWR Unit #1 is often surviving, albeit not thriving, in soil salinity conditions that are above published thresholds. Expanded studies of vegetation response to variable soil and groundwater salinity conditions would inform management by clearly defining the response of vegetation to different soil salinity levels under field conditions. Based on these results, management could establish clearer soil and groundwater salinity target and action levels. Annual vegetation monitoring for the LCR MSCP currently covers the four LCR MSCP conservation areas (the BLCA, PVER, CVCA, and Cibola NWR Unit #1) and one reference site (Bill Williams River National Wildlife Refuge) (Bill Williams River-East), with approximately 450 plots surveyed per year by 2015 (D. Bangle 2015, personal communication). Collection of soil texture and salinity samples on this vegetation monitoring grid would likely provide sufficient data to accomplish these goals. Based on the recommended sampling frequency (once per 3 years for the BLCA, Bill Williams River-East, PVER, and CVCA; every year for Cibola NWR Unit #1), approximately 200 locations would be sampled per year. This does not include potential sampling at other conservation areas (e.g., Hart Mine Marsh or the Laguna Division Conservation Area).

Groundwater elevation and salinity monitoring would require installation of additional piezometer grids and sensors with data loggers at the PVER, CVCA, and Cibola NWR Unit #1 as shown on figures 56–58. Fifty-one additional piezometers should be considered. The current grid at the BLCA is sufficient.

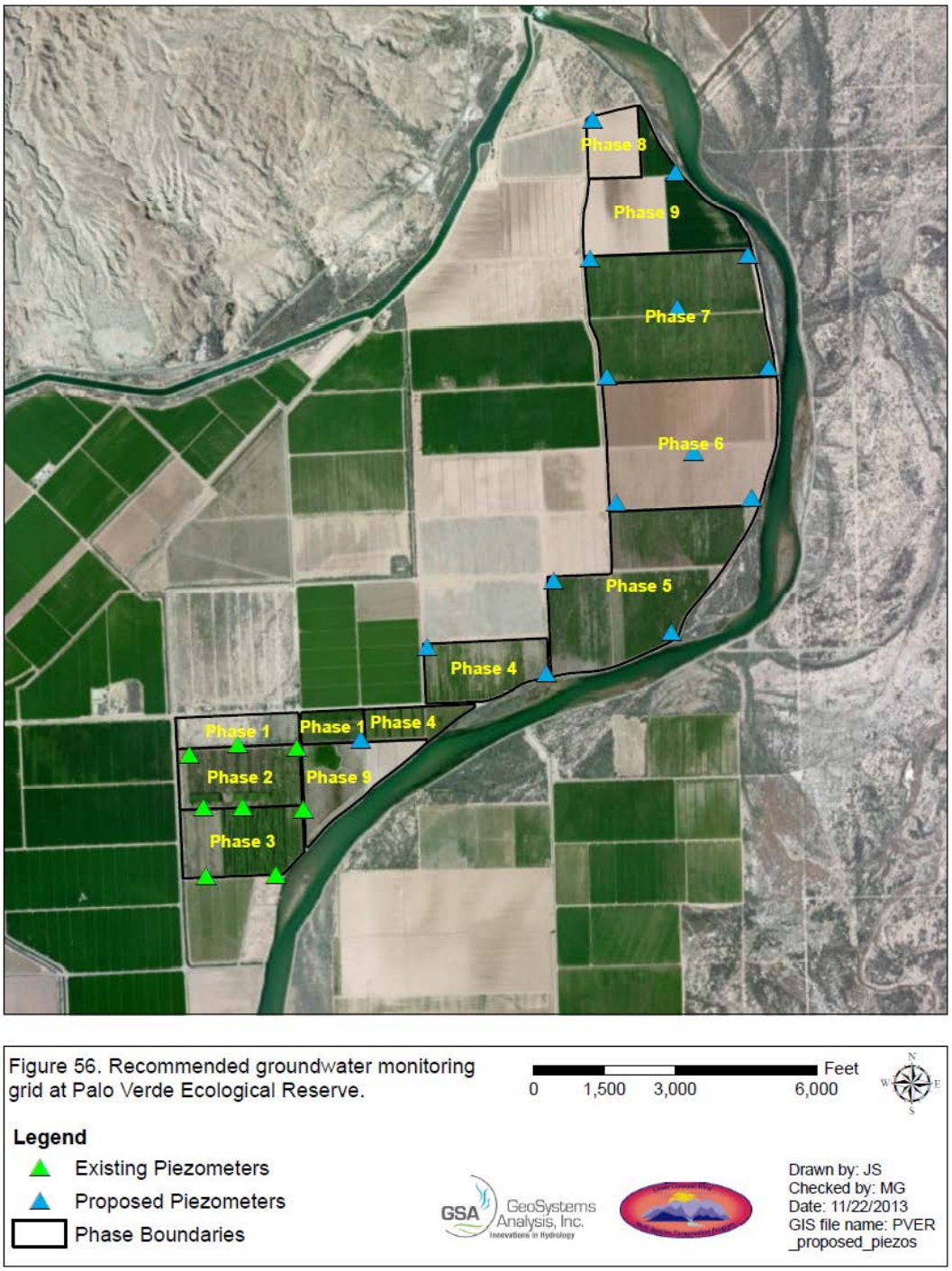

Figure 56.—Recommended groundwater monitoring grid at the PVER.

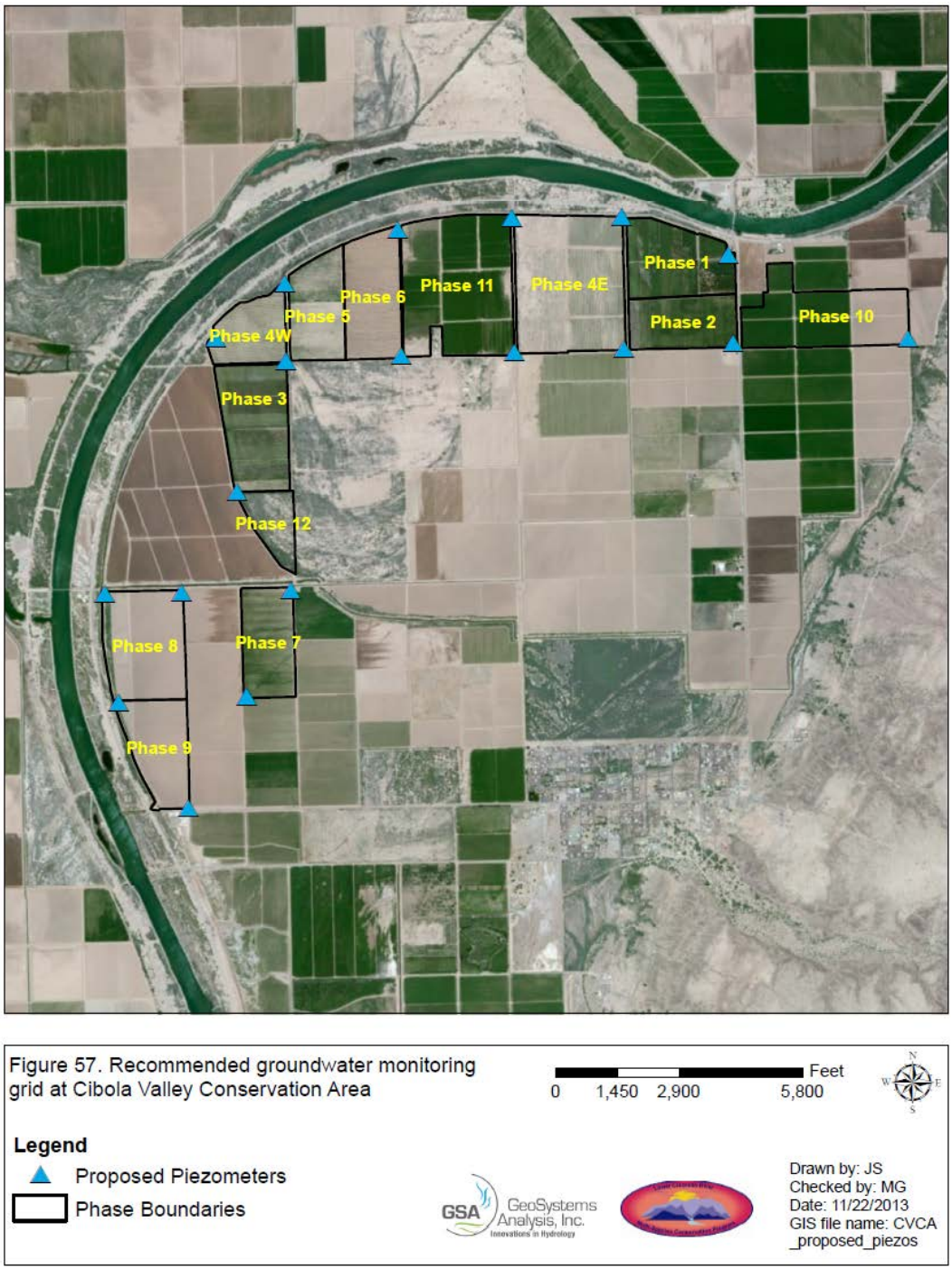

Figure 57.—Recommended groundwater monitoring grid at the CVCA.

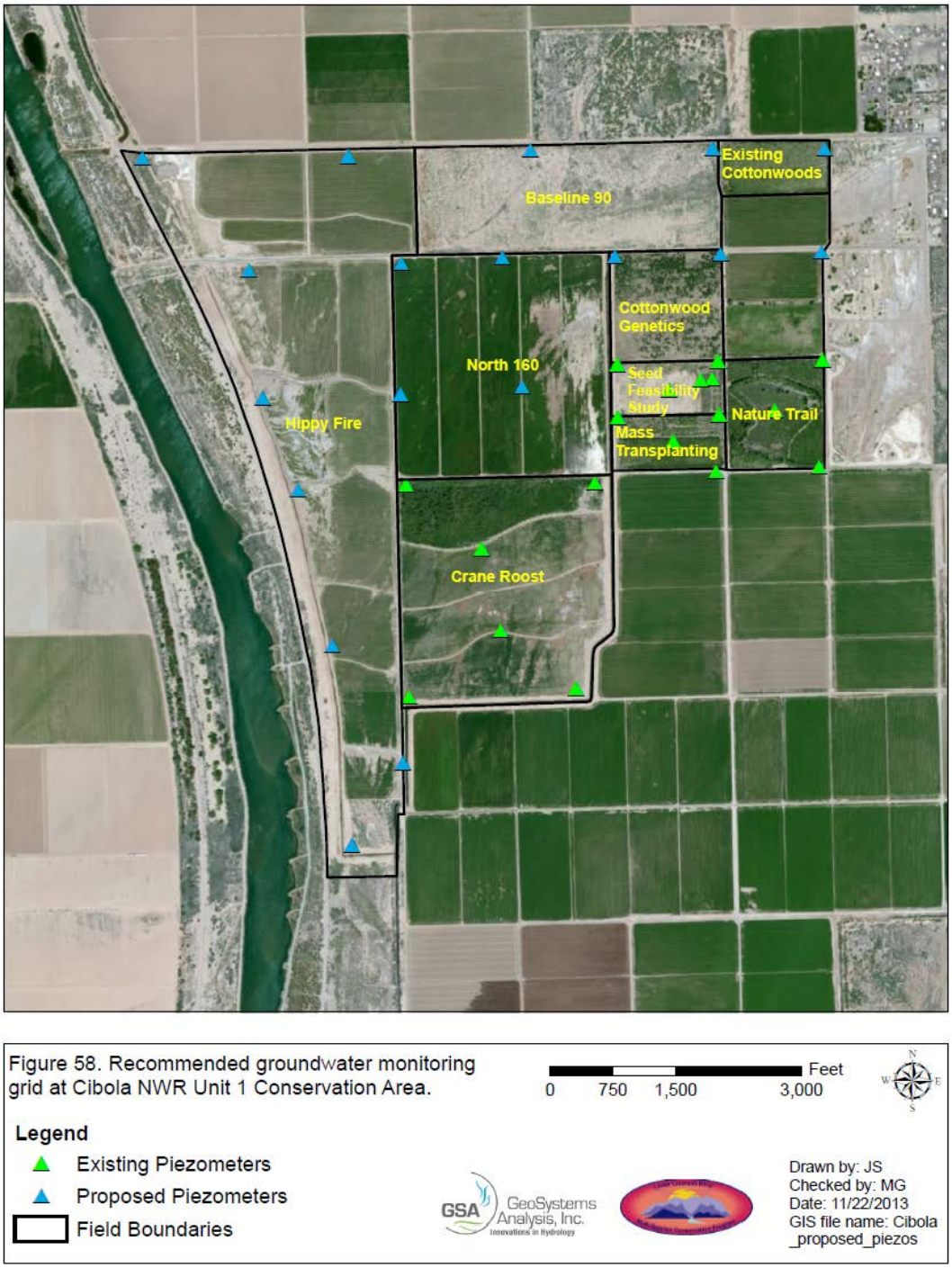

Figure 58.—Recommended groundwater monitoring grid at Cibola NWR Unit #1.

7.0 LITERATURE CITED

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8.0 ACKNOWLEDGMENTS

We thank the LCR MSCP and the Reclamation Lower Colorado Regional Office for its funding and guidance for this project. Additionally, we thank the U.S. Fish and Wildlife Service management and staff at the Cibola and Havasu National Wildlife Refuges for their assistance at the field sites and the California Fish and Game for their assistance at the PVER.