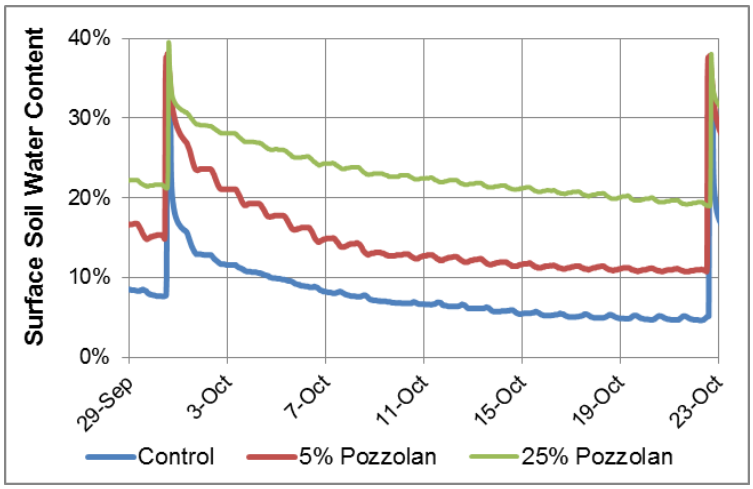
Lower Colorado River Multi-Species Conservation Program

Balancing Resource Use and Conservation

Lassenite Pozzolan Soil Amendment Study at the Beal Lake Conservation Area



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Lower Colorado River Multi-Species Conservation Program

Lassenite Pozzolan Soil Amendment Study at the Beal Lake Conservation Area

Prepared by:

GeoSystems Analysis, Inc.
3393 N. Dodge Blvd.
Tucson, AZ 85716
www.gsanalysis.com

Lower Colorado River
Multi-Species Conservation Program
Bureau of Reclamation
Lower Colorado Region
Boulder City, Nevada
http://www.lcrmscp.gov

September 2015

Name	Affiliation	Project role
Mike Milczarek	GeoSystems Analysis, Inc.	Technical Director
Matt Grabau	GeoSystems Analysis, Inc.	Project Supervisor
Lindsey Hovland	GeoSystems Analysis, Inc.	Field Supervisor
Jaime Bañuelos	GeoSystems Analysis, Inc.	Field Scientist
Theresa Norris	GeoSystems Analysis, Inc.	Field Scientist
Jason Harris	GeoSystems Analysis, Inc.	Field data collection
Arien Chavez	GeoSystems Analysis, Inc.	Field data collection
Robert Rice	GeoSystems Analysis, Inc.	Field data collection

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ACRONYMS AND ABBREVIATIONS

ANOVA	analysis of variance
ASTM	American Society for Testing and Materials
bgs	below ground surface
Bill Williams River NWR	Bill Williams River National Wildlife Refuge
BLCA	Beal Lake Conservation Area
Cibola NWR	Cibola National Wildlife Refuge
dS/m	decisiemens per meter
EC	electrical conductivity
GSA	GeoSystems Analysis, Inc.
Havasu NWR	Havasu National Wildlife Refuge
LCR MSCP	Lower Colorado River Multi-species Conservation Program
pozzolan	Lassenite pozzolan
PVC	polyvinyl chloride
PVER	Palo Verde Ecological Reserve
Reclamation	Bureau of Reclamation
UTM	Universal Transverse Mercator
VWC	volumetric water content

Symbols

>	greater than
<	less than
%	percent

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Attachments

Attachment

1 2012 Goodding's Willow Seed Collection Locations
2 Single-Ring Cylinder Infiltrometer Methods
3 Graphical Monitoring Station Data Summary

EXECUTIVE SUMMARY

GeoSystems Analysis, Inc., completed a soil amendment study at Beal Lake Conservation Area in 2013 to assess the ability of Lassenite pozzolan (pozzolan) to improve the quality of restored riparian habitats by increasing Goodding's willow (*Salix gooddingii*) seedling establishment and/or increasing surface soil moisture. The project objectives were as follows:

1. Determine if a pozzolan amendment of 5, 25, and/or 75% by volume increases the success of Goodding's willow seedling establishment.

2. Determine if a pozzolan amendment of 5, 25, and/or 75% by volume increases soil moisture between irrigation events

Two experimental fields with predominantly sandy soils were subdivided into plots and subplots amended at the prescribed rates. Irrigation monitoring stations were installed to detect irrigation arrival, recession, and therefore duration of inundation. Soil moisture sensors were installed at a subset of subplots to monitor the soil water content in surface and subsurface soils and were supplemented with soil grab sampling and laboratory analyses. Plots were hydroseeded with Goodding's willow in May 2013, and vegetation was monitored after one growing season, in December 2013.

Key results were as follows:

- Pozzolan did not result in high Goodding's willow seedling establishment likely due to the combination of inadequate surface moisture and increased salinity.

- The addition of pozzolan at rates of 25% or greater increased soil moisture retention in surface soils between irrigation events; the addition of pozzolan at 5% did not significantly increase soil moisture.

Additional observations from the project were:

- Following pozzolan addition at 25 or 75% application rates (those observed to increase soil moisture), surface soil saturated paste electrical conductivity increased from a mean of approximately 1 decisiemen per meter (dS/m) to over 3 dS/m (range of 2.7 to 6.9 dS/m). Mean surface soil electrical conductivity returned to less than 4 dS/m (mean of 1.7 and 2.8 dS/m for 25 and 75% rates, respectively) by the end of the 2013 growing season but still exceeded pre-amendment rates. This result indicates that extended leaching is needed to remove soil salinity added by pozzolan incorporation.

- Infiltration rates (rate of drainage of water from the surface) decreased for soils amended with 25% (mean reduction over 40% for 25% application) and 75% pozzolan (mean reduction over 90%). These amendment rates would be useful for lining depressions where standing water would remain for extended periods after irrigation and enhance habitat quality for riparian birds and/or irrigation distribution channels across fields to improve irrigation efficiency.

- While automated soil moisture monitoring results were inconclusive due to a low sample size and soil texture variation among monitoring locations, manual soil moisture sampling results, which allowed a pairwise comparison of soil moisture between adjacent amended and unamended areas, showed that pozzolan rates of 25 and 75% resulted in higher soil moisture following irrigation. Subsurface soil moisture was sometimes reduced below the pozzolan amendment layer likely because the amendment slowed drainage from above. Pozzolan rates of 5% did not increase soil moisture retention.

1.0 INTRODUCTION

Through implementation of the Lower Colorado River Multi-species Conservation Program (LCR MSCP), the Bureau of Reclamation (Reclamation) is tasked with the creation and maintenance of habitat to conserve 26 covered species while potentially benefitting 5 additional evaluation species. To achieve these objectives, the Habitat Conservation Plan specifies the creation of 8,132 acres of various habitat types, including 5,940 acres of cottonwood-willow cover (Reclamation 2004, 2011). Revegetation is being implemented in the disconnected Colorado River flood plain, where supplemental irrigation is required to establish key plant species. In addition to supporting vegetation, irrigation will be required to provide inundated or moist soils in created cottonwood-willow habitats as specified in conservation measures for the federally endangered southwestern willow flycatcher (Reclamation 2004). High irrigation efficiency at restoration sites would allow Reclamation to support vegetation and provide moist soils while minimizing the amount of irrigation.

Maintenance of high surface soil moisture is essential for revegetation efforts that utilize seeding methods for planting of riparian tree species. However, sandy soils at LCR MSCP habitat creation sites have limited the establishment of native riparian tree seedlings and precluded maintenance of elevated soil moisture as desired for avian habitat. Soil amendments have been proposed as a method for increasing moisture retention of sandy soils. Preliminary laboratory work by Reclamation indicates that Lassenite pozzolan (pozzolan), a soil amendment mined in northern Nevada, might effectively increase soil moisture retention capacity and increase irrigation efficiency in sandy soils such as those found at the Beal Lake Conservation Area (BLCA) (Reclamation 2011). This pozzolan deposit was formed 26 million years ago after a volcanic eruption deposited ash into a protozoa-rich lake. The porous nature of volcanic ash, combined with siliceous microskeletons of diatoms, produced a material highly effective at retaining water and increasing moisture availability to plants when used as a soil amendment.

An initial study was completed at BLCA fields MM and II during 2011 to assess the effect of mixing 5 percent (%) pozzolan by volume into the top 6 inches of soil on soil moisture retention and irrigation efficiency as suggested by the material supplier. Pozzolan application at this level did not have significant beneficial effects; however, it was speculated that this could be at least partially due to the use of insufficiently crushed pozzolan aggregates (GeoSystems Analysis, Inc., [GSA] 2013a).

The effects of higher application rates and more thoroughly incorporated pozzolan were analyzed through Project R13PX30205, Lassenite Pozzolan Soil Amendment Study. The objectives of the project were to determine the

effectiveness of pozzolan in enhancing Goodding's willow (*Salix gooddingii*) seedling establishment, improving irrigation distribution, and increasing soil moisture retention between irrigation events. Uncrushed pozzolan delivered to the project site for the previous study was used. Eight project tasks were included, as follows:

Task 1: Project management
Task 2: Preparation of experimental design and study plan
Task 3: Seed collection and preparation
Task 4: Site preparation
Task 5: Seeding
Task 6: Monitoring
Task 7: Data management
Task 8: Reporting

The project site is described in section 2.0, methods are described in section 3.0, results are provided in section 4.0, conclusions are presented in section 5.0, and recommendations are provided in section 6.0.

2.0 PROJECT SITE

The BLCA is a LCR MSCP riparian habitat creation site located within the Havasu National Wildlife Refuge (Havasu NWR) (figure 1). The BLCA was constructed on material excavated during the dredging of Beal Lake, which began in 2001. The site was leveled and divided into 30 fields, 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 independent surface irrigation (Reclamation 2008). Soils at the site are generally very high in sand, with small components of loamy sand, sandy loam, and silt loam.

The project site was comprised of fields J and E at the BLCA (figure 2). The fields were approximately 3 acres in size each after completion of site preparation. The pozzolan test plot layout was designed to maximize the strength of statistical analysis while considering logistical factors and anticipated windy conditions at the site. The test plot width was assigned to account for anticipated machinery dimensions while minimizing boundary effects. Typical farm tilling equipment width is 20 feet; consequently, the plot width was assigned as 40 feet to allow two passes of equipment. A 10-foot buffer, consisting of a berm, was placed between the plots to avoid partition irrigation and to avoid edge and overlap effects.

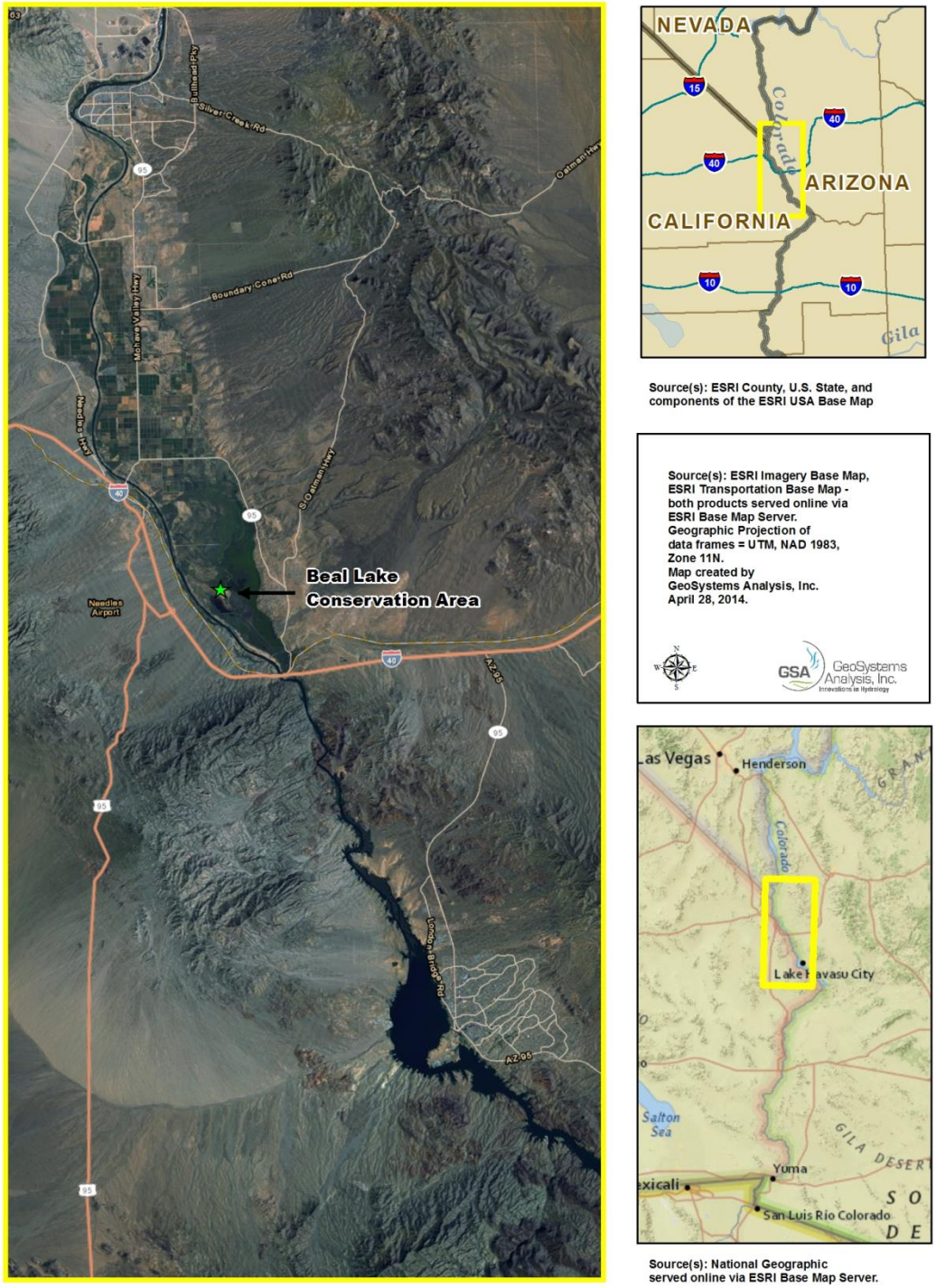

Figure 1.—Location of the BLCA.

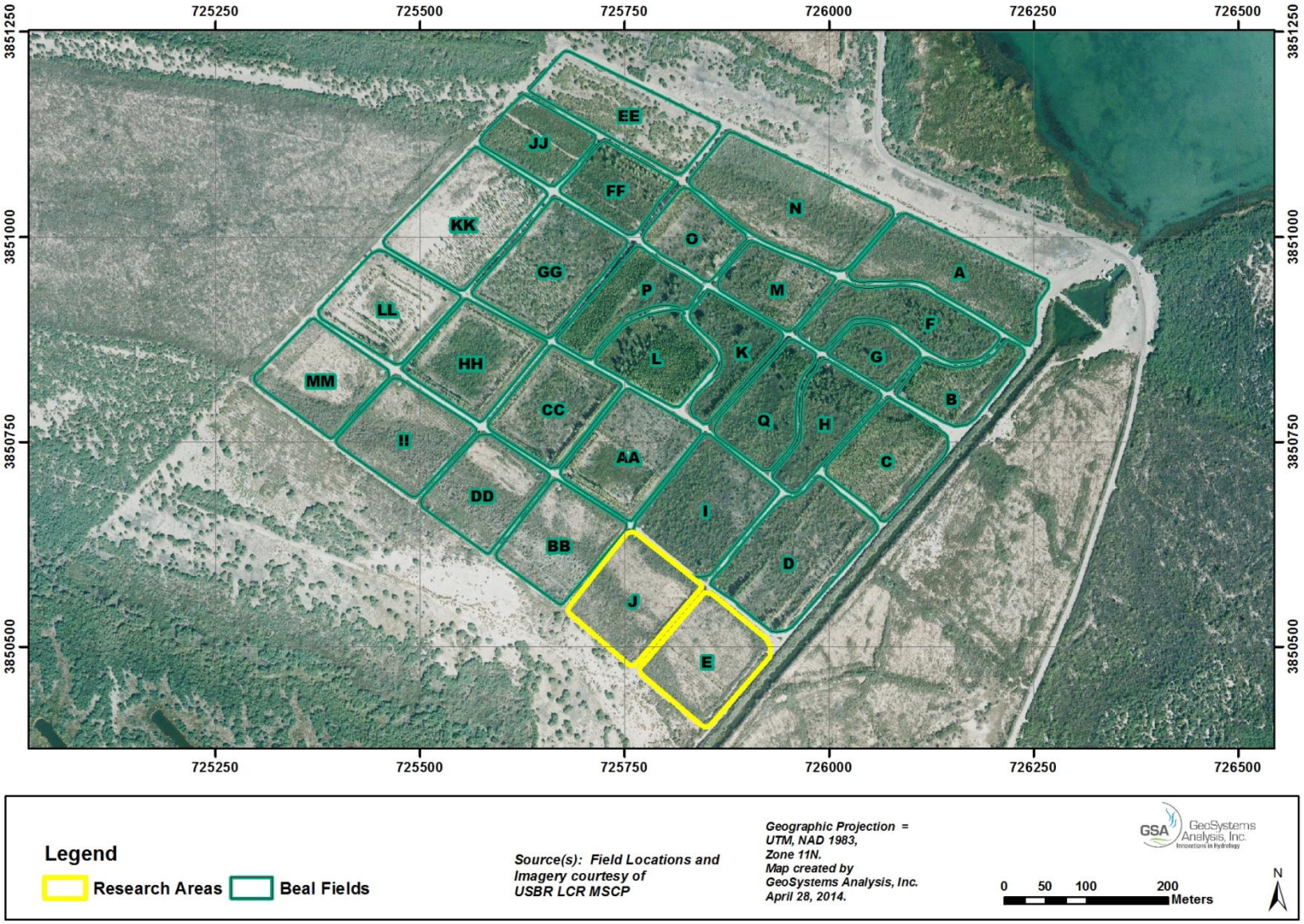

Figure 2.—Location of fields J and E within the BLCA.

2.1 Study Design

The study design was detailed in GSA (2013b). The considerations and design are described briefly below. The effects of the pozzolan amendment on Goodding's willow establishment, soil moisture retention, and irrigation efficiency were studied through application of four distinct rates:

1. Control: 0% by volume to 6 inches below ground surface (bgs)
2. 5%: 5% by volume to 6 inches bgs
3. 25%: 25% by volume to 6 inches bgs
4. 75%: 75% by volume to 6 inches bgs

A randomized complete block layout was implemented on eight plots distributed across the two fields (plots 3 through 6 are blocks within each field) to determine the effects of pozzolan application on Goodding's willow seedling establishment. These study plots were not intended to assess the effects of amendment on irrigation distribution. Within each plot, subplots of 10 by 40 feet were centered 20, 40, 60, and 80% of the distance across the plot. One repetition of each pozzolan rate was randomly assigned to each subplot. The resulting study layout is shown on figure 3.

To determine if more thorough mixing of a 5% broadcast application would improve irrigation distribution compared to previous studies (GSA 2013a), four paired 5% versus control plots were placed in plots, 1, 2, 7, and 8 of both fields (figure 3). For these broadcast treatments, pozzolan was applied uniformly across the entire 45- by 300-foot field plot.

3.0 METHODS

3.1 Seed Collection and Preparation

Collection, transport, and storage of seed followed methods developed under a previous contract (GSA 2007). During March 2012, Goodding's willow seed was collected at the Bill Williams River National Wildlife Refuge (Bill Williams River NWR); in April, seed was collected at the Cibola National Wildlife Refuge (Cibola NWR); in May, seed was collected from a remnant tree at the Palo Verde Ecological Reserve (PVER); and, in June, seed was collected from the Havasu NWR and Bureau of Land Management property in California adjacent to the Cibola NWR. Seed collected in 2012 was collected exclusively from remnant (not planted for LCR MSCP habitat creation) Goodding's willow trees. In 2013, additional seed was collected from four planted trees along the eastern edge of PVER2 to supplement the seed supply. Global Positioning System coordinates and seed amounts were recorded for all source trees and are provided in table 1. Maps showing the locations of all source trees are provided in attachment 1.

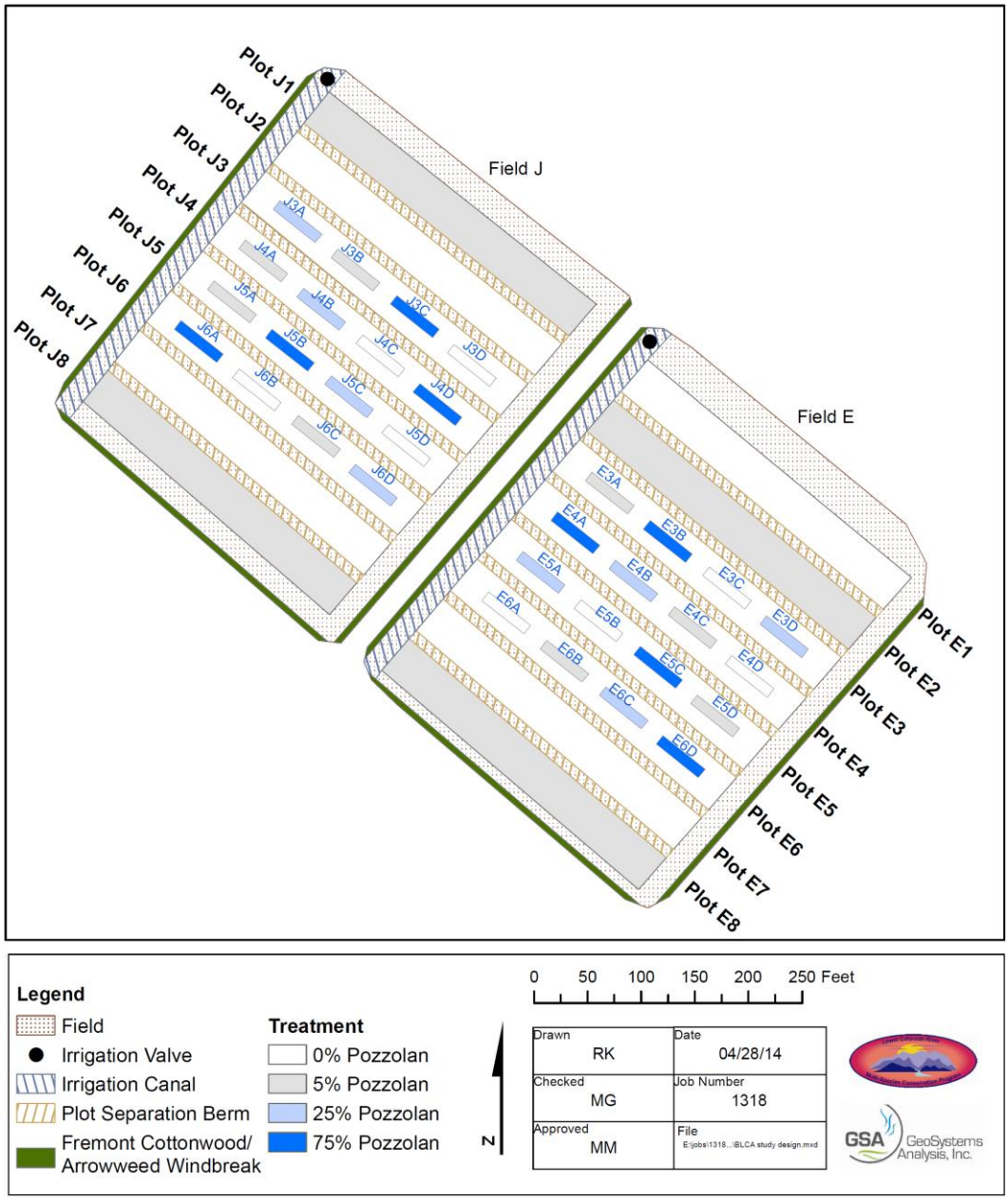

Figure 3.—Pozzolan study design for the BLCA.

All collected seed was transported to Tucson, Arizona, in either paper bags or cardboard boxes. Upon arrival in Tucson, seed was placed in cardboard drying boxes vented with a window screen. A fan was used to force air through the screen. After a minimum of 3 days of drying, the seed was removed from the drying boxes, transferred to freezer bags, and placed in freezers for storage.

To confirm the success of revised seed processing methods, preliminary germination trials were completed in early May 2012 for seed from 25 trees located within the Bill Williams River NWR and Cibola NWR. Additional trials

Table 1.—Locations, Universal Transverse Mercator (UTM) coordinates, and dry weight of Goodding's willow seed collected during 2012–13

Collection location	Tree ID	Date collected	UTM E[a]	UTM N	Weight (grams)
Bill Williams River NWR – West	bwr-salgoo-2	3/14/2012	771879	3796328	108
	bwr-salgoo-3		771941	3796163	25
	bwr-salgoo-4		772504	3795826	11
	bwr-salgoo-5		771973	3796115	17
	bwr-salgoo-6		771968	3796133	17
Cibola NWR	cnwr-salgoo-1	4/2/2012, 4/17/2012	717240	3686420	632
	cnwr-salgoo-2		717148	3686635	701
	cnwr-salgoo-3		717197	3687071	811
	cnwr-salgoo-4	4/16/2012	717277	3686905	735
Havasu NWR	hnwr-salgoo-1	6/9/2012	729981	3849398	421
	hnwr-salgoo-2		730294	3849391	557
Mineral Wash (Bill Williams River NWR – East)	mw-salgoo-1	3/17/2012	775781	3794344	19
	mw-salgoo-2		775714	3794367	14
	mw-salgoo-3		775652	3794380	23
	mw-salgoo-4		775348	3794501	19
	mw-salgoo-5		775355	3794498	20
	mw-salgoo-7	4/3/2012	775279	3794491	175
	mw-salgoo-13	4/5/2012	775886	3794332	158
	mw-salgoo-14		776188	3794441	611
	mw-salgoo-15		776210	3794439	723
	mw-salgoo-16		776082	3794381	306
	mw-salgoo-17		775285	3794575	177
	mw-salgoo-18		775327	3794558	1,256
PVER	pver-salgoo-1	3/29/2013	729031	3730105	266
	pver-salgoo-2	3/29/2013	729022	3730348	193
	pver-salgoo-3	5/25/2012	730455	3733621	1,379
	pver-salgoo-4	3/29/2013	729027	3730244	141
	pver-salgoo-6	3/29/2013	729037	3730128	175
Bureau of Land Management – California	wc-salgoo-1	4/16/2012	716381	3681295	1,140

[a] Zone 11 North, North American Datum 1983.

were conducted in late September 2012 for seed from four additional trees at the Havasu NWR, PVER, and wc-salgoo-1. Final germination trials were completed in March and April 2013 to get viability estimates for hydroseeding rate calculations. For germination trials, seeds were counted and placed on moist paper towels in petri dishes. They were then incubated in the dark at 25 degrees Celsius for 4 to 6 days. Emergent seedlings were counted and divided by the total number of seeds to determine the germination rates.

Seed weight calibrations were completed on April 23, 2013, to determine the number of seeds per unit weight. Seed lots were sorted into three categories according to the amount of non-seed plant material (leaves, stems, seed hair fibers, and dried capsules), including:

1. Seed with seed hair fibers only
2. Seed with moderate amounts of plant material
3. Seed with high amounts of plant material

Samples were taken from three seed lots for each of the three categories. Each weight calibration sample contained between 141 and 305 seeds. All seeds that had separated from all biomass or had dehisced fully from pods and were embedded in seed hair fibers were counted. Seeds remaining in partially open or closed pods were not included. The average of the three subsamples was used to determine the number of seeds per gram for each biomass category.

Weight calibrations and germination rates were used to determine the weight of seed required for each hydroseeding tank in order to cover 15,000 square feet (section 3.4). Seed lots for each tank were placed in 1-gallon Ziploc bags and stored in a freezer prior to seeding. The number of live seeds in each bag of frozen seed was estimated, and these amounts were used to calculate the amount of each seed lot to combine into the tanks. Weight-calibrated seed was measured and placed into labeled 1-gallon Ziploc bags to provide seed for one 15,000-square-foot plot seeded at a density of 36 pure live seed per square foot.

3.2 Site Preparation

Site preparation consisted of clearing existing vegetation, placing irrigation management infrastructure, pozzolan incorporation, and planting riparian trees around the perimeter of the fields in an attempt to provide a windbreak. Sub-contractor equipment operators could not be found within a reasonable distance to the project despite an extensive search. In order to complete site preparation, a local excavating company was contracted, and GSA rented and operated a small tractor and attachments.

3.2.1 Perimeter Pole Planting

GSA anticipated planting Fremont cottonwood (*Populus fremontii*) poles around the perimeter of fields J and E during spring of 2012. However, due to the later than expected contract award date, pole collection would not have been allowed until after the 2012 growing season. As an alternative to pole planting, Fremont cottonwood "deep pots" were planted around the fields as an alternative. Deep pots allow for placement of tree roots directly into the groundwater, thereby eliminating the need for irrigation during establishment (Dreesen and Fenchel 2010).

Fremont cottonwood seedlings were purchased from Greenheart Farms (Arroyo Grande, California) in March 2012. These trees were propagated from seed collected previously along the lower Colorado River. Seedlings were transplanted to 2- and 3-inch diameter, 30- to 40-inch-long polyvinyl chloride (PVC) pipes at a nursery in Lake Havasu City, Arizona, on March 16–17, 2012 (figure 4). Each PVC pipe contained a mix of purchased potting soil and sand obtained from the project site. Trees averaged approximately 3 feet in height by early July 2012 (figure 5), and roots were emerging from the bottom of the PVC tubes.

Figure 4.—Transplanted Fremont cottonwood seedlings in PVC deep pots, March 16, 2012.

Trees with extensive rooting out the bottom of the PVC tubes were planted along the southeast, southwest, and northwest borders of both fields (see figure 3) on July 17 and 18, 2012. Planting holes were dug to 4 feet bgs using a gas-powered soil auger. Augering was continued with a hand auger until groundwater was encountered. Trees were removed from the PVC tubes, and the root mass was inserted in the holes. Soil was backfilled around the root mass and saturated with water from the adjacent Beal Lake ditch. The stem height above the soil was measured and recorded (figure 6) to allow followup documentation of the success of this transplanting method. Tree spacing was approximately 10 feet along the field edges, alternating between the lower and upper edge of the outer field berms. One hundred seventy-nine trees were planted.

Figure 5.—Fremont cottonwood deep pot nursery prior to outplanting at the BLCA, June 2012.

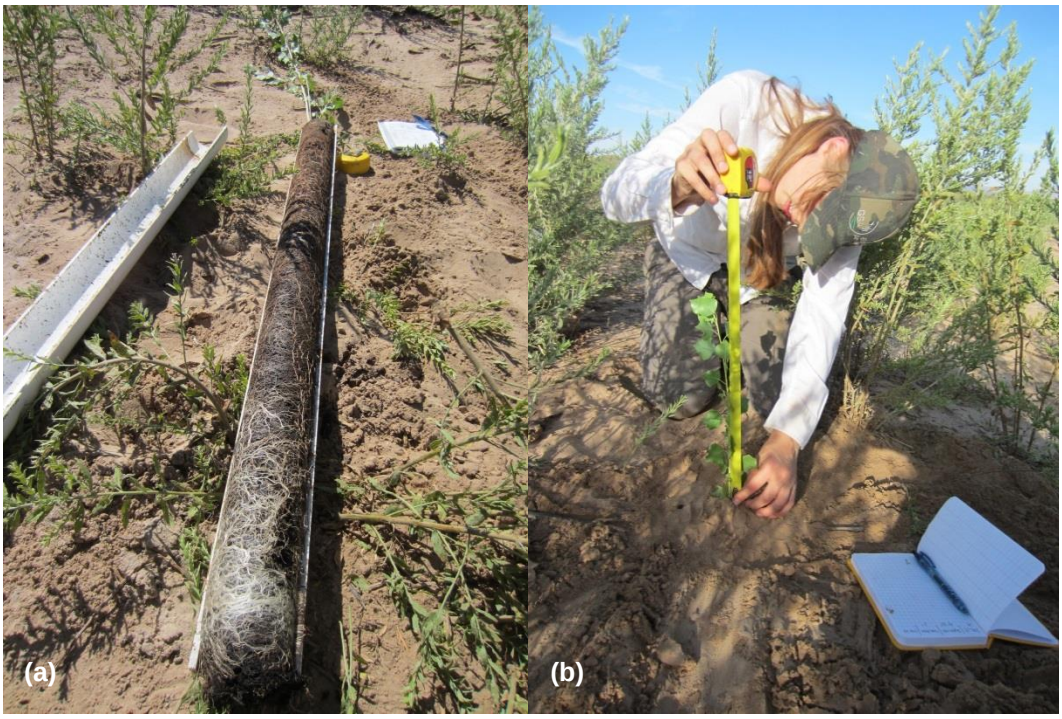

Figure 6.—Fremont cottonwood deep pot (a) being prepared for planting and (b) being measured after planting.

3.2.2 Removal of Existing Vegetation and Salt Leaching

Weed management focused on mechanical removal of existing weedy vegetation, spot treatment of re-sprouted vegetation, and additional tillage of vegetation re-sprouts. Fields were cleared of existing vegetation on February 5–6, 2013, by GnT Pipeworks of Lake Havasu City, Arizona (figure 7). Vegetation prior to clearing consisted of arrowweed (*Pluchea sericea*), with minor components of mesquite, cottonwood, and salt cedar. Both fields had been cleared approximately 1 year prior, so initial vegetation density was low. Clearing was carried out with a skid steer bobcat equipped with a toothed bucket. Irrigation was initiated to leach soil salts in January 2013.

Figure 7.—Clearing of existing vegetation on field J on February 5, 2013.

3.2.3 Lassenite Pozzolan Incorporation

Plot construction began with the placement of prescribed pozzolan volumes and incorporation to 6 inches bgs. To maximize decomposition of pozzolan aggregates and homogenization within the 6-inch soil profile, an additional irrigation event and tillage cycle was completed. Pozzolan preparation, delivery, and application were completed by GnT Pipeworks and Darisel Excavating (Lake Havasu City, Arizona). Prior to application of pozzolan to subplots and broadcast areas, the stockpile (figure 8) was wetted using a pump drawing water from the adjacent Beal Lake canal. Piles were wetted thoroughly using a firehose and mixed using the buckets of two bobcats. Wetted pozzolan was loaded into a dump truck (8-cubic-yard capacity) and delivered to the road separating fields E and J. A total of 24 dump truck loads, or 192 cubic yards of pozzolan, was utilized for this study.

Figure 8.—(a) Contractors wetting, mixing, and crushing pozzolan and (b) dump truck delivering pozzolan to field area.

Each 40- by 10-foot subplot pozzolan application location was marked with pin flags on each corner. Pozzolan application rates were determined from the total volume of soil in the top 6 inches of each subplot or broadcast section and the application rate of 5, 25, or 75% pozzolan. The bobcat bucket was estimated to contain approximately 15 cubic feet of pozzolan when full. This value was used to calculate the number of bobcat buckets of pozzolan needed for application to each treatment area (table 2). This method was used in lieu of a surface spreader, for which a contractor could not be located within a reasonable distance of the project site.

Table 2.—Pozzolan application rates for field J and E broadcast and subplot treatments, where a bucket of pozzolan is estimated to contain 15 cubic feet based on manufacturer specifications and field measurements

Treatment	Pozzolan rate (%)	Length (feet)	Width (feet)	Depth (feet)	Total volume (cubic feet)	Volume of pozzolan needed (cubic feet)	Buckets of pozzolan
Broadcast	5	30	20	0.5	300	15	1
Subplot	5	40	10		200	10	0.67
	25					50	3.33
	75					150	10

Each 5% broadcast application plot (300 by 40 feet) was divided into 20- by 30-foot sections by marking the corners with pin flags. One full bucket was then spread evenly over each section and incorporated into the surface soil using the bobcat bucket (figure 9).

Figure 9.—Application of pozzolan to a 25% subplot.

For 25% subplots, the top 2–3 inches of surface soil were removed, and 3-1/3 buckets of pozzolan were applied. Then, the material removed from the surface was reapplied within the subplot and the surface mixed using the teeth of the bucket. For 75% subplots, the top 4–5 inches of surface soil were removed. Five buckets of pozzolan were incorporated along with one bucket of previously removed surface soil. After mixing, another five buckets of pozzolan were added with 1-1/2 buckets of soil and thoroughly mixed.

Fields were rototilled on March 26–27 using a rototiller tractor attachment (figure 10) to masticate any vegetation established since initial field clearing in February, homogenize pozzolan distribution in the soil surface, and encourage the breakdown of pozzolan aggregates. This method was recommended by the material provider for application of non-crushed pozzolan material.

3.2.4 Placement of Irrigation Canal, Irrigation Control Berms, and Furrows

An irrigation canal was placed along the northwest edge of each field to direct water more evenly into irrigation furrows. Irrigation canals were constructed on February 28 – March 1, 2013, using a Bobcat excavator operated by Darrell Long of Darisel Excavating, Lake Havasu City, Arizona (figure 11a). Canals were dug

Figure 10.—Rototilling of field E on March 27, 2013.

approximately 3 feet wide by 2 feet deep along the northwest edge of both fields. After excavation, canals were lined with 6-mil black polyethylene plastic sheeting to promote water conveyance and minimize infiltration losses (figure 11b). Sheeting was laid on the bottom of the canal, and the edges were manually buried in trenches dug with shovels along the perimeter of the canal. A small berm was left in place on the east side of the canal so that it could be broken down as needed to allow passage of irrigation water into plots.

Figure 11.—(a) Excavation of irrigation canal on field E and (b) placement of irrigation lining in canal on field E.

Between April 14 and April 18, 2013, fields J and E were furrowed, and berms were built to separate the plots within each field. Farming contractors were

unavailable to prepare the site, so a smaller tractor was used and operated by GSA personnel. First, a border disk was attached to a tractor to build the berms (figure 12a). A plow was then used to create furrows of approximately 4 inches in height on spacing of approximately 48 inches from crest to crest (figure 12b).

Figure 12.—(a) Construction of irrigation control berms on field E and (b) furrowing of field E.

Dry, sandy soils and high winds resulted in extensive caving of the furrows. As a result, fields were re-furrowed on May 7, 2013, immediately after irrigation. Furrowing of moist soils initially produced stable furrows; however, most collapsed after drying and/or during subsequent irrigation. Extensive maintenance of berms and furrows was carried out on May 7–8 due to significant wind and water erosion of furrows and berms. Areas where the lining of the irrigation canals had been exposed were reburied to prevent the plastic from being displaced by wind or irrigation water.

3.3 Soil Characterization

3.3.1 Infiltration Testing

In-situ soil infiltration rates were determined using the single-ring cylinder infiltrometer method (Bouwer et al. 1999) for both fields after clearing them of existing vegetation. Cylinder infiltrometers provide an intermediate-scale estimate of effective K_{sat}, and can be used to determine infiltration curve (i.e., the depth of infiltrated water versus time of inundation) fitting parameters. A detailed description of the method is presented in attachment 1. An infiltration test in progress is shown on figure 13. Pre-amendment infiltration testing occurred from February 5–7, and post-amendment infiltration testing occurred on March 26–27. Infiltration testing locations are shown on figure 14.

Figure 13.—Cylinder infiltrometer testing on February 6, 2013, prior to pozzolan application.

Ten locations per field were selected for analysis, six in the subplots of plots 3–6 and four in the plots 1–2 and 7–8. Three subplots of each pozzolan treatment percentage were selected for infiltration testing in both fields, and effort was taken to space those subplots out as much as possible across each field to capture any spatial variability in soil characteristics that influence infiltration rates.

Significant effects of pozzolan on infiltration rates were analyzed in JMP 9.0 using student's t-tests run on log(K_{sat}) values. Infiltration testing results were used to determine Kostiakov formula parameters k and a for each location (equation 1):

$$I = kt^a \qquad \text{(equation 1)}$$

where I is the total (cumulative) infiltration, t is the time of inundation, and k and a are fitting parameters. Infiltration test data were fitted to a power function in TableCurve 2d (Version 5.0, Systat Software, Inc., San Jose, California), which provided k and a parameters. These parameters were then used to create infiltration curves for each location.

3.3.2 Soil Salinity Testing

Soil salinity was sampled three times between February and October 2013 to determine background soil salinity, the effects of amendment on soil salinity, and if a year of irrigation sufficiently leached out any additional salts. Soil samples

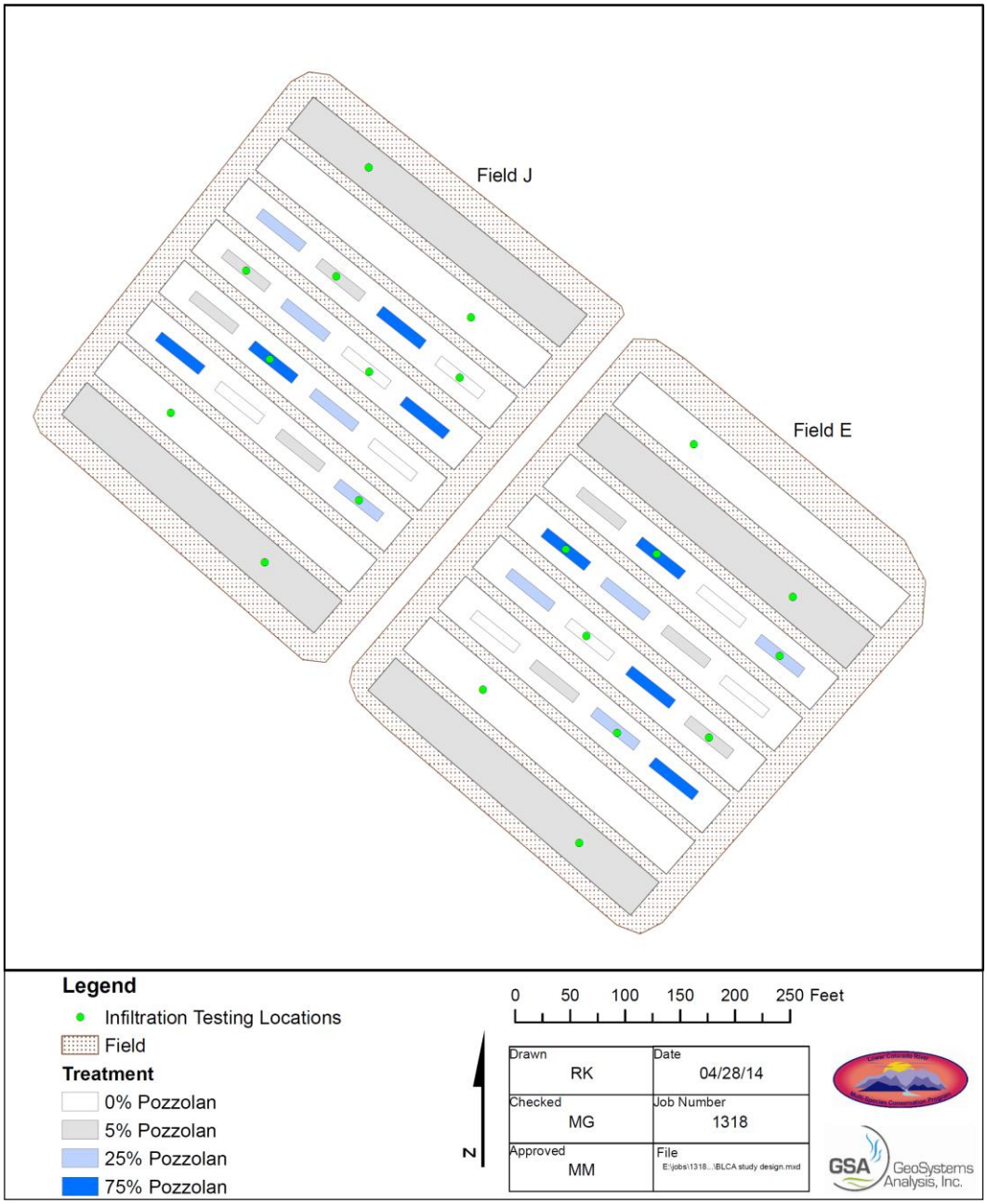

Figure 14.—Infiltration testing locations at BLCA fields J and E.

were collected prior to pozzolan application between February 5 and 6, 2013, at all subplot locations to 6 inches bgs using a 3-inch auger bucket (no samples were collected from plots 1, 2, 7, or 8 of either field). At the four corner subplots (3-A, 3-D, 6-A and 6-D) of both fields, samples were also collected and analyzed at 6 to 24 inches, 24 to 48 inches, and 48 inches to groundwater. All samples were sent to IAS Laboratories (Phoenix, Arizona) to determine saturated paste extraction electrical conductivity (EC).

On March 25 and 26, 2013, surface (0–6 inch) soil samples were collected at infiltration test locations (see figure 14) after pozzolan application. This allowed for re-sampling of 12 subplots analyzed in February and 8 additional locations. Infiltration test locations were sampled again on October 23, 2013, to determine if salinity changed following a season of irrigation.

3.3.3 Soil Texture

Surface soil texture was characterized at all subplot locations and two locations within uniform application plots 1, 2, 7, and 8 using visual-manual (hand texture) methods (American Society for Testing and Materials [ASTM] D2488-09a) to approximate percent sand, silt, and clay. The soil profiles at instrumented locations and the four corner subplots (3-A, 3-D, 6-A, and 6-D) were logged up to the depth of groundwater. During augering for sensor installation, the depth at which soil texture changed was recorded and the soil texture for each depth interval was determined using hand texturing methods.

Six samples were analyzed for particle size distribution (percent sand, silt, and clay) using the hydrometer method (ASTM D422-63) to allow calibration of hand texture data. Three samples were selected from each field, and samples were chosen to represent the range in soil textures observed across the site. Calibration was performed by plotting hydrometer-determined percentage versus the hand texture-estimated percentage of each particle type (sand, silt, and clay) using Table Curve 2D V 5.0 (Cranes Software International Limited, Karnataka, India). The regression equations for each particle type were applied to produce calibrated hand texture results.

3.4 Hydroseeding

Hydroseeding was completed between May 8 and May 9, 2013, during the period of natural seed dispersal, using a Turbo Turf (Beaver Falls, Pennsylvania) HS-500-EH 500-gallon hydroseeder (figure 15). Plots were seeded at a density of 36 pure live seed per square foot. This represents a target tree density of one tree for every two square feet, assuming an establishment rate of 1.67%. Beal Lake

Figure 15.—Hydroseeding field J, plot 8, on May 9, 2013.

water was mixed with wood fiber mulch (Rainer Veneer, Inc., Spanaway, Washington) and sufficient seed for one plot. The final application rate was approximately 1,340 gallons of water and 43 pounds of mulch per acre.

The seed slurry was allowed to mix for several minutes as the hydroseeder was towed to the plot for seeding. Seed was then applied evenly within the designated plot. Fields were irrigated on the afternoon of May 8 and again on May 10, 2013, to prevent seed desiccation due to high temperatures and windy conditions. Following hydroseeding, irrigation occurred at a frequency of every 2 to 3 days to promote seed germination and establishment.

3.5 Irrigation

Irrigation was coordinated with the BLCA irrigation contractor (American Landscape Service, LLC) to ensure that the fields were irrigated three times a week (Monday, Wednesday, and Friday) for the first 6 weeks after hydroseeding. The irrigation frequency was reduced to twice a week (Tuesday and Friday) between 6 and 17 weeks after hydroseeding. Beginning in September 2013, irrigation frequency was decreased to once a week. The fields were irrigated until irrigation reached the far end of the field. Higher elevations prevented inundation in some portions of the field, particularly 75% subplots where high amounts of pozzolan were added.

Watering of fields J and E was documented in an irrigation log. Technicians noted the irrigation start time, end time, average flow rate, and water volume applied. This total applied water was divided by the plot area per field to determine the mean depth of water applied.

3.6 Soil Moisture and Irrigation Monitoring

3.6.1 Automated Monitoring Stations

Soil moisture and irrigation monitoring was accomplished through a network of 20 stations (figure 16). ECH2O-10HS (Decagon Devices, Pullman, Washington) soil moisture sensors were used to monitor soil volumetric water content (VWC) (soil moisture expressed as the fraction of water occupying the total soil volume) for moist to saturated soil conditions. The sensors are frequency domain reflectometry (capacitance) probes, which infer VWC from the bulk soil permittivity. Soil moisture sensors were wired to EM50 dataloggers (Decagon Devices, Pullman, Washington) and programmed to take readings every 30 minutes. Irrigation was monitored using custom-fabricated irrigation sensors (GSA, Tucson, Arizona) wired to either EM50 dataloggers or Hobo U12 4-port dataloggers (Onset Computer Corporation, Bourne, Massachusetts) mounted in weather-proof field enclosures (figure 17). Irrigation sensors are circuit loop sensors used to determine inundation. The sensor is placed such that stainless steel screws are immediately above the soil surface. A gap is left between the two bolts so that the circuit is open when water is absent. When water is present, it closes the circuit between the bolts, therefore changing the sensor reading. When all of the water has infiltrated, the circuit opens, and sensor readings return to initial levels. All datalogger enclosures were encased in wire mesh following installation to prevent exposed wires from being chewed by wildlife.

Irrigation monitoring stations were designed to detect irrigation arrival, recession, and therefore inundation duration. Irrigation sensors placed in broadcast plots (1, 2, 7, and 8 of both fields) were designed to monitor for significant effects of 5% pozzolan on irrigation efficiency and inundation duration. Irrigation sensors placed in pozzolan subplots were intended to detect any effects of pozzolan treatment on the duration of surface water inundation. Soil moisture and irrigation monitoring stations were designed to monitor inundation duration as well as soil moisture on the surface and at 18 inches bgs. Monitoring station information for both fields, including location and depth of sensors, is presented in table 4.

Monitored parameters and sensor counts for each station type are described in table 3. Sensor models used for this project and their monitoring objectives are summarized in table 4; sensors listed in the table are described in detail, including the calibration methods, where applicable, in the following sections.

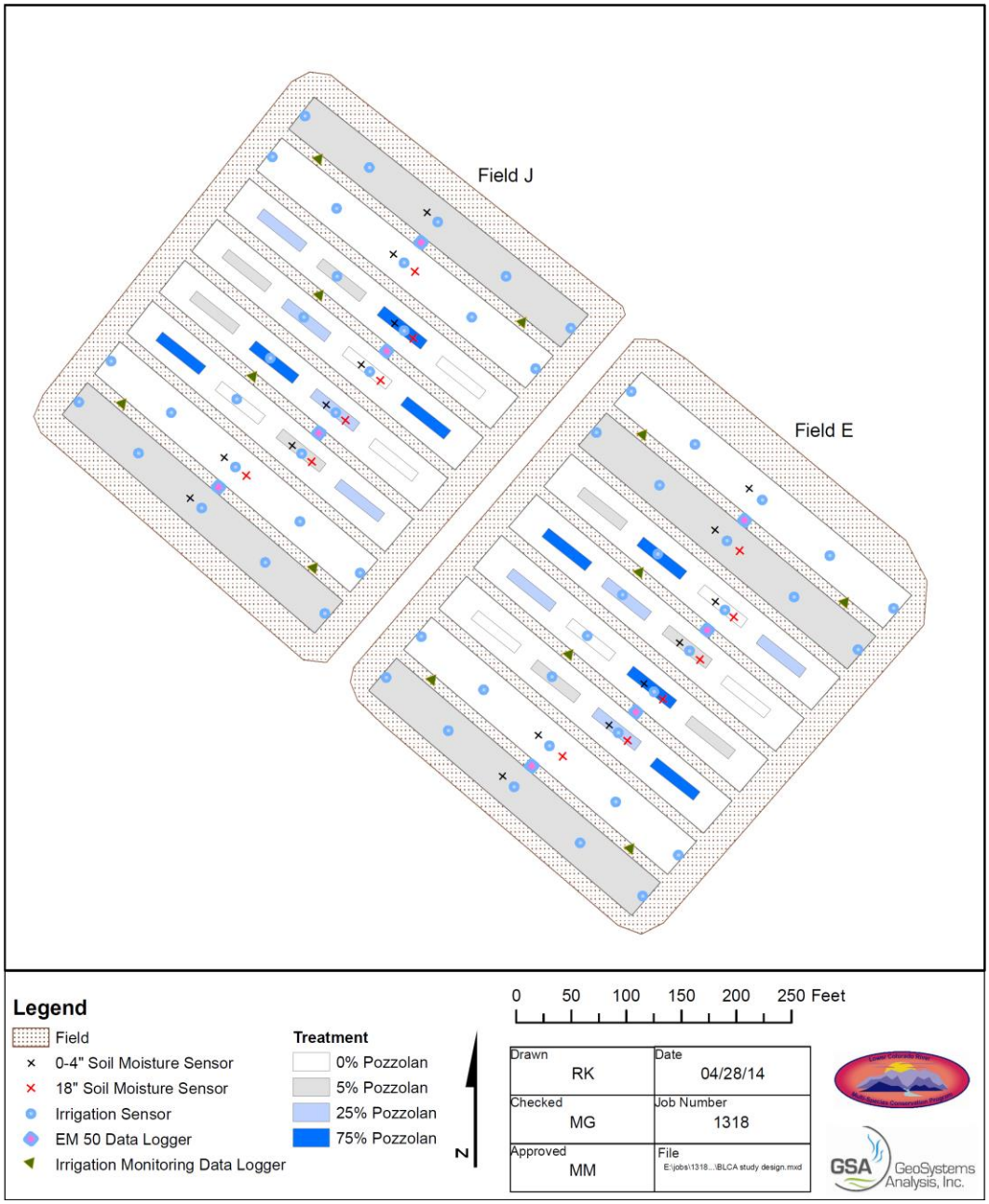

Figure 16.—Automated soil moisture and irrigation monitoring system installed at BLCA fields J and E.

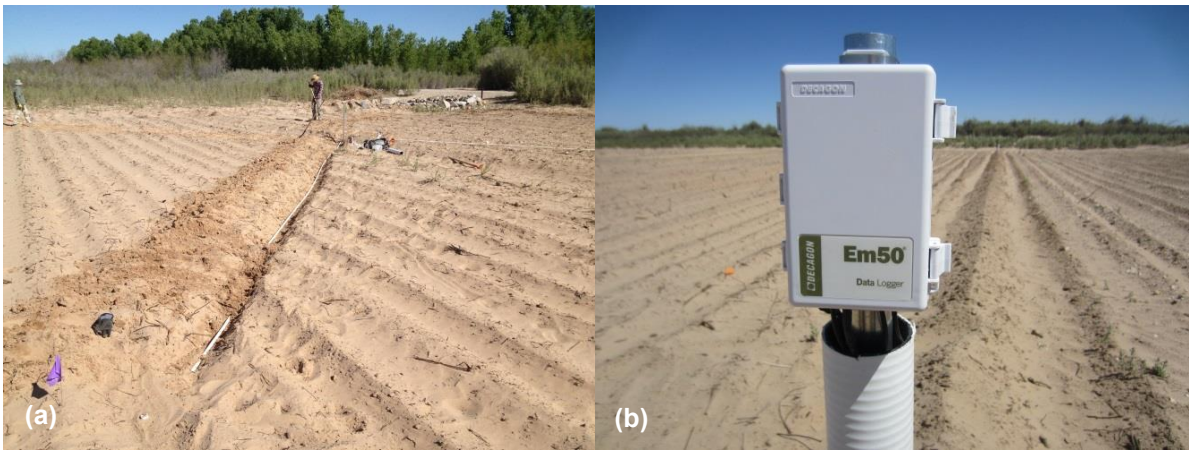

Figure 17.—(a) Backfilling sensor and protective PVC housing after installation and (b) completed datalogger installation.

Table 3.—Observation objectives and sensor types and counts for each automated monitoring station

Monitored parameters	Irrigation monitoring A[a]	Irrigation monitoring B[b]	Soil moisture and irrigation monitoring stations A[c]	Soil moisture and irrigation monitoring stations B[d]
Irrigation/inundation	X	X	X	X
Surface soil moisture			X	X
Subsurface soil moisture (18 inches)			X	X
Sensor model	**Sensor count per station**			
Irrigation[e]	4	3	1	2
ECH_2O-10HS soil moisture[f]	0	0	4	3

[a] Includes stations 1, 3, 8, and 10 in both fields.
[b] Includes stations 4 and 5 in both fields.
[c] Includes stations 5 and 7 in both fields.
[d] Includes stations 2 and 9 in both fields.
[e] GSA., Tucson, Arizona.
[f] Decagon Devices, Inc., Pullman, Washington.

3.6.2 Sensor Calibration

Decagon Devices, Inc., provides standard VWC versus signal voltage calibrations for all ECH2O probes. However, signal relationships are affected by soil texture, bulk density, and salinity. Due to a large variation in these soil properties at LCR MSCP habitat creation sites, GSA conducts site-specific laboratory calibrations. Soil moisture sensors were calibrated on composited grab samples for each of the pozzolan percentage classes, including one composite each for

Table 4.—Monitoring station details for fields J and E

Logger ID	Logger type[a]	Sensor type[b]	Logger port	Sensor location (plot – subplot)	Installation depth (inches)
1	U-12	IS	1	1-A	0
			2	1-B	
			3	2-A	
			4	2-B	
2	EM50	IS	1	1-C	0
		SM	2	1-C	3
		IS	3	2-C	0
		SM	4	2-C	3
		SM	5	2-C	18
3	U-12	IS	1	1-D	0
			2	1-E	
			3	2-D	
			4	2-E	
4	U-12	IS	1	3-B	0
			2	3-C	
			3	4-B	
5	EM50	SM	1	3-C	3
		SM	2	3-C	18
		IS	3	4-C	0
		SM	4	4-C	3
		SM	5	4-C	18
6	U-12	IS	1	5-B	0
			2	5-C	
			3	6-B	
7	EM50	SM	1	6-C	3
		SM	2	6-C	18
		IS	3	6-C	0
		SM	4	5-C	3
		SM	5	5-C	18
8	U-12	IS	1	7-A	0
			2	7-B	
			3	8-A	
			4	8-B	
9	EM50	IS	1	7-C	0
		SM	2	7-C	3
		SM	3	7-C	18
		IS	4	8-C	0
		SM	5	8-C	3
10	U-12	IS	1	7-D	0
			2	7-E	
			3	8-D	
			4	8-E	

[a] Hobo U-12 4-port datalogger, Onset Computer Corporation, Bourne, Massachusetts; Decagon EM50 5-port datalogger, Decagon Devices, Pullman, Washington.
[b] IS = irrigation sensor, and SM = Decagon 10HS soil moisture sensor.

25 and 75% pozzolan subplots, and two composites each for 0 and 5% pozzolan subplots, which represent the fine-textured and coarse-textured soils observed across the fields. Samples were collected in November 2013 to allow for a full irrigation season and leaching of soluble salts, which may otherwise affect sensor response and calibrations. VWC sensors were calibrated at VWC between 0.02 and 0.43 cubic centimeter per cubic centimeter (2 and 43%, respectively) and bulk densities between 0.84 and 1.53 grams per cubic centimeter. Sensors were calibrated in one of six composite samples representing soil texture and pozzolan amendment rates. This allowed for application of soil-specific calibration parameters at each sensor location. Starting moisture content of air-dried soil was determined using the oven drying method (ASTM D2216). Soil was then packed into a rectangular calibration chamber of known volume with the ECH2O-10HS probe inserted in the middle. The sensor was connected to a Decagon EM50 datalogger. Soil was compacted in steps, and the output readings were recorded at each bulk density. This process was repeated for increasing soil water contents until saturation was reached.

EM50 datalogger output units for ECH2O sensors are processed VWC estimates based on the manufacturer standard calibration. This output is post-processed to estimate VWC via correlation of VWC to EM50 unprocessed parts, which are a scaled output calculated from sensor voltage by the EM50's analog to digital converter. Laboratory measured VWC versus EM50 unprocessed parts output were plotted graphically using Microsoft Excel, and calibration equations were obtained for each sensor and soil type combination.

3.6.3 Maintenance and Troubleshooting

The site was visited approximately monthly after sensor installation. Data were downloaded and inspected onsite for any sensor or datalogger malfunctions. Sensors were repaired or replaced as necessary. The ECH2O-10HS 3-inch sensor in the 25% subplot of field E, plot 6, was replaced on July 16, 2013. Two sensor cables needed to be repaired after being chewed by an animal at stations J-1 and E-4. Due to sand displacement by wind and irrigation, the height of the irrigation sensors needed periodic adjustment so that the sensor bolts were immediately above the soil surface to maximize the accuracy of irrigation monitoring data.

3.6.4 Manual Soil Moisture Sampling

Automated soil moisture sensors were established at a subset of plots with high variation in background soil texture. To provide an increased sample size, account for spatial variability in soil texture, and allow statistical comparison of soil moisture between pozzolan treatment levels, samples were collected and laboratory tested following an irrigation event as described in the following.

Soil grab samples were collected on October 23, 2013, approximately 20 hours after an irrigation event to determine gravimetric (and estimated volumetric) moisture retention (approximation of field capacity) following irrigation. Samples were composited from 0 to 6 inches inside and outside of each subplot in plots 3–6 of both fields. Additionally, composite 15- to 21-inch samples were collected underneath five of each of the subplot amendment rates (five repetitions total for each amendment rate) to compare moisture availability beneath the amended soil interval. Samples were collected at four areas of each broadcast plot (plots, 1, 2, 7, and 8 of each field) spaced equally with field subplots to compare soil moisture retention between 5% pozzolan application and the control. Samples were labeled, dated, and triple bagged for storage until analysis in the GSA laboratory following ASTM D2216-10.

Soil moisture sample results for plots 3–6 of both fields were analyzed in JMP 9.0 using a one-way analysis of variance (ANOVA) blocked by plot. The "Compare Means," "Each Pair, Student's t" (0.05 alpha) options were selected in the "Fit Y by X" platform to detect significant differences in surface soil moisture between pozzolan percentages and inside versus outside the plots (t-test on the paired differences). Broadcast plots were not included in this analysis.

3.7 Vegetation Monitoring

3.7.1 Vegetation Data Collection

Vegetation monitoring, completed in December 2013, was designed to document the establishment of seeded and volunteer vegetation in the fields. Vegetation monitoring protocols closely followed reduced effort protocols according to LCR MSCP habitat monitoring protocols for all LCR restoration sites within the first two years after planting (D. Bangle 2013, personal communication). However, additional factors only included in enhanced level protocols were monitored because of their potential effect on seedling establishment. A stratified random survey design was implemented, whereby three 0.5- by 2-meter quadrats were randomly placed within each subplot of plots 3–6 in both fields. For areas of plots 1, 2, 7, and 8 of each field, vegetation survey areas were placed the same distances across the field as for pozzolan subplots. These areas were termed "vegetation monitoring plots." Vegetation surveys are summarized as follows:

Within quadrats:

- Tally, height, and diameter at breast height (as applicable) of all trees.
- Tally, height, and stem diameter (as applicable) of all shrubs.
- Tally and height of clonal species (arrowweed and coyote willow [*Salix exigua*]) stems.
- Depth of litter and height of herbaceous vegetation at three locations.

- Herbaceous foliar cover – visual estimate of non-woody plants from the ground up to 0.5 meter, by species and following cover classes: 1 = < 1%, 2 = 1–10%, 3 = 11–25%, 4 = 26–50%, 5 = 51–75%, 6 = 76–90%, and 7 = > 90%.

- Ground cover – for the following: herbaceous, woody, litter, dead plants, water, rock/gravel layer, and bare ground, using the following cover classes: 1 = < 1%, 2 = 1–10%, 3 = 11–25%, 4 = 26–50%, 5 = 51–75%, 6 = 76–90%, and 7 = > 90%. Pozzolan aggregates were considered to be rock/gravel.

- Canopy closure recorded at the southeast corner for quadrats with vegetation above 1.2 meters in height using a concave spherical densitometer and recording the number of line intersections or corners covered by canopy. The total number of intersections is multiplied by 2.702 to obtain the percent crown closure.

Within subplots:

- Foliar cover of trees and shrubs—total and by species

- Incidental species—species within the subplots that were not detected in quadrat areas

- Tally, height, and diameter at breast height or stem diameter (as applicable) for all trees

In addition to vegetation assessment within subplots and quadrats, all Goodding's willows established were measured in plot 8 of field J, where germination was the highest. If the tree was taller than 4 inches, it was tagged, and the Universal Transverse Mercator location was recorded. The condition was recorded based on leaf abundance and color (poor, fair, or good). Good condition trees are at least 75% foliated with green leaves, fair condition trees are between 25 and 75% foliated with green leaves, and poor condition trees are less than 25% foliated with green leaves. Signs of herbivory were also noted. Trees that had been subjected to extensive herbivory and where only small stems were found were noted as present and used only in the determination of initial seedling establishment.

3.7.2 Vegetation Data Analysis

Vegetation data collected in plots 3–6 of both fields were analyzed to determine the effects of pozzolan rates on establishment of Goodding's willow and volunteer vegetation. The design of plots 1, 2, 7, and 8 did not accommodate this analysis. Thus, data were simply summarized to document vegetation

established in each plot. Data were analyzed in Microsoft Excel and JMP 9.0 (SAS Institute, Inc., Cary, North Carolina) to summarize the following parameters by plot (broadcast plots) or subplot (plot 3–6 of both fields):

- Tree and shrub plant and/or stem density
- Tree and shrub height
- Ground cover by type
- Foliar cover by species
- Average vegetation height and litter depth

The densities of trees and shrubs were calculated by dividing the total count of individuals by the total area surveyed (either one quadrat or one subplot). Because vegetation had only recently established and was less than 3.4 meters tall, no size or height class analysis was completed. The average height and density of arrowweed was calculated from measured heights of stems in quadrats. The average tree and salt cedar height and density were calculated from measured heights of all individuals encountered in subplots. Ground cover and foliar cover were summarized by cover type. The midpoint percentage for each cover class (e.g., 0.5% for less than 1%, 5% for 1 to 10%, 95% for 90 to 100%, etc.) was used to estimate cover percentages for each species or type. Ground cover was summarized from quadrat data, and foliar cover was summarized from subplot data for all species except arrowweed, which was summarized from quadrat data.

4.0 RESULTS

Seed collection and preparation results are provided in section 4.1. Results of perimeter pole planting for establishment of a wind break are provided in section 4.2. Soil moisture results, both from grab samples and automated monitoring station data, are presented in section 4.4. Results from field infiltration and soil salinity testing are summarized in section 4.3. Vegetation monitoring results are presented in section 4.5.

4.1 Seed Collection and Preparation

Locations of all trees from which Goodding's willow seed was collected are presented in table 1, and maps of all collection locations are presented in attachment 1. Results of germination testing after seed collection in 2012 and prior to hydroseeding in 2013 are summarized in table 5. Germination rates ranged from 34 to 100% and averaged 72% for all trees after seed collection. Only seed with viability greater than 70% was selected for inclusion in

Table 5.—Goodding's willow seed germination testing results for 2012 and 2013 prior to hydroseeding

Site	Tree ID	Collection date	Germination rates			Percent of total seed
			2012	2013	Hydroseeding[a]	
Bill Williams River NWR	2	3/14/12	1.00	0.95	0.95	3
	4	3/14/12	0.60	–	0.60	0.2
	5	3/14/12	0.60	1.00	0.80	0.4
	6	3/14/12	0.98	1.00	0.99	0.4
Cibola NWR	1	4/2/12, 4/17/12	0.78	0.89	0.84	10
	2	4/2/12, 4/17/12	0.94	0.84	0.89	9
	3	4/2/12, 4/16/12	0.91	0.83	0.87	14
	4	4/16/12	0.80	1.00	0.90	12
	Miscellaneous	4/2/12 – 4/17/12	–	0.76	0.76	3
Havasu NWR	1	6/9/12	0.80	0.86	0.83	2
	2	6/9/12	0.76	0.60	0.68	7
Mineral Wash (Bill Williams River NWR)	1	3/17/12	0.84	0.80	0.82	0.4
	2	3/17/12	0.65	–	0.65	0.2
	3	3/17/12	0.88	0.90	0.89	1
	4	3/17/12, 4/2/12	0.78	–	0.78	0.4
	5	3/17/12	0.54	1.00	0.77	0.4
	7	4/5/12	0.88	1.00	0.94	3
	13	4/5/12	0.89	1.00	0.95	2
	14	4/5/12	0.65	1.00	0.83	3
	17	4/5/12	0.78	1.00	0.89	2
	18	4/5/12	0.56	0.74	0.65	11
	Unknown	4/5/12	–	0.80	0.80	2
Unknown (seed collected in 2008)	104	4/5/08	0.74	–	0.71	3
	303	4/6/08	0.75	–	0.71	0.2
	302	4/6/08	0.64	–	0.71	1
	2	4/5/08	–	0.69	0.71	1
	16	–	–	–	0.71	0.04
PVER	1	3/29/13	–	0.87	0.87	3
	2	3/29/13	–	0.97	0.97	2
	4	3/29/13	–	0.97	0.97	2
	6	3/29/13	–	0.97	0.97	2

[a] Rate used for seed lot allocation for hydroseeding tanks.

hydroseeding tank allocation. Seed was then assigned into a weight calibration category based on the amount of biomass present in addition to seed (figure 18). The results of seed weight calibrations are provided in table 6.

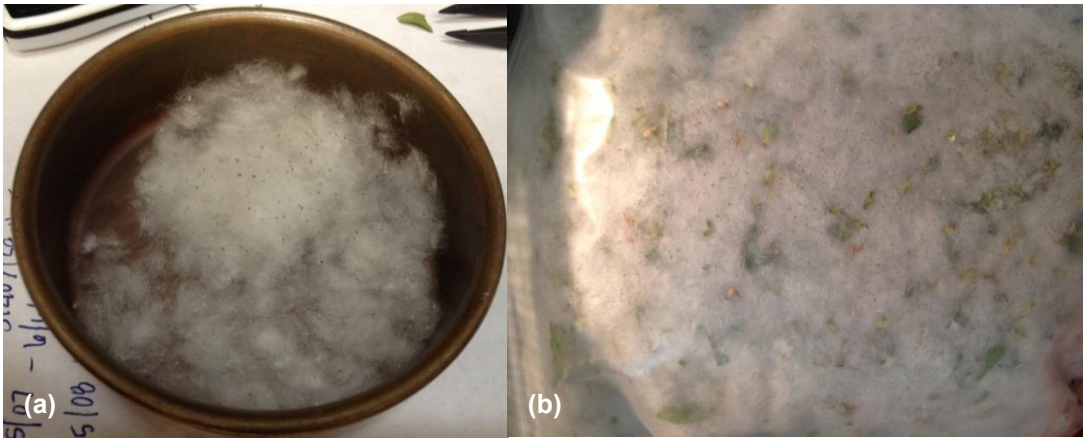

Figure 18.—(a) Goodding's willow weight calibration seed category 1 and (b) Goodding's willow weight calibration seed category 2.

Table 6.—Goodding's willow seed calibration results by category

Category[a]	Tree ID	Counted seed weight (grams)	Seeds per gram
1	CNWR 3	0.80	2,108
	BWR 5	0.13	3,015
	MW 1	0.07	2,466
	Mean	–	2,530
2	CNWR 1	0.14	1,786
	HNWR 2	0.09	1,567
	CNWR 2	0.11	1,991
	Mean	–	1,781
3	PVER 1	0.20	1,010
	MW 18	0.17	1,788
	MW 16	0.33	924
	Mean	–	1241

[a] 1 = seed with seed hair fibers only, 2 = seed with moderate amounts of plant material, and 3 = seed with high amounts of plant material.

4.2 Perimeter Pole Planting

Extensive mortality of deep-potted Fremont cottonwoods was observed due to herbivory by rabbits. Additionally, several trees showed moisture stress as evident by desiccated leaves and branches. During a survey in March 2014, a total of 12 perimeter cottonwoods were found to have survived on field E, and a total of 3 perimeter cottonwoods survived on field J. These results indicate that tree cages should be used for future applications of this technique at LCR MSCP habitat creation sites.

4.3 Soil Characterization

4.3.1 Infiltration Characteristics

Summarized field saturated hydraulic conductivity (K_{sat}) data are provided in table 7. Observed hydraulic conductivity values for 0 and 5% locations were generally higher after pozzolan incorporation most likely because the fields had been cleared and tilled immediately prior to infiltration testing. This disturbance likely reduced soil compaction, which would be expected to increase infiltration rates until soils re-settle and compact following irrigation. Infiltration rates for the 25% pozzolan plots were approximately equal before and after amendment incorporation. Saturated hydraulic conductivity decreased significantly following 75% pozzolan application, indicating that the higher amendment rate overcame the tendency of disturbance to increase hydraulic conductivity. A lack of significant difference for amendment rates below 75% is likely due to a combination of low sample numbers and disturbance during pozzolan incorporation.

Table 7.—Soil saturated hydraulic conductivity estimated from single-ring cylinder infiltrometer testing

Pozzolan rate (%)	n	Saturated hydraulic conductivity (meters/day)							
		Pre-amendment				Post-amendment			
		Geometric mean	Max.	Min.	Standard deviation[a]	Geometric mean	Max.	Min.	Standard deviation
0	7	0.46	2.00	0.04	0.73	0.69	2.53	0.04	0.81
5	7	0.32	0.89	0.02	0.35	0.72	1.96	0.24	0.66
25	3	0.24	0.74	0.05	0.35	0.22	0.27	0.20	0.04
75	3	0.42	0.99	0.27	0.41	0.03*[b]	0.15	0.01	0.08

[a] Presents the standard deviation for untransformed data.
[b] * Indicates a significantly lower post-amendment K_{sat}, Student's t-test, 0.05 alpha.

Infiltration curves for 0, 5, 25, and 75% treatments are presented on figures 19 through 22. As for saturated hydraulic conductivity, there was no clear change in infiltration rates due to the 5% pozzolan treatments, although the two highest infiltration rates were observed after pozzolan incorporation. Two of the three 25% pozzolan subplots had decreases in infiltration rates following pozzolan application, and all three of the 75% pozzolan subplots had decreased infiltration rates following pozzolan application. As for saturated hydraulic conductivity testing, these infiltration curves do not likely represent long-term infiltration rates at the site; followup testing after a year of irrigation would more accurately predict long-term effects.

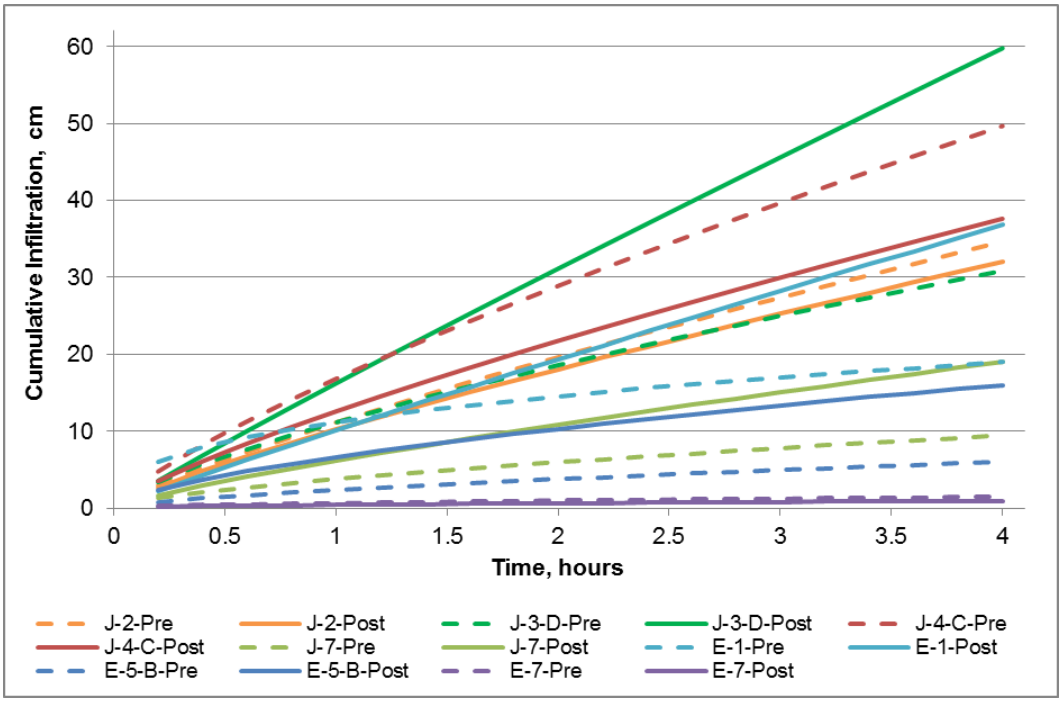

Figure 19.—Pre-amendment (pre) and post-amendment (post) infiltration versus time results for cylinder infiltrometer tests in control (0%) pozzolan locations.

4.3.2 Soil Salinity

Soil salinity results for all sampling locations are summarized in table 8. Soil salinity results for the 12 subplot locations tested for all 3 sampling events are summarized on figure 23. Soil EC for the 0 and 5% plots was relatively constant for all three sampling events. Soil EC for both 25 and 75% pozzolan plots increased by more than 100% due to pozzolan addition. Soil EC at these plots declined over the 2013 growing season due to irrigation and leaching effects, but EC was still higher than initial, pre-amendment levels. None of the EC values exceeded 8 dS/m (the highest was 6.9 dS/m in subplot J-5-B), which would be expected to cause severe stress or mortality of mature cottonwood and willow (GSA 2014). However, the mean EC values for 25 and 75% amendment rates in March 2013 exceeded dS/m and would therefore be expected to reduce

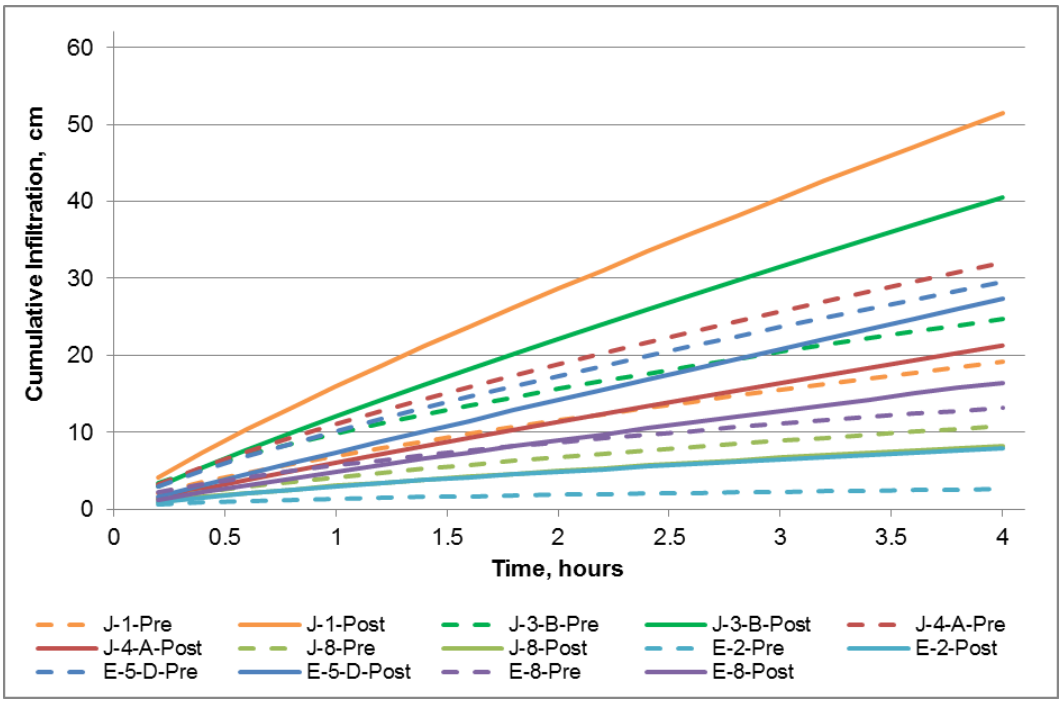

Figure 20.—Pre-amendment (pre) and post-amendment (post) infiltration versus time results for cylinder infiltrometer tests in 5% pozzolan locations.

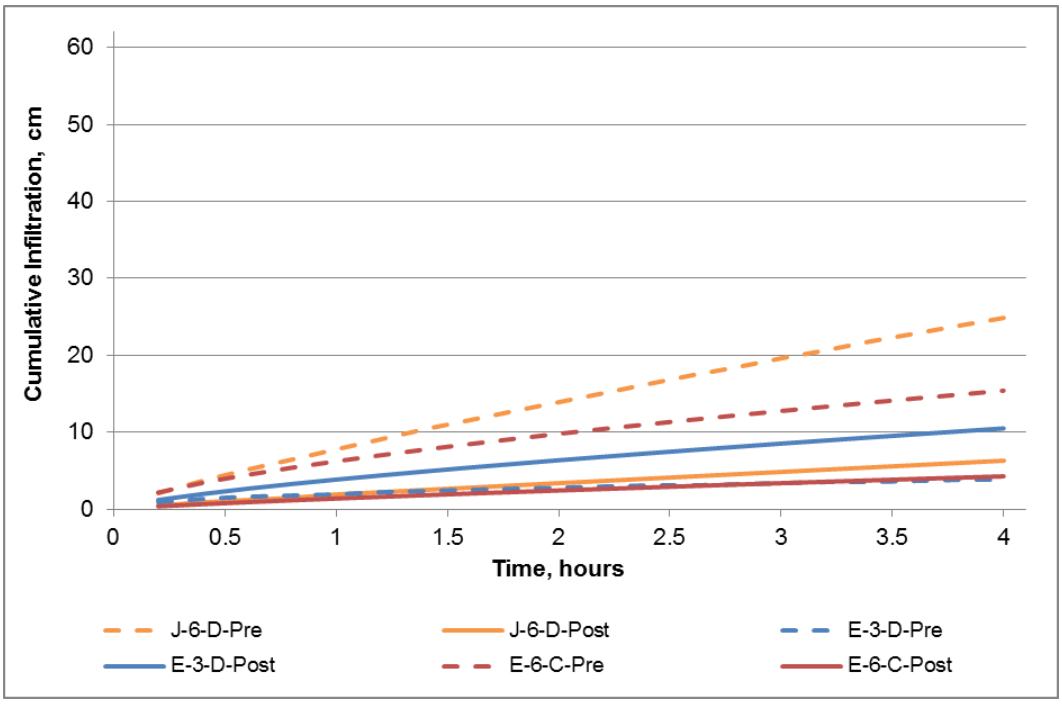

Figure 21.—Pre-amendment (pre) and post-amendment (post) infiltration versus time results for cylinder infiltrometer tests in 25% pozzolan subplots.

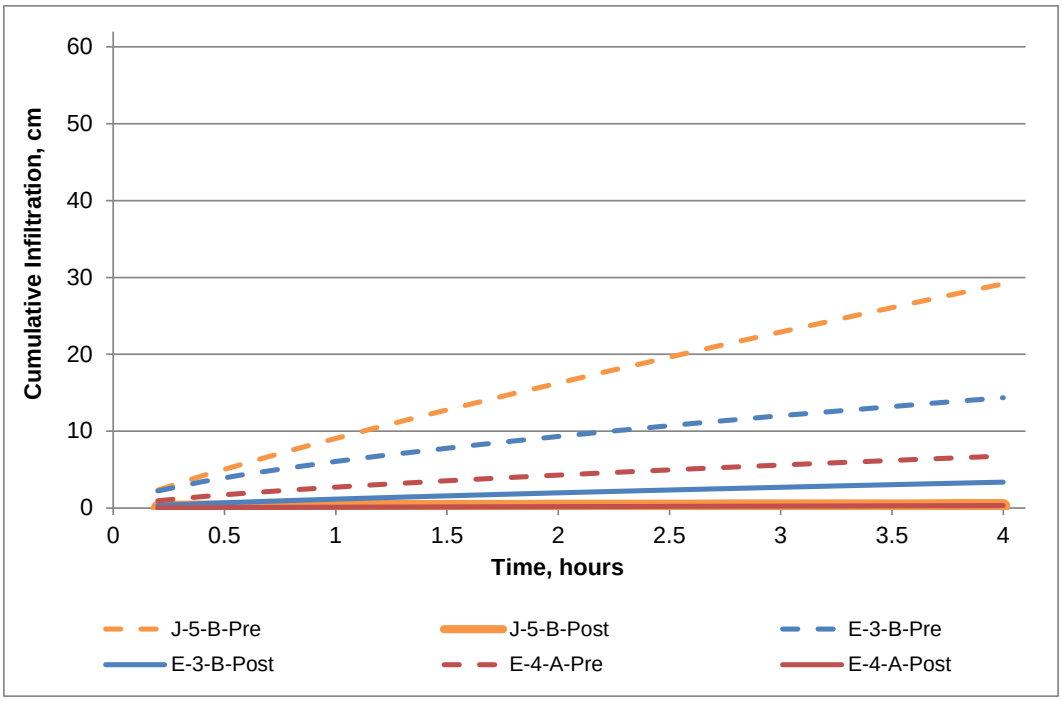

Figure 22.—Pre-amendment (pre) and post-amendment (post) infiltration versus time results for cylinder infiltrometer tests in 75% pozzolan subplots.

Table 8.—Baseline, post-amendment, and post-growing season saturated paste extract EC for fields J and E

Pozzolan rate (%)	Saturated paste extract EC, dS/m mean (n) range		
	Pre-amendment (2/2013)	Post-amendment (3/2013)	After irrigation and leaching (10/2013)
0	0.9 (8) 0.4–3.4	1.7 (7) 0.7–6.2	1.0 (7) 0.7–1.6
5	1.3 (8) 0.4–3.9	1.9 (7) 0.7–4.2	1.0 (7) 0.7–1.4
25	0.8 (8) 0.3–1.9	3.2 (3) 2.7–3.6	1.7 (3) 1.6–1.8
75	0.9 (8) 0.4–2.3	4.7 (3) 3.1–6.9	2.8 (3) 1.5–3.7

Goodding's willow germination rates (GSA 2011). The mean EC at the end of the growing season after extensive irrigation and leaching was below 3 dS/m; however, two 75% subplots (E-4-A and J-5-B) still exceeded 3 dS/m.

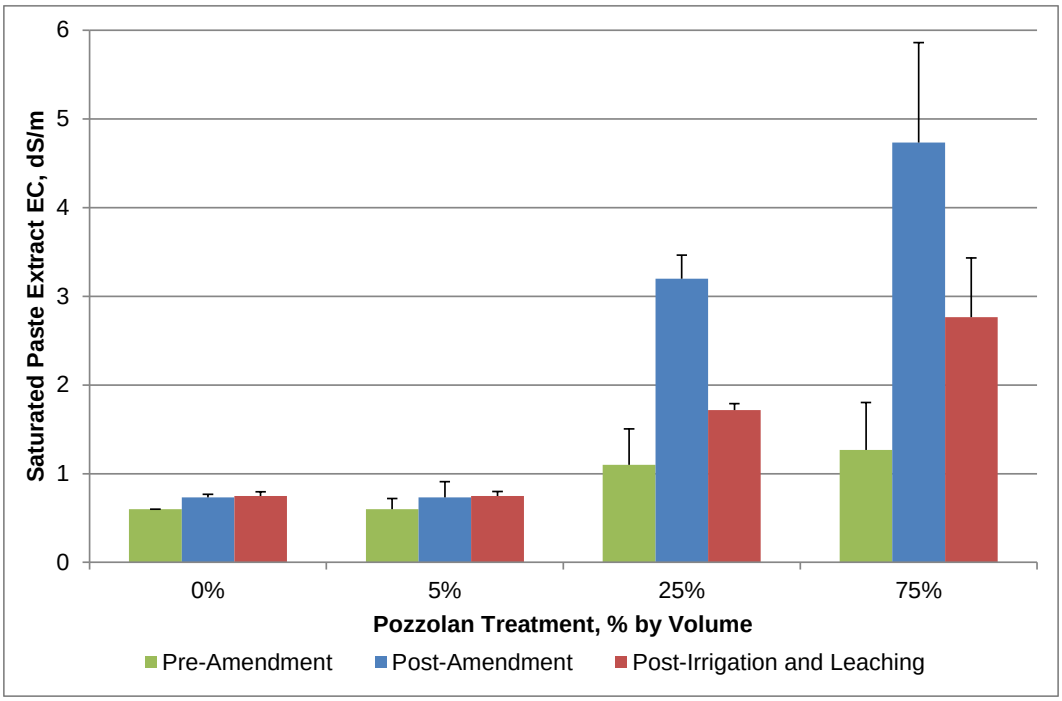

Figure 23.—Saturated paste extract soil EC for subplots sampled in February (pre-amendment), March (post-amendment), and October (post irrigation and leaching) 2013.
Data from 3 plots per pozzolan treatment level, for 12 plots total: J-3-B, J-3-D, J-4-A, J-4-C, J-5-B, J-6-D, E-3-B, E-3-D, E-4-A, E-5-B, E-5-D, and E-6-C. Error bars encompass one standard error.

4.3.3 Soil Texture

Hydrometer soil texture results are presented in table 9. Hydrometer-calibrated soil hand texture results are presented in table 10. Soil were predominantly classified as sands (> 90% sand) from the surface to groundwater, with minor components of loamy sands, sandy loams, and loams being observed in the fields. The finest-textured soils were located in plots 7 and 8 of field J, where textures ranged from loamy sands to loams. This soil distribution would be anticipated to result in higher soil moisture levels regardless of pozzolan rates.

Table 9.—Hydrometer soil particle size distribution for select samples from fields J and E

Field	Plot	Subplot	Depth	Percent sand	Percent silt	Percent clay
J	3	C	0–0.5	96.4	1.9	1.7
	5	A	0–0.5	85.4	11.4	3.3
	7	B	0–0.5	55.0	33.3	11.7
E	4	A	0–0.5	71.6	26.6	1.9
	6	A	2–4	97.9	1.1	1.0
	8	A	0–0.5	81.9	14.6	3.5

Table 10.—Hydrometer-calibrated visual-manual soil texture results

Plot	Subplot	Depth (feet)	Percent sand	Percent silt	Percent clay
J-3	A	0–0.5	92	8	0
		0.5–2	92	8	0
		2–4	91	9	0
		4–4.75	91	9	0
	B	0–0.5	91	9	0
	C	0–0.5	92	8	0
		0.5–2	92	8	0
		2–3.75	92	8	0
	D	0–0.5	92	8	0
		0.5–2	91	9	0
		2–4	92	8	0
		4–4.75	92	8	0
J-4	A	0–0.5	92	8	0
	B	0–0.5	90	9	0
	C	0–0.5	92	8	0
		0.5–2	92	8	0
		2–3.75	92	8	0
	D	0–0.5	95	6	0
J-5	A	0–0.5	79	18	3
	B	0–0.5	93	7	0
	C	0–0.5	92	8	0
		0.5–2	92	8	0
		2–3.5	92	8	0
	D	0–0.5	92	8	0
J-6	A	0–0.5	93	7	0
		0.5–2	79	19	2
		2–4	79	19	2
	B	0–0.5	87	12	0
	C	0–0.5	93	7	0
		0.5–1	81	16	3
		1–2.5	74	19	6
		2.5–2.7	60	27	13
		2.7–3	74	19	6
		3–3.5	65	23	12
		3.5–4.25	51	31	19
	D	0–0.5	93	7	0
		0.5–2	91	9	0
		2–4	92	8	0
		4–4.75	93	7	0

Table 10.—Hydrometer-calibrated visual-manual soil texture results

Plot	Subplot	Depth (feet)	Percent sand	Percent silt	Percent clay
J-7	A	0–0.5	65	25	10
		0.5–1.5	87	12	1
		1.5–2	74	19	6
		2–3.5	65	23	12
		3.5–3.75	55	31	14
		3.75–4.5	60	29	11
	D	0–0.5	60	27	13
		0.5–1	79	17	4
		1–1.25	86	13	1
		1.25–2.5	75	19	6
		2.5–3	70	23	7
		3–3.5	60	25	14
		3.5–4.25	55	27	18
		4.25–4.75	65	23	12
J-8	A	0–0.5	92	8	0
	C	0–0.5	82	15	3
		0.5–2	87	12	1
		2–2.5	74	20	6
		2.5–2.75	60	27	13
		2.75–3	51	31	19
		3–4	70	23	7
		4–4.5	60	27	13
		4.5–5	46	35	19
	D	0–0.5	93	7	0
E-3	A	0–0.5	92	8	0
		0.5–2	93	7	0
		2–4	93	7	0
		4–4.5	93	7	0
	B	0–0.5	93	7	0
	C	0–0.5	94	6	0
		0.5–2.75	92	8	0
		2.75–3	79	16	5
		3–3.5	88	10	1
	D	0–0.5	92	8	0
		0.5–2	91	8	0
		2–4	92	8	0
		4–4.75	93	7	0

Table 10.—Hydrometer-calibrated visual-manual soil texture results

Plot	Subplot	Depth (feet)	Percent sand	Percent silt	Percent clay
E-4	A	0–0.5	74	13	13
	B	0–0.5	93	7	0
	C	0–0.5	92	8	0
		0.5–2	94	6	0
		2–4.5	94	6	0
	D	0–0.5	92	8	0
E-5	A	0–0.5	79	18	3
	B	0–0.5	92	8	0
	C	0–0.5	92	8	0
		0.5–2	92	8	0
		2–4	92	8	0
	D	0–0.5	89	10	0
E-6	A	0–0.5	92	8	0
		0.5–2	92	8	0
		2–4	94	6	0
		4–4.5	91	9	0
	B	0–0.5	91	9	0
	C	0–0.5	92	8	0
		0.5–1	90	9	0
		1–1.5	81	15	4
		1.5–3.5	92	8	0
	D	0–0.5	91	9	0
		0.5–2	92	7	0
		2–4	93	7	0
		4–5	94	6	0
E-7	A	0–0.5	65	25	10
	D	0–0.5	91	9	0
		0.5–2	91	9	0
		2–4	91	9	0
		4–4.5	95	6	0
E-8	A	0–0.5	90	9	0
		0.5–1.5	91	8	0
		1.5–2	88	10	1
		2–2.5	70	23	7
		2.5–3	63	27	10
		3–4	71	22	7
	D	0–0.5	93	7	0

4.4 Soil Moisture and Irrigation Monitoring

4.4.1 Water Content Sensor Calibration

Soil water content sensor calibration equation parameters are provided in table 11. Sensor calibration curves for all six composite samples and the manufacturer standard calibration are presented on figure 24. Field hand texturing data were used to assign sensor locations to coarse or fine calibration equations where applicable. Subsurface sensors installed at 18 inches bgs were assigned to 0% coarse categories, with the exception of the sensor in plot 6 of both fields J and E, where hand texturing revealed more loamy texture, and sensors were assigned to the 0% fine category.

Table 11.—ECH_2O 10HS soil moisture sensor calibration parameters by soil type

Calibration equation[a]: $\theta_v = A * X + B$				
Soil type	**Percent pozzolan**	**A**	**B**	**R^2**
Fine	0	4.71E-04	-0.3149	0.958
	5	6.70E-04	-0.4773	0.978
Coarse	0	6.04E-04	-0.4277	0.971
	5	4.78E-04	-0.3008	0.986
N/A	25	5.61E-04	-0.3719	0.991
	75	6.05E-04	-0.4160	0.986

[a] θ_v = the calibrated VWC in cubic centimeters per cubic centimeter, A and B = fitting parameters, and X = the unprocessed parts output from the EM50 datalogger.

4.4.2 Soil Moisture Automated Monitoring

Automated results are discussed in this section first by field and then within and between soil texture classifications.

Surface VWC for the four instrumented pozzolan subplots (Subplots 3B, 4B, 5B, and 6B) in field J for the 2013 irrigation season is presented by 2-month periods on figures 25 through 28. The period without irrigation for the first 3 weeks of October 2013 (figure 27) provided the opportunity to see how different pozzolan levels affected soil moisture over an extended period. This was also relatively late in the growing season, and soil particles would have settled since disturbance during vegetation clearing and pozzolan incorporation. Surface soil water content

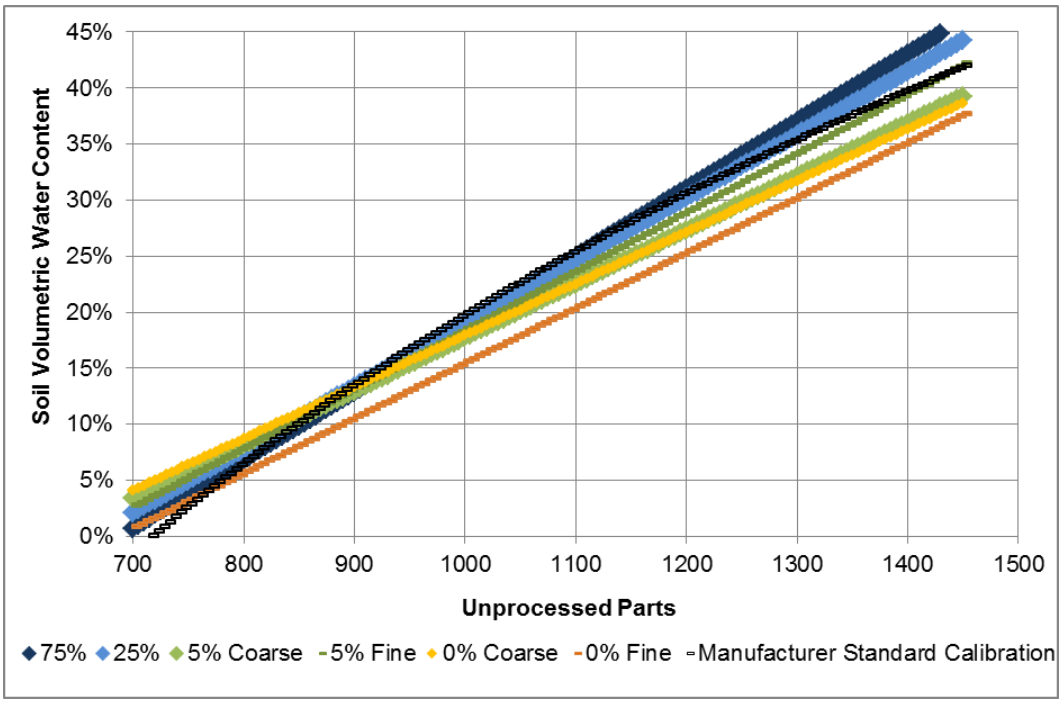

Figure 24.—Calibration data for ECH2O-10HS VWC probes for all soil composites for an EM50 datalogger.

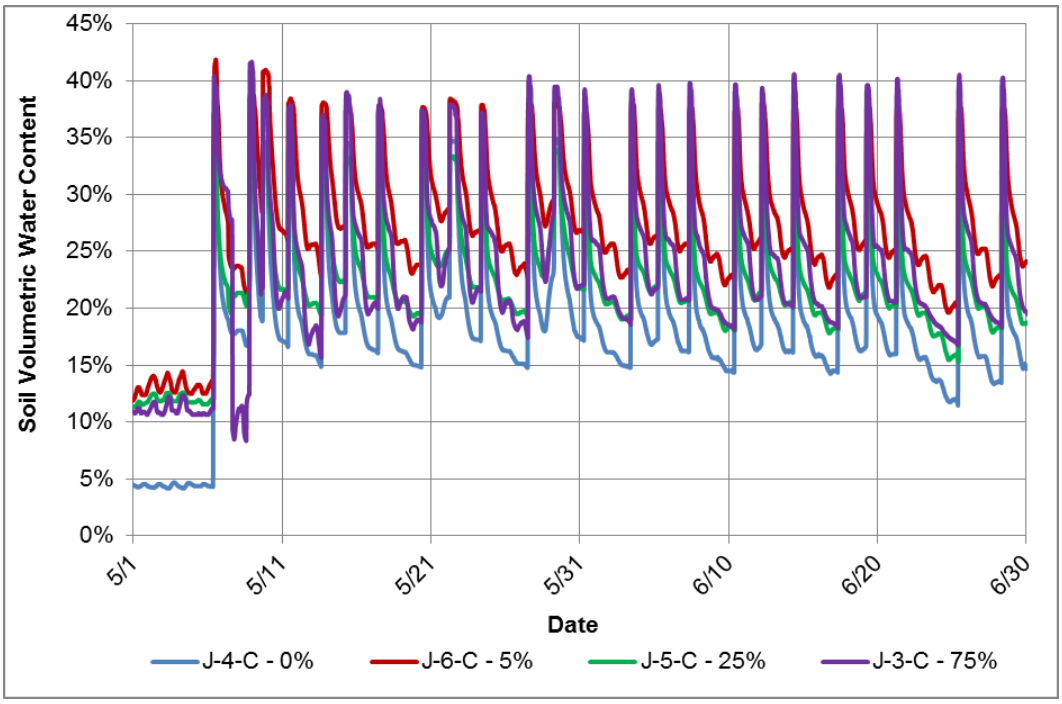

Figure 25.—Field J surface soil moisture content for each of the four instrumented pozzolan subplots for May and June 2013.

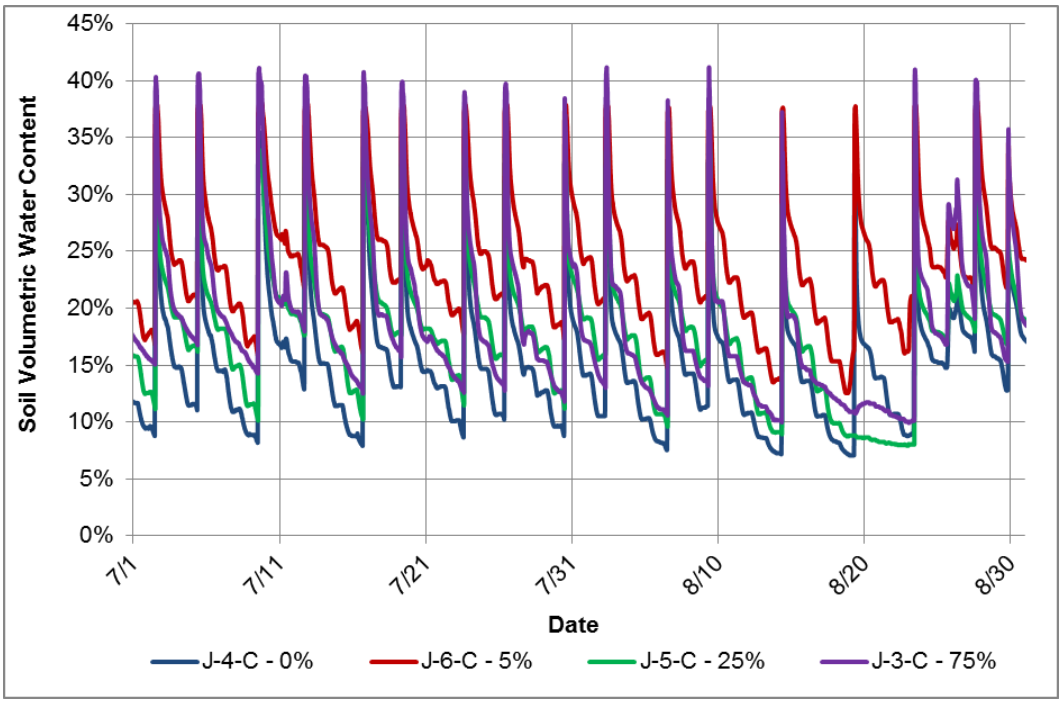

Figure 26.—Field J surface soil moisture content for each of the four instrumented pozzolan subplots for July and August 2013.

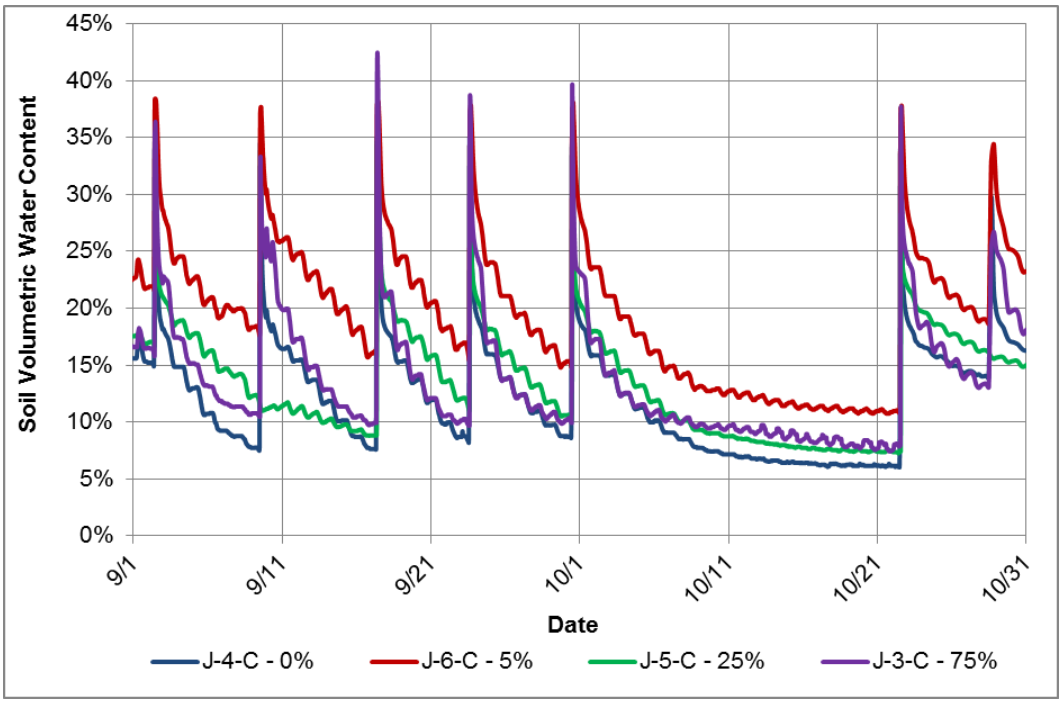

Figure 27.—Field J surface soil moisture content for each of the four instrumented pozzolan subplots for September and October 2013.

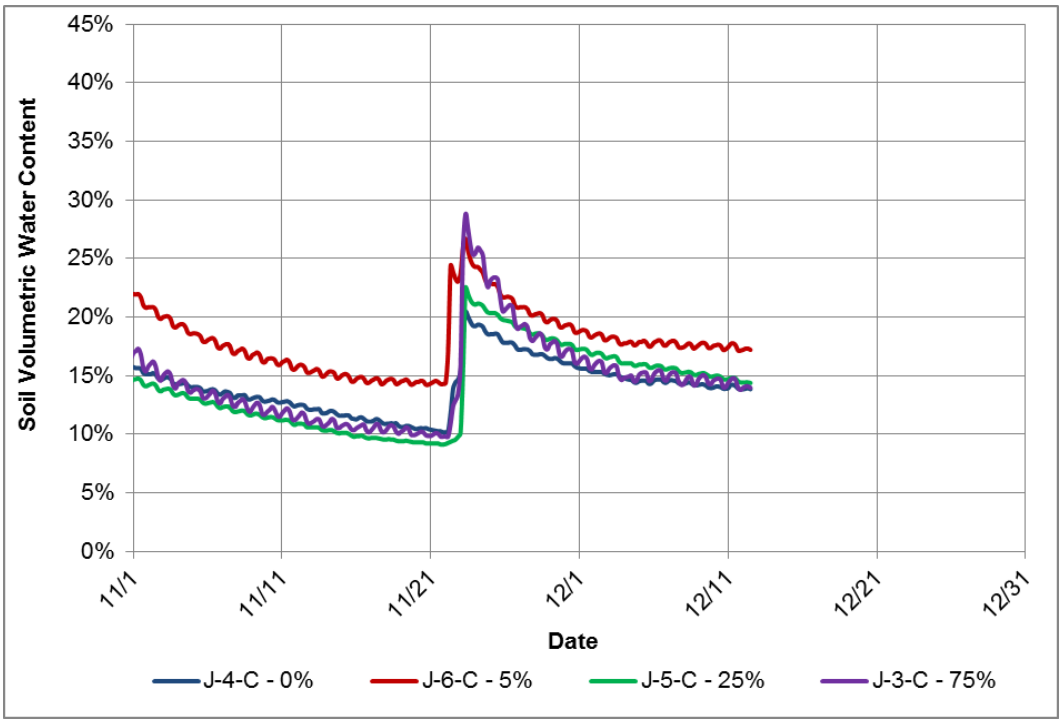

Figure 28.—Field J surface soil moisture content for each of the four instrumented pozzolan subplots for November and December 2013.

declined at similar rates for 0, 25, and 75% pozzolan plots to water content of between 6 and 8%. Soil moisture was higher for the 5% subplot (14%) most likely due to finer textured subsurface soil (between 50 and 75% sand between 1 and 4.25 feet bgs) which slowed the drainage of irrigation water from the soil profile.

Surface VWC for the four instrumented pozzolan subplots (3-B, 4-B, 5-B, and 6-B) in field E for the 2013 irrigation season is presented by 2-month periods on figures 29 through 32. As for field J, soil moisture retention during October provided the opportunity to observe how surface soil moisture responded to a longer period without irrigation. During this period, soil moisture retention was greatest for the 75% plot at 16%, and declined most (to 5% VWC) for the unamended plot, and was approximately 8% for the 5% pozzolan plot. The amended locations had consistently sandy subsurface profiles (> 90% sand throughout the soil profile), and therefore, water content differences are likely attributed to pozzolan amendment. Moisture in the 25% subplot remained elevated (approximately 20% VWC) during October, but in this case, finer-textured subsurface soils (81% sand between 1 and 1.5 feet bgs) likely impeded drainage and caused soil moisture to remain higher as compared to other subplots in the field.

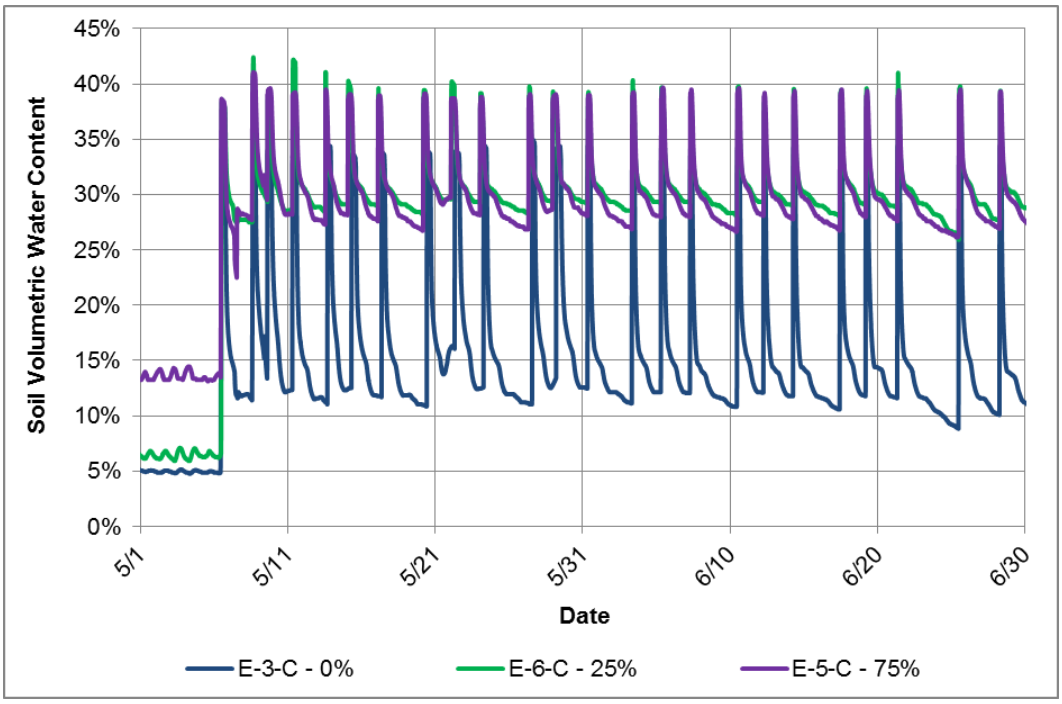

Figure 29.—Field E surface soil moisture content for three of the four instrumented subplots for May and June 2013 (the sensor in subplot E-4-C was not working during this period).

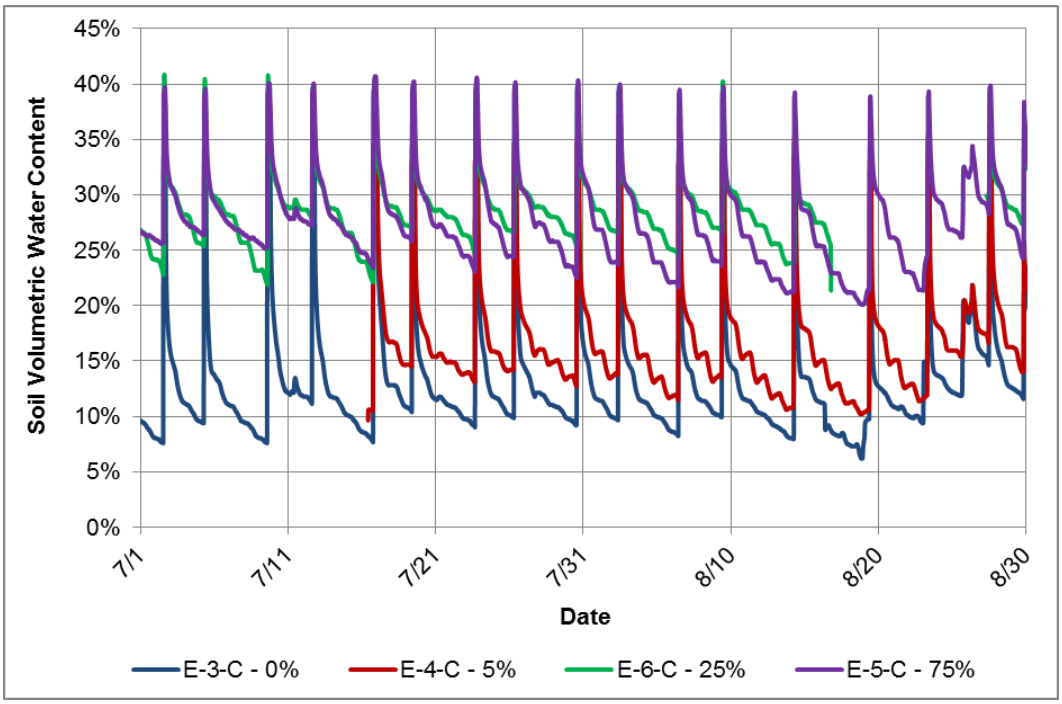

Figure 30.—Field E surface soil moisture content for each of the four instrumented subplots for July and August 2013.

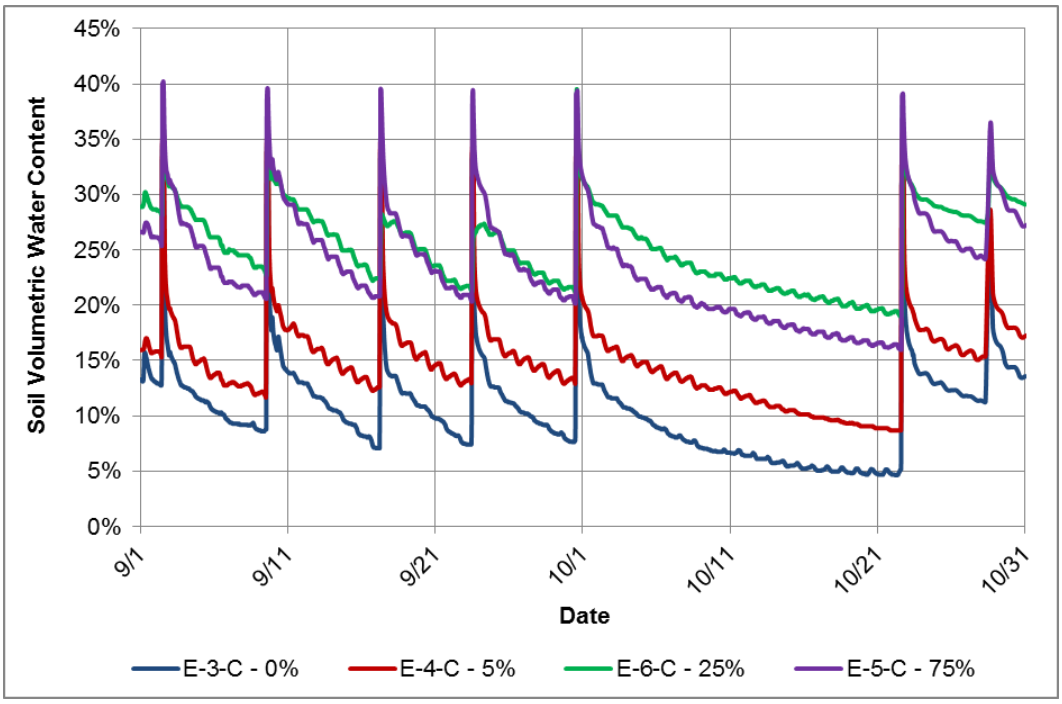

Figure 31.—Field E surface soil moisture content for each of the four instrumented subplots for September and October 2013.

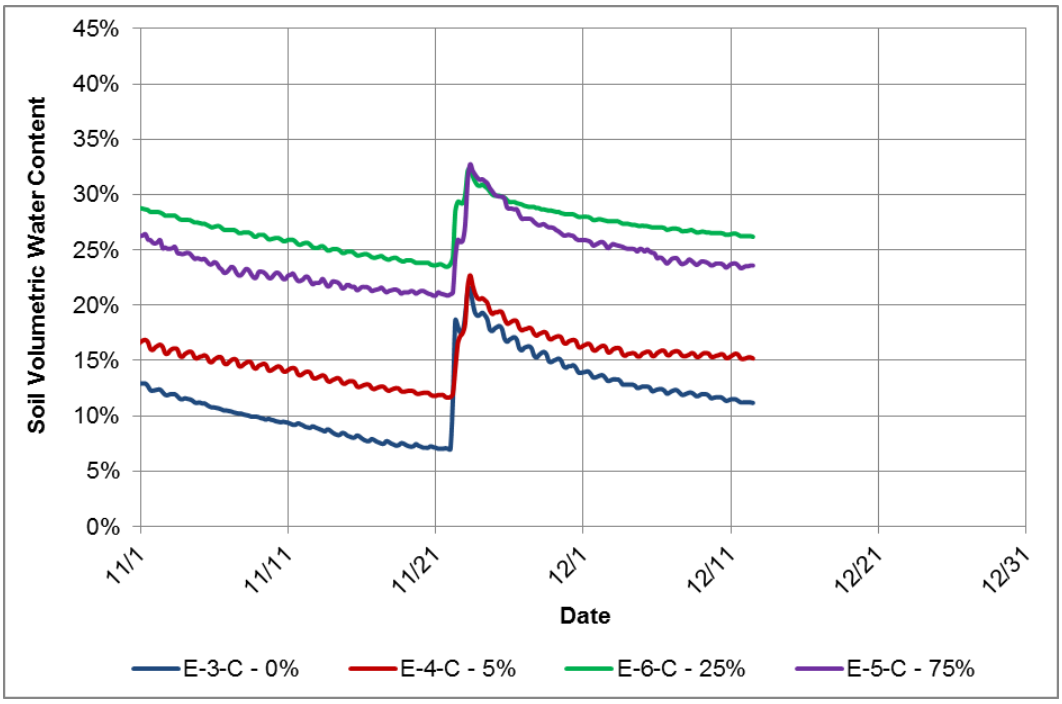

Figure 32.—Field E surface moisture content for each of the four instrumented subplots for November and December 2013.

Inconsistencies in pozzolan effects on soil moisture between fields J and E are likely due to a combination of factors. Underlying soil texture is likely the primary reason. While the surface soil for all instrumented subplots was between 92 and 95% sand, subsurface soil texture ranged from 51% (J-6-C) to 94% (E-4-C) (see table 10). The study was not designed to test for the interaction of soil texture and percent pozzolan on surface soil moisture. However, collected data allow an initial assessment because soil moisture instrumentation was installed in plot locations with a range of subsurface soil textures. Automated data are analyzed separately in the following section for subplots where the percent sand was greater than 90% throughout the soil profile (J-4-C, E-4-C, J-5-C, J-3-C, and E-5-C) and subplots that had at least 3 continuous inches of soil that were less than 85% sand (E-3-C, E-6-C, and J-6-C) (see table 10).

Figure 33 shows surface and subsurface soil moisture following irrigation on September 30, 2013, in coarse soil subplots (90% sand or greater for the entire soil profile). Subplot J-4-C (0% pozzolan) had the lowest soil moisture for the month, and subplot E-5-C (75% pozzolan) had the highest soil moisture. However, surface soil moisture for the other three subplots did not follow a trend of higher soil moisture with higher percent pozzolan. J-5-C (25% pozzolan) and J-3-C (75% pozzolan) had similar soil moisture levels that were less than subplot E-4-C (5% pozzolan). Subsurface soil moisture was similar for most subplots aside from E-5-C, which was much drier.

Figure 34 shows surface and subsurface soil moisture following irrigation on September 30, 2013, in subplots that had a finer-textured soils (less than 85% sand) for at least 3 continuous inches in the soil profile. For these three subplots, surface soil moisture was higher for 5% amendment rates than for the control (0%) and was again higher for 75% pozzolan rates. Subsurface soil moisture was highest for subplot J-6-C, which had the finest soil profile (less than 75% sand).

Figure 35 shows surface and subsurface soil moisture for the same period as the previous two figures for pozzolan treatments (0, 5, and 25%) that had one replicate in both soil types (continuously greater than 90% sand and less than 85% sand for at least 3 continuous inches in the soil profile). For control subplots (0% pozzolan), fines subsurface soil texture did not result in a markedly higher surface soil moisture. For 5% pozzolan plots, the finer-textured soil profile resulted in higher surface soil moisture for approximately a week after irrigation, after which only minor differences (less than approximate 5% VWC) in surface soil moisture were observed. Conversely, finer-textured subsurface soils at subplot E-6-C were associated with much higher surface soil water content (over 25% difference for most of the time between irrigation). While conclusions from these data should be tempered due to a lack of repetitions, these data indicate that higher rates of pozzolan soil amendment might have larger effects on finer-textured soils.

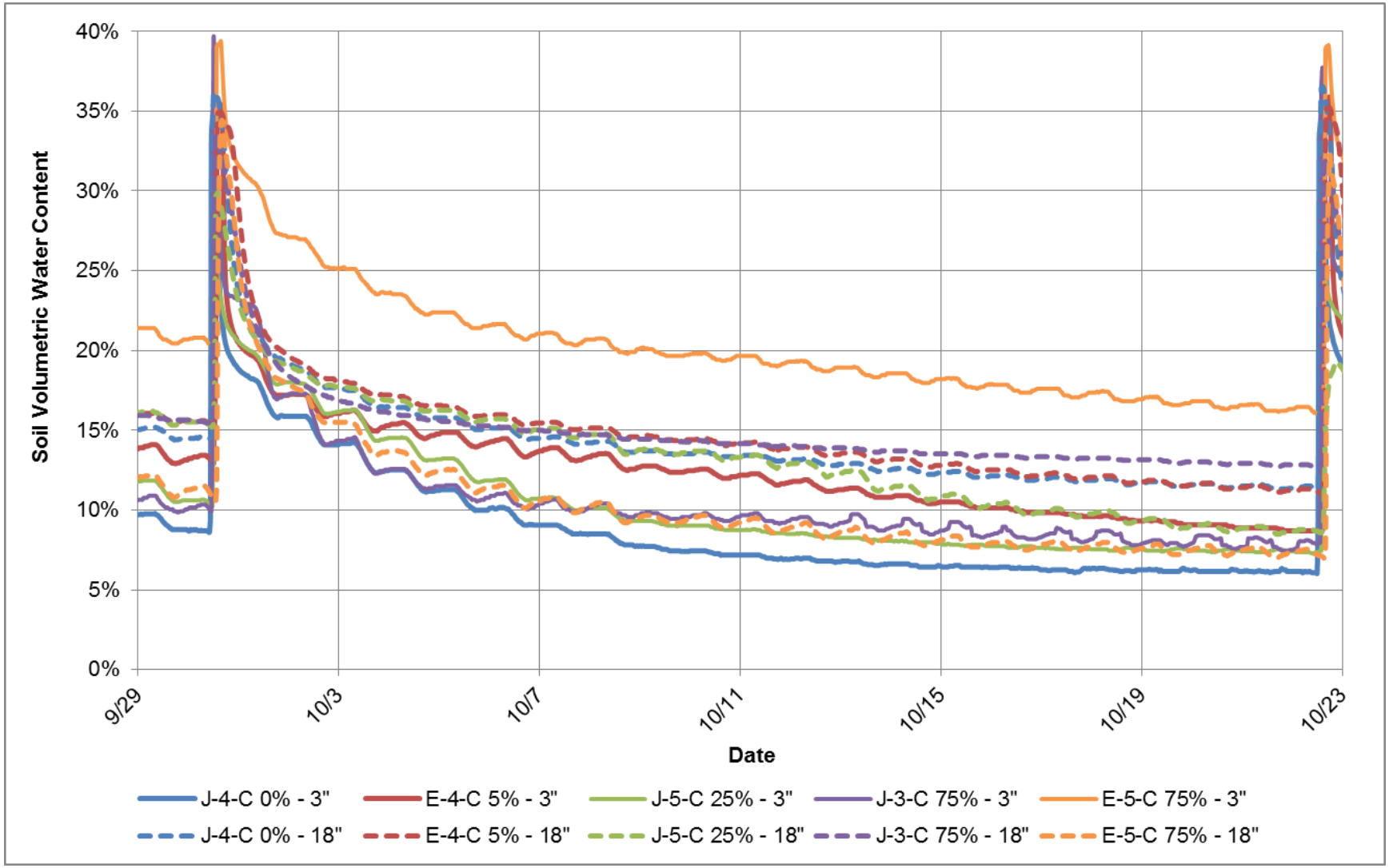

Figure 33.—Surface and subsurface soil moisture retention following an irrigation event on September 30, 2013, for soil profiles entirely above 90% sand.
Legend entries indicate the subplot name, pozzolan application rate, and sensor depth.

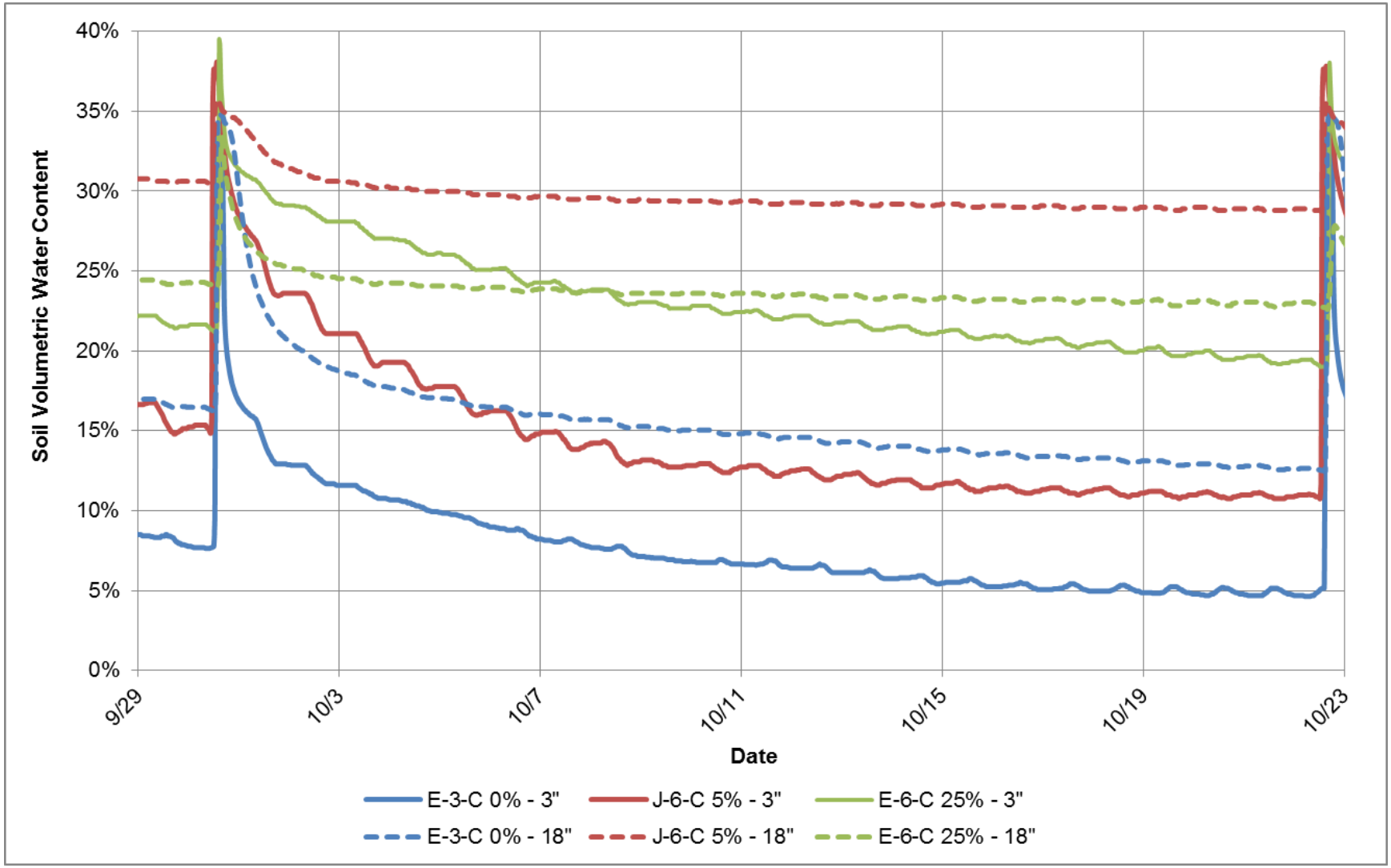

Figure 34.—Surface and subsurface soil moisture retention following an irrigation event on September 30, 2013, for soil profiles with at least 3 inches of soils with less than 85% sand.
Legend entries indicate the subplot name, pozzolan application rate, and sensor depth.

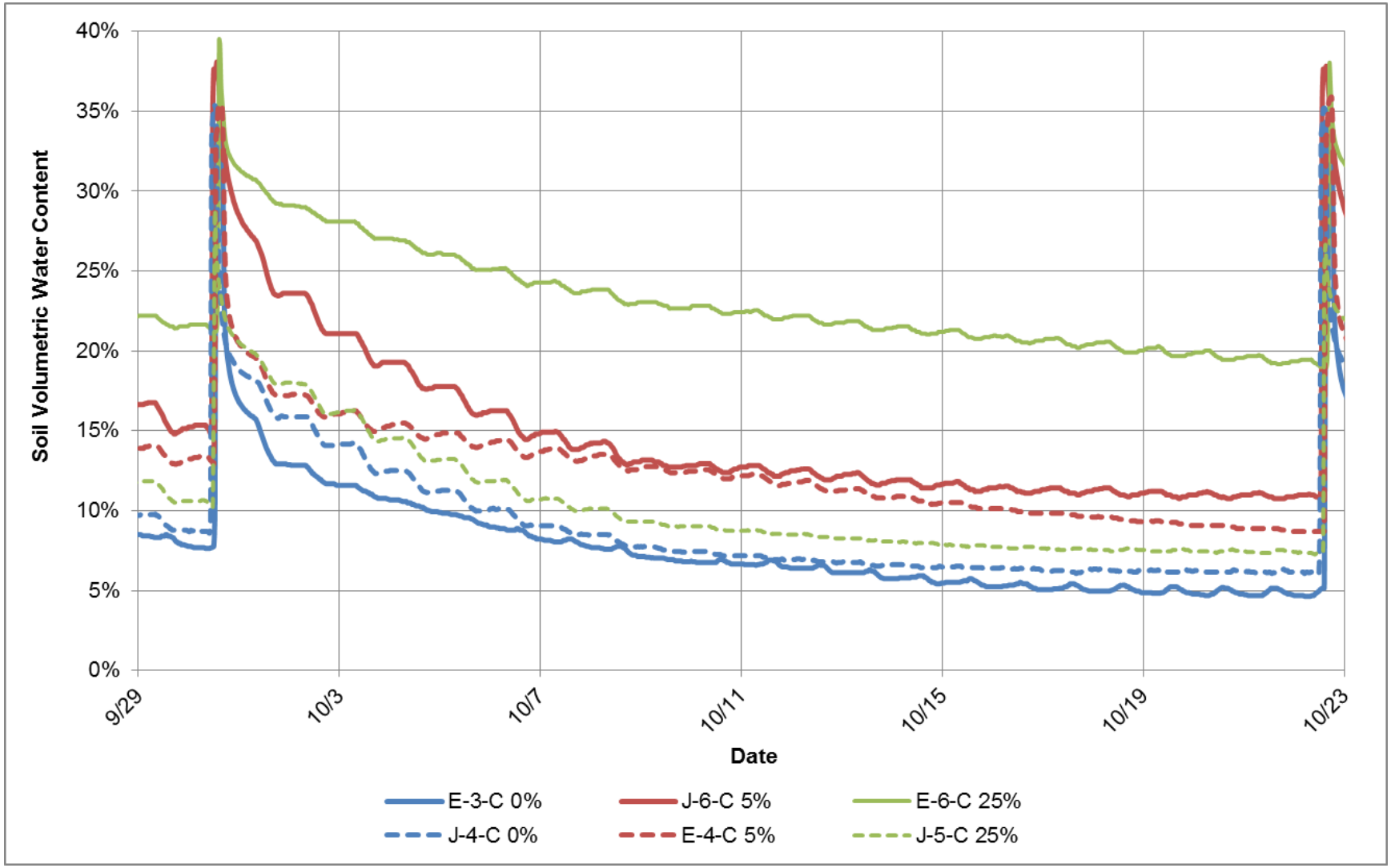

Figure 35.—Comparison of surface soil moisture retention following an irrigation event on September 30, 2013, for soil profiles with at least 3 inches of soils with less than 80% sand (solid lines) versus continuously sandy soils (dashed lines).
Legend entries indicate the subplot name, pozzolan application rate, and sensor depth.

In addition to background soil textural profiles, two other factors were identified as likely contributors to variation in automated water content monitoring data. First, pozzolan was incompletely crushed, so moisture within the pozzolan amended soils was likely very heterogeneous; sensors installed in subplots with the same amendment rates could measure significantly different moistures depending on the evenness of pozzolan mixing. The second factor was that some 75% subplots were slightly elevated above field level (up to approximately 4 inches), which could limit the amount of percolation occurring near sensors. Elevated soil would be inundated for a reduced duration, and if infiltration rates were lower, irrigation water would run off the subplot surface and infiltrate into surrounding soils.

Figures 36 and 37 present surface soil moisture for the month of September 2013 in broadcast amended plots of fields J and E, respectively. Surface moisture remained higher in plot J-7 and J-8 (mean of 78% surface sand) than plots J-1 and J-2 (soil surface texture similar to J-3, with above 90% sand) due to sandier soil textures in plots J-1 and J-2. Plot J-1, which was amended with 5% pozzolan by volume, appeared to retain slightly more moisture in the surface as compared to plot J-2, which is a control plot. Similarly, plot J-8, amended with 5% pozzolan, generally had slightly higher surface soil moisture than plot J-7. Plots J-7 and J-8 stayed nearly saturated (> 30% VWC) for over 2 days following irrigation events, whereas plots J-1 and J-2 dropped below 30% VWC within hours of irrigation ending. Although these data indicate that 5% pozzolan may increase moisture slightly in sandy soils as encountered in plots J-1 and J-2, the moisture retention of nearby finer-textured soils without pozzolan amendment (plot J-7) was higher.

Soil moisture was very similar between plots E-1 (control) and E-2 (5% pozzolan). Comparison between plots E-7 and E-8 is precluded by irrigation typically not saturating the sensor location of plot E-8 due to topographic variation. Plot E-7, a control plot, retained more moisture than plots E-1 and E-2 likely because of finer-textured underlying soils, which slow the percolation of water through the soil profile. Soil moisture in all broadcast amended plots of field E drained to less than 30% moisture within hours of irrigation ending. Soils in plots 7 and 8 of field E were sandier (mean 85% in surface soil, 83% below) than those in field J (mean 78% in surface soil, 67% below) (see table 10).

4.4.3 Irrigation Monitoring

Figure 38 provides a subset of irrigation monitoring data at BLCA field E plot 1 (0% pozzolan) for the two weeks after hydroseeding. Irrigation events, represented by peaks in the data, occurred every 2–3 days for the first 7 weeks to maintain the highest logistically feasible surface soil moisture to support germination and seedling survival. An example of the arrival and recession of water for an irrigation event on May 15, 2013, is shown on figure 39.

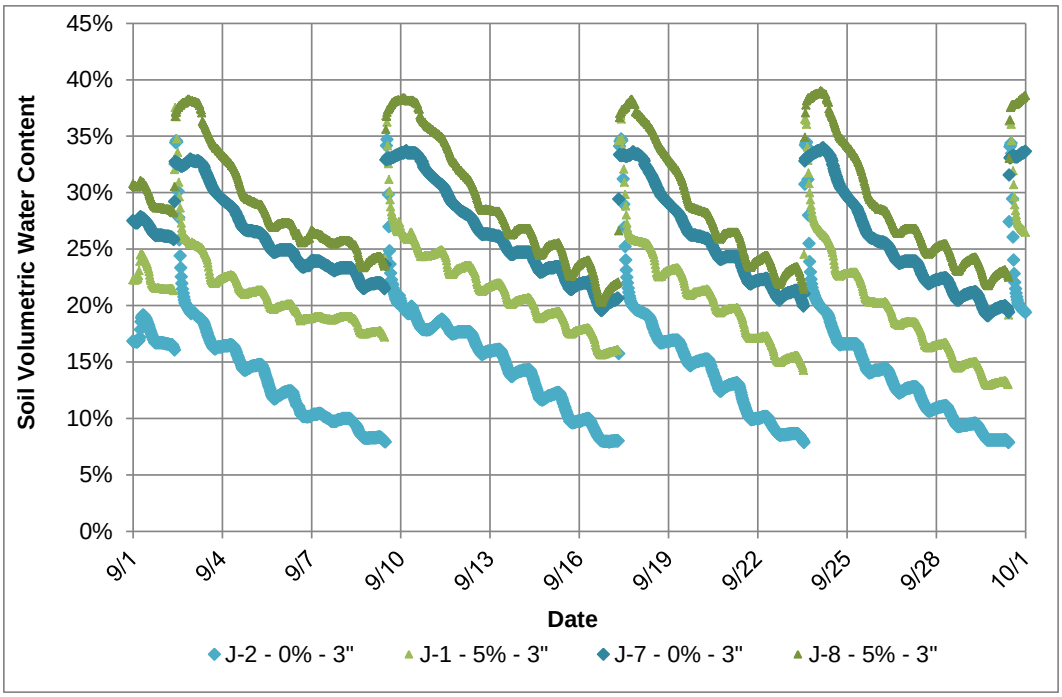

Figure 36.—Surface (3 inches bgs) VWC for the month of September 2013 for plots J-1, J-2, J-7, and J-8.

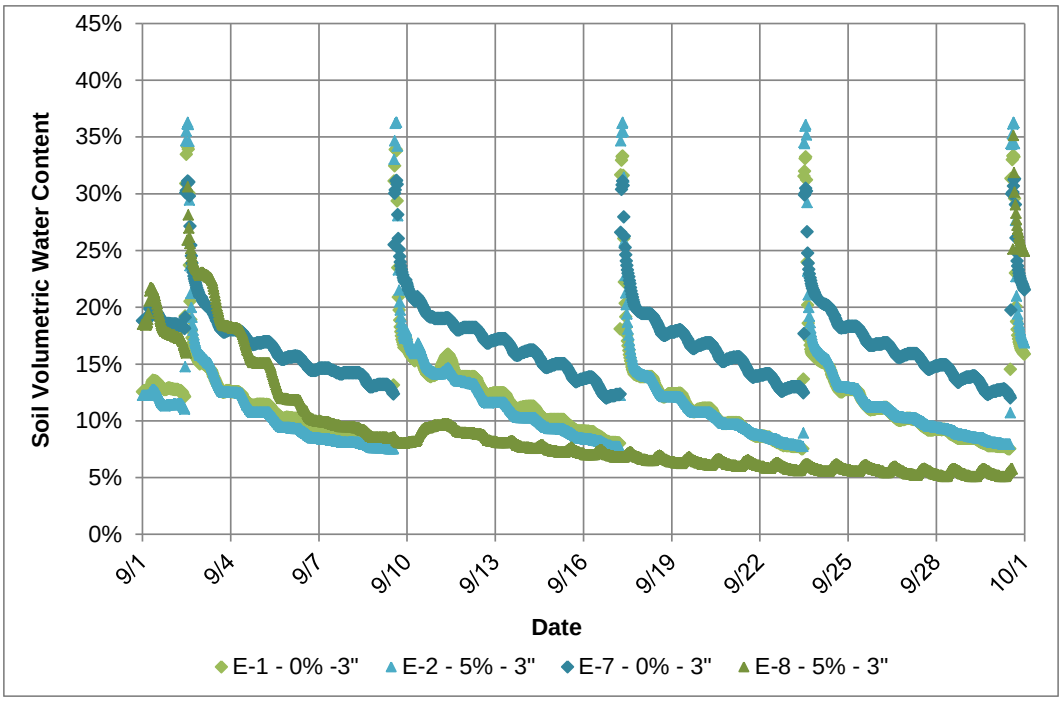

Figure 37.—Surface (3 inches bgs) VWC for the month of September 2013 for plots E-1, E-2, E-7, and E-8.

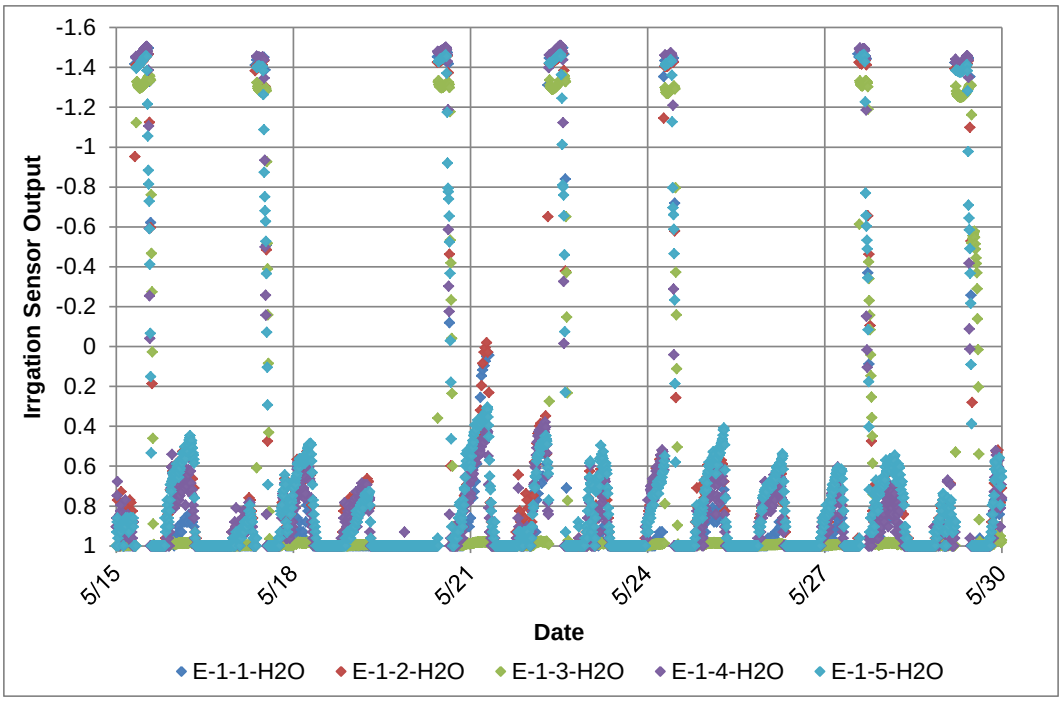

Figure 38.—Irrigation station monitoring data for field E, plot 1 (0% pozzolan), for a subset of the 2013 irrigation season.
Numbers less than zero indicate irrigation presence; numbers above zero indicate irrigation absence.

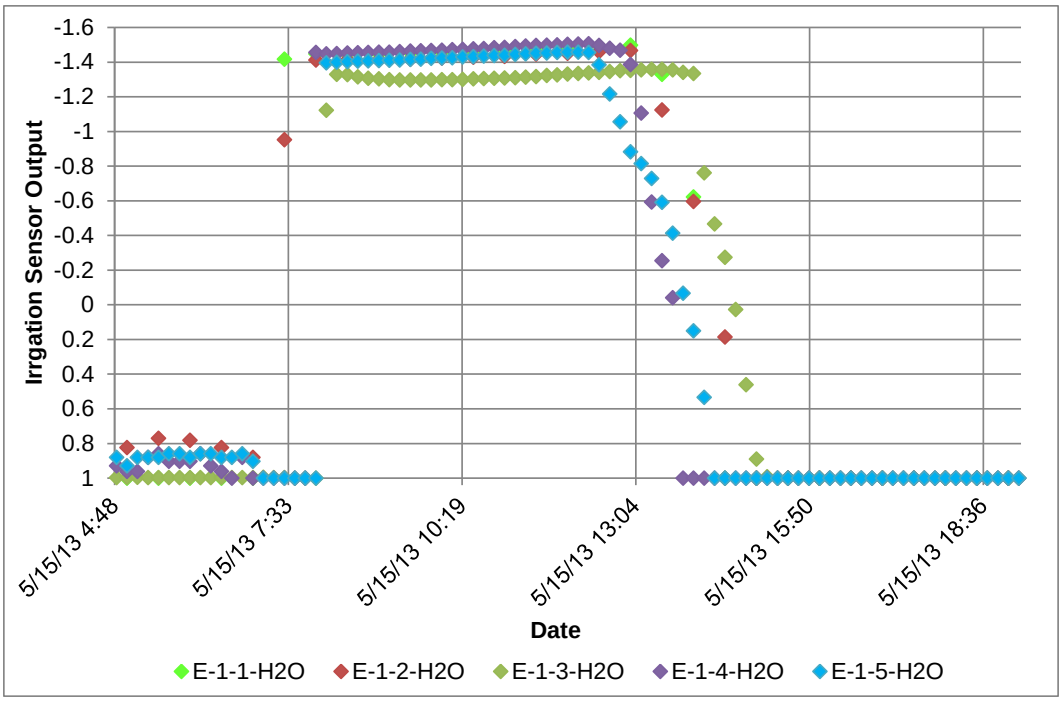

Figure 39.—Irrigation station monitoring data for field E, plot 1 (0% pozzolan), for an irrigation event on May 15, 2013.
Numbers less than zero indicate irrigation presence; numbers above zero indicate irrigation absence.

When irrigation is not present, sensor outputs are positive values. When irrigation is present, output values drop to negative numbers.

Monitoring of irrigation distribution and inundation duration with irrigation sensors proved to be limited in use due to site preparation challenges. Specifically, irrigation distribution was difficult to control due to sandy soils and high winds. Constructed furrows collapsed soon after construction, and wind re-distributed leveled soils to create topographic variation. Additionally, while the plastic-lined irrigation canals did increase the rate that water moved to all plots, plots E-1 and E-2 received more water than plots further from the irrigation valve.

Summary statistics for the 47 irrigation events in the 2013 irrigation season are provided in table 12. Average irrigation duration and applied water were slightly higher for field E as compared to field J likely due to differences in efficiency of water conveyance down the irrigation canal. Applying water to the edge of field E was often unachievable due to the higher elevation at this corner of the field compared to the irrigation source location.

Table 12.—BLCA fields J and E irrigation summary statistics for 2013 growing season[a]

	Irrigation duration (hours)			Flow rate (cubic feet per second)		Applied water (feet)		
Field	**Mean**	**n**	**Standard deviation**	**Mean**	**Standard deviation**	**Mean**	**Standard deviation**	**Total**
J	1.52	47	0.27	14.6	1.08	0.65	0.10	30.36
E	1.72	47	0.30	15.0	0.56	0.75	0.11	35.06

[a] Irrigation duration and flow rate data were provided by the irrigation contractor. The applied water was calculated by dividing the total water application (irrigation duration multiplied by flow rate) by the square feet irrigated (the size of each field).

Inundation duration indicates the amount of time that water was present and infiltrating during irrigation events. Higher inundation duration indicates that infiltration rates were lower. Inundation duration data for an irrigation event on July 5, 2013, are summarized by percent pozzolan in table 13. Summaries by field include data from the four instrumented subplots (two per field) of each pozzolan percentage. The longest inundation was seen for field J 0 and 5% subplots because these two subplots were in plot J-6, where finer-textured subsurface soils slowed infiltration. The broadcast plot summary includes the inundation duration for sensors in fields J and E, plots 1, 2, 7 and 8.

Inundation during this irrigation event averaged 14.3 hours for plot J-7 (0% pozzolan) and 8.2 hours for plot J-8 (5% pozzolan). Inundation duration averaged

Table 13.—Inundation duration summary for all surface irrigation sensors for an irrigation event on July 5, 2013

Location	Pozzolan rate (%)	n[a]	Average inundation duration (hours)
Field J	0	2	6.33
	5	2	5.17
	25	2	3.92
	75	2	3.17
Field E	0	2	3.42
	5	2	3.50
	25	2	2.42
	75	2	3.25
Broadcast plots	0	20	6.01
	5	17	4.78

[a] Number of irrigation sensors for the given pozzolan rate.

2.9 hours for plot E-7 (0% pozzolan) and 2 hours for plot E-8 (5% pozzolan). It took between 20 minutes (plot J-8) and 1.3 hours (plot E-7) for water to travel from the sensor closest to the canal to the sensor furthest from the canal. In the case of plot E-8, the water did not typically reach the farthest sensor due to high surface elevation at this location.

4.4.4 Soil Moisture Manual Sampling

Manual soil moisture sampling results for pozzolan subplots approximately 20 hours after the end of irrigation are summarized on figure 40. These results indicate that either 25 or 75% pozzolan amendment increased initial soil moisture retention after irrigation (i.e., soil moisture was higher in subplots than adjacent soils without pozzolan), whereas a 5% application rate did not. Soils amended with 75% pozzolan also resulted in significantly higher soil moisture than all other pozzolan rates tested.

Subsurface (15–21 inches bgs) soil moisture results for manual soil moisture sampling 20 hours after irrigation are presented on figure 41. Soil moisture was significantly lower beneath the 75% subplots than beneath the 0% subplots, but other differences were insignificant. Decreased soil moisture below 75% pozzolan application was likely due to less infiltration and higher moisture retention in the above amended layer.

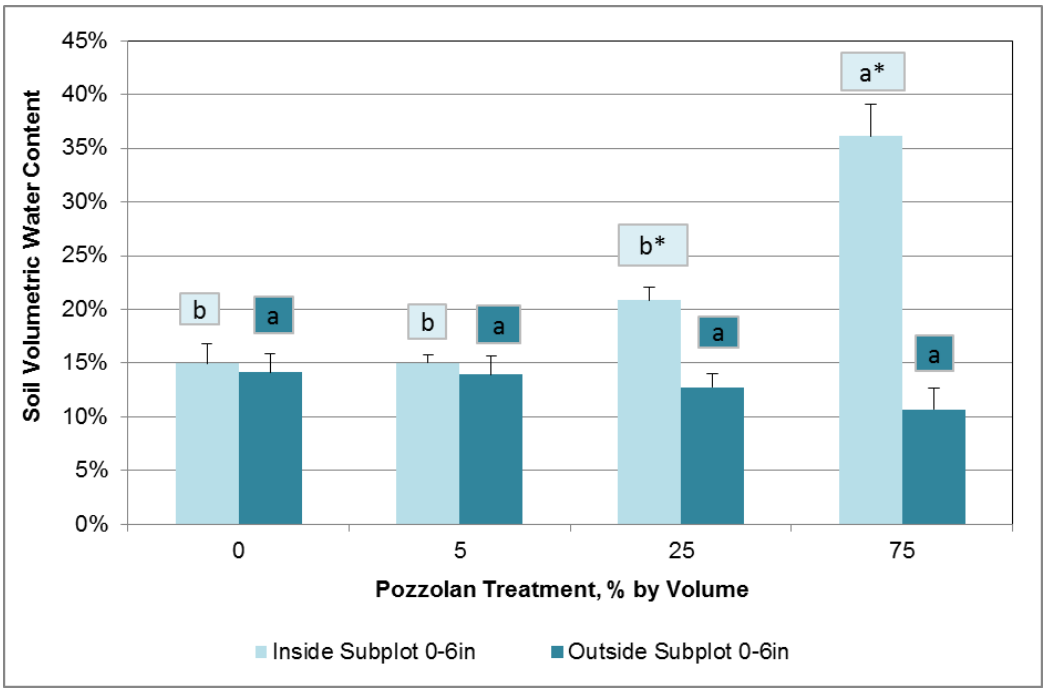

Figure 40.—ANOVA results for subplot surface soil moisture grab samples collected on October 23, 2013.
* Indicates significantly higher moisture inside the pozzolan treatment as compared to outside (Student's T-test, 0.05 alpha). Letters indicate significant differences (Student's T-test, 0.05 alpha) between pozzolan treatments.

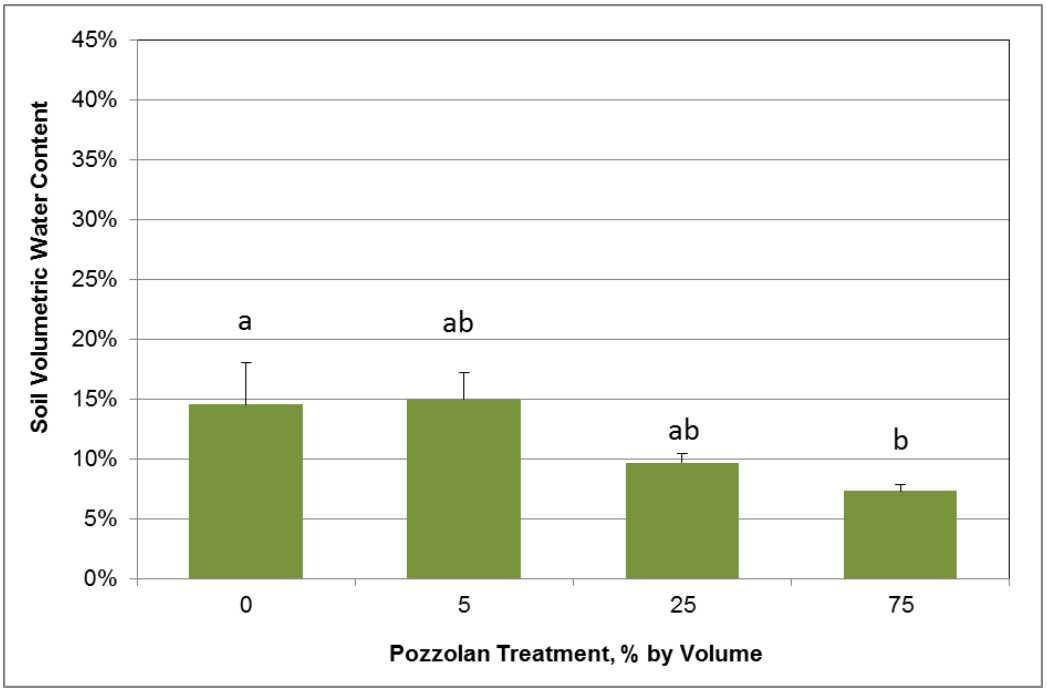

Figure 41.—ANOVA results for subplot subsurface (15–21 inches bgs) soil moisture grab samples collected on October 23, 2013.
Letters indicate significant differences between pozzolan treatments (Student's t-test, 0.05 alpha).

Results of soil sampling in plots 1, 2, 7, and 8 on October 23, 2013, 20 hours following an irrigation event, are presented on figure 42. Surface soil water content did not differ between 0 and 5% pozzolan broadcast treatments.

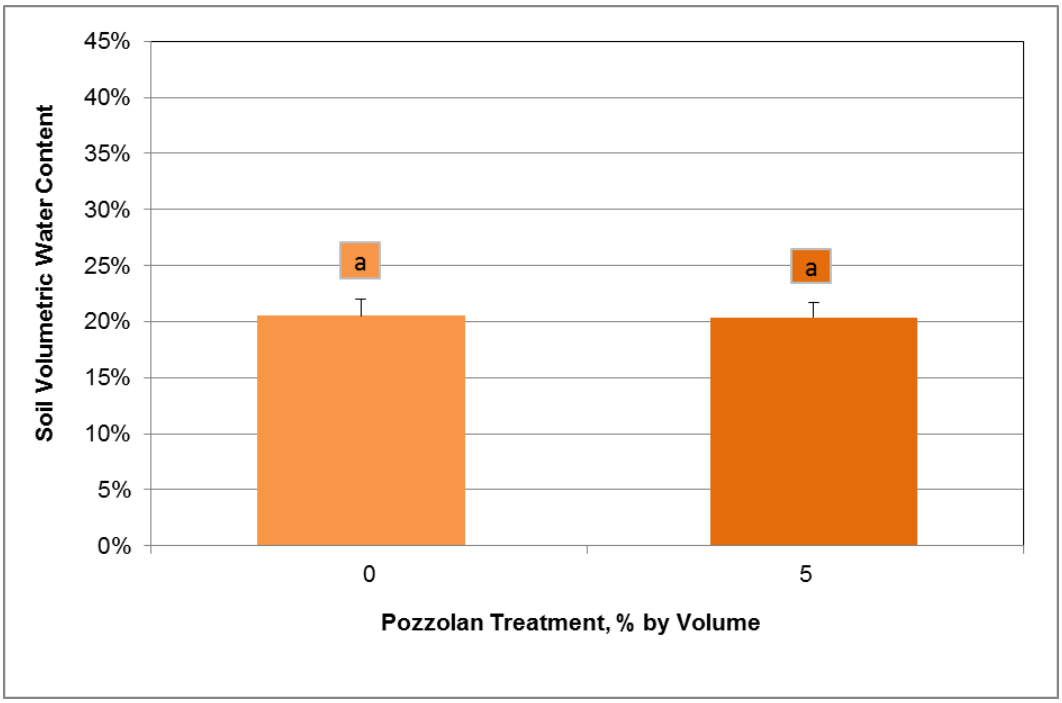

Figure 42.—Mean VWC in the surface of broadcast treatments on October 23, 2013, approximately 20 hours after irrigation.
Similar letters indicate lack of significant differences (Student's t-test, 0.05 alpha).

4.5 Vegetation Monitoring

As detailed below, Goodding's willow establishment at the study site was minimal and precluded detailed statistical analyses of this species based on the complete randomized block study design (seedlings were detected in only one subplot, J-6-A). Results are discussed in a qualitative context in this section.

Vegetation at fields J and E was dominated by arrowweed ,which re-sprouted from the roots remaining on the fields despite repeated clearing and tilling events and spot treatment with herbicide. Screwbean mesquite (*Prosopis pubescens*) was the most common species observed. The seedlings were generally small (less than 6 inches in height), occurring uniformly across sandy areas and in pozzolan subplots (figure 43). Coyote willow and Fremont cottonwood were present in both fields. Fremont cottonwood was primarily comprised of re-sprouts (figure 44), although some seedlings were also observed. Patches of coyote willow re-sprouts were fairly common and were similar in height to arrowweed (figure 45).

Figure 43.—Screwbean mesquite seedlings in plot E-5 (0% pozzolan) on August 15, 2013.

Figure 44.—Fremont cottonwood re-sprouts near subplot E-5-B (0% pozzolan) on August 15, 2013.

Figure 45.—Coyote willow re-sprouts near subplot J-6-C (5% pozzolan), August 15, 2013.

Goodding's willow seedlings did not successfully establish in most areas; seedlings were only observed in plots J-6, J-7, and J-8. During a preliminary, qualitative vegetation survey in October 2013, numerous Goodding's willow seedlings were observed in these plots and ranged from approximately 2 to 4 inches in height (figure 46). These plots are much finer grained (less sand, more silt) than other plots (see section 4.3.3), and the surface remained visibly wet several days after irrigation events. No Goodding's willows were observed in field E. The extent of fine-textured soils was also much lower in field E as compared to field J, both on the surface and with depth. To avoid trampling of seedlings, a quantitative survey was not performed in October.

Quantitative surveys were completed during December. Detailed vegetation data were collected in subplot areas, and a Goodding's willow count was conducted for the entirety of plot J-8 (farthest from irrigation valve, 5% pozzolan). Nearly all Goodding's willows were either chewed off 1–4 inches above the ground due to rabbits (rabbit droppings were abundant) or had been buried by feral pig rooting activity. Most willows were re-sprouting. The tallest tree, which had not been chewed, was 37 inches in height.

Figure 46.—Goodding's willow seedling in relatively fine soils of plot J-7 (0% pozzolan) on October 23, 2013.

Goodding's willow density was highest in the southeastern portion of plot J-8, where 13 willows were counted in vegetation survey area J-8-D. A total of 132 Goodding's willows were observed in plot J-8 (13,500 square feet), for an estimated 436 trees per acre.

The abundance of other plant species also varied due to soil type and resultant moisture conditions. In coarser soils, the most commonly observed species were arrowweed, mesquite, and salt heliotrope (*Heliotropium curassavicum*). The most common species found in finer-textured soils were small grasses and succulent forbs (i.e., salt heliotrope and purslane [*Portulaca oleracea*], as shown on figure 47). Arrowweed less abundant in these finer-textured areas, which were present in plots J-7, J-8, E-6, E-7, and E-8; however, for field E, this vegetation assemblage was only for the first 40 feet (northwest edge of the plot) adjacent to the irrigation canal. A list of all plant species observed in fields J and E at the time of the surveys is provided in table 14.

Pozzolan subplots often had distinct vegetation distribution compared to surrounding areas (figure 48). Plots with high (75%) pozzolan percentages had less arrowweed, a higher cover of salt heliotrope, and a higher density of mesquite compared to areas without pozzolan.

Figure 47.—Plot J-8 (5% pozzolan), looking northwest, August 15, 2013.

Table 14.—Vegetation present at BLCA fields J and E in December 2013

Vegetation class	Scientific name	Common name
Tree	*Salix exigua*	Coyote willow
	Salix gooddingii	Goodding's willow
	Populus fremontii	Fremont cottonwood
	Prosopis pubescens	Screwbean mesquite
Shrub	*Tamarix ramosissima*	Salt cedar
	Pluchea sericea	Arrowweed
	Baccharis sarothroides	Desert broom
Sedge	*Eleocharis geniculata*	Canada spikesedge
	Cyperus spp.	Nut sedge
Grass	*Sporobolus contractus*	Spike dropseed
Herbaceous	*Heliotropium curassavicum*	Salt heliotrope
	Trianthema portulocastrum	Desert horse purslane
	Portulaca oleracea	Common purslane
	Conyza canadensis	Canadian horseweed
	Plantago sp.	Plantain/fleawort

Figure 48.—Subplot J-5-B amended with 75% pozzolan had less arrowweed compared to the surrounding area.

5.0 CONCLUSIONS

5.1 Pozzolan Effects on Gooding's Willow Germination Success

Pozzolan incorporation for this study did not increase Goodding's willow seedling establishment. This is likely due to a combination of salinity in excess of seedling tolerance combined with inadequate surface soil moisture. Goodding's willow seedlings established only on naturally finer-textured soils in plots 6, 7, and 8 of field J, which remained near saturation for an extended period after irrigation and had a much different vegetation community comprised primarily of succulent herbs instead of arrowweed. Extensive herbivory by rabbits and disturbance from feral pigs negatively impacted seedlings in late fall of 2013, and by December 2013, only a few seedlings remained in good condition. The survival of established seedlings over the winter of 2013–14 is uncertain.

Arrowweed was the dominant vegetation species across both fields, with minor components of screwbean mesquite, coyote willow, cottonwood, and salt cedar. Pozzolan application at 75% resulted in shorter, less dense vegetation.

5.2 Pozzolan Effects on Soil Moisture Retention

Based on laboratory analyses of soil samples, 25 and 75% pozzolan effectively increased soil moisture retention following irrigation (GSA 2007). Pozzolan (5%) did not result in increased soil moisture retention. Automated soil moisture monitoring station results were not consistent: automated data from field E showed higher surface soil moisture with higher amendment rates, whereas differences were absent or minimal in field J. This inconsistency is likely due to higher than anticipated subsurface soil variation at the site. Subplots with fine-textured underlying soil maintained the most surface moisture following irrigation regardless of the pozzolan amendment rate. More complete crushing of pozzolan aggregates might also enhance soil moisture differences among pozzolan application rates.

5.3 Pozzolan Effects on Infiltration Rates and Irrigation Efficiency

Infiltration field testing results indicated that pozzolan amendment rates of 25 and 75% reduced infiltration rates (drainage of irrigation) by over 40% for the 25% amendment rate and over 90% for the 75% amendment rate (based on saturated hydraulic conductivity). Amendment with pozzolan at 5% by volume did not reduce infiltration rates. Infiltration rates actually increased after incorporation of 5% pozzolan likely due to the surface disturbance during incorporation. This was likely a transient effect; future infiltration testing would be required to determine changes in infiltration rates after soils re-settled.

The effects of broadcast amendment of 5% pozzolan by volume on irrigation efficiency or inundation duration could not be well quantified due to a lack of irrigation distribution control at the site. However, based on the results from comparing the 0% pozzolan plots with the 5% plots, amendment rates of 5% would not be expected to increase irrigation efficiency. Lower infiltration rates observed at higher (25 or 75%) amendment rates would likely increase irrigation efficiency.

6.0 RECOMMENDATIONS

Goodding's willow successfully established only in portions of the site where background soil texture promoted prolonged surface soil saturation. While pozzolan amendment did not increase the germination and establishment of Goodding's willow, at 25 and 75% levels, it increased soil moisture retention after irrigation and reduced infiltration rates. These effects would be beneficial for LCR MSCP site management in terms of increasing soil moisture as needed for

riparian obligate bird species (Reclamation 2004) and increasing irrigation efficiency. These two benefits would likely result in less required irrigation for LCR MSCP conservation areas.

Specific recommendations for the LCR MSCP are as follows:

- *Crush pozzolan prior to incorporation*: Despite attempts at in-situ crushing, pozzolan aggregates remained. Crushing prior to application would likely increase amendment effectiveness and/or reduce the volume of required material to achieve desired results.

- *Irrigate pozzolan to leach salts to acceptable levels prior to planting*: Results from this study indicate that a full year of irrigation might reduce soil salinity to acceptable levels for native riparian seedling recruitment. However, mass planting of cuttings or seedlings, the preferred revegetation method of Reclamation, is likely to be less limited by salinity levels since salinity tolerance increases with tree size (GSA 2011) and would thus require less extensive leaching prior to planting.

- *Conduct laboratory analyses of saturated hydraulic conductivity and soil moisture retention for different amendment levels*: The volume of pozzolan required to achieve target soil attributes is likely to vary based on soil conditions, and surface soils at the BLCA are sandier than at most other LCR MSCP conservation areas (GSA 2014). This analysis would allow Reclamation to economically select amendment rates for field testing.

- *For creation of moist soil patches, place soil amendments in depressions*: If soil amendment patches are not in depressions, irrigation water will preferentially infiltrate into surrounding soils. If placed in depressions, soil inundation and soil moisture retention benefits would likely be enhanced.

- *Where irrigation efficiency is poor, consider strategic placement of irrigation distribution canals across fields*: Canals lined with pozzolan would likely convey irrigation more quickly to the portion of the fields furthest removed from the irrigation lateral, potentially increasing irrigation efficiency. These canals would likely also retain higher soil moisture between irrigation events, providing moist areas within created habitat.

Despite the potential benefits of pozzolan application, the long-term availability of this material is uncertain since the source facility is not currently in operation. However, other amendments known to improve soil moisture retention, such as biochar, compost, peat moss, bentonite, and vermiculite, could also be considered.

Clays present at other LCR MSCP conservation areas could also be used as borrow material. If any of these amendment options are explored, we recommend testing materials similarly to the field methods presented in this report and the laboratory tests described above.

7.0 ACKNOWLEDGEMENTS

We thank the staff of the LCR MSCP and Reclamation (Lower Colorado Regional Office) for its funding and guidance for this project. We also thank the U.S. Fish and Wildlife Service management and staff at the Havasu NWR for their assistance and access to the Beal Lake Conservation Area. In addition, we thank Allen, with American Landscape Services, LLC, for irrigation assistance.

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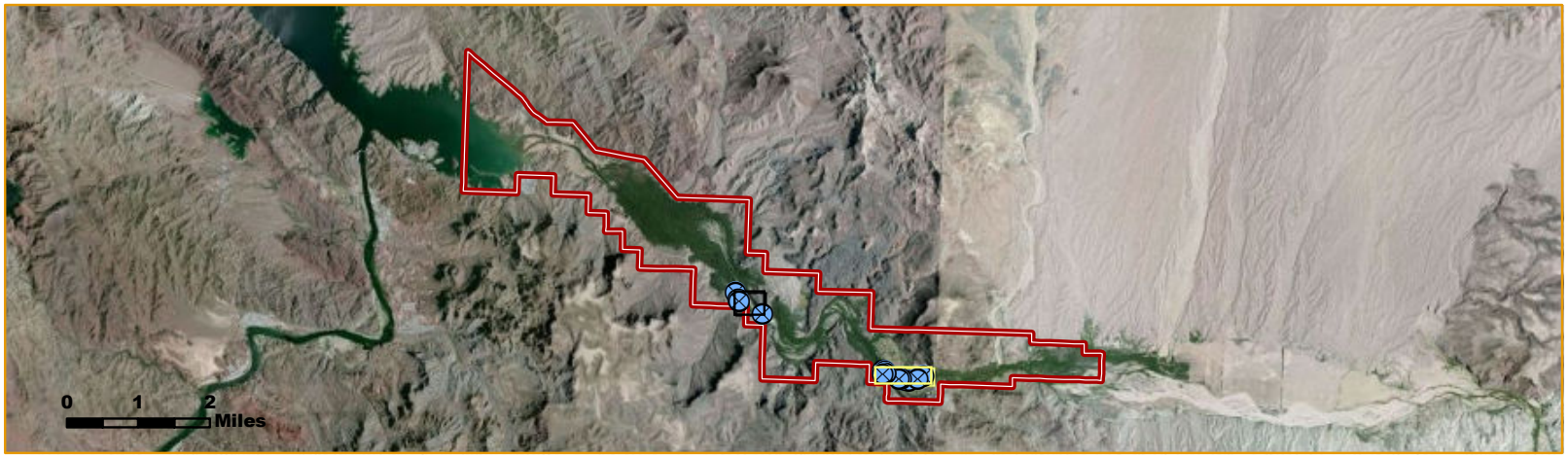
ATTACHMENT 1

2012 Goodding's Willow Seed Collection Locations

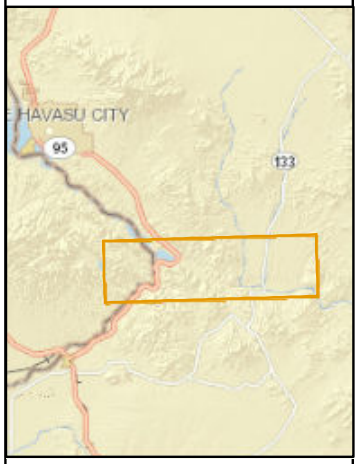
March/April 2012 Seed Collection Locations: Bill Williams River National Wildlife Refuge



Legend

Species Collected

- Populus fremontii
- Salix exigua
- Salix gooddingii
- **USFWS Refuge Boundary**



Map projection = UTM NAD 1983, Zone 12N, meters
Map created by Chad McKenna, GeoSystems Analysis, Inc. on July 9, 2012.

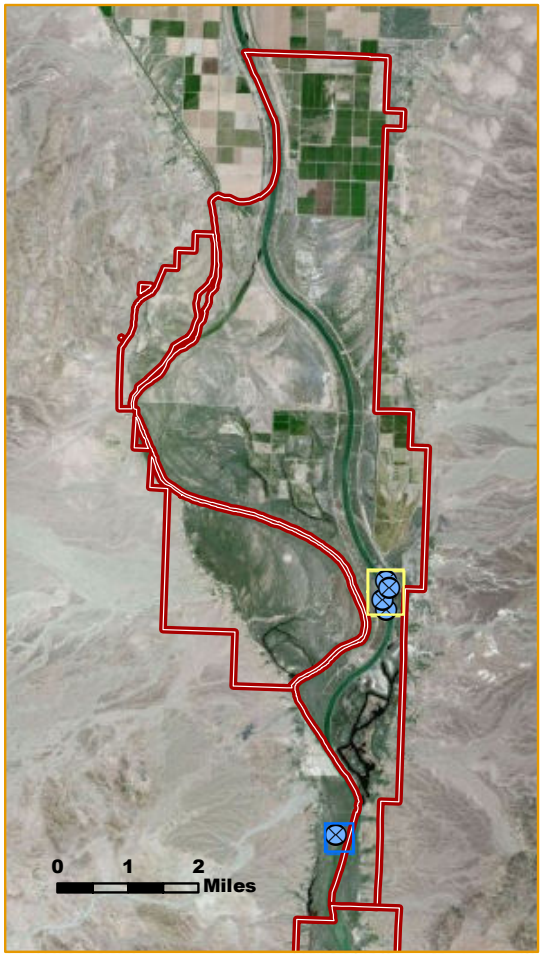
Background imagery: Bing Basemap served via ESRI online

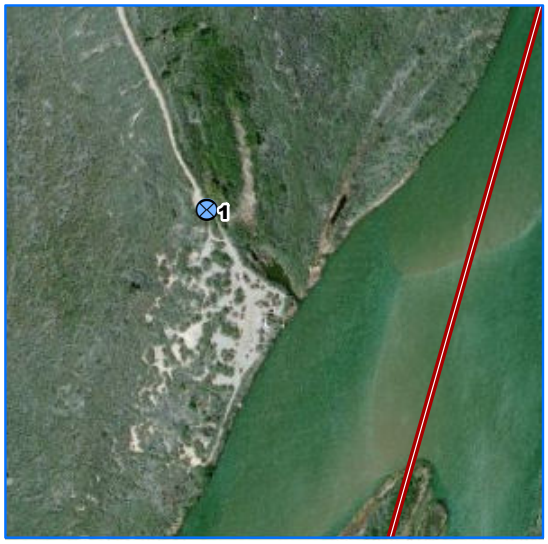
Refuge boundary: USFWS Cadastral Geodatabase

Seed collection locations: Sub-meter field GPS locations GeoSystems Analysis

GSA GeoSystems Analysis, Inc.
Innovations in Hydrology

March/April 2012 Seed Collection Locations: Cibola National Wildlife Refuge

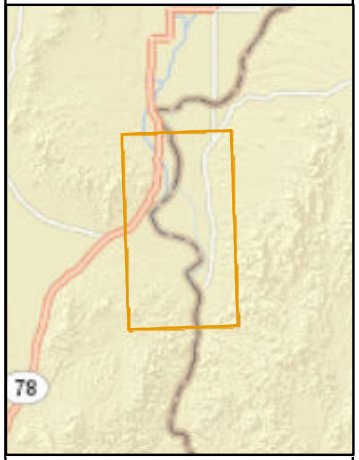




Legend

Species Collected

- Populus fremontii
- Salix exigua
- Salix gooddingii
- USFWS Refuge Boundary



Map projection = UTM NAD 1983, Zone 12N, meters
Map created by Chad McKenna, GeoSystems Analysis, Inc. on July 9, 2012.

Background imagery: Bing Basemap served via ESRI online

Refuge boundary: USFWS Cadastral Geodatabase

Seed collection locations: Sub-meter field GPS locations GeoSystems Analysis

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March/April 2012 Seed Collection Locations:
Havasu National Wildlife Refuge

Legend

Species Collected

- Populus fremontii
- Salix exigua
- Salix gooddingii
- **USFWS Refuge Boundary**

Map projection = UTM NAD 1983, Zone 12N, meters
Map created by Chad McKenna, GeoSystems Analysis, Inc. on July 9, 2012.

Background imagery:
Bing Basemap served via ESRI online

Refuge boundary:
USFWS Cadastral Geodatabase

Seed collection locations:
Sub-meter field GPS locations
GeoSystems Analysis

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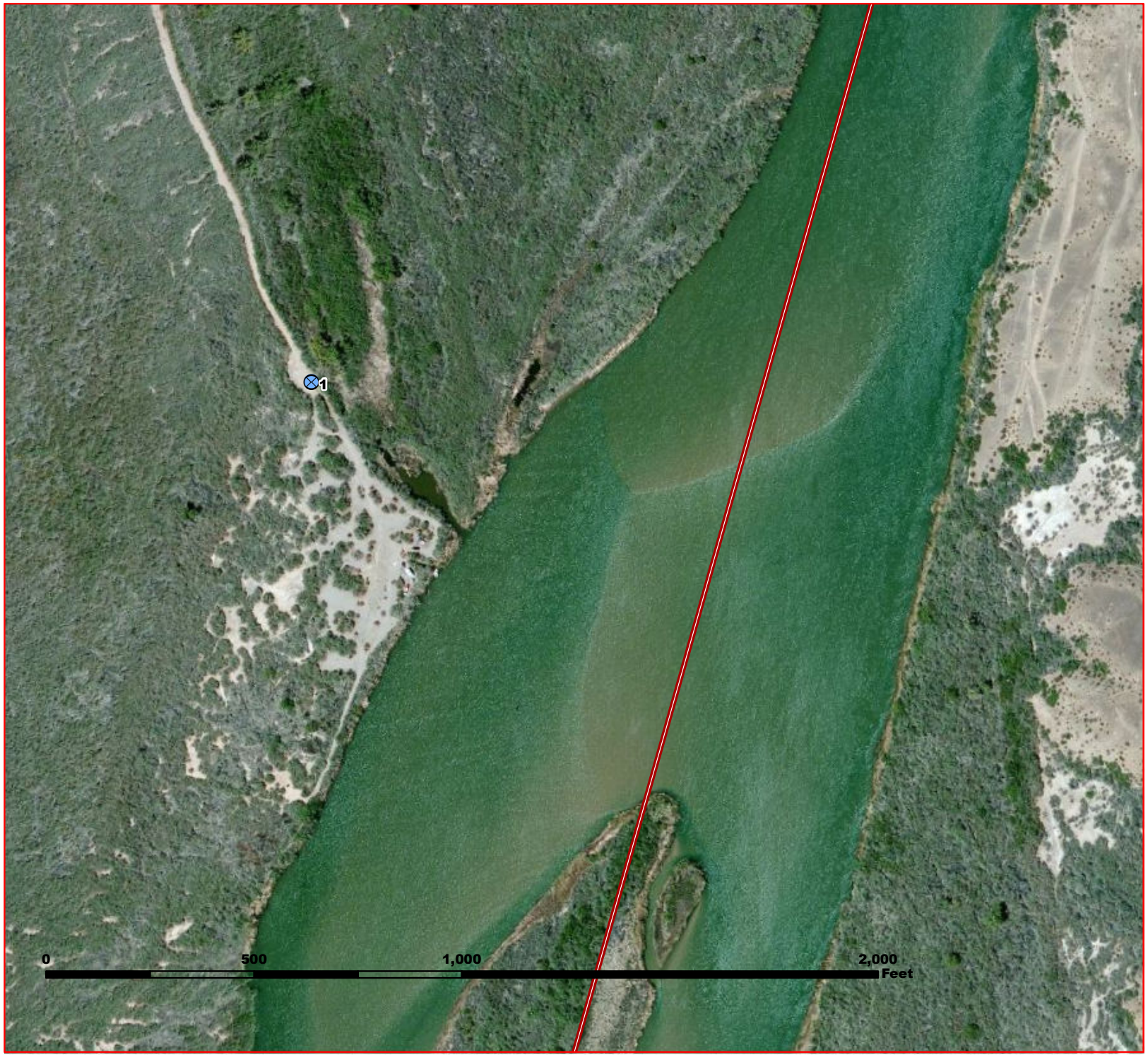
March/April 2012 Seed Collection Locations:
Walter's Camp



Legend

Species Collected

- Populus fremontii
- Salix exigua
- Salix gooddingii
- **USFWS Refuge Boundary**

Map projection = UTM NAD 1983, Zone 12N, meters
Map created by Chad McKenna, GeoSystems Analysis, Inc. on July 9, 2012.

Background imagery:
Bing Basemap served via ESRI online

Refuge boundary:
USFWS Cadastral Geodatabase

Seed collection locations:
Sub-meter field GPS locations
GeoSystems Analysis

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March 2012 - 2013 Seed Collection Locations:
Palo Verde Ecological Reserve

Legend

Seed Collection Location

0 250 500 Feet

Map projection = UTM NAD 1983, Zone 11N, meters
Map created by Chad McKenna, GeoSystems Analysis, Inc. on May 27, 2014.

Background imagery: Provided by LCR-MSCP

Seed collection locations: Sub-meter field GPS locations GeoSystems Analysis

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ATTACHMENT 2

Single-Ring Cylinder Infiltrometer Methods

The cylinder infiltrometer method used for this study is described in detail in Bouwer et al. (1999). Briefly, this method is a short-term, single-ring infiltration test. The cylinders are 20 inches in diameter and 12 inches tall. Each cylinder was driven approximately 1 to 4 inches into the ground using a driver. The soil against the inside and outside of the ring was lightly compacted to minimize preferential flow at the ring-soil contact. Following installation, the cylinders were filled with water to the top, and monitoring of the decline in water level (y) was initiated. After the water had fallen about 2 inches, the time (Δt) and exact decrease in water level (y_n) were recorded, and the cylinder was refilled to the top. This process was continued until 4 hours had elapsed. A shovel was then used to dig outside of the cylinder to determine the distance (x) of lateral divergence. The depth of wetting was determined by augering to dryness when possible. When the wetting depth could not be determined by augering, the depth of wetting was estimated from cumulative infiltration.

CALCULATION OF EFFECTIVE SATURATED HYDRAULIC CONDUCTIVITY

In order to calculate the effective saturated hydraulic conductivity (K), the downward flow rate, i_w, must first be corrected for the effect of lateral divergence, based on the radius of the observed wetting front:

$$i_w = \frac{i_n \pi r^2}{\pi (r + x)^2} \qquad \text{(equation 1)}$$

Where:

i_n = Infiltration rate during the last water drop ($y_n/\Delta t_n$)
r = Radius of the cylinder
x = Lateral divergence from the cylinder
Δt_n = Time of last water drop

When the depth of the wetting front at the end of the test, L, is difficult to measure, such as in soil that is already moist, it can be calculated from the cumulative infiltration (y_t) as:

$$L = \frac{y_t \pi r^2}{n \pi (r + x)^2} \qquad \text{(equation 2)}$$

where n is the estimated fillable porosity of the soil, based on the field description of soil texture and initial moisture content. When the depth of the wetting front was directly measured in the field, equation 2 was solved for n to more accurately estimate fillable porosity.

Applying Darcy's equation to the downward flow i_w (equation 1) and assuming vertical flow in the wetted zone yields:

$$i_w = K \frac{z + L - h_{we}}{L} \qquad \text{(equation 3)}$$

Where:

K	=	Effective saturated hydraulic conductivity of the wetted zone
z	=	Average depth of water in the cylinder during the last water drop y_n
h_{we}	=	Water entry value of the soil (estimate of soil suction, from Bouwer et al. 1999)

Material property estimates made in the field were used to assign the water entry value for each sample.

Equation 2 was rearranged to solve for K:

$$K = \frac{i_w L}{(z + L - h_{we})} \qquad \text{(equation 4)}$$

This calculated value is an estimate of K and may be less than the true hydraulic conductivity due to air entrapment within the pores. Nonetheless, because of scale effects, cylinder infiltrometers provide a more accurate estimation of saturated hydraulic conductivity than smaller-scale laboratory measurements.

REFERENCES

Bouwer, H., J.T. Back, and J.M. Oliver. 1999. Predicting infiltration and ground water mounds for artificial recharge *in* Journal of Hydrologic Engineering, ASCE (4) pp. 350–357.

ATTACHMENT 3

Graphical Monitoring Station Data Summary

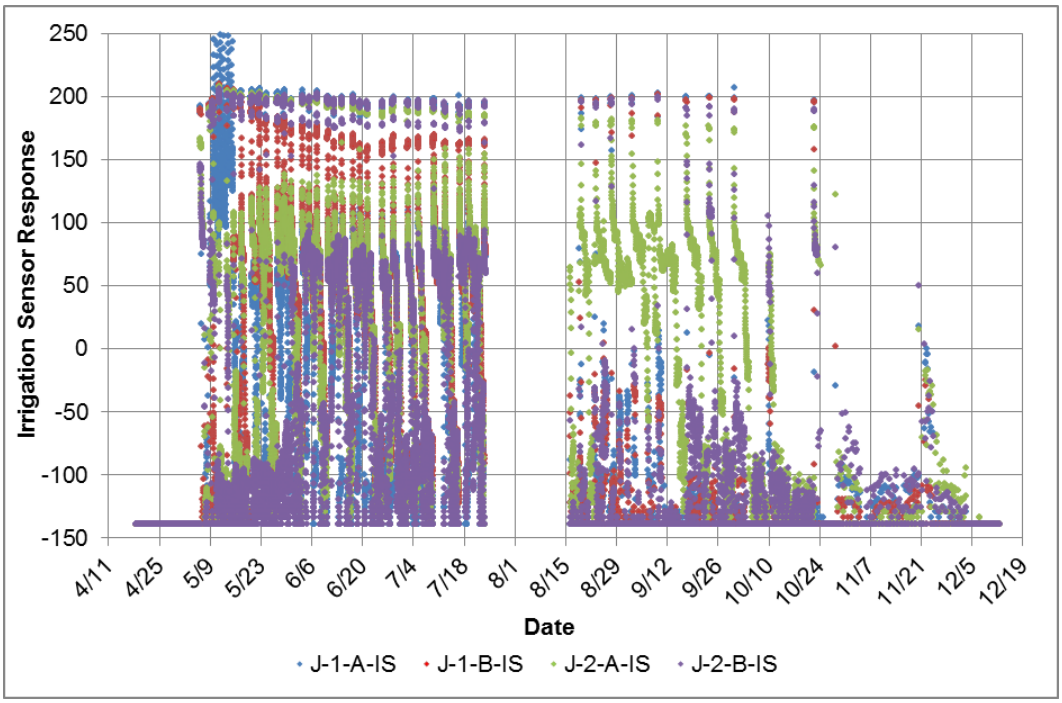

Figure 1.—2013 irrigation sensor data from BLCA field J, datalogger 1. Values above zero indicate surface inundation, whereas values below zero indicate no inundation.

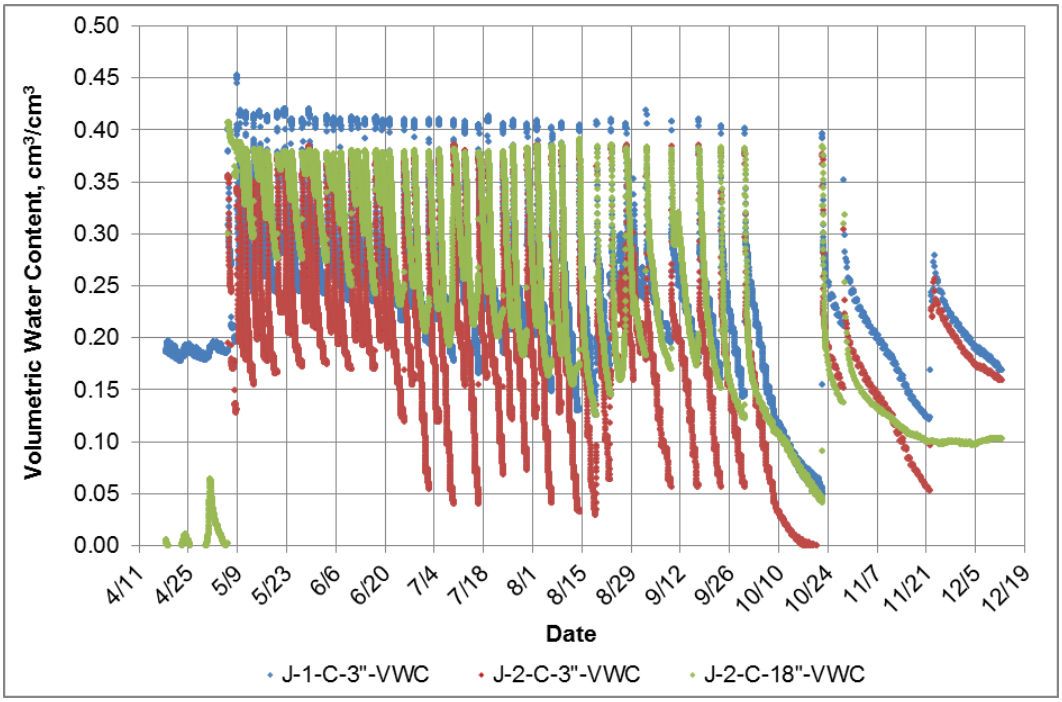

Figure 2.—2013 volumetric water content at 0–3 and 15–21 inches below ground surface at BLCA field J, datalogger 2, estimated using ECH$_2$O-10HS volumetric water content probes.

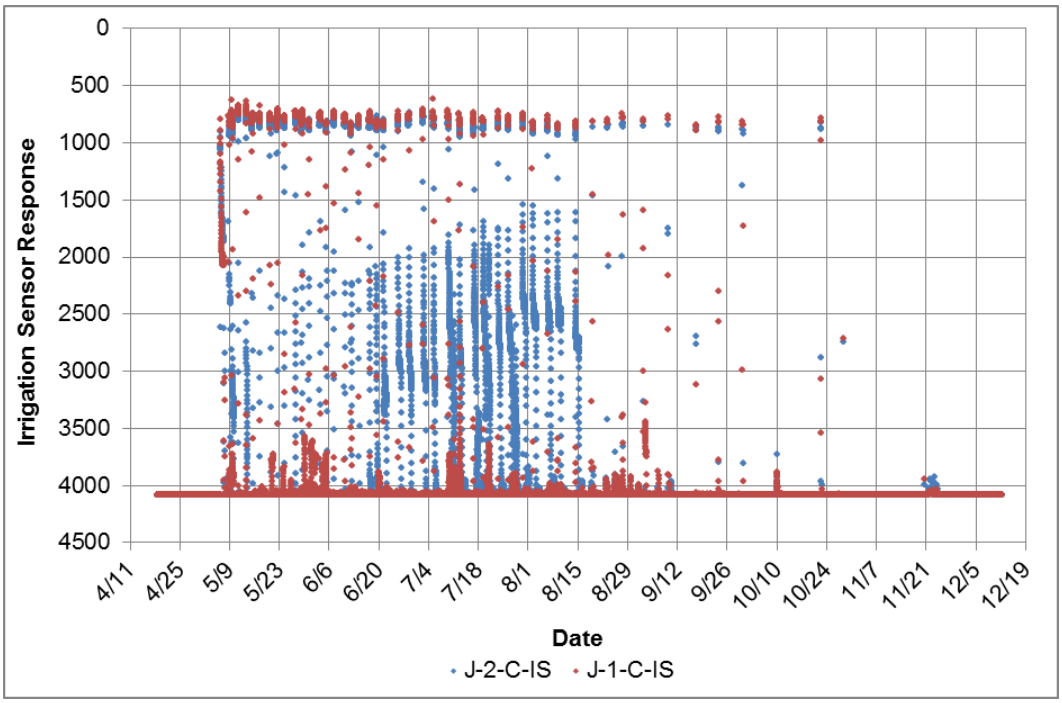

Figure 3.—2013 irrigation sensor data from BLCA field J, datalogger 2. Values below 2,000 indicate surface inundation, whereas values above 2,000 indicate no inundation.

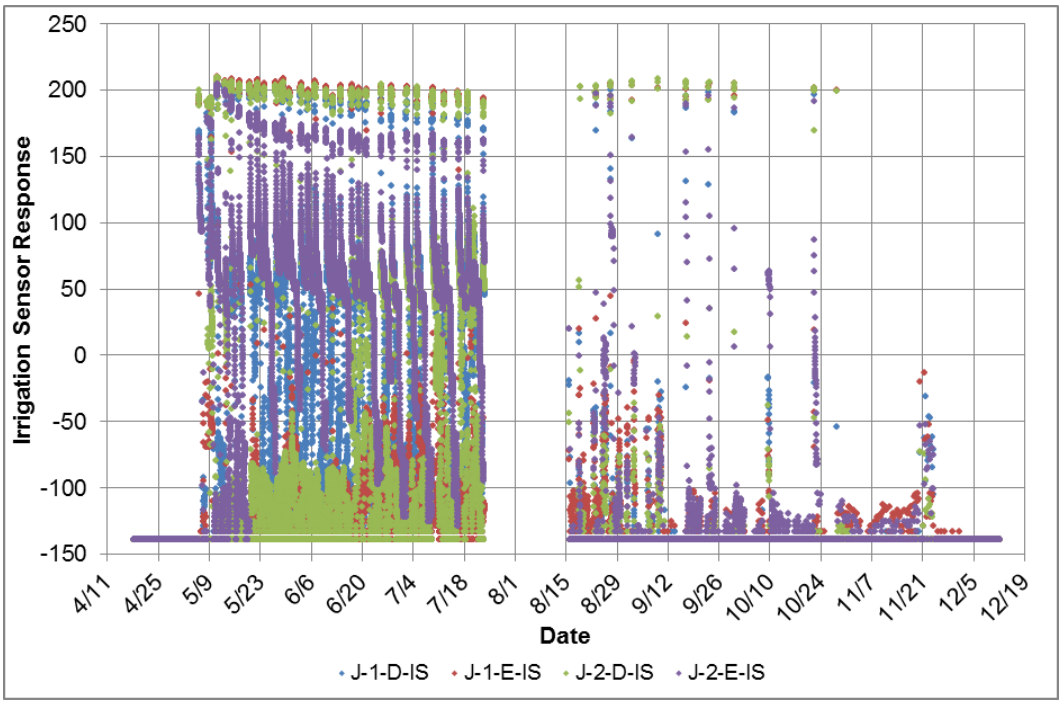

Figure 4.—2013 irrigation sensor data from BLCA field J, datalogger 3. Values above zero indicate surface inundation, whereas values below zero indicate no inundation.

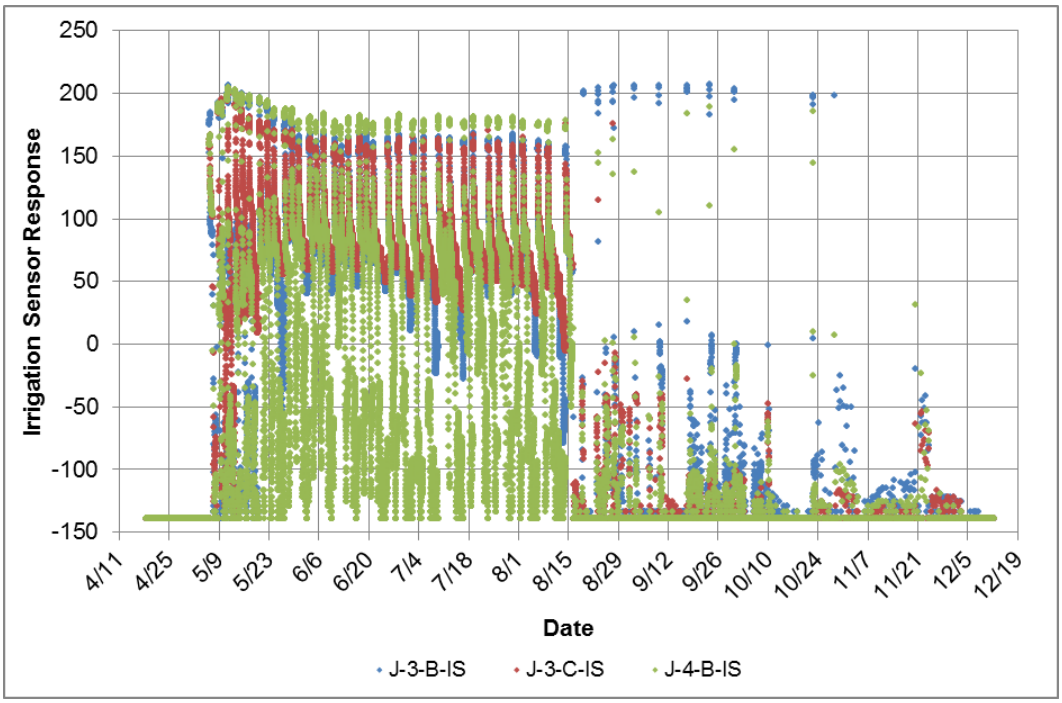

Figure 5.—2013 irrigation sensor data from BLCA field J, datalogger 4. Values above zero indicate surface inundation, whereas values below zero indicate no inundation.

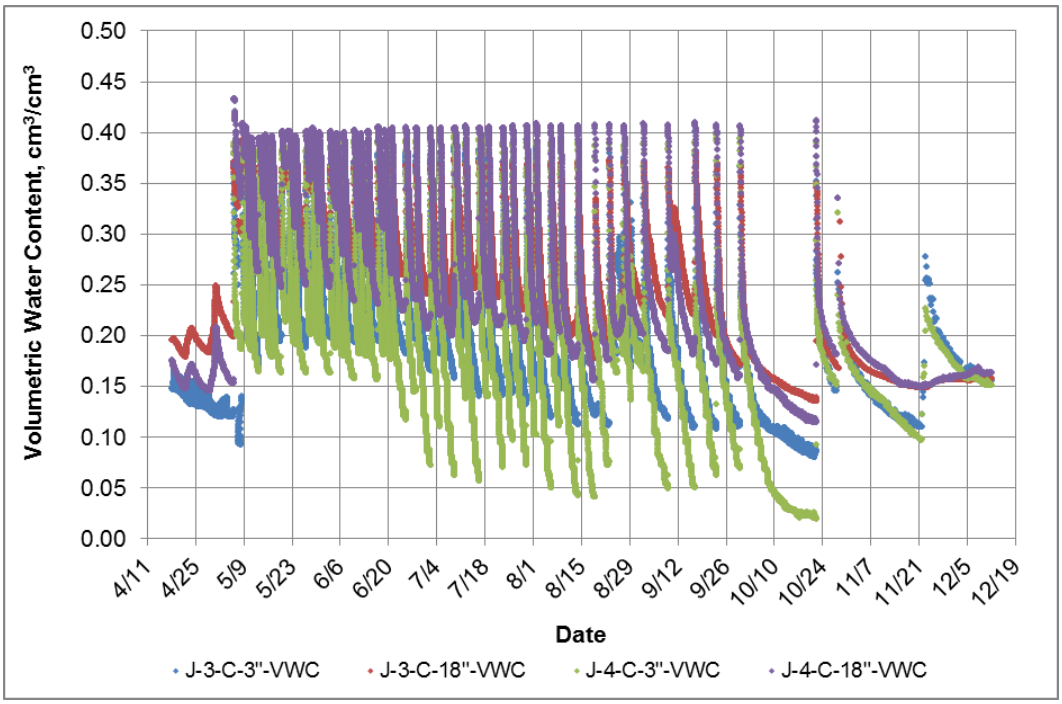

Figure 6.—2013 volumetric water content at 0–3 and 15–21 inches below ground surface at BLCA field J, datalogger 5, estimated using ECH$_2$O-10HS volumetric water content probes.

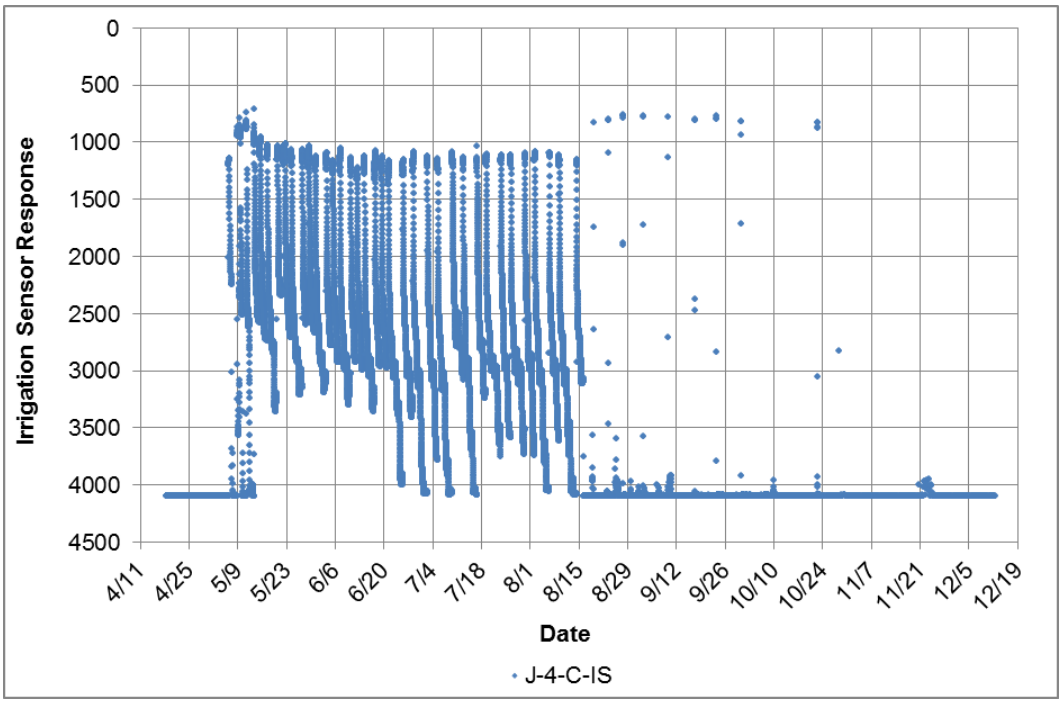

Figure 7.—2013 irrigation sensor data from BLCA field J, datalogger 5. Values below 2,000 indicate surface inundation, whereas values above 2,000 indicate no inundation.

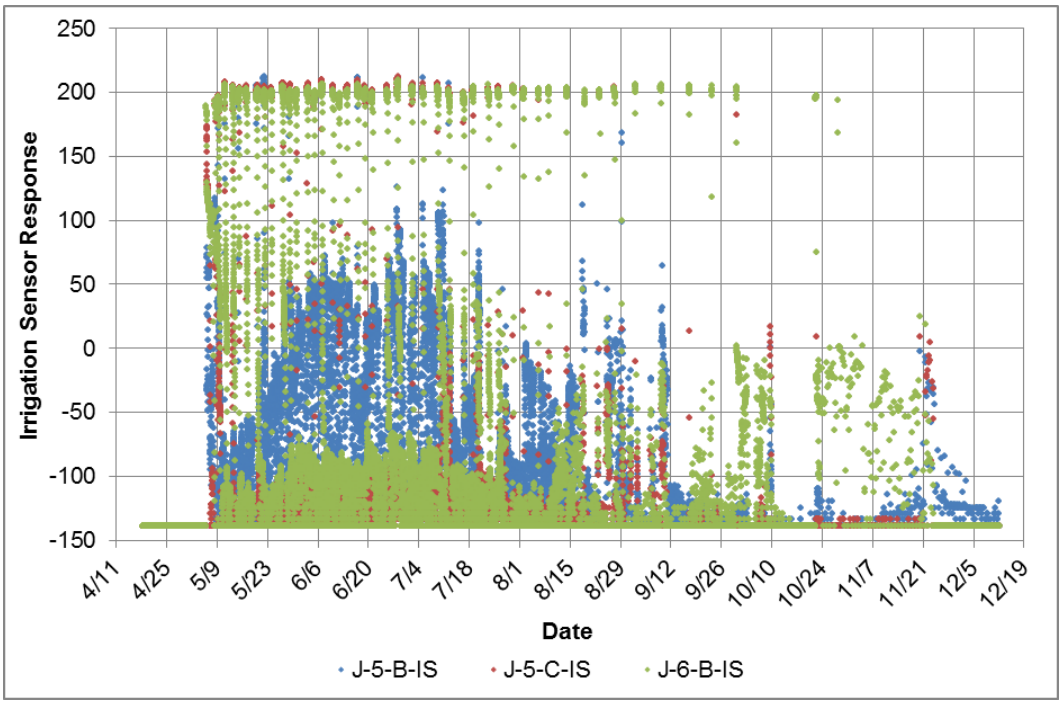

Figure 8.—2013 irrigation sensor data from BLCA field J, datalogger 6. Values above zero indicate surface inundation, whereas values below zero indicate no inundation.

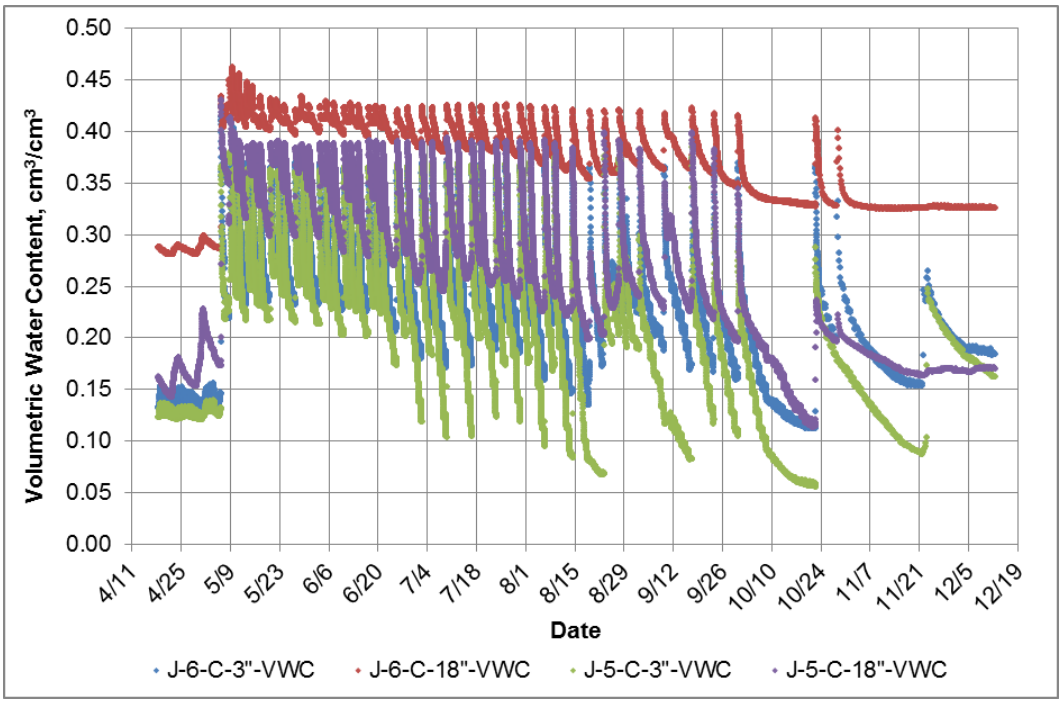

Figure 9.—2013 volumetric water content at 0–3 and 15–21 inches below ground surface at BLCA field J, datalogger 7, estimated using ECH_2O-10HS volumetric water content probes.

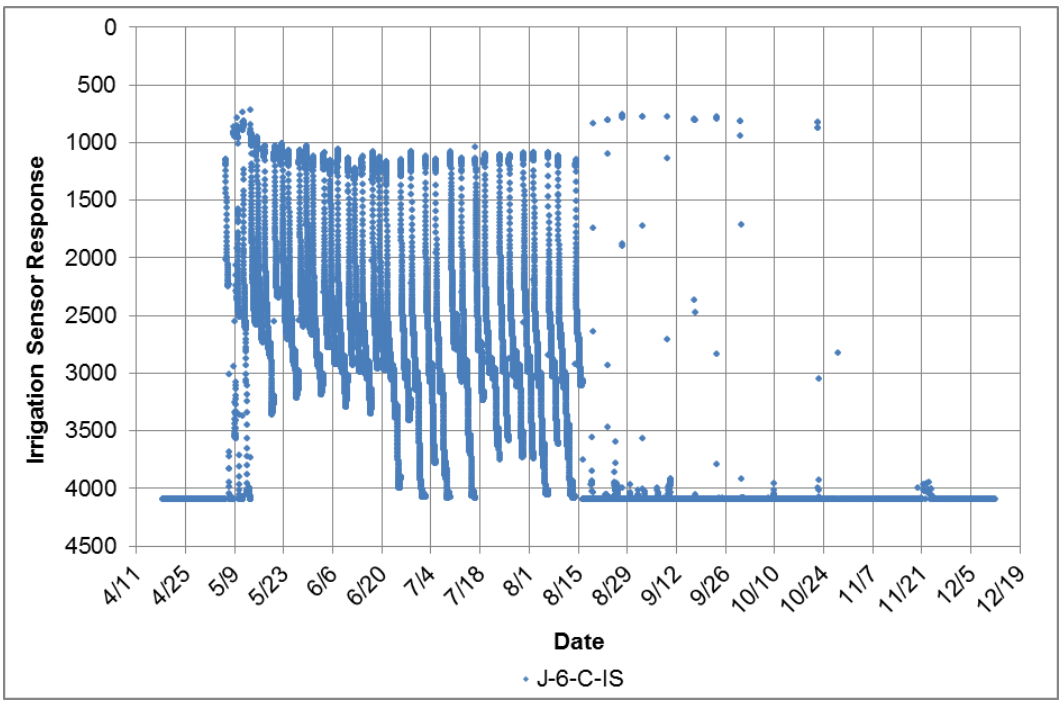

Figure 10.—2013 irrigation sensor data from BLCA field J, datalogger 7. Values below 2,000 indicate surface inundation, whereas values above 2,000 indicate no inundation.

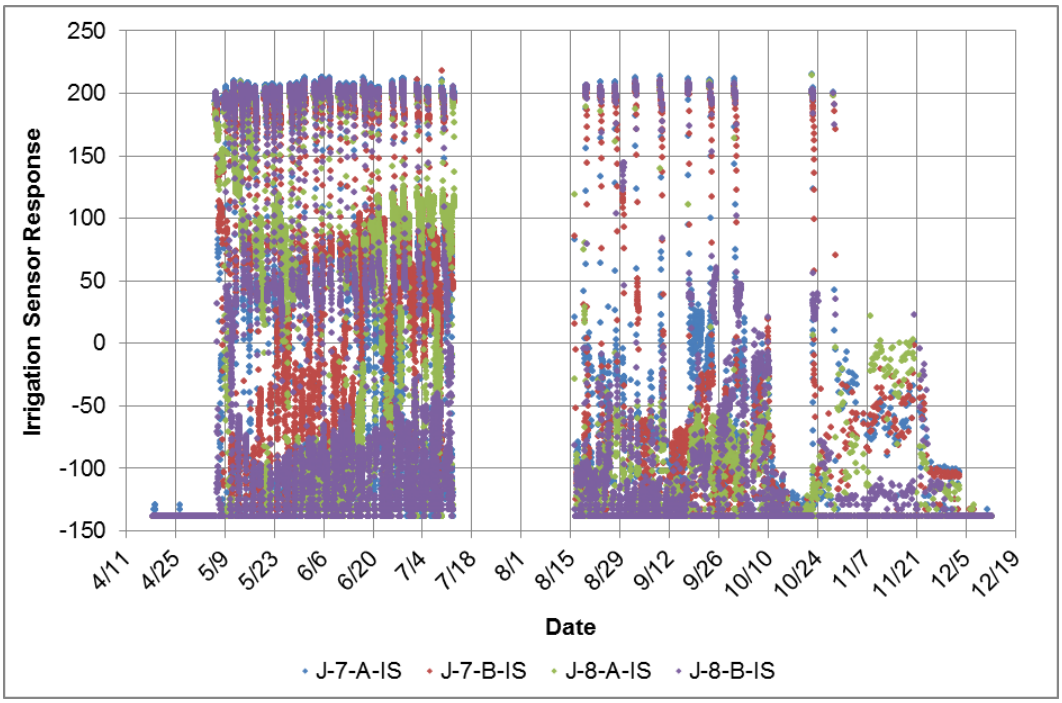

Figure 11.—2013 irrigation sensor data from BLCA field J, datalogger 8. Values above zero indicate surface inundation, whereas values below zero indicate no inundation.

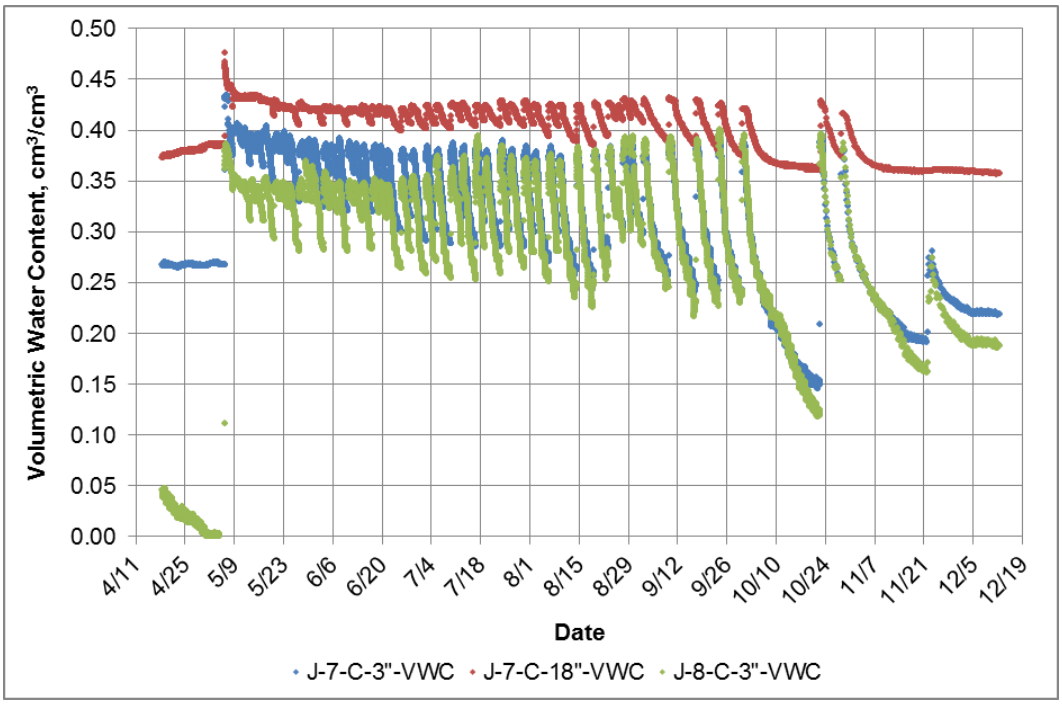

Figure 12.—2013 volumetric water content at 0–3 and 15–21 inches below ground surface at BLCA field J, datalogger 9, estimated using ECH$_2$O-10HS volumetric water content probes.

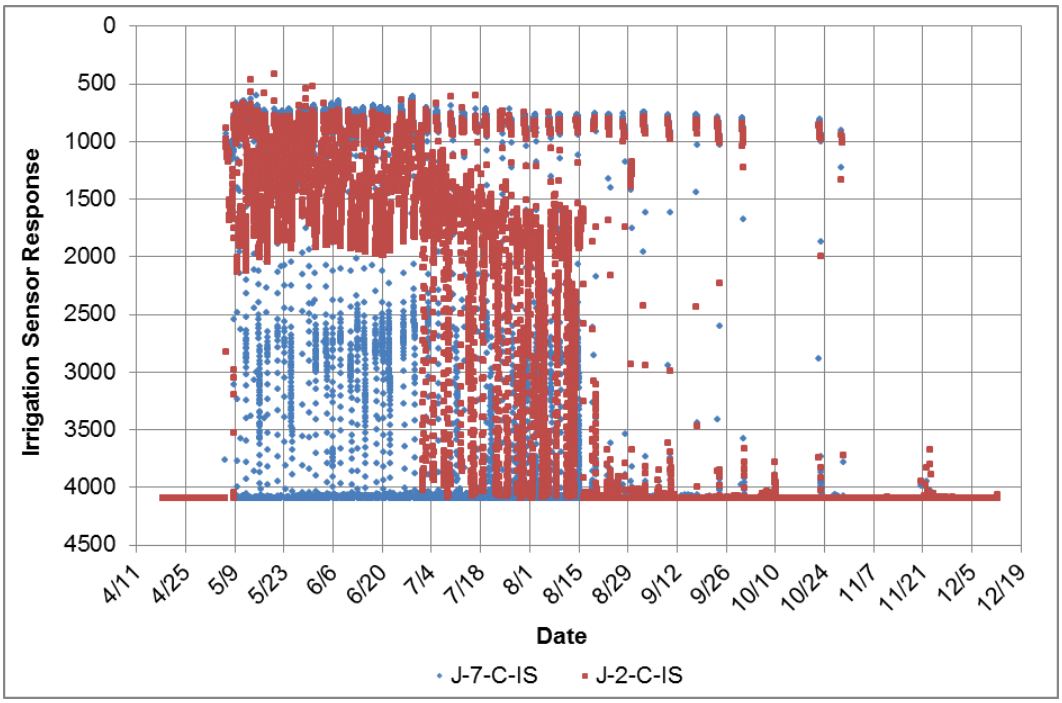

Figure 13.—2013 irrigation sensor data from BLCA field J, datalogger 9. Values below 2,000 indicate surface inundation, whereas values above 2,000 indicate no inundation.

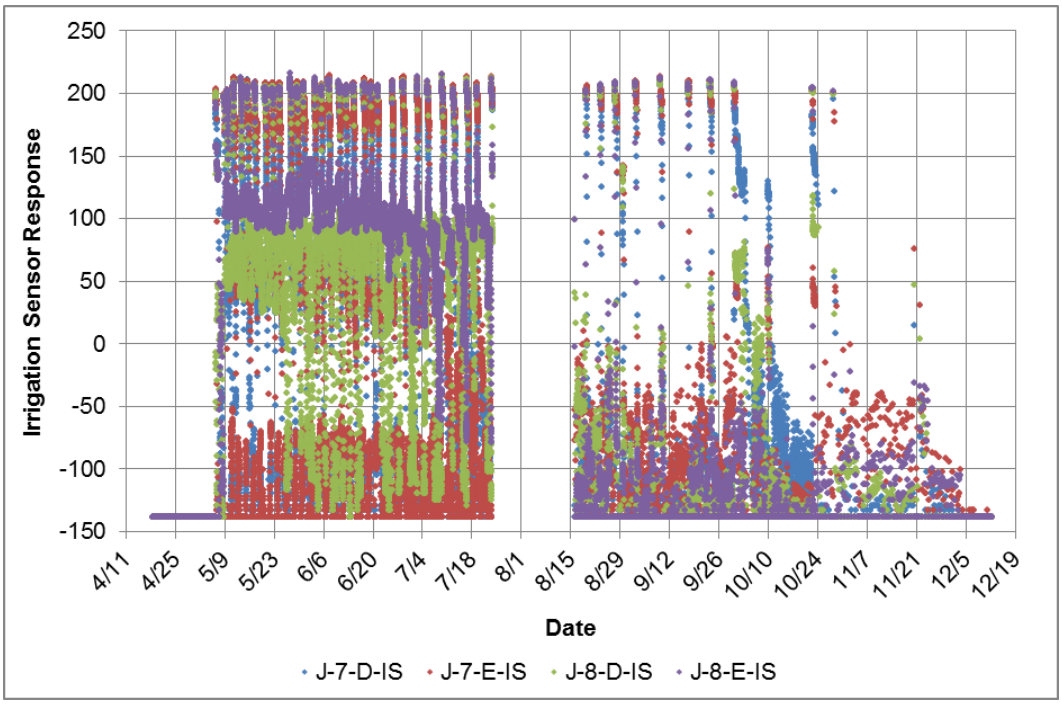

Figure 14.—2013 irrigation sensor data from BLCA field J, datalogger 10. Values above zero indicate surface inundation, whereas values below zero indicate no inundation.

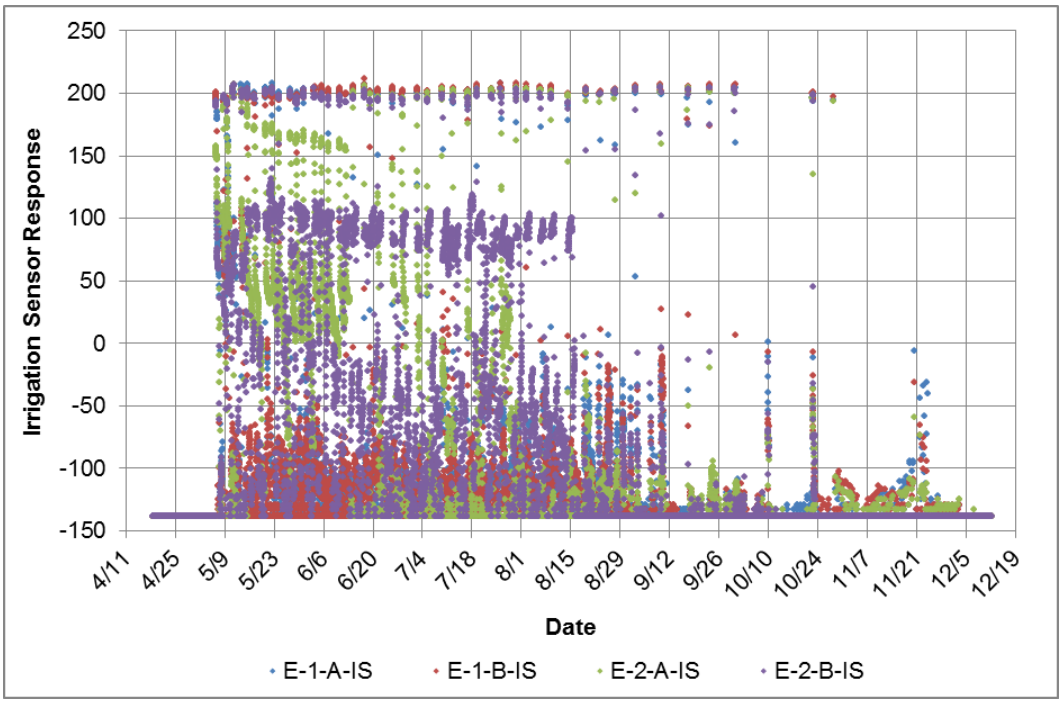

Figure 15.—2013 irrigation sensor data from BLCA field E, datalogger 1. Values above zero indicate surface inundation, whereas values below zero indicate no inundation.

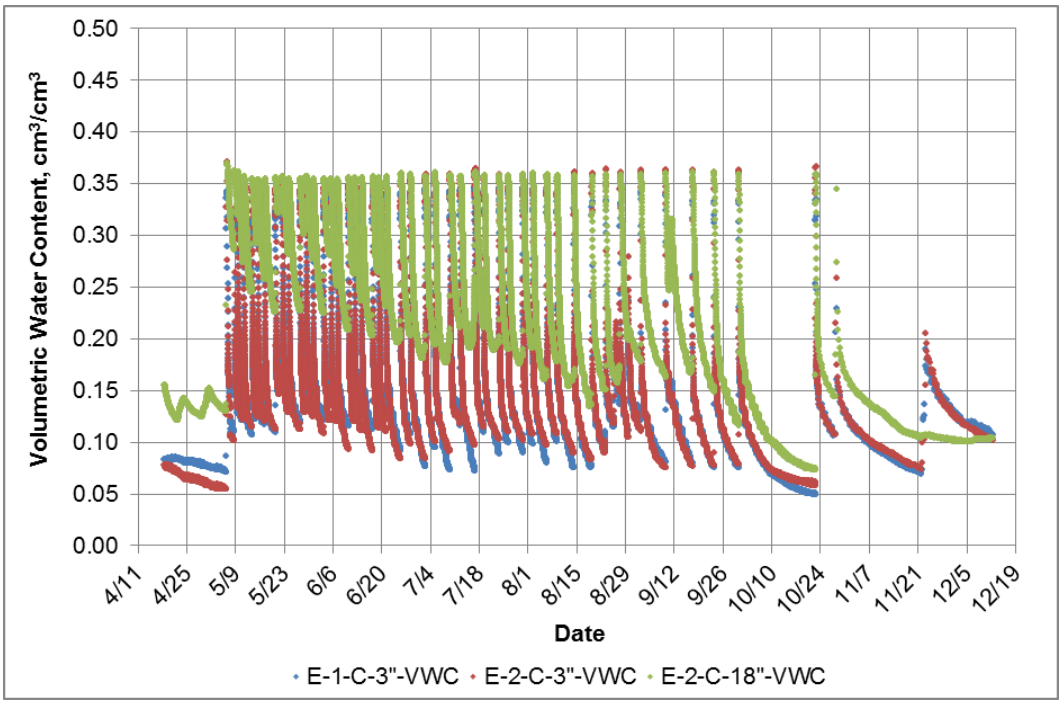

Figure 16.—2013 volumetric water content at 0–3 and 15–21 inches below ground surface at BLCA field E, datalogger 2, estimated using ECH$_2$O-10HS volumetric water content probes.

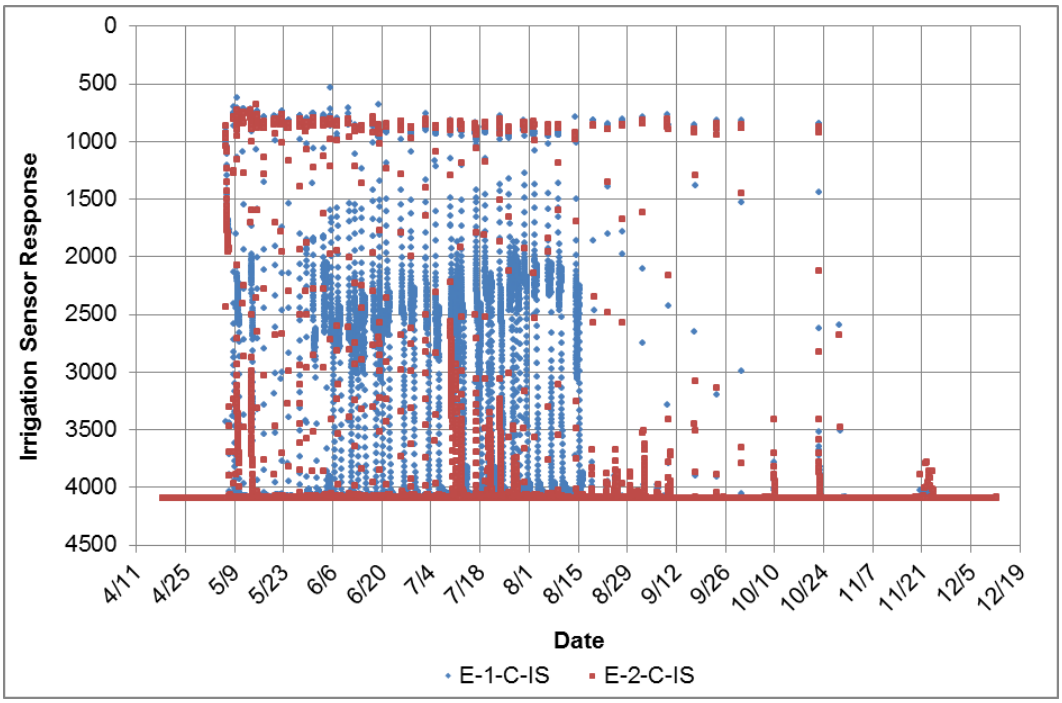

Figure 17.—2013 irrigation sensor data from BLCA field E, datalogger 2. Values below 2,000 indicate surface inundation, whereas values above 2,000 indicate no inundation.

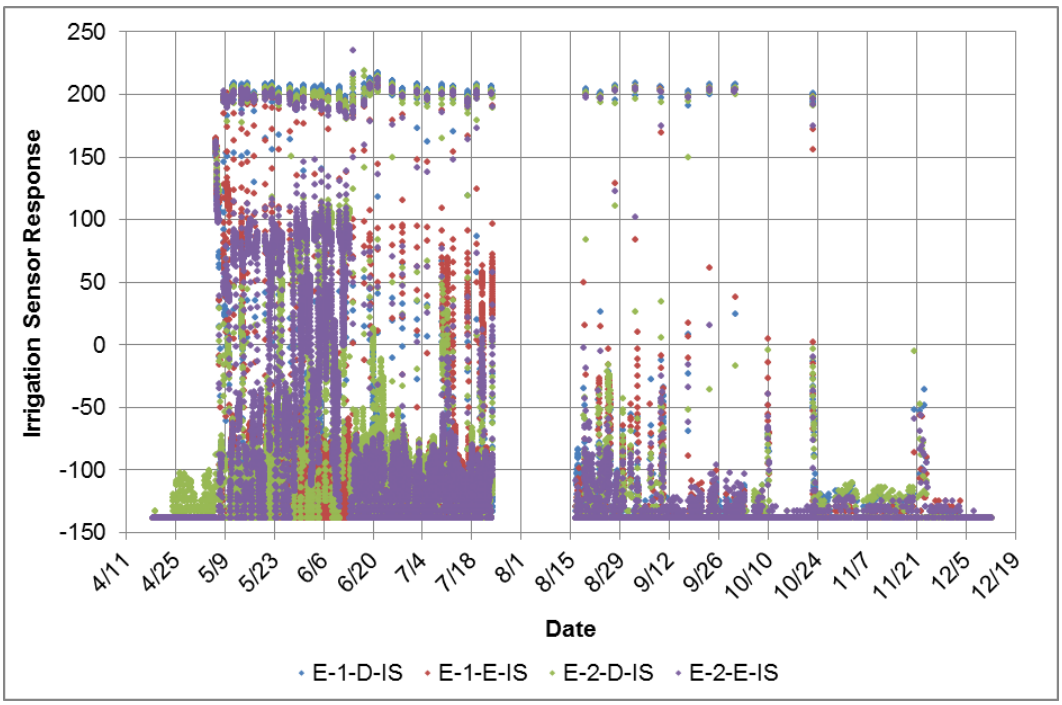

Figure 18.—2013 irrigation sensor data from BLCA field E, datalogger 3. Values above zero indicate surface inundation, whereas values below zero indicate no inundation.

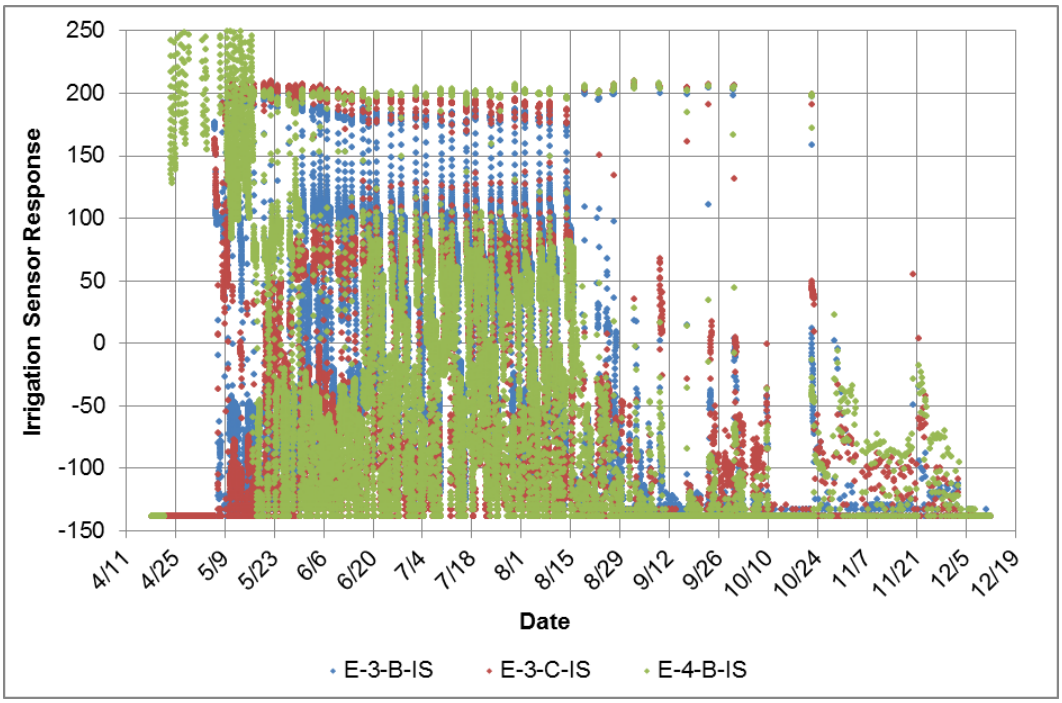

Figure 19.—2013 irrigation sensor data from BLCA field E, datalogger 4. Values above zero indicate surface inundation, whereas values below zero indicate no inundation.

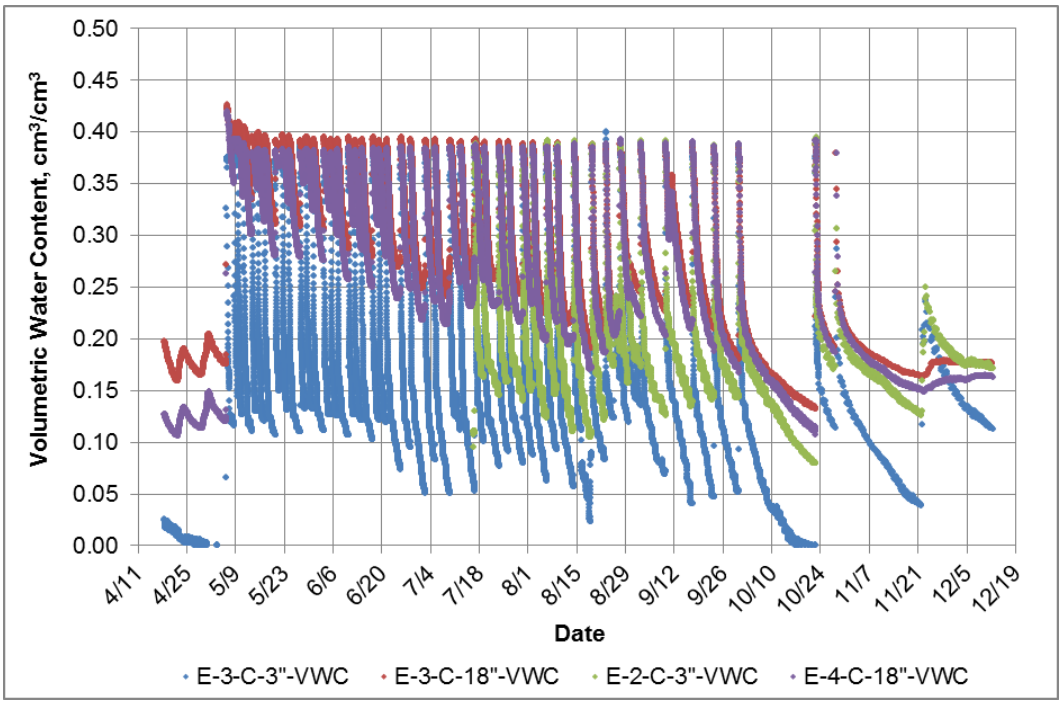

Figure 20.—2013 volumetric water content at 0–3 and 15–21 inches below ground surface at BLCA field E, datalogger 5, estimated using ECH$_2$O-10HS volumetric water content probes.

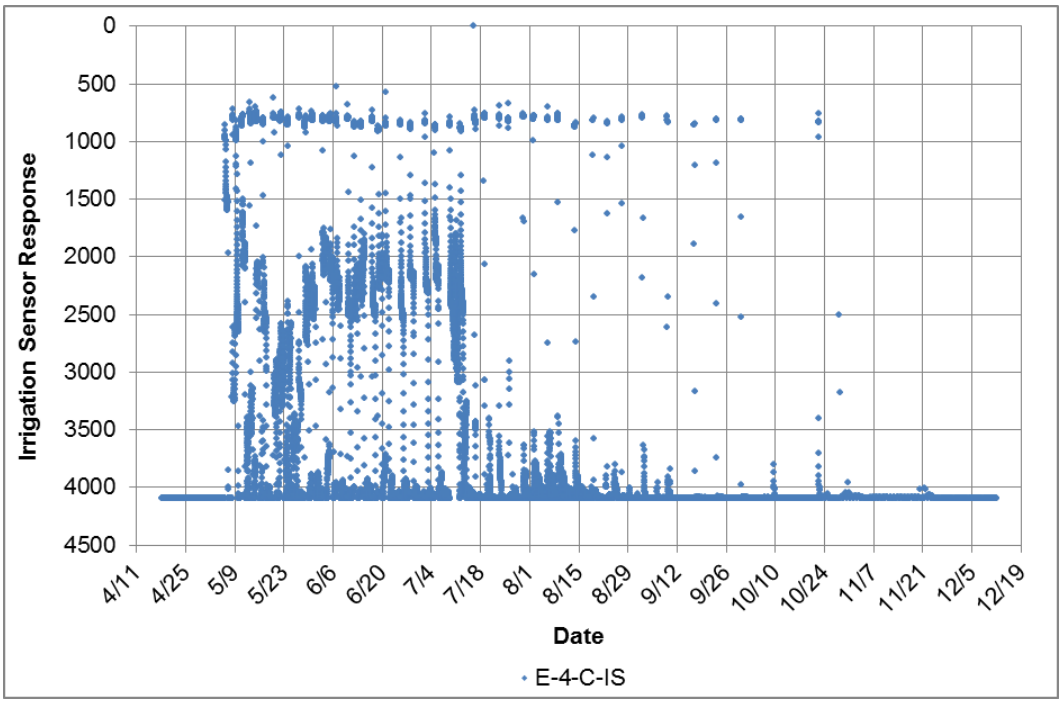

Figure 21.—2013 irrigation sensor data from BLCA field E, datalogger 5. Values below 2,000 indicate surface inundation, whereas values above 2,000 indicate no inundation.

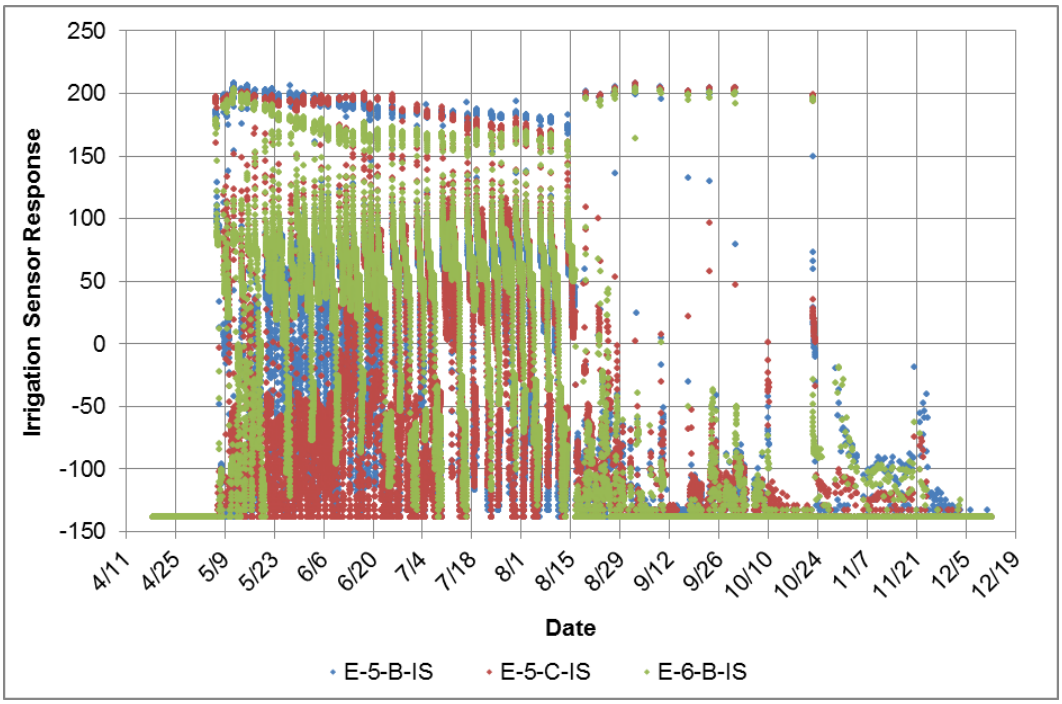

Figure 22.—2013 irrigation sensor data from BLCA field E, datalogger 6. Values above zero indicate surface inundation, whereas values below zero indicate no inundation.

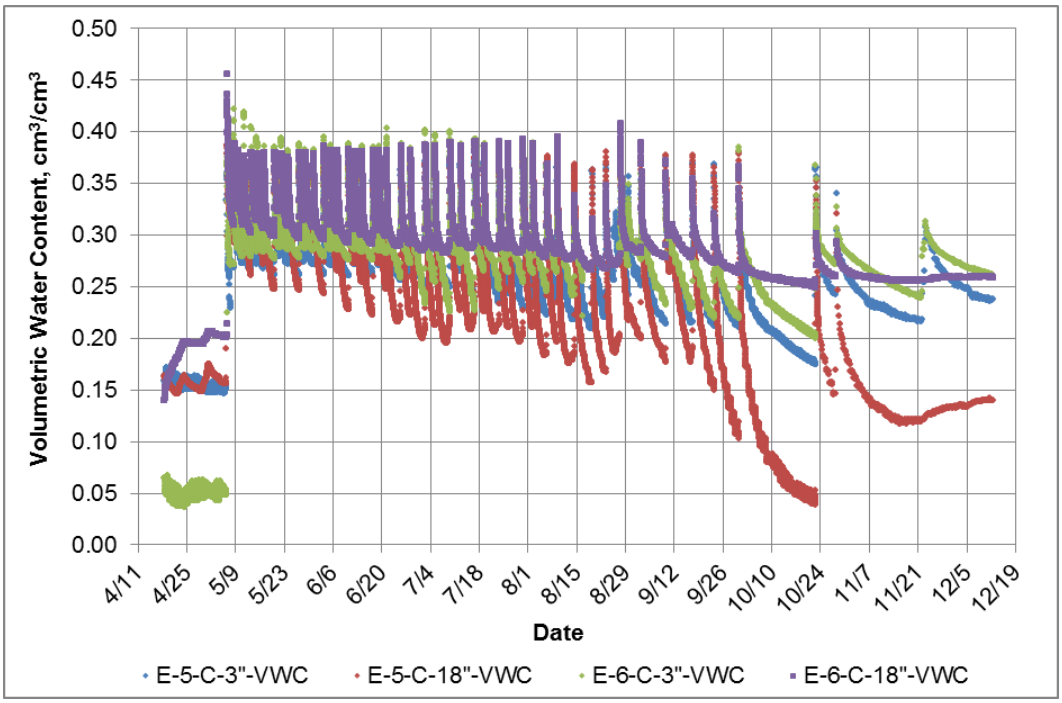

Figure 23.—2013 volumetric water content at 0–3 and 15–21 inches below ground surface at BLCA field E, datalogger 7, estimated using ECH$_2$O-10HS volumetric water content probes.

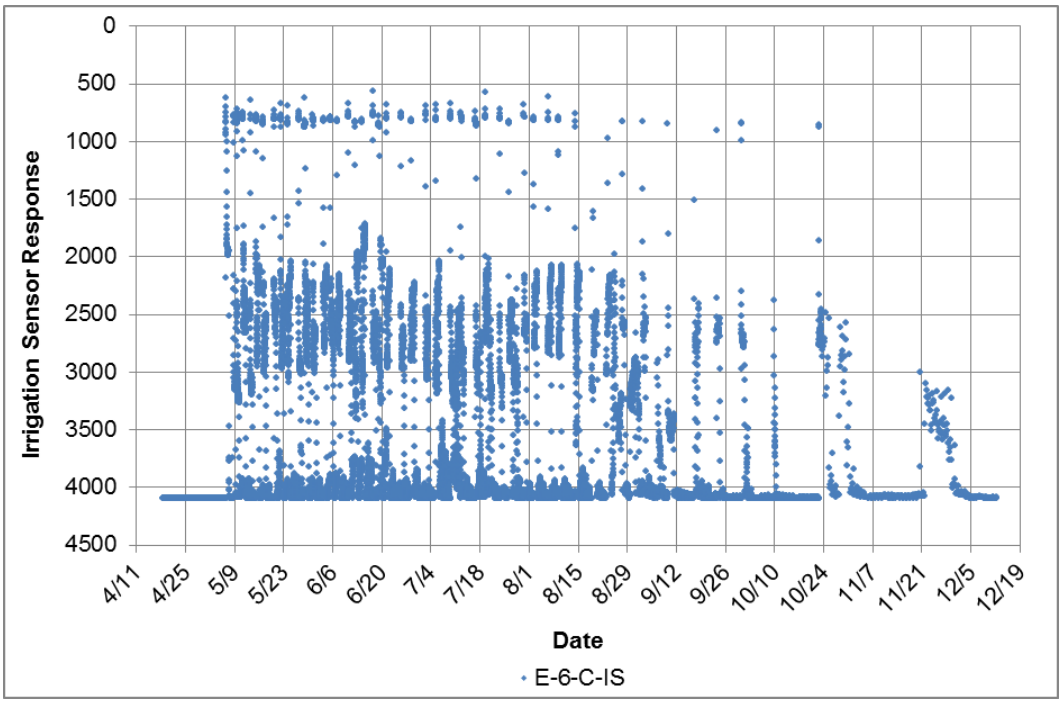

Figure 24.—2013 irrigation sensor data from BLCA field E, datalogger 7. Values below 2,000 indicate surface inundation, whereas values above 2,000 indicate no inundation.

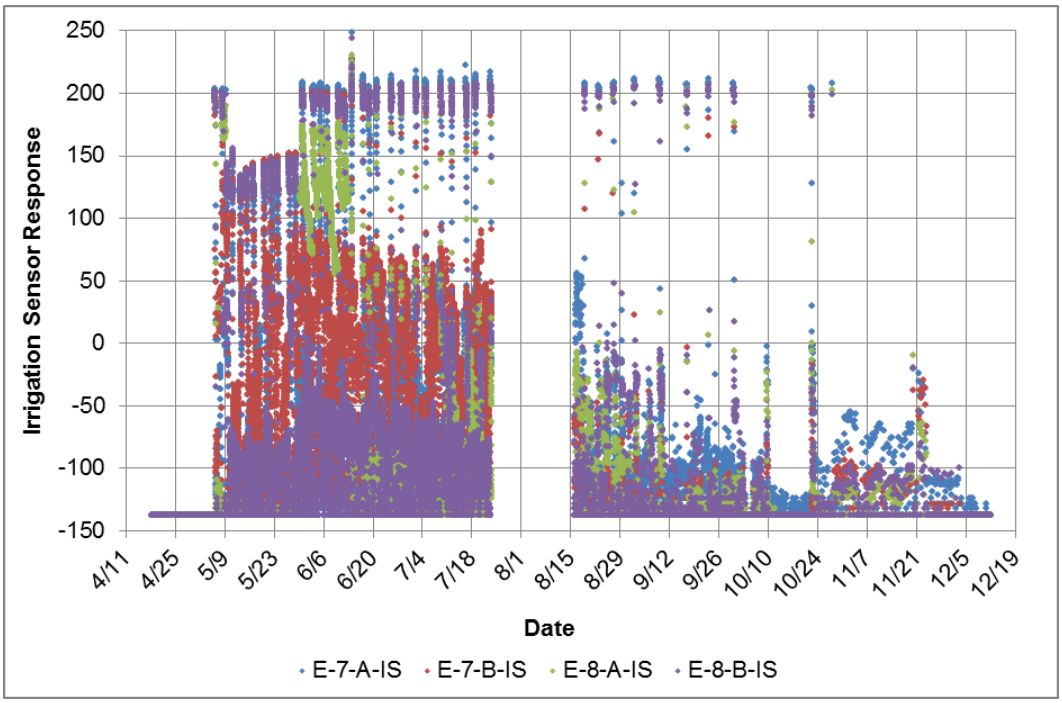

Figure 25.—2013 irrigation sensor data from BLCA field E, datalogger 8. Values above zero indicate surface inundation, whereas values below zero indicate no inundation.

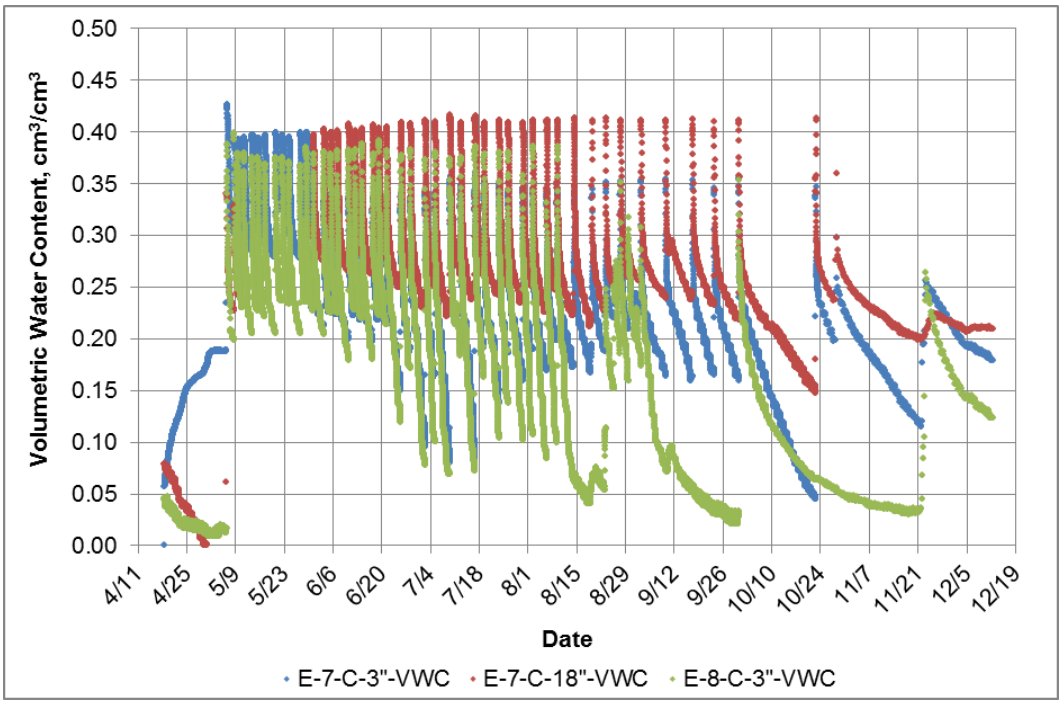

Figure 26.—2013 volumetric water content at 0–3 and 15–21 inches below ground surface at BLCA field E, datalogger 9, estimated using ECH_2O-10HS volumetric water content probes.

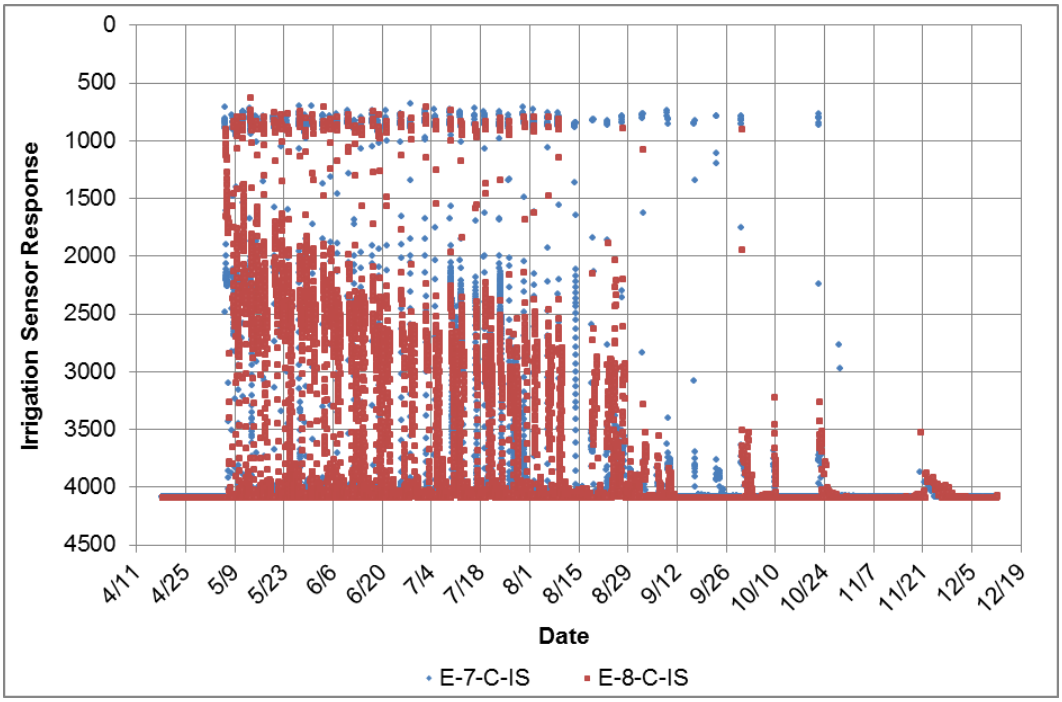

Figure 27.—2013 irrigation sensor data from BLCA field E, datalogger 9. Values below 2,000 indicate surface inundation, whereas values above 2,000 indicate no inundation.

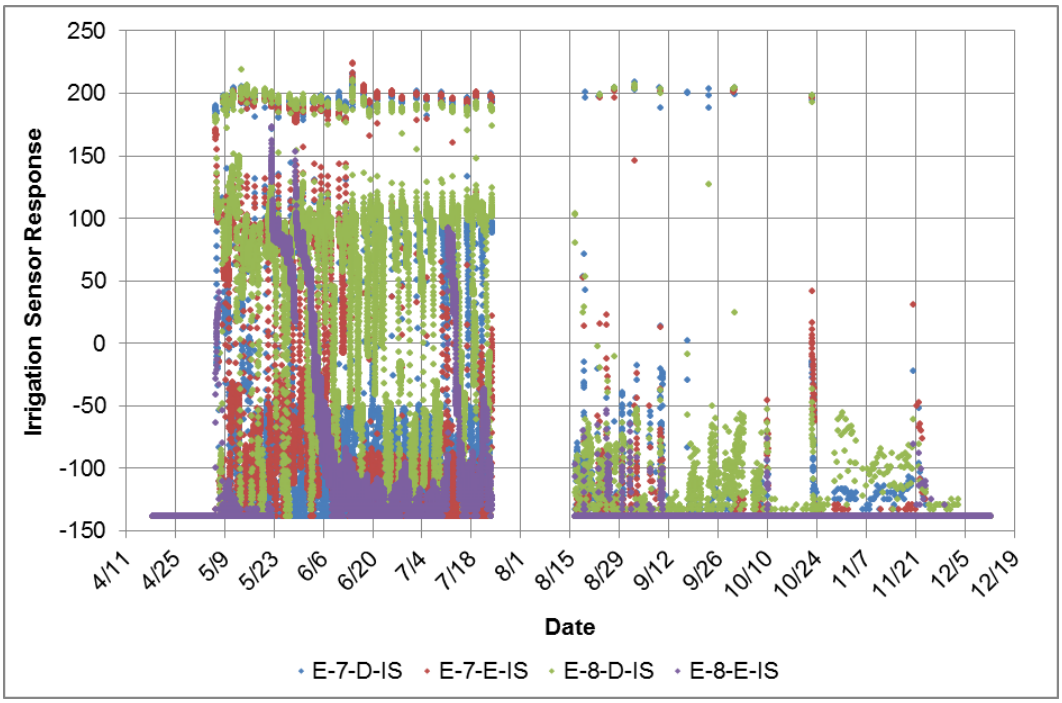

Figure 28.—2013 irrigation sensor data from BLCA field E, datalogger 10. Values above zero indicate surface inundation, whereas values below zero indicate no inundation.