Lower Colorado River Multi-Species Conservation Program

Balancing Resource Use and Conservation

CIBOLA NATIONAL WILDLIFE REFUGE FIELD 51 SITE CHARACTERIZATION REPORT

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

April 2008

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Lower Colorado River Multi-Species Conservation Program

CIBOLA NATIONAL WILDLIFE REFUGE
FIELD 51
SITE CHARACTERIZATION REPORT

Prepared for
The United States Department of the Interior
Bureau of Reclamation
Lower Colorado Region
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EXECUTIVE SUMMARY

GeoSystems Analysis, Inc.(GSA) has conducted an intensive site characterization of Field 51 at Cibola National Wildlife Refuge (Cibola NWR) in support of the "Feasibility Study Using Native Seeds in Restoration" being funded by the Bureau of Reclamation in support of habitat restoration activities conducted under the LCR Multi-Species Conservation Plan.

The intent of the site characterization activities was to screen for vegetation-limiting soil and groundwater conditions, variability across Field 51, and changes during the course of the three-year study as a result of study implementation and management practices in adjacent agricultural fields and restoration sites. The following parameters have been characterized at various scales at Field 51 (sampling dates in parentheses):

- Soil texture (April 2006)
- Soil bulk density (April 2006)
- Soil infiltration rate (May 2007)
- Soil field water capacity (April 2006)
- Soil nutrients and geochemistry (July 2006)
- Soil salinity (July 2006)
- Depth to groundwater/groundwater elevation (July 2006, ongoing)

Additionally, GSA characterized soil texture and soil salinity at higher frequencies within the small-scale field study area to aid in the calibration of soil moisture content and soil salinity sensors installed at these locations. Sampling was conducted in November and December, 2007. As groundwater elevation monitoring is ongoing, updated results are provided in the 2007 annual report.

Key findings to date for the site characterization are the following:

1. Soil texture varies from fine- (silt and silt loam) to coarse-grained (sand and sandy loam) across the study site. Near-surface soil from 0 to 60 cm bgs was typically silt or silt loam. Sandy soil was found at depths greater than approximately 85 cm below ground surface, but was not spatially continuous.
2. Near-surface soil bulk density averaged 1.25 g/cm^3, which is not likely to limit growth of riparian seedlings. Bulk density generally increased with depth and was also associated with soil texture.
3. Soil infiltration rates were well approximated with Kostiakov parameters of 19.0 and 0.665 for k and a, respectively. Saturated hydraulic conductivity was between 6.2 and 10.4 cm per day, a relatively low rate as expected for fine-grained soils at Field 51.

4. Soil field capacity averaged 20.2% a week after flood irrigation. Lower values were observed in near surface samples (due to evaporation and drainage), and areas with higher soil bulk density, which was likely associated with sandier soil texture.
5. Soil nutrients were highly variable in Field 51. Macro-nutrients varied from very low to very high agricultural levels. Copper, iron, sulfur, and manganese levels were consistently high, whereas boron levels were consistently low. Relatively high pH (> 7.5) and calcium concentrations were observed.
6. Near-surface soil salinity ((electrical conductivity (EC)) was generally below 3.5 dS/m, with the exception of the northwest corner of the field, where EC was greater than 6 dS/m. Soil salinity in Field 51 generally increased with depth to levels of greater than 4 dS/m. In the small-scale study area, soil salinity increased greatly with depth on the north and south ends of the study area to levels typically in the stressful range (i.e. greater than 10 dS/m) for riparian plants. For deeper soil samples, salinity was lower for sandy soils compared to silt loam soils.
7. Groundwater depth is typically between two and three meters bgs. Therefore, mature cottonwood and willow plants may eventually have access to groundwater. Groundwater elevations and gradients indicate mounding due to irrigation cycles of Field 51 and adjacent fields.
8. Laboratory calibrations of soil moisture content and soil salinity sensors showed that one laboratory calibration-derived equation can be applied to each of the two types of soil water content probes regardless of the soil type:
    a. EC-10 Sensors: $\theta_v = 6.44 * 10^{-4} * mV - .0.229$
    b. ECH_20-TE Sensors: $\theta_v = 1.15 * 10^{-3} * mV - .0.651$

    where: θ_v is the volumetric water content, and mV is the sensor signal.

1.0 INTRODUCTION

This report documents the Cibola National Wildlife Refuge (NWR) Field 51 site characterization conducted by GeoSystems *Analysis*, Inc. (GSA) as part of Task 6 for Contract No. 06CR308057, *Feasibility Study Using Native Seeds in Restoration*, *California-Arizona-Nevada*.

Field 51 is the site for small-scale and large-scale test plot studies being conducted under the aforementioned contract at the Cibola NWR as shown in Figure 1. The Field 51 site characterization was designed to screen for physical and chemical parameters that would reduce the potential for plant success, and also to determine spatial and temporal variability in key soil and groundwater parameters which could affect the results of the small- and large-scale field plots for the current feasibility study.

Figure 1. Overview of Field 51 study site.

Laboratory and field tests were conducted to determine the spatial distribution of the following parameters within the Field 51 area:

- Soil texture (sand, silt, clay)
- Soil bulk density
- Soil infiltration rate
- Soil field capacity
- Soil nutrients and geochemistry
- Soil salinity
- Depth to groundwater/groundwater elevation
- Calibration of soil moisture and soil salinity sensor

Soil Bulk Density

Soil bulk density (degree of compaction) may greatly affect growth of desired plant species, either through restrictions in root growth or alteration of hydrologic properties (Smith et al., 2001; Kaspar et al., 1991; and GSA, 2007a). The objective of the bulk density characterization was to determine if there was a hard subsurface layer within the first 60 cm below ground surface (bgs), which may result from long-term agricultural use.

Soil Texture

Soil texture at proposed revegetation areas on the lower Colorado River (LCR) varies greatly, from fine sands (e.g. the Ahakhav Tribal Preserve, Beal Lake Restoration Site) to clay or silt loam soils (eg. The Nature Trail). The objective of the soil texture characterization was to: (1) map the spatial distribution of different topsoil types in Field 51, and (2) to characterize variability in soil texture at depths of up to 2.5 m bgs at the site.

Infiltration Rates

Infiltration rates are critical parameters for irrigation management to aid in the determination of optimal border strip dimensions, furrow length, and slope. The objective of the infiltration testing was to estimate parameters for the Kostiakov Formula (USDA, Natural Resources Conservation Service,1991), which is commonly used for irrigation analysis in optimization programs such as WinSRFR V1.2 (USDA, Agricultural Research Service, 2007, Maricopa, AZ).

Soil Field Capacity

The ability of soil to retain moisture and support plant growth is a function of the soil texture, bulk density and particle sorting/packing. Fine-grained soils with high available water holding capacity can support vegetation with less applied irrigation water than is required in sandier soils. The objective of the field capacity testing was to determine the water content distribution in Field 51 shortly after irrigation (seven days). These data were used to provide an estimate of the field capacity (water content retained after gravity drainage of irrigation water).

Soil Nutrients and Geochemistry

Although cottonwood and willow are observed to grow well in nutrient-limited environments, absolute growth rates and root to shoot ratios may still vary due to the availability of macro-nutrients (GSA 2007a, Marler et al., 2001). The objective of the soil nutrient/geochemistry analysis was to determine the availability and spatial variability of macro- and micro-nutrients, and screen for the presence of phytotoxic levels of elements, if any.

Soil Salinity

Soil salinity is a common limitation to the success of native riparian plant revegetation. Cottonwood and willow germination is limited by soil saturated paste electrical conductivity (EC) levels as low as 3 dS/m, and is prohibited at 10 dS/m (GSA 2007a, Desert Research Institute, 1990). Even established riparian trees may be greatly limited if EC levels are greater than 10 dS/m (Glenn et al., 1998), and soil salinity has limited the revegetation success at other sites on the LCR (i.e. Raulston, 2003). The objective of the salinity survey was to screen for the presence of high soil salinity conditions that may require leaching cycles prior to seeding, and to collect initial soil condition data to aid in the interpretation of results from the small- and large-scale test plots. An additional salinity survey was conducted for the small-scale test plot area following one growing season of irrigation to: (1) provide greater spatial resolution for the test-plot area, and (2) to determine the effectiveness of irrigation water in leaching salts through the soil profile.

Depth to Groundwater

Available groundwater at less than 2 m below ground surface greatly increases the competitive advantage of cottonwood and willow species over non-desirable species such as saltcedar (Stromberg et al. 2006). The objective of the depth to groundwater monitoring is to determine spatial and temporal variations at Field 51 in: (1) depth to groundwater, and (2) groundwater depth and gradient response to irrigation cycles (i.e. mounding and dissipation).

Calibration of Soil Moisture Content and Soil Salinity Sensors

For Task 5 small-scale field studies, soil moisture content and soil salinity and temperature sensor nests were installed in the center of each small-scale study plot. Each sensor nest consisted of:

1. One ECH_2O-TE (Decagon Devices, Inc., Pullman, WA) sensor at 15 cm below ground surface (bgs) to monitor soil temperature, soil specific conductance (EC), and soil volumetric water content.
2. One EC-10 sensor (Decagon Devices, Inc.) each at 46 cm and 91 cm bgs to monitor soil volumetric water content.

Manufacturer standard calibrations for volumetric water content are provided from Decagon Devices, Inc. However, these calibrations are not recommended for "high EC" conditions (i.e. greater than 0.5 dS/m for the EC-10, and greater than 8 dS/m for the ECH_2O-TE) or sandy soils. Because both are prevalent at Field 51, soil-specific calibrations were conducted in the GSA laboratory

Section 2.0 discusses the technical approach and methods used for the site characterization; Section 3.0 discusses the study results; and Section 4.0 presents study conclusions.

2.0 TECHNICAL APPROACH

Field tests and sample collections for bulk density and soil field water capacity were conducted on a regular grid of nominal 30 meter spacing. A subset of these locations was selected for sampling of soil texture and soil geochemistry/macro- and micro-nutrients. Additional sampling locations for soil texture, soil geochemistry/macro- and micro-nutrients, and soil salinity were selected to increase the resolution of these parameters in the proposed small-scale study area. An electromagnetic (EM) survey was also conducted to assess soil salinity across Field 51 on a grid of 15 m to increase spatial resolution (Section 2.6). Finally, eight well point piezometers were established across the field and adjacent to the small-scale test-plot area. Detailed methods for the different analyses are provided in the following sections.

2.1 Soil Bulk Density

Soil bulk density was characterized during April 24-25, 2006. Direct measurements of bulk density were made by collection of brass sleeve core samples (5 cm diameter x 10 cm length) at 12 locations (Figure 2) and 3 depth intervals, (5-15 cm bgs, 25-35 cm bgs, and 45-55 cm bgs) with an AMS sampler (AMS Inc., American Falls, ID). Soil moisture and mass within each core was analyzed to determine the water content and soil bulk density (MOSA Part 4, Method 2.1.2).

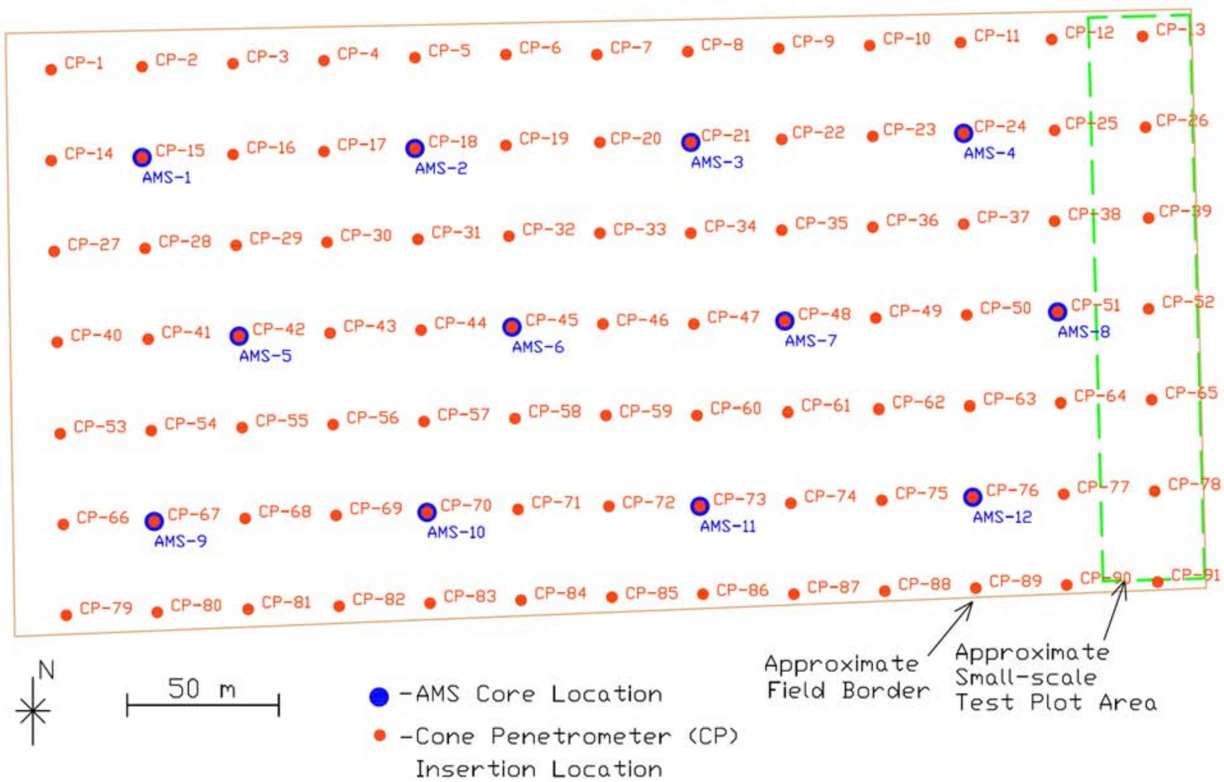

Figure 2. Bulk density analysis sampling locations.

Estimates of bulk density were made at 91 locations on a 30 meter grid (Figure 2) from measurements of penetration resistance using a manually operated Rimnik CP40 (Agridry Rimik Pty Ltd, Qld, Australia) cone penetrometer. The cone penetrometer (CP) measures the force required to push a steel rod into the soil at 2-cm increments to a depth of 60 cm (Figure 3).

Figure 3. Cone penetrometer insertion for bulk density estimation.

Penetration resistance is dependent on soil water content, soil structure, soil texture, and soil bulk density. Increases in soil water content will generally decrease penetration resistance. Coarser soil textures will result in higher penetration resistance, as will higher soil bulk density.

For the bulk density analysis, it was assumed that soil texture and structure were relatively homogeneous between 0 to 60 cm bgs between each location. To account for differences in water content at depth, grab samples were collected at 10, 30, and 50 cm bgs at each CP location and gravimetric water content was determined (refer to Section 2.4).

Soil bulk density at each CP locations was determined from Equation 2.2.1, a multiple regression of penetration resistance and water content to soil bulk density at the AMS core sampling locations:

$$\rho_b = AR + B\theta_g + C \qquad 2.2.1$$

where: ρ_b is the soil dry bulk density; R is the average force (in kPa) required per 2 cm over the given depth interval; θ_g is the soil gravimetric water content; and A, B, and C are calibration coefficients calculated via multiple regression using Table Curve V 5.0 (Cranes Software International Limited, Karnataka, India).

2.2 Soil Texture

Continuous core soil samples were collected at Field 51 with a JMC Environmentalist's Subsoil Probe (ESP) (Clements Associates Inc., Newton, IA), which can collect core in an acrylic tube from the ground surface to greater than 200 cm bgs. ESP core locations are shown in Figure 4, and sampling depths are provided in Table 1. Initially, locations ESP-4 and ESP-5 were sampled on April 12, 2006. Twelve additional CP locations were sampled on April 26, 2006. Soil core samples were frozen and then split based on visual observations of change of soil texture or color, or at maximum intervals of 30 cm between sample depths.

The resulting 75 samples from the ESP cores were classified using visual-manual methods (ASTM D 2488); 15 of these samples were laboratory tested for soil texture using the hydrometer method (ASTM D 422). It was anticipated that this would allow for the visual-manual results to be calibrated to the hydrometer results via correlation between percent sand, silt, and clay. However, due to minimal variation in soil texture of samples analyzed using the hydrometer method (refer to Section 3.1), the visual-manual texture calibration was effective only in approximating percent sand and percent fines.

A separate analysis of small-scale study-plot texture was conducted in conjunction with the small-scale instrumentation calibration (Section 2.8). The ESP probe was used to collect soil samples to a depth of 100 cm bgs in the center of each small-scale study plot as shown in Figure 4. Samples were collected on either November 18, 2007 (ESP-SS 1 through ESP-SS 18) or December 18, 2007 (ESP-SS 19 through ESP-SS 36). Sample intervals were separated to bracket each water content probe depth (15, 46, and 91 cm bgs), such that a sample interval was collected for 10-20 cm bgs, 41-51 cm bgs, and 86-97 cm bgs. Eighty of the resulting 108 samples were analyzed using visual-manual methods—all 41-51 cm bgs and 86-97 cm bgs core samples, and eight 10-20 cm bgs samples (minimal texture variation has been observed in the field at this near surface depth). Ten ESP-SS samples were laboratory tested for soil texture using the hydrometer method. Because different personnel conducted the visual-manual soil separates estimations, these data were calibrated to hydrometer data independent of previous ESP soil core texture analysis.

Percent sand was predicted for all samples via exponential regression of hydrometer separates versus visual-manual estimations. Because no gravel was observed, percent fines was estimated as the remaining percentage of soil separates. Samples were then classified into the following USDA soil types:

- Sand - Greater than 80 percent estimated sand.
- Sandy loam - Between 46 and 80 percent estimated sand.
- Silt loam - less than 46 percent estimated sand.

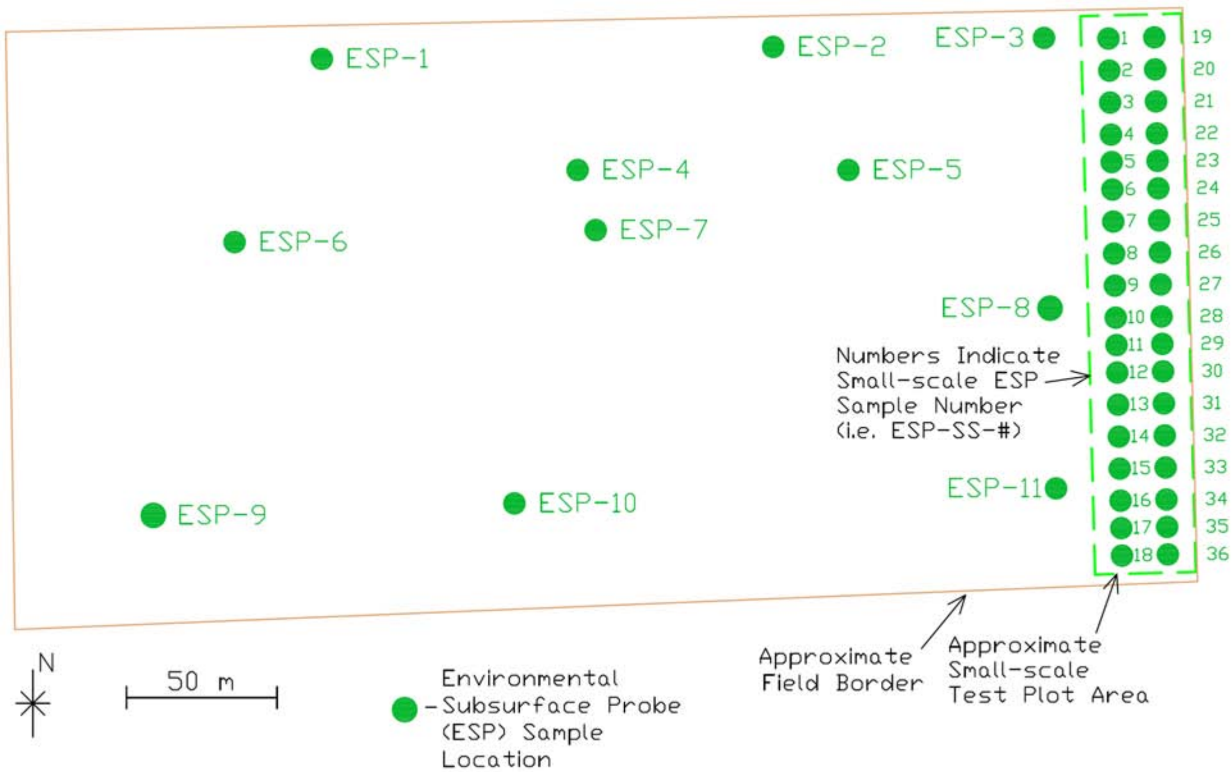

Figure 4. ESP core sampling locations for texture (all samples) and texture and salinity (small-scale test plot area only).

Table 1. ESP core (soil texture) sampling detail for large-scale study area.

Location	Depth of Sampling (cm bgs)	Number of Sub-Samples	Number of Laboratory Texture Analyses
ESP-1	0-176	6	2
ESP-2	0-211	11	0
ESP-3	0-198	8	3
ESP-4	0-81	4	0
ESP-5	0-154	7	1
ESP-6	0-141	5	4
ESP-7	0-179	7	0
ESP-8	0-193	9	1
ESP-9	0-164	6	2
ESP-10	0-113	5	2
ESP-11	0-186	7	0

2.3 Infiltration Testing

Soil infiltration rates were determined using the cylinder infiltrometer method (Bouwer et al., 1999). Seven cylinder infiltrometer tests were conducted at Field 51 on May 10, 2007. Four locations were adjacent to the small-scale test plot area, and three were spread across the large-scale area to determine potential spatial variability (Figure 5). Cylinder infiltrometers provide an intermediate-scale estimate of effective saturated hydraulic conductivity. A detailed description of the cylinder infiltrometer method is presented in Appendix A.

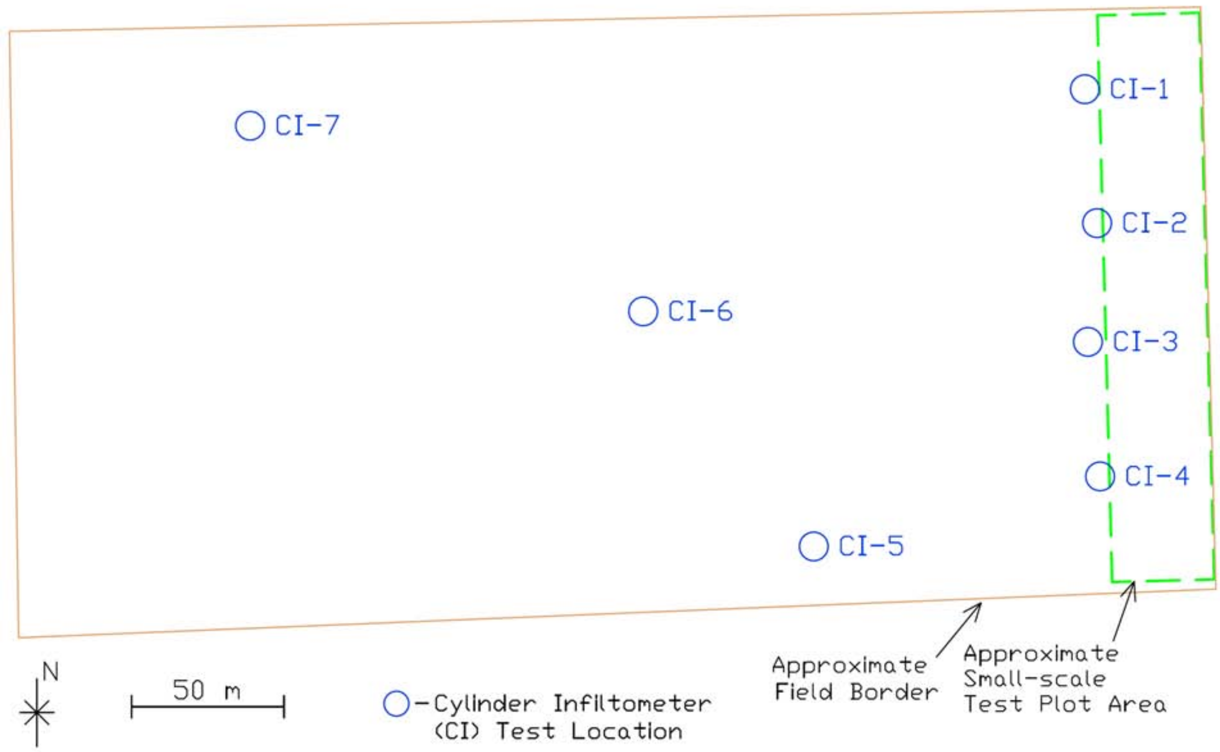

Figure 5. Cylinder infiltrometer test locations.

For irrigation analyses (e.g. WinSRFR V1.2 (USDA, Agricultural Research Service, 2007, Maricopa, AZ)), the Kostiakov Formula is regularly used:

$$Z = kT^{a} \qquad 2.3.1$$

Where Z is the depth of water infiltrated at a given time T, and k and a are coefficients.

Representative Kostiakov k and a coefficients were determined by fitting infiltration data to a power function using Table Curve 2D V 5.0 (Cranes Software International Limited, Karnataka, India).

2.4 Soil Water Content and Estimated Field Capacity

Soil samples were collected across Field 51 approximately 7 days after flood irrigation (April 24 and 25, 2006). Two types of soil samples were collected for water content analyses: (1) AMS core samples; and (2) grab samples collected at CP testing locations (Figure 2) at 10, 30 and 50 cm bgs, The latter soil samples were collected adjacent to the CP measurement points using a hand operated bucket auger. Soil samples were stored in double sealed zip lock bags to prevent moisture loss during transportation. All samples were then analyzed for gravimetric water content in the GSA laboratory following ASTM D 2216.

Gravimetric water content (θ_g) was converted to volumetric water content (θ_v) according to Equation 2.3.2:

$$\theta_v = \theta_g \times \rho_b \qquad 2.3.2$$

Where ρ_b is the dry soil bulk density previously estimated from Equation 2.2.1.

2.5 Soil Nutrients

Soil fertility (macro- and micro-nutrients) and basic geochemical parameters were characterized throughout the field at the 0 to 30 cm bgs and 60 to 90 cm bgs intervals at nine sample locations were samples within the proposed small-scale field study area, and nine locations in the remainder of Field 51 (Figure 6). It should be noted that changes in the 2007 Scope of Work (SOW) resulted in an approximate doubling of the small-scale study area. These SOW changes occurred subsequent to soil sampling; therefore, soil sampling for nutrients and geochemistry was not evenly distributed in the small-scale study area.

A hand operated bucket auger (AMS Inc., American Falls, ID) was used to collect grab samples at each interval. Samples were stored in sealed zip lock bags and delivered to IAS Laboratories (Phoenix, Arizona), which performed analytical testing for parameters shown in Table 2.

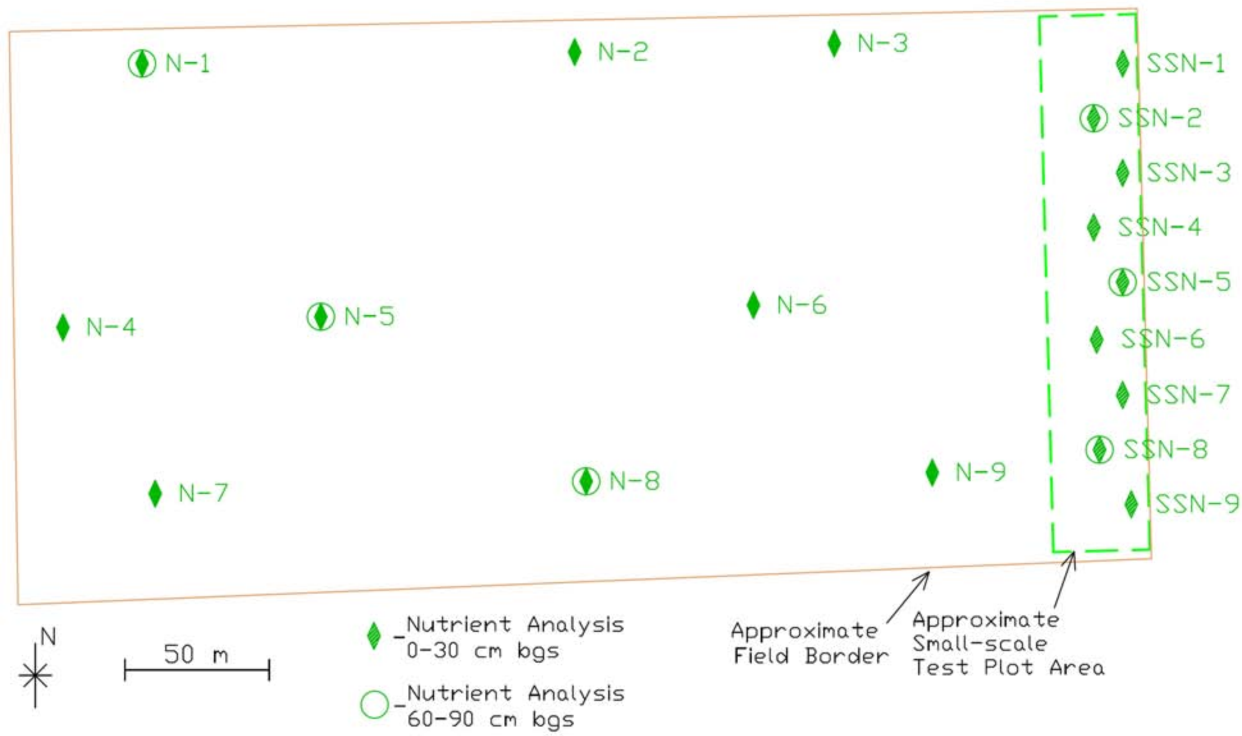

Figure 6. Nutrient and geochemistry sampling locations in Field 51.

Table 2. Standard methods for soil fertility and geochemical analysis.

Parameter	Analytical Method
1:1 pH	MOSA Part 2, 12-2
Soluble Salts EC	MOSA, Part 2, 10-3.3
Available Ca, K, Na Mg	CSTPA, 1974a
Available Cu, Fe, Mn, Zn	CSTPA, 1974b
Nitrate-Nitrogen	Carter, 1993a, Method 7.3.3
Phosphate	CSTPA, 1974c
Boron	Walsh and Beaton, 1973
Sulfate Sulfur	Carter, 1993b
Exchangeable Sodium Percentage (ESP)	USDA, 1954

2.6 Soil Salinity

Soil salinity (EC) was measured by an electromagnetic (EM) survey using an EM38 sensor (Geonics Limited, Mississauga, Ontario, Canada), and laboratory testing of collected soil samples at various locations and depth intervals in Field 51.

The EM38 sensor was used to estimate soil salinity on July 17, 2006. The EM38 measures ground conductivity to depths of 1.5 m bgs, which is governed by soil texture, soil water content and bulk soil EC. EM38 readings were taken at 379 locations (Figure 7). Sixty soil samples were taken at sixteen locations in Field 51 at 30 cm depth intervals for calibration of the EM38 readings (Figure 7) to EC. These samples consisted of grab samples collected with a bucket auger at 30 cm depth intervals to a depth of 120 cm bgs. Samples were double-sealed in freezer bags, and shipped to the University of Arizona College of Agriculture and Life Sciences Yuma County Cooperative Extension (Yuma, Arizona).

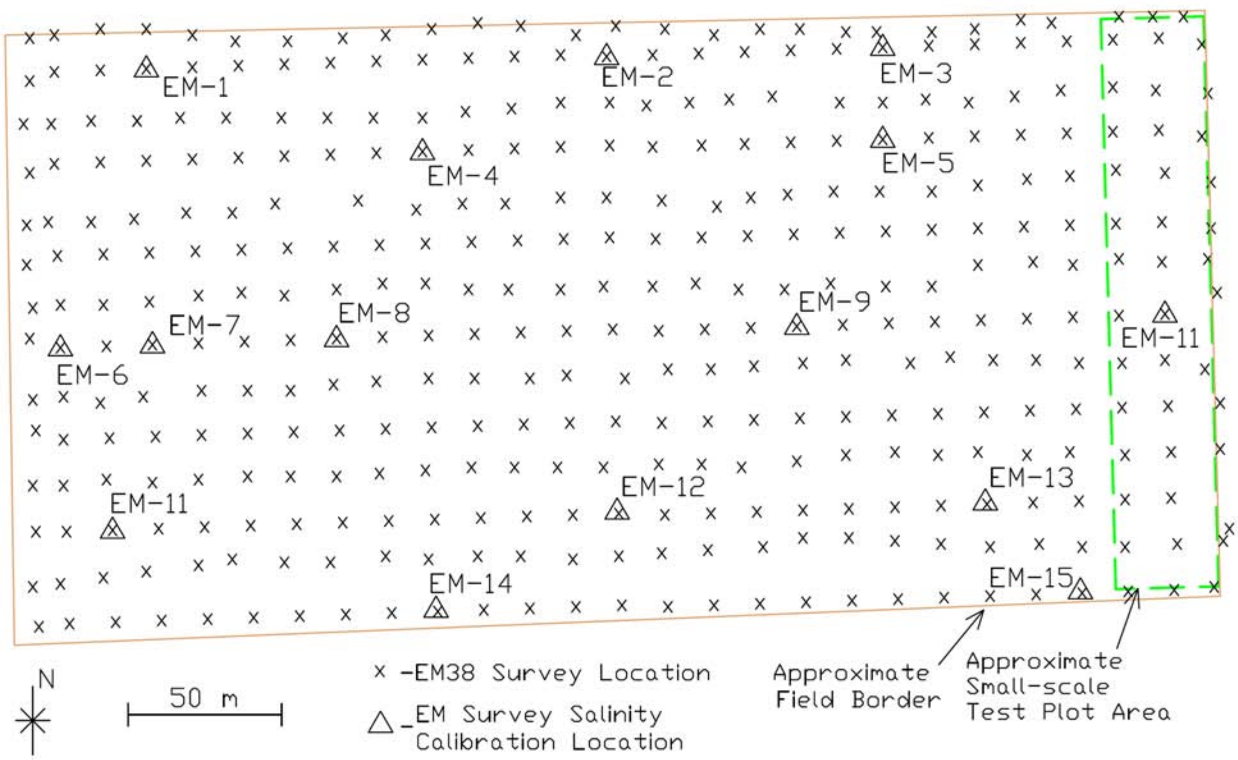

Figure 7. EM38 survey data collection locations (July 27, 2006).

Saturated paste extract EC was determined for soil samples collected on July 27, 2006 at Yuma County Cooperative Extension laboratory (Yuma, Arizona). Multiple regression analyses were conducted using JMP 6.0 (SAS Institute, Cary, N.C.) between EC and EM38 readings at these reference locations to obtain calibration constants for the following equation:

$$\ln EC = b_0 + b_1 z_1 + b_2 z_2 \qquad 2.5.1$$

where: EC is the average saturated paste EC over a given depth, z_1 and z_2 are the horizontal and vertical EM38 readings, respectively, and b_0, b_1, and b_2 are calibration constants. Once appropriate coefficients were determined, Equation 2.5.1 was applied to the 379 EM38 survey locations to calculate saturated paste EC at one-foot depth intervals as well as bulk EC, defined as the average EC over the entire depth of readings (1.2 m bgs).

To supplement EM38 estimates of EC, 1:1 paste EC was also determined by IAS Laboratories (Phoenix, Arizona) for nine sample locations within the large-scale study area, and nine sample locations within the small-scale study area (the soil nutrient and geochemistry samples). Samples were either at 0 to 30 cm bgs or 60 to 90 cm bgs (refer to Section 2.5).

Finally, to assist in small-scale study instrumentation calibration, and to analyze soil salinity after one season of irrigation, soil samples collected for textural analysis in the small-scale study area (refer to Section 2.2) were also analyzed in the GSA laboratory for 1:1 paste EC, following Rhoades (1986). All ESP samples from the small-scale study area (refer to Figure 4—108 samples total, three per plot at 10-20 cm bgs, 41-51 cm bgs, and 96-97 cm bgs), collected on November 18, 2007 (ESP-SS 1 through ESP SS-18) or December 18, 2007 (ESP-SS 19 through ESP-SS 36) were analyzed for EC.

To approximate saturated past EC, IAS Laboratories multiplies 1:1 results by 2, which assumes soil paste gravimetric water contents of 50 g/g soil (approximately 65 cm^3/cm^3 volumetric water content for an assumed soil dry bulk density of 1.3 g/cm^3). Therefore, GSA 1:1 results were also multiplied by 2 for consistency.

2.7 Depth to Groundwater

Five groundwater elevation monitoring well point piezometers were installed within the Field 51 area on July 28, 2007. One piezometer was placed in each corner of the field, and one in the center. Three additional well point piezometers were placed in the small scale field study area in May 2007 prior to seeding and irrigation (Figure 8). Each piezometer consists of a screened 1.7-inch outer diameter (OD) well point (Johnson Screens, New Brighton, Minnesota) connected to stainless steel extensions as presented in Figure 10. Groundwater elevation is being collected twice daily using WL16 Water Level Loggers (Global Water Instrumentation, Inc., Gold River, CA) pressure transducer/dataloggers.

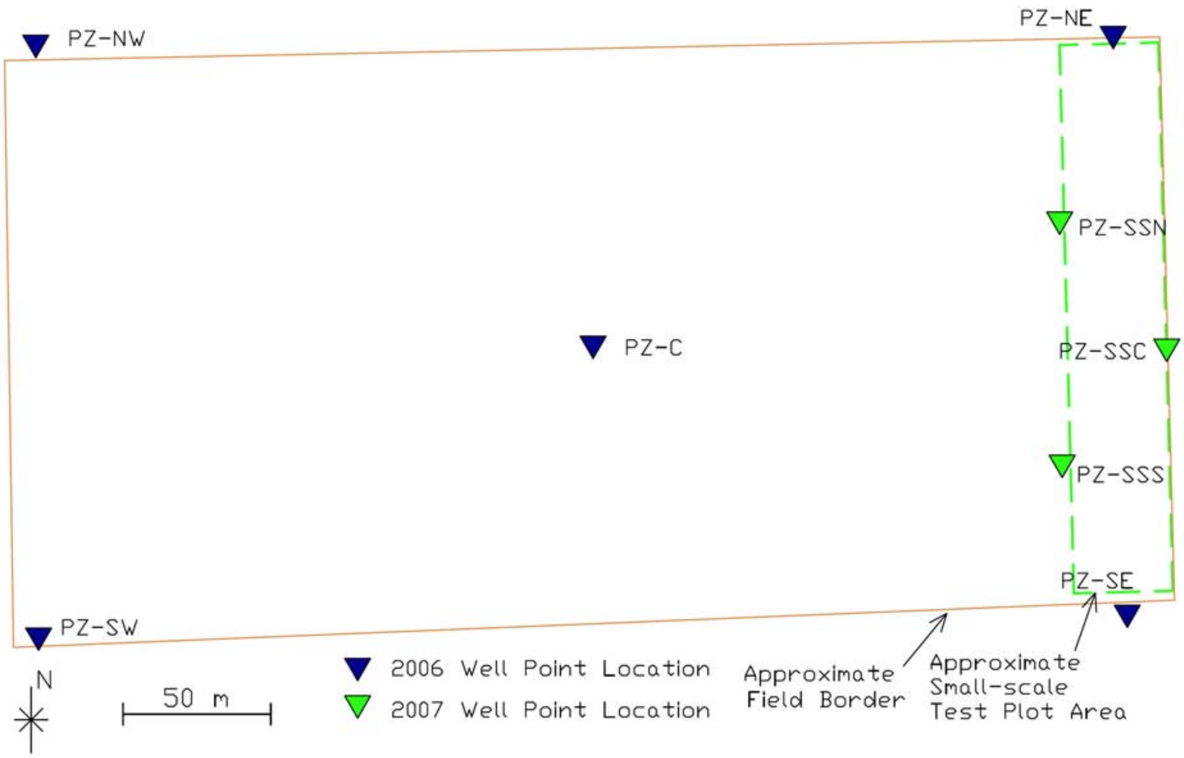

Figure 8. Well point piezometer locations at Field 51.

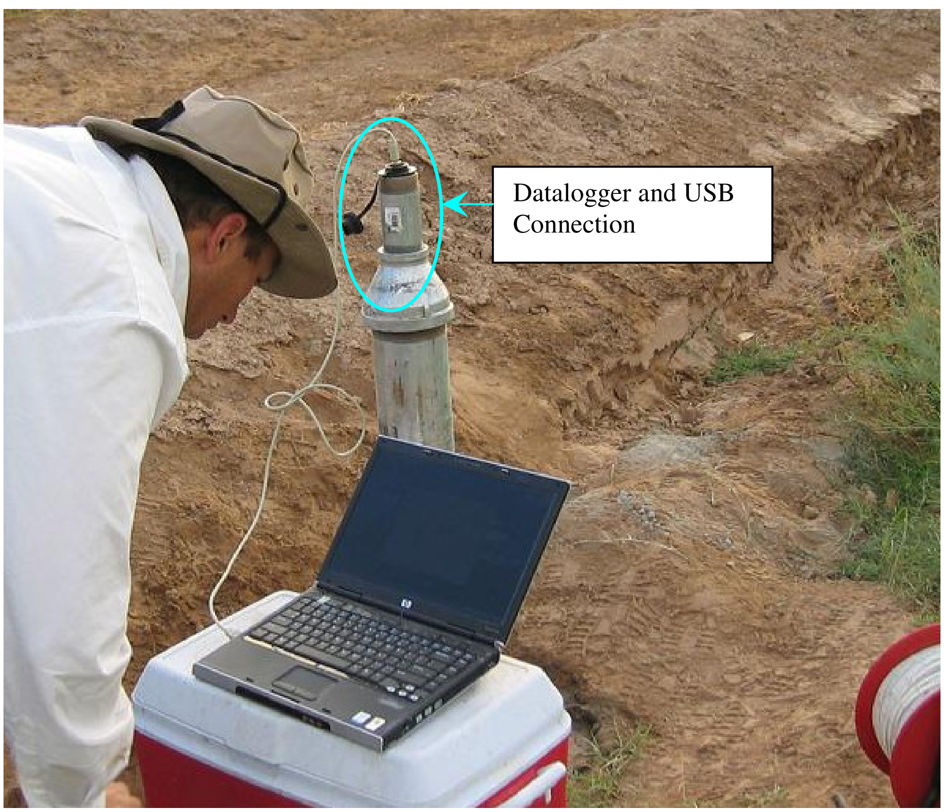

Figure 9. Downloading initial depth to groundwater data during piezometer installation.

The pressure transducers were placed in each well point at a minimum depth of 40 cm below the initial groundwater level. The dataloggers rest on the 2-inch OD steel pipe placed below the locking cap (Figure 9). Data are downloaded manually to a laptop via USB cable connections at approximately two-month intervals.

The well point piezometers were surveyed by Reclamation personnel on December 19, 2007 using a survey-grade GPS unit. The datum of each well point is the top of the cap attached to the 2-inch OD steel casing (locking portion of cap removed by GSA personnel). Datums for all well points are presented in Table 3. Groundwater elevations above mean sea level (amsl) are then estimated from these well point datums. Note that PZ-SW was damaged by farm equipment after September 23, 2007, and prior to December 19, 2007. A stake was placed approximately one meter to the west of this piezometer, and the top of the stake was surveyed. The height of this piezometer datum (and therefore groundwater elevation) was estimated based on previous estimates of piezometer height above ground level.

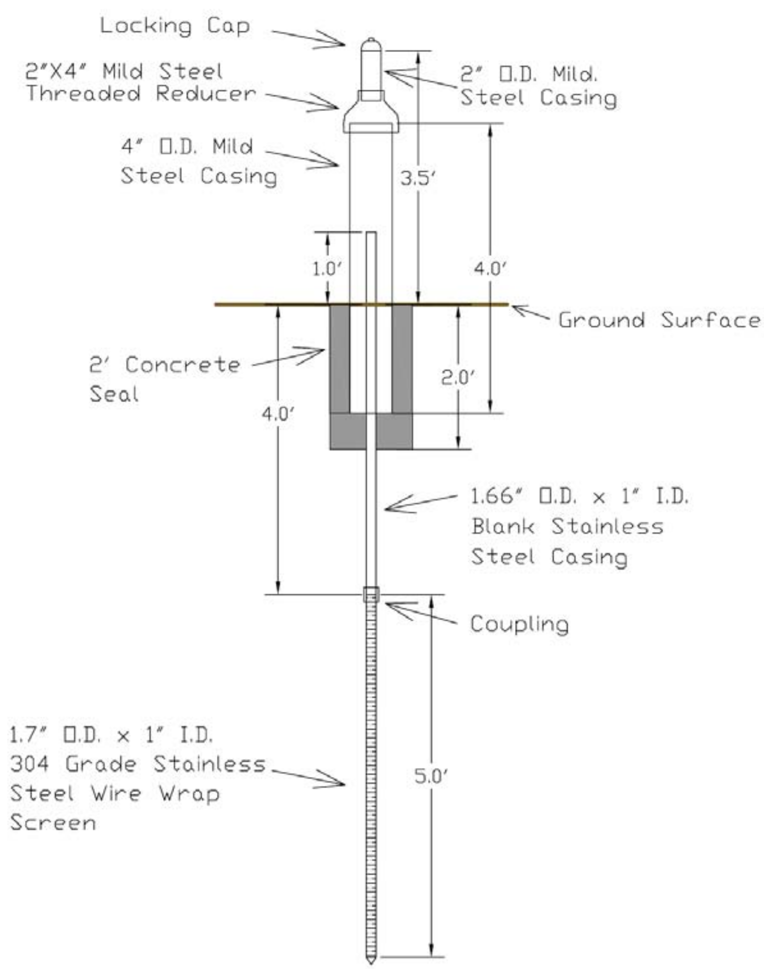

Figure 10. Cross-section of typical well point piezometer.

Table 3. Datums for well point piezometers established in Field 51.

Specification	Piezometer Name							
	PZ-NE	PZ-NW	PZ-SW[1]	PZ-SE	PZ-C	PZ-SSN	PZ-SSC	PZ-SSS
Datum Elevation, m amsl	71.61	71.59	70.86	71.63	71.56	71.64	71.65	71.62
Datum Elevation, feet amsl	234.9	234.9	232.5	235.0	234.8	235.0	235.1	235.0
Approximate Ground Elevation, m amsl	70.67	70.53	70.68	70.64	70.46	70.87	70.59	70.64
Approximate Ground Elevation, feet amsl	231.9	231.4	231.9	231.8	231.2	232.5	231.6	231.8

1 Datum elevation estimated due to damage to piezometer from farming equipment prior to survey.

2.8 Soil Moisture Content and Soil Salinity Sensor Calibration

2.8.1 Instrument and Datalogger Installation

Instrument nests were placed in the center of each small-scale study plot to monitor soil moisture content, salinity, and temperature as a result of irrigation, environmental conditions, and vegetation establishment and growth. A typical sensor nest is shown in Figure 11. An ECH$_2$O-TE (Decagon Devices, Inc., Pullman, WA) sensor was placed at six inches (15 cm) below ground surface (bgs) to monitor soil temperature, soil specific conductance (EC), and soil volumetric water content. EC-10 sensors (Decagon Devices, Inc.) were placed eighteen inches (46 cm) and 36 inches (91 cm) bgs to monitor soil volumetric water content.

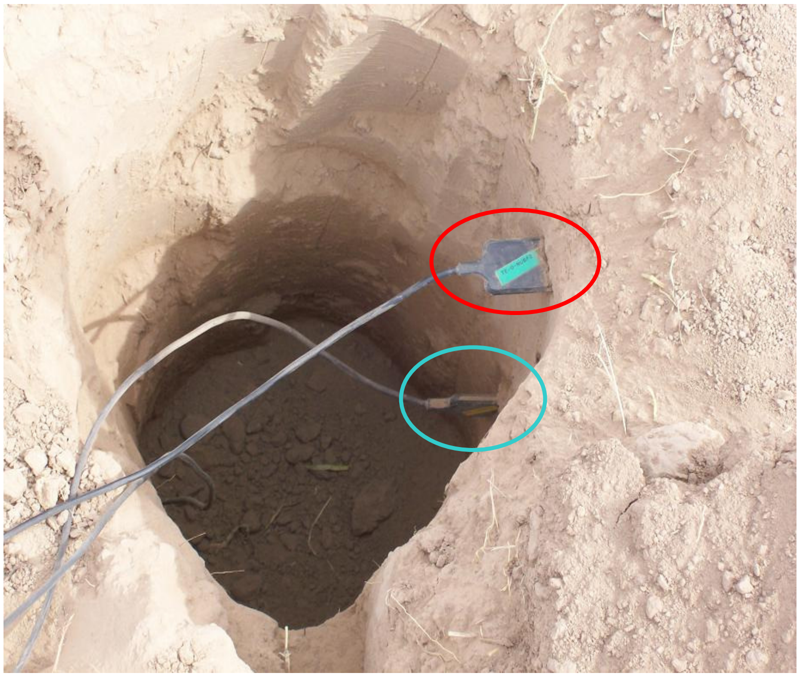

Figure 11. Instrumentation nest in small-scale study field plot prior to soil backfilling. The red oval encircles an ECH$_2$O-TE sensor at six inches (15 cm) below ground surface, and the blue oval encircles an EC-10 sensor at eighteen inches (46 cm) below ground surface.

For installation, a hole was excavated with a shovel to approximately 100 cm bgs in the center of the plot. In furrow-irrigated plots, the instrument nest was placed below one of the two crests adjacent to the north-south median of each plot. The sensor depth was measured from the adjacent furrow crest. In border-strip irrigated plots, the sensor depth was measured from the soil surface adjacent to the hole.

An Echo Installer (Decagon Devices, Inc.) blade was used to create a slot for each EC-10 sensor at the prescribed depth. The sensors were inserted into the slots, and backfill was placed in the hole until the sensor depth was reached. Hydrated bentonite was placed around the sensor cable. The installation of low-permeability bentonite should prevent preferential water flow to the sensor location. Backfill material was compacted lightly on top of the bentonite until the next sensor depth (i.e. 46 cm bgs) was reached, and installation procedure repeated. The hole was then backfilled to 15 cm bgs. Because the soil was loose at 15 cm bgs due to soil tillage, the ECH_2O-TE was inserted into the soil by hand (i.e. the Echo Installer was not used). The remaining backfill was placed, and the soil was re-surfaced to either flat (border-strip plots) or furrows (furrowed plots).

CR-1000 dataloggers were placed in the center of each the north and south halves of the plots. This approach allowed all cable lengths to be less than 60 m long, and therefore minimize sensor signal attenuation that may occur with longer cables. From the datalogger, sensor cabling was routed through a ¾-inch- (1.9 cm) diameter drip irrigation tube in batches of two plots per tube (six sensors per tube) to protect the cables from burrowing animals. The tubing was buried a minimum of 10 cm bgs adjacent to the north-south dividing berm. The tubing was routed until immediately adjacent to the two plots. At this point, cables emerged from the irrigation tubing, and were routed to the center of each plot via a 10 cm-deep trench. Following probe insertion into the soil, all trenches were backfilled.

The dataloggers are programmed to download date from all sensors at ½-hour intervals. The datalogger program is provided in Appendix B.

2.8.2 Instrument Location Soil Type Characterization

Sensor data during the 2007 growing season showed large variability in the range of readings, particularly for the EC-10 sensors. The variability was generally attributable to observed differences in soil texture. It was apparent that EC-10s in sandier areas were generally providing lower mV, even during and immediately after irrigation events. Additionally, there appeared to be two types of mV responses for finer-grained soils. Therefore, ESP-SS samples representing EC-10 locations and depths (i.e. 41-51 and 86-97 cm bgs) were divided into three groups for classification, based on the percent of sand for hydrometer-calibrated visual-manual laboratory results:

Group 1: Less than two percent of sand by weight.

Group 2: Between two and 30 percent sand by weight.

Group 3: Greater than 30 percent sand by weight.

Soil sample locations are indicated by ESP-SS-# in Figure 4. Intervals were collected such that they encompassed 5 cm above and sensors in each plot (as described in Section 2.2). Soil samples from each of the soil groups were composited to obtain sufficient sample for laboratory EC-10 and ECH_2O-TE calibrations. Soil EC was not considered as a variable for the calibration because soil salinity was correlated with percent sand—therefore, splitting samples into three general soil types resulted in separation of samples with a generally higher EC (non-sandy) from those with low EC (sandy).

Large-scale Field 51 soils texture analyses had shown relatively little variation in soil texture for surface samples, and were classified as either silt loam or sandy loam.

2.8.3 Laboratory Calibration Methods

The GSA ECH_2O laboratory calibration method consists of obtaining volumetric water content sensor readings in soil repacked at prescribed water content and soil dry bulk density. After a reading is taken, the soil is mixed thoroughly with additional water to achieve higher water content. Subsequent readings are taken in progressively wetter soil until approximate soil saturation. Regression analyses are applied to the observed relationship to develop appropriate calibration equations between the mV sensor output (independent variable) and volumetric water content (dependent variable). A detailed description of the ECH_2O sensors and GSA laboratory calibration protocol is provided in Appendix C.

Four ECH_2O calibrations were conducted for the Task 5 small-scale field studies; one calibration was conducted for the EC-10 sensor with each of the three soil groups described above; because of minimal observed soil texture variation at shallow depth, one calibration was conducted for the ECH_2O-TE. All near-surface (10-20 cm bgs) soil samples with a saturated paste EC of less than 10 dS/m were combined and used for the calibration (excluding the high salinity samples, the average soil paste EC was approximately 4.4 dS/m). Note that manufacturer calibration equations are utilized for ECH_2O-TE measurement of soil temperature and EC due to the high accuracy of thermistor temperature measurements and the difficulty in conducting laboratory sensor calibrations for soil salinity.

3.0 RESULTS

Site characterization field and laboratory results are provided in the following sections.

3.1 Soil Texture

Soil samples sent for hydrometer analyses (IAS Laboratories) fell into three USDA soil texture classifications: silt loam, sandy loam, and sand (Table 4), whereas those analyzed by GSA indicated soil samples in the silt texture classification as well. This discrepancy was likely due to laboratory inconsistencies; specifically, IAS Laboratory hydrometer analysis indicated a higher percent of sand separates compared to GSA hydrometer analysis.

Regression of the hydrometer results with the visual-manual samples showed poor correlation for silt and clay; however, correlation between the percent sand values (Figure 12 and Figure 13 for the large-scale and small-scale study areas, respectively) was sufficient to correct the visual-manual predictions as described in Section 2.2.

Raw and hydrometer corrected GSA soil separates are provided in Appendix D. The calibrated visual manual classifications indicate that:

- Approximately 76 percent of the Field 51 samples were Silt Loam.
- Approximately 15 percent of the Field 51 samples were Sandy Loam.
- Approximately 9 percent of the Field 51 samples were Sand.

Figure 14 shows a 3-D representation of soil texture within Field 51 as interpolated from the calibrated visual manual classification data. The silt-loam texture dominates the upper 60 cm of the soil profile, particularly in the 30 to 60 cm depth interval. Texture becomes coarser with depth, and a sand layer is present through the center of the field from north to south at the 105 cm depth. Finer-grained material persists with depth on the west and northeast portions of the field.

Table 4. Soil texture results (hydrometer data).

Location	Depth (cm bgs)	Sand %	Silt %	Clay %	Fines % (Silt % + Clay %)	USDA Texture Classification
ESP-1[1]	0-30	26	55	19	74	Silt Loam
ESP-1[1]	30-60	20	65	15	80	Silt Loam
ESP-3[1]	0-30	24	58	18	76	Silt Loam
ESP-3[1]	30-60	20	67	13	80	Silt Loam
ESP-5[1]	0-30	22	62	16	78	Silt Loam
ESP-6[1]	0-28	20	57	23	80	Silt Loam
ESP-6[1]	115-141	12	68	20	88	Silt Loam
ESP-7[1]	0-23	16	67	17	84	Silt Loam
ESP-7[1]	23-48	12	68	20	88	Silt Loam
ESP-8[1]	127-145	16	69	15	84	Silt Loam
ESP-9[1]	0-20	20	65	15	80	Silt Loam
ESP-9[1]	20-41	16	69	15	84	Silt Loam
ESP-10[1]	0-30	16	68	16	84	Silt Loam
ESP-10[1]	60-90	62	31	7	38	Sandy Loam
ESP-10[1]	117-147	96	2	2	4	Sand
ESP-SS-6[2]	86-97	0	84	16	100	Silt Loam
ESP-SS-8[2]	10-20	6	84	10	94	Silt
ESP-SS-8[2]	86-97	1	87	12	99	Silt Loam
ESP-SS-9[2]	10-20	7	83	10	93	Silt
ESP-SS-9[2]	86-97	51	49	0	49	Sandy Loam
ESP-SS-11[2]	41-51	1	85	14	99	Silt Loam
ESP-SS-24[2]	86-97	0	96	4	100	Silt
ESP-SS-25[2]	86-97	89	10	1	11	Sand
ESP-SS-27[2]	41-51	5	87	8	95	Silt
ESP-SS-32[2]	41-51	2	82	16	98	Silt Loam

1 Samples tested by IAS Laboratories.
2 Samples tested by GSA.

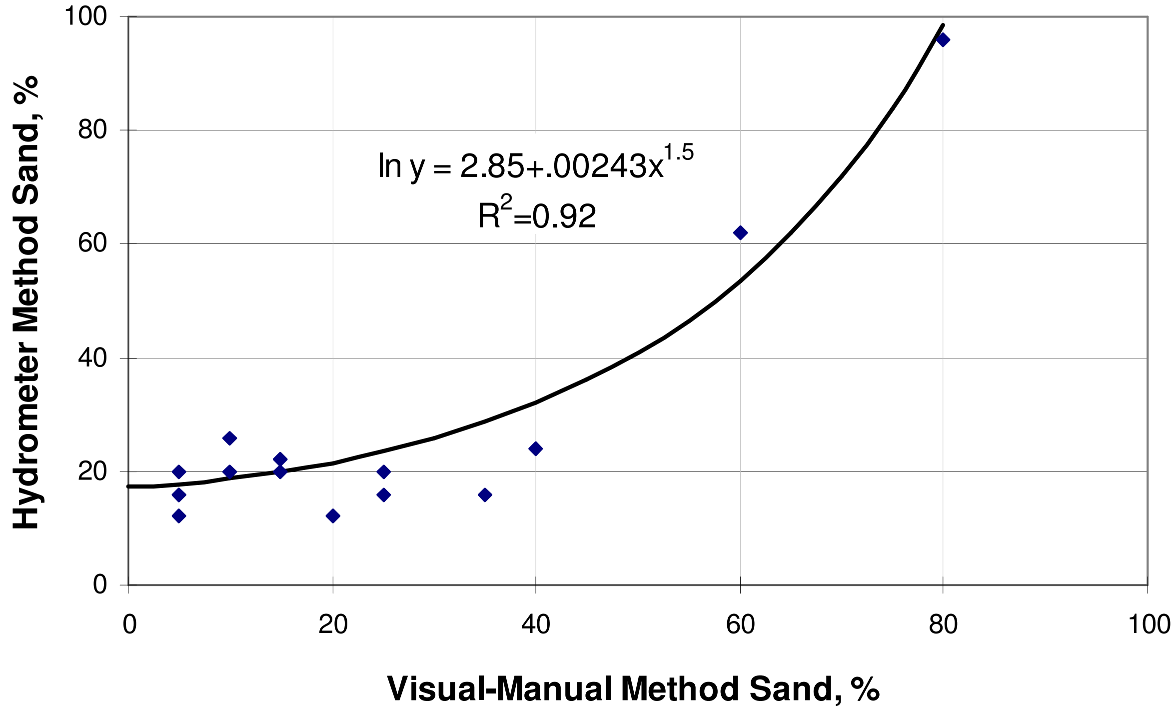

Figure 12. Regression of percent sand: IAS Laboratories hydrometer method versus visual manual method (2006 samples).

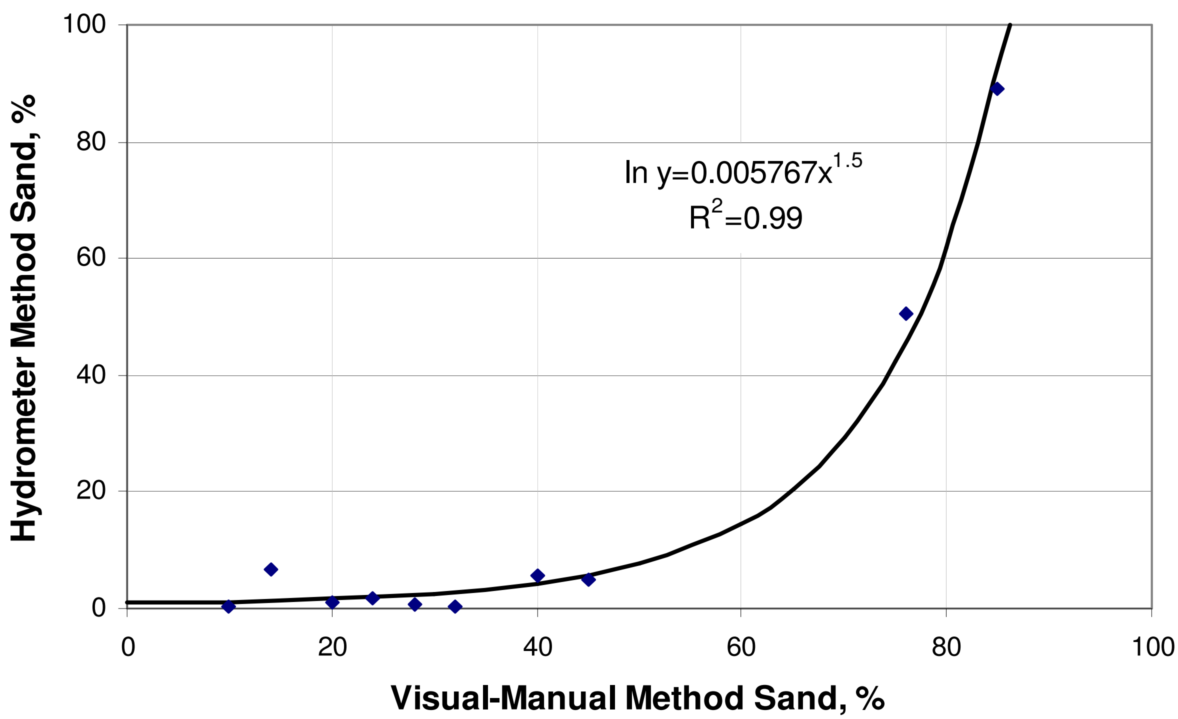

Figure 13. Regression of percent sand: GSA hydrometer method versus visual manual method (2007 samples).

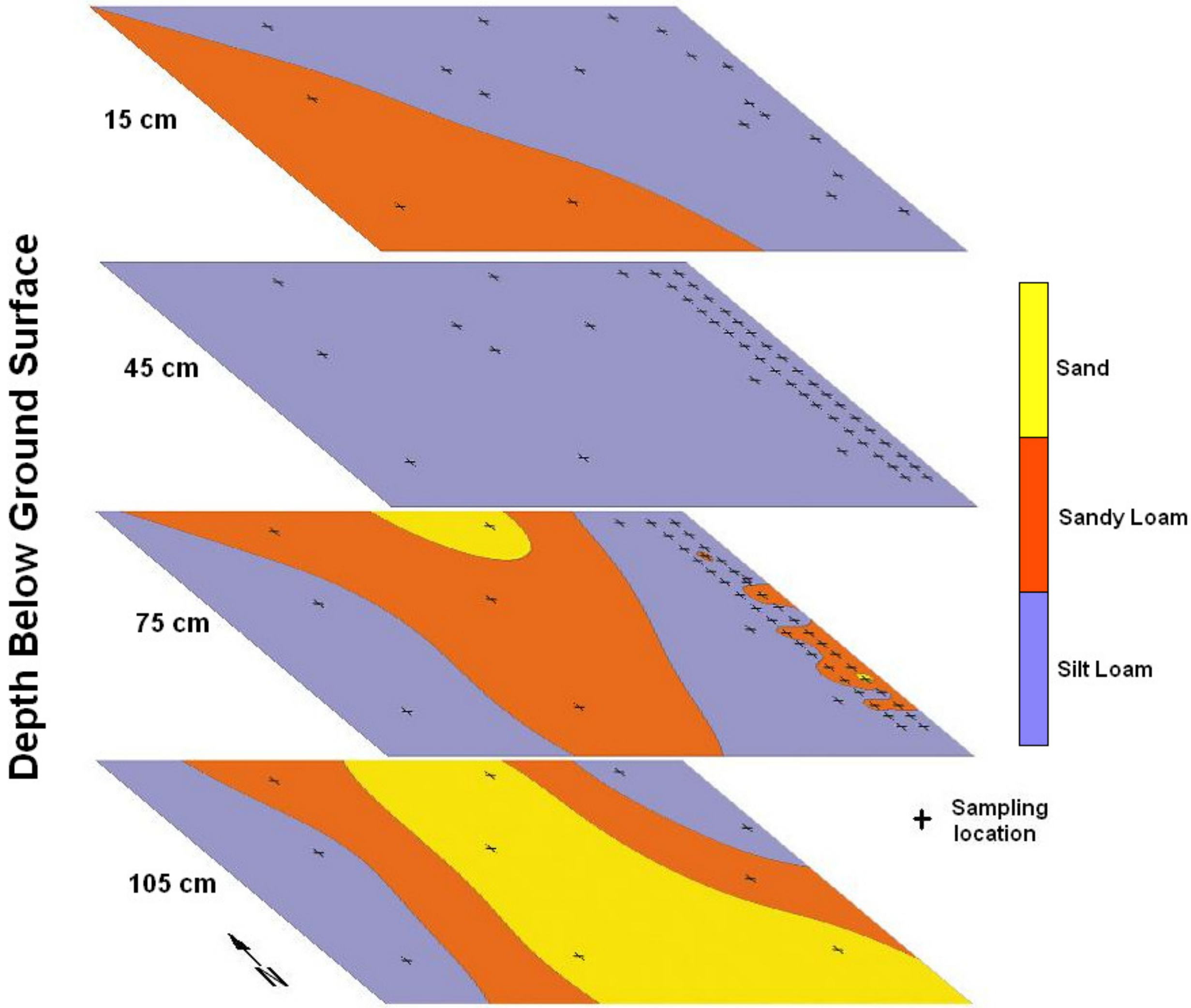

Figure 14. Field 51 soil texture distribution (interpolated).

3.2 Soil Bulk Density

Table 5 provides the results of the AMS core sample laboratory measurements of bulk density by location (refer to Figure 2) and depth. Measured bulk densities ranged from 1.14 to 1.60 g/cm^3 with an average of 1.32 g/cm^3. The measured bulk density of 1.60 g/cm^3 at location AMS-3 is most likely due to its sandier soil texture. All other measured values are reasonable and within the expected values for silt or silt loam soil.

Table 5. Bulk density and gravimetric water content measured in AMS core samples.

Sample Location	Sample Depth (cm)	Gravimetric Water Content (g/g)	Dry Bulk Density (g/cm3)	Sample Location	Sample Depth (cm)	Gravimetric Water Content (g/g)	Dry Bulk Density (g/cm3)
AMS-1	5-15	0.184	1.14	AMS-7	5-15	0.151	1.24
AMS-1	25-35	0.253	1.44	AMS-7	25-35	0.193	1.37
AMS-1	45-55	0.303	1.21	AMS-7	45-55	0.288	1.41
AMS-2	5-15	0.140	1.26	AMS-8	5-15	0.164	1.21
AMS-2	25-35	0.201	1.31	AMS-8	25-35	0.207	1.21
AMS-2	45-55	0.271	1.46	AMS-8	45-55	0.244	1.45
AMS-3	5-15	0.152	1.31	AMS-9	5-15	0.157	1.24
AMS-3	25-35	0.204	1.31	AMS-9	25-35	0.236	1.29
AMS-3	45-55	0.150	1.60	AMS-9	45-55	0.303	1.34
AMS-4	5-15	0.160	1.26	AMS-10	5-15	0.164	1.19
AMS-4	25-35	0.188	1.24	AMS-10	25-35	0.200	1.29
AMS-4	45-55	0.286	1.37	AMS-10	45-55	0.238	1.42
AMS-5	5-15	0.127	1.36	AMS-11	5-15	0.135	1.34
AMS-5	25-35	0.176	1.32	AMS-11	25-35	0.198	1.33
AMS-5	45-55	0.357	1.27	AMS-11	45-55	0.275	1.33
AMS-6	5-15	0.140	1.21	AMS-12	5-15	0.153	1.27
AMS-6	25-35	0.216	1.21	AMS-12	25-35	0.190	1.37
AMS-6	45-55	0.290	1.31	AMS-12	45-55	0.253	1.36
Minimum					5-15	0.127	1.14
					25-35	0.176	1.21
					45-55	0.150	1.21
Maximum					5-15	0.184	1.36
					25-35	0.253	1.44
					45-55	0.357	1.60
Average					5-15	0.152	1.25
					25-35	0.205	1.31
					45-55	0.272	1.38

Multiple regression analysis was applied to penetration resistance and gravimetric water content to develop bulk density predictions at three depth intervals for all of the CP testing locations. Table 6 provides the CP-bulk density calibration equations for depths ranging from 5-15 cm, 25-35 cm and 45-55 cm bgs. Values of R^2 ranged from 0.55 to 0.72 with depth interval 2 having the lowest R^2 (0.55). These calibration equations were used to predict the bulk density from the CP penetration resistance data at each of the CP sample locations and depth intervals (Figure 2).

Figure 15 and Figure 16 provide examples of multiple regression results for soil water content, CP penetration resistance and measured bulk density data at depth interval 1 (5-15 cm bgs).

Figure 17 provides a 3-D representation of Field 51 as interpolated from the predicted CP bulk density data. The lowest predicted bulk densities were observed at depth interval 1 (5-15 cm bgs) whereas the predicted bulk density increased with increasing depth. The highest estimated bulk density values correspond to the observed sandy loam areas (Figure 14). Thus changes in bulk density at these locations are likely due to soil texture variation, rather than compaction.

Table 6. CP calibration equations from multiple regression of bulk density versus penetration resistance and soil water content.

Calibration Equation:	$\rho_g = AR + B\theta_g + C$					
Interval	**Top Depth (cm)**	**Bottom Depth (cm)**	***A***	***B***	***C***	**R^2**
1	5	15	1.61E-05	-3.268	1.738	0.717
2	25	35	2.43E-04	-0.010	0.986	0.547
3	45	55	-7.46E-06	-1.763	1.870	0.718

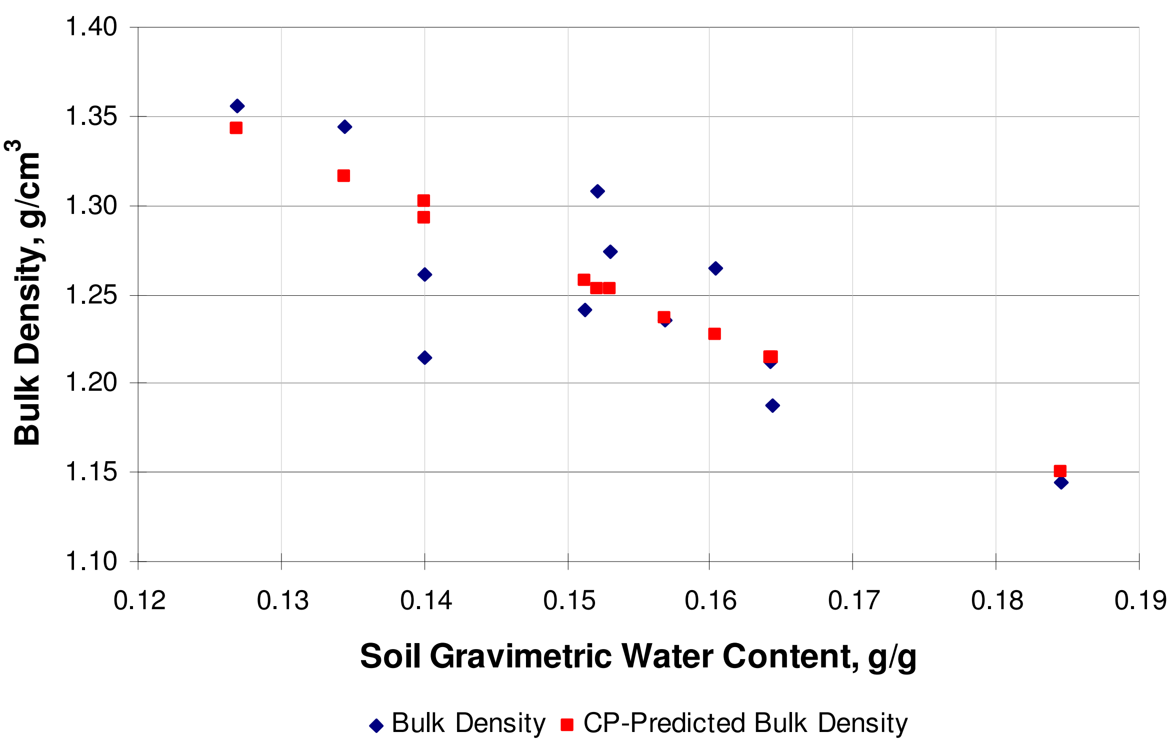

Figure 15. Results of multiple regression analyses of measured bulk density versus soil water content for depth interval 1 (5-15 cm bgs).

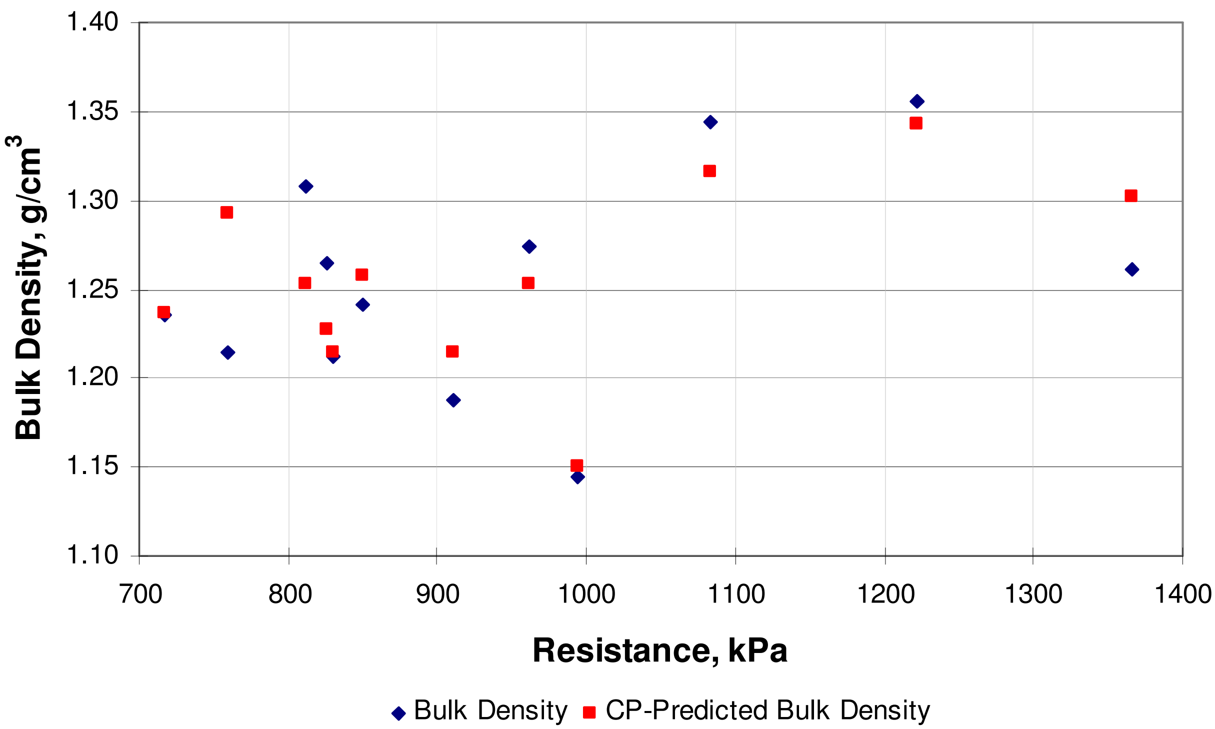

Figure 16. Results of multiple regression analyses of measured bulk density versus CP resistance for depth interval 1 (5-15 cm bgs).

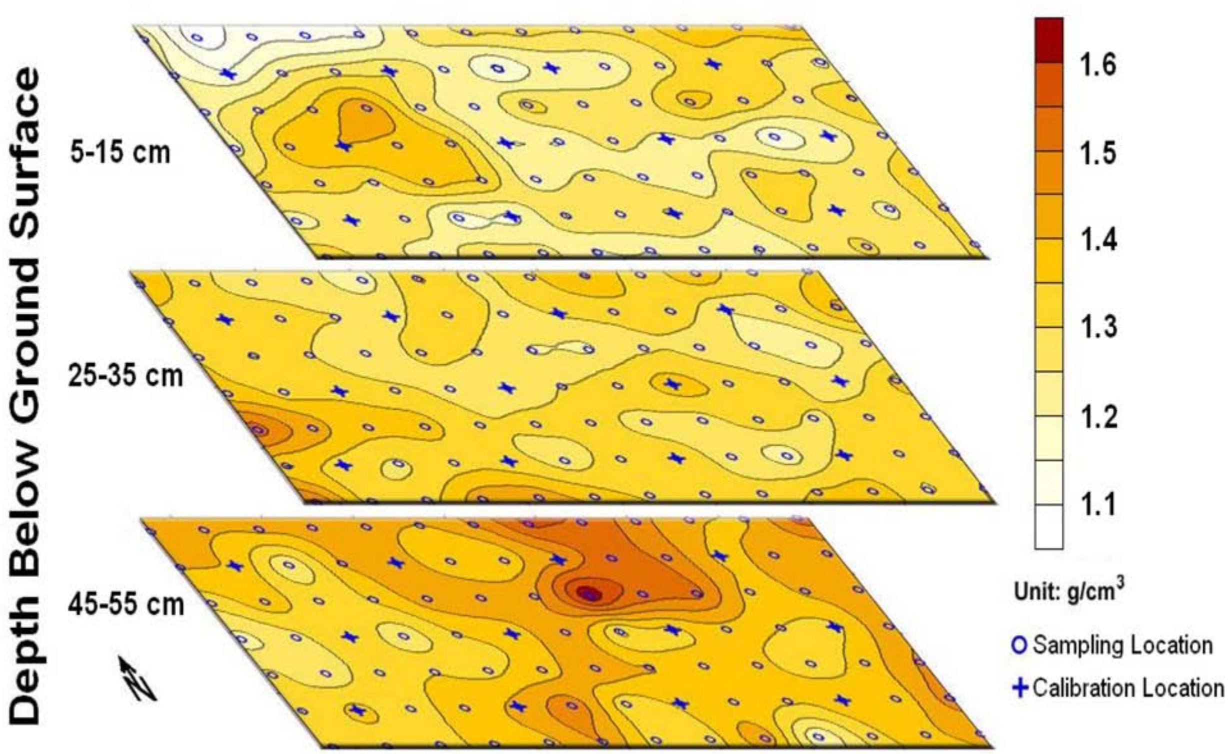

Figure 17. Estimated Field 51 soil bulk density (interpolated) from calibrated CP penetration resistance data.

3.3 Infiltration Rates

Table 7 summarizes infiltration data for Field 51. The estimated effective saturated hydraulic conductivity (K) was not highly variable, ranging from 6.23 cm/day to 10.2 cm/day. The relatively slow infiltration rates are likely due to the fine-textured silt and silt loam soil material.

All results and the fitted Kostiakov formula are provided in Figure 18. The combined results in Table 7 produced coefficient values of 19.0 and 0.665 for *k* and *a*, respectively, with an R^2 of 0.956.

Table 7. Infiltration data and Kostiakov formula fitting summary.

Location	Test Duration (min)	Corrected Total Infiltration[1] (mm)	Number of Data Points	Estimated K (cm/day)[2]	Wetting Depth[3] (cm bgs)	Kostiakov Approximation ($Z=kT^a$)		
						k	*a*	R^2
CI-1	348	64.4	7	8.23	36	19.1	0.684	0.997
CI-2	341	67.5	6	10.2	45	20.0	0.693	0.999
CI-3	327	45.6	7	6.23	38	14.6	0.659	0.997
CI-4	341	64.5	6	9.84	43	18.6	0.706	0.998
CI-5	315	59.9	5	9.02	36	18.8	0.691	0.998
CI-6	326	61.5	5	7.60	32	20.6	0.638	0.998
CI-7	331	59.5	4[3]	7.50	37	20.3	0.628	1.000
					Combined:	19.0	0.665	0.956

1 Adjusted for lateral wetting of soil.
2 Effective field hydraulic conductivity, per Bouwer et al. (1999).
3 Depth of wetting front at the end of infiltration test, measured as the depth of soil saturation.

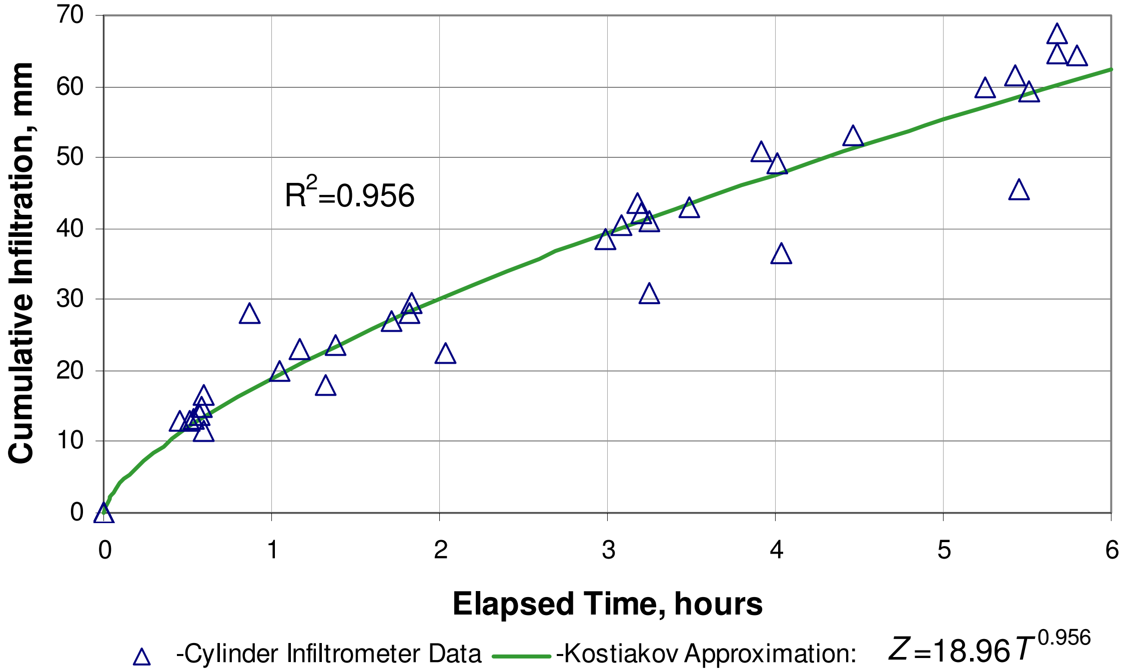

Figure 18. Kostiakov infiltration curve fitting for all cylinder infiltrometer data.

3.4 Soil Water Content and Estimated Field Capacity

Gravimetric water content approximately seven days after flood irrigation (April 24 and 25, 2006) ranged from 0.09 to 0.36 (g/g), with water contents generally lower near the surface and increasing with increasing depth (refer to Table 5 for gravimetric water content at AMS sampling sites, and Appendix E for all CP sample sites). Estimated soil volumetric water content averaged 0.19, 0.27, and 0.36 cm^3/cm^3 for the 5-15 cm bgs, 25-35 cm bgs, and 45-55 cm bgs sample intervals. Figure 19 shows the interpolated volumetric water content as calculated from the estimated gravimetric water content and estimated bulk density values at each of the CP sample sites (refer to Section 2.1). At the 50 cm depth, lower water content areas correspond with sandier, higher bulk density areas (Figure 14 and Figure 17).

Because a week passed between field irrigation and soil sampling, evaporation undoubtedly occurred in the shallow soil. Therefore, deeper samples (i.e. the 45-55 cm bgs interval) should provide a more accurate estimate of soil water capacity. Consequently, the average field capacity is estimated to be approximately 0.36 cm/cm of soil (36 cm/m of soil). This estimate is within ranges provided in the NRCS handbook for silt loam soil (USDA, 1991).

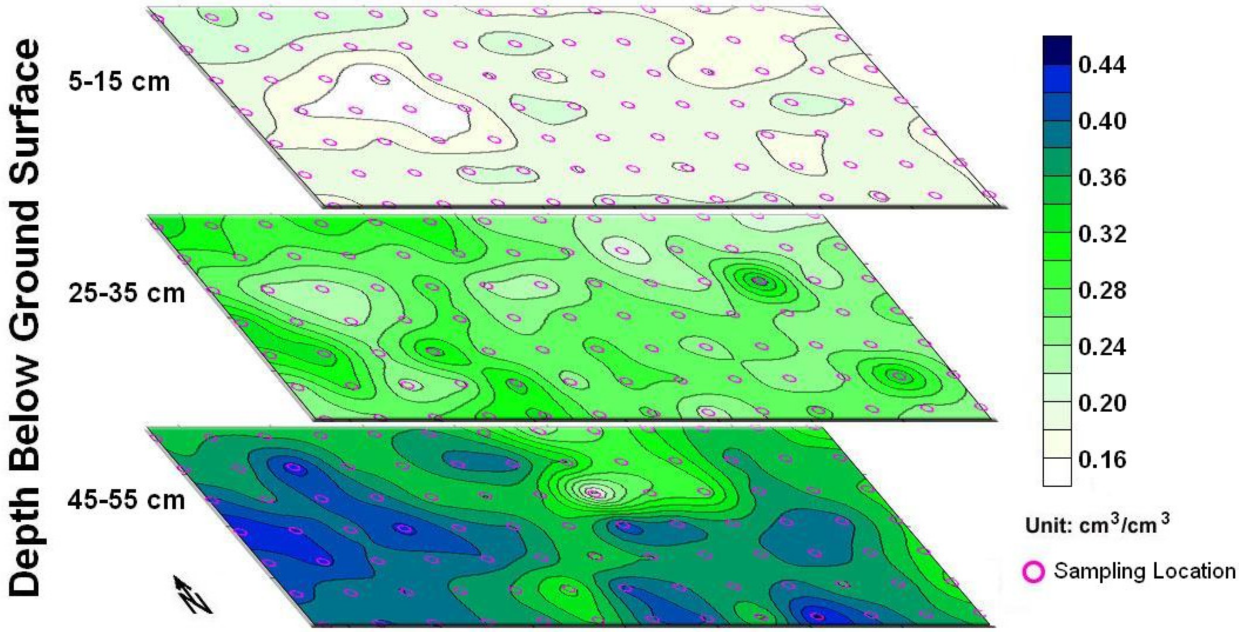

Figure 19. Field 51 estimated volumetric water content (interpolated).

3.5 Soil Nutrients and Geochemistry

Soil macro-nutrient fertility results are provided in Table 8. Table 9 provides micro-nutrient and geochemical results.

Nitrate (N) concentrations varied from 1.2 mg/kg to 49.0 mg/kg. 50% of samples showed moderate to high nitrate values and 50% showed low to very low levels. Phosphorus (P) and potassium (K) concentrations showed 58% and 67 % of samples with moderate to high levels, respectively. P and K generally decreased with depth and N values did not exhibit this trend. These data show that N is more limiting than either P or K.

Micronutrient analyses indicate that the Field 51 soils are highly alkaline with Sodium Adsorption Ratio (SAR) values below levels considered to harm vegetation (i.e. SAR > 12). The observed soil salinity was variable, and showed levels potentially adverse to riparian vegetation (i.e. paste EC > 5 dS/m) at four locations (N-1, N-8, NSS-2, and NSS-8). Micronutrient levels of copper (Cu), iron (Fe) and sulfur (S) were consistently high throughout Field 51; however, their biological availability and potential phytotoxicity to riparian species are unknown. With the exceptions of high manganese (Mn) and low boron (B), other micronutrients were not measured at very low or high concentrations to potentially affect riparian revegetation. Given the high pH/alkalinity and calcium values, phosphorus availability might also be limited.

Table 8. Soil fertility results for Field 51.

Sample Depth (cm)	Location	NO_3^- (mg/kg)	Agricultural Level[1]	P (mg/kg)	Agricultural Level[1]	K (mg/kg)	Agricultural Level[1]
0-30	N-1	16.0	M	15	M	240	H
61-91	N-1	17.0	M	4	VL	58	L
0-30	N-2	31.0	H	15	M	130	M
0-30	N-3	28.0	H	10	L	90	M
0-30	N-4	2.2	VL	31	H	210	H
0-30	N-5	3.3	VL	17	M	100	M
61-91	N-5	4.3	VL	4	VL	73	L
0-30	N-6	2.4	VL	7	L	80	L
0-30	N-7	18.0	M	10	M	74	L
61-91	N-8	8.1	L	3	VL	88	M
0-30	N-8	8.4	L	6	L	86	M
0-30	N-9	3.4	VL	20	H	150	M
0-30	NSS 1	2.2	VL	31	H	110	M
0-30	NSS 2	49.0	H	20	H	93	M
61-91	NSS 2	38.0	H	3	VL	93	M
0-30	NSS 3	16.0	M	32	H	90	M
0-30	NSS 4	19.0	M	29	H	86	M
0-30	NSS 5	20.0	M	52	VH	86	M
61-91	NSS 5	18.0	M	6	L	41	L
0-30	NSS 6	1.2	VL	23	H	84	M
0-30	NSS 7	8.8	L	26	H	82	M
0-30	NSS 8	4.5	VL	38	H	78	L
61-91	NSS 8	6.4	L	4	VL	39	VL
0-30	NSS 9	19.0	M	17	M	77	L
Average:		14.3		17.6		97.4	

1 Acronyms indicate very low (VL), low (L), moderate (M), high (H), or very high (VH) for typical agricultural crops.

Table 9. Micronutrients and geochemistry results for Field 51.

Location	Depth (cm bgs)	pH	Ca (mg/kg)	Ag Level[1]	Mg (mg/kg)	Ag Level	Na (mg/kg)	Ag Level	Fe (mg/kg)	Ag Level	Zn (mg/kg)	Ag Level	Mn (mg/kg)	Ag Level	Cu (mg/kg)	Ag Level	Salinity (dS/m)	Ag Level	ESP[2]	Ag Level	S (mg/kg)	Ag Level	B (mg/kg)	Ag Level	Free Lime	OM[3] (%)	SAR[4]
N-1	0-30	7.7	6300	VH	620	VH	720	VH	20	VH	3.20	VH	9.6	VH	2.0	VH	9.0	VH	7.7	VH	420.0	VH	0.67	L	High	4	3.7
N-1	61-91	8.3	5700	VH	410	VH	660	VH	9	VH	0.39	L	1.8	H	0.7	H	7.8	VH	8.2	VH	540.0	VH	0.58	L	High	2	15.1
N-2	0-30	8.2	6000	VH	470	VH	150	M	23	VH	2.60	H	7.2	VH	1.8	VH	1.3	L	1.9	M	46.0	VH	0.40	L	High	4	4.6
N-3	0-30	8.2	6100	VH	480	VH	210	H	20	VH	2.50	H	5.9	VH	1.9	VH	1.8	L	2.6	H	59.0	VH	0.33	L	High	3	3.5
N-4	0-30	7.7	5700	VH	430	VH	350	VH	33	VH	4.40	VH	13.0	VH	2.3	VH	4.8	H	4.5	VH	220.0	VH	0.64	L	High	3	3.2
N-5	0-30	7.8	5200	VH	400	VH	220	H	25	VH	2.90	H	10.0	VH	1.7	VH	2.3	L	3.1	H	62.0	VH	0.41	L	High	3	3.2
N-5	61-91	8.4	6800	VH	630	VH	460	VH	24	VH	0.54	L	4.6	VH	1.9	VH	3.5	M	4.8	VH	180.0	VH	0.38	L	High	3	3.7
N-6	0-30	8.1	5600	VH	430	VH	190	M	26	VH	2.30	H	5.9	VH	1.5	VH	1.8	L	2.5	M	62.0	VH	0.37	L	High	3	3.8
N-7	0-30	8.0	5700	VH	410	VH	190	M	23	VH	2.80	H	5.9	VH	1.5	VH	1.8	L	2.5	M	55.0	VH	0.38	L	High	4	3.9
N-8	61-91	8.1	6700	VH	600	VH	750	VH	30	VH	1.30	M	4.4	VH	1.8	VH	7.0	VH	7.8	VH	430.0	VH	0.49	L	High	3	6.5
N-8	0-30	8.0	6100	VH	460	VH	190	M	25	VH	2.50	H	6.0	VH	1.6	VH	2.0	L	2.3	M	78.0	VH	0.35	L	High	3	3.5
N-9	0-30	7.8	5200	VH	370	VH	190	M	26	VH	3.00	H	9.0	VH	1.8	VH	2.5	L	2.7	M	80.0	VH	0.43	L	High	3	3.7
NSS-1	0-30	8.1	5600	VH	490	VH	210	H	39	VH	2.50	H	6.5	VH	1.9	VH	1.9	L	2.7	H	67.0	VH	0.56	L	High	3	3.5
NSS-2	0-30	8.3	5600	VH	460	VH	240	H	21	VH	2.40	H	7.3	VH	1.5	VH	2.4	L	3.2	H	92.0	VH	0.47	L	High	3	3.3
NSS-2	61-91	8.4	8700	VH	1000	VH	1900	VH	28	VH	3.40	VH	5.7	VH	2.6	VH	16.8	VH	13.7	VH	1700.0	VH	0.93	L	High	4	9.5
NSS-3	0-30	8.0	6100	VH	500	VH	230	H	33	VH	2.30	H	5.6	VH	1.7	VH	4.3	M	2.8	H	300.0	VH	0.52	L	High	3	3.2
NSS-4	0-30	8.1	5700	VH	450	VH	170	M	26	VH	2.60	H	6.4	VH	1.6	VH	1.5	L	2.2	M	46.0	VH	0.34	L	High	3	3.1
NSS-5	0-30	8.1	5700	VH	440	VH	220	H	34	VH	3.10	H	8.4	VH	1.8	VH	2.1	L	2.9	H	96.0	VH	0.36	L	High	3	3.2
NSS-5	61-91	8.3	5000	VH	280	VH	160	M	11	VH	0.43	L	2.3	H	0.6	M	3.0	M	2.5	M	160.0	VH	0.23	VL	High	1	4.2
NSS-6	0-30	8.1	5800	VH	450	VH	200	M	26	VH	2.50	H	6.6	VH	1.6	VH	1.6	L	2.6	M	59.0	VH	0.40	L	High	3	4.1
NSS-7	0-30	8.1	5800	VH	460	VH	180	M	30	VH	2.50	H	6.0	VH	1.7	VH	1.5	L	2.3	M	51.0	VH	0.42	L	High	3	7.6
NSS-8	0-30	8.0	5700	VH	500	VH	180	M	26	VH	2.40	H	6.3	VH	1.6	VH	1.5	L	2.3	M	54.0	VH	0.40	L	High	4	9.1
NSS-8	61-91	8.1	5100	VH	410	VH	280	H	8	H	0.42	L	2.1	H	0.6	M	5.3	H	4.0	H	340.0	VH	0.31	L	High	2	2.7
NSS-9	0-30	8.2	5800	VH	530	VH	240	H	28	VH	2.40	H	5.5	VH	1.8	VH	1.8	L	3.0	H	75.0	VH	0.48	L	High	3	3.7
Average:		8.1	5900		490		350		25		2.31		6.3		1.7		3.7		4.0		220.0		.45		3		5

1 Acronyms indicate very low (VL), low (L), moderate (M), high (H), or very high (VH) for typical agricultural crops.
2 Exchangeable sodium percentage. The percent of sodium relative to other exchangeable cations.
3 Organic matter, percent by weight.
4 The proportion of sodium ions compared to the concentration of combined calcium and magnesium.

3.6 Soil Salinity

Figure 20 shows the spatial distribution of saturated paste extract EC as determined from IAS Laboratories and the University of Arizona Yuma Agricultural Extension for samples collected on July 27, 2006. These laboratory data are provided in Table 10.

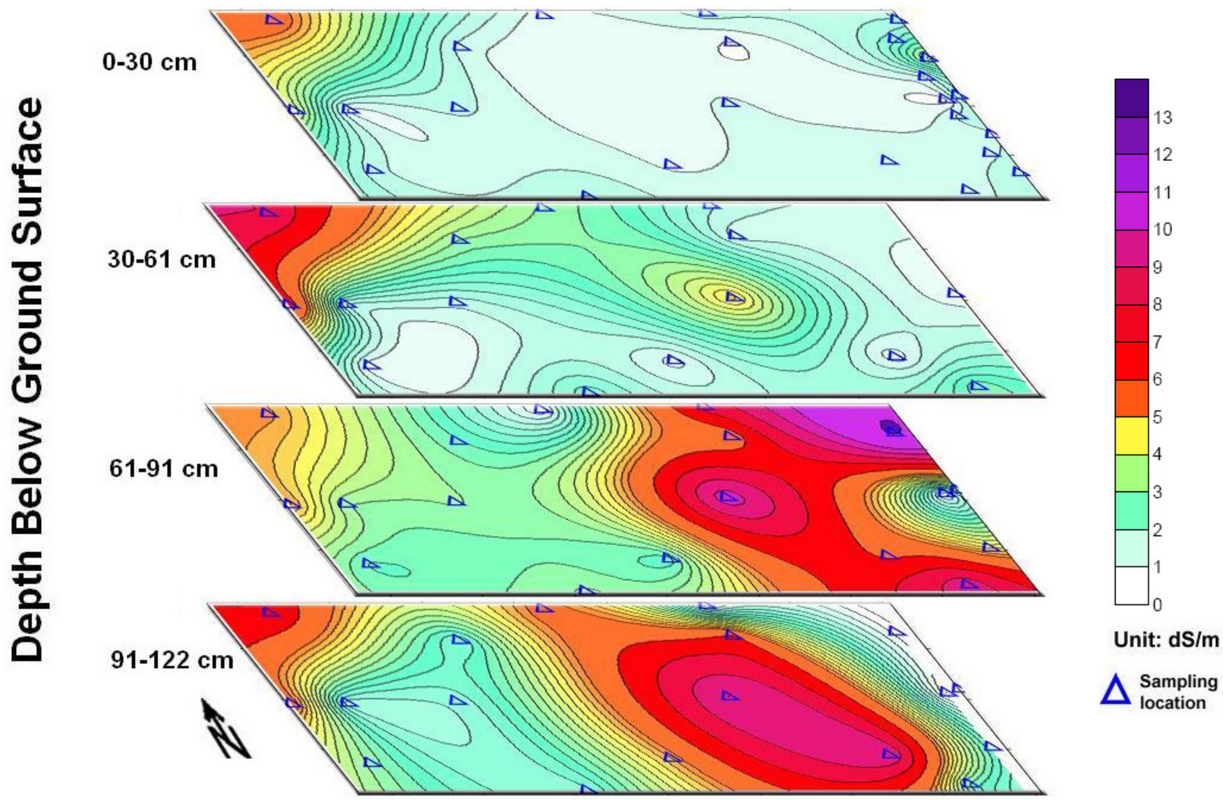

Figure 20. Interpolated saturated paste extract EC, from the University of Arizona Yuma Agricultural Extension and IAS Laboratories, samples collected July 27, 2006.

Table 11 shows the calibration parameter approximation of saturated paste extract EC from EM38 readings. Overall, the EM38 method provided a poor prediction of depth interval or bulk soil EC ($R^2 < 0.51$). The spatial distribution of EM38 predicted bulk soil EC as derived from Equation 2.5.1 is shown in Figure 21; however, the extensive laboratory salinity data obtained for this site should be relied on more heavily than EM 38 data.

Table 10. Estimated saturated paste extract EC for July 27, 2006 Field 51 soil samples.

Location	Soil Sample Depth (cm bgs)			
	0-30	31-61	61-91	91-122
	Saturated Paste EC (dS/m)			
EM-1	5.6[1]	8.0[2]	4.9[1]	7.0[2]
EM-2	0.9[1]	3.0[2]	0.7[2]	5.3[2]
EM-3	1.4[1]	1.6[2]	7.4[2]	0.7[2]
EM-4	1.1[2]	3.0[2]	2.6[2]	2.0[2]
EM-5	0.7[2]	1.1[2]	5.4[2]	6.2[2]
EM-6	3.7[1]	6.6[2]	4.8[2]	5.4[2]
EM-7	0.9[2]	1.5[2]	3.0[2]	1.6[2]
EM-8	1.4[1]	1.3[2]	3.0[1]	1.8[2]
EM-9	1.1[1]	4.4[2]	9.7[2]	9.0[2]
EM-10	0.6[2]	0.8[2]	0.8[2]	0.5[2]
EM-11	1.3[1]	0.8[2]	2.5[2]	2.9[2]
EM-12	1.0[1]	0.9[2]	2.3[2]	4.7[2]
EM-13	1.3[1]	0.8[2]	5.8[1]	9.0[2]
EM-14	1.5[2]	2.2[2]	3.1[2]	1.9[2]
EM-15	1.2[2]	2.7[2]	8.8[2]	2.7[2]
SSN-1[3]	1.5			
SSN-2[3]	1.9		13.4	
SSN-3[3]	3.4			
SSN-4[3]	1.2			
SSN-5[3]	1.7		2.4	
SSN-6[3]	1.3			
SSN-7[3]	1.2			
SSN-8[3]	1.2		4.2	
SSN-9[3]	1.4			
Average:	1.6	2.6	4.7	4.1
Minimum:	0.6	0.8	0.7	0.5
Maximum:	5.6	8.0	13.4	9.0

1 Average of sample results from the University of Arizona Yuma Agricultural Extension (Yuma, AZ) and IAS Laboratories (Phoenix, AZ)
2 Samples results from the University of Arizona Yuma Agricultural Extension (Yuma, AZ).
3 1:1 paste EC sample results from IAS Laboratories (Phoenix, AZ) were multiplied by 2:1.

Table 11. EM 38 salinity calibration equation for Field 51.

Calibration Equation:	$\ln EC = b_0 + b_1 z_1 + b_2 z_2$				
Sample Interval	Depth Interval (cm)	b_0	b_1	B_2	R^2
1	0-30	0.442	0.011	-0.010	0.05
2	30-60	0.380	0.020	-0.009	0.28
3	61-91	0.442	0.003	0.008	0.08
4	91-121	-1.178	-0.001	0.021	0.59
1-4 (bulk EC)	0-120	0.084	0.010	0.002	0.51

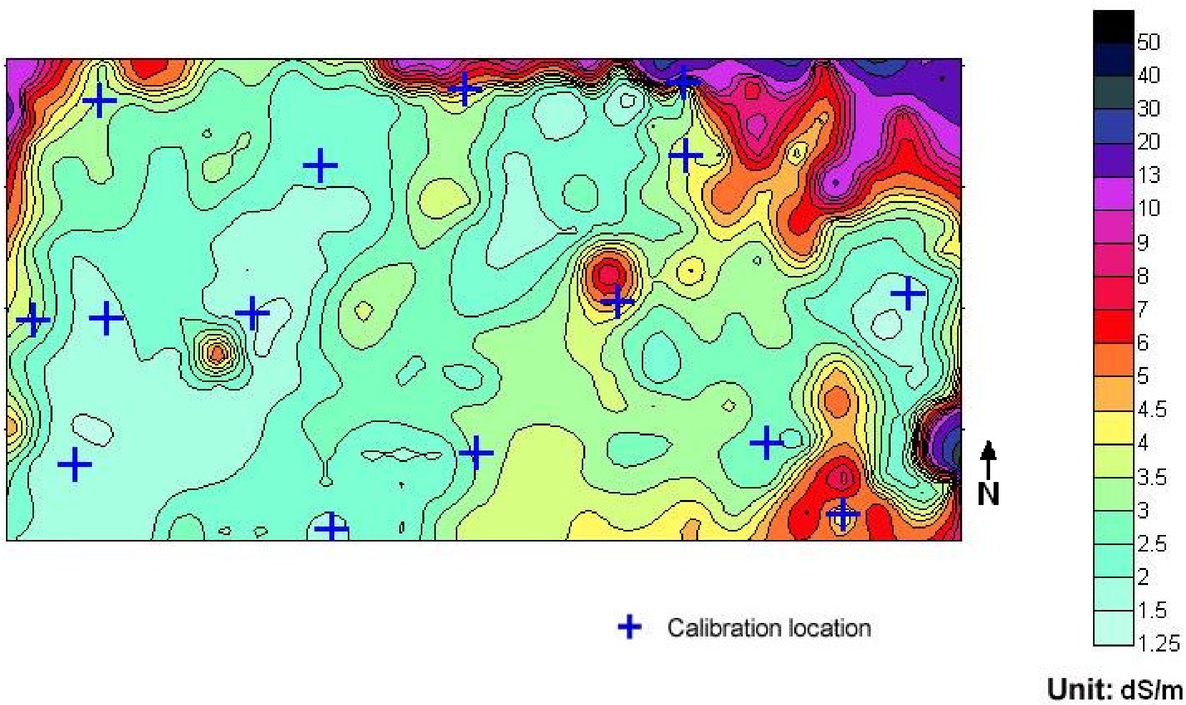

Figure 21. Predicted bulk EC predicted from EM38 for Field 51, July 17, 2006.

3.6.1 Small-Scale Study Area Soil Salinity Results

The estimated saturated paste EC results for the ESP-SS core samples collected after one growing season (i.e. November and December, 2007) are provided in Table 12. Near-surface (10-20 cm bgs) EC values ranged from 1.80 dS/m (ESP-SS-5) to 22.3 dS/m (ESP-SS-19). EC generally increased with depth, with a maximum of 26.9 dS/m at ESP-SS-21. Interpolated salinity for the small-scale study area is provided in Figure 22.

Surface (10-30 cm bgs) soil EC values were generally highest at the north end of the small-scale study plots. Salinity at 41-51 cm bgs was generally greater than tolerance thresholds for riparian species (i.e. 10 dS/m) on both the north and south end of the study area. The very high salinity (> 20 dS/m) along the northern edge of the two upper depth intervals in small plots is a potential problem for long-term success of riparian vegetation established at this site. Salinity at 86-97 cm bgs was also highest in on the northern part of the study area but was generally lower in sandy soil areas (Figure 14). As shown in Figure 23, all 86-97 cm bgs soil samples with greater than 30% sand had EC values of less than 5 dS/m. No trends were observed between soil salinity and percent sand for 10-20 cm bgs or 41-51 cm bgs (data not shown), likely because of the lack of sandy soils at this depth.

Table 12. Estimated saturated paste extract EC data for ESP-SS samples (November and December 2007).

Sample Location	Depth bgs (cm)			Sample Location	Depth bgs (cm)		
	10-20	41-51	86-97		10-20	41-51	86-97
	Saturated Paste EC[1] (dS/m)				Saturated Paste EC[1] (dS/m)		
ESP-SS-1	5.6	22.9	22.4	ESP-SS-19	22.3	22.6	7.9
ESP-SS-2	3.3	20.3	10.8	ESP-SS-20	8.7	6.9	13.7
ESP-SS-3	4.7	4.0	5.6	ESP-SS-21	6.5	15.5	26.9
ESP-SS-4	5.2	7.1	18.8	ESP-SS-22	2.5	10.9	10.9
ESP-SS-5	1.8	4.3	6.5	ESP-SS-23	4.4	6.9	10.1
ESP-SS-6	2.9	5.1	7.0	ESP-SS-24	5.8	11.4	19.7
ESP-SS-7	2.3	2.5	5.5	ESP-SS-25	2.3	9.8	1.4
ESP-SS-8	2.2	2.8	3.0	ESP-SS-26	4.3	6.5	3.8
ESP-SS-9	3.2	6.4	2.9	ESP-SS-27	5.9		2.3
ESP-SS-10	2.8	6.9	3.4	ESP-SS-28	2.3	4.8	0.6
ESP-SS-11	2.2	3.8	3.4	ESP-SS-29	1.9	2.4	1.0
ESP-SS-12	3.9	7.3	0.5	ESP-SS-30	5.9	2.7	0.9
ESP-SS-13	3.0	5.1	2.1	ESP-SS-31	2.8	3.0	0.9
ESP-SS-14	5.5	3.9	2.5	ESP-SS-32	2.3	8.5	1.8
ESP-SS-15	2.2	12.5	2.3	ESP-SS-33	3.4	7.5	11.2
ESP-SS-16	2.1	11.6	1.5	ESP-SS-34	2.9	6.5	2.1
ESP-SS-17	2.9	9.1	2.8	ESP-SS-35	11.0	8.1	6.7
ESP-SS-18	5.2	12.8	2.9	ESP-SS-36	2.6	11.7	2.6
				Average	4.4	8.4	6.3
				Minimum	1.8	2.4	0.5
				Maximum	22.3	22.9	26.9

1 Saturated paste EC was approximated by multiplying the GSA laboratory 1:1 paste EC by 2.

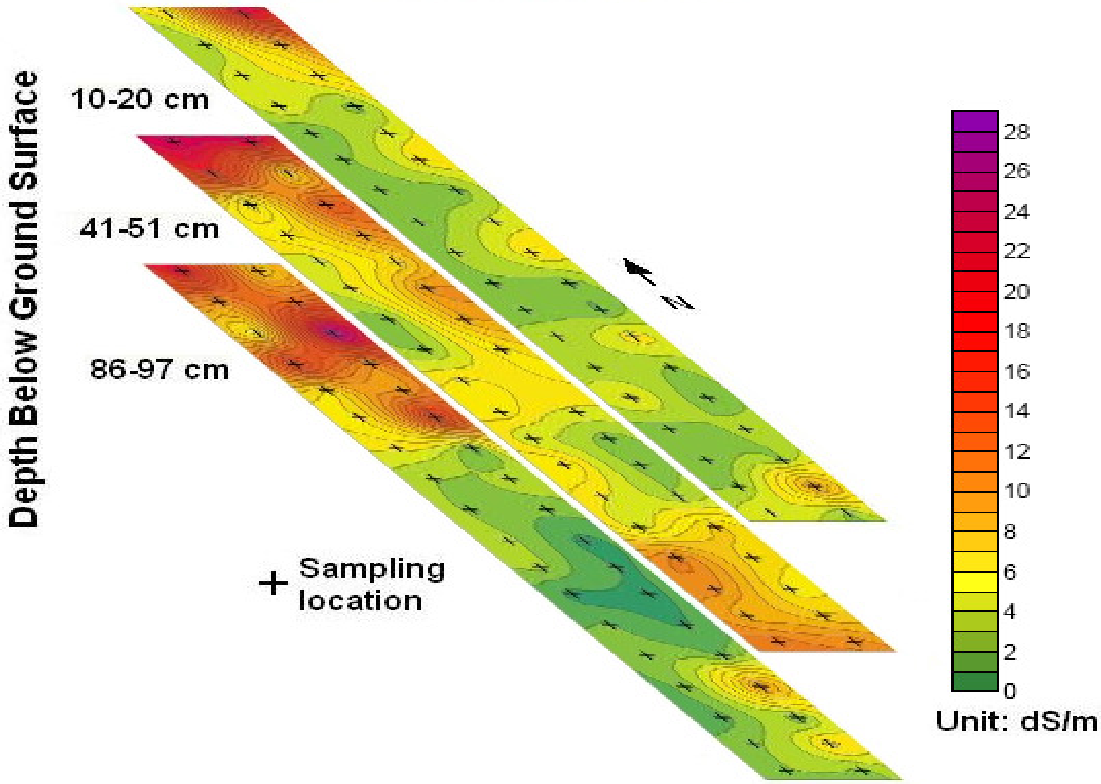

Figure 22. Estimated saturated paste-extract EC for the small-scale field study area following one season of irrigation (interpolated)

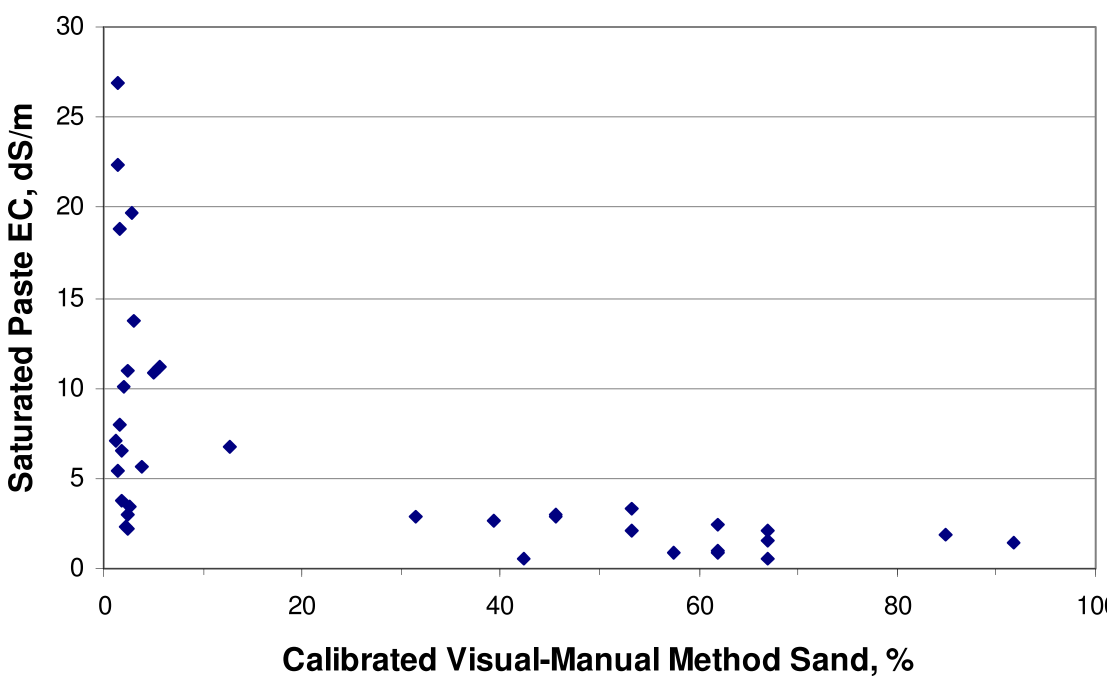

Figure 23. Estimated saturated paste soil EC versus percent sand for 86-97 cm bgs ESP-SS core samples.

Since germination of the planted riparian species was observed during small-scale studies (GSA, 2008), the EC values may have increased during the summer of 2007 near the soil surface due to salt accumulation on micro-topography (e.g. furrow crests). With increasing soil depth through the rooting zone, the increase of salinity is likely due to plant transpiration. Salts are added to the soil with each irrigation event. Plant roots uptake water but very little salt, thus resulting in an increase of soil salinity from the surface soil to the maximum rooting depth. An additional source of salts is shallow groundwater, as present at Field 51. Groundwater is continuously supplied to the bottom of the rooting zone due to capillary flow. Shallow groundwater also prevents effective salt leaching (FAO, 1985). The large increase of soil salinity with depth in the small-scale field study area suggests that irrigation is insufficiently leaching salts.

In order to assess the irrigation efficiency, the leaching fraction (LF, the portion of irrigation water that percolates through the root zone) which should maintain the soil salinity below a given value was calculated for the 2007 irrigation schedule. The equation for LF is as follows:

$$LF = \frac{AW - ET}{AW} \qquad 3.1$$

where AW is the applied water depth and ET is evapotranspiration (FAO, 1985).

To maintain a soil salinity of less than 2 dS/m, a LF of greater than 0.1 is recommended (following Rhoades, 1974). The 2007 growing season (May 16 through October 31) ET was estimated to be approximately 162 cm using Penman-Monteith estimations from Western Regional Climate Center Cibola, Arizona weather station (Table 13). Applied water in the small-scale study area was approximately 250 cm. Therefore, the 2007 irrigation leaching fraction is estimated to be 0.35. Because salinity was elevated despite the large leaching fraction, the buildup of soil salts is likely due to shallow groundwater impeding salt leaching.

Table 13: Growing season ET estimates for the 2007 small-scale field study.

Month	Penman ET (average cm per day)[1]	Days	Estimated ET (cm)
May	1.02	16	16.32
June	1.17	30	35.10[2]
July	1.07	31	33.17[3]
August	1.02	31	31.62
September	0.85	30	25.50
October	0.65	31	20.15
Total:	**0.95**	**169**	**161.86**

[1] Data from Western Regional Climate Center Cibola, Arizona weather station. Available www: http://www.wrcc.dri.edu/cgi-bin/rawMAIN.pl?azACBL

[2] Data unavailable for May 22 through July 16, 2007. May 21, 2007 ET (1.07 cm) used as an estimate of daily ET for missing data in May. The maximum estimated ET for July (1.17 cm) used as an estimate for daily ET in June. 1.07 cm used as an estimate of daily ET for July 1, 2007 through July 16, 2007.

In summary, estimated saturated paste EC values at Field 51 for July, 2006, ranged from less than 1 dS/m to 13.4 dS/m. Most surface soil salinity values were less than 3 dS/m. EC generally increased with depth. The EM38 survey and laboratory data suggest elevated salinity in the extreme northeast and northwest corners of the field. However, EM data showed poor correlation with actual laboratory measured values. For example, the EM survey predicted much higher EC values than laboratory measured EC values and EM did not show elevated ECs in the east central portion of Field 51 at depths from 61 to 122 cm as observed for lab EC values.

The small-scale study area surface soil EC values in winter of 2007 averaged 4.4 dS/m, and generally increased with depth to values as high as 26.9 dS/m. EC values observed at all depths in the northern part of the small-scale study could be limiting to riparian species success. Sandier soil textures resulted in lower soil salinity at depth.

3.7 Depth to Groundwater

Groundwater elevation and depth to groundwater data collected prior to May 2007 (i.e. prior to regular irrigation for the current feasibility study) is presented in Figure 24. Subsequent groundwater elevation results are presented in GSA (2008).

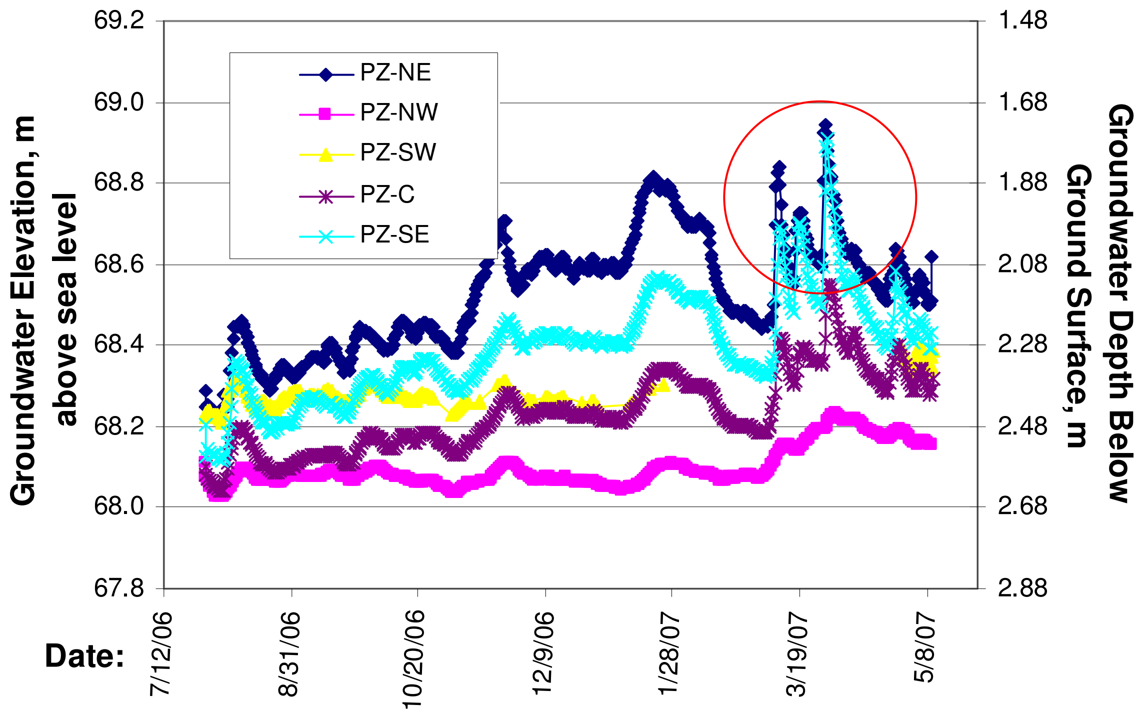

Figure 24. Groundwater elevation data for ten months prior to small-scale field study. The red outline indicates response to pre-planting irrigation events for small-scale study (GSA, 2008).

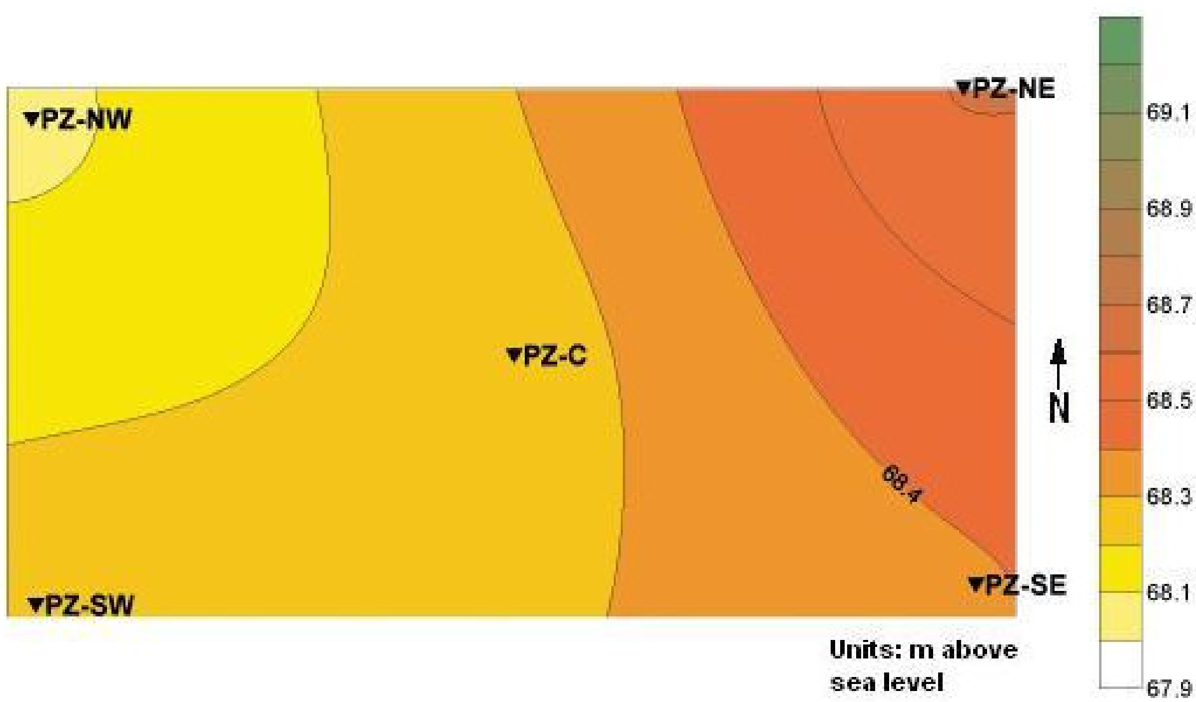

Figure 25. Winter groundwater elevation prior to any Field 51 irrigation for small-scale studies, December 15, 2006.

3.8 Soil Moisture and Soil Salinity Sensor Calibration

The calibration for sensor response to volumetric water content is summarized in Table 14. The three different soil types resulted in only marginally-variable intercepts and slopes for the EC-10, which indicated that application of three different calibration equations might not be required. As shown in Figure 26, combining the datasets resulted in one equation highly correlated (R^2=0.94) with volumetric water content for all observed soil types. The manufacturer standard calibration was a poor fit to the observed data. The calibration for the ECH2O-TE sensors is provided in Figure 27.

Table 14. Calibration parameters for water content sensors established for small-scale field studies.

Calibration Equation:	$\theta_v = A * mV + B$ [1]			
Sensor Type	**Calibration**	***A***	***B***	**R^2**
EC-10	<2% Sand	6.72E-04	-0.240	0.94
	2-30% Sand	6.29E-04	-0.222	0.96
	>30% Sand	6.43E-04	-0.232	0.93
	All Data	6.44E-04	-0.229	0.94
ECH_20-TE	Combined 10-20 cm bgs samples	1.15E-03	-0.651	0.93

[1] θv is the volumetric water content (cm3/cm3); mV is the signal from the sensor, in mV.

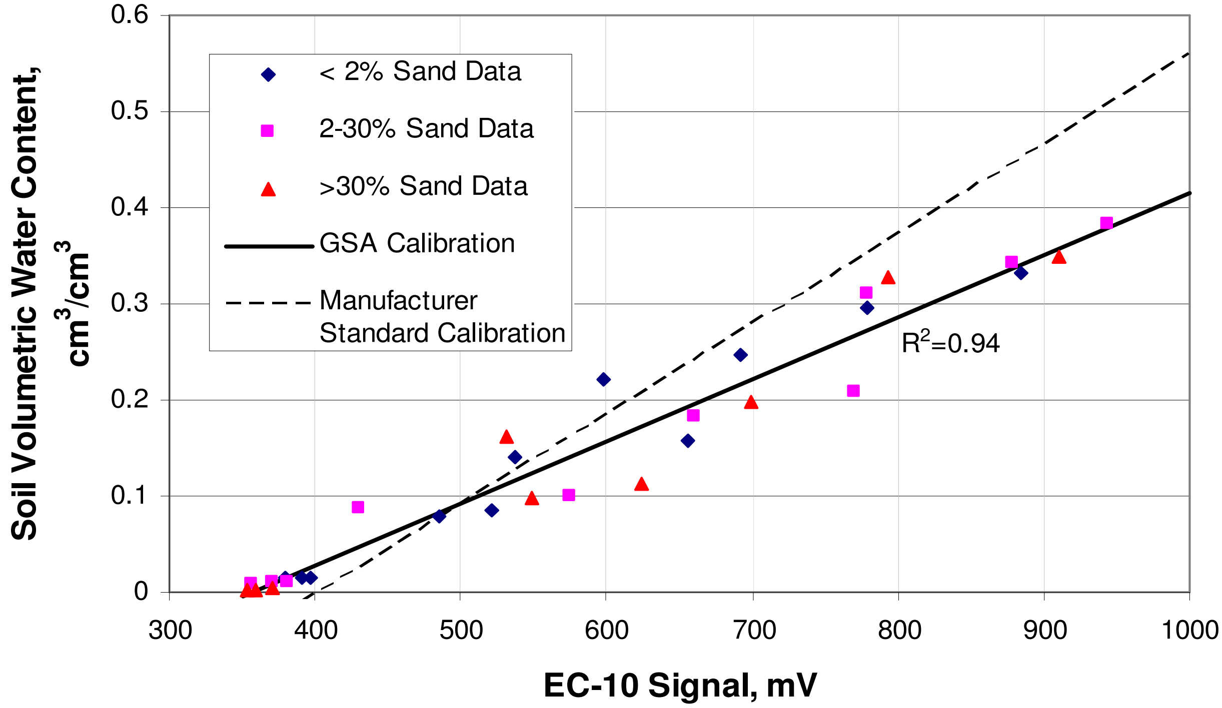

Figure 26. Calibration data for EC-10 sensors, volumetric water content versus sensor signal. Manufacturer standard calibration from Decagon Devices, Inc. (Pullman, WA).

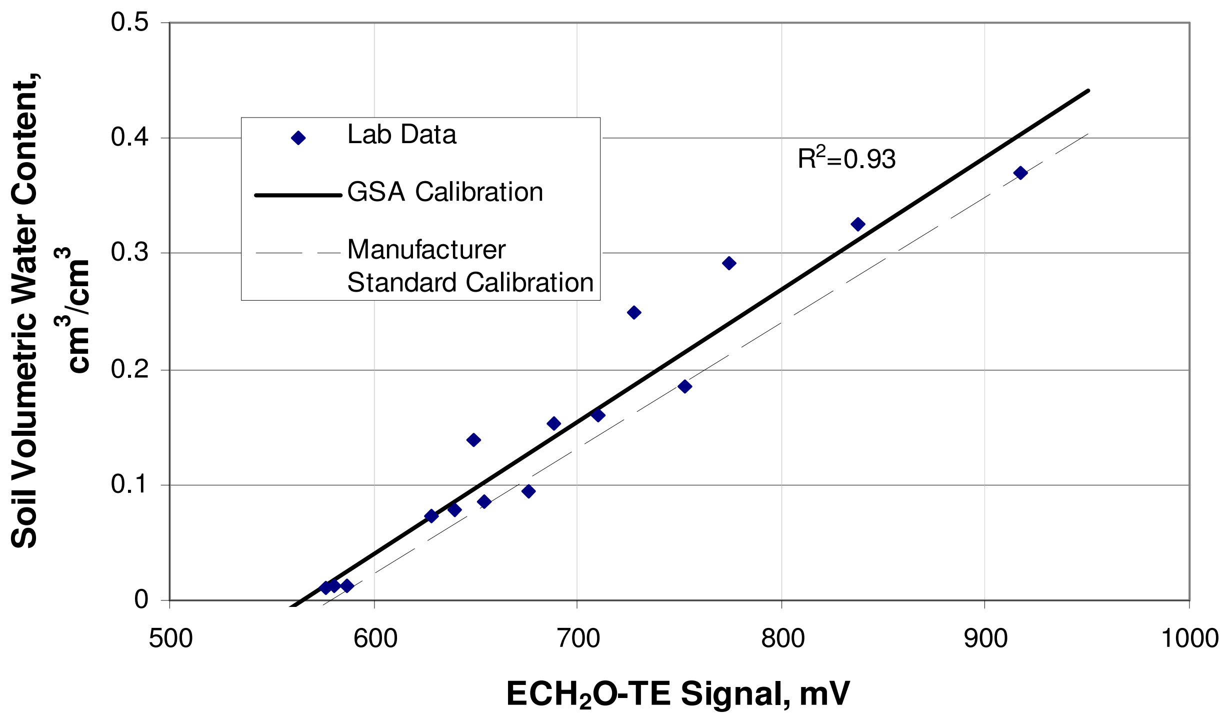

Figure 27. Calibration data for ECH_2O-TE sensors, volumetric water content versus sensor signal. Manufacturer standard calibration from Decagon Devices, Inc. (Pullman, WA)

4.0 CONCLUSIONS

Soil Texture

Field 51 soil textures at the near-surface are dominated by silt and silt loam material. Compared to other revegetation sites on the LCR these soil textures are relatively fine-grained (Raulston 2003). Therefore, Field 51 surface soils can be expected to more effectively retain moisture, but conversely could be subject to greater accumulation of salinity. Sandy loam layers are present at depths exceeding 85 cm. These sand deposits are expected to have lower moisture retention and fertility than the upper silt-loam layers; however, such variation is normal for river alluvial deposits and should not affect the long-term viability of riparian vegetation. Sandier soil textures (sands and sandy loams) in the central portion of the small-scale study area also resulted in lower soil salinity.

Soil Bulk Density/Compaction

The surface soil bulk density measured in soil cores taken to depths of 10 cm bgs averaged 1.25 g/cm^3. Soil bulk density increased with depth throughout the field, with a maximum estimated bulk density of 1.60 g/cm^3. The higher bulk densities were associated with sandier materials. The observed values are lower than the compacted layer bulk density (1.45 g/cm^3) of silt loam topsoil which decreased growth of target riparian species in the greenhouse studies (GSA 2007a).

Infiltration Rates

Estimated effective K values for Field 51 varied from 6.2 to 10.2 cm per day. The Kostiakov formula, with values of 19.0 and 0.665 for Kostiakov parameters k and a respectively, provided a good approximation of infiltration rates versus time (R^2 of 0.96). These parameters will be considered for the proposed design of large-scale test plot studies.

Soil Field Capacity

Soil volumetric water content one week after surface irrigation averaged 26.7 cm^3/cm^3 and 36.4 cm^3/cm^3 for 25-25 cm bgs and 45-55 cm bgs depth intervals, respectively. Lower water content is attributed to coarser soil textures at these depth intervals. The average volumetric water content for the shallow sampling interval (5-15 cm bgs) was 18.6 cm^3/cm^3. This lower value is likely due to evaporation between irrigation and soil sampling a week later.

It is estimated that the field capacity for typical Field 51 surface soil (silty loam) averages 0.36 cm/cm of soil, which corresponds with NRCS estimates for this soil classification (USDA, 1991). Field capacity will be lower in areas with coarser soil textures (sandy loam and sand), and may be higher in areas or soil with increased clay content.

Soil Nutrients and Geochemistry

Soil macro-nutrients varied from very low to high range, but did not show consistent spatial trends. As observed during small-scale pot studies, nutrient levels are not likely to limit plant growth at Field 51 (GSA, 2007a). Levels of copper, iron, sulfur, and manganese were consistently high across the field, and boron was consistently low. High pH and calcium were also observed.

It should be noted that due to changes in the scope of the summer 2007 small-scale plot studies, the size of the small-scale study area was approximately doubled (GSA 2007b). Therefore, the soil sampling grid established for the site characterization was not equally distributed through the small-scale study area.

Soil Salinity

Pre-planting soil salinity in the upper soil layers of Field 51 from estimated saturated paste EC values was not generally high enough to inhibit seed germination. However, the northwest and northeast corners of the field showed higher surface EC values than the rest of the field and soil salinity levels at depth often exceeded those levels capable of causing detrimental effects on cottonwood and willow growth and survival (Glenn et al. 1998). The EM38 survey also suggested that bulk soil salinity may be higher than desirable for salt-intolerant species such as cottonwood and willow however, a significant portion of the EM 38 EC data were inconsistent with laboratory data.

Soil salinity in the small-scale study area after summer 2007 was generally above the tolerance thresholds for germination of riparian plant species. Salinity also increased with depth which suggests that irrigation is insufficiently leaching salts. This is likely due to shallow groundwater across the field. Soil samples at 41 to 51 cm bgs showed saturated paste EC values often greater than 10 dS/m despite heavy surface water irrigation for several months. Consequently, long-term monitoring of existing small-scale study plot vegetation should be implemented to determine long-term survival of established cottonwood and willow. Rooting surveys would be useful to determine if cottonwood and willow roots are propagating into or through saline soil layers.

Depth to Groundwater

Depth to groundwater in Field 51 is generally between two and three m, which is within the depth needed for mature riparian trees to access groundwater. This groundwater depth also approaches the depth allowing riparian trees to out-compete saltcedar (Stromberg et al.2006). Prior to irrigation events (summer 2006), minor gradients were observed. During winter 2006-2007, groundwater gradients were from the northeast to west, likely due to flooding of the adjacent “Cornfield” for waterfowl.

Soil Moisture Content Instrument Calibration

Laboratory calibrations of soil moisture content sensors indicated that the standard calibration provided by the manufacturer should not be utilized for EC-10 sensors in Field 51. GSA calibration curves did not vary between soil types for EC-10 sensors. Therefore, a single laboratory calibration-derived equation is applicable for all EC-10 sensors installed in Cibola NWR Field 51 small-scale study field plots.

The manufacturer’s standard calibration for the ECH2O-TE sensor estimation of volumetric water content provided a reasonable fit, but the fit was improved by the GSA laboratory calibration.

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