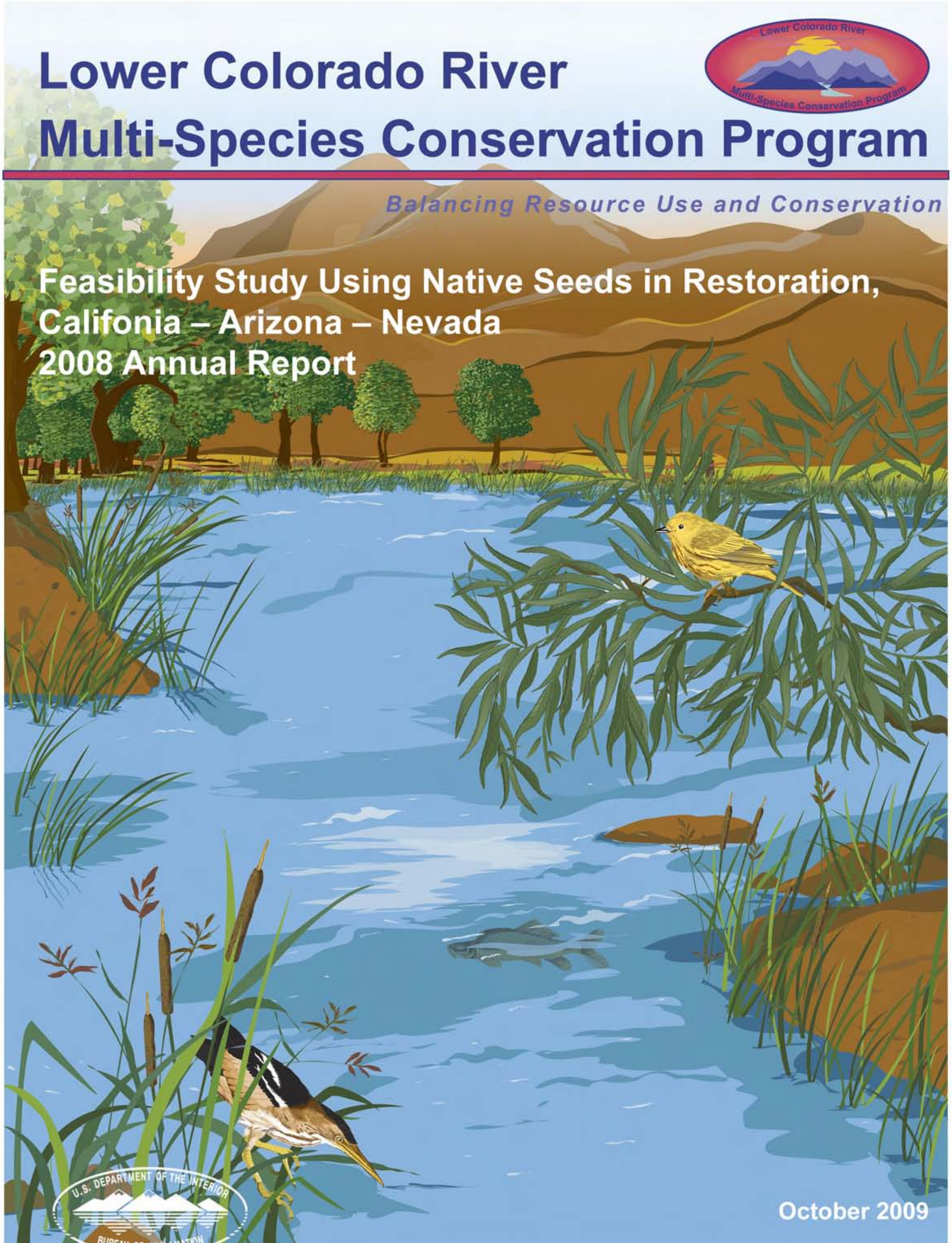
Lower Colorado River Multi-Species Conservation Program

Balancing Resource Use and Conservation

Feasibility Study Using Native Seeds in Restoration, California – Arizona – Nevada 2008 Annual Report



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October 2009

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Lower Colorado River
Multi-Species Conservation Program

Feasibility Study Using Native Seeds in Restoration, Califonia – Arizona – Nevada
2008 Annual Report

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Lower Colorado Region
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TABLE OF CONTENTS

TABLES

FIGURES

APPENDICES

EXECUTIVE SUMMARY

GeoSystems *Analysis*, Inc., in conjunction with the University of Arizona Office of Arid Lands Studies is conducting a three-year research project to determine the feasibility of using native seeds for restoration of riparian and transition vegetation along the Lower Colorado River (LCR). This feasibility study is funded by the Bureau of Reclamation in support of habitat restoration activities conducted under the LCR Multi-Species Conservation Plan. The tasks associated with this research plan are as follows.

- Task 1 consists of assessing seed collection and preservation feasibility for the riparian cohort species Fremont cottonwood (*Populus fremontii* Watts), Goodding's willow (*Salix gooddingii* Ball), and coyote willow (*S. exigua* Nutt).
- Tasks 2, 3, and 4 consist of small-scale (7-gallon, approximately one square foot) greenhouse pot studies for cohorts of mesquite, riparian, and shrub species, respectively.
- Task 5 consists of a small-scale field study for riparian cohort species at the Cibola National Wildlife Refuge (Cibola NWR) Field 51.
- Task 6 consists of a large-scale field study at Cibola NWR Field 51.
- Task 7 consists of extended seed preservation trials for the riparian cohort species, and germination study trials for *Baccharis* spp.

This report presents task activities and results for calendar year 2008 (Year 3) which consisted of the following activities:

1) Task 7: Extended cottonwood and willow seed storage germination studies for up to 27 months to evaluate frozen seed treatments with seed cleaning versus no cleaning and storage with or without oxygen. Seed viability was tested intermittently via incubator and soil germination studies. Conducted germination trials for Emory's baccharis (*Baccharis emoryi* Gray), mule's fat (*B. salicifolia* (Ruiz & Pavón) Pers.), and desertbroom (*B. sarothroides* Gray).

2) Task 5U-5: Continued monitoring small-scale field study plots established in 2007 at Cibola NWR Field 51 to evaluate original study parameters (i.e. planting technique, seed treatment, and irrigation type) and the effects of two distinct irrigation regimes during the growing season on plant establishment, survival, and growth:
   a) Shallow, frequent irrigation; application of 7 cm of water once per week throughout the growing season.
   b) Deep, infrequent irrigation; application of 21 cm of water once per three weeks throughout the growing season.

3) Task 5U-6: Conducted small-scale field studies at Cibola NWR Field 51 to evaluate seeding technique, seed treatment, and irrigation type effects on germination, establishment, and growth of Goodding's willow for one growing season. Experimental parameters were:

   a) Cleaned broadcast seed versus hydroseeeded un-cleaned seed.

   b) Furrow versus border (small-scale basin) irrigation.

KEY RESULTS SUMMARY

Key findings from Task 7 germination studies for riparian tree species include:

- Freezing treatments resulted in viability greater than 80% for a period of at least 27 months.
- Removing oxygen from seed storage containers did not extend viability of seeds stored at room temperature, and did not increase viability of seed stored in freezers.
- Removing seed hairs (cleaning) resulted in higher germination rates on soil beds due to enhanced soil contact, but did not affect germination rates in incubators.

Key findings from Task 7 germination studies for baccharis include:

- Mule's fat germination rates were maintained above 30% for four months after seed collection by freezing seed. Room temperature or refrigerated storage did not result in favorable germination rates (0% and 3% germination, respectively).
- Mule's fat germination rates diminished after four months of frozen seed storage until approximately 0% germination was observed after nine months.
- Emory's baccharis seed germination rates were favorable after nine months of storage for all treatments (greater than 80% germination on soil beds for all treatments). A germination rate of 92% was observed for seed stored at room temperature.
- Desertbroom germination rates were greater than 25% for all storage treatments after four months of storage. Germination rates were above 20% after nine months of storage at room temperature or in freezers at -10^{o}C. Eight percent germination was observed following refrigerated storage for nine months.

Key findings from Task 5U-5 small-scale field studies are the following:

- Fremont cottonwood has maintained dominance of crown cover in the small-scale study plots. Crown cover of cottonwood increased from 8% in September 2007 to 41% in October 2008. Crown cover of saltcedar increased from 3.7% to 12.0% during that time period. Cover of other non-seeded species did not increase.
- Canopy cover of Fremont cottonwood is now greater than that of saltcedar. Canopy cover of cottonwood increased from 16% to 60% between September 2007 and October 2008. Canopy cover of saltcedar increased from 18% to 36%.
- Overall mortality of Fremont cottonwood and saltcedar was 5.9% and 11.6%, respectively, during the 2008 growing season. Mortality was higher for trees that were smaller at the beginning of the growing season.

- Despite very high tree densities, mortality was not observed during 2008 for any cottonwood or saltcedar that were greater than 150 cm tall at the onset of the growing season.
- Fremont cottonwood growth rates were superior to those of saltcedar across initial tree heights and irrigation treatments.
- Irrigation treatments did not significantly affect mortality or growth rates. Soil water depletion was less than anticipated, likely due to tree utilization of groundwater.
- Cottonwood and saltcedar roots have penetrated the soil profile to depths greater than 150 cm.

Key findings from Task 5U-6 Goodding's willow small-scale field plots are:

- Goodding's willow establishment ranged from less than 0.09% for broadcast seeding, border irrigation, to 0.95% for hydroseeded border and furrow irrigation. Tree densities ranged from 0 per m^2 in one plot (broadcast, border) to 37 per m^2 (hydroseed, border irrigation).
- Grasses were abundant in study plots, but grass canopy cover was limited to 36%, compared to over 90% in 2007 study plots. These data indicate that repeated applications of grass-specific herbicide were effective in limiting grass growth.
- Saltcedar was again abundant in study plots, ranging from 33 to 75 per m^2, with an average density (51.3 per m^2) approximately double that observed for 2007 study plots.
- Canopy cover of other unseeded species (shrubs and forbs) was nearly double that observed for 2007 small-scale study plots (88% versus 47%), indicating that the reduction of grass and/or Fremont cottonwood enhanced weed growth.
- Hydroseeding un-cleaned seed resulted in three to four times higher establishment of Goodding's willow compared to broadcasting cleaned seed.
- Goodding's willow establishment was not affected by surface irrigation treatment (i.e. furrow versus border), but furrow irrigation resulted in lower growth rates of saltcedar.

1.0 INTRODUCTION

This report documents activities conducted by GeoSystems *Analysis*, Inc. (GSA) and the University of Arizona (The GSA Team) for Contract No. 06CR308057, *Feasibility Study Using Native Seeds in Restoration*, *California-Arizona-Nevada*, during calendar year 2008. The feasibility study consists of a three-year research program initiated in 2005 by the Bureau of Reclamation (Reclamation) to determine whether native seed can be used, in combination with large-scale agricultural practices, to expand cottonwood-willow and mesquite bosque plant communities on the Lower Colorado River (LCR). Development of such methods is desired given the long-term revegetation goals of the LCR Multi-Species Conservation Program (MSCP), and the current high costs of vegetative propagation. The following plant species are the focus of investigations for the current study:

1) Riparian Tree Species: Fremont cottonwood (*Populus fremontii* S Wats., POFR), Goodding's willow (*Salix gooddingii* Ball, SAGO), and coyote willow (*S. exigua* Nutt, SAEX).

2) Mesquite Bosque Tree Species: honey mesquite (*Prosopis glandulosa* Torr., PRGL), screwbean mesquite (*P. pubescens* Benth., PRPU), and possibly desert willow (*Chilopsis linearis* (Cav.) Sweet, CHLI).

3) Shrub Species: mule's fat (*Baccharis salicifolia* (Ruiz & Pavón) Pers., BASAL), Emory's baccharis (*B. emoryi* Gray, BAEM), desertbroom (*B. sarothroides* Gray, BASAR) quailbush (*Atriplex lentiformis* (Torr.) S. Wats., ATLE), fourwing saltbush (*A. canescens* (Pursh) Nutt., ATCA), cattle saltbush (*A. polycarpa* (Torr.) S. Wats., ATPO), wolfberry (*Lycium* spp.), and desert globemallow (*Sphaeralcea ambigua* Gray, SPAM).

A combination of greenhouse and field-scale studies were designed and conducted at the University of Arizona Southwest Center for Natural Products Research and Commercialization Center (NPC) and the Cibola National Wildlife Refuge (Cibola NWR), respectively (GSA, 2006, 2007b, 2008b). Specific tasks and schedules are as follows.

Year 1 (2006) Greenhouse Studies

- Task 1: Conducted germination studies to determine the best methods to collect, process, and store cottonwood and willow seed from the LCR. In addition, conducted studies to evaluate the effect of different levels of soil salinity on riparian seed germination and seedling survival.
- Task 3: Conducted greenhouse 7-gallon pot studies to evaluate seed treatment, seeding rate, and soil condition effects on germination, establishment, and growth of Fremont cottonwood, Goodding's willow, and coyote willow.

- Task 4: Conducted greenhouse 7-gallon pot studies to evaluate seeding method, seeding rate, and soil condition effects on germination, establishment, and growth of various shrub species native to the LCR: quailbush, fourwing saltbush, cattle saltbush, and desert thorn[1].

Year 2 (2007) Greenhouse Studies and Small-scale Field Studies

- Task 1: Continued cottonwood and willow seed storage and viability study for frozen seed treatments to determine potential for long term seed storage prior to seeding.
- Task 2: Conducted greenhouse 7-gallon pot studies to evaluate effects of seeding rate and soil condition on germination, establishment, and growth of screwbean mesquite, honey mesquite, and quailbush.
- Task 3: Conducted greenhouse 7-gallon pot studies to evaluate effects of one-year of frozen seed storage and organic fertilizer on germination, establishment, and growth of Fremont cottonwood, Goodding's willow, and coyote willow.
- Task 4: Conducted greenhouse 7-gallon pot studies to evaluate effects of seeding rate and soil condition on germination, establishment, and growth of mule's fat, Emory's baccharis, and desertbroom.
- Task 5: Conducted small-scale field studies at Cibola NWR Field 51 to evaluate effects of planting technique, seed treatment, and irrigation type on germination, establishment, and growth of Fremont cottonwood, Goodding's willow, and coyote willow for one growing season.
- Task 6: Continued site characterization of Field 51 to incorporate ongoing soil and groundwater data collection. Initiate planning for Year 3 (2008) studies.

Year 3 (2008) Greenhouse Studies and Small-scale Studies

- Task 7: Continued cottonwood and willow seed storage and viability study (replacing 2007 Task 1) for frozen seed treatments to determine potential for long term seed storage prior to seeding. Implemented germination studies for baccharis.
- Task 5U-5: Continued monitoring of small-scale field study plots at Cibola NWR Field 51 implemented in May 2007 to evaluate survival and growth of Fremont cottonwood, Goodding's willow, coyote willow, and saltcedar through the 2008 growing season. Analyzed the effects of irrigation depth and frequency.
- Task 5U-6: Conducted small-scale field studies at Cibola NWR Field 51 to evaluate planting technique, seed treatment, and irrigation type effects on germination, establishment, and growth of Goodding's willow for one growing season. .

Final results for germination studies (Tasks 1 and 7) are presented in Section 2. Current Task 5 (small-scale field studies) results are presented in Section 3. Results for Tasks 2 through 4 are

[1]For 2006 studies, desert thorn (*Lycium exsertum* Gray, LYEX) was used for analysis of *Lycium* spp.

presented in GSA (2007a, 2008a). Detailed site characterization work conducted as a portion of Task 6 at Field 51 is presented in GSA (2008c). The large-scale studies portion of Task 6 has been postponed due to ongoing Task 5 studies and interpretation of results.

2.0 TASKS 1 AND 7: LCR SEED AVAILABILITY AND SALICACEAE GERMINATION STUDY

During 2008, GSA continued germination studies at the University of Arizona NPC. The primary objectives of the 2008 germination studies were as follows:

- Evaluate the effectiveness of frozen seed storage treatments on seed viability for riparian tree species (Fremont cottonwood, Goodding's willow, and coyote willow) for a period of 27 months.
- Evaluate the viability of mule's fat, desertbroom, and Emory's baccharis seed following storage under variable environmental conditions.

Previous results from Task 1, including a detailed analysis of seed availability, are provided in GSA (2008a). A secondary objective of this task was to determine the effect of various levels of soil salinity on Baccharis seed during 2007 (GSA 2007b). However, poor viability of seed stored in the laboratory precluded any germination trials. Consequently, storage trials were incorporated into the 2008 study plan (GSA 2008b) to determine the effectiveness of various storage conditions on extending the viability of baccharis seed.

Task 1 results were also used to guide seed collection timing and seed storage for 2008 field studies. Specifically, cottonwood and willow seed was collected over three months and stored in freezers after collection. Task 1 results also provide confidence in the feasibility of bulk collection and longer-term freezer storage, and will help in the development of best management practices for seed collection and storage.

2.1 Technical Approach

2.1.1 Seed Collection

Riparian tree species seed was collected in April 2006 as detailed in GSA (2007a). Baccharis seed was collected at Cibola NWR and Cibola Valley Conservation Area on December 19, 2007. Seed was collected by manually stripping seed from seeding branches into paper bags. Following collection, seed was transported to the NPC and allowed to dry at the NPC laboratory for one week before being split into storage treatments.

2.1.2 Riparian Tree Seed Treatment and Storage Trials

Germination studies were conducted at the NPC for Fremont cottonwood, Goodding's willow, and coyote willow, as detailed in GSA (2007a). Seed storage specifications are provided in Table 1, and details on seed source trees used for the germination study are provided in Table 2. Three germination trials were conducted for cottonwood and willow seed during 2008. The germination trial schedule for the duration of the study is provided in Table 3.

Because of the extended viability observed for frozen seed, the original seed store was supplemented with additional frozen seed collected during April 2006 as detailed in GSA (2008a).

Seed Viability Determination

During 2008, seed viability was evaluated in incubators and on un-heated soil. Incubator trials were conducted by placing seed between moist paper towels and placing the towels in an incubator (VWR Economy Incubator CSA1500E, VWR International, West Chester, PA) for several days. A minimum of 20 seeds from each treatment were placed in the incubators. Two incubators were used to maintain optimal conditions for germination (i.e. 19^{o} C for Fremont cottonwood, and 27^{o} C for Goodding's and coyote willow (Baskin and Baskin, 1998)).

To mimic germination conditions at the site, soil used for germination trials was collected from Field 51 at Cibola NWR. Five-gallon buckets were filled with soil collected from a site adjacent to the small-scale field study area on several occasions (April 2006, November 2006, and May 2007). Because the germination trials were designed only to establish seed viability trends, the seed bank was removed from the soil by pasteurization. Pasteurization was implemented by passing steam through a covered bin (fabricated by the University of Arizona) for one hour at the Controlled Environment Agricultural Center using a steam generator. Finally, the soil was sieved through a 1-inch by 5/16-inch (25.4 mm by 7.93 mm) screen to remove large plant waste.

After sieving, the soil was placed into seeding trays by hand and moderately compressed to prevent caving when watered. Trays were placed into a plastic bin containing approximately one inch of water. Soil was allowed to moisten by capillary action. Finally, five to ten seeds of each seed species and treatment were placed on the surface of each cell in the seeding tray, with three cells for each species-treatment combination.

2.1.3 Baccharis spp. Germination Trials

2007 Greenhouse results indicated very poor viability for Baccharis seed stored at room temperature for five months (GSA 2008a), which therefore precludes the feasibility of direct seeding of these species for large-scale revegetation. Germination trials were implemented during 2008 to determine the effectiveness of refrigeration or freezing seed in maintaining or elevating germination rates over time. The species included in the germination studies were mule's fat, Emory's baccharis, and desertbroom.

Seed Treatments

On December 19, 2007, Emory's baccharis seed was collected from the Nature Trail (Cibola NWR), and Mule's fat and desertbroom seed was collected from Cibola Valley Conservation Area. After drying seed for one week, one third of the seed from each species was placed in a refrigerator at 4^{o}C, a freezer at -10^{o}C, or at room temperature (average of 21^{o}C to serve as the control).

Seed Viability Determination

Two germination trials were conducted for baccharis during 2008, with seeding dates of April 8 and September 8. A literature review indicated that variable light requirements exist for different species of Baccharis (Karrfalt and Olson, Jr. 2008). Therefore, germination tests were carried out both on sterilized soil in a greenhouse and in incubators (incubator temperature of 27^{o} C). A known number of seeds were placed either within moist paper towels (incubator) or on moist soil. After a period of two weeks, the number of emergent seedlings was counted.

2.1.4 Data Analysis

Data were analyzed graphically and statistically using Microsoft Excel®. Data for storage trials are presented graphically. Ninety-five percent probability distributions are provided, where the error band size (*L*) is given by Equation 2.1:

$$L = z\sqrt{\frac{\hat{p}(1-\hat{p})}{n}} \qquad 2.1$$

where $\hat{p}$ is the observed proportion (i.e. viability), and z is the z-distribution statistic (1.96 for 95% confidence interval on the mean seed viability) (Milton 1999). Thus, non-overlapping error bars indicate a significant difference at P=0.05.

2.2 Seed Availability and Germination Study Results

No additional results for seed availability and collection techniques were observed during 2008. A detailed discussion of seed collection locations and timing is provided in (GSA 2008a). Final storage trial germination study results are presented below.

2.2.1 Storage Trials for Riparian Species

Final germination study results, spanning a trial period of 27 months, are provided in Figure 1 through Figure 9; expanded data are available in Appendix B. Overall, favorable viability has been maintained for Fremont cottonwood, Goodding’s willow, and coyote willow for 27 months.

Fremont Cottonwood

Incubator viability of frozen cottonwood seed stored with oxygen since May 2006 has typically been greater than 80%. The last of the seed collected in 2006 was germinated on July 9, 2008. After 27 months of storage, incubator viability of frozen seed at ambient oxygen concentrations was 87% for cleaned seed and 95% for un-cleaned seed (Figure 1). Oxygen removal did not increase incubator viability compared to ambient oxygen storage. Viability was typically higher for seed stored at ambient oxygen compared to that stored without oxygen (Figure 1, Figure 2).

Germination on soil was approximately three to four times higher for frozen, cleaned seed than for frozen, un-cleaned seed (Figure 3). As discussed previously in GSA (2007a, 2008a), this is likely due to better seed-soil contact resulting in higher moisture availability.

Goodding's Willow

Incubator viability of frozen Goodding's willow seed stored since May 2006 has also typically been greater than 80%. The last of the seed collected in 2006 was germinated on July 9, 2008. After 27 months of storage, incubator viability of seed stored in freezers at ambient oxygen concentrations was 87% for cleaned seed and 80% for un-cleaned seed (Figure 4). Oxygen removal from seed storage containers has not resulted in higher germination rates.

Germination on soil was approximately two to three times higher for frozen cleaned seed than frozen un-cleaned seed (Figure 5). The average germination rate for cleaned seed on soil beds was higher for oxygen removal than for ambient oxygen storage (Figure 6). The same trend was observed for un-cleaned seed on soil beds (data in Appendix B).

Coyote Willow

Incubator viability of frozen coyote willow seed stored since May 2006 has also typically been greater than 80%; the only incubator trials indicating less than 80% viability were in July 2007. The last of the seed collected in 2006 was germinated on July 9, 2008. After 27 months of storage, incubator viability of frozen seed under ambient oxygen concentrations was 91% for cleaned seed and 89% for un-cleaned seed (Figure 7). Oxygen removal has not had a consistent effect on incubator viability of coyote willow (Figure 7).

Germination on soil was higher (approximately two to three times) for cleaned seed than un-cleaned seed (Figure 8). The average germination rate for frozen, cleaned seed on soil beds was slightly higher for oxygen removal than for ambient oxygen storage (Figure 9).

2.2.2 Storage Trials for Baccharis

Germination study results are presented in Figure 10 through Figure 12, and treatment effects are discussed in detail below for each species.

Mule's Fat

Mule's fat germination rates were less than 40% for all treatments on both seeding dates (Figure 10). The only germination trial that showed favorable results was for seed stored in freezers for four months (viability of 31.6%). For a germination trial after nine months of storage, only one seed out of 48 germinated. These results are comparable with 2007 greenhouse study results, where very poor viability was observed after five months of storage (GSA 2008a).

Emory’s Baccharis

Emory’s baccharis germination rates were favorable across storage treatments for the nine-month duration of seed storage. Seed viability results showed viability greater than 25% incubator germination and 80% germination on soil for all storage treatments after nine months (Figure 11). Freezing or refrigeration did not result in higher viability compared to storage at room temperature.

Desertbroom

Desertbroom germination rates were maintained above 20% for nine months under room temperature storage and under storage at -10° C. Neither freezer nor refrigerator storage increased viability compared to storage at room temperature. Germination rates were similar at four months and nine months after seed collection (Figure 12).

3.0 TASK 5: SMALL-SCALE FIELD STUDIES AT CIBOLA NATIONAL WILDLIFE REFUGE

During 2007, small-scale field plots of mixed Fremont cottonwood, Goodding's willow, and coyote willow seeding were implemented. The objective was to determine the effectiveness of seeding method (seed cleaning and seed-application technique) on the establishment and growth of Fremont cottonwood, Goodding's willow, and coyote willow. These 6-m by 12 m plot studies were implemented on the east end of Cibola NWR Field 51 (Figure 13). Additional detail, including study approach and results are presented in GSA (2008a).

During 2008, two additional activities were conducted for Task 5:

1. Task 5U-5: Continued monitoring of vegetation in 2007 riparian tree study plots, with additional analyses to include two different irrigation regimes.

2. Task 5U-6: Implementation of additional study plots for Goodding's willow.

Finally, GSA continued collection and analysis of soil water content and groundwater elevation data. Methods and results are provided in Section 3.3.

3.1 Task 5U-5: Continued Monitoring of 2007 Small-scale Study Plots

During 2007, a randomized block study was conducted to determine the effectiveness of various irrigation treatments and seeding methods on the establishment of Fremont cottonwood, Goodding's willow, and coyote willow. Study methods and results from 2007 monitoring are detailed in GSA (2008a). As a result of the implemented research variables, a range of densities for riparian species and saltcedar trees were established in the small-scale study plots. Overall, high establishment was observed for Fremont cottonwood and saltcedar, with very low establishment of Goodding's and coyote willow. Therefore, cottonwood and saltcedar are the focal species of continued monitoring efforts on the 2007 small-scale study plots. Monitoring in 2008 was implemented with the following objectives:

- Determine growth and survival rates for seeded riparian species and volunteer saltcedar plants during a second growing season.
- Quantify additional establishment of native or introduced species.
- Determine the effects of two different irrigation regimes on cottonwood and saltcedar growth and survival.

3.1.1 Technical Approach

GSA managed irrigation management during the 2008 growing season, and conducted above and below-ground (root) vegetation surveys following a protocol developed in 2007 (refer to GSA 2008a). Detailed study methods are described below.

Irrigation Water Application

As described in GSA (2008b), irrigation treatments were imposed to look at two disparate irrigation regimes. Specifically, half of the 2007 study plots were irrigated once per week (Blocks A1 and A2), and half of the plots were irrigated approximately once per three weeks (Blocks B1 and B2). Irrigation block layout is depicted in Figure 13. The objective was to apply similar depths of irrigation water over the year under the two regimes, but to allow two soil water depletion rates within the rooting zone. The target irrigation rates were approximately 1 cm per day, i.e. irrigation of approximately 7 cm of water once per week was desired for A blocks, and irrigation of approximately 21 cm of water once per three weeks for B blocks. Irrigation management by GSA began on May 1, 2008 and continued through October 31. Prior to May, small-scale study plots were watered by Riverbottom Farms on six occasions (first on March 2, 2008).

During May through October, one irrigation block was watered at a time (i.e. A1, A2, B1, or B2). As described in GSA (2008a), a totalizing flowmeter was installed adjacent to the irrigation pump. However, the flowmeter malfunctioned from May 1, 2008 through June 15, 2008. During this period, required irrigation volumes were estimated based on flow rates from the previous growing season (i.e. flow rates were recorded for the pump during the final irrigation events in 2007). The irrigation pump was allowed to run for the duration required to deliver a given irrigation depth based on the recorded flow rate. Following replacement of the flowmeter on June 16, irrigation volumes were prescribed in order to apply the desired depth of applied irrigation water.

Prior to each irrigation event, the cumulative flow volume was recorded from the flowmeter display, and flow volume was monitored until the required volume of water was applied. The irrigation protocol was as implemented during 2007 (refer to GSA 2008a). The prescribed irrigation depth for B blocks was greater than combined daily infiltration and surface storage capacity of the plot area. Therefore, irrigation water application to the B blocks occurred over a period of two days for each irrigation event.

Above-ground Vegetation Surveys

2008 vegetation monitoring of the 2007 small-scale study plots consisted of canopy cover measurements and quadrat monitoring at the beginning and end of the growing season (i.e. May and October, 2008). Monitoring was a stratified random design, whereby one sample type was located randomly within each third of the plot (with plot divisions into thirds based on distance from the gated irrigation pipe). An example survey schematic is shown in Figure 14. Because biomass sampling was implemented in the fall of 2007, repeat measurements could not be made at quadrats previously monitored. Therefore, new transects and quadrats were randomly placed using another set of random numbers.

Point transects were monitored to determine crown and canopy cover, and quadrats were monitored to determine tree density, height, growth rate, and survival. Initial data were collected in May 2008, when height of all Fremont cottonwood, Goodding's willow, coyote willow, and saltcedar in each quadrat was recorded, and these trees were tagged with a unique ID number to allow repeat measurements. This procedure allowed follow-up measurements of individual trees at the end of the growing season. Furthermore, tags remain on trees within quadrats to allow longer-term monitoring if desired.

As for 2007 surveys, species-specific data were analyzed for seeded riparian species (Fremont cottonwood, Goodding's willow, and coyote willow) and saltcedar. Grasses and sedges were lumped as Gramineae, and other species were classified as shrubs and forbs, denoted "S/F". Survey methods are briefly reviewed below.

Cover Point Transects

Species-specific crown and canopy cover was estimated via point transects. Two wood stakes were placed on either side of the plot (north or south), and a tape measure was attached to each side of the stake. A dowel was held vertically at each transect point at one-foot (approximately 30-cm) intervals and each cover type below the dowel at each point was recorded on datasheets (Appendix A). Each cover type was recorded a maximum of once per point. The cover percentage of each component was obtained by dividing the number of "hits" by the number of sample points, as described by Equation 3.1:

$$Cover = (x/n) \times 100\% \qquad 3.1$$

where x is the number of hits for a given cover, and n is the number of observation points per plot (i.e. n = 63 at 20 feet of plot width with 1 observation per foot times three transects per plot).

The first cover type below the dowel represented crown cover, whereas canopy cover included both crown cover and understory cover. Crown cover indicates the dominant (tallest) species in the observation area, whereas canopy cover indicates total abundance of a given cover. Therefore, canopy cover is greater than or equal to crown cover. By definition, the combined crown cover of all cover types must equal 100%, whereas the total canopy cover per species must be less than or equal to 100%.

Quadrat Analysis

Quadrats consisted of 1- by 0.5-m rectangles (0.5 m^2) constructed from ¾-inch diameter PVC pipe. Three random numbers were selected to determine the location of each quadrat. The combination of random numbers determined the location of the reference corner for quadrats within each third of a given plot. For plots on the west side of the irrigation pipes, the random numbers determined the location for the northeast corner of the quadrat. For plots on the east side of the irrigation pipes, the random numbers determined the location for the northwest corner on the quadrat. Once this corner was located, the adjacent north-south edge was aligned with the cover transects. As noted previously, a new set of random numbers was used to avoid surveying near 2007 biomass sampling locations.

Within quadrats, cover of all species was visually estimated using sociologic classification; crown and canopy cover for each observed species was estimated to cover classes. An aluminum tag with a unique identification number was affixed to each Fremont cottonwood, Goodding's willow, coyote willow, and woody saltcedar within a given quadrat. It should be noted that tags were not placed on small saltcedar plants with stems incapable of supporting the tag. During the October 2008 survey, saltcedar plants which had grown significantly were also tagged. This will allow additional monitoring of these plants should longer-term monitoring be implemented.

Tree heights were measured to the nearest 0.5 cm, and the number of height measurements was used to tabulate stem density (stems per square meter). During the fall 2008 survey, diameter at breast height (DBH) was measured for all seeded trees and saltcedar greater than 147-cm tall, and each tree was given an alphanumeric condition index, as outlined in Table 4. All other species were monitored by assigning a relevé index measuring the average plant height. Data for the three quadrats per plot were combined to provide an overall estimate for the plot. The combined quadrat area represented approximately two percent of the total plot area.

Repeat measurements of tagged trees allowed for calculations of growth rates. The growth rate was determined via equation 3.2:

$$GrowthRate = \frac{(h - h_0)}{n} \qquad 3.2$$

Where h is the height measured during the fall survey (between October 3 and October 5, 2008), and h_0 is the height measured in the spring survey (between May 14 and June 1, 2008), and n is the number of days between measurements. Values of n ranged from 125 to 142 days.

Root Survey

Root surveys were conducted on October 28 and 29, 2008. The goal of the root survey was to qualitatively analyze the propagation of Fremont cottonwood and saltcedar roots toward groundwater. An additional objective was to detect potential effects of irrigation treatments on root growth and correlate root abundance with vegetation density.

Plots to be surveyed were selected to cover the range of observed densities for cottonwood and saltcedar within both irrigation treatments ("A" and "B"). Cottonwood and saltcedar survey results for plots in which root surveys were conducted are provided in Table 5. Survey data are presented for the fall 2008 vegetation survey (i.e. after two growing seasons) and summarize vegetation characteristics within the outermost quadrat of the plots, below which rooting surveys were conducted.

Root surveys were conducted using a modified NRCS classification system (Schoeneberger et al., 2002). On the outside edges of ten plots, trenches were excavated to a minimum depth of four feet, adjacent to the outermost survey quadrat. A survey was conducted on each sidewall of the trench below the midpoint of the quadrat. Roots within 10-cm by 10-cm areas on the trench sidewall were counted for a given size class, and abundance of each size class was recorded according to the key provided in Table 6. An example survey schematic is provided in Figure 15. The shallowest 100-cm^2 survey area was placed at 10 to 20 cm below ground surface, and the second was placed at 20 to 30 cm below ground surface. Below 30 cm, surveys were conducted every other 10 cm depth interval (i.e. 40 to 50 cm, 60 to 70 cm, etc.), and continued to the bottom of the trench or to the point below which no roots were encountered.

Statistical Analysis

For graphical purposes, statistics were analyzed via Student's t-tests for treatment variable effects. Additionally, linear analysis of variance (ANOVA) modeling was conducted using JMP 6™ (SAS Institute, Cary, N.C.).

In order to determine if treatment effects observed in the initial survey were sustained over more than one growing season, the effects of the original treatments (seed application method, surface irrigation method, and seeding rates, refer to GSA 2008a) were analyzed for the following:

- Crown cover of seeded and non-seeded species.
- Canopy cover of target and non-seeded species.
- Stem density of seeded species and saltcedar.
- Height of seeded species and saltcedar.

Least-squared means were compared via Student's t-tests to determine significant differences between treatments. Because seeding rate was not a major variable, it could not be included as part of the factorial design, but was included as a continuous variable in the ANOVAs. Therefore, least-squared means were not available in the results. However, direct (increasing) or inverse (decreasing) relationships were calculated and the P-values associated with those relationships are presented.

ANOVAs were also conducted to assess the effects of initial tree height (during May 2008 survey), irrigation treatment (A or B, as described previously), cottonwood and saltcedar crown cover, and cottonwood and saltcedar stem density, on growth rates of cottonwood and saltcedar. The overall crown cover from each plot and the average stem density for the three quadrats were used as independent variables.

Additionally, graphical results are presented for the with 95% confidence intervals from the mean. In the ANOVA tables, the P-values for effects and interactions are based on F-tests. Significant differences for least-squared means are based on Student's t-tests with a P of 0.05.

3.1.2 Results: Continued Monitoring of 2007 Small-scale Study Plots

Irrigation Water Application

Irrigation event application depths are shown in Table 8 and Table 9 for the A and B irrigation blocks, respectively. The total depth of applied water for the 2008 growing season (March 1 through October 31) was approximately 171 cm for A blocks. Based on estimated reference crop evapotranspiration (ET_o) at the nearby Cibola weather station calculated via the Penman-Monteith equation (FAO 1998), the applied water to the A Blocks correlates to approximately 80% of ET_o. The total depth of applied water was approximately 181 cm for B blocks correlating to approximately 85% of ET_o. The higher total applied water for B blocks was primarily due to an additional irrigation event on October 16 and 17, 2008, applied in order to irrigate B blocks at least once during October (the previous irrigation event was on September 19, 2008). The final irrigation event for A blocks occurred on October 3, 2008.

The leaching fraction of the irrigation water applied depends on the actual ET of riparian species. Previous authors have suggested that cottonwood ET demand might average 74% of ET_o over the growing season (Gazal et al. 2006). Soil water content and groundwater elevation data (Section 3.3) indicate minimal depletion of soil water below 3 feet and rising groundwater elevations late in the growing season. The actual volume of groundwater and soil water utilized by trees in the small-scale study area has not been quantified, and would require additional analysis (groundwater flow quantification, sap flux meters, and/or isotope analysis). This information would aid in quantification of the leaching fraction to ensure successful salinity management.

Vegetation Monitoring: 2007 Treatment Variables

2008 ANOVA results for the 2007 small-scale study treatments are provided in Table 10 and Table 11 for seeded and non-target species, respectively. These results evaluate establishment and cover after two growing season (i.e. May 2007 through October 2008). Treatment effects are discussed in detail below.

Lower crown and canopy cover of Fremont cottonwood in sprinkler-irrigated plots compared to no sprinkler irrigation continued to be observed in 2008 despite no difference in establishment rates between the irrigation treatments (Table 10). Average cottonwood tree height also remained lower in sprinkler-irrigated plots (Table 10), indicating that total tree growth in sprinkler-irrigated plots continued to be less than in plots irrigated by surface irrigation only. 2008 results also indicate that sprinkler irrigation reduced the cover of saltcedar (Table 11). Crown cover of grasses and shrubs and forbs was greater in sprinkler-irrigated plots (Table 11), likely due to reduced growth of cottonwood and saltcedar.

Average cottonwood crown and canopy cover and tree densities were highest for hydroseeded, un-cleaned seed compared to broadcasted or hydroseeded, cleaned seed, however, ANOVA least-squared means were not significantly different at P=0.05 (Table 10). Seed treatment also did not result in significant differences for saltcedar or shrubs and forbs (Table 11).

Furrow irrigation resulted in significantly greater crown and canopy cover of Fremont cottonwood compared to border-strip irrigation. Cottonwood stem density was not significantly different between surface irrigation treatments, whereas average cottonwood height was significantly greater in furrow-irrigated plots (Table 10). Goodding's willow density was significantly higher in furrow-irrigated plots (Table 10). Surface irrigation method did not significantly affect saltcedar establishment or growth (Table 11). However, Gramineae cover was greater in border-strip irrigated plots, and shrub and forb cover was greater in furrow-irrigated plots (Table 11).

Plot position 1 (northern portion of Field 51) caused significant reductions in cottonwood density, crown and canopy cover compared to plot position 2 or 3 (central and southern portions of the field, respectively) (Table 10). Moreover, saltcedar establishment and growth were greatest for plot position 1 (Table 11). These results may be due to higher subsurface salinity observed on the northern side of the field (GSA 2008c).

Vegetation Monitoring: Long-term Trends

ANOVA results for Fremont cottonwood and salt cedar growth rates between the spring and fall monitoring events are provided in Table 12; summary charts for long-term vegetation trends between 2007 and 2008 are provided in Figure 16 through Figure 24 and discussed in detail below. All field data are provided in Appendix C. Due to minimal establishment in 2007 and high mortality in 2008 of willow species, results are only presented for cottonwood and saltcedar. It should also be noted that growth rate data are available only for tagged plants. Therefore, many saltcedar plants were not included in the growth analysis because their stems were not sturdy enough to support identification tags. Non-tagged trees are included in plant density and overall species mortality analyses.

Average Fremont cottonwood crown cover across all plots increased from 8% in September 2007 to 41% in September 2008 (Figure 16), and canopy cover increased from 16% to 60% in that time period (Figure 17). Saltcedar crown cover increased from 3.7% in September 2007 to 12.0% in October 2008 (Figure 16) and canopy cover doubled from 18% to 36% (Figure 17). Crown and canopy cover of cottonwood is now greater than of saltcedar. This result is likely due to superior growth rates and survival observed for Fremont cottonwood compared to saltcedar (Figure 18 and Figure 19, respectively).

Fremont cottonwood tree density slightly decreased from September 2007 to October 2008, whereas the density of saltcedar decreased from 25 stems per m^2 to 14.4 stems per m^2 (Figure 20). Mortality was observed for both species during the 2008 growing season, but the overall mortality of saltcedar was greater than that of cottonwood (Figure 19). Mortality occurred primarily in smaller plants. Mortality for saltcedar less than 50 cm tall at the beginning of the growing season was nearly 60% and mortality for cottonwood less than 50 cm tall was nearly 40% (Figure 21). No mortality was observed for saltcedar plants taller than 150 cm during the

May 2008 survey and only one Fremont cottonwood greater than 150 cm tall died during the 2008 growing season (*n* of 40 and 246 for saltcedar and cottonwood, respectively).

Fremont cottonwood growth rates were greater than those for saltcedar across tree heights (Figure 22). Note that the error bars for certain size categories are quite large for saltcedar due to the small number of individuals in that category. Growth rates for cottonwood and saltcedar increased with higher initial tree height (Table 12), likely due to greater light and soil water availability.

Gramineae (combined grasses and sedges) crown cover decreased from September 2007 to May 2008 due to senescence over the winter and expanding growth of cottonwood and saltcedar (Figure 16). Crown cover of shrubs and forbs (S/F) did not significantly change (Figure 16), but canopy cover decreased during the 2008 growing season (Figure 17).

Irrigation Treatment Effects

Irrigation treatments did not significantly affect mortality rates of Fremont cottonwood or saltcedar (Figure 23). Growth rates were likewise unaffected by irrigation treatment (Table 12, Figure 24). A lack of treatment effects is likely due to less soil water depletion than predicted in the plots receiving the B irrigation treatment. Soil water availability is discussed in detail in Section 3.3.

Competition Effects

Fremont cottonwood growth rates decreased with higher cottonwood and saltcedar crown cover (Table 12). Additionally, lower growth rates were observed at higher Fremont cottonwood stem density. Cottonwood growth rates were not affected by saltcedar stem density (Table 12). Greater initial tree height resulted in higher growth rates.

Saltcedar growth rates were not affected by crown cover of cottonwood or saltcedar or by stem density of Fremont cottonwood (Table 12). However, lower growth rates were observed at higher saltcedar stem density. As for Fremont cottonwood, greater initial height of saltcedar resulted in higher growth rates (Table 12).

2008 results indicate that there is a tree density beyond which higher cottonwood densities do not result in increased canopy cover. Additionally, higher cottonwood tree density did not result in reduced growth or higher mortality of saltcedar. As shown in Figure 25, beyond an intermediate Fremont cottonwood tree density of approximately ten to fifteen per m^2 (approximately one per square foot), average cottonwood crown cover remains above 60%, with less than 20% saltcedar crown cover. It should be noted that these results are still considered preliminary, and extended monitoring is recommended to assist in the development of a recommended Fremont cottonwood seeding and establishment rate.

Root Survey

Roots were relatively sparse on the sidewalls of excavated trenches, likely due to dominance of riparian trees and relatively low growth of shrubs and forbs in plots selected for the root survey. An example trench is shown in Figure 26 for Plot 16. Tap roots of both cottonwood and saltcedar were regularly encountered, but fine roots were not abundant. When a survey was conducted directly below a tree, the main root was encountered in each survey area. The low abundance of roots precluded statistical analysis. However, surveys are qualitatively useful for observation of rooting depth. All data for the root surveys are provided in Appendix E, and results are summarized below.

Many Fremont cottonwood trees were sacrificed during the survey, which allowed basic observations of root elongation. A typical excavated cottonwood is shown in Figure 27 (excavated from plot 30), with several lateral as well as vertical roots. Similar root structure was observed for saltcedar. Tap roots have penetrated deep within the soil profile, with numerous roots observed at greater than 150 cm, as shown in Figure 28 for Plot 16.

The primary observation of interest from the root survey was that medium to coarse roots were regularly observed at the bottom of trenches (i.e. deeper than 150 cm below ground surface) for both A and B irrigation treatments, and that soil at the base of trenches was often near saturation. This condition indicates that capillary wetting from groundwater and/or mounding of irrigation water/groundwater is prevalent and that many cottonwood and saltcedar plants established in the small-scale study area are likely phreatophytic after two growing seasons.

3.2 Task 5U-6: Additional Small-scale Study Plots for Goodding's Willow

The objectives of the 2008 Goodding's willow small-scale study were to evaluate the effect of seed application and irrigation methods on plant establishment and to determine whether Goodding's willow establishment can be improved by reducing competition with other species. Specifically, the poor establishment rates of Goodding's willow in the 2007 test plots were most likely due to high competition from non-native grasses and Fremont cottonwood. In the 2008 study plots, Fremont cottonwood and coyote willow were eliminated from the seed mix, grass-specific herbicide was applied repeatedly, and the nominal Goodding's willow seeding rate was elevated to 1600 PLS/m^2.

3.2.1 Technical Approach

Small-scale study variables were designed to analyze potential large-scale seeding and irrigation methods for the establishment of Goodding's willow from native seed. Small-scale study variables are presented in Table 13. Additional detail and reasoning are provided below.

The seed cleaning treatment was implemented to investigate potential increases in willow establishment with removal of seed hairs. Cleaning of Goodding's willow seed resulted in an approximate doubling of establishment in 7-gallon test pot studies (GSA 2007a). Consequently, it was anticipated that seed cleaning would minimize seed translocation via wind and water flow, and maximize germination due to better soil-seed contact.

The seeding method treatment was implemented to determine the effectiveness of standard large-scale seeding techniques on Goodding's willow establishment. Standard seeding techniques include broadcast seeding and hydroseeding. Consequently, the following seeding methods were used for the 2008 small-scale field studies:

- Broadcasted, cleaned seed.
- Hydroseeded, un-cleaned seed.

For statistical analysis seed cleaning and seed application method are combined into a single effect, denoted "Seed Treatment".

Standard surface irrigation methods consisted of furrows or border-strip irrigation. Furrows were on 40-inch (approximately 1-m) spacing, constructed east to west across the plots. Border-strip irrigation consisted of small-scale basins with shallow ditches circumscribing them, thereby potentially enhancing uniformity of irrigation water distribution compared to standard basin irrigation.

Although seeding rate was not a design variable, the seeding rate varied between hydroseeded plots due to variable application time per plot (range of 1505 to 1851 PLS/m^2) and small variation in plot size, and was therefore required for statistical analysis. For the hydroseeded plots, the actual seeding rate was estimated based on the duration of application from the hydroseeder. The seeding rate for broadcast plots also slightly varied due to variation in actual plot size. Seeding rates for the broadcast plots ranged from 1525 to 1680 PLS/m^2.

Plot Design and Implementation

The small-scale field study consisted of a factorial design with four replications wherein the treatments were randomly assigned to constructed plots. The small-scale study layout is depicted in Figure 29. The 2008 small-scale study plots were designed to accommodate the limitations of furrowing equipment. Plots were designed to be 6 m (20 feet) by 12 m (40 feet), as they were for the 2007 small-scale study. Two soil berms were placed between plots, with a total buffer width of approximately 5 m (15 feet).

Seed Collection, Treatment, and Application

During 2007 and 2008, Goodding's willow seed was collected from the Ahakhav Tribal Preserve and Cibola NWR. Seed was allowed to dry at NPC laboratories for a period of one week. Thereafter, seed was stored in freezers. UTM coordinates and other data (e.g. abundance of collected species, ease of collection, tree size, etc.) were recorded on datasheets (Appendix A).

Clinometer (Brunton Clino Master® 31198, Brunton, Riverton, WY) readings were used to determine tree height, as detailed in GSA (2007a).

Seed was allowed to dry in the laboratory for a minimum of one week. After drying, seed was stored un-cleaned in freezers. Sufficient seed for the "cleaned, broadcast" plots was cleaned by seed hair removal in a Wiley mill (Model #2 and Model #4, Arthur H. Thomas Company, Philadelphia, PA) and subsequent separation of seed from debris with a #25 sieve (Newark Wire Cloth Company, Newark, NJ). Final cleaning was accomplished with an air-screen machine, which uses a stream of air to separate debris from seeds based on weight and aerodynamics (Model D, E.L. Erickson Products, Brookings, SD). After cleaning, seed was returned to freezers. Incubator germination studies were conducted for each seed source to determine the PLS rate for the small-scale studies.

Sufficient seed was obtained for each seeding method by mixing seed from multiple source trees. Approximately one half of the Goodding's willow seed utilized for the small-scale study was collected during 2008, with the other half collected during 2007. As discussed below, cleaned, broadcast treatment seed was allocated per plot at the rate of 1600 PLS/m^2 (for an assumed plot area of 74 m^2) of Goodding's willow. Hydroseed treatment seed was allocated for nine plots, to allow sufficient seed for the eight treatment plots and an additional test area. The allocated seed was then placed back into NPC freezers until transport to Field 51 small-scale plots for seeding.

On the day of seeding in small-scale plots (May 28, 2008), seed was transported to Cibola NWR in insulated coolers. Block ice was placed in the bottom of coolers, and the seed was placed above. Coolers with seed were stored in shade on-site until seed was applied. Hydroseeding was completed by 12:45 PM on May 28, 2008.

Hydroseed was applied with a 2.1 m^3 (550-gallon) capacity Finn Hydroseeder (Finn Corporation, Fairfield, OH). The application rate was approximately 20.5 cubic meters per hectare (2200 gallons per acre) of hydroseed consisting of water, mulch, and seed. Note that no chemical tackifiers were applied. Mulch consisting of Conwed® Fibers 2000 wood fiber (Profile Products, LLC, Buffalo Grove, IL) cellulose fiber was applied at approximately 112 kg per hectare (100 pounds per acre). A known number of seeds was placed in the hydroseeder mixing tank based on 1600 PLS/m^2 and an assumed application rate of 20.5 cubic meters per hectare. The actual time of seed application in each plot was noted in field books, as was the total duration of seed application (unused seed was sprayed onto an adjacent portion of the field until all seed was applied). The seeding rate for a given plot was then calculated from Equation 4.1:

$$\frac{PLS}{ft^2} = \frac{\frac{T_p}{T_t}(S_t)}{A} \qquad 4.1$$

where T_p is the time of application within a given plot, T_t is the total time of hydroseed application, S_t is the total seeds placed in the hydroseeder, and A is the plot area.

Broadcast seed was applied with a broadcast spreader (The Scotts Company, Marysville, OH). The desired seeding rate for broadcast-seeded plots was the nominal rate (i.e. 1,600 PLS/m^2 total). However, as noted previously, the actual seeding rates varied from 1,525 to 1,680 PLS/ft^2 due to inconsistency in plot area. Seed for each plot was placed in the spreader, and all seed was spread in each plot. Broadcast seeding was completed by 1:30 PM on May 28, 2008.

Irrigation Design

Furrow and border-strip irrigation methods were applied to determine the effects of these standard irrigation methods on plant establishment and growth. Border-strip irrigation consisted of small-scale basins enclosed by soil berms with small ditches along the entire perimeter to minimize sheet overflow, as water travels around the plots in the ditches before cresting onto the seeded area. Furrow irrigation was implemented via ripping in an east-west orientation. Furrows were placed on 1.02 m (40 inch) centers, and furrow depth was approximately 0.16 m (6 inches).

Six-inch outer diameter aluminum gated pipe was used to maximize uniformity of irrigation water distribution for border and furrow methods. A gated pipe lateral was placed along each side of the center, north-south plot dividing berm, as shown in Figure 30. This highly-controlled surface irrigation system allowed for minimal variation between plots and therefore reduced potential for study bias due to differences in water availability.

A totalizing flow meter was placed adjacent to the gated pipe pump, and flow volumes were recorded for each irrigation event. Irrigation of the Goodding's willow small-scale study plots was managed using the following protocol:

1) Record cumulative flow volume from totalizing flow meter.
2) Start gated pipe pump. Record time.
3) Allow irrigation to continue until water levels in furrow troughs are approximately 2/3 of the height of furrow crests and border plots are approximately 75% inundated.
4) Turn pump off. Record time and cumulative flow volume.

Vegetation Monitoring

Vegetation monitoring consisted of canopy cover measurements and harvested quadrats. As for 2007 plots, monitoring was a stratified random design, whereby one transect was located randomly within each third of the plot (with plot divisions based on distance from the gated pipe). However, to assist in germination surveys, six quadrats were located on the edge of the plots in the July surveys to allow germination counts to be conducted while minimizing impact to seedlings. An additional three quadrats were randomly placed in the fall survey per the same procedure applied to the 2007 plots for a total of nine quadrats in each plot. The survey design for a hypothetical plot is provided in Figure 32.

Vegetation success during the fall for the Goodding's willow small-scale field studies was monitored as for 2007 plots; point transects were monitored to determine crown and canopy cover and quadrats were monitored to determine stem density and height. Data were collected in September 2008, after approximately three and a half months of growth. Although plant growth continued into October, surveys were implemented in September to facilitate growth comparison with 2007 plots.

Statistical Analysis

For graphical purposes, statistics were analyzed via Student's t-tests for treatment variable effects. Additionally, linear analysis of variance (ANOVA) modeling was conducted using JMP 6™ (SAS Institute, Cary, N.C.) to determine the effects of treatments (seed application method, surface irrigation method) on the following:

- Crown cover of Goodding's willow and non-seeded species.
- Canopy cover of Goodding's willow and non-seeded species.
- Stem density of target species and saltcedar.
- Height of Goodding's willow and saltcedar.

To account for potential bias due to variable PLS rates, seeding rate was included as an independent variable in the ANOVA analysis. Significant treatment effects and interactions on a given result were determined by F-tests. Least-squared means were compared via Student's t-tests to determine significant differences between treatments.

Graphical results are presented with 95% confidence intervals from the mean. In the ANOVA tables, the P-values for effects and interactions are based on F-tests. Significant differences for least-squared means are based on Student's t-tests with a P of 0.05.

Because seeding rate was not a major variable, it could not be included as part of the factorial design, but was included as a continuous variable in the ANOVAs. Therefore, least-squared means were not available in the results. However, direct (increasing) or inverse (decreasing) relationships were calculated, as were the P-values associated with those relationships.

3.2.2 Results: 2008 Goodding's Willow Small-scale Field Study

Linear ANOVA modeling results are provided in Table 15 and treatment effects are discussed in detail below. All field data are provided in Appendix F. Crown and canopy cover results are presented for Goodding's willow, saltcedar, combined shrubs and forbs, and Gramineae (combined grasses and sedges, no rushes were observed). Stem count (per m^2) and average height results are presented for only Goodding's willow and saltcedar.

Seed Cleaning and Application Method (Seed Treatment)

The un-cleaned seed, hydroseeding method resulted in higher canopy cover and stem count for Goodding's willow compared to the cleaned, broadcast seed treatment (Table 15). Establishment rates (percent of applied seeds resulting in a seedling during the fall survey) were likewise greater for hydroseed than for broadcast cleaned seed (Figure 33). The seed treatment variable did not have a significant effect on any of the non-target species (Table 15).

Surface Irrigation Method

Surface irrigation method had no significant effects on Goodding's willow establishment or growth (Table 15, Figure 33). Surface irrigation method did not affect the establishment of saltcedar; however, the crown cover and height of saltcedar in furrow-irrigated plots was significantly lower compared to border plots, indicating that established saltcedar exhibited lower growth rates in furrowed plots (Table 15).

Furrow irrigation resulted in a lack of plant growth on the crest of furrows, as was the case for 2007 study plots. The furrow crests were wetted during irrigation through capillary action. However, seed germination and plant growth on the crest may have been prevented by salt accumulation due to evaporation and lack of leaching on the crest.

Seeding Rate

Actual seeding rates in the hydroseeded plots varied from 1505 to 1850 PLS/m^2, with an average of 1709 PLS/m^2. Actual seeding rates in the broadcast plots varied from 1525 to 1680 PLS /m^2, with an average of 1633 PLS/m^2. Seeding rate was directly correlated with Goodding's willow plant establishment (stems/m^2). Other relationships were not significant at P=0.05 (Table 15).

Small-scale Field Study Vegetation Summary

Stem density calculated from quadrat surveys ranged from zero (BB3) to greater than 30 per m^2 (HB1, Figure 34). The average Goodding's willow stem density was approximately 9.3 per m^2 (all plots and treatments combined).

Compared to 2007 plots there was an overall reduction in grass abundance and increase in shrub abundance (including saltcedar). Qualitative data are provided in Table 14. Bermudagrass established immediately after irrigation, but was reduced by four applications of Arrow 2EC grass-specific herbicide during June and July, 2008. Mortality was not observed for all grasses, but growth was severely retarded. As a result, average Gramineae canopy cover for 2008 study plots averaged 36% (Figure 35) compared to over 91% for 2007 study plots (GSA 2008a). However, canopy cover of non-target shrubs and forbs averaged 88% (Figure 35) compared to 47% for 2007 study plots (GSA 2008a).

Saltcedar was abundant in the 2008 small-scale study plots. The stem counts ranged from 33.8 to 74.7 per m^2, with an average of 51.3 per m^2 (Figure 34), which was approximately double the establishment in 2007 plots (GSA 2008a). Compared to the 2007 plots, saltcedar crown cover was much greater, averaging 25% (Figure 36) compared to 4% in 2007 plots. Average Goodding's willow and saltcedar height per plot is shown in Figure 37. Saltcedar height in the fall survey averaged 45 cm for 2008 plots compared to 28 cm for 2007 plots. Fremont cottonwood height after averaged 48 cm for 2007 plots after four months of growth compared to 33 cm for Goodding's willow in 2008 plots.

The increased abundance of saltcedar and other shrubs and forbs are likely due to a combination of lower competition with Goodding's willow in 2008 compared to Fremont cottonwood in 2007, and reduced competition with grasses due to enhanced weed control for the 2008 Goodding's willow plots.

Irrigation Water Application

Irrigation application for Goodding's willow plots during the 2008 growing season is shown in Table 16. The total depth of applied water was approximately 160 cm. The applied water was higher than in the 2007 plots primarily due to the early-season need to keep the near-surface soil moist during seedling establishment.

3.3 Small-scale Study Area Site Characterization

A detailed characterization of Cibola NWR Field 51 was conducted during 2006 and 2007, and a detailed presentation of methods and results is available in GSA (2008c). Soil instrumentation was installed in 2007 small-scale study plots during 2007. Additional instruments were installed in the Goodding's willow test plots as described below. Instrumented well point piezometers were established across Field 51 in 2006. Additional piezometers were installed in both 2007 and 2008 to provide additional data near the small-scale study area.

3.3.1 Technical Approach

Soils Moisture Content, Temperature, and Electrical Conductivity

Instrument nests were established in the 2007 small-scale study plots prior to seeding as discussed in GSA (2008c). Volumetric water content, soil temperature, and pore water salinity (electrical conductivity, EC) are being monitored at 15 cm below ground surface (bgs) in each plot using ECH_2O-TE sensors (Decagon Devices, Inc., Pullman, WA). Additionally, volumetric water content is being monitored at 45 and 91 cm bgs using an EC-10 sensor. During 2008, data were recorded at four-hour intervals using a remote data acquisition system.

In the 2008 study plots, ECH_2O-TE sensors were installed in eighth of the sixteen plots at 15 cm bgs to correspond to the instrumentation depth of 2007 plots. No EC-10 sensors were installed. Plots were selected based on proximity to the existing Campbell Scientific, Inc. (Logan, UT) dataloggers. Selected plots are shown in Figure 31. The goal of instrumentation for the 2008 study plots was to monitor irrigation events and soil EC in the shallow subsurface.

Depth to Groundwater

Depth to groundwater/groundwater elevation has been monitored since July 2006 using instrumented well point piezometers (GSA, 2008c). During 2007, eight well point piezometers were installed and instrumented across Field 51 (five pre-existing from the large-scale site characterization, and three additional for 2007 small-scale field studies). However, during late 2007, the PZ-SW was destroyed by farming equipment. The piezometer was repaired, but the datalogger was damaged beyond repair. Additionally, dataloggers from PZ-C and PZ-NW were moved to PZ-SAGO N and PZ-SAGO S. As a result, during 2008, data were collected twice per day for the seven well points located in the small-scale study area using WL16 Levelloggers (Global Water Instrumentation, Inc, Gold River, CA). Manual readings were taken for the three well points on the west side of Field 51 (PZ-C, PZ-SW, and PZ-NW) a minimum of once per month using a well sounder. An updated map with well point locations and names in the small-scale study area is provided in Figure 31.

3.3.2 Results

Soil Moisture Content, Electrical Conductivity and Temperature

Soil sensor data for each small-scale study plot are presented in Appendix D and Appendix G for the 2007 and 2008 plots, respectively. Overall trends and specific examples are discussed in detail below.

The main objective of the 2008 irrigation treatments on the 2007 small-scale study plots was to observe differences in water use at depth between the A and B blocks. Specifically, the objective was to allow depletion of plant-available soil water to greater depths in the B blocks. Higher depletion of soil water was observed at 15 and 46 cm bgs for B blocks compared to A blocks (for example Figure 38 versus Figure 39). However, little depletion of soil water was observed at 91 cm bgs in either of the irrigation blocks. In fact, reduction in soil water content at 91 cm bgs relative to the non-growing season soil water content was not correlated to either irrigation block treatment or tree density. For example, relatively stable volumetric water content at 91 cm bgs was observed for plots NCBF 1 (irrigation block B1) and NUHF 1 (irrigation block A1) as shown in Figure 38 and Figure 39, respectively. Soil water depletion was observed for plot NCHF 1 (irrigation block A1) at 91 cm bgs during June through August (Figure 40), whereas an overall increase in volumetric water at 91 cm bgs was observed in plot YCBF 3 (irrigation block B2) Figure 41.

These results indicate that (1) irrigation water was applied at a higher rate than plant water use of vadose zone moisture and/or; (2) capillary rise of groundwater contributed to vadose zone moisture, and/or; 3) trees were using groundwater in addition to vadose zone water such that dry conditions were never observed below 90 cm bgs. It is likely that all factors contributed to high volumetric water content at depth over the growing season. As observed during the root survey, cottonwood roots had penetrated the soil profile to near groundwater. Therefore, it is likely that trees utilized groundwater as well as vadose zone water. Consequently, cottonwood water demand at this location cannot be observed soley by monitoring soil moisture content.

At 15 cm below ground surface, ECH_2O-TE readings in the 2007 small-scale plots indicate short-term increases in soil specific conductance following irrigation events, likely due to downward flushing of salts accumulated in the near-surface soil between irrigation events. An example of this scenario for plot NCBF 3 is shown in Figure 42.

Volumetric water content data for the 2008 Goodding's willow study plots are shown in Figure 43 and Figure 44, respectively, for the northern and southern instrumented Goodding's willow study plots. It should be noted that sensors in plots HF 1 and BB 2 malfunctioned soon after the onset of irrigation, and data are unavailable for late in the growing season (Figure 43). Northern plots show volumetric water content response due to irrigation events and rainfall events such as the 2 cm rainfall event on September 11, 2008. More extensive drying was observed between irrigation events later in the growing season when irrigation frequency was reduced and transpiration demand from the young plants increased.

In the southern plots, sensor readings in two of the three instrumented border irrigation plots did not show significant responses to irrigation events during mid summer (Figure 44). This is possibly due to less uniformity of irrigation compared to the furrow-irrigated plots.

Soil EC estimated from ECH_2O-TE readings in the 2008 Goodding's willow study plots indicate maximum soil EC values of less than 3 dS/m. The maximum observed specific conductance value for the Goodding's willow test plots was approximately 3 dS/m (plots BB 2 and HB 4). Soil specific conductance in the other instrumented Goodding's willow plots was typically below 2 dS/m. An example plot of soil temperature and EC data are shown in Figure 45. Following irrigation events, an immediate increase in soil EC was observed followed by an exponential decrease. This scenario is likely due to the flushing of salts accumulated between irrigation events through the soil profile.

Groundwater Elevation

Depth to groundwater during 2008 in the vicinity of the Goodding's willow small-scale study area is shown in Figure 46. Of note, PZ-SSN showed similar elevation trends over time, however, the depth to groundwater was offset by approximately 20 cm relative to the other piezometers. These data indicate that the surveyed elevation for the PZ-SSN transducer is incorrect; therefore PZ-SSN data are not presented at this time. The transducer depth will be re-measured during 2009 to allow integration of data from this location. Depth to groundwater during 2008 in the vicinity of the 2007 small-scale study plots is shown in Figure 47.

Depth to groundwater prior to irrigation for the small scale-study plots (i.e. January and February, 2008) was between 1.9 and 2.1 m. When evapotranspirative demand was greatest

(May through July), depth to groundwater increased to as much as 2.65 m. Depth to groundwater responded rapidly to large irrigation events, with short-term mounding of up to 40 cm (Figure 46 and Figure 47). Groundwater elevations began to rise in August, indicating that the evaporative demand decreased in response to increased humidity resulting from seasonal climatic conditions. By the end of October, groundwater elevations had returned to levels near those observed during the winter of 2008.

As described in GSA (2008c), the general gradient of groundwater is from the northeast to the southwest. Groundwater elevation maps for Field 51 over the 2008 growing season are provided in Figure 48 through Figure 50. Groundwater elevation was highest in the vicinity of the 2008 Goodding's willow plots due to mounding of irrigation water. Groundwater elevations also indicate that roots penetrating less than 1.75 m bgs would have access to groundwater for at least a portion of the growing season. The decrease in groundwater elevations observed from May through July 2008 and subsequent recovery in the fall is not readily explained by the estimated plant water use and irrigation scheduling.

4.0 CONCLUSIONS

Phase I (greenhouse) study results to date indicate that seed availability and viability are not constraints to large-scale revegetation or riparian and other target species. Riparian species seed can be stored for periods greater than two years using freezing as a storage method; with the exception of native mule's fat, target shrub species seed can be stored for minimum of nine months.

Phase II (small-scale) study results demonstrate that maximum riparian tree establishment is observed with hydroseeding of un-cleaned seed and furrow irrigation.

Task7/Task 1 Riparian Seed Availability and Long-Term Storage Germination Trials

Seed Availability

Seed of Fremont cottonwood, Goodding's willow and Coyote willow species are generally available in abundance on the LCR. Seed of Emory's baccharis, honey mesquite, screwbean mesquite, and quailbush is likewise readily available. Currently, there is limited availability of native mule's fat on the LCR, and, in addition, viable storage time appears to be less than four months. However, planned propagation in Reclamation nurseries may alleviate this constraint. Desertbroom seed is not available in abundance at Cibola NWR, but is abundant on northern portions of the LCR. Additionally, this species is also being planted at revegetation sites (e.g. Cibola Valley Conservation Area), and seed availability will therefore increase with the expansion of Reclamation's revegetation efforts.

Seed Viability and Storage Methods

Fremont cottonwood, Goodding's willow, and coyote willow seed viability is not favorable after two months of storage at room temperature. Viability of cottonwood and willow seed can be maintained for at least 27 months after seed collection by freezing to -10^{o}C for Goodding's willow or -19^{o}C for Fremont cottonwood. Seed cleaning and oxygen removal did not increase seed viability over the duration of the study and are thus not required for seed storage.

Viability of Emory's baccharis and desertbroom can be maintained with storage at room temperature for a period of at least nine months. Mule's fat seed viability has been very low for all germination trials. Should Reclamation desire to pursue further feasibility analysis for the direct seeding of this species, additional collection and storage trials should be implemented. It is notable that all baccharis seed utilized for both 2007 and 2008 studies was collected during December. It is likely that these species produce seed again in the spring. It may be advisable to conduct germination trials with mule's fat seed collected during this time of year.

Task 5 Riparian Small-Scale Field Studies

Ongoing Monitoring of 2007 Mixed Riparian Seed Small-scale Study Plots

In the 2007 small-scale study plots, Fremont cottonwood established and dominated the crown cover of many plots after the first growing season as shown in the September, 2007 vegetation survey (approximately four months of growth). However, Goodding's and coyote willow establishment was poor. Non-target species (primarily grass and sedges) dominated biomass in the small-scale plots and saltcedar stems were a significant proportion of total stem counts.

During the 2008 growing season, cottonwood growth expanded in the small-scale study plots, increasing in crown cover from 15.9% in September, 2007, to 60.0% in September 2008. Growth rates for Fremont cottonwood were superior to those for saltcedar, with both the crown and canopy cover of Fremont cottonwood dominating saltcedar. Although the saltcedar canopy cover was greater than that of cottonwood in September 2007, Fremont cottonwood canopy cover was nearly twice that of saltcedar after the second growing season (September 2008). These results suggest that cottonwood is likely to maintain dominance in the study area. Less frequent irrigation did not significantly affect growth rates or mortality of cottonwood or saltcedar, which indicates that infrequent irrigation (i.e. once per month) may be acceptable for well-established riparian trees.

During the 2008 growing season, Fremont cottonwood crown cover greater than 75% or saltcedar cover greater than 18% were correlated with decreased Fremont cottonwood growth rates. Additionally, Fremont cottonwood stem density of greater than 10 per square meter resulted in decreased cottonwood growth rates, but did not decrease saltcedar growth rates. These results indicate that an intermediate cottonwood establishment (e.g. ten to fifteen stems per square meter) may be sufficient to maintain high growth rates and reduce saltcedar growth.

Establishment of 2008 Goodding's Willow Seed Small-scale Study Plots

Establishment rates of Goodding's willow were greater in the 2008 small-scale study plots compared to 2007 plots. Maximum establishment rates were observed with hydroseeding un-cleaned seed with an observed increase in willow establishment to 0.95% from 0.1% in 2007. . Broadcasting of cleaned seed showed low establishment rates (< 0.2%). Surface irrigation method did not affect the overall establishment rates of Goodding's willow. However, the visual distribution of trees appeared superior in furrow-irrigated plots, and furrow irrigation resulted in lower growth rates of saltcedar compared to border irrigation. Growth rates of Goodding's willow were lower than those observed for Fremont cottonwood in 2007, with the average height of Goodding's willow after one growing season less than that of saltcedar. Although slightly different seeding rates were used, no correlation between seed rate and willow establishment was observed.

In the 2008 Goodding's willow study plots, enhanced management of undesired grass species through repeated application of herbicide reduced the abundance of grass in plots. However, growth of shrubs (primarily saltcedar and goosefoot) increased, perhaps due to reduced competition with grass. These results indicate the need for an integrated weed management plan, whereby herbaceous and shrubby weed growth are reduced via effective pre-seeding weed management (e.g. irrigation, herbicide, and tillage cycles), and grass growth is reduced after seeding through application of grass-specific herbicide.

Estimated Costs for Large-scale Seeding of Riparian Species

Based the Task 5 field study results, GSA conducted preliminary cost analyses for large-scale hydroseeding of Fremont cottonwood and Goodding's willow (GSA, 2008d). Cost estimates were conducted for a nominal seeding area of 6 hectares (approximately 15 acres) to represent a typical field on the LCR. Analyzed costs include seed collection, treatment, storage, and hydroseed application as well as field preparation and application of grass-specific herbicide over one growing season. Only direct costs were considered, project management and design costs were not addressed.

For a desired Fremont cottonwood density of 10.8 trees per square meter (1 per square foot), costs were estimated at $4,000 per hectare ($1,600 per acre). For a desired Goodding's willow density of 10.8 trees per square meter, costs were estimated at $7,900 per hectare ($3,200 per acre). Similarly-estimated costs for mass transplanting of both Fremont cottonwood and Goodding's willow (Iglitz and Singleton 2008) have been estimated at $10,233 per hectare ($4,141 per acre), with a tree density of 0.58 trees per square meter (0.05 per square foot).

Based on these preliminary calculations, hydroseeding of Fremont cottonwood could result in cost savings of approximately $6,300 per hectare ($2,500 per acre) while providing an 18-fold increase in tree density. At this time the long-term success of hydroseeded Goodding's willow is unknown, but successful seeding of willow could result in cost savings of approximately $2,300 per hectare ($940 per acre), while providing an 18-fold increase in tree density.

It should be noted that initial cost estimates demonstrate a potentially large economic advantage to be gained from use of seed in revegetation. However, a large-scale seed collection and implementation effort would be necessary to confirm and refine these cost estimates. If large-scale seed collection, treatment, and hydroseeding application are shown to be feasible, and seeding results in the desired vegetation type, implementation of direct seeding as one of the standard methods for the MSCP could result in dramatic cost savings while improving the genetic diversity of vegetation on the LCR.

5.0 RECOMMENDATIONS

Although the greenhouse and small-scale studies have achieved the objectives of determining optimum seed storage, treatment, application and irrigation methods, there are a number of remaining questions on the practicality of using seed for large-scale revegetation.

1) Long-term mortality and resulting tree densities of both Fremont cottonwood and Goodding's willow are unknown.
2) The ability of Goodding's willow to out-compete saltcedar is currently unknown.
3) The effect of lower or higher seeding rates on Goodding's willow establishment is unknown (the ten-fold increase seen in willow establishment could be due to weed control)
4) The sources of saltcedar and effect on large-scale seeding is unknown, specifically,
    a) Did the small-scale plots concentrate saltcedar from irrigation water (less volume per flush of canal)?
    b) Why are there much lower rates of saltcedar at other revegetation sites?
5) What are the actual costs and vegetation success for large-scale revegetation efforts?

Recommendations for future study consist of three projects:

- Continued monitoring and irrigation management of 2007 and 2008 small-scale study plots.
- Establishment of a small (9 plots) experiment to evaluate different willow seeding rates with weed control.
- Establishment of a large-scale demonstration plot to evaluate revegetation using seed costs and vegetative success for Fremont cottonwood and potentially Goodding's willow.

Continued Monitoring and Irrigation Management of 2007 and 2008 Small-scale Study Plots

It is recommended that vegetation monitoring and irrigation management be continued for the existing (2007 and 2008) small-scale study plots. These plots provide a unique opportunity to evaluate the effect of irrigation management on native vegetation survival. Additionally, monitoring of the diversity of vegetation composition and density allows for analysis of long-term inter- and intra-species competition. Of particular interest for the current plots are studies of (1) natural thinning of cottonwood and saltcedar plants in 2007 plots, (2) growth of Goodding's willow and saltcedar in 2008 plots, and (3) irrigation management effects for both 2007 and 2008 plots to evaluate depth and frequency of irrigation.

Establishment of Different Goodding's Willow Seeding Rate Experiment

To analyze the effectiveness of lower seeding rates, it is recommended that additional small-scale study plots adjacent to the 2008 small-scale study area be hydroseeded with Goodding's willow at rates below and equal to the 2008 study rates (1560 PLS/m^2 or 145 PLS/ft^2). Furrow irrigation should be used. Relatively low seeding rates of Fremont cottonwood have shown favorable results for initial tree survival and extended growth and competition. Because seed collection and treatment costs compose approximately 80% of Goodding's willow hydroseeding costs (GSA 2008d), reduced seeding rates that can maintain favorable establishment of willow, would further reduce potential costs.

Establishment of Large-scale Demonstration Plot

It is recommended that Phase III of the feasibility analysis (large-scale demonstration plot) be implemented for Fremont cottonwood seeding and potentially Goodding's willow, pending the results of the 2008 Goodding's willow test plots. The small-scale studies were designed to optimize the methods needed for a large-scale demonstration study, not as a final determination of the feasibility of direct seeding for restoration. Consequently, a large-scale demonstration study is necessary to determine scaling effects on both desired and weedy vegetation establishment as well as the feasibility of large-scale irrigation and weed management techniques to promote native species establishment and survival.

Prior to possible implementation of seeding studies during 2010, seed collection and site preparation must be implemented. Seed collection should be initiated during 2009 to secure a large portion of the seed required for a large-scale demonstration plot. Site preparation during 2009 should consist of pre-seeding weed management, including spraying existing vegetation with general herbicide, disking, and possibly seeding of a cover crop. Based on current small-scale field study results, it is recommended that un-cleaned seed be hydroseeded onto furrows.

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TABLES

Table 1. Seed storage treatments for Fremont cottonwood, Goodding's willow, and coyote willow germination trials.

Variable	Treatment	Specifications
Seed Cleaning	Cleaned	Seed removed from pods, blown through a sieve series using compressed air to remove hairs.
	Un-Cleaned	Seed removed from pods, stored with hairs still attached.
Oxygen Condition	Oxygen Purged	Oxygen removed via air purging with a vacuum and replacement with nitrogen gas. Seed stored in vials.
	Ambient	Seed stored at ambient oxygen. Seed stored in envelopes (ambient temperature) or plastic bags (frozen).
Storage Temperature	Frozen	Seed stored in freezers at -10°C (Goodding's willow and coyote willow) or -19°C (Fremont cottonwood).
	Ambient	Seed stored in the laboratory at an average temperature of 21°C (thermostat-controlled).

Table 2. Seed source information for Fremont cottonwood, Goodding's willow, and coyote willow germination trials.

Seed Description	Species[1]	Tree Number	Collection Date	UTM Easting (m)[2]	UTM Northing (m)	Tree Location	Tree Source
Original Seed—Split April 2006 into Eight Storage Treatments	POFR	4	4/28/2006	715838	3694760	North of the Nature Trail (Cibola NWR)	Native
	POFR	22	4/26/2006	716410	3694158	Along Goose Loop adjacent to the Nature Trail	Mountain State Nursery
	SAGO	2	4/27/2006	716169	3694398	The Nature Trail	Mountain State Nursery
	SAGO	21	4/27/2006	716043	3694381	The Nature Trail	Mountain State Nursery
	SAEX	18	4/27/2006	745724	3779004	The Ahakhav Tribal Preserve	Unknown
	SAEX	32	4/27/2006	745711	3779205	The Ahakhav Tribal Preserve	Unknown
Supplemental—Stored as Frozen, Un-Cleaned	POFR	4	4/10/2006	715838	3694760	North of the Nature Trail (Cibola NWR)	Native
	SAEX	20	4/14/2006	745720	3779012	The Ahakhav Tribal Preserve	Unknown
	SAGO	5	4/10/2006	716076	3694376	The Nature Trail	Mountain State Nursery

1 Species codes indicate Fremont cottonwood (POFR), Goodding's willow (SAGO), and coyote willow (SAEX).
2 UTM coordinates are NAD 83, Zone 11.

Table 3. Schedule for Fremont cottonwood, Goodding's willow, and coyote willow germination trials.

Trial Number	Seeding Date	Original Seed	Supplemental Seed[1]	Notes
1	5/05/06	X		Initial viability trial (Un-cleaned seed, room temperature storage only)
2	5/26/06	X		
3	6/07/06	X		
4	6/22/06	X		
5	7/06/06	X		
6	7/21/06	X		
7	8/08/06	X		
8	8/23/06	X		
9	9/08/06	X		
10	10/12/06	X		21^{o}C (room temperature) storage treatment trials discontinued
11	11/16/06	X		
12	12/6/06	X		Heated soil trials discontinued
13	1/2/07		X	Incubator only
14	2/15/07	X		
15	4/18/07	X		
16	6/4/07	X		
17	7/18/07		X	Poor viability for Salix spp.
18	8/22/07		X	
19	10/5/07	X		
20	10/29/07		X	
21	11/29/07		X	
22	1/24/08	X		
23	3/17/08		X	Poor viability for Goodding's willow
24	7/9/08	X		

1 Supplemental seed consists of seed collected in April 2006, and stored thereafter in freezers with ambient oxygen conditions.

Table 4. Condition codes for long-term tree monitoring.

Characteristic	Code	Foliage
Percent with Leaves	0	dead
	1	<25% foliated
	2	25-50% foliated
	3	50-75% foliated
	4	75-100% foliated
Color	G	green
	YG	yellow-green
	Y	yellow
	D	dead

Table 5. Cottonwood and saltcedar vegetation summary for plots selected for root survey.

Plot Number[1]	Treatment	POFR[2] Stems/m^2	Average POFR Height, cm	TARA Stems/m^2	Average TARA Height, cm
5	NUHB 1	6	303	30	69
9	YCHB 2	12	140	4	41
11	NCHB 2	12	174	16	94
14	YUHF 3	6	173	4	50
16	NUHB 3	42	189	62	66
18	NUHF 3	30	270	4	50
27	YCHF 2	32	199	2	36
30	NCBF 2	18	259	24	71
32	YUHB 3	20	238	6	65
36	NCBF 3	12	213	12	37

1 Data from outside quadrat only, below which root surveys were conducted.

2 Species codes indicate Fremont cottonwood (POFR) or saltcedar (TARA).

Table 6. Root survey classifications for small-scale field study analysis.

Root Size		Root Abundance	
Class	Diameter	Class	Count
Very Fine	<1 mm	None	0
Fine	1-2 mm	Very Few	1-5
Medium	2-5 mm	Few	5-10
Coarse	5-10 mm	Common	10-50
Very Coarse	>10 mm	Many	50-100
		Abundant	>100

Table 7. 2008 rainfall data for Cibola NWR. Data available: http://www.wrcc.dri.edu/cgi-bin/rawMAIN.pl?azACBL.

Date	Rainfall (mm)
1/7/2008	3.3
1/8/2008	0.3
1/24/2008	1.5
1/26/2008	0.3
1/27/2008	13.2
5/23/2008	8.4
7/9/2008	1.0
7/10/2008	4.8
8/6/2008	0.3
8/14/2008	1.3
8/30/2008	0.8
9/11/2008	19.6
9/17/2008	3.3
11/26/2008	4.3
11/27/2008	0.3
12/15/2008	2.3
12/16/2008	7.1
12/17/2008	18.8
12/20/2008	0.3
Total:	**90.9**

Table 8. Applied water summary for 2008 growing season, 2007 plots, A Blocks.

Block A1			Block A2		
Date	Irrigation Depth (cm)[1]	Elapsed Time (days)[2]	Date	Irrigation Depth (cm)	Elapsed Time (days)
3/5/2008	7.00	--	3/5/2008	7.00	--
3/15/2008	7.00	10	3/15/2008	7.00	10
3/20/2008	7.00	5	3/20/2008	7.00	5
3/29/2008	7.00	9	3/29/2008	7.00	9
4/15/2008	7.00	17	4/15/2008	7.00	17
4/24/2008	7.00	9	4/24/2008	7.00	9
5/2/2008	5.76	8	5/1/2008	5.76	7
5/7/2008	5.76	5	5/7/2008	5.76	6
5/15/2008	5.76	8	5/15/2008	5.76	8
5/27/2008	5.76	12	5/27/2008	5.76	12
6/3/2008	5.76	7	6/3/2008	5.76	7
6/10/2008	5.76	7	6/10/2008	5.76	7
6/16/2008	8.23	6	6/16/2008	8.23	6
6/23/2008	5.02	7	6/23/2008	5.02	7
6/24/2008	1.34	1	6/24/2008	1.34	1
7/7/2008	4.79	13	7/7/2008	4.79	13
7/16/2008	4.50	9	7/16/2008	5.06	9
7/23/2008	7.00	7	7/23/2008	7.00	7
7/30/2008	7.00	7	7/30/2008	7.00	7
8/6/2008	7.14	7	8/6/2008	7.14	7
8/11/2008	7.00	5	8/11/2008	6.98	5
8/18/2008	7.00	7	8/19/2008	7.02	8
8/29/2008	7.00	11	8/29/2008	6.98	10
9/5/2008	7.00	7	9/5/2008	6.99	7
9/19/2008	7.00	14	9/19/2008	7.46	14
9/26/2008	7.00	7	9/26/2008	7.00	7
10/3/2008	7.00	7	10/3/2008	7.00	7
Total Irrigation (cm)		170.57	Total Irrigation (cm)		171.57
Rainfall (cm)[3]		3.94	Rainfall (cm)		3.94
Estimated Reference Evapotranspiration (cm)[3]		218	Estimated Reference Evapotranspiration (cm)[3]		218
Irrigation and Precipitation/ET_o		0.80	Irrigation and Precipitation/ET_o		0.81

[1] Irrigation prior to May 2, 2008 conducted by Riverbottom Farms. Applied depth estimated.
[2] Days since previous irrigation event (rainfall not included).
[3] Data from US Fish and Wildlife Service Cibola weather station, available: http://www.wrcc.dri.edu/cgi-bin/rawMAIN.pl?azACBL.

Table 9. Applied water summary for 2008 growing season, 2007 plots, B Blocks.

B1 Block			B2 Block		
Date	Irrigation depth (cm)[1]	Elapsed Time (days)[2]	Date	Irrigation depth (cm)	Elapsed Time (days)
3/5/2008	7.00	--	3/5/2008	7.00	--
3/15/2008	7.00	10	3/15/2008	7.00	10
3/20/2008	7.00	5	3/20/2008	7.00	5
3/29/2008	7.00	9	3/29/2008	7.00	9
4/15/2008	7.00	17	4/15/2008	7.00	17
4/24/2008	7.00	9	4/24/2008	7.00	9
5/2/2008	17.28	8	5/2/2008	15.87	8
5/22/2008	4.15	20	5/27/2008	10.58	25
5/27/2008	5.76	5	6/16/2008	15.11	20
6/16/2008	15.11	20	7/7/2008	15.11	21
7/7/2008	15.11	21	7/8/2008	4.79	1
7/8/2008	4.79	1	7/29/2008	12.80	21
7/29/2008	12.93	21	7/30/2008	8.21	1
7/30/2008	8.08	1	8/19/2008	13.64	20
8/19/2008	13.64	20	8/20/2008	7.53	1
8/20/2008	7.36	1	9/19/2008	14.15	30
9/19/2008	14.15	30	10/17/2008	21.00	28
10/16/2008	21.00	27			
Total Irrigation (cm)		181.35	Total Irrigation (cm)		180.78
Rainfall (cm)[3]		3.94	Rainfall (cm)		3.94
Estimated Reference Evapotranspiration (cm)[3]		218	Estimated Reference Evapotranspiration (cm)[3]		218
Irrigation and Precipitation/ET_o		0.85	Irrigation and Precipitation/ET_o		0.85

[1] Irrigation prior to May 2, 2008 conducted by Riverbottom Farms. Applied depth estimated.
[2] Days since previous irrigation event (rainfall not included).
[3] Data from US Fish and Wildlife Service Cibola weather station, available: http://www.wrcc.dri.edu/cgi-bin/rawMAIN.pl?azACBL.

Table 10. ANOVA linear modeling results after two growing seasons (October 2008 survey) for seeded riparian species in 2007 small-scale field study plots.

Results	POFR[1] Crown Cover[2]	POFR Canopy Cover[3]	SAGO Canopy Cover	SAEX Canopy Cover	POFR Stems/ m^2	SAGO Stems/ m^2	SAEX Stems/ m^2	POFR Average Height[4]
Main Effects	**p Values[5]**							
Sprinklers	<0.0001	<0.0001	0.016	0.091	0.488	0.051	0.521	<0.001
Seed Treatment	0.543	0.362	0. 199	0.077	0.077	0.005	0.143	0.269
Surface Irrigation Method	0.518	<0.001	0.671	0.090	0.111	0.513	0.078	0.002
Plot Position	0.682	<0.001	0.202	0.391	0.002	0.286	0.096	0.266
Seeding Rate PLS/m^2	0.750	0.648	0.974	0.568	0.924	<0.001	0.697	0.542
Interactions								
Sprinklers*Seed Treatment	0.474	0.479	0.182	0.068	0.856	0.029	0.118	0.930
Sprinklers*Surface Irrigation Method	0.390	0.379	0.663	0.107	0.099	0.563	0.543	0.995
Seed Treatment* Surface Irrigation Method	0.746	0.557	0.128	0.067	0.805	0.048	0.352	0.835
Sprinklers*Seed Treatment*Surface Irrigation Method	0.537	0.395	0.117	0.082	0.435	0.712	0.005	0.993
Sprinklers	**Means and Significant Differences[6]**							
No Sprinklers	0.738 A	0.763 A	0.011 A	0.003 A	13.87 A	0.288 A	0.113 A	211.99 A
Sprinklers	0. 411 B	0.432 B	0.000 B	0.000 A	11.76 A	0.082 A	0.072 A	149.57 B
Seed Treatment								
Un-cleaned Hydroseed	0.616 A	0.648 A	0.009 A	0.004 A	17.88 A	0.437 A	0.166 A	176.48 A
Cleaned Hydroseed	0.570 A	0.588 A	0.007 A	0.000 B	10.37 A	0.004 B	0.105 A	198.57 A
Cleaned Broadcast	0.538 A	0.557 A	0.000 A	0.000 AB	10.19 A	0.115 B	0.007 A	167.29 A
Surface Irrigation Method								
Border-strip	0.458 B	0.477 B	0.004 A	0.000 A	10.31 A	0.152 B	0.035 A	154.14 B
Furrow	0.692 A	0.718 A	0.006 A	0.003 A	15.32 A	0.218 A	0.150 A	207.43 A
Plot Position								
Block 1	0.403 B	0.428 B	0.001 A	0.003 A	5.19 B	0.237 A	0.109 AB	165.08 A
Block 2	0.642 A	0.662 A	0.003 A	0.001 A	12.81 A	0.071 A	-0.002 B	195.68 A
Block 3	0.680 A	0.703 A	0.003 A	0.000 A	20.44 A	0.248 A	0.171 A	181.58 A
Seeding Rate, PLS/m^2								
Correlation Relationship[7] – direct	0.997	0.648	0.974					
Correlation Relationship[7] – inverse				0.568	0.924	<0.001	0.697	

1 Codes are for Fremont cottonwood (POFR), Goodding's willow (SAGO), and coyote willow (SAEX).
2 Crown cover is the first cover type below a transect point; cover percentage is the ratio of the cover type to the total number of counting points (63) examined.
3 Canopy cover is the total canopy cover of the given vegetation type, including crown cover.
4 Height is the shoot length (cm).
5 Tests were run using JMP V 6.0.0 (SAS Institute, Cary, NC).
6 Numbers denote least-squared means, letters denote significant differences at p=0.05 within each main effect column according to Least-squared Means Differences Student's t-test; the same letters indicate that the difference between means is not significant, and different letters indicate that the means are statistically significant. Means are compared within a result (column), not between them.
7 Relationships denote a direct or inverse correlation between treatments and respective seeding rates.

Table 11. ANOVA linear modeling results after two growing seasons (October 2008 survey) for non-target riparian species in 2007 small-scale field study plots.

Results	TARA[1] Crown Cover[2]	Gramineae[3] Crown Cover[4]	S/F[5] Crown Cover	TARA Canopy Cover	Gramineae Canopy Cover	S/F Canopy Cover	TARA Stems/m^2	TARA Average Height[5]
Main Effects	**p Values[6]**							
Sprinklers	0.607	<0.0001	<0.0001	<0.001	0.011	0.002	<0.0001	0.854
Seed Treatment	0.866	0.075	0.543	0.612	0.322	0.827	0.289	0.610
Surface Irrigation Method	0.382	<0.0001	0.614	0.509	0.043	0.049	0.192	0.813
Plot Position	0.001	0.019	0.682	0.048	0.002	0.165	0.966	0.019
Seeding Rate, PLS/m^2	0.875	0.790	0.750	0.386	0.313	0.158	0.618	0.909
Interactions								
Sprinklers*Seed Treatment	0.708	0.423	0.260	0.625	0.603	0.117	0.951	0.877
Sprinklers*Surface Irrigation Method	0.729	0.259	0.960	0.925	0.803	0.556	0.082	0.185
Seed Treatment* Surface Irrigation Method	0.369	0.571	0.594	0.508	0.900	0.586	0.298	0.461
Sprinklers*Seed Treatment*Surface Irrigation Method	0.710	0.040	0.880	0.183	0.223	0.084	0.403	0.567
Sprinklers	**Means and Significant Differences[7]**							
No Sprinklers	0.108 A	0.116 B	0.031 B	0.469 A	0.618 B	0.172 B	22.4 A	76.24 A
Sprinklers	0.127 A	0.297 A	0.156 A	0.248 B	0.794 A	0.318 A	6.39 B	74.69 B
Seed Treatment								
Un-cleaned Hydroseed	0.128 A	0.166 B	0.077 A	0.377 A	0.650 A	0.228 A	14.86 A	79.97 A
Cleaned Hydroseed	0.121 A	0.191 AB	0.109 A	0.375 A	0.698 A	0.259 A	17.04 A	77.00 A
Cleaned Broadcast	0.103 A	0.262 A	0.093 A	0.323 A	0.770 A	0.247 A	11.32 A	69.41 A
Surface Irrigation Method								
Border-strip	0.134 A	0.294 A	0.101 A	0.342 A	0.774 A	0.201 B	16.23 A	74.46 A
Furrow	0.101 A	0.118 B	0.085 A	0.375 A	0.638 B	0.289 A	12.59 A	76.47 A
Plot Position								
Block 1	0.236 A	0.277 A	0.079 A	0.447 A	0.893 A	0.212 A	14.87 A	93.57 A
Block 2	0.072 B	0.175 B	0.097 A	0.303 A	0.629 B	0.304 A	14.37 A	69.60 B
Block 3	0.045 B	0.166 B	0.103 A	0. 326 A	0.596 B	0.304 A	13.99 A	63.22 B
Seeding Rate, PLS/m^2								
Correlation Relationship[8] — direct		0.790						
Correlation Relationship[8] — inverse	0.875		0.750	0.386	0.313	0.158	0.618	0.909

1 Code is for Tamarix ramosissima (TARA).
2 Crown cover is the first cover type below a transect point; cover percentage is the ratio of the cover type to the total number of counting points (63) examined.
3 Gramineae is for combined grasses and sedges, no rushes observed; see Table 14.
4 Canopy cover is the total canopy cover of the given vegetation type, including crown cover.
5 Code is for combined shrubs and forbs (S/F) excluding TARA.
6 Height is the shoot length (cm).
7 Tests were run using JMP V 6.0.0 (SAS Institute, Cary, NC).
8 Numbers denote least-squared means, letters denote significant differences at p=0.05 within each main effect column according to Least-squared Means Differences Student's t-test; the same letters indicate that the difference between means is not significant, and different letters indicate that the means are statistically significant. Means are compared within a result (column), not between them.
9 Relationships denote a direct or inverse correlation between treatments and respective seeding rates.

Table 12. ANOVA modeling results for Fremont cottonwood and saltcedar growth rates for the 2007 small-scale field study plots during the 2008 growing season.

Results	**POFR[1] Growth Rate[2], cm/day**	**TARA Growth Rate, cm/day**
Main Effects	**p Values[3]**	
Irrigation Treatment	0.264	0.448
Fremont Cottonwood Crown Cover	<0.0001	0.133
Fremont Cottonwood Stem Density	<0.0001	0.141
Saltcedar Crown Cover	<0.0001	0.155
Saltcedar Stem Density	0.432	0.038
Initial Tree Height	<0.0001	<0.0001
Irrigation Treatment	**Means and Significant Differences[4]**	
A	0.354 A	0.076 A
B	0.328 A	0.086 A
Fremont Cottonwood Crown Cover		
0-25%	0.294 BC	0.010 AB
25-50%	0.457 A	0.098 A
50-75%	0.375 B	0.055 B
75-100%	0.238 C	0.071 AB
Fremont Cottonwood Stem Density, stems/m^2		
0-10	0.621 A	0.063 B
10-20	0.248 BC	0.057 B
20-30	0.293 B	0.112 A
30-40	0.201 C	0.090 AB
Saltcedar Crown Cover		
0-9%	0.484 A	0.052 B
9-18%	0.421 A	0.092 AB
18-27%	0.283 B	0.073 AB
27-36%	0.175 B	0.107 A
Saltcedar Stem Density, stems/m^2		
0-11	0.336 A	0.113 A
11-22	0.339 A	0.078 AB
22-33	0.381 A	0.061 B
33-45	0.308 A	0.072 B
Initial Tree Height, cm[5]		
Correlation Relationship[6] direct	<0.0001	<0.0001
Correlation Relationship[6] inverse		

1 Codes are for Fremont cottonwood (POFR) and saltcedar (TARA).
2 Growth rate between May, 2008 and October, 2008 surveys. Time period varied from 125 to 142 days.
3 Tests were run using JMP V 6.0.0 (SAS Institute, Cary, NC).
4 Numbers denote least-squared means, letters denote significant differences at p=0.05 within each main effect column according to Least-squared Means Differences Student's t-test; the same letters indicate that the difference between means is not significant, and different letters indicate that the means are statistically significant. Means are compared within a result (column), not between them.
5 Height as measured during May 2008 surveys.
6 Relationships denote a direct or inverse correlation between treatments and respective seeding rates.

Table 13. 2008 Goodding's willow small-scale field plot specifications.

Variable	Treatment	Specifications
Seeding Treatment	Un-cleaned, hydroseed	Pubescence not removed from seed coats, seed applied with a hydroseeder.
	Cleaned, broadcast	Pubescence removed from seed coats, seed applied with a broadcast seed spreader.
Surface Irrigation Method	Border	Small-scale basin irrigation.
	Furrow	Furrows on 1.02 m spacing.
Seeding Rate	Variable	Estimated by hydroseed application duration.

Table 14. Non-target species observed in 2008 Goodding's willow small-scale field study plots.

Species	Common Name	Growth Form	Lifespan	Nativity	Relative Abundance
Tamarix ramosissima	Saltcedar	Shrub or Tree	Perennial	Non-Native	Abundant
Chenopodium spp.	Goosefoot	Shrub or Forb	Annual or Perennial	Some Native, some Non-Native	Abundant
Cyperus odoratus	Fragrant flatsedge	Sedge	Annual	Native	Common
Cynodon dactylon	Bermudagrass	Sod Grass	Perennial	Non-native	Common
Echinochloa colona	Barnyard Grass	Bunchgrass	Perennial	Non-native	Common
Prosopis glandulosa	Honey Mesquite	Tree	Perennial	Native	Few
Sesbania herbaceae	Colorado River Hemp	Forb	Annual	Native	Few
Leptochloa mucronata	Mucronate Sprangletop	Bunchgrass	Annual	Native	Common
Panicum capillare	Witchgrass	Bunchgrass	Annual	Native	Few
Setaria pumila	Yellow Foxtail	Bunchgrass	Annual	Non-native	Few
Un-Identified Grass	Unknown	Bunchgrass	Perennial	Unknown	Abundant

Table 15. ANOVA linear modeling results for the 2008 Goodding's willow small-scale field study (Task 5U-6).

Results	SAGO[1] Crown[2] Cover	SAGO Canopy[3] Cover	SAGO Stems/m²	SAGO Average Height	SAGO Maximum Height/ Quadrat	TARA Crown Cover	Gramineae Crown Cover	S/F Crown Cover	TARA Canopy Cover	Gramineae Canopy Cover	S/F Canopy Cover	TARA Stems/m²	TARA Average Height	TARA Maximum Height/ Quadrat
Main Effects	**p Values[4]**													
Seed Treatment	0.067	0.018	0.009	0.997	0.496	0.491	0.479	0.839	0.211	0.322	0.950	0.556	0.578	0.898
Surface Irrigation Method	0.649	0.727	0.873	0.539	0.393	0.047	0.853	0.145	0.447	0.694	0.607	0.145	0.028	0.044
Seeding Rate PLS/m²	0.903	0.178	0.040	0.758	0.732	0.583	0.427	0.817	0.107	0.436	0.291	0.066	0.282	0.310
Interaction														
Seed Treatment* Surface Irrigation Method	0.371	0.085	0.600	0.264	0.390	0.242	0.442	0.751	0.045	0.409	0.443	0.327	0.159	0.045
Seed Treatment	**Means and Significant Differences[5]**													
Un-cleaned Hydroseed	0.037 A	0.100 A	14.90 A	32.7 A	48.5 A	0.221 A	0.299 A	0.425 A	0.388 A	0.404 A	0.879 A	49.46 A	45.8 A	83.3 A
Cleaned Broadcast	0.012 A	0.034 B	3.76 B	32.7 A	41.0 A	0.278 A	0.237 A	0.450 A	0.503 A	0.320 A	0.876 A	53.15 A	43.2 A	84.6 A
Surface Irrigation Method														
Border-strip	0.022 A	0.063 A	9.069 A	30.5 A	40.5 A	0.330 A	0.276 A	0.349 A	0.477 A	0.377 A	0.867 A	55.67 A	49.8 A	93.9 A
Furrow	0.027 A	0.071 A	9.597 A	34.9 A	49.1 A	0.168 B	0.261 A	0.525 A	0.414 A	0.347 A	0.889 A	46.94 A	39.3 B	74.0 B
Interactions														
Broadcast, Border	0.004 A	0.009 B	2.63 C	26.3 A	32.4 A	0.314 AB	0.276 A	0.380 A	0.444 AB	0.367 A	0.847 A	54.64 A	47.9 AB	84.6 AB
Broadcast, Furrow	0.020 A	0.059 AB	4.90 BC	39.0 A	49.7 A	0.241 AB	0.198 A	0.520 A	0.562 A	0.272 A	0.904 A	51.65 A	43.7 AB	84.5 AB
Hydroseed, Border	0.039 A	0.117 A	15.51 A	34.6 A	48.6 A	0.347 A	0.276 A	0.318 A	0.509 AB	0.387 A	0.885 A	56.70 A	51.7 A	103.1 A
Hydroseed, Furrow	0.034 A	0.083 A	14.29 AB	30.8 A	48.5 A	0.095 B	0.323 A	0.531 A	0.266 B	0.422 A	0.873 A	42.23 A	34.8 B	63.6 B
Seeding Rate, PLS/m²														
Correlation Relationship[6] — direct	0.9025	0.1783	0.0396	0.7579	0.7315	0.5833		0.8167	0.1073		0.2907	0.0661	0.282	0.3101
Correlation Relationship[6] — inverse							0.4272			0.4363				

1 Codes are for Goodding's willow (SAGO), saltcedar (TARA), combined grasses and sedges (Gramineae), and shrubs and forbs excluding saltcedar (S/F).
2 Crown cover is the first cover type below a transect point; cover percentage is the ratio of the cover type to the total number of counting points (63) examined.
3 Canopy cover is the total canopy cover of the given vegetation type, including crown cover.
4 Tests were run using JMP V 6.0.0 (SAS Institute, Cary, NC).
5 Numbers denote least-squared means, letters denote significant differences at p=0.05 within each main effect column according to Least-squared Means Differences Student's t-test; the same letters indicate that the difference between means is not significant, and different letters indicate that the means are statistically significant. Means are compared within a result (column), not between them.
6 Relationships denote a direct or inverse correlation between treatments and respective seeding rates.

Table 16. Applied water summary for 2008 growing season, 2008 Goodding's willow plots.

Northern Plots			Southern Plots		
Date	Irrigation depth (cm)	Elapsed Time (days)[1]	Date	Irrigation depth (cm)	Elapsed Time (days)
5/29/2008	3.71	--	5/29/2008	4.35	--
5/30/2008	4.47	1	5/30/2008	4.81	1
5/31/2008	4.29	1	5/31/2008	4.29	1
6/2/2008	4.23	2	6/2/2008	4.41	2
6/3/2008	4.23	1	6/3/2008	4.41	1
6/5/2008	6.88	2	6/5/2008	5.05	2
6/6/2008	4.00	1	6/6/2008	4.00	1
6/9/2008	4.23	3	6/9/2008	4.23	3
6/10/2008	3.83	1	6/10/2008	3.83	1
6/13/2008	3.83	3	6/13/2008	4.87	3
6/16/2008	4.64	3	6/16/2008	4.64	3
6/17/2008	3.15	1	6/17/2008	6.30	1
6/19/2008	7.71	2	6/19/2008	3.85	2
6/20/2008	2.48	1	6/20/2008	5.30	1
6/23/2008	4.22	3	6/23/2008	4.22	3
6/24/2008	5.88	1	6/24/2008	5.88	1
6/25/2008	4.05	1	6/26/2008	7.18	2
7/7/2008	4.64	12	7/7/2008	4.64	11
7/15/2008	5.70	8	7/16/2008	6.20	9
7/22/2008	7.18	7	7/22/2008	7.18	6
7/29/2008	5.04	7	7/29/2008	5.04	7
8/6/2008	6.47	8	8/6/2008	6.47	8
8/11/2008	4.97	5	8/11/2008	4.98	5
8/19/2008	7.18	8	8/20/2008	7.19	9
8/29/2008	6.42	10	8/29/2008	6.37	9
9/5/2008	6.41	7	9/5/2008	6.43	7
9/19/2008	6.85	14	9/19/2008	6.79	14
9/26/2008	6.79	7	9/26/2008	6.79	7
10/3/2008	6.79	7	10/3/2008	6.79	7
10/16/2008	6.79	13	10/16/2008	6.79	13
Total Irrigation (cm)		157.04	Total Irrigation (cm)		163.28
Rainfall (cm)[2]		3.94	Rainfall (cm)		3.94
Estimated Reference Evapotranspiration (cm)[2]		146	Estimated Reference Evapotranspiration (cm)		146
Irrigation and Rainfall/ET_o		1.11	Irrigation and Rainfall/ET_o		1.15

1 Days since previous irrigation event (rainfall not included).
2 Data from Western Regional Climate Center Cibola weather station, available: http://www.wrcc.dri.edu/cgi-bin/rawMAIN.pl?azACBL.

FIGURES

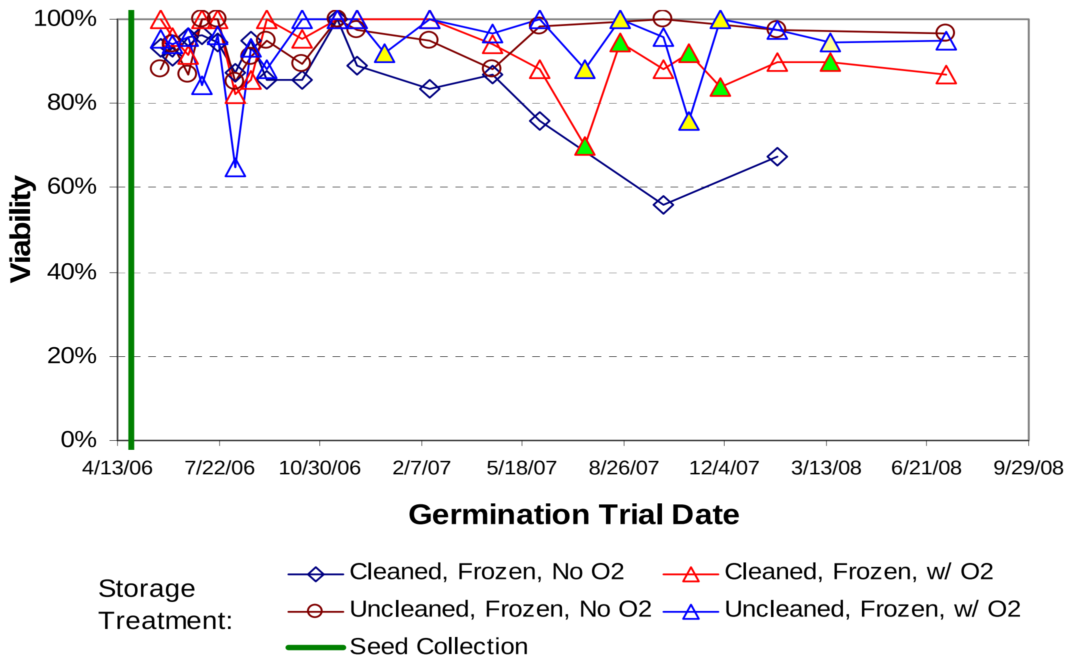


Figure 1. Incubator viability for frozen Fremont cottonwood seed germination trials. Yellow or green data symbols indicate "supplemental seed" analysis.

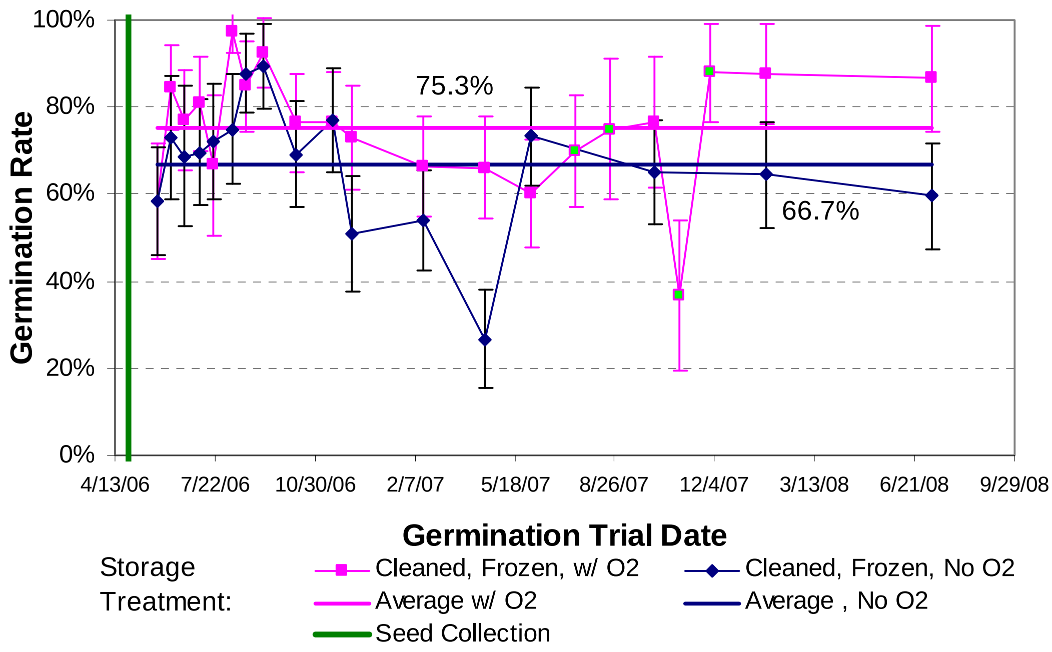


Figure 2. Soil germination rates for ambient versus oxygen-removal treatment for Fremont cottonwood seed (frozen, cleaned) germination trials. Green data symbols indicate "supplemental seed" analysis.

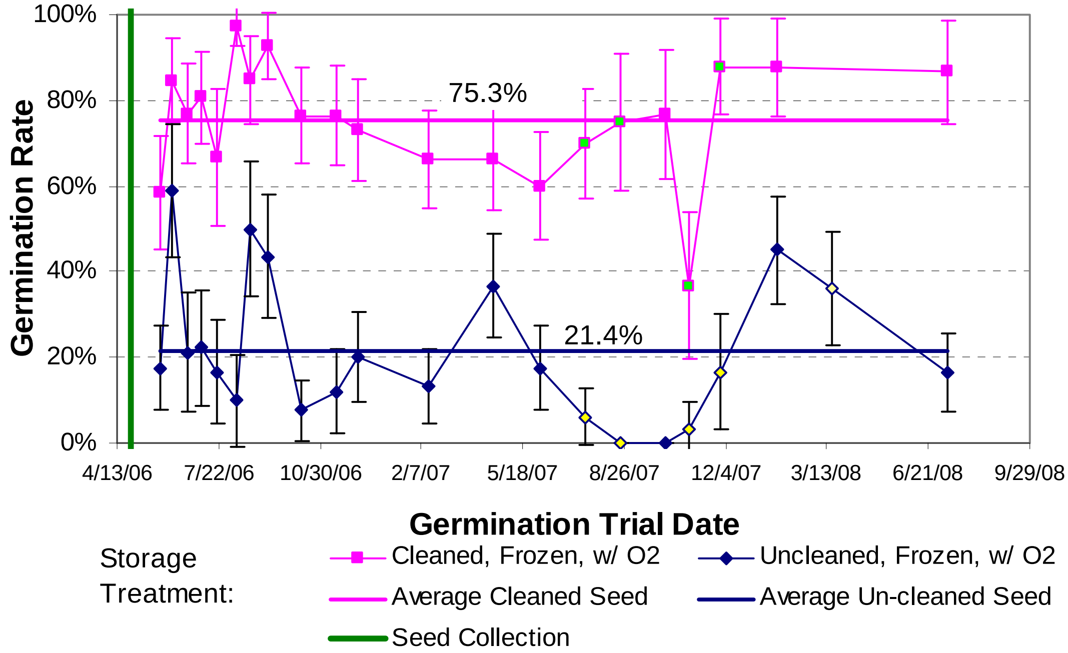


Figure 3. Soil germination rates for cleaned versus un-cleaned Fremont cottonwood seed (frozen, ambient oxygen) germination trials. Yellow or green data symbols indicate "supplemental seed" analysis.

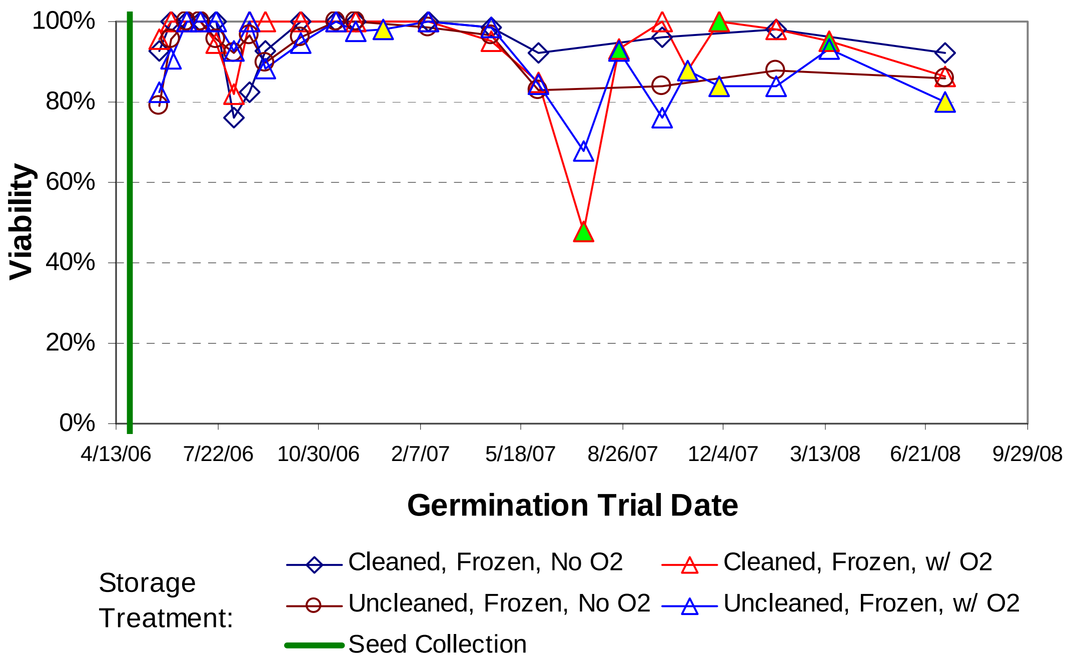


Figure 4. Incubator viability for frozen Goodding's willow seed germination trials. Yellow or green data symbols indicate "supplemental seed" analysis.

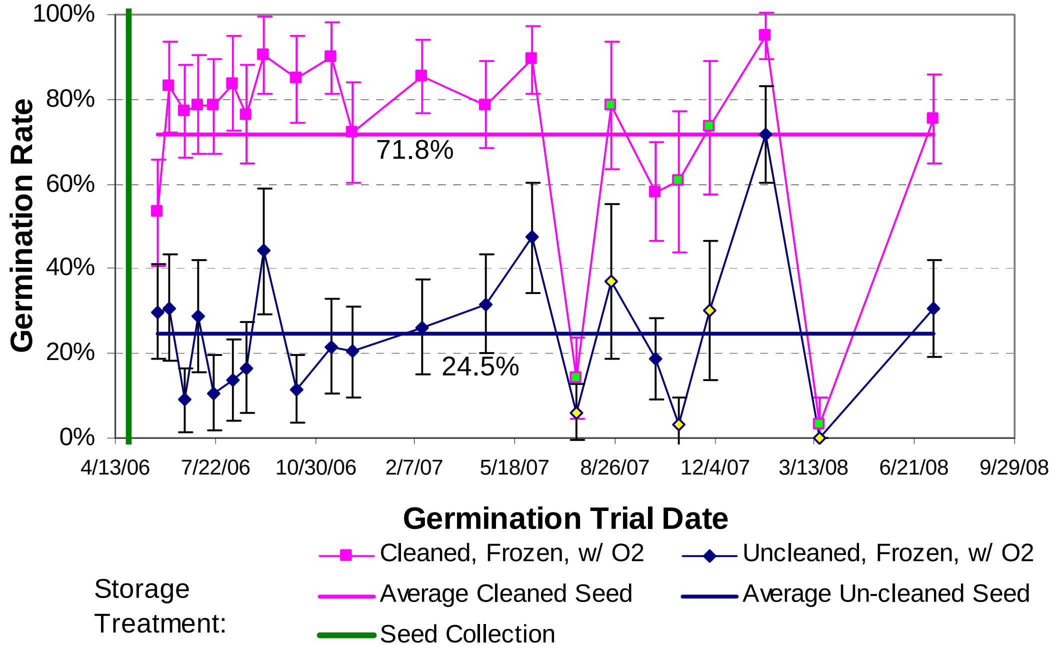


Figure 5. Soil germination rates for cleaned versus un-cleaned Goodding's willow seed (frozen, ambient oxygen) germination trials. Yellow or green data symbols indicate “supplemental seed” analysis.

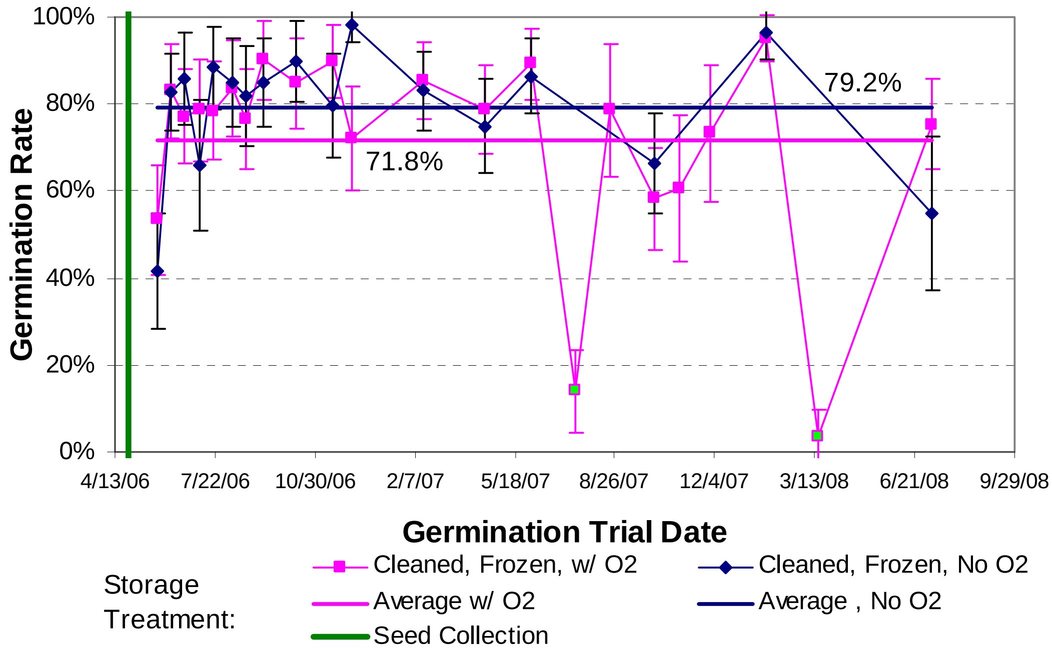


Figure 6. Soil germination rates for ambient versus oxygen-removal treatment for Goodding's willow seed (frozen, cleaned) germination trials. Green data symbols indicate “supplemental seed” analysis.

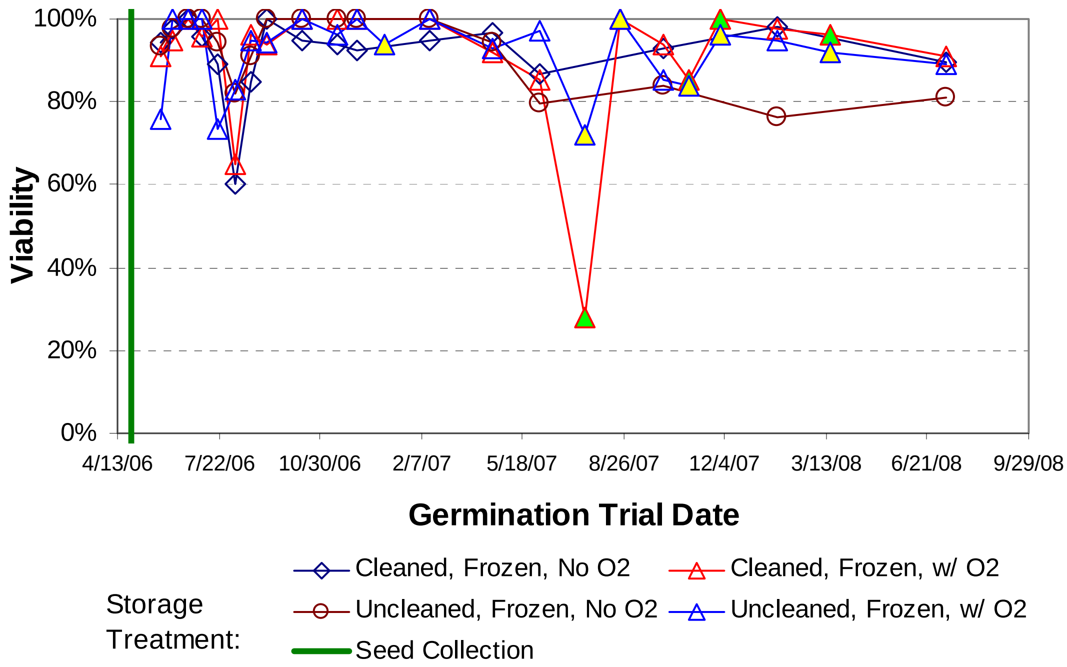


Figure 7. Incubator viability for frozen coyote willow seed germination trials. Yellow or green data symbols indicate "supplemental seed" analysis.

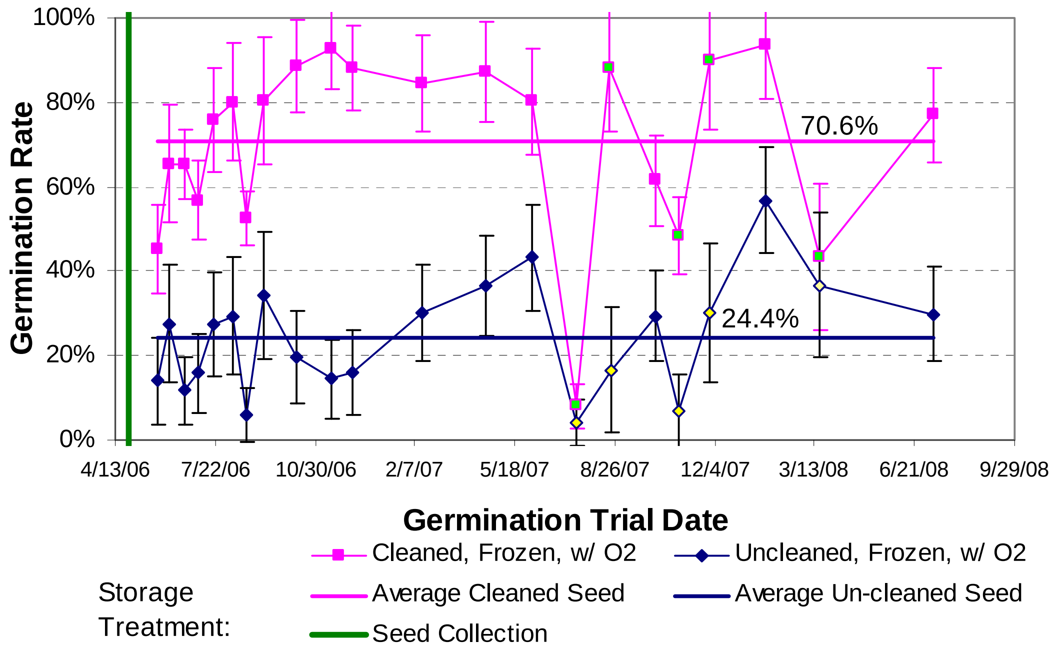


Figure 8. Soil germination rates for cleaned versus un-cleaned coyote willow seed (frozen, ambient oxygen) germination trials. Yellow or green data symbols indicate "supplemental seed" analysis.

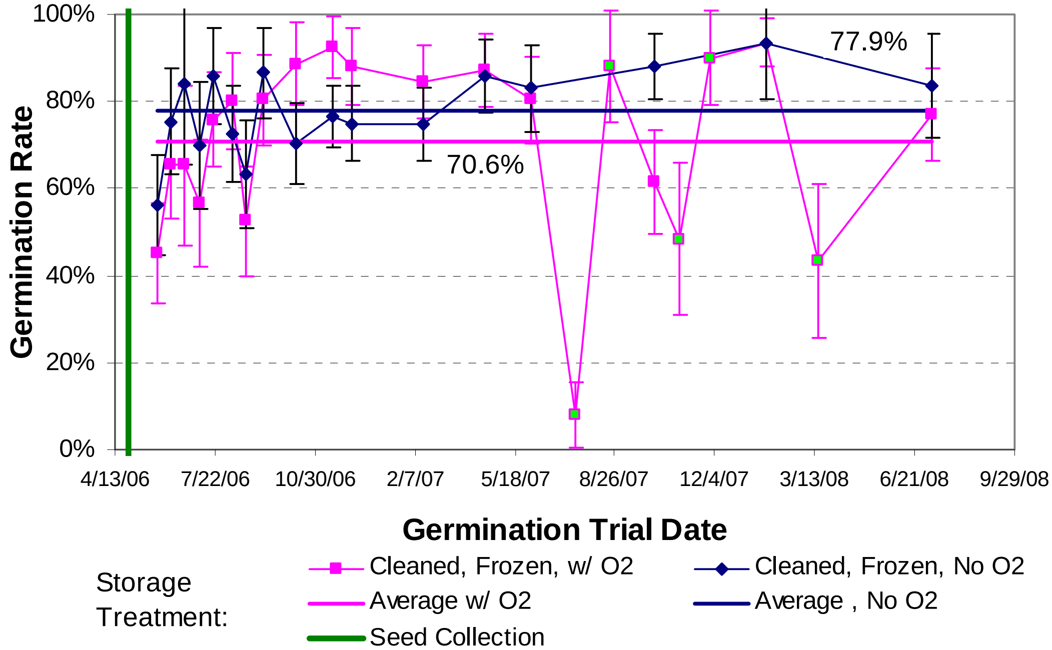


Figure 9. Soil germination rates for ambient versus oxygen-removal treatment for coyote willow seed (frozen, cleaned) germination trials. Green data symbols indicate “supplemental seed” analysis.

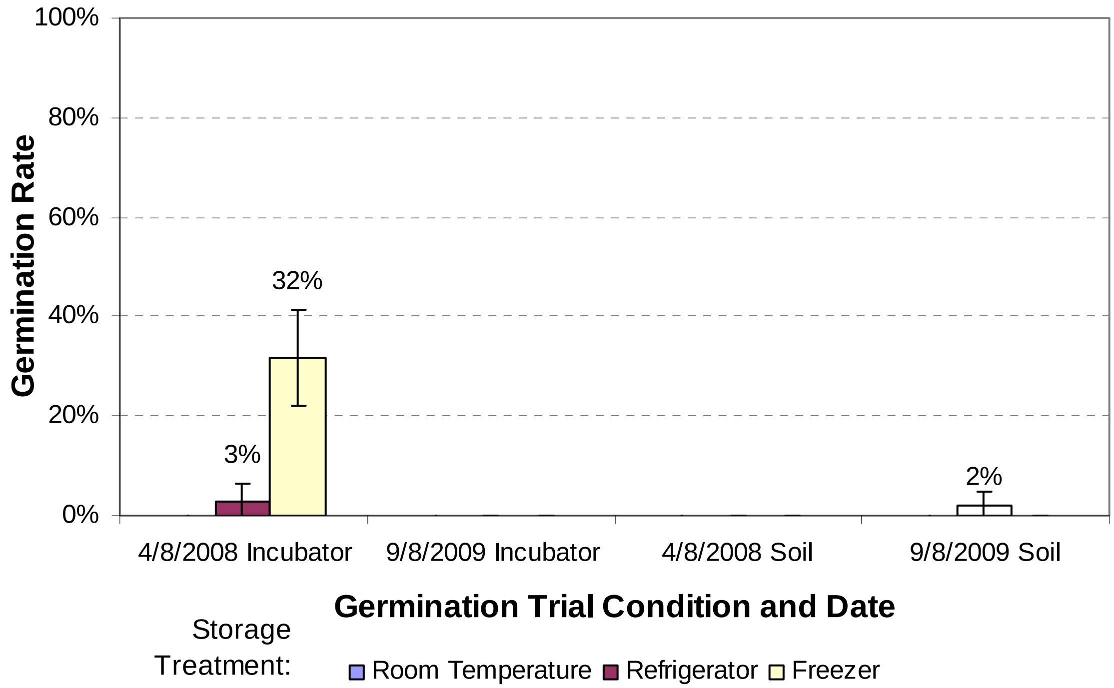


Figure 10. Germination rates for mule’s fat seed during 2008 trials.

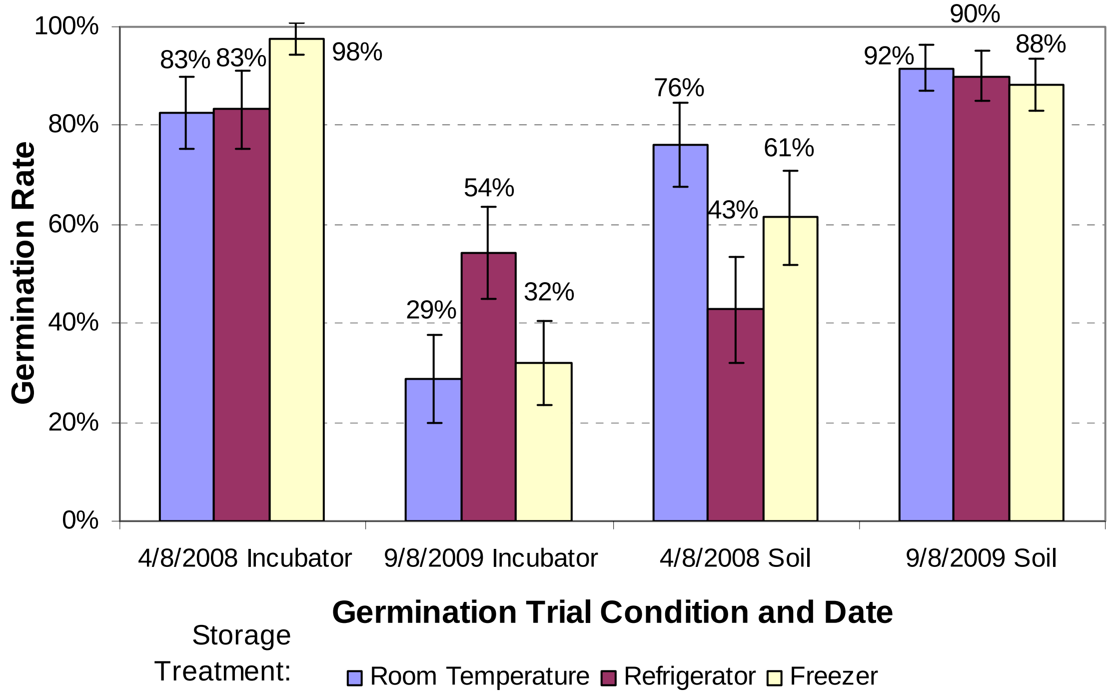


Figure 11. Germination rates for Emory's baccharis seed during 2008 trials.

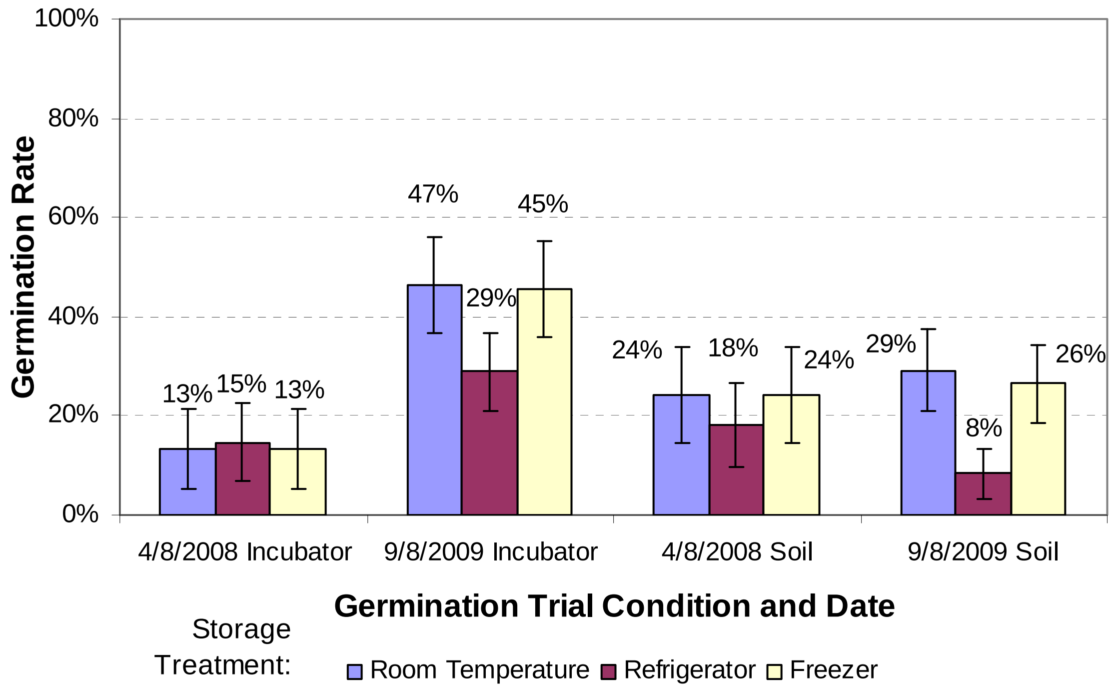
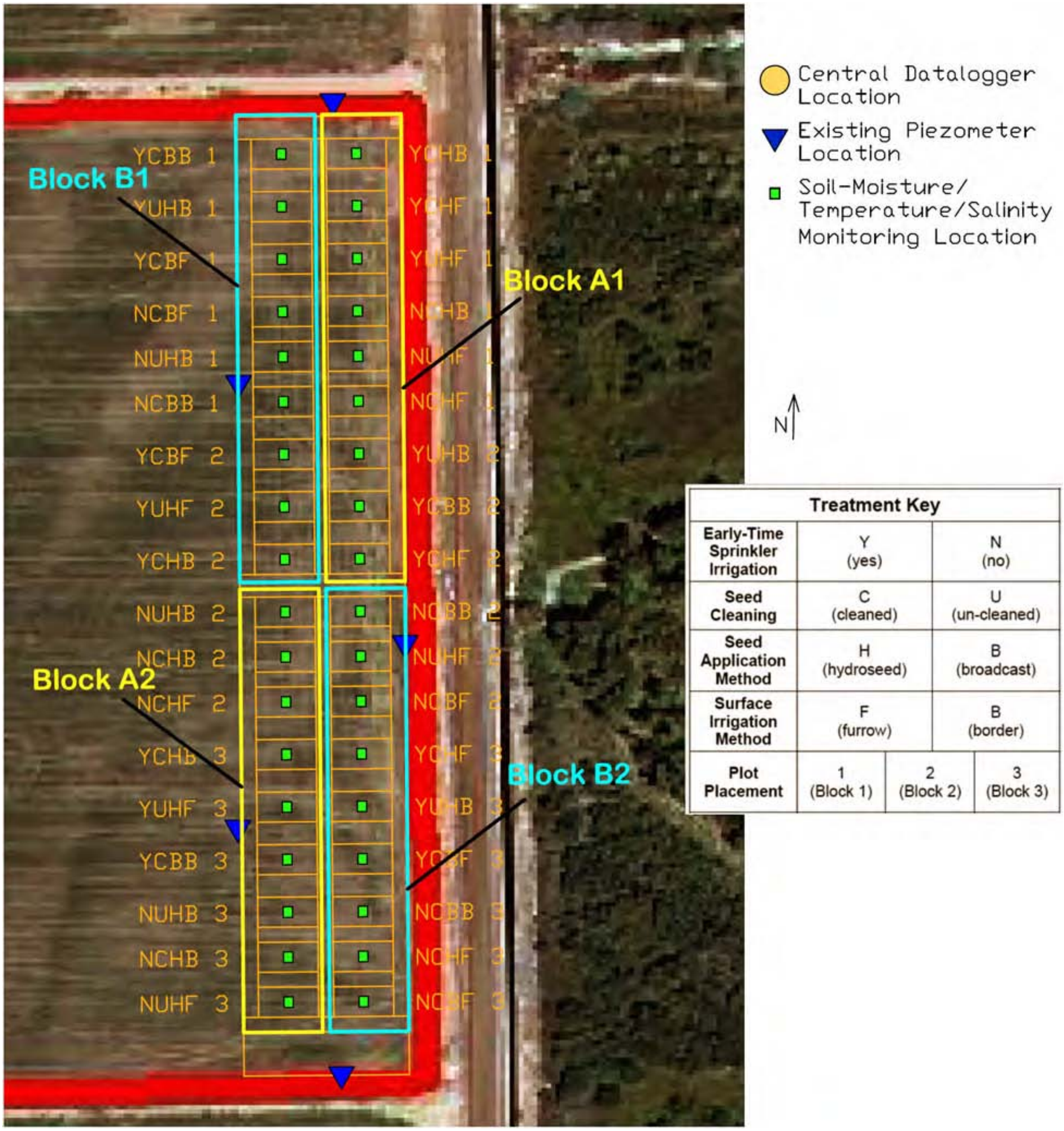


Figure 12. Germination rates for desertbroom seed during 2008 trials.



Treatment Key

Early-Time Sprinkler Irrigation	Y (yes)	N (no)	
Seed Cleaning	C (cleaned)	U (un-cleaned)	
Seed Application Method	H (hydroseed)	B (broadcast)	
Surface Irrigation Method	F (furrow)	B (border)	
Plot Placement	1 (Block 1)	2 (Block 2)	3 (Block 3)

Figure 13. Irrigation block layout for small-scale study plots established in 2007.

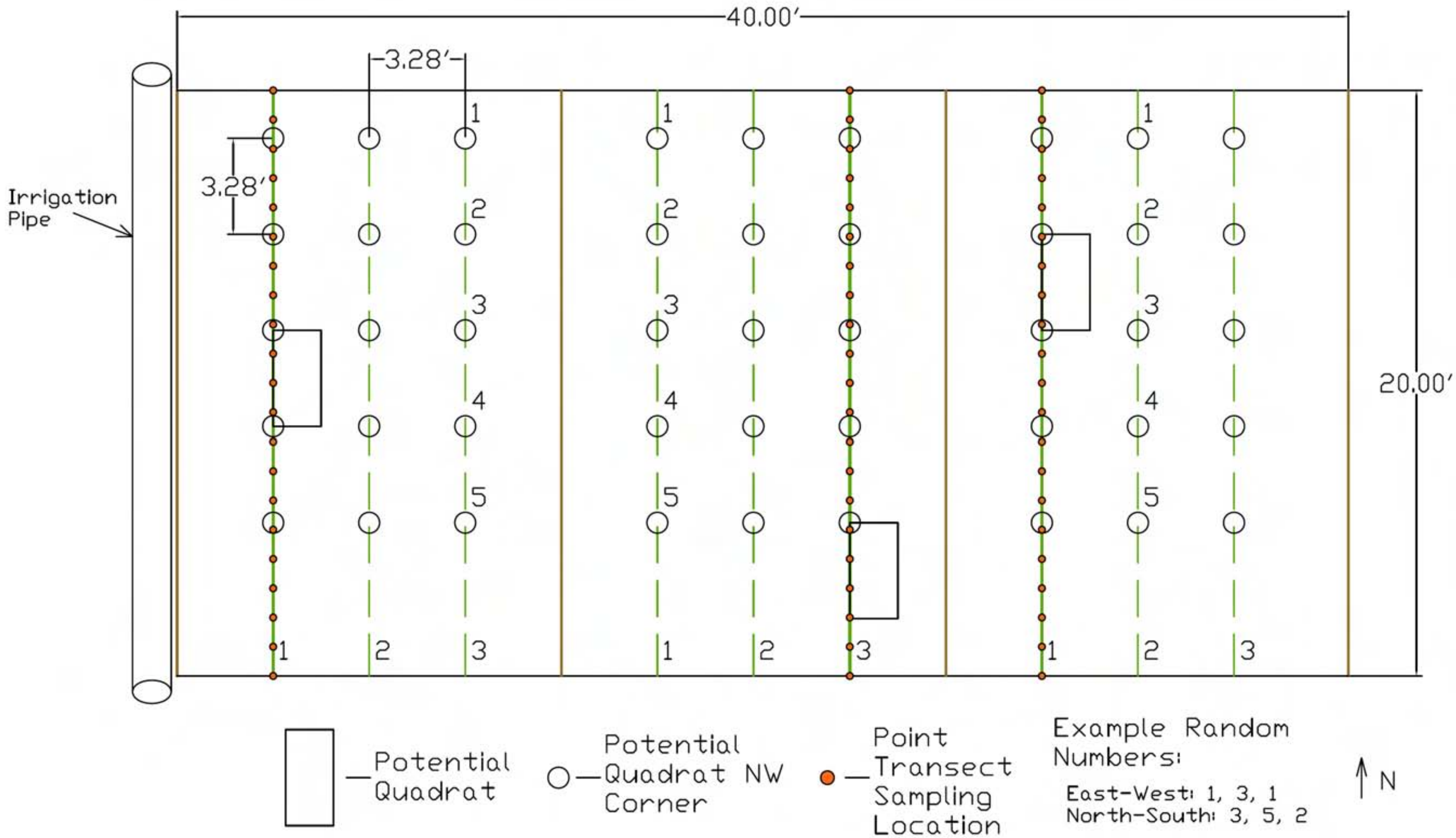


Figure 14. Example vegetation survey schematic for long-term monitoring of 2007 small-scale study plots.

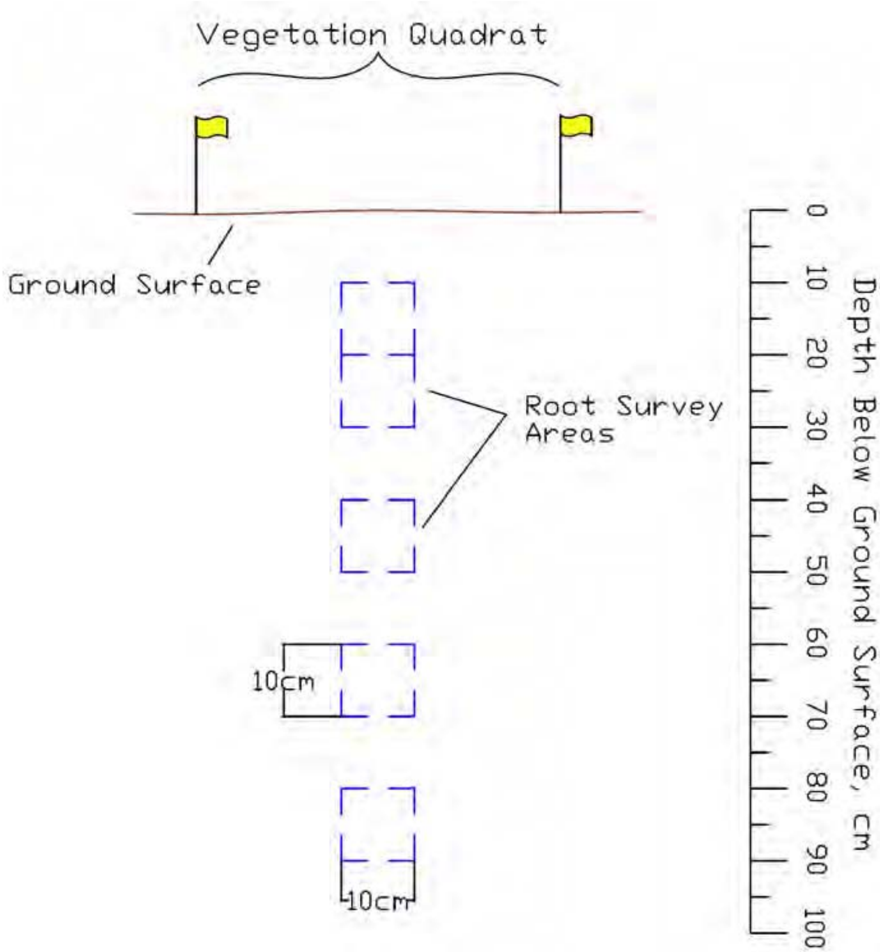


Figure 15. Typical root survey schematic for 2007 small-scale test plots.

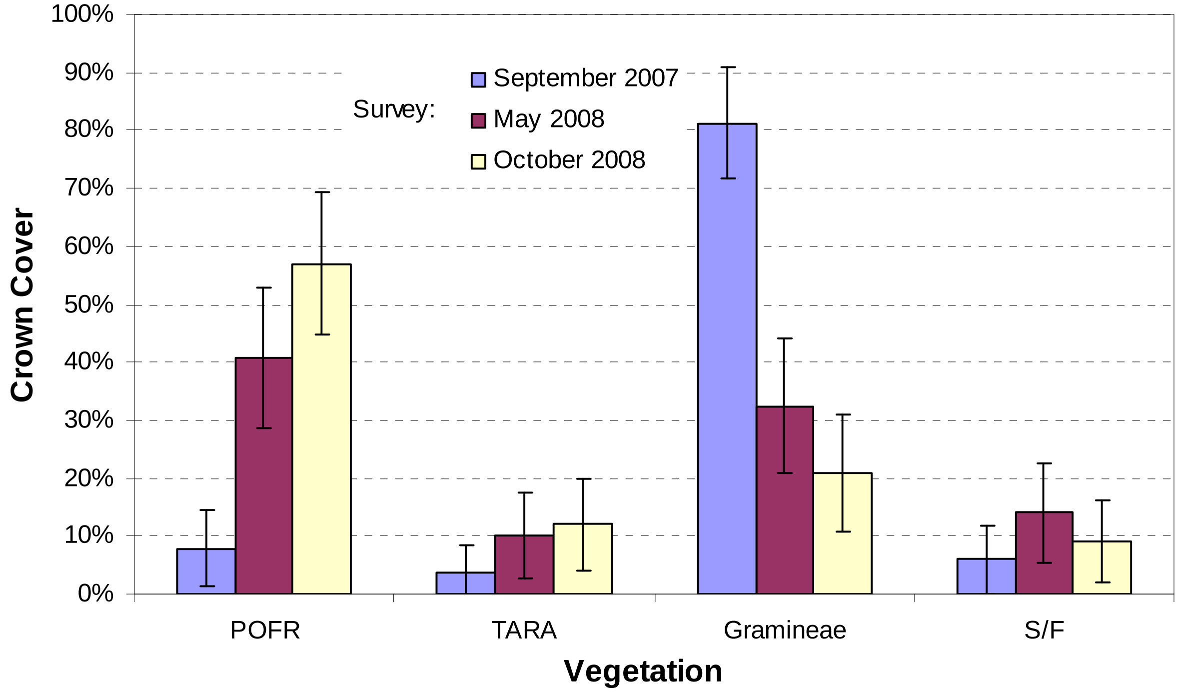


Figure 16. Vegetation crown cover trends for Fremont cottonwood (POFR), saltcedar (TARA), grasses and sedges (Gramineae), and shrubs and forbs (S/F) in 2007 study plots.

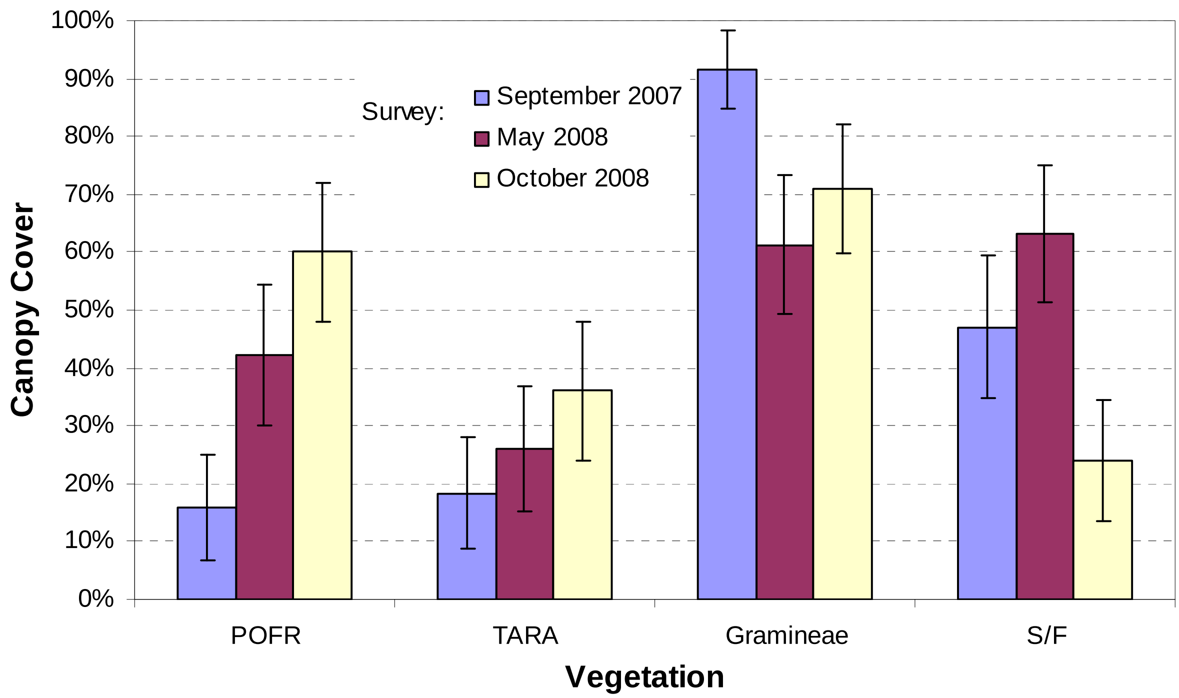


Figure 17. Vegetation canopy cover trends for Fremont cottonwood (POFR), saltcedar (TARA), grasses and sedges (Gramineae), and shrubs and forbs (S/F) in 2007 study plots.

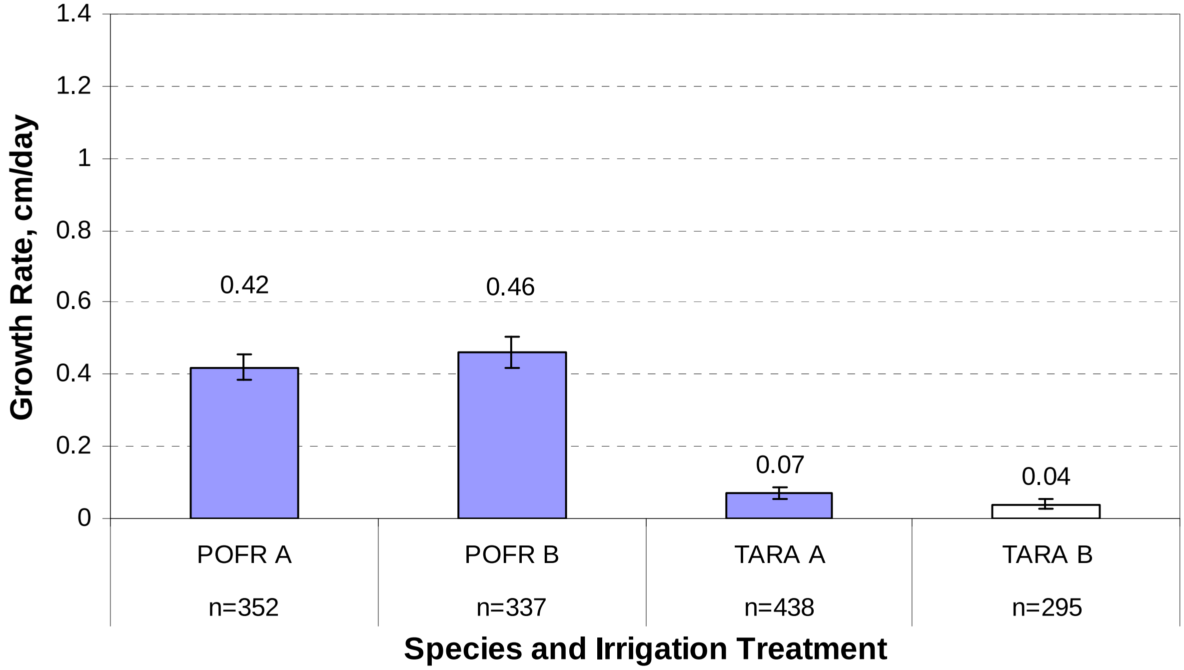


Figure 18. 2008 growing season growth rates for Fremont cottonwood (POFR) and saltcedar (TARA) in 2007 study plots.

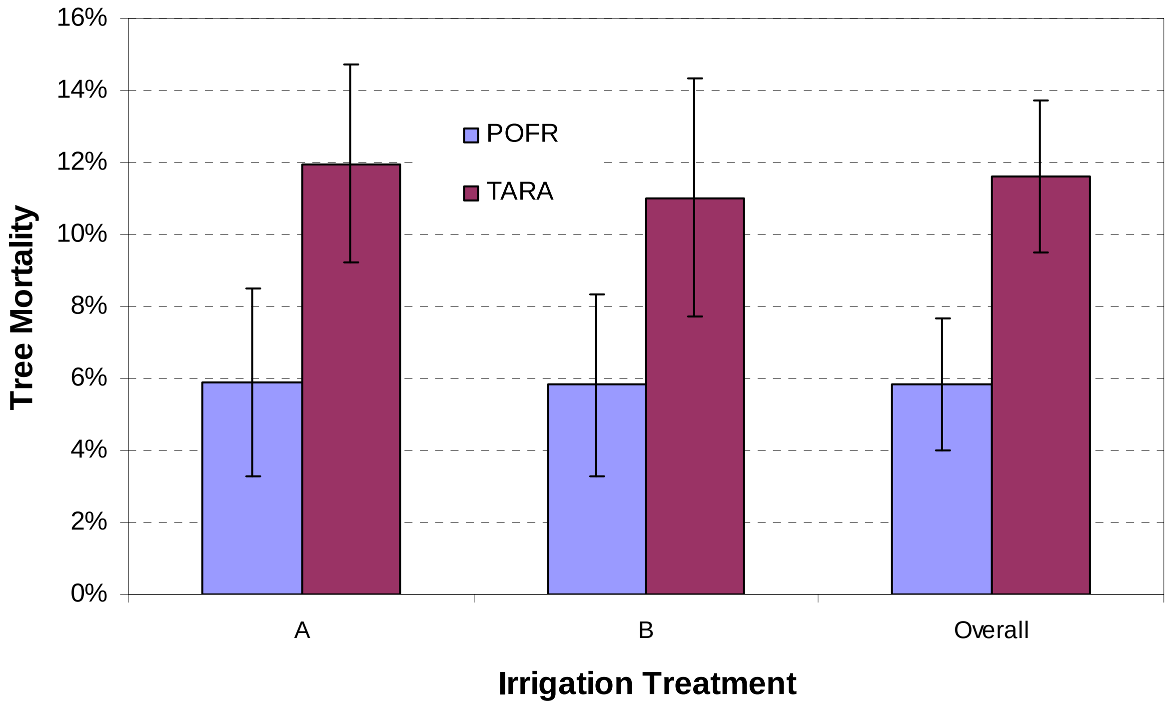


Figure 19. Fremont cottonwood (POFR) and saltcedar (TARA) mortality rates (all initial tree heights combined) in 2007 study plots during the 2008 growing season.

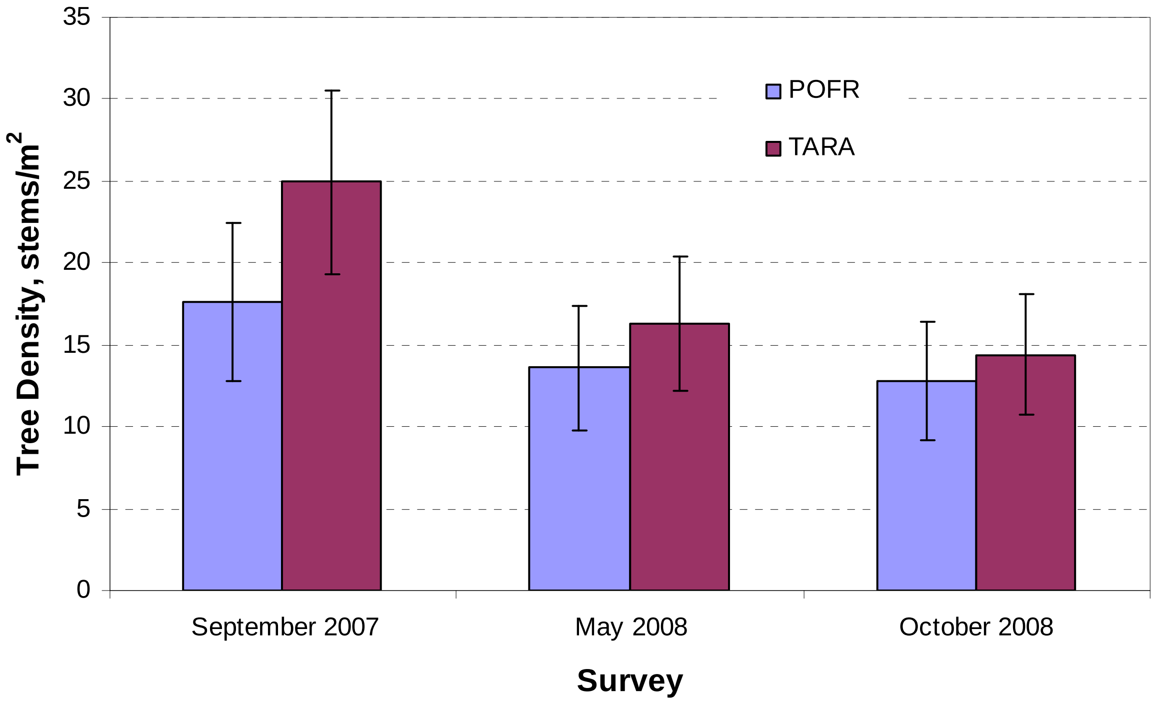


Figure 20. Fremont cottonwood (POFR), saltcedar (TARA) tree density trends in 2007 small-scale study plots.

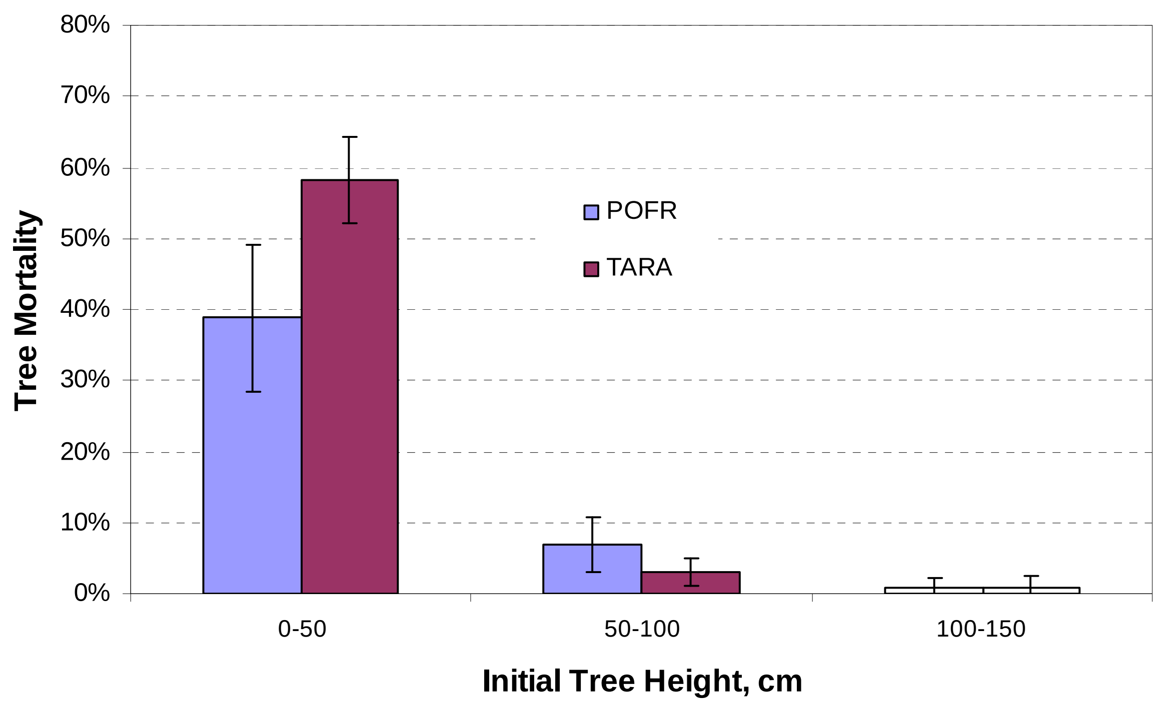


Figure 21. Fremont cottonwood (POFR) and saltcedar (TARA) mortality rates (combined irrigation treatments) by initial tree height (May 2008) in 2007 study plots during the 2008 growing season.

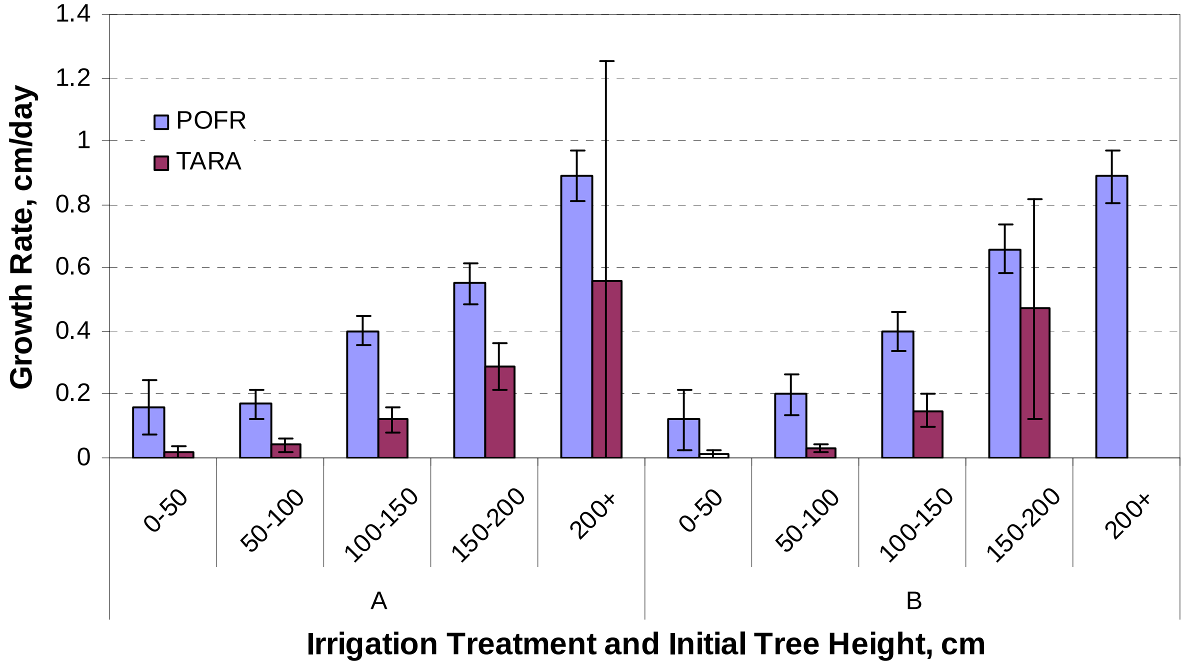


Figure 22. Tree growth rates by species for Fremont cottonwood (POFR) and saltcedar (TARA) growth rates versus initial tree height (May 2008) and irrigation treatment in 2007 study plots during the 2008 growing season.

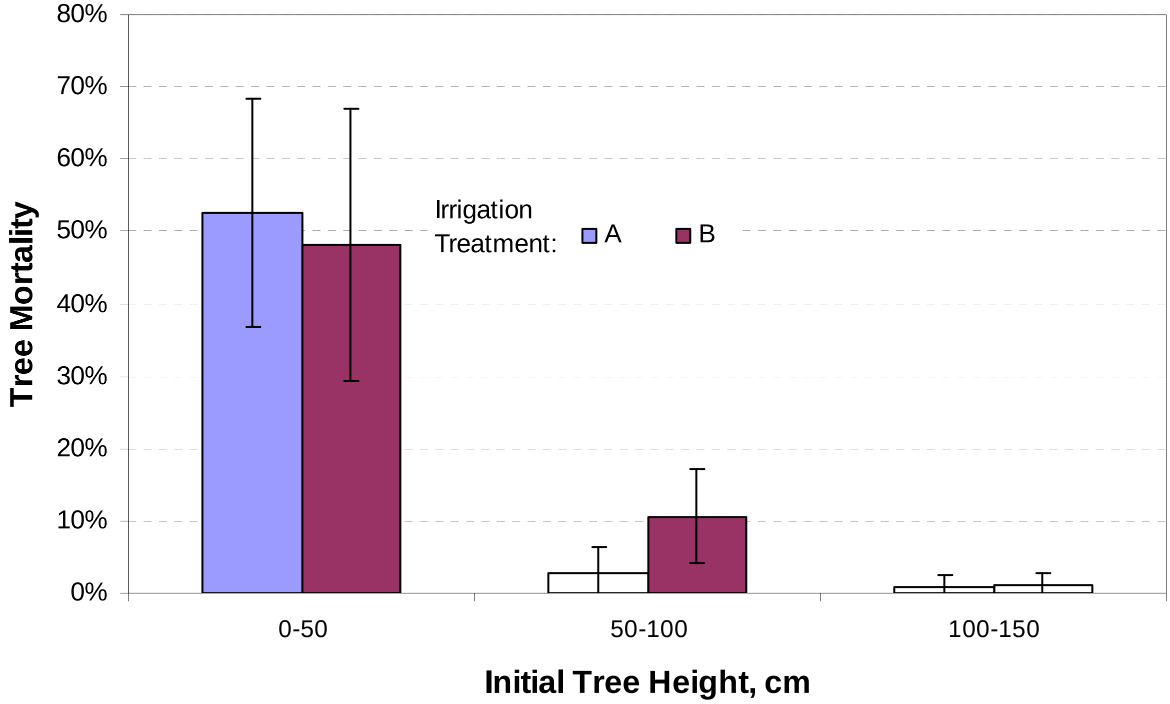


Figure 23. Fremont cottonwood (POFR) and saltcedar (TARA) mortality rates by initial tree height (May 2008) and irrigation treatment in 2007 study plots during the 2008 growing season.

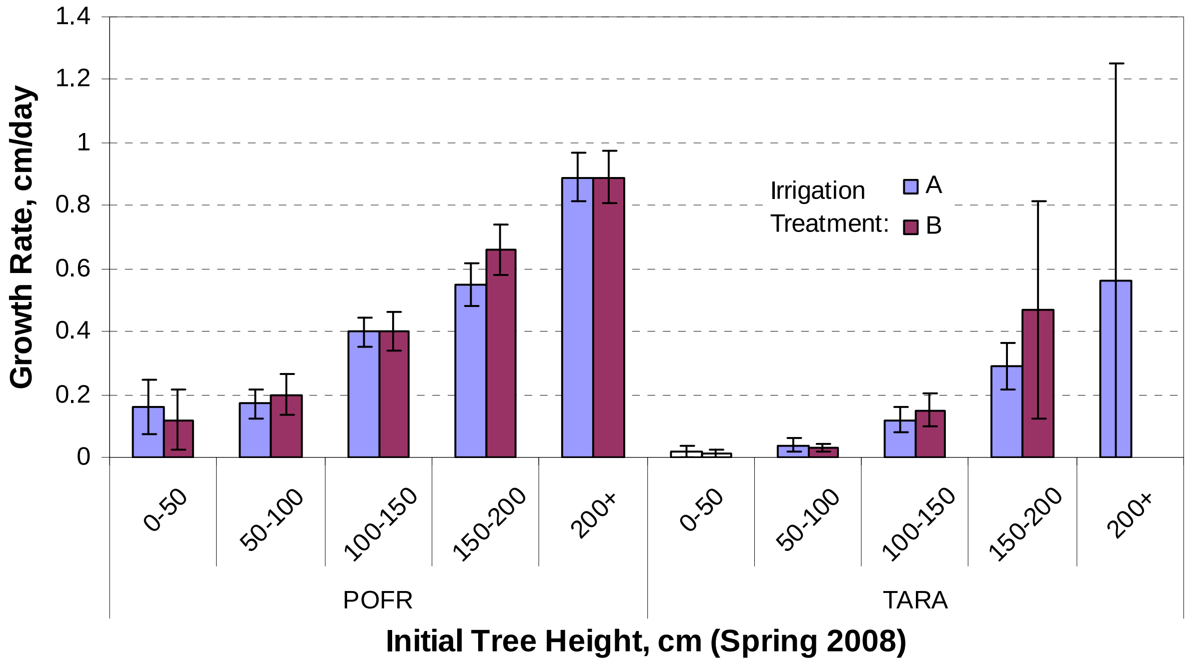


Figure 24. Fremont cottonwood (POFR) and saltcedar (TARA) growth rates by irrigation treatment and initial tree height in small-scale study plots during the 2008 growing season.

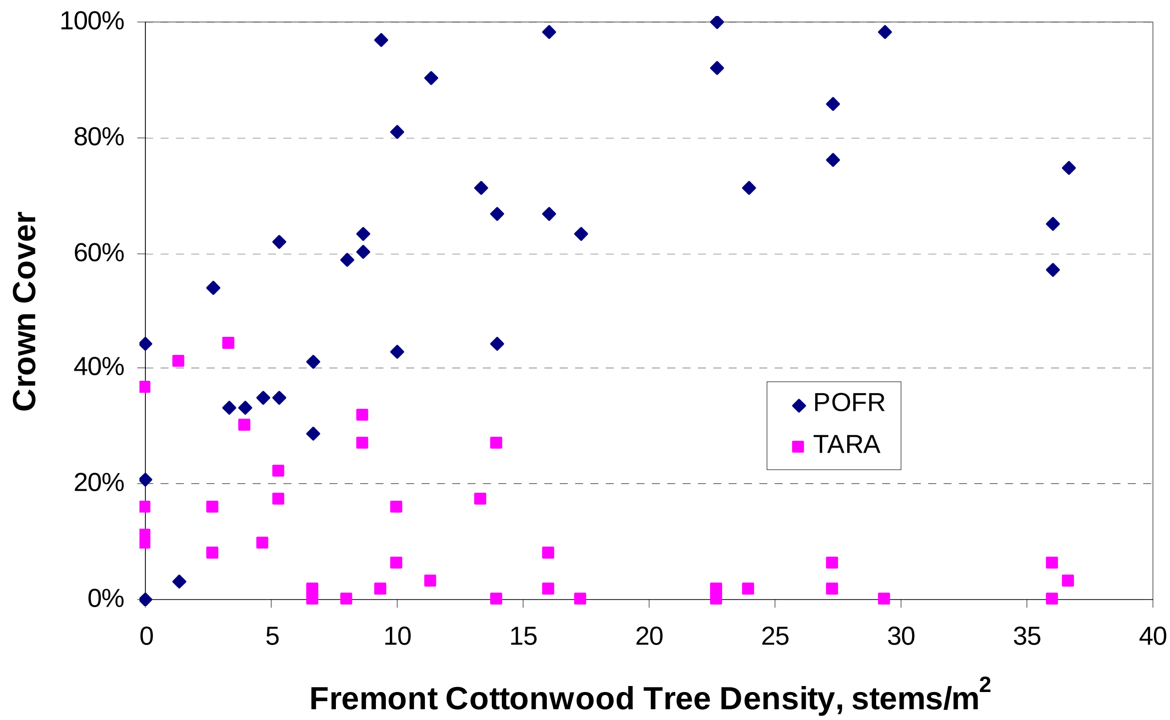


Figure 25. Fremont cottonwood (POFR) and saltcedar (TARA) crown cover after two growing seasons (October 2008) versus cottonwood tree density.

Figure 26. Root survey trench for small-scale study, Plot 16.

Figure 27. Typical root growth pattern for Fremont cottonwood observed during root survey.

Figure 28. Fremont cottonwood root at greater than 150 cm bgs after two growing seasons, small-scale plot 16.

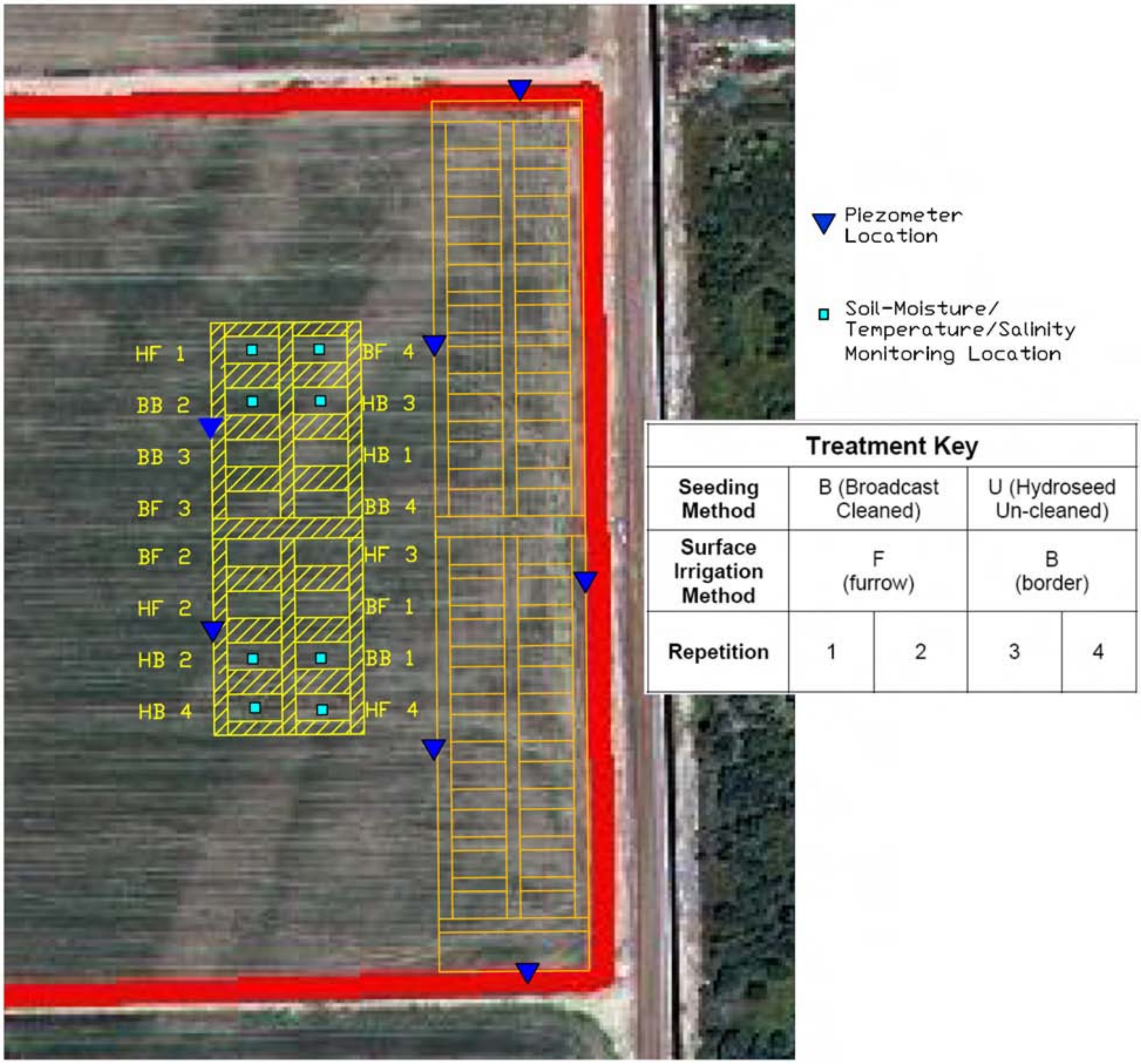


Figure 29. 2008 Small-scale study plot treatment layout on Cibola NWR Field 51.

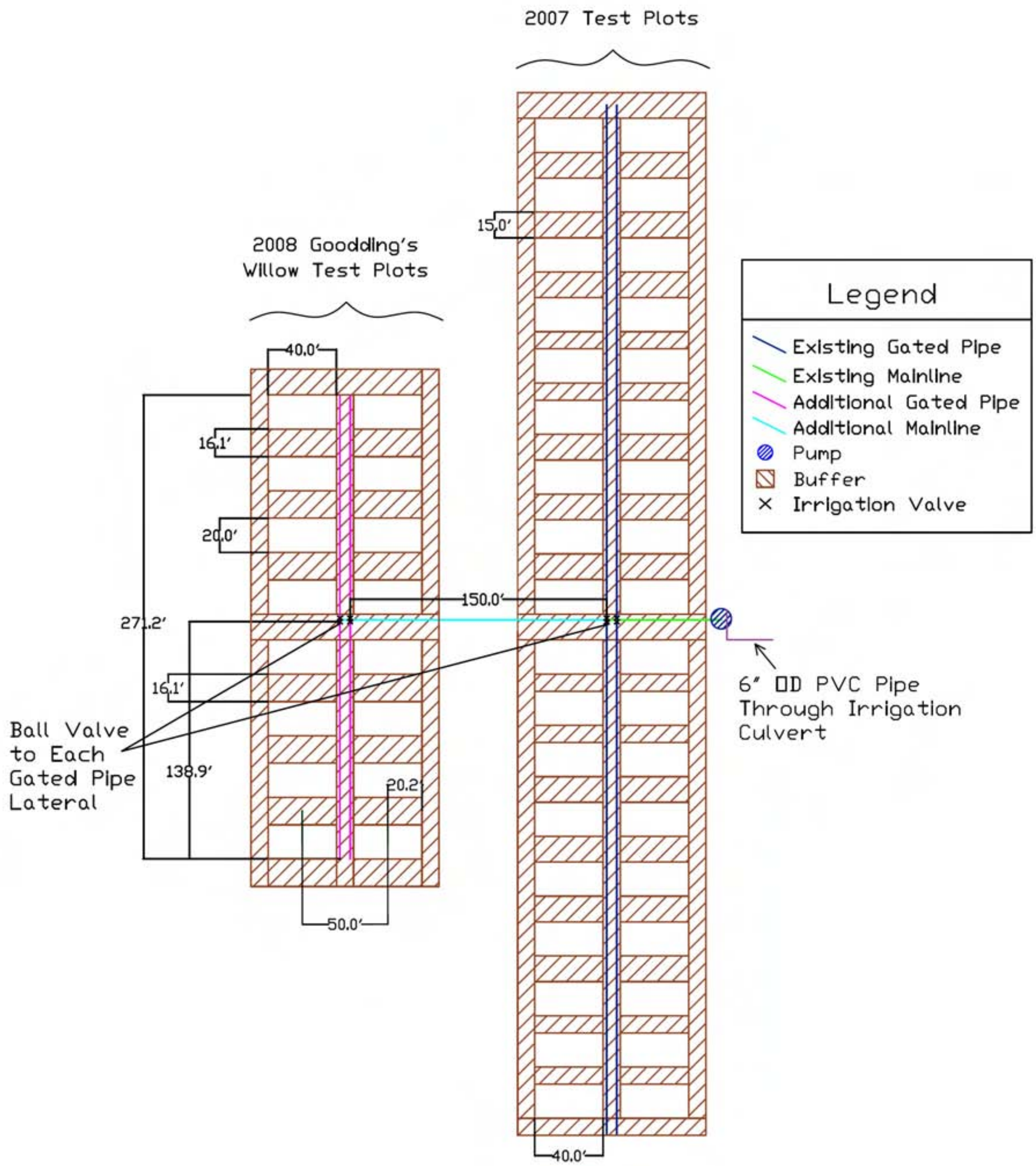


Figure 30. As-built irrigation specifications for 2007 and 2008 Goodding's willow small-scale study at Cibola NWR Field 51.

Figure 31. Instrumented well point piezometers and soil moisture monitoring locations in the small-scale study area.

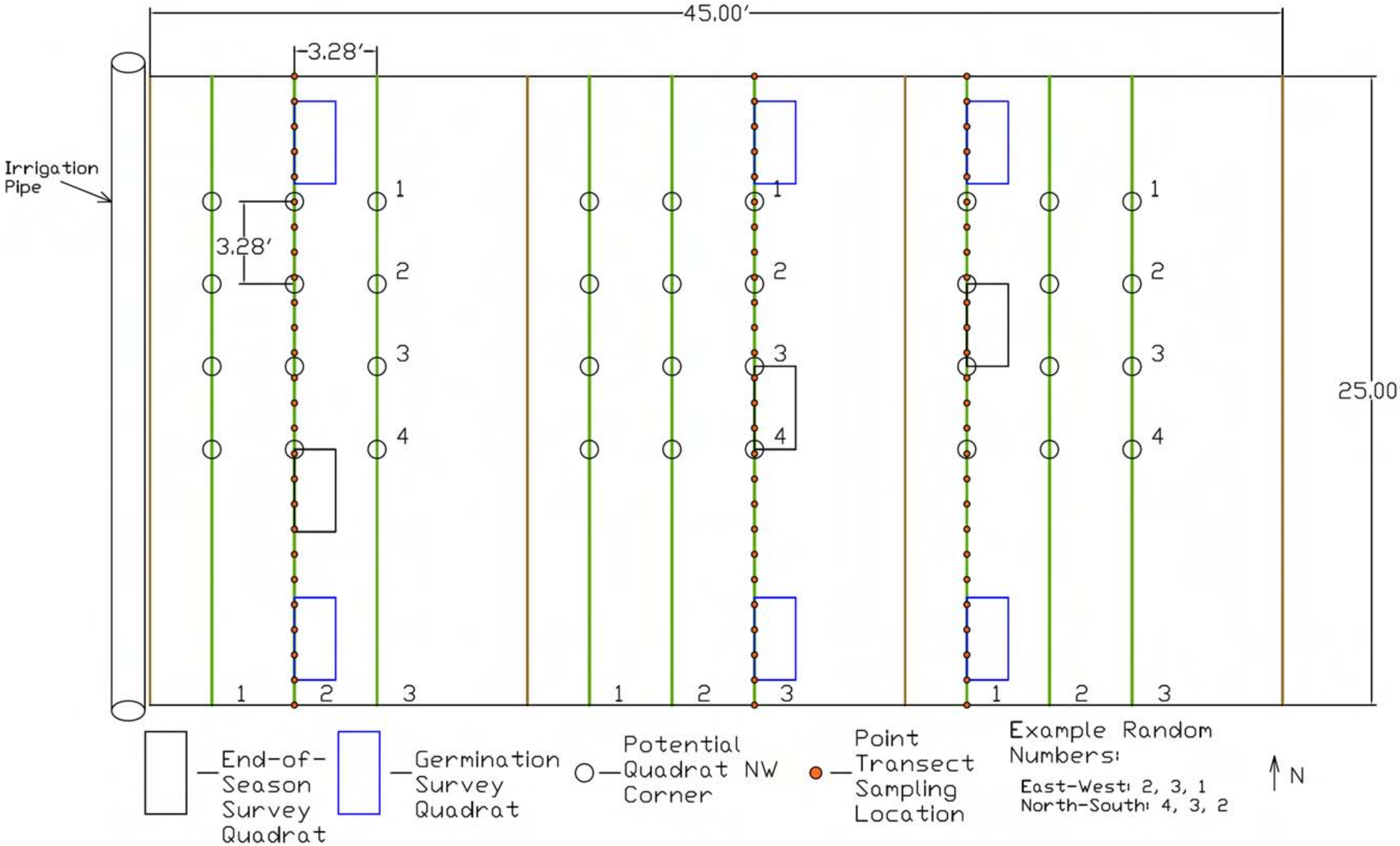


Figure 32. Example vegetation survey schematic for 2008 Goodding's willow small-scale plot studies (typical plot dimensions).

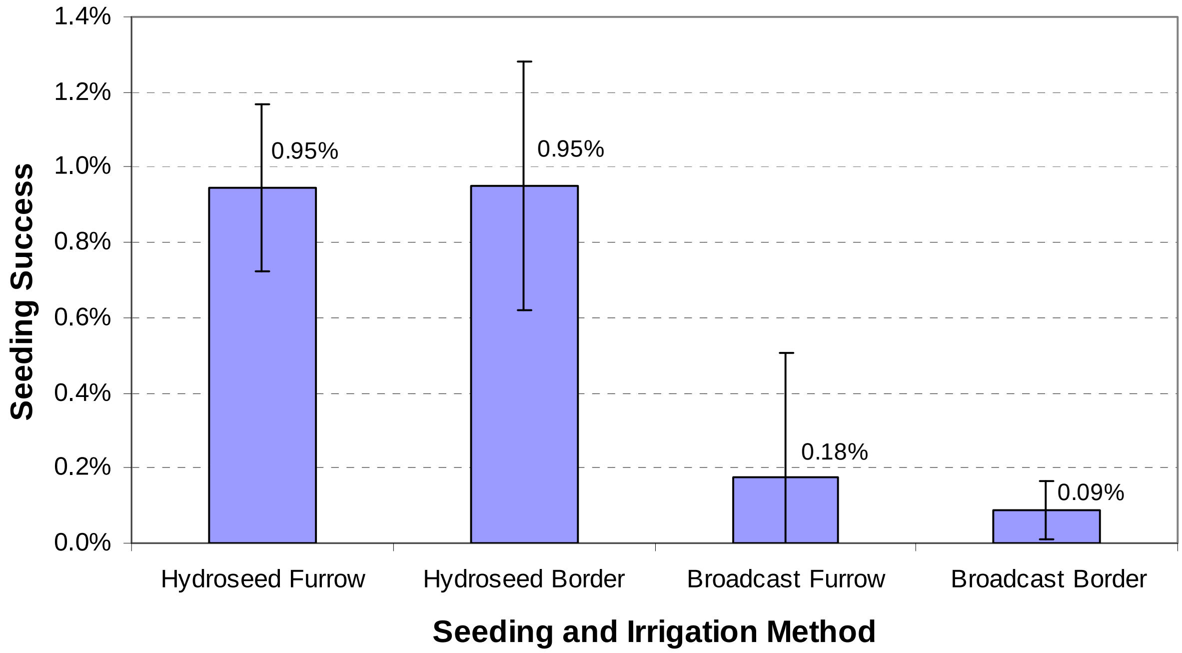


Figure 33. Effects of seeding and surface irrigation methods on Goodding's willow establishment during 2008 small-scale plot studies.

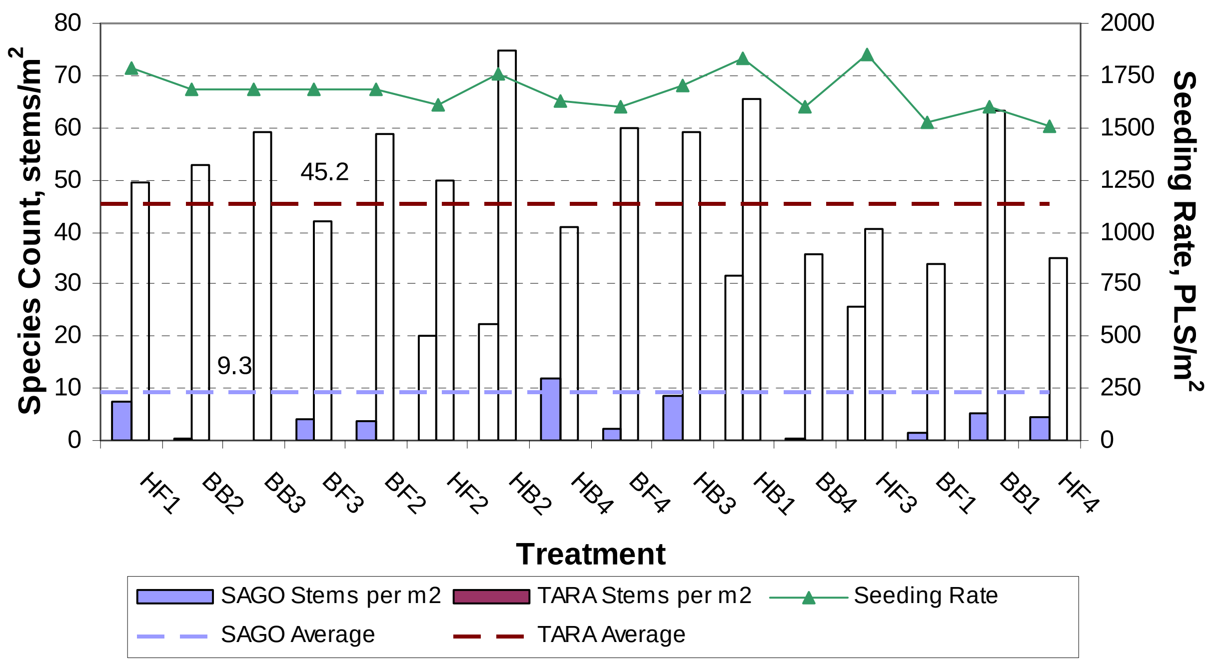


Figure 34. Average (per plot) stem density of Goodding's willow (SAGO) and saltcedar (TARA) in 2008 Goodding's willow small -scale plot studies.

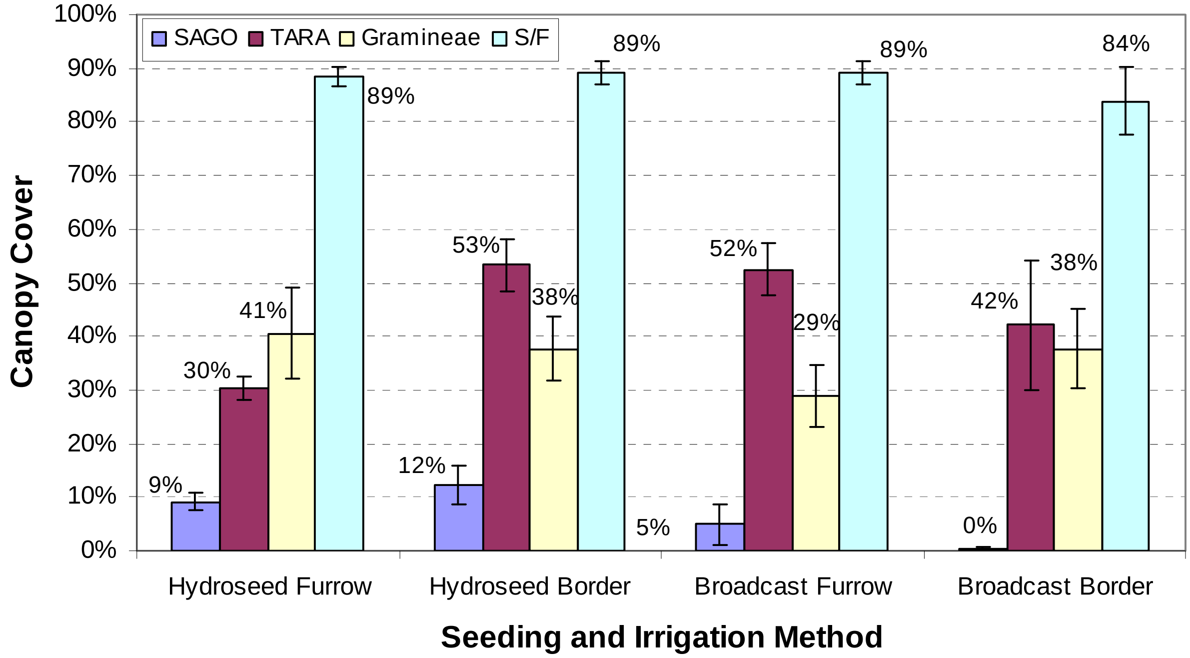


Figure 35. Average (per treatment) canopy cover of Goodding's willow (SAGO), saltcedar (TARA), grass and sedges (Gramineae), and shrubs and forbs (S/F) in 2008 Goodding's willow small -scale field studies.

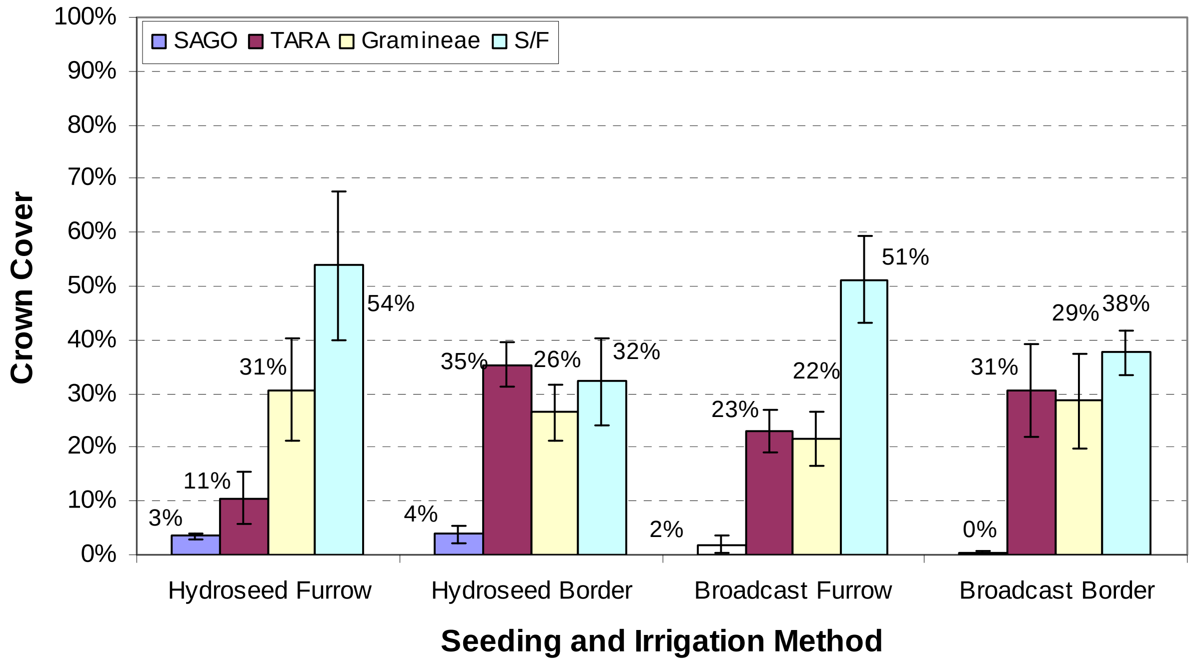


Figure 36. Average (per treatment) crown cover of Goodding's willow (SAGO), saltcedar (TARA), grass and sedges (Gramineae), and shrubs and forbs (S/F) in 2008 Goodding's willow small -scale field studies.

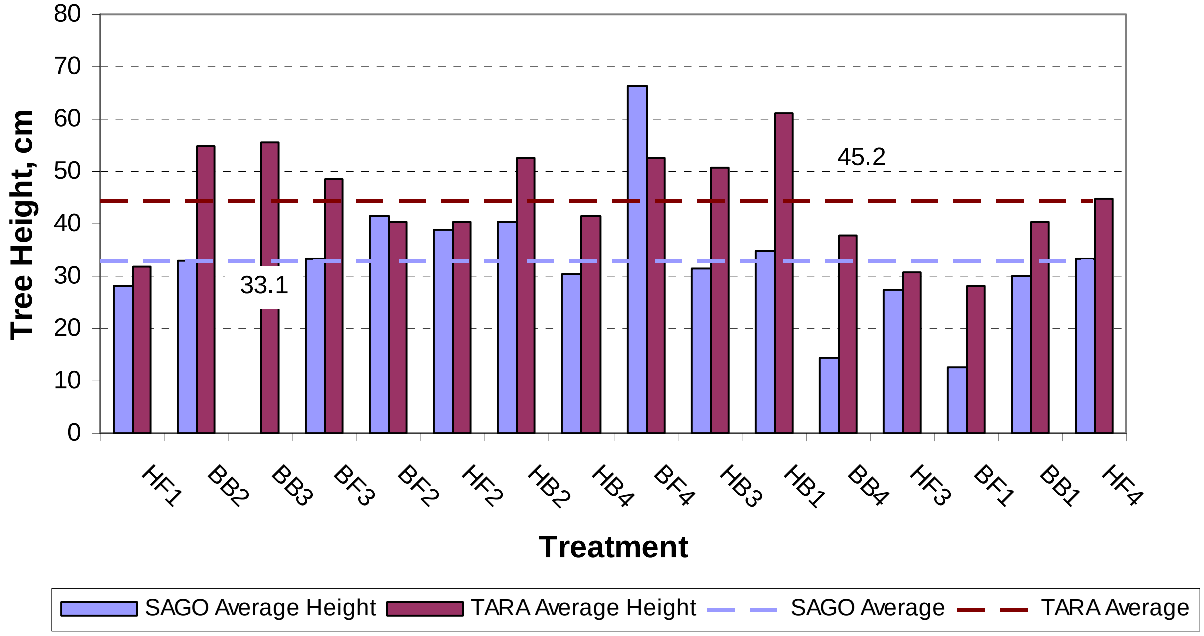


Figure 37. Average (per plot) height of Goodding's willow (SAGO) and saltcedar (TARA) in 2008 Goodding's willow small -scale field studies after approximately four months of growth.

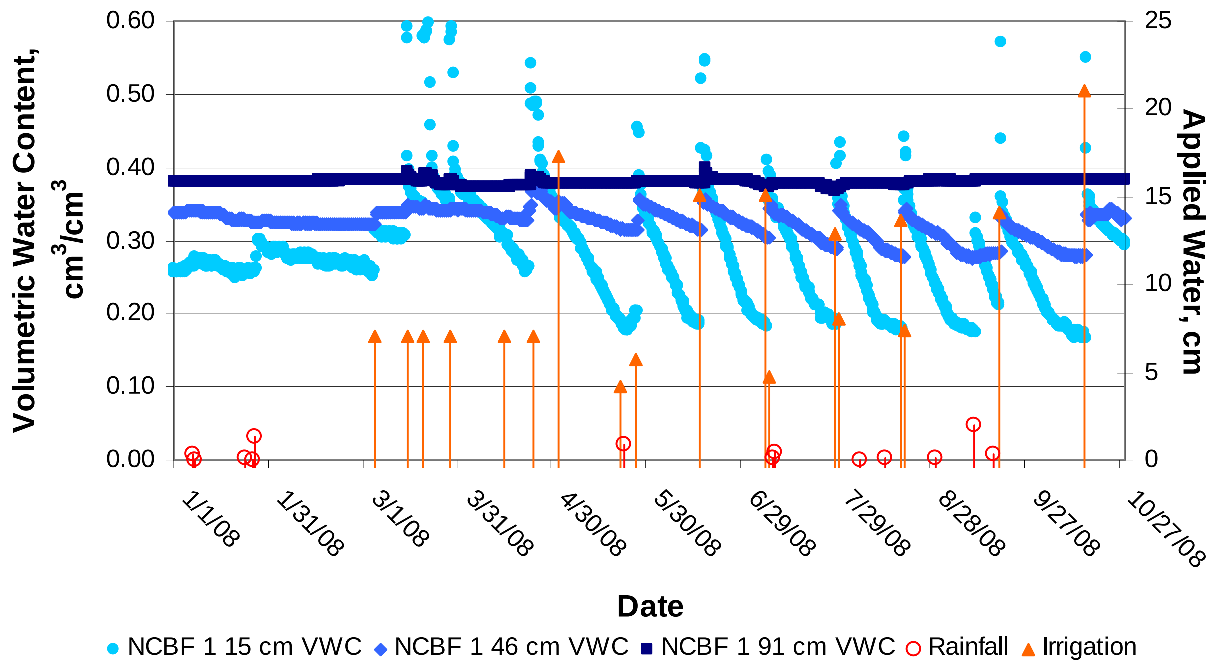


Figure 38. Soil volumetric water content for 2007 small-scale study plot NCBF 1 during the 2008 growing season.

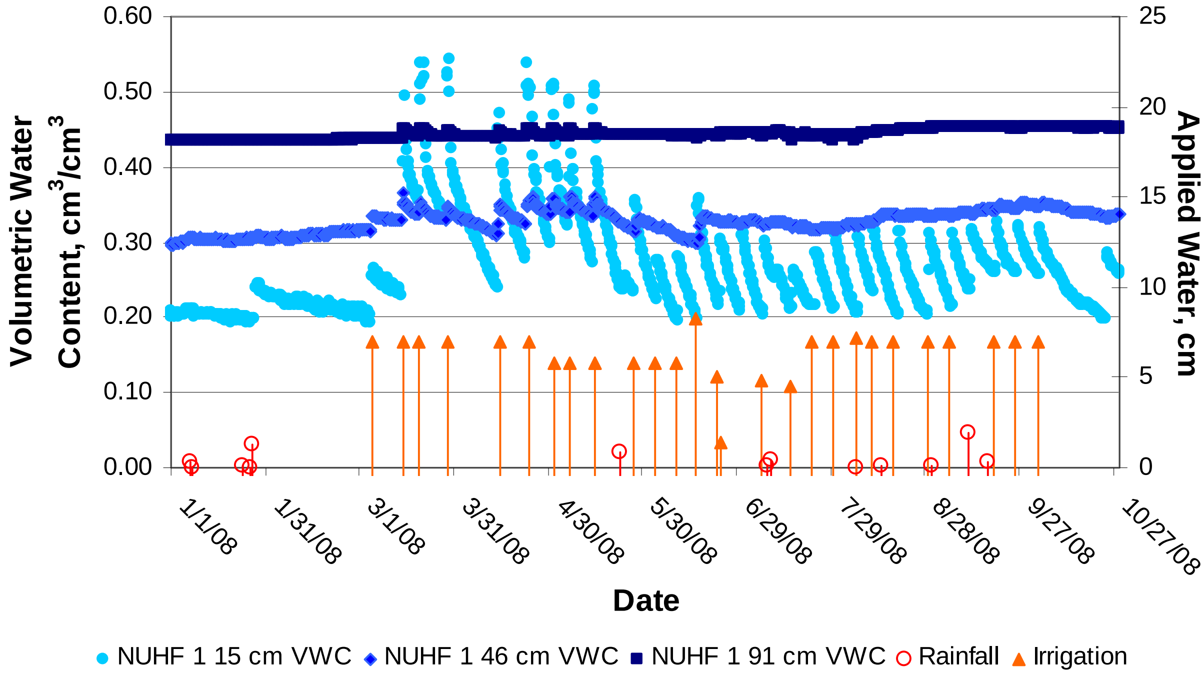


Figure 39. Soil volumetric water content for 2007 small-scale study plot NUHF 1 during the 2008 growing season.

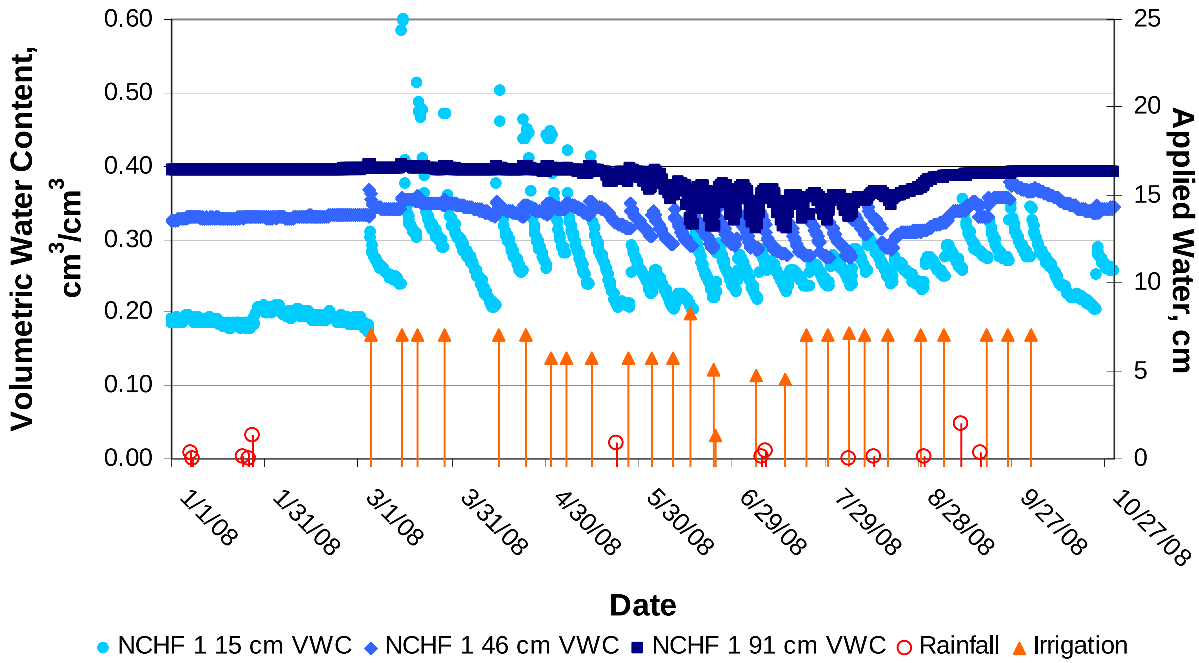


Figure 40. Soil volumetric water content for 2007 small-scale study plot NCHF 1 during the 2008 growing season.

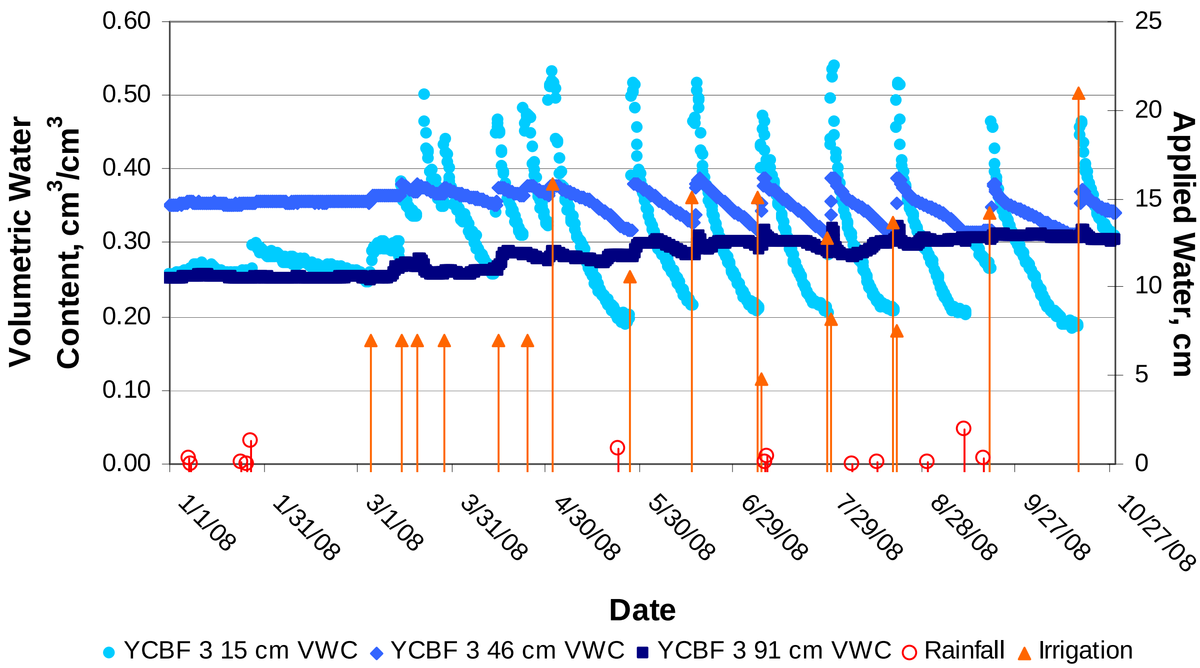


Figure 41. Soil volumetric water content for 2007 small-scale study plot YCBF 3 during the 2008 growing season.

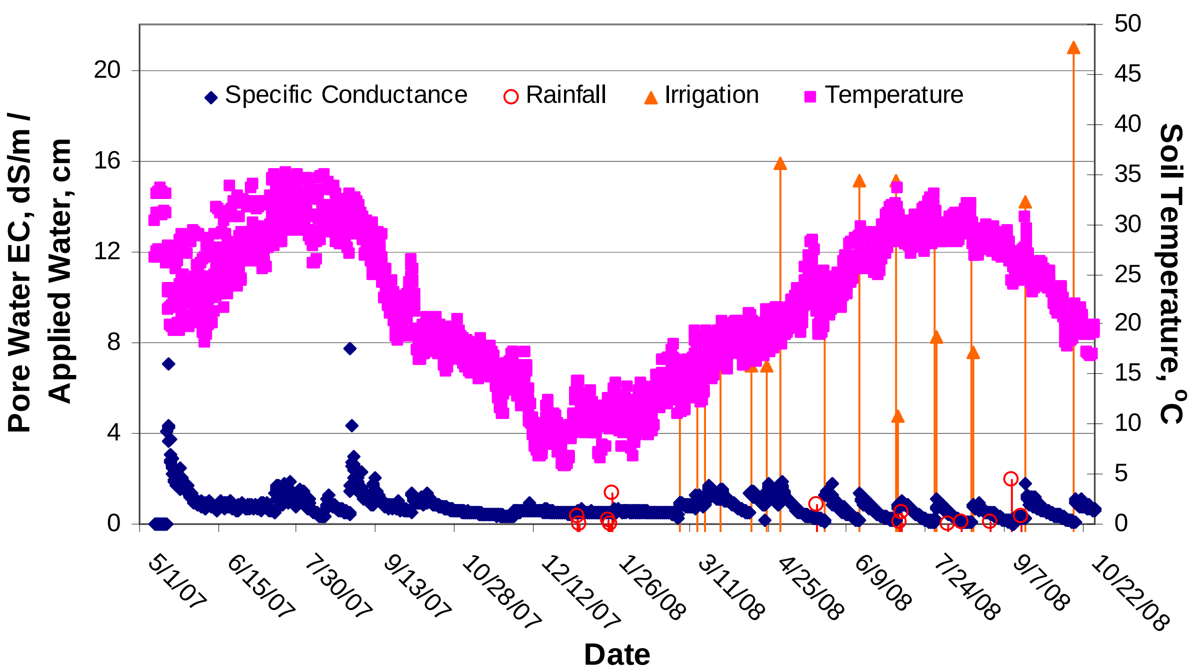


Figure 42. Soil salinity (EC) and temperature (T) versus time for small-scale field study plot NCBF 3.

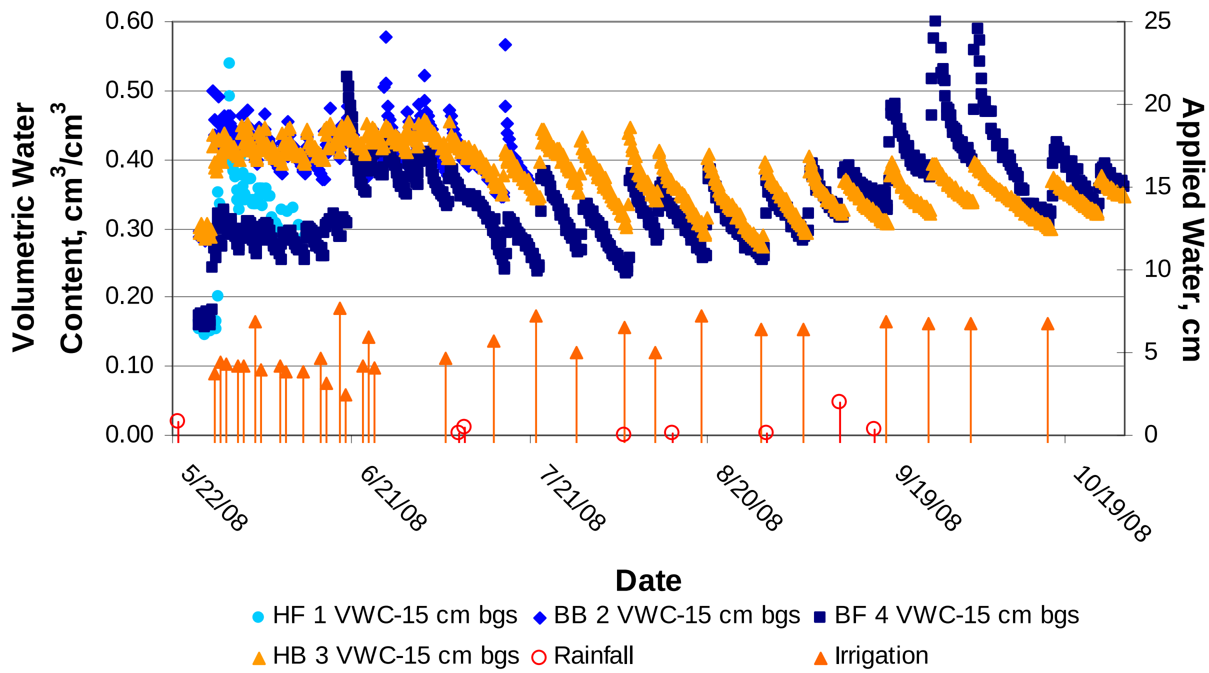


Figure 43. Soil volumetric water content at 15 cm below ground surface in northern portion of 2008 small-scale study plots.

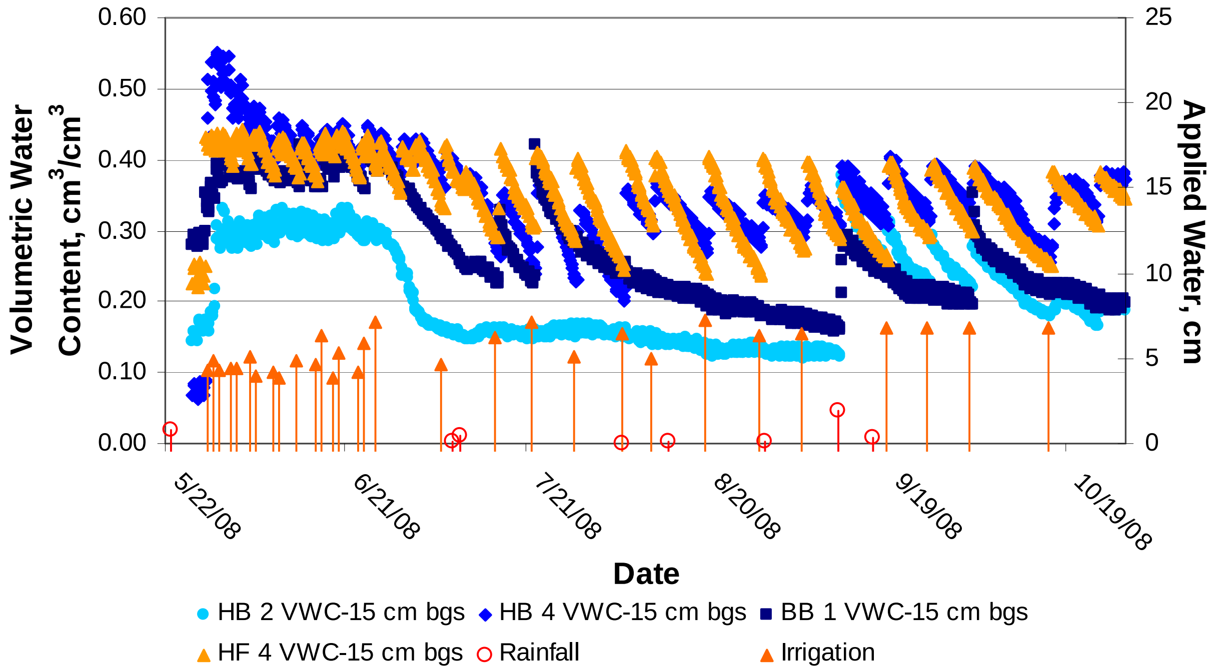


Figure 44. Soil volumetric water content at 15 cm below ground surface in southern portion of 2008 small-scale study plots.

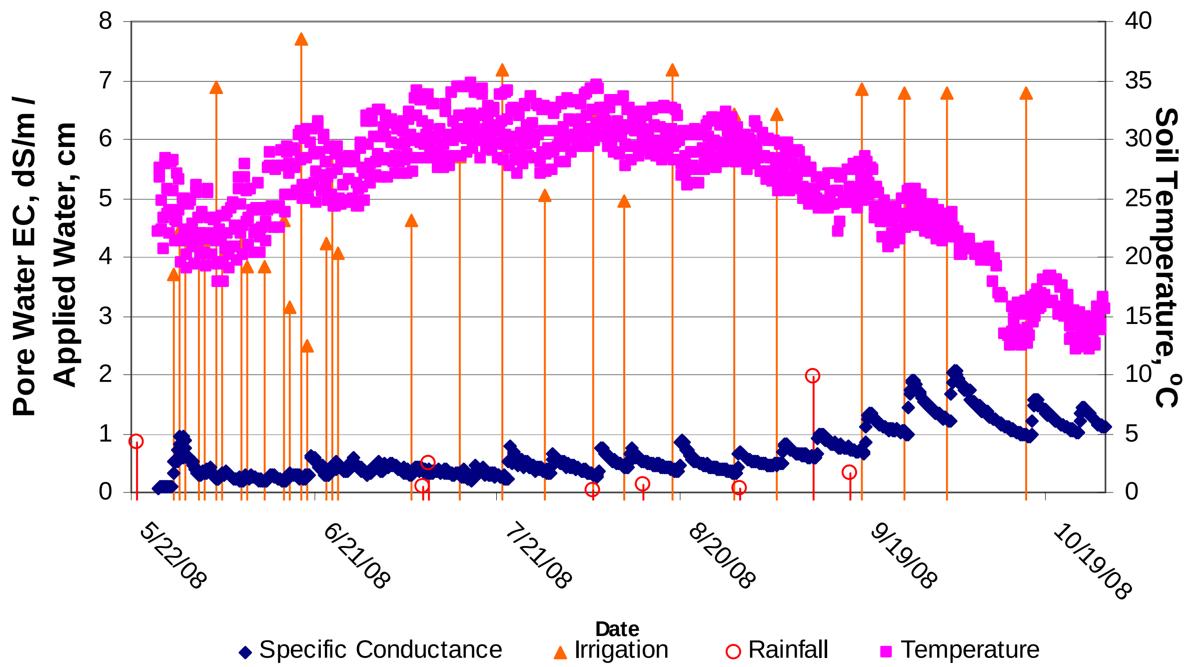


Figure 45. Soil EC and temperature at 15 cm below ground surface for 2008 small-scale study plot BF 4.

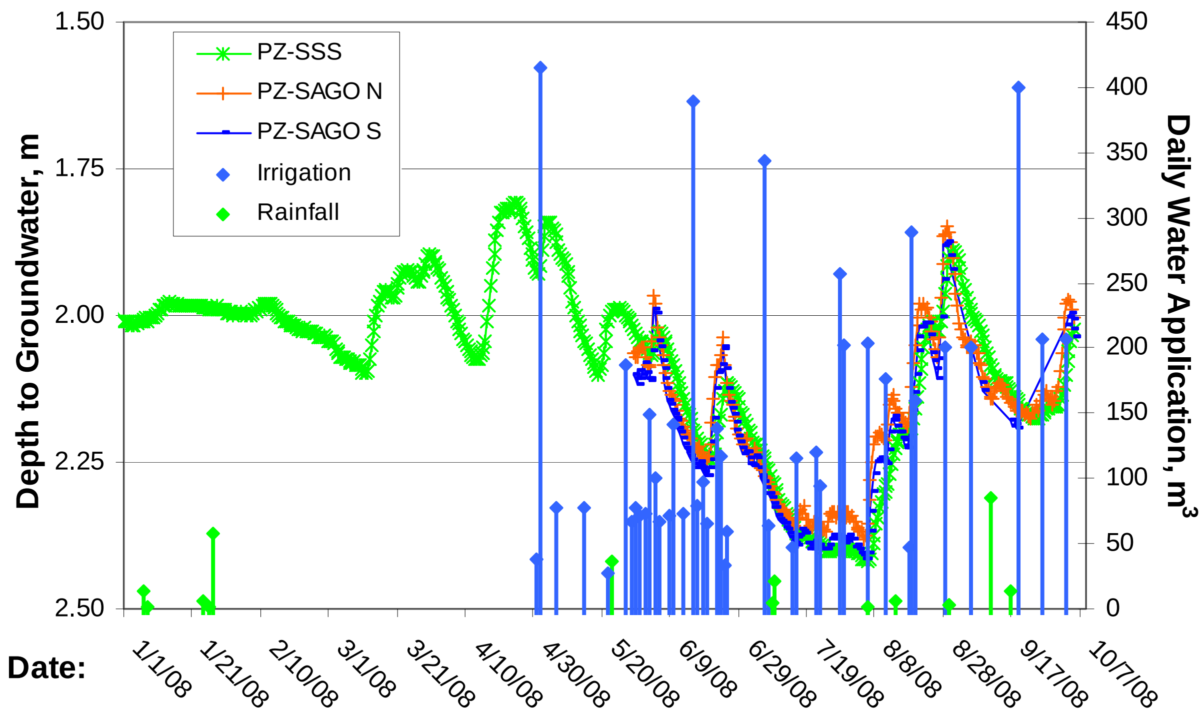


Figure 46. Depth to groundwater in the 2008 Goodding's willow plot area. Irrigation volumes are combined for 2007 and 2008 study plots. Prior to May 1, irrigation volumes are unknown.

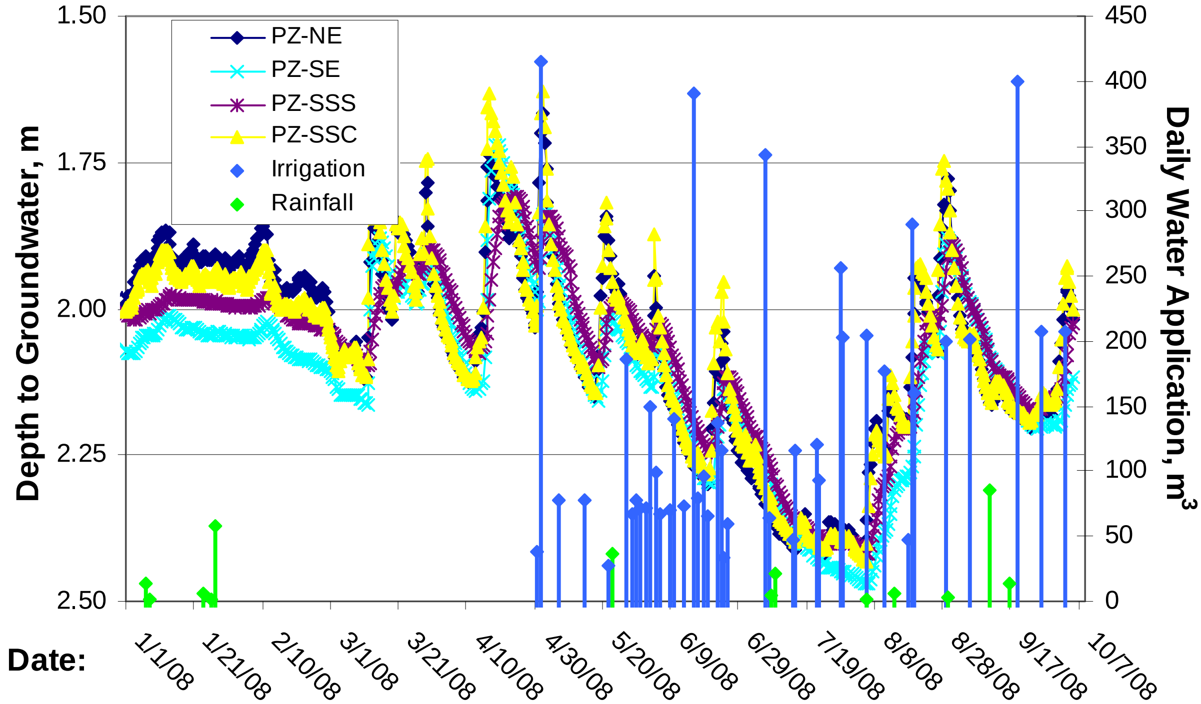


Figure 47. Depth to groundwater in the 2007 small-scale field study area. Irrigation volumes are combined for 2007 and 2008 study plots. Prior to May 1, irrigation volumes are unknown.

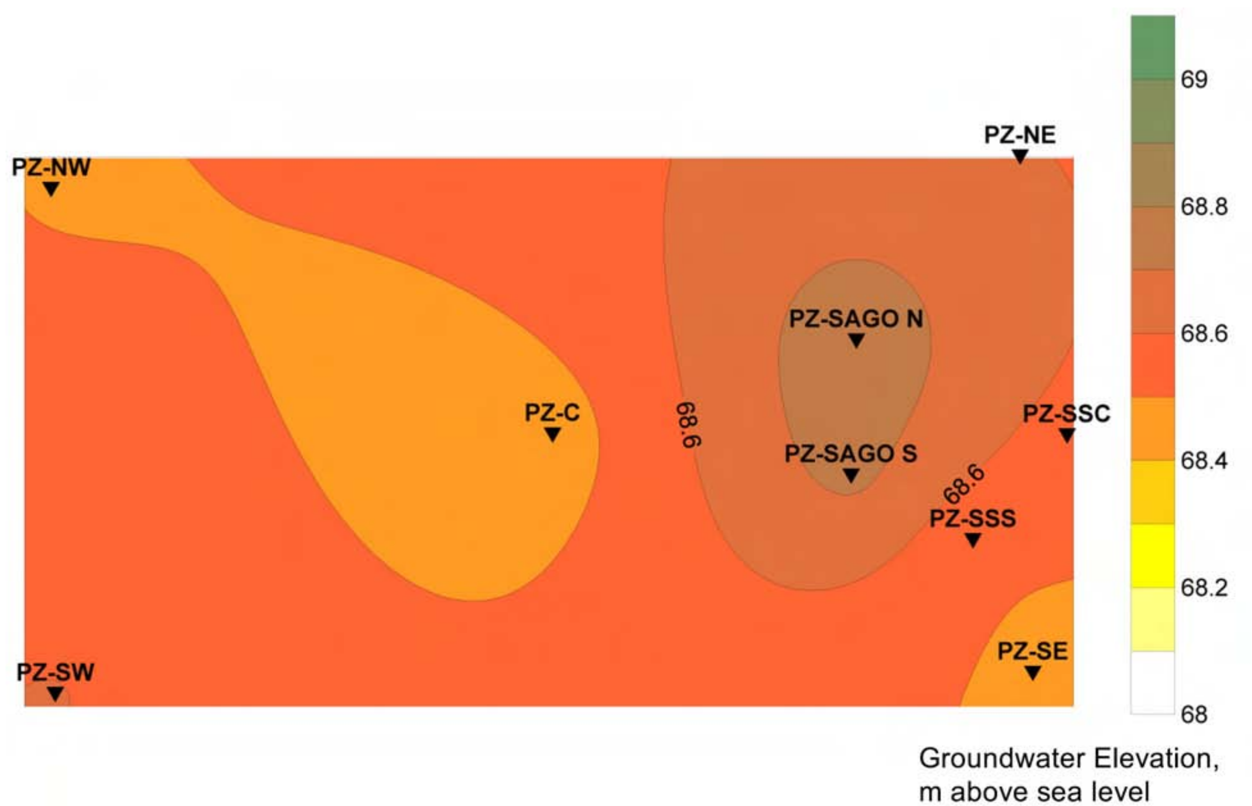


Figure 48. Groundwater elevation at Cibola NWR Field 51 on May 28, 2008.

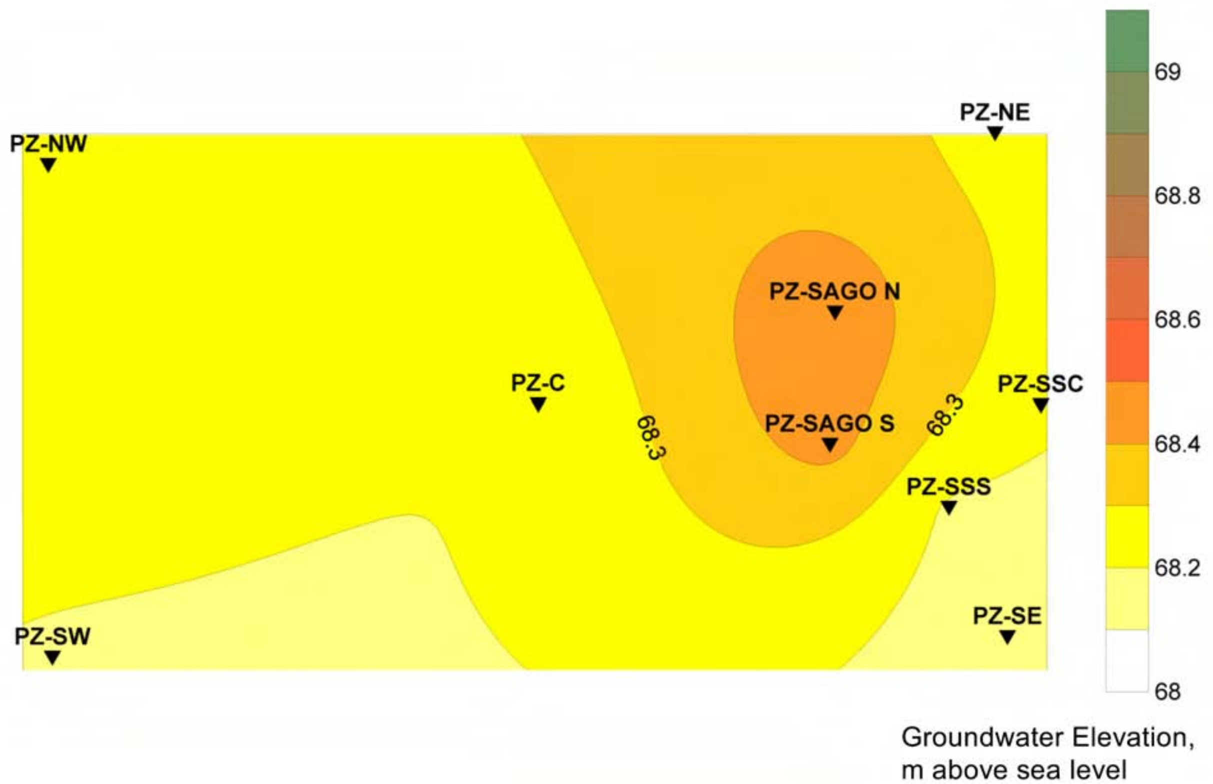


Figure 49. Groundwater elevation at Cibola NWR Field 51 on July 23, 2008.

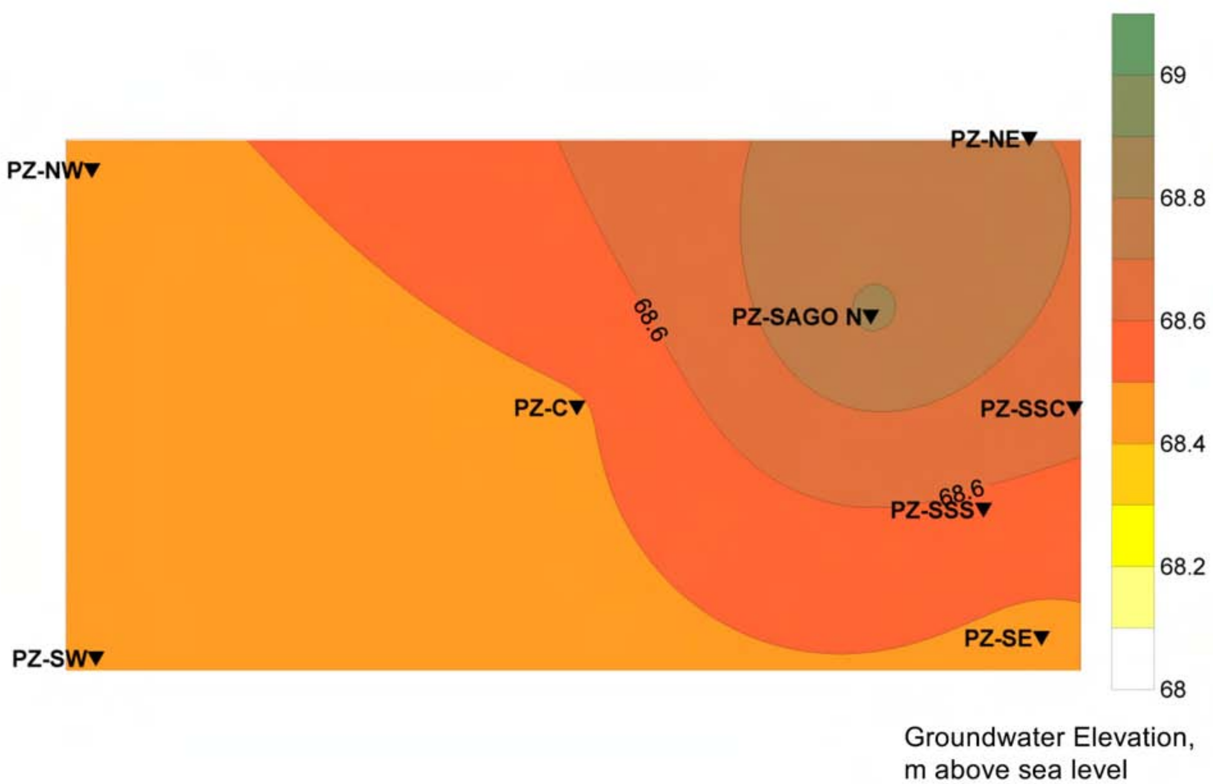


Figure 50. Groundwater elevation at Cibola NWR Field 51 on October 29, 2008.