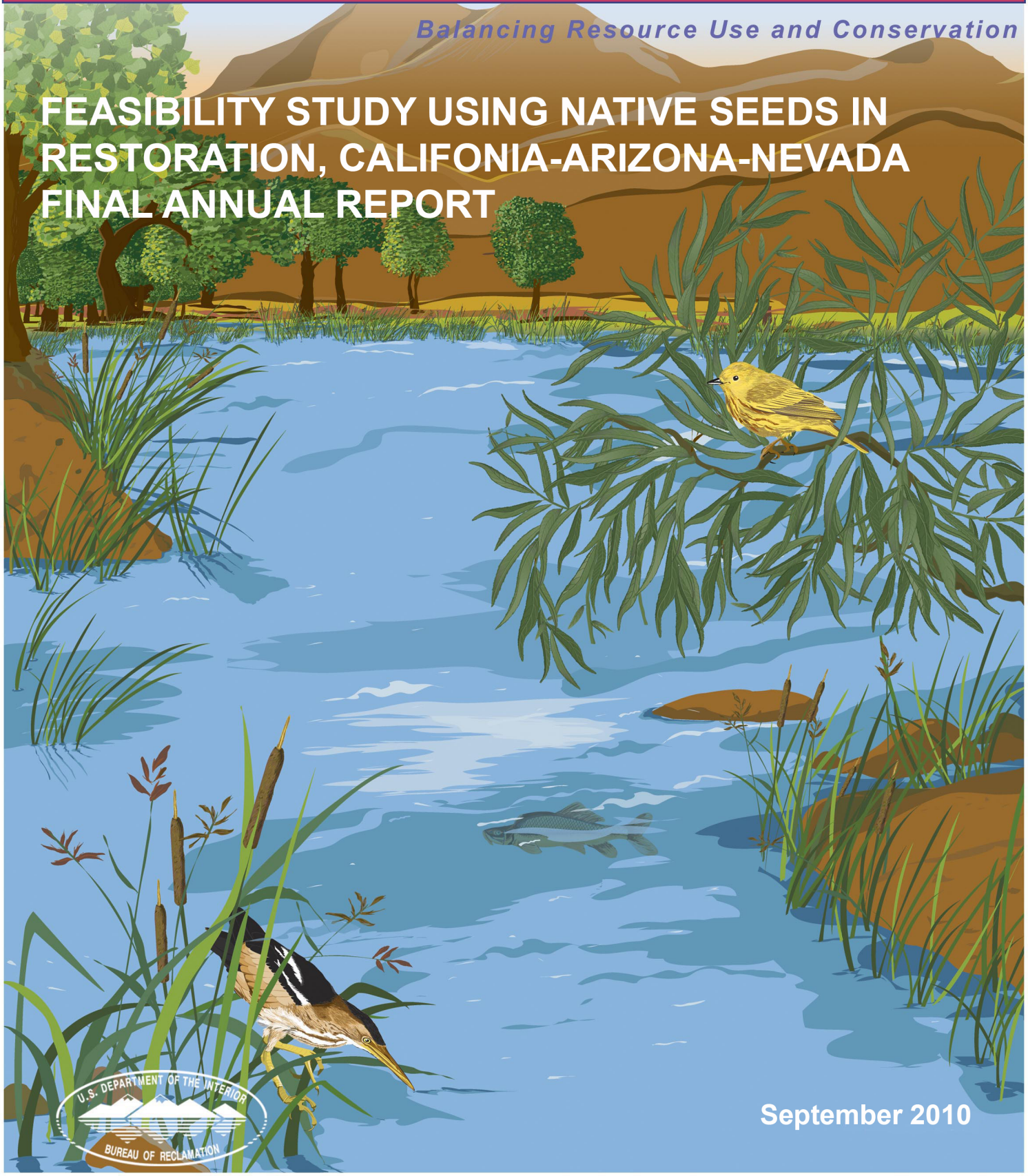
Lower Colorado River Multi-Species Conservation Program

Balancing Resource Use and Conservation

FEASIBILITY STUDY USING NATIVE SEEDS IN RESTORATION, CALIFONIA-ARIZONA-NEVADA FINAL ANNUAL REPORT



September 2010

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Multi-Species Conservation Program

FEASIBILITY STUDY USING NATIVE SEEDS IN RESTORATION, CALIFONIA-ARIZONA-NEVADA
FINAL ANNUAL REPORT

Prepared by:

GeoSystems Analysis, Inc.

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

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TABLE OF CONTENTS

TABLES iii
FIGURES iv
APPENDICES ix
EXECUTIVE SUMMARY 1
1.0 INTRODUCTION 4
2.0 TASK 8: CONTINUED MONITORING OF SMALL-SCALE FIELD STUDIES AT CIBOLA NATIONAL WILDLIFE REFUGE 7
2.1 Technical Approach 8
2.1.1 Irrigation Water Application 8
2.1.2 Vegetation Surveys 10
2.2 Results: Continued Monitoring of 2007 Small-scale Study Plots 13
2.2.1 2007 Small-scale Plots: Rainfall and Irrigation Water Application 13
2.2.2 Vegetation Monitoring: 2007 Small-scale Plots: Treatment Variables 13
2.2.3 Vegetation Monitoring 2007 Small-Scale Plots: Long-term Trends 15
2.2.4 Vegetation Monitoring: 2007 Small-scale Plots: Irrigation Treatment Effects 16
2.2.5 Vegetation Monitoring: 2007 Small-scale Plots: Competition Effects 16
2.3 Results: Continued Monitoring of 2008 Small-scale Study Plots 17
2.3.1 2008 Small-scale Plots: Rainfall and Irrigation Water Application 17
2.3.2 Vegetation Monitoring: 2008 Small-scale Plots: Treatment Variables 17
2.3.3 Vegetation Monitoring: 2008 Small-scale Plots: Long-term Trends 18
2.3.4 Vegetation Monitoring: 2008 Small-scale Plots: Irrigation Treatment Effects 19
2.3.5 Vegetation Monitoring: 2008 Small-scale Plots: Competition Effects 19
3.0 TASK 9: ADDITIONAL SMALL-SCALE STUDY PLOTS FOR GOODDING'S WILLOW 21
3.1 Technical Approach 21
3.1.1 Plot Design and Implementation 22
3.1.2 Seed Collection, Treatment, and Application 22
3.1.3 Irrigation Design 23
3.1.3 Vegetation Monitoring 24
3.2 Results: 2009 Goodding's Willow Small-scale Field Study 24
3.2.1 2009 Small-scale Plots: Rainfall and Irrigation Water Application 24
3.2.2 2009 Small-scale Plots: Treatment Variables 25
4.0 SMALL-SCALE STUDY AREA SUBSURFACE MONITORING 27
4.1 Technical Approach: Soil and Groundwater Monitoring 27
4.1.1 Soils Moisture Content, Temperature, and Electrical Conductivity 27
4.1.2 Groundwater Elevation 28
4.1.3 Groundwater Quality 28

4.1.4 Water Budget Analysis 28
4.2 Results: Soil and Groundwater Monitoring 29
4.2.1 Soil Moisture Content, Electrical Conductivity and Temperature 29
4.2.2 Depth to Groundwater 31
4.2.3 Groundwater Quality 32
4.2.4 Water Budget Analysis 33
5.0 CONCLUSIONS 37
6.0 RECOMMENDATIONS 42
7.0 ACKNOWLEDGMENTS 45
8.0 REFERENCES 46
TABLES 48
FIGURES 64

TABLES

Table 1. 2009 rainfall data for Cibola NWR..... 49
Table 2. Applied water summary for 2009 growing season, 2007 small-scale plots, A Blocks. . 50
Table 3. Applied water summary for 2009 growing season, 2007 small-scale plots, B Blocks... 51
Table 4. ANOVA linear modeling results after three growing seasons (October 2009 survey) for seeded riparian species in 2007 small-scale field study plots..... 52
Table 5. ANOVA linear modeling results after two growing seasons (October 2008 survey) for non-target riparian species in 2007 small-scale field study plots. 53
Table 6. ANOVA modeling results for Fremont cottonwood and saltcedar growth rates for the 2007 small-scale field study plots during the 2009 growing season. 54
Table 7. Applied water summary for 2009 growing season, 2008 plots, Block A3..... 55
Table 8. Applied water summary for 2009 growing season, 2008 plots Block B3. 56
Table 9. ANOVA linear modeling results for the 2008 Goodding's willow small-scale field study (Task 5U-6)..... 57
Table 10. ANOVA modeling results for Goodding's willow and saltcedar growth rates for the 2008 small-scale field study plots during the 2009 growing season. 58
Table 11. 2009 Goodding's willow small-scale field plot specifications..... 59
Table 12. Applied water summary for 2009 growing season, 2009 Goodding's willow plots. . 60
Table 13. 2009 Goodding's willow small-scale study result averages and significant differences for Goodding's willow (SAGO), saltcedar (TARA), grasses and sedges (G/S), and shrubs and forbs (S/F) per plot.[1] 61
Table 14. 2009 Goodding's willow small-scale study result averages and significant differences for Goodding's willow (SAGO) density and percent establishment, and saltcedar (TARA) density.[1]..... 61
Table 15. Number of functioning soil volumetric water content sensors by year for 2007 study plots..... 61
Table 16. Field conductivity meter-measured groundwater specific conductance for Field 51 piezometers monitoring during the 2009 growing season. 61
Table 17. Laboratory results for major cations and anions for Field 51 piezometers monitored during the 2009 growing season. 62
Table 18. Laboratory results for alkalinity, specific conductivity (EC), and total dissolved solids (TDS) for Field 51 piezometers monitored during the 2009 growing season. 62
Table 19. Decrease in total soil water between 3/1/08 and 10/31/08 by depth interval, location and irrigation block..... 62
Table 20. Decrease in total soil water between 3/1/09 and 10/11/09 by depth interval, location and irrigation block..... 63

FIGURES

Figure 1. Layout and treatments for 2007 small-scale field study plots at Cibola NWR Field 51. 65
Figure 2. Layout and treatments for 2008 small-scale field study plots at Cibola NWR Field 51.....66
Figure 3. 2009 growing season irrigation block layout for 2007 and 2008 small-scale field study plots at Cibola NWR Field 51..... 67
Figure 4. Example vegetation monitoring schematic for small-scale field study plots at Cibola NWR Field 51..... 68
Figure 5. Vegetation crown cover trends for Fremont cottonwood (POFR), saltcedar (TARA), grasses and sedges (G/S), and shrubs and forbs (S/F) in 2007 study plots..... 69
Figure 6. Vegetation canopy cover trends for Fremont cottonwood (POFR), saltcedar (TARA), grasses and sedges (G/S), and shrubs and forbs (S/F) in 2007 study plots..... 69
Figure 7. Fremont cottonwood (POFR) and saltcedar (TARA) tree density trends in 2007 small-scale study plots. 70
Figure 8. Fremont cottonwood (POFR) and saltcedar (TARA) mortality rates versus irrigation method and growing season in 2007 study plots for all heights combined. Letters indicate significant differences across all columns (Student's t-test, α=0.05). 70
Figure 9. Fremont cottonwood (POFR) and saltcedar (TARA) mortality rates (combined irrigation treatments) versus initial tree height (May 2009) in 2007 study plots during the 2009 growing season. Letters indicate significant differences across all columns (Student's t-test, α=0.05)..... 71
Figure 10. Fremont cottonwood (POFR) and saltcedar (TARA) growth rate versus initial height (May 2009) in 2007 study plots during the 2009 growing season, A blocks only. * indicates significant differences between paired columns (Student's t-test, α=0.05)..... 71
Figure 11. Fremont cottonwood (POFR) and saltcedar (TARA) growth rate versus initial height (May 2009) in 2007 study plots during the 2009 growing season, B blocks only. * indicates significant differences between paired columns (Student's t-test, α=0.05)..... 72
Figure 12. Fremont cottonwood (POFR) and saltcedar (TARA) mortality rates versus irrigation method in 2007 study plots between the fall 2008 and fall 2009 surveys for all heights combined. Letters indicate significant differences across all columns (Student's t-test, α=0.05). 72
Figure 13. Fremont cottonwood (POFR) and saltcedar (TARA) mortality rates versus initial height (May 2009) and irrigation method in 2007 study plots during the 2009 growing season. Letters indicate significant differences across all columns (Student's t-test, α=0.05). 73
Figure 14. Fremont cottonwood growth rate versus initial height (May 2009) and irrigation method in 2007 study plots during the 2009 growing season. * indicates significant differences between paired columns (Student's t-test, α=0.05). 73

Figure 15. Saltcedar growth rate versus initial height (May 2009) and irrigation method in 2007 study plots during the 2009 growing season. * indicates significant differences between paired columns (Student's t-test, α=0.05). 74
Figure 16. Fremont cottonwood (POFR) and Saltcedar (TARA) crown cover after three growing seasons (October 2009) versus Fremont cottonwood stem density after the first growing season (September 2007). 74
Figure 17. Vegetation crown cover trends for Goodding's willow (SAGO), saltcedar (TARA), grasses and sedges (G/S), and shrubs and forbs (S/F) in 2008 study plots. 75
Figure 18. Vegetation canopy cover trends for Goodding's willow (SAGO), saltcedar (TARA), grasses and sedges (G/S), and shrubs and forbs (S/F) in 2008 study plots. 75
Figure 19. Goodding's willow (SAGO) and saltcedar (TARA) tree density trends in 2008 small-scale study plots. 76
Figure 20. Goodding's willow (SAGO) and saltcedar (TARA) mortality rates versus irrigation method in 2008 study plots between the fall 2008 and fall 2009 surveys for all heights combined using quadrat data. Letters indicate significant differences across all columns (Student's t-test, α=0.05). 76
Figure 21. Goodding's willow (SAGO) and saltcedar (TARA) mortality rates (combined irrigation treatments) by initial tree height (May 2009) in 2008 study plots during the 2009 growing season. Letters indicate significant differences across all columns (Student's t-test, α=0.05). 77
Figure 22. Goodding's willow (SAGO) and saltcedar (TARA) growth rate versus initial height (May 2009) in 2008 study plots during the 2009 growing season, A blocks only. * indicates significant differences between paired columns (Student's t-test, α=0.05). 77
Figure 23. Goodding's willow (SAGO) and saltcedar (TARA) growth rate versus initial height (May 2009) in 2008 study plots during the 2009 growing season, B blocks only. * indicates significant differences between paired columns (Student's t-test, α=0.05). 78
Figure 24. Goodding's willow (SAGO) and saltcedar (TARA) mortality rates versus initial tree height (May 2009) and irrigation method in 2008 study plots during the 2009 growing season. Letters indicate significant differences across all columns (Student's t-test, α=0.05). 78
Figure 25. Goodding's willow (SAGO) and saltcedar (TARA) growth rates versus initial tree height (May 2009) and irrigation method in 2008 study plots during the 2009 growing season. * indicates significant differences between paired columns (Student's t-test, α=0.05). 79
Figure 26. Goodding's willow (SAGO) and saltcedar (TARA) mortality rates versus irrigation method in 2008 study plots over the 2008-2009 winter and the 2009 growing seasons for all heights combined. Letters indicate significant differences across all columns (Student's t-test, α=0.05). 79

Figure 27. Layout and treatments for 2009 small-scale field study plots at Cibola NWR Field 51. 80
Figure 28. Average (per plot) stem density of Goodding's willow (SAGO) and saltcedar (TARA) in 2009 Goodding's willow small-scale field studies after one growing season. 81
Figure 29. Average (per treatment) tree density of Goodding's willow (SAGO) and saltcedar (TARA) in 2009 Goodding's willow small-scale field studies after one growing season. Letters indicate significant differences across all columns (Student's t-test, α=0.05)..... 81
Figure 30. Average (per treatment) establishment of Goodding's willow after one growing season in 2009 Goodding's willow small-scale field studies. Letters indicate significant differences across columns (Student's t-test, α=0.05). 82
Figure 31. Average (per plot) crown cover of Goodding's willow (SAGO) and saltcedar in 2009 Goodding's willow small-scale field studies after one growing season. 82
Figure 32. Average (per plot) canopy cover of Goodding's willow (SAGO) and saltcedar in 2009 Goodding's willow small-scale field studies after one growing season. 83
Figure 33. Average (per plot) height of Goodding's willow (SAGO) and saltcedar in 2009 Goodding's willow small-scale field studies after one growing season. * indicates significant differences between paired columns (Student's t-test, α=0.05). 83
Figure 34. Average (per treatment) height of Goodding's willow (SAGO) and saltcedar in 2009 Goodding's willow small-scale field studies after one growing season. No significant differences were observed between paired columns at α=0.05. 84
Figure 35. Average (per treatment) crown cover of Goodding's willow (SAGO), saltcedar (TARA), grass and sedges (G/S), and shrubs and forbs (S/F) in 2009 Goodding's willow small-scale field studies after one growing season. 84
Figure 36. Average (per treatment) canopy cover of Goodding's willow (SAGO), saltcedar (TARA), grass and sedges (G/S), and shrubs and forbs (S/F) in 2009 Goodding's willow small-scale field studies after one growing season. 85
Figure 37. Goodding's willow tree establishment after one growing season versus seeding rate in 2009 Goodding's willow small-scale field studies. 85
Figure 38. Well point piezometer and soil instrumentation locations for small-scale field studies at Cibola NWR Field 51. 86
Figure 39. Average volumetric water content and applied water for small-scale field study plots in irrigation block A1. 87
Figure 40. Average volumetric water content and applied water for small-scale field study plots in irrigation block A2. 87
Figure 41. Average volumetric water content and applied water for small-scale field study plots in irrigation block B1. 88

Figure 42. Average volumetric water content and applied water for small-scale field study plots in irrigation block B2. 88
Figure 43. Volumetric water content and applied water for small-scale field study plot YCBB 1, in irrigation block A2. 89
Figure 44. Volumetric water content and applied water for small-scale field study plot NUHF 3, in irrigation block A2. 89
Figure 45. Volumetric water content and applied water for small-scale field study plot NUHF 1, in irrigation block A1. 90
Figure 46. Volumetric water content and applied water for small-scale field study plot NCBB 1, in irrigation block B1. 90
Figure 47. Volumetric water content and applied water for small-scale field study plot YCBF 1, in irrigation block B1. 91
Figure 48. Volumetric water content and applied water for 2008 small-scale field study plots in irrigation block A3. 91
Figure 49. Volumetric water content and applied water for 2008 small-scale field study plots in irrigation block B3. 92
Figure 50. Pore water electrical conductivity (EC), soil temperature, and applied water for 2007 small-scale field study plot NUHF 1, in irrigation block A1. 92
Figure 51. Pore water electrical conductivity (EC), soil temperature, and applied water for 2007 small-scale field study plot NUHF 1, in irrigation block A1. 93
Figure 52. Pore water electrical conductivity (EC), soil temperature, and applied water for 2008 small-scale field study plots in irrigation block A3. 93
Figure 53. Pore water electrical conductivity (EC), soil temperature, and applied water for 2008 small-scale field study plots in irrigation block B3. 94
Figure 54. Average depth to groundwater and applied water for the 2007 small-scale study plot area. Depth to groundwater is the average for piezometers PZ-NE, PZ-SSN, and PZ-SSC, and applied water is the total volume applied to 2007 plots divided by the total area of the 2007 small-scale study plots. 94
Figure 55. Depth to groundwater and applied water for the 2008 small-scale study plots in irrigation Block A3. Depth to groundwater is from PZ-SAGON, and applied water is the volume applied to Block A3 divided by the area of Block A3. 95
Figure 56. Depth to groundwater and applied water for the 2008 small-scale study plots in irrigation Block B3. Depth to groundwater is from PZ-SAGON, and applied water is the volume applied to Block B3 divided by the area of Block B3. 95
Figure 57. Cumulative groundwater elevation change and applied water during for 2007 small-scale study plots between March 1, 2008 and October 31, 2008. 96

Figure 58. Cumulative groundwater elevation change and applied water during for 2007 small-scale study plots between March 1, 2009 and October 11, 2009..... 96

EXECUTIVE SUMMARY

GeoSystems *Analysis*, Inc., in conjunction with the University of Arizona, Office of Arid Lands Studies is conducting a 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 Program.

This report presents task activities and results for calendar year 2009 (Year 4) which consisted of the following activities:

1) Task 8: Continued monitoring small-scale field study plots established in 2007 and 2008 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) 2007 Mixed cottonwood-willow test plots—Shallow, frequent irrigation (application of 5.5 cm of water approximately once per week throughout the growing season) vs. deep, infrequent irrigation (application of 22 cm of water approximately once per month throughout the growing season).
   b) 2008 Goodding's willow test plots—Shallow, frequent irrigation (application of 7 cm of water approximately once per week throughout the growing season) vs. deep, infrequent irrigation (application of 21 cm of water approximately once per three weeks throughout the growing season).
2) Task 9: Conducted additional small-scale field studies at Cibola NWR Field 51 to evaluate seeding rate effects on germination, establishment, and growth of hydroseeded Goodding's willow for one growing season. Nominal seeding rates were prescribed at 540, 1,150, and 1,680 pure live seeds per square meter.

KEY RESULTS SUMMARY

Key findings from 2009 study activities include the following:

2007 Small-scale Study Plots:

- Fremont cottonwood has maintained dominance of crown cover in the small-scale study plots. Crown cover of cottonwood increased from 57% in October 2008 to 70% in October 2009. Crown cover of saltcedar remained approximately constant at 12% during that time period. Crown cover of other non-seeded species combined decreased from 30% to 16%.
- Fremont cottonwood canopy cover was approximately double that of saltcedar after three growing seasons. Canopy cover of cottonwood increased from 60% to 72% between October 2008 and October 2009. Canopy cover of saltcedar increased from 36% to 37%.
- Overall mortality of Fremont cottonwood and saltcedar was 9.0% and 10.6%, respectively, between October 2008 and October 2009. Mortality was higher for smaller trees.

- Despite very high tree densities, mortality was observed for only three (0.8%) cottonwoods and no saltcedar greater than 150 cm tall at the onset of the growing season.
- Generally, Fremont cottonwood growth rates in 2009 were no longer superior to those of saltcedar. However, height dominance of cottonwood remains.
- Fremont cottonwood mortality was greater for shallow, frequent irrigation, whereas saltcedar mortality was greater for deep, infrequent irrigation. Growth rates of Fremont cottonwood were unaffected by irrigation treatment, whereas growth rates of small (<100 cm) saltcedar were greater for shallow, frequent irrigation. These results indicate that deep, infrequent irrigation might promote long-term dominance of cottonwood over saltcedar at this site.
- As for the 2008 growing season, soil water depletion was minimal at depths greater than 46 cm bgs. This indicates that established trees are likely utilizing groundwater.

2008 Small-scale Study Plots:

- Saltcedar has maintained dominance of crown cover in the 2008 small-scale study plots. Crown cover of saltcedar increased from 25% in September 2008 to 44% in October 2009. Crown cover of Goodding's willow increased from 2% to 9% during that time period. Crown cover of other non-seeded decreased during that time period.
- Canopy cover of saltcedar increased from 45% in September 2008 to 78% in October 2009. Canopy cover of Goodding's willow increased from 7% to 19% during that time period. Canopy cover of grass and sedge species increased slightly, whereas canopy cover of non-seeded shrubs and forbs decreased.
- Goodding's willow growth rates were superior to those of saltcedar across tree heights.
- Goodding's willow density remains much lower than saltcedar density, at an overall average of 6.4 stems per square meter compared to 30.8 stems per square meter for saltcedar.
- Overall mortality of Goodding's willow and saltcedar was 31% and 40%, respectively, between October 2008 and October 2009. Mortality was higher for smaller Goodding's willow, whereas saltcedar mortality did not differ across tree heights.
- For smaller Goodding's willow (<50 cm) and intermediate saltcedar (50.5-100 cm) mortality was greater for shallow, frequent irrigation. For both species, growth rates were typically greater for deep, infrequent irrigation. These results indicate that neither irrigation regime will promote out-competition of saltcedar by Goodding's willow.

Key findings from the 2009 Goodding's willow small-scale study plots are the following:

- The seeding success rate (established trees per pure live seed) for Goodding's willow was approximately 1.6% compared to 0.4% and 0.9% for hydroseeding of Goodding's willow onto furrowed plots during 2007 and 2008 field studies, respectively.
- The resulting average Goodding's willow density was 17.5 trees per square meter for all seeding rates combined.

- Higher seeding rates resulted in increased tree density, with no reduction in establishment rates for higher seeding rates.
- The increased establishment of Goodding's willow can be attributed to:
    - Aggressive application of grass-specific herbicide reduced grass competition effects during the establishment phase.
    - Saltcedar establishment was greatly reduced for 2009 studies, at 5.6 per square meter, compared to 25.0 and 51.3 per square meter for 2007 and 2008 studies, respectively, after the first growing season. This is most likely due to saltcedar clearing in the vicinity of Field 51 and around the irrigation canal

Four years of study on the feasibility of using native seeds for riparian restoration indicate the following conclusions:

- Fremont cottonwood, Goodding's willow, and coyote willow seed can be stored cleaned or un-cleaned in freezers for over two years while retaining viability of greater than 80%.
- The optimal seeding method for Fremont cottonwood and Goodding's willow is hydroseeding on to furrows.
- Fremont cottonwood and Goodding's willow should be seeded separately to avoid cottonwood dominance of seeded areas.
- When co-established, Fremont cottonwood dominates volunteer saltcedar.
- Establishment of undesirable species (primarily saltcedar and grasses) can be controlled by reducing the seed bank on and adjacent to revegetation areas and by spraying revegetation areas with grass-specific herbicide during the first growing season.
- Infrequent, deep irrigation appears to enhance survival of Fremont cottonwood and Goodding's willow compared to frequent, shallow irrigation.
- Large-scale direct seeding of Fremont cottonwood would likely result in cost reductions of over 60% compared to mass transplanting.
- Large-scale direct seeding of Goodding's willow would likely result in cost reductions of over 40% compared to mass transplanting.

Despite the success of seed storage and seedling establishment in small-scale study fields, additional work should be completed prior to implementation of direct seeding for large-scale revegetation. Specifically:

- Continued monitoring of established small-scale plots—additional vegetation monitoring will allow for long-term observations of vegetation success.
- Large-scale demonstration plot—a large-scale seeding demonstration would allow determination of direct seeding costs and scaling effects on direct seeding success.

1.0 INTRODUCTION

This report documents activities conducted by GeoSystems *Analysis*, Inc. (GSA) for Contract No. 06CR308057, *Feasibility Study Using Native Seeds in Restoration*, *California-Arizona-Nevada*, during calendar year 2009. The task plan for the 2009 study year is described in the Year 4 Research Plan (GSA 2009a).

The feasibility study consists of a 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 potential for reduced planting costs compared to 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, as described in the annual study plans (GSA 2006, 2007a, 2008a, 2009a). 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.
- 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.

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

- 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.

Year 4 (2009) Small-scale Studies

- Task 8: Continued monitoring of existing Task 5 small-scale field study plots previously established at Cibola NWR Field 51.
- Task 9: Conducted additional small-scale field studies at Cibola NWR Field 51 to evaluate seeding rate effects on the establishment of hydroseeded Goodding's willow for one growing season.

Task 8 study methods and results are presented in Section 2 for the 2009 growing season. Task 9 methods and results for one growing season are presented in Section 3. Field 51 subsurface monitoring methods and results are presented in Section 4. Final results for germination studies (Tasks 1 and 7) were presented in the 2008 Annual Report (GSA 2009b). Initial Task 5 (small-scale field studies) results were presented in the 2007 Annual Report (GSA 2008b). Results for Tasks 2 through 4 are presented in the 2006 and 2007 annual reports (GSA 2007b, 2008b). Detailed site characterization work conducted as a portion of Task 6 at Field 51 was presented in the site characterization memorandum (GSA 2008c).

2.0 TASK 8: CONTINUED MONITORING OF SMALL-SCALE FIELD STUDIES AT CIBOLA NATIONAL WILDLIFE REFUGE

2007 Small-scale Study Plots

During 2007, 36 small-scale field plots of mixed Fremont cottonwood, Goodding's willow, and coyote willow seeding were established. The objective was to determine the effectiveness of seeding method (seed cleaning and seed-application technique) and irrigation techniques 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 1). Additional detail, including study approach and results from the 2007 growing season are presented in the 2007 Annual Report (GSA 2008b). A range of riparian species and saltcedar densities were established in the 2007 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 were the focal species of continued monitoring efforts during 2008 and 2009 on the 2007 small-scale study plots.

Results from the 2008 growing season are detailed in the 2008 Annual Report (GSA 2009b). Monitoring during the 2008 growing season indicated higher survival and growth rates of Fremont cottonwood compared to saltcedar. Additionally, watering frequency of once per three weeks did not result in greater soil water depletion at 1 m below ground surface (bgs) or increased mortality rates compared to an irrigation frequency of once per week.

Monitoring in 2009 had the following objectives:

- Determine growth and survival rates for seeded riparian species and volunteer saltcedar plants during a third growing season.
- Quantify additional establishment of native and introduced species.
- Determine the effects of two different irrigation regimes to allow either 1× or 4× depletion on cottonwood and saltcedar growth and survival. Water was applied at a rate of 60% of reference evapotranspiration (ET_0).

2008 Small-scale Study Plots

During 2008, additional small-scale field plots of Goodding's willow were implemented. The objective was to determine the effectiveness of seeding method (seed cleaning and seed-application technique) on the establishment and growth of Goodding's willow, provided removal

of potential competition with Fremont cottonwood and enhanced weed control compared to 2007 plots. These 6-m by 12 m plot studies were implemented on the east end of Cibola NWR Field 51, adjacent to 2007 plots (Figure 2). Additional detail, including study approach and results are presented in GSA (2009b).

A range of densities were established for Goodding's willow and saltcedar in the small-scale study plots, with approximately five times higher density of saltcedar than Goodding's willow. Continued monitoring in 2009 pursued the following objectives:

- Determine growth and survival rates for seeded Goodding's willow and volunteer saltcedar plants during a second growing season.
- Quantify additional establishment of native or introduced trees.
- Determine the effects of two different irrigation regimes to allow either 1× or 3× depletion on Goodding's willow and saltcedar growth and survival. Water was applied at a rate of 80% of ET_0, similar to the water application for 2007 study plots during the 2008 growing season (GSA 2009b).

Finally, GSA continued collection and analysis of soil water content and groundwater elevation data. Methods and results are provided in Section 4.

2.1 Technical Approach

GSA managed irrigation during the 2009 growing season, and conducted vegetation surveys following protocols detailed in the 2007 Annual Report (GSA 2008b). Study methods are summarized below.

2.1.1 Irrigation Water Application

As described in the Year 4 Research Plan (GSA 2009a), irrigation treatments in 2009 were used to look at two disparate irrigation regimes for each set (2007 or 2008) of study plots. For a given set (i.e. either 2007 mixed riparian small-scale study plots or 2008 Goodding's willow small-scale study plots) of small-scale study plots, the objective was to apply similar depths of irrigation water over the year under the two regimes, but to allow two soil water depletion levels in the rooting zone between irrigation events. Irrigation block layout is depicted in Figure 3.

For 2007 study plots, the target irrigation rate was 60% of reference evapotranspiration (ET_0) (i.e. a crop coefficient (K_c), of 0.6 was assumed). Thus, the evapotranspiration (ET) rate for the 2007 plots was estimated by Equation 2.1:

$$ET = K_c \times ET_0 \qquad 2.1$$

Half of the 2007 study plots (shallow irrigation Blocks A1 and A2) were irrigated when 5.5 cm of ET, as estimated by Equation 2.1, had accumulated since the previous irrigation event. The other half of the plots (deep irrigation Blocks B1 and B2), were irrigated when 22 cm of ET, as estimated by Equation 2.1, had accumulated since the previous irrigation event. During the summer, the irrigation frequencies required based on these guidelines were approximately once per ten days (A blocks) or once per five weeks (B blocks).

For 2008 study plots, the target irrigation rate was approximately 80% of ET_0 (K_c of 0.8). Half of the 2008 study plots (shallow irrigation Block A3) were irrigated when 7 cm of ET, as estimated by Equation 2.1, had accumulated since the previous irrigation event. The other half of the plots (deep irrigation Block B3), were irrigated when 21 cm of ET, as estimated by Equation 2.1, had accumulated since the previous irrigation event. During the summer, the irrigation frequencies required based on these guidelines were approximately once per week (A Blocks) or once per three weeks (B Blocks).

Irrigation management by GSA followed this schedule between March 19, 2009 and October 31, 2009. The irrigation schedule was interrupted in mid-May, during which vegetation surveys were being implemented in 2007 and 2008 plots.

One irrigation block was watered at a time (i.e. A1, A2, A3, B1, B2, or B3). As described in the 2007 Annual Report (GSA 2008b), a totalizing flow meter was installed adjacent to the irrigation pump and was used to guide irrigation application. When the flow meter malfunctioned, prescribed irrigation volumes were applied based on flow rates and irrigation duration required for previous irrigation events.

Prior to each irrigation event, the cumulative flow volume was recorded from the flow meter display, and the flow volume was monitored until the required volume of water was applied. The irrigation protocol in 2009 was implemented as described in the 2007 Annual Report (GSA 2008b). The prescribed irrigation depth for B blocks was sometimes greater than the combined daily infiltration and surface storage capacity of the plot area. Therefore, irrigation water application to the B blocks sometimes occurred over a period of two days for each irrigation event.

2.1.2 Vegetation Surveys

2009 vegetation monitoring of the 2007 and 2008 small-scale study plots consisted of canopy cover measurements and quadrat monitoring early and late in the growing season (i.e. May and October, 2009). A stratified random design of monitoring was used, 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 (for 2007 small-scale plots in this case) is shown in Figure 4. Point transects were monitored to determine crown and canopy cover, and quadrats were monitored to determine tree density, height, growth rate, and survival. Three 0.5-m by 1.0-m quadrats and three transects along one edge of each quadrat, traversing the plot from north to south, were monitored.

Because root surveys were previously implemented in the 2007 small-scale plots, repeat measurements could not be made at ten of the quadrats. For these plots, only un-disturbed quadrats and transects were used for vegetation monitoring. No root surveys were conducted in the 2008 small-scale study plots. Therefore, previously-monitored quadrats and transects in these plots were used for vegetation monitoring. The number of quadrats per 2008 study plot was reduced to three from nine during 2008 in order to mimic the study design of the 2007 small-scale plots.

To determine growth rates for individual trees and mortality of Fremont cottonwood, Goodding's willow, and saltcedar, GSA monitored individual trees within survey quadrats. Initial data for the 2007 small-scale plots were collected in May 2008, when every Fremont cottonwood, Goodding's willow, coyote willow, and saltcedar within each quadrat was 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 and during subsequent growing seasons. During 2009, an early-season survey was conducted in May to obtain initial tree heights for the 2009 growing season. The end-of-season survey was conducted in October, 2009. Individual tree tagging for 2008 plots was implemented in May, 2009, and the end-of-season survey was conducted during October, 2009.

As for 2007 and 2008 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 (denoted "G/S"), 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 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 2.2:

$$Cover = (x / n) \times 100\% \qquad 2.2$$

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 Analyses

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 (i.e. Figure 4). 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.

Within quadrats, the 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. Due to the abundance of saltcedar plants in the 2008 small-scale plots, saltcedar plants were only tagged and counted for

half of each quadrat.

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). All other species were monitored by assigning a relevé index and estimating 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 allow for calculations of growth rates. The growth rate was determined via equation 2.3:

$$GrowthRate = \frac{(h - h_0)}{t} \qquad 2.3$$

Where h is the height measured during the fall survey (between October 3 and October 10, 2009), and h_0 is the height measured in the spring survey (between May 18 and May 20, 2009), and t is the time in days between measurements. t ranged from 136 to 145 days.

Statistical Analyses

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, seed application method, surface irrigation method, and seeding rates were analyzed to assess the effects of the original treatments, described in the 2007 Annual Report (GSA 2008b) on:

- 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 ANOVA model. As a result least-squared means for different seeding rates were not available in the results. Direct

(increasing) or inverse (decreasing) relationships were calculated and the P-values associated with those relationships are presented.

ANOVAs were also constructed to assess the effects of initial tree height (during May 2009 survey), irrigation treatment (A, shallow or B, deep, as described previously), surface irrigation method (furrow or border-strip irrigation), cottonwood and saltcedar crown cover, and cottonwood and saltcedar stem density on cottonwood and saltcedar growth rates. The overall crown cover from each plot and the average stem density for the three quadrats were used as independent variables. In the ANOVA results 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 an α of 0.05.

Additionally, graphical results are presented for the with 95% confidence intervals on the mean. For selected comparisons, Student's t-tests were conducted to determine significant differences with an α of 0.05.

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

2.2.1 2007 Small-scale Plots: Rainfall and Irrigation Water Application

Rainfall data for 2009 are provided in Table 1. Irrigation event application depths are shown in Table 2 and Table 3 for the A and B irrigation blocks, respectively. The total depth of applied water for the 2009 growing season (March 19 through October 31) averaged 132 cm for the A blocks. Based on ET_0 (calculated via the Penman-Monteith equation (FAO 1998)) and rainfall at the nearby Cibola weather station, the applied water to the A Blocks correlates to approximately 61% of ET_0, compared to 80% of ET_0 applied during the 2008 growing season (GSA, 2009b). The total depth of applied water averaged 129 cm for the deep irrigation B blocks correlated to approximately 60% of ET_0 compared to 85% of ET_0 applied during the 2008 growing season.

2.2.2 Vegetation Monitoring: 2007 Small-scale Plots: Treatment Variables

2009 ANOVA results for the 2007 small-scale study treatments are provided in Table 4 and Table 5 for seeded and non-target species, respectively. These results evaluate the effects of initial seeding and irrigation methods on plant establishment and cover after three growing seasons (i.e. May 2007 through October 2008). Treatment effects are discussed in detail below.

Crown and canopy cover of Fremont cottonwood in sprinkler-irrigated plots were lower compared to no sprinkler irrigation, similar to 2007 and 2008 surveys, despite no difference in establishment rates between the irrigation treatments (Table 5). Average cottonwood tree height

was no longer significantly lower in sprinkler-irrigated plots (Table 5), indicating that the slower tree stem growth rates initially observed in sprinkler-irrigated plots recovered after three growing seasons. Canopy cover of saltcedar was also lower in sprinkler-irrigated plots; however, crown cover of this species did not differ between these treatments (Table 6). Crown and canopy cover of grasses continue to be greater in sprinkler-irrigated plots (Table 6), likely due to reduced growth of cottonwood and saltcedar.

Cottonwood crown and canopy cover and tree densities were highest for hydroseeded, un-cleaned seed compared to broadcast or hydroseeded, cleaned seed. However, ANOVA least-squared means were not significantly different at P=0.05 (Table 5). Seed treatment did not result in significant differences within volunteer saltcedar or shrubs and forbs (Table 6).

Furrow irrigation continued to result 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. Average cottonwood height was no longer significantly greater in furrow-irrigated plots compared to border-strip irrigation after three growing seasons (Table 5). Surface irrigation methods did not significantly affect saltcedar establishment or growth (Table 6), whereas grass and sedge cover was greater in border-strip irrigated plots compared to furrow-irrigated plots (Table 6).

Lower cottonwood density, crown and canopy cover were observed in plot position 1 (northern portion of Field 51, Figure 1) compared to plot position 2 or 3 (central and southern portions of the field, respectively, Figure 1, Table 5). Conversely, saltcedar crown cover and growth were greatest for plot position 1 (Table 6). These results may be due to higher subsurface salinity observed on the northern side of the field (GSA 2008c).

2.2.3 Vegetation Monitoring 2007 Small-Scale Plots: Long-term Trends

ANOVA results for Fremont cottonwood and saltcedar growth rates between the spring and fall 2009 monitoring events are provided in Table 6; summary charts for long-term vegetation trends between 2007 and 2009 are provided in Figure 5 through Figure 7 and discussed in detail below. All field data are provided in Appendix B. Due to minimal establishment of willow species in 2007 and high mortality of willow in 2008, results are only presented for cottonwood and saltcedar. Growth rate data are available only for tagged plants (Section 2.1.2). Therefore, many saltcedar plants were not included in the growth analysis because their stems were not sturdy enough to support identification tags. By monitoring the total number of trees in each quadrat, non-tagged trees within quadrats were included in plant density and overall species mortality analyses.

Average Fremont cottonwood crown cover across all plots increased from 57.0% in fall 2008 to 70.3% in fall 2009 (Figure 5), and; canopy cover increased from 60.0% to 71.5% during that time period (Figure 6). Saltcedar crown cover slightly increased from 12.0% in fall 2008 to 12.3% in fall 2009 (Figure 5) with a corresponding increase in canopy cover from 36.0% to 37.0% (Figure 6). Despite initially-greater canopy cover of saltcedar after the first (2007) growing season, both crown and canopy cover of cottonwood have exceeded saltcedar since May 2008, indicating superior growth rates and survival for Fremont cottonwood compared to saltcedar.

The overall average Fremont cottonwood tree density slightly decreased from fall 2008 to fall 2009 (12.8 stems per m^2 to 11.9 stems per m^2), and the density of saltcedar decreased from 14.4 stems per m^2 to 12.8 stems per m^2 (Figure 7). Overall mortality decreased from the 2008 to 2009 monitoring period for both species (Figure 8).

Mortality of both cottonwood and saltcedar was greatest for plants less than 50 cm (Figure 9). Mortality for tagged saltcedar less than 50 cm tall at the beginning of the growing season was approximately 22% and mortality for cottonwood less than 50 cm tall was 70% (Figure 9). Most saltcedar less than 50 cm tall were not tagged, and therefore are not represented in these percentages. No mortality was observed for saltcedar plants taller than 150 cm during the 2009 growing season and only three Fremont cottonwoods greater than 150 cm tall died during the 2009 growing season (n = 67 and 374, for saltcedar and cottonwood, respectively). Saltcedar mortality was greater than that of cottonwood for trees less than 50 cm (again, not considering un-tagged tree mortality); however, cottonwood mortality was greater than that of saltcedar for trees between 50 and 100 cm tall at the beginning of the growing season.

In general, Fremont cottonwood and saltcedar growth rates were not significantly different (Figure 10 and Figure 11). Growth rates for cottonwood and saltcedar increased with higher initial tree height (Table 6), likely due to greater light and soil water availability.

Combined grass and sedge crown cover decreased from fall 2008 to fall 2009 due to senescence over the winter and the continued growth of cottonwood and saltcedar (Figure 5). Grass and sedge canopy cover remains high (Figure 6), indicating abundance of these species in the understory. Crown cover of shrubs and forbs (S/F) decreased from 9% in fall 2008 to 0% in fall 2009 (Figure 5), likely due to larger trees inhibiting annual recruitment. Canopy cover also decreased during from 24% to 2% during that time period (Figure 6).

2.2.4 Vegetation Monitoring: 2007 Small-scale Plots: Irrigation Treatment Effects

Mortality between September 2008 and September 2009 was significantly affected by irrigation treatments. Specifically, Fremont cottonwood mortality was greater under the shallow, frequent irrigation treatment (A) than the deep, infrequent irrigation treatment (B) (Figure 12). The opposite trend was observed for saltcedar, i.e. higher mortality of saltcedar was observed for the B irrigation treatment than A (Figure 12). Mortality differences due to irrigation treatment were not observed for different size classes of trees during the 2009 growing season (Figure 13). It is possible that a significant portion of mortality occurred during the winter prior to the May survey, and was therefore not accounted for between the May and October 2009 surveys.

Fremont cottonwood growth rates were unaffected by irrigation treatment for any tree size classes (Figure 14). However, when accounting for other treatments, ANOVA results showed higher cottonwood growth rates for the B irrigation treatment than for A (Table 6). Growth rates of saltcedar less than 100 cm tall during the May 2009 surveys were also significantly reduced for deep, infrequent irrigation compared to shallow, frequent irrigation (Figure 15). Overall, saltcedar growth rates were not significantly affected by irrigation treatment (Table 6).

ANOVA analysis indicated greater growth rates for Fremont cottonwood under the border-strip irrigation method than furrow (Table 6).

2.2.5 Vegetation Monitoring: 2007 Small-scale Plots: Competition Effects

No trends were observed for the effects of Fremont cottonwood crown cover, Fremont cottonwood stem density, or saltcedar crown cover on Fremont cottonwood growth rates (Table 6). However, cottonwood growth rates were significantly reduced at saltcedar stem densities greater than 30 cm/m^2. Greater initial cottonwood tree height also resulted in higher cottonwood growth rates (Table 6).

Saltcedar growth rates were not significantly affected by Fremont cottonwood stem density, or by saltcedar crown cover. However, saltcedar growth rates decreased if Fremont cottonwood crown cover was greater than 50% (Table 6). Higher saltcedar growth rates were observed with high saltcedar stem density. As for Fremont cottonwood, a greater initial height of saltcedar resulted in higher growth rates.

2008 results indicated that beyond an intermediate Fremont cottonwood tree density of approximately ten to fifteen per m^2 (approximately one per square foot), the average cottonwood crown cover was above 60%, with less than 20% saltcedar crown cover after two growing seasons (GSA 2009b). As shown in Figure 16, saltcedar crown cover was less than 60% in all plots after three growing seasons, whereas Fremont cottonwood crown cover is greater than 50% in 29 of 36 plots. At Fremont cottonwood stem densities of over 20 per m^2, cottonwood crown cover always exceeded than that of saltcedar, and at cottonwood stem densities of over 25 per m^2, saltcedar crown cover was always less than 10%. These results are still preliminary, and extended monitoring is recommended to assist in the development of a recommended Fremont cottonwood seeding and establishment rate.

2.3 Results: Continued Monitoring of 2008 Small-scale Study Plots

2.3.1 2008 Small-scale Plots: Rainfall and Irrigation Water Application

Irrigation event application depths are shown in Table 7 and Table 8 for irrigation block A3 (shallow irrigation) and B3 (deep irrigation), respectively. The total depth of applied water for the 2009 growing season (March 19 through October 31) was 161 cm for Block A3. Based on estimated ET_0, the applied water to block A3 was approximately 74% of ET_0. The total depth of applied water averaged 147 cm for Block B3, correlating to approximately 68% of ET_0.

2.3.2 Vegetation Monitoring: 2008 Small-scale Plots: Treatment Variables

2009 ANOVA results for the 2008 small-scale study treatments are provided in Table 9 for seeded and non-target species. These results evaluate the relationship between initial seeding and irrigation treatments on plant establishment and cover after two growing seasons (i.e. May 2008 through October 2009). Treatment effects are discussed in detail below.

Although Goodding's willow crown cover did not vary with seeding methods, both canopy cover and tree densities were significantly higher for hydroseeded, un-cleaned seed compared to broadcasted or cleaned seed (Table 9). Variations in seed treatment did not accompany significant differences for volunteer saltcedar or shrubs and forbs (Table 9). Furrow irrigation

resulted in significantly greater canopy cover of Goodding's willow compared to border-strip irrigation (Table 9). No other results varied significantly between irrigation methods.

Interaction results show that hydroseeding onto furrows resulted in greater Goodding's willow density than broadcasting on to either leveled (border) or furrowed plots (Table 9). Hydroseeding onto furrows resulted in significantly-higher canopy cover than for broadcast seeding onto border plots. Saltcedar crown cover was lowest in plots that were furrowed and hydroseeded. Other interactions were not significant at P=0.05.

No results were significantly-correlated with seeding rates (Table 9). The actual seeding rates varied only between 1,500 and 1,850 pure live seeds (PLS) per m^2, so effects of large variation in seeding rates cannot be effectively analyzed based on the 2008 plots.

2.3.3 Vegetation Monitoring: 2008 Small-scale Plots: Long-term Trends

ANOVA results for Goodding's willow and saltcedar growth rates between the spring and fall 2009 monitoring events are provided in Table 10; summary charts for long-term vegetation trends between 2007 and 2009 are provided in Figure 17 through Figure 26 and discussed in detail below. All field data are provided in Appendix C. As for 2007 study plots, the 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 Goodding's willow crown cover across all plots increased from 2.4% in fall 2008 to 8.6% in fall 2009 (Figure 17), and canopy cover increased from 6.7% to 19.5% in that time period (Figure 18). Saltcedar crown cover increased from 24.9% in fall 2008 to 44.0% in fall 2009 (Figure 17) and canopy cover increased from 44.5% to 77.7% (Figure 18). Shrub and forb crown cover remained at approximately 40% (Figure 17), whereas canopy cover decreased from 87.7% to 61.7% (Figure 18). Although grass and sedge crown cover greatly declined from 26.8% to 4.3% (Figure 17), canopy cover increased slightly from 36.2% to 40.0% (Figure 18).

The overall average Goodding's willow tree density slightly decreased from fall 2008 to fall 2009 (9.3 stems per m^2 to 6.4 stems per m^2,), whereas the density of saltcedar decreased from 51.3 stems per m^2 to 30.8 stems per m^2 (Figure 19). These changes correspond to overall mortality of approximately 30% and 40% for Goodding's willow and saltcedar, respectively (Figure 20).

Mortality was greater for smaller Goodding's willow trees (Figure 21). Although mortality appears similar across tagged saltcedar tree heights (Figure 21), it is likely that small, un-tagged saltcedar experienced higher mortality based on the overall reductions in stem density. No mortality was observed for Goodding's willow or saltcedar taller than 100 cm during the 2009 growing season (*n* of 44 and 330 for Goodding's willow and saltcedar, respectively). Of tagged trees, Goodding's willow mortality was greater than that of saltcedar for trees between 0 and 50 cm tall at the beginning of the growing season (without considering non-tagged saltcedar, Figure 21). No difference in mortality was observed between species for trees greater than 50 cm tall at the beginning of the growing season.

For all size classes in both A and B irrigation treatments, Goodding's willow growth rates were greater than those of saltcedar (Figure 22 and Figure 23). As observed in the 2007 plots, growth rates for Goodding's willow and saltcedar increased with greater initial tree height (Table 10).

2.3.4 Vegetation Monitoring: 2008 Small-scale Plots: Irrigation Treatment Effects

Mortality between September 2008 and September 2009 was significantly affected by irrigation treatments. Specifically, both Goodding's willow and saltcedar mortality was greater under the shallow, frequent irrigation treatment (Block A3) than the deep, infrequent irrigation treatment (Block B3) (Figure 20). The higher mortality for Goodding's willow for irrigation treatment A appears to be a result primarily of trees less than 50 cm tall at the beginning of the 2009 growing season (Figure 24).

In addition to reduced mortality, growth rates of both Goodding's willow and saltcedar were significantly higher for the B irrigation treatment, specifically for trees between 50 and 150 cm tall at the beginning of the growing season (Figure 25). This result is supported by the ANOVA analysis for saltcedar, which indicate higher growth rates for the B irrigation treatment than for A (Table 10). Goodding's willow growth rate was not significantly affected by irrigation block according to the ANOVA analysis.

ANOVA analysis did not identify significant differences in growth rates of Goodding's willow or saltcedar between border-strip and furrow irrigation (Table 10).

2.3.5 Vegetation Monitoring: 2008 Small-scale Plots: Competition Effects

Goodding's willow growth rates were higher with increased Goodding's willow crown cover and lower Goodding's willow stem density (Table 10). Goodding's willow growth rates were not significantly affected by saltcedar crown cover or stem density. Taller initial tree height resulted in higher growth rates.

Saltcedar growth rates were not significantly affected by Goodding's willow density or saltcedar crown cover (Table 10). Greater than 20% Goodding's willow crown cover reduced saltcedar growth rates. Saltcedar density appeared to affect growth rates, but trends are not apparent. As indicated by the Goodding's willow data, greater initial saltcedar height accompanied higher growth rates.

2009 results indicate that Goodding's willow growth rates are greater than those of saltcedar (Figure 22 and Figure 23). Additionally, overall mortality of saltcedar was greater for saltcedar than Goodding's willow between September 2008 and October 2009 (Figure 20). However, the much lower initial density of Goodding's willow compared to saltcedar in 2008 plots (Figure 19) has resulted in continued dominance of crown and canopy cover by saltcedar (Figure 17 and Figure 18, respectively). Figure 26 shows that greater saltcedar mortality was observed over the dormant season (i.e. stems that did not continue growing at the onset of the second growing season) compared to the growing season. The opposite trend was observed for Goodding's willow (i.e. the majority of mortality occurred between the spring and fall 2009 surveys, during the active growing season).

3.0 TASK 9: ADDITIONAL SMALL-SCALE STUDY PLOTS FOR GOODDING'S WILLOW

The primary objectives of the 2009 Goodding's willow small-scale study were to evaluate the repeatability of Goodding's willow establishment observed in the 2008 small-scale study plots, and assess the viability of seed that had been stored in excess of one year. Additionally, it was desired to determine the potential effectiveness of reduced seeding rates in conjunction with repeated treatment with grass-specific herbicide to reduce grass competition during the initial growth period. The only seeding and irrigation method investigated was hydroseeding onto furrows. Goodding's willow seeding was implemented at three rates. The baseline rate was 1,600 PLS/m^2, as for 2008 study plots, and reduced design seeding rates of 540 and 1,080 PLS/m^2 were also implemented.

3.1 Technical Approach

2009 Goodding's willow small-scale studies were implemented to evaluate three different seeding rates of Goodding's willow and assess saltcedar establishment. Gooding's willow was hydroseeded at three different rates onto furrowed plots at Cibola Field 51. In addition, an aggressive program of grass-control using grass-specific herbicide was implemented. Small-scale study variables are presented in Table 11. Additional detail and reasoning are discussed in the Year 4 Research Plan (GSA 2009a) and summarized below.

The seeding treatment of "un-cleaned, hydroseed" was selected because this method showed the highest establishment rate in the 2007 and 2008 small-scale study plot results. Cleaned seed did not result in higher establishment compared to un-cleaned seed, and requires additional labor. Therefore hydroseeding of un-cleaned seed was used as the seeding treatment for the 2009 small-scale study plots.

The furrow surface irrigation treatment was selected because this the 2007 and 2008 small-scale study plots results indicated that that furrows promote more even distribution of seedlings compared to border-strip irrigation. Therefore, all plots were furrowed for the 2009 small-scale study.

Three different seeding rates were investigated, with a baseline seeding rate of 1,600 PLS/m^2, approximately equal to that applied for 2008 Goodding's willow small-scale study plots. Plots were also seeded at a target of 1/3 and 2/3 of that rate (540 and 1,080 PLS/m^2, respectively). The actual field seeding rate was estimated based on the duration of application from the

hydroseeder, as detailed below. The estimated seeding rates for the three seeding rate levels were 580, 1150, and 1680 PLS/m^2.

3.1.1 Plot Design and Implementation

The small-scale field study used a randomized design in which four replications of each seeding rate were randomly assigned to constructed plots (Figure 27.) Due to erroneous application by the hydroseeder, only three replications were seeded at the highest seeding rate level. The un-seeded plot was excluded from data analysis.

The 2009 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 and 2008 small-scale studies. Soil berms were placed between plots, with a total buffer width of approximately 1 m (3 feet).

3.1.2 Seed Collection, Treatment, and Application

Seed applied for 2009 studies was collected during 2007 and 2008, and stored in freezers until transport to Cibola NWR. As detailed in the 2008 Annual Report (GSA 2009b), Goodding's willow seed was collected from the Ahakhav Tribal Preserve and Cibola NWR. Seed was allowed to dry in a laboratory 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. Incubator germination studies were conducted for each seed source to determine the pure live seed (PLS) percentage and amount of seed needed for the small-scale studies.

Sufficient seed was obtained 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. On the day of seeding in small-scale plots (June 4, 2009), 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.

Seed was mixed and 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. 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 PLS was placed in the hydroseeder mixing

tank, and the application time required to apply the desired PLS rate to each plot was estimated based on the total time required to empty the hydroseed tank. The actual time of seed application in each plot was noted in field books, as was the total duration of seed application. The seeding rate for a given plot was then calculated from Equation 3.1:

$$\frac{PLS}{ft^2} = \frac{\frac{T_p}{T_t}(S_t)}{A} \qquad 3.1$$

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.

3.1.3 Irrigation Design

Furrows were ripped in an east-west orientation on 1.02 m (40 inch) centers, 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. Additional gated pipe extensions were added to the existing laterals traversing the southern 2008 Goodding's willow study plots (deep irrigation Block B3). The surface irrigation system design allows for minimal variation between plots in order to reduce potential bias in results due to water availability.

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.

Because laterals were connected to those in existing plots, irrigation was controlled by closing gates in Block B3 and opening gates for the 2009 plots. However, leaks were prevalent in Block B3 (southern 2008 study plots) even when gates were closed. Therefore, the actual applied water volumes for the 2009 small-scale study plots (Section 3.2.1) are likely to be overestimated.

3.1.3 Vegetation Monitoring

Vegetation monitoring consisted of canopy cover measurements and harvested quadrats. As for the 2007 and 2008 plots, monitoring followed a stratified random design and one transect was located randomly within each third of the plot (plot divisions based on distance from the gated pipe). To provide greater spatial coverage for plant establishment data, six quadrats were located along each transect (compared to three for 2007 study plots), with north-south locations randomized along each transect.

Vegetation success during the fall for the Goodding's willow small-scale field studies was monitored using point transects to determine crown and canopy cover and quadrats to determine stem density and height. Although plant growth continued into October, vegetation data were collected in September 2009, after approximately three and a half months of growth to facilitate growth comparison with previous field studies.

Statistical Analyses

Statistics were analyzed via Student's t-tests for treatment variable effects on:

- 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.

Arithmetic means were compared via Student's t-tests with a with an α of 0.05 to determine significant differences between treatments. Graphical results are presented with 95% confidence intervals from the mean.

3.2 Results: 2009 Goodding's Willow Small-scale Field Study

3.2.1 2009 Small-scale Plots: Rainfall and Irrigation Water Application

Irrigation application for Goodding's willow plots during the 2009 growing season, as estimated by the flow meter, is shown in Table 12. The total depth of applied water was estimated as 291 cm, or approximately 216% of ET_0. However, as described previously, a significant portion of the water measured by the flow meter leaked into 2008 study plots. Therefore, the applied water to 2009 plots was less than 291 cm.

3.2.2 2009 Small-scale Plots: Treatment Variables

Results are provided in Table 13 and Table 14 and treatment effects are discussed in detail below. All field data are provided in Appendix D. Crown and canopy cover results are presented for Goodding's willow, saltcedar, combined shrubs and forbs, and combined grasses and sedges. Stem count (per m^2) and average height results are presented for only Goodding's willow and saltcedar.

Vegetation Summary

Goodding's willow stem density calculated from quadrat surveys ranged from 2 to greater than 40 per m^2, whereas the saltcedar stem density ranged from 0 to 9 per m^2. The average Goodding's willow stem density was approximately 17.5 per m^2, and the average saltcedar stem density was approximately 5.6 per m^2 (Figure 28). Additionally, even for the lowest seeding rate, the average Goodding's willow stem density was greater than that of saltcedar (Figure 29). Compared to 2008 plots, the density of saltcedar was reduced by approximately 75% (Figure 29). Also, average Goodding's willow establishment rates nearly doubled from 2008 study plots to 1.67% of PLS rates (Figure 30).

Despite higher density of Goodding's willow than saltcedar, crown cover of saltcedar was greater in over half of the study plots (Figure 31). Nonetheless, saltcedar crown cover was reduced by approximately half compared to 2008 study plots (GSA 2009b). Canopy cover of saltcedar was also greater than that of Goodding's willow in over half of the 2009 study plots, although the average cover of the two species did not differ significantly ($P>0.3$, Figure 32).

Average Goodding's willow and saltcedar height per plot is shown in Figure 33. Saltcedar height in the 2009 small-scale study plot fall survey averaged 59 cm compared to 45 cm for the 2008 plots (GSA 2009b) and 28 cm for the 2007 plots (GSA 2008b). Goodding's willow height after four months averaged 54 cm for 2009 plots compared to 33 cm for Goodding's willow in the 2008 plots. For a given seeding rate, the average height of Goodding's willow and saltcedar did not differ significantly (Figure 34).

After one growing season, mean crown cover of the 2009 small-scale study plots was dominated by volunteer shrubs and forbs (56%), with mean crown cover of Goodding's willow, saltcedar, and grasses and sedges ranging between 13% and 17% (Figure 35). As in the 2007 and 2008 field studies, Bermudagrass established immediately after irrigation. Grass growth was limited by repeated applications of Arrow 2EC (Arysta LifeScience, Tokyo, Japan) grass-specific herbicide during June, July, and August 2009. As a result, average grass and sedge canopy cover

for 2009 study plots averaged 29% (Figure 36) compared to 36% and 91% for the 2008 and 2007 study plots, respectively (GSA 2009b, GSA 2008b). Canopy cover of non-target shrubs and forbs in the 2008 small-scale study plots averaged 91% compared to 88% and 47% for the 2008 and 2007 study plots, respectively (GSA 2009b, GSA 2008b).

Seeding Rate Effects

Actual seeding rates in the plots varied from 560 to 1,740 PLS/m^2. Despite an approximate 3-fold increase in seeding rate from the low to high seeding rate, significant differences were not observed for Goodding's willow crown cover or canopy cover between treatments (Table 13). This could be due to the relatively short (3.5 month) growth period as the resulting tree density was significantly greater for the 1,685 PLS/m^2 compared to 1,150 or 579 PLS/m^2 (Table 14, Figure 29). No correlations were observed between seeding rate and seedling establishment (Figure 30, Figure 37), whereas seedling density was directly correlated with seeding rate (Figure 37), indicating that, in general, higher Goodding's willow seeding rates should result in greater seedling density.

No decline in Goodding's willow growth rates was observed with increasing seeding rate (Figure 34). This result indicates that competition was not observed between Goodding's willow trees during the first growing season, even at the highest seeding rate.

Increases in Goodding's willow seeding rates resulted in significant increases in crown cover for grasses and sedges and decreases in shrub and forb crown cover (Table 13). Reasons for these differences are not apparent but could include increased competition between the willows and the shrubs and forbs and less efficient application of herbicides with higher Goodding's willow establishment.

Saltcedar establishment was greatly-reduced in the 2009 study plots compared to the 2007 and 2008 study plots, such that native, seeded species outnumbered saltcedar after the first growing season for the first time. Removal of saltcedar along the main Cibola NWR Farm Unit irrigation canal and from the fields west of Field 51 cleared for LCR MSCP riparian vegetation likely resulted in reduced air- and water-borne seed sources.

4.0 SMALL-SCALE STUDY AREA SUBSURFACE MONITORING

A soils characterization of Cibola NWR Field 51 was conducted during 2006 and 2007, and a detailed presentation of methods and results is available in the Field 51 site characterization memorandum (GSA 2008c). Soil water content, temperature and salinity monitoring instruments were installed in the 2007 small-scale study plots during 2007. Additional water content instruments were installed in the 2008 Goodding's willow test plots as described in the 2008 Annual Report (GSA 2009b). Well point piezometers and groundwater elevation monitoring instruments were established across Field 51 in 2006 (GSA 2008c) and additional piezometers were installed in both 2007 and 2008 within the small-scale study area to determine groundwater fluctuations due to irrigation events and evapotranspirative water demand. The location of soil and groundwater monitoring instruments are shown in Figure 38.

4.1 Technical Approach: Soil and Groundwater Monitoring

4.1.1 Soils Moisture Content, Temperature, and Electrical Conductivity

Instrument nests were established in the 2007 small-scale study plots prior to seeding (GSA, 2008c) as shown in Figure 38. Two types of sensors were installed. Volumetric water content, soil temperature, and pore water salinity (electrical conductivity, EC) were installed at 15 cm below ground surface (bgs) in each plot using ECH2O-TE sensors (Decagon Devices, Inc., Pullman, WA). EC-10 volumetric water content sensors were installed in each plot at 45 and 91 cm bgs. The number of functioning volumetric water content sensors in each irrigation block at each depth is summarized in Table 15. During the 2009 growing season, only eight of the original 36 ECH2O-TE sensors were operating. Of the initial 72 EC-10 sensors, 69 of the sensors were operating for the entire 2009 growing season. During 2009, 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 eight of the sixteen plots at 15 cm bgs to correspond to the instrumentation depth of 2007 plots (Figure 38). No EC-10 sensors were installed below those depths. Four plots were instrumented on the northern and southern portion of the 2008 study plots to correspond to irrigation blocks A3 and B3, and allow for observations of variation in the shallow subsurface due to 2009 growing season irrigation regimes. During the 2009 growing season, two of the four southern sensors were operating. Two of the northern sensors were operating until mid-February, and one sensor was operating until mid-May; thereafter, none of the northern sensors were operating.

Previous soil monitoring data for the 2007 and 2008 growing seasons is presented in the 2007 and 2008 annual reports (GSA 2008b, 2009b).

4.1.2 Groundwater Elevation

Depth to groundwater/groundwater elevation has been monitored since July 2006 using instrumented well point piezometers (Figure 38). In 2006 and 2007, ten well point piezometers were installed and instrumented across Field 51 (five in 2006 for the large-scale site characterization, and five additional for 2007 small-scale field studies). During 2008 and 2009, automated groundwater elevation data were collected twice per day for the seven well points located in the small-scale study area using WL16 Level Loggers (Global Water Instrumentation, Inc, Gold River, CA). The primary objective of groundwater level monitoring during 2009 was to monitor for groundwater mounding and dispersion following irrigation events, and to observe potential drawdown during the growing season due to riparian tree evapotranspirative demand. Previous groundwater elevation data for the 2006, 2007, and 2008 growing seasons is presented in the 2007 annual report (GSA 2008b), the Field 51 site characterization memorandum (GSA 2008c), and the 2008 annual report (GSA 2009b).

4.1.3 Groundwater Quality

Groundwater bailers were used to sample groundwater from the piezometers six times during the 2009 growing season. A minimum of three well volumes were purged from each piezometer prior to sampling, and the final sample was field-tested for specific conductance (EC) using a field conductivity meter. Additionally, samples were collected near the beginning and end of the growing season (April 27, 2009 and October 11, 2009), and sent to Turner Laboratories (Tucson, AZ) for analysis of major cations, anions, and alkalinity in addition to EC.

4.1.4 Water Budget Analysis

A water budget approach can be taken to estimate plant water use via soil water and groundwater budget. The water budget presented herein is intended for preliminary trend analyses, and should only be considered semi-quantitative.

<u>Soil Water and Groundwater Budget</u>

A soil water budget to estimate riparian tree evapotranspiration can be formulated as in Equation 4.1:

$$AET = P + I + \Delta S - R \qquad 4.1$$

where AET is actual evapotranspiration, P is precipitation, I is irrigation, ΔS is soil water storage change, R is recharge (net percolation). Recharge can also be expressed as the change in groundwater storage (ΔGW) and groundwater flow leaving the study area (Q_{gw}). Since precipitation and irrigation are monitored at the study plots, ΔS, ΔGW and Q_{gw} are needed to

estimate AET. Since soil water content data and groundwater elevation data are collected within the 2007 study plot area, AET for the 2007 study plots in the 2008 and 2009 growing season is estimated as discussed below. The 2008 study plots were not analyzed due to the absence of soil water content data.

Soil water content data from the 2007 study was analyzed by sensor depth (15 cm, 46 cm and 91 cm bgs), location (north versus south), and by irrigation block (shallow irrigation Block A and deep irrigation Block B). To estimate ΔS, the 15 cm, 46 cm and 91 cm bgs sensors were assumed to represent water content conditions from 0 to 30 cm, 30 to 69 cm and 69 to 165 cm bgs, respectively. A bottom boundary of 165 cm bgs for the deepest sensor was selected since 165 cm bgs was approximately the maximum depth of the groundwater table observed during the monitoring period. Daily changes in soil water content at each of these intervals was calculated and then averaged for sensors within the north and south areas. Decreases in ΔS result from either evapotranspirative demand or drainage, and are assumed represent evapotranspiration. Increases in ΔS (resulting from irrigation or precipitation) were not used in this analysis, but were compared to total -ΔS values as a data quality check. Differences between +ΔS and - ΔS values were within 2.5 cm (0.5 to 6%) for all areas in 2008 and 2009, except for shallow irrigation Block A, south area during 2008. These data indicate the sensors accurately detect irrigation water replacement and soil water depletion; the greater differences in 2008 south area Block A response (+7.5 cm) was still within 8% due to the higher irrigation rates (80% ET_0) in 2008.

4.2 Results: Soil and Groundwater Monitoring

4.2.1 Soil Moisture Content, Electrical Conductivity and Temperature

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

Soil Water Content

The main objective of the irrigation treatments for 2007 small-scale study plots was to observe potential differences in water use and depletion 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. Similar to 2008, lower soil water content values were observed at 15 and 46 cm bgs for B blocks compared to A blocks in 2009. Daily average soil water content data for each irrigation block are provided in Figure 39 through Figure 42, for both the 2008 and 2009 growing seasons. Depletion of soil water at 15 cm bgs was observed in both irrigation blocks,

whereas depletion of water at 46 cm bgs was generally only observed in plots within deep irrigation Block B2 (Figure 39 through Figure 42). Minimal depletion of soil water was observed at 91 cm bgs in both irrigation blocks. Reduction in soil water content at 91 cm bgs relative to the non-growing season soil water content was observed in only four of 36 plots.

Two trends in the soil water content data are apparent. The maximum and minimum soil water content values at 15 cm generally decrease over the growing season (Figure 40 and Figure 41). These data indicate that irrigation rates probably exceeded ET demand early in the growing season and may not be completely meeting ET demand late in the season (e.g. in August). Secondly, many of the shallow irrigation plots showed water content increases at 46 cm bgs after the onset of irrigation that were sustained into July (i.e. Figure 39, Figure 40, and Figure 43), whereas the deep irrigation plots did not show similar trends. Since the water application rates were similar between irrigation regimes (Table 2 and Table 3), the latter data indicate that soil water depletion in the shallow irrigation plots may be concentrated at the near surface.

Soil water depletion at 91 cm bgs in the 2007 study plots did not appear to be strongly correlated to either irrigation treatment or tree density. Volumetric water content data from specific plots which contain either high or low densities of Fremont cottonwood showed variable trends as discussed below (refer to Figure 38 for locations of plots discussed). For example, depletion of water content at 91 cm bgs was observed in plot NUHF 3 (Block A2), as shown in Figure 44. It should be noted that this plot is largely composed of Fremont cottonwood with crown cover of 95%, and tree density of approximately 29 per m^2 at the end of the 2009 growing season. However, plot NUHF 1 (Block A1), which is also composed of relatively high cover of Fremont cottonwood crown cover (81%), and tree density (14 per m^2) at the end of the 2009 growing season, showed relatively stable (or increasing) volumetric water content at 91 cm bgs (Figure 45). Likewise, YCBB 3 (low Fremont cottonwood density, Figure 43), showed minor depletion at 91 cm bgs.

Water content data in plots NCBB 1 (high Fremont cottonwood density, Figure 46) and YCBF 1 (low Fremont cottonwood density, Figure 47), both subject to the deep, infrequent irrigation regime, show similar trends for water content at 15 cm bgs and 91 cm bgs; more depletion was observed at 46 cm bgs between irrigation events in plot YCBF 1 (lower Fremont cottonwood density). Volumetric water content data for the 2008 Goodding's willow study plots is also shown in Figure 48 and Figure 49 for irrigation blocks A3 and B3, respectively. Extensive drying is observed at 15 cm bgs in both irrigation blocks between irrigation events. However, malfunctioning of sensors in Block B3 precludes any general observations of discrepancies between irrigation treatments.

Overall, the absence of significant wetting and drying (depletion) of soil water at deeper depths indicate the following may be occurring: (1) irrigation water was applied at a higher rate than plant water use of soil moisture at depths deeper than 46 cm; (2) capillary rise of groundwater continually replaced depleted soil moisture, and/or; 3) trees were using sufficient groundwater such that soil water depletion was not regularly observed below 46 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 (Fall 2008), cottonwood roots had penetrated the soil profile to near groundwater after two growing seasons. Therefore, it is likely that trees within the study plots are using groundwater as well as soil water.

As of October, 2009, eight of the initial 36 ECH_2O-TE sensors installed at 15 cm bgs are functioning, whereas the majority of EC-10 sensors at 46 and 91 cm bgs are functioning. If continued soil water content monitoring is desired past the 2010 growing season, it is suggested that replacement sensors be installed at 15 cm bgs. Specifically, the ECH_2O-TE sensors should be replaced with volumetric water content monitoring sensors demonstrated to have a longer life in Cibola NWR field conditions (i.e. EC-10s).

Soil Electrical Conductivity and Temperature

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. Examples of this scenario for plot NUHF 1 (irrigation Block A1) and NCBB 1 (irrigation Block B1) are shown in Figure 50 and Figure 51, respectively. Further analysis is precluded by the low number of sensors remaining at 15 cm bgs in the 2007 study plots.

As for 2007 study plots, sensors in the 2008 small-scale study plots indicate a decrease in pore water EC between irrigation events with an increase during and immediately after irrigation, likely due to flushing of accumulated surface salts (Figure 52 and Figure 53).

4.2.2 Depth to Groundwater

Depth to groundwater during 2008 and 2009 in the vicinity of the 2007 small-scale study area is shown in Figure 54. Depth to groundwater during 2008 and 2009 in the vicinity of the 2008 small-scale study plots is shown in Figure 55 and Figure 56 for the A3 and B3 irrigation blocks, respectively.

Near the 2007 study plots, the average depth to groundwater in 2009 prior to the onset of

irrigation (January and February) was approximately 2.1 m. The average depth to groundwater increased to over 2.4 m during July and August, during the period of greatest evapotranspirative demand, and then slowly decreased during September and October (Figure 54) as the water table recovered. Depth to groundwater responded rapidly to large irrigation events, with short-term mounding of up to 50 cm. Groundwater mound dissipation most likely reflects plant water use and groundwater re-distribution (flow away from the study plot areas).

Near the 2008 study plots, the average depth to groundwater in 2009 to the onset of irrigation (January and February) also averaged approximately 2.1 m. The average depth to groundwater increased to approximately 2.2 m during September (Figure 55 and Figure 56). Depth to groundwater also responded rapidly to large irrigation events, with short-term mounding of up to 30 cm and rapid dissipation of the mound.

It is of note that over the 2009 growing season, groundwater decline was greater in the 2007 plots than in the 2008 plots (Figure 54 versus Figure 55 and Figure 56). This could be due to 1) higher irrigation rates for the 2008 study plots than 2007 study plots (80% of ET_0 and 60% of ET_0, respectively) and/or 2) less groundwater utilization by trees in the 2008 study plots than the 2007 study plots.

4.2.3 Groundwater Quality

Results from field measurements of groundwater EC are provided in Table 16. Irrigation water EC was near 1.0 dS/m in both March and June, 2009. Groundwater EC in the Cibola NWR Field 51 area ranged between 1.1 and 4.0 dS/m, and averaged between 1.7 and 2.3 dS/m. These data indicate elevated groundwater salinity compared to irrigation water and in general, increasing salinity over the irrigation season. Groundwater also showed variably increasing or decreasing EC values (i.e. PZ-SSN, PZ-SSC, PZ-NW), indicating evapoconcentration of irrigation water and flushing of salts may be variable at different locations within the study plot areas.

Groundwater quality laboratory analysis results are provided in Table 17 and Table 18. Calcium and sodium were the dominant cations observed in Field 51 groundwater, and sulfate was the dominant anion (Table 17). Calcium and magnesium were generally observed in lower concentrations at the end of the growing season, whereas sodium and potassium levels were similar throughout the growing season. Trends were not observed for bicarbonate and alkalinity, EC, or total dissolved solids (Table 18), with generally similar values in April and October. Field EC measurements were consistent with laboratory data in April, although there was approximately 10%-15% error at the end of the season in October.

4.2.4 Water Budget Analysis

Soil Water and Groundwater Budget

Table 19 shows the estimated cumulative decrease in ΔS from 3/1/08 to 10/31/08 for each of the depth intervals in the South and North areas. In 2008, decreases in ΔS below 30 cm were approximately 30% of the total decrease in ΔS in both the shallow and deep irrigation blocks. The observed cumulative -ΔS within each of the areas (Table 19) was typically less than half of the target irrigation depth of 80% ET_0 applied to the shallow (175.03 cm) and deep irrigation blocks (187.09 cm), indicating that capillary movement of water into the soil profile minimized declines in soil water at the deeper depths, and/or groundwater use by the riparian trees may account for more than 50% of the plant water use.

During this period of time groundwater elevation rose and declined in response to irrigation and evapotranspiration (Section 4.2.2). Groundwater flow rates (Q_{gw}) leaving the study area are unknown (and beyond the scope of this study), but are directly related to the groundwater elevation gradient. Historical groundwater elevation data indicate that average depth to groundwater during the non-growing season was within 2.1 to 2.3 m bgs with groundwater elevation gradients of approximately 0.0005 m/m towards the west of the site (GSA 2008c, 2009b). During the 2008 and 2009 growing period, depths to groundwater were greater than 2.1 m bgs approximately 60% of the time (145 days), consequently, significant increases in Q_{gw} resulting from irrigation during the growing seasons are not believed to have occurred and we assume that the Q_{gw} into the study area and out Q_{gw} remained relatively constant (or decreased).

Assuming cumulative decreases in groundwater elevations (ΔGW) represent evapotranspiration or capillary movement into the soil profile, the average decline in groundwater elevation (in PZ-NE, PZ-SSN, PZ-SSS, PZ-SSC, and PS-SE) during the 2008 growing season was 38.5 cm. Adding the observed decease in ΔGW to the estimated decrease in ΔS (Table 19) to calculate AET results in values of 123 cm (56.5% of ET_0) for the shallow irrigation B block areas, to 116 cm (53.4% of ET_0) for the deep irrigation B block areas.

Table 20 shows the estimated decrease in cumulative ΔS from 3/1/09 to 10/10/09 for each of the depth intervals in the South and North areas. As previously noted, the deep irrigation blocks showed greater decreases in soil water content in the depth intervals below 30 cm bgs; decreases in cumulative ΔS below 30 cm were approximately 13% of the total decrease in ΔS in the shallow irrigation blocks and 31% in the deep irrigation blocks. As in 2008, the observed decreases in cumulative ΔS (Table 20) were significantly less than the target irrigation depths of 60% ET_0 applied to the shallow (126.5 cm) and deep irrigation blocks (112.1 cm), indicating that capillary movement of water into the soil profile, and/or groundwater use by the riparian trees may account for more than 50% of the plant water use.

As for 2008, groundwater elevation rose and declined in response to irrigation and evapotranspiration (Section 4.2.2). During the 2009 growing period, depths to groundwater were greater than 2.1 m bgs approximately 80% of the time (177 days), consequently, significant increases in Q_{gw} resulting from irrigation during the growing seasons are not believed to have occurred. Again assuming cumulative decreases in groundwater elevations (ΔGW) represent evapotranspiration or capillary movement into the soil profile, the average decline in groundwater elevation (in PZ-NE, PZ-SSN, and PZ-SSC) was 43.4 cm. Adding the observed decease in ΔGW to the estimated decrease in ΔS (Table 20) to calculate AET results in values of 105.6 cm (51.9% of ET_0) for the shallow irrigation Block A North Area, 80.0 cm (39.3% of ET_0) for the shallow irrigation Block A south Area, and 92 cm (45.3% of ET_0) for the deep irrigation block B South Area.

Comparison between years shows that greater cumulative ΔS was observed in 2008 (Table 19) compared to 2009 (Table 20) at all soil intervals. This data reflects generally higher increases in soil water content and greater declines in 2008 due to the 33% higher irrigation rate (80% of ET_0 versus 60% of ET_0 for 2009). In particular, very little change in water content at 91 cm bgs was observed during 2009. It is likely that 91 cm bgs water content was maintained by groundwater (i.e. provided via capillary rise). Consequently, these data also indicate that, even with target irrigation of only 60% of ET_0, evapotranspirative demand did not impact the soil water content at 91 cm bgs. Therefore, it is likely that sufficient water was available for trees due to shallow groundwater.

Irrigation Water and Groundwater Budget

Figure 57 shows the average (both irrigation blocks) cumulative applied irrigation water depths to the 2007 study plots during 2008. In addition the cumulative change in depth to groundwater is shown. From approximately 3/1/08 to 6/8/08 the depth to groundwater varied but did not

decrease below the initial depth to water of 2.2 m bgs. Between 6/8/08 and 8/20/08 the groundwater elevations decreased below 2.1 m bgs with a maximum depth of 2.45 m bgs. The decline in groundwater depth during the months of June through August indicate that even 80% ET_0 irrigation rates were insufficient to maintain the groundwater table and AET was causing groundwater elevations to decrease. After 8/5/08 the groundwater elevations began to rise in response to irrigation with a depth to groundwater of 2.1 m bgs observed by 8/20/09, similar to the initial depths to groundwater at the beginning of the growing season.

For purposes of comparison, the cumulative target irrigation rate (80% of ET_0) is also presented in Figure 57. The groundwater response to irrigation indicates that during the initial (3/1/09 to 6/8/10) and final periods (8/5/08 to10/31/08) the AET is probably less than or equivalent to 80% of ET_0, whereas during the summer months AET might exceeds 80% ET_0.

Figure 58 shows the average (both irrigation blocks) cumulative applied irrigation water depths to the 2007 study plots during 2009. As for 2008, the cumulative change in depth to groundwater is shown. From approximately 3/1/09 to 5/31/09 the groundwater elevations varied but did not decrease below the initial depth to water of 2.2 m bgs. Between 5/31/09 and 8/31/09 the groundwater elevations decreased below 2.2 m bgs to a maximum depth of 2.45 m bgs. Similar to 2008, the irrigation rates were insufficient to balance AET and groundwater elevations decreased. After 8/31/09 the groundwater elevations began to rise in response to irrigation with a depth to groundwater of 2.1 m bgs observed by 9/31/09, similar to the initial depths to groundwater at the beginning of the growing season.

For purposes of comparison, the cumulative estimated evapotranspirative demand (60% of ET_0) is also presented in Figure 57. The groundwater response to irrigation indicates that during the initial (3/1/09 to 5/31/09) and final periods (8/31/09 to10/11/09) the AET is probably less than or equivalent to 60% of ET_0, whereas during the summer months AET exceeds 60% ET_0.

Of note, the period of groundwater decline in 2008 was shorter than that in 2009 by 34 days. This result indicates that when 80% of ET_0 was applied during 2008, groundwater was more readily replenished by recharge (drainage from irrigation). This is supported by increased $-\Delta S$ observed during 2008 (Table 19) compared to 2009 (Table 20). However, significant groundwater elevation declines were still observed in 2008 and the maximum change in groundwater elevation was greater in 2008 (0.38 m) compared to 2009 (0.25 m). The relatively consistent decline in groundwater elevations in June through August indicate that areas surrounding the 2007 study plots (i.e. barren areas of Field 51) are also contributing to ET demand and influencing groundwater elevations. These groundwater elevation data also provide

evidence that capillary rise of groundwater into the soil profile is occurring and providing groundwater to the atmosphere even in the absence of vegetation.

5.0 CONCLUSIONS

Three years of monitoring dynamics of densely-established Fremont cottonwood and volunteer saltcedar since 2007 indicate that hydroseeding and furrow irrigation of cottonwood, even with high initial establishment of saltcedar, will result in a re-vegetated plant community dominated by Fremont cottonwood. The minimum seeding rate required to achieve a robust cottonwood community was 95 PLS/m^2 (for a target stem density of ten per m^2).

Two years of monitoring densely seeded Goodding's willow intermixed with high-density volunteer saltcedar in 2008 study plots indicates that greater growth rates are observed for Goodding's willow, but saltcedar remains the dominant species. Therefore, limiting saltcedar establishment during the first growing season is desirable to promote re-vegetated Goodding's willow communities.

The first year of monitoring for 2009 study plots seeded at variable Goodding's willow seeding rates indicates that saltcedar and grass volunteer establishment can be limited during the initial establishment of native species. Furthermore, the density of Goodding's willow is directly correlated to seeding rates, which indicates willow density (and costs of large-scale revegetation) on the lower Colorado River can be optimized. Finally, these plots demonstrate that riparian tree seeds can be stored for up to two years and still be viable for plant establishment in field conditions. Additional monitoring of these plots will be necessary to assess long-term vegetation dynamics and minimum seeding rates.

Specific conclusions for each of the small-scale plot experiments are provided below:

<u>2007 Mixed Riparian Seed Small-scale Study Plots</u>

In the 2007 small-scale study plots, Fremont cottonwood established and dominated the crown cover of many plots after the first growing season (refer to Section 2.2). 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 after the first growing season.

During the 2008 and 2009 growing season, cottonwood growth expanded in the small-scale study plots, increasing in crown cover from 15.9% in September, 2007, to 70.3% by October, 2009. Growth rates for Fremont cottonwood exceeded saltcedar growth rates during the 2008 growing season, but growth rates were similar between the two species in 2009. However, Fremont cottonwood crown and canopy cover dominated saltcedar after two growing seasons;

canopy cover was nearly twice that of saltcedar after the second and third growing seasons (October 2008 and 2009, respectively). Deep and less frequent irrigation (i.e. frequency of once per month or less), appeared to favor cottonwood growth and survival over saltcedar during the third growing season.

2007 study plot results to dates indicate that cottonwood is likely to maintain dominance in the study area. The 2008 vegetation survey results indicated 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 (GSA 2008b). During the 2009 growing season, cottonwood crown cover and density did not affect saltcedar growth. Nevertheless, a Fremont cottonwood stem density greater than 25 stems/m^2 after the first growing season always resulted in saltcedar crown cover of less than 10%.

2008 Goodding's Willow Small-scale Study Plots

During the 2009 growing season, Goodding's willow growth expanded in the 2008 study plots, increasing in crown cover from 2.4% in September, 2008, to 8.6% in October, 2009. Saltcedar crown cover expanded from 24.9% to 44.0% during that same period, indicating that saltcedar dominance is expanding. Results to date suggest that saltcedar is likely to maintain dominance in the study area; however, superior growth rates of Goodding's willow indicate that, if establishment of Goodding's willow can be enhanced and/or saltcedar establishment can be suppressed, then seeding of Goodding's willow may result in favorable vegetation communities.

Less frequent irrigation (i.e. frequency of once per three weeks) resulted in higher survival rate of established Goodding's willow. Greater survival of saltcedar was also observed for this irrigation treatment, indicating that reduced frequency of irrigation will not necessarily promote native species dominance. Long-term monitoring of the 2008 Goodding's willow plots will be required to observe the ultimate vegetation community structure.

2009 Goodding's Willow Small-scale Study Plots

Establishment rates of Goodding's willow increased from 0.1% in the 2007 study plots to 0.95% and 1.67% in the 2008 and 2009 small-scale study plots, respectively. The increased seeding success was due to better grass management and use of hydroseeding un-cleaned seed as an optimum seed treatment. Surface irrigation method did not affect the overall establishment rates of Goodding's willow, although the visual distribution of trees appeared superior in furrow-

irrigated plots. Additionally, furrow irrigation resulted in lower growth rates of saltcedar compared to border irrigation in 2008 study plots.

Three-fold increases in seeding rate for the 2009 study plots did not result in significant increases in Goodding's willow crown or canopy cover. Increasing seeding rates resulted in higher stem densities, with no reduction in establishment percentage or growth rates observed with high seeding rates. The average height of Goodding's willow was similar to that of saltcedar after one growing season. Continued monitoring of these plots is needed to determine the long-term vegetation communities that will result from variable seeding rates.

In the 2008 and 2009 Goodding's willow study plots, enhanced management of undesired grass species through repeated application of herbicide reduced the abundance of grass in plots. Growth of shrubs (primarily goosefoot and (in 2008 plots) saltcedar) increased, perhaps due to reduced competition with grass. Additionally, the abundance of saltcedar was greatly-reduced in the 2009 study plots compared to the 2007 and 2008 experiments, most likely due to removal of saltcedar sources along the main Cibola NWR Farm Unit irrigation canal and from the fields west of the study site. 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 within in the field (e.g. irrigation, herbicide, and tillage cycles); volunteer establishment of saltcedar is reduced by removal of adjacent undesired seed sources, and; grass growth is reduced after seeding through application of grass-specific herbicide.

Estimated Costs for Large-scale Seeding of Riparian Species

Based on the small-scale study results, GSA conducted preliminary cost analyses for large-scale hydroseeding of Fremont cottonwood and Goodding's willow (GSA 2008d). Cost estimates were developed 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.

Revision of these initial cost estimates is as follows:

1) For a desired Fremont cottonwood density of 10.8 trees per square meter (1 per square foot), costs are estimated at $4,000 per hectare ($1,600 per acre) using hydroseeding of un-cleaned seed onto furrow irrigated fields.

2) For a desired Goodding's willow density of 10.8 trees per square meter (1 per square foot), costs are estimated at $5,700 per hectare ($2,300 per acre) using hydroseeding of un-cleaned seed onto furrow irrigated fields.

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 a 20-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 $4,500 per hectare ($1,840 per acre), while providing a 20-fold increase in tree density.

Initial cost estimates demonstrate potentially large cost savings while improving the genetic diversity of revegetation on the LCR using native seed. A large-scale seed collection and implementation effort would be necessary to confirm and refine these cost estimates.

Small-scale Study Area Subsurface Monitoring

The feasibility study plot area provides detailed soil water and groundwater monitoring data provides insight into how riparian trees utilize water during the growing season. Soil water content data from 2008 and 2009 indicate that relatively little soil water depletion was observed at 46 and 91 cm bgs. Water budget analyses indicate that soil water depletion resulting from irrigation and drainage/ET was typically less than 50% of the applied irrigation water (i.e. 40% or 30% of ET_0 for 2008 and 2009, respectively). Previous authors have suggested that cottonwood ET demand might average 74% of ET_0 over the growing season (Gazal et al. 2006). These numbers indicate that 46 (during 2008) to 54% (2009) of water required to support established cottonwoods might be coming from groundwater. This result is supported by modeling results, which indicated that more than 30% (2008) or 40% (2009) of the plant water use may be coming directly from groundwater or from soil depths supplied by capillary rise of groundwater. Thus, riparian trees established at Cibola NWR are likely utilizing groundwater for a significant portion of AET demand.

For shallow, frequent irrigation, the percentage of soil water depletion accounted for in the near surface (i.e. 0-30 cm bgs) varied between irrigation rates (60% or 80% of ET_0). When water application was reduced from 80% to 60% of ET_0, the percentage of depletion accounted for by the 0-30 cm depth interval increased from 70 to 87. These data indicate that less percolation was

likely observed at depth during 2009. For both application rates, the percentage of depletion accounted for by the 0-30 cm depth interval was approximately 70 for the deep, infrequent irrigation. This result indicates that 1) depletion at depth was encouraged after extensive drying of the near-surface and/or 2) large irrigation pulses resulted in increased percolation at depth. The former was supported by observed enhanced drying at 46 cm bgs in B blocks versus A blocks, and the latter was supported by larger increases in water content immediately after irrigation events in B blocks versus A blocks.

Additionally, groundwater elevations near the 2007 study plots have been observed to decline during the growing season with application of either 60% or 80% of ET_0 irrigation supply. The duration of groundwater decline was observed to be less under the 80% ET_0 irrigation scheme, nonetheless, the consistent groundwater elevation decline in the summer months indicates that areas surrounding the study plot are most likely contributing to ET demand and loss of groundwater through capillary rise.

Preliminary groundwater quality data indicate elevated TDS and EC in groundwater compared to irrigation water with increases observed in both parameters over the growing season in several of the monitoring wells.

6.0 RECOMMENDATIONS

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

1) Long-term (i.e. 5 to 10 years) mortality and resulting revegetation success of seeded Fremont cottonwood and Goodding's willow are unknown.
2) Fremont cottonwood has been shown to out-compete saltcedar; however the ability of Goodding's willow to out-compete saltcedar is currently unknown.
3) Deep irrigation has been shown to improve the success of Fremont cottonwood and Goodding's willow. In addition, data indicates that these riparian trees may preferentially use groundwater. Consequently, a better understanding of plant water use dynamics could assist the revegetation efforts on the LCR.
4) The costs and vegetation success for large-scale revegetation efforts are unknown.

Recommendations for future study consist of two projects:

- Continued monitoring of 2007, 2008, and 2009 small-scale study plots to include irrigation management and installation of soil moisture and tree water dynamics monitoring equipment to determine plant water use
- Establishment of a large-scale demonstration plot to evaluate revegetation using seed costs and vegetative success for Fremont cottonwood and Goodding's willow.

<u>Continued Monitoring of 2007, 2008 and 2009 Small-scale Study Plots</u>

It is recommended that vegetation monitoring and irrigation management be continued for the existing 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 and 2009 plots, (3) additional establishment and growth of volunteer vegetation, and (4) irrigation management effects to evaluate depth and frequency of irrigation. Vegetation monitoring could be scaled back to biennial events.

Due to the existing infrastructure and vegetation composition, the Field 51 seed feasibility study

area represents a valuable data source to Reclamation in evaluating riparian tree water requirements and the long-term sustainability of re-vegetated areas. Continued soil water and groundwater monitoring is recommended and the following additional studies are recommended:

1. Groundwater salinity should be monitored in greater detail (spatially and temporally) to determine if and/or when salinity approaches thresholds for tree stress or mortality.
2. Soil water, ground water, and salt fluxes should be modeled on a local scale to determine the potential for long-term salinization of restoration areas.
3. Unsaturated flow numerical modeling should be conducted to better estimate plant use of soil water and ground water as a function of soil and groundwater parameters and irrigation management scenarios.

Items 1 and 2 are being implemented by GSA through a separate contract with Reclamation, whereas 3 is outside the scope of the current contract. For a minimal additional investment, it may also be possible to enhance monitoring to allow quantification and partitioning of tree water use, and support modeling of salt fluxes and long-term salinization potential.

If additional study plot monitoring is implemented past the 2010 growing season, we also recommend replacing failed sensors at 15 cm bgs along with installation of sensors outside of the study area (i.e. the un-irrigated Field 51) to determine how soil water content changes over time as a result of only evaporative demand and capillary rise of groundwater. If unsaturated flow modeling is implemented, soil samples from the study plot area should be collected for hydraulic conductivity and moisture retention characteristic testing.

Establishment of Large-scale Demonstration Plot

It is recommended that Phase III of the original feasibility analysis (large-scale demonstration plot) be implemented for Fremont cottonwood and Goodding's willow seeding. Results of the small-scale study have indicated the efficacy of direct seeding for establishing dense native riparian trees, and the potential to limit saltcedar establishment. However, a large-scale demonstration study designed to create a desired vegetation mosaic to provide habitat for various native fauna 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, seed collection and site preparation must be implemented. Seed collection should be initiated a year prior to seeding to secure a large portion

of the seed required for a large-scale demonstration plot. Site preparation the year before seeding, while being site-dependent, should include pre-seeding weed management. If a site is set aside for years prior to seeding, establishment of a cover crop might be desired to limit weed establishment. Based on current small-scale field study results, it is recommended that un-cleaned seed be hydroseeded onto furrows.

7.0 ACKNOWLEDGMENTS

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TABLES

Table 1. 2009 rainfall data for Cibola NWR.

Date	Rainfall (mm)[1]
2/7/2009	15.0
2/16/2009	0.5
5/18/2009	0.3
7/1/2009	0.3
7/24/2009	2.0
8/22/2009	2.0
9/5/2009	6.6
11/7/2009	5.1
Total:	**31.75**

1 Data available: http://www.wrcc.dri.edu/cgi-bin/rawMAIN.pl?azACBL. Data unavailable 1/3-1/31, 2/1-2/4, 2/10-2/15, 2/18-2/26, 3/7-3/9, 12/9-12/14, 12/18-12/25, 2009 due to weather station malfunction

Table 2. Applied water summary for 2009 growing season, 2007 small-scale plots, A Blocks.

Block A1			Block A2		
Date	**Irrigation Depth (cm)**	**Elapsed Time (days)[1]**	**Date**	**Irrigation Depth (cm)**	**Elapsed Time (days)**
3/19/2009	5.50	—	3/19/2009	5.50	—
3/30/2009	7.76	11	3/30/2009	5.50	11
4/10/2009	5.73	11	4/10/2009	5.56	11
4/22/2009	5.51	12	4/22/2009	5.68	12
4/30/2009	5.51	8	4/30/2009	5.50	8
5/11/2009	5.51	11	5/11/2009	5.51	11
6/1/2009	5.50	21	6/1/2009	5.50	21
6/15/2009	5.50	14	6/15/2009	5.50	14
6/24/2009	6.37	9	6/24/2009	5.52	9
7/1/2009	5.51	7	7/1/2009	5.50	7
7/9/2009	5.51	8	7/9/2009	5.50	8
7/16/2009	5.57	7	7/16/2009	5.52	7
7/24/2009	5.52	8	7/24/2009	5.52	8
7/30/2009	5.74	6	7/30/2009	5.50	6
8/5/2009	5.30	6	8/5/2009	5.50	6
8/12/2009	5.51	7	8/12/2009	5.48	7
8/14/2009	4.71	2	8/14/2009	4.72	2
8/20/2009	5.50	6	8/20/2009	5.59	6
8/27/2009	5.16	7	8/27/2009	5.18	7
9/4/2009	5.50	8	9/4/2009	5.50	8
9/11/2009	4.36	7	9/11/2009	3.85	7
9/17/2009	4.56	6	9/17/2009	5.12	6
10/2/2009	8.82	15	10/2/2009	4.73	15
10/22/2009	4.74	20	10/22/2009	4.67	20
Total Irrigation (cm)		134.87	Total Irrigation (cm)		127.66
Rainfall (cm)[2]		1.12	Rainfall (cm)		1.12
Estimated Reference Evapotranspiration (cm)[2]		216.34	Estimated Reference Evapotranspiration (cm)[2]		216.34
Irrigation and Precipitation/ET_0		0.629	Irrigation and Precipitation/ET_0		0.595

1 Days since previous irrigation event (rainfall not included).
2 Data from US Fish and Wildlife Service Cibola weather station, available: http://www.wrcc.dri.edu/cgi-bin/rawMAIN.pl?azACBL.

Table 3. Applied water summary for 2009 growing season, 2007 small-scale plots, B Blocks.

Block B1			Block B2		
Date	**Irrigation depth (cm)**	**Elapsed Time (days)[1]**	**Date**	**Irrigation depth (cm)**	**Elapsed Time (days)**
3/19/2009	22.00	—	3/19/2009	22.00	—
4/30/2009	13.66	42	4/30/2009	11.48	42
5/1/2009	8.35	1	5/1/2009	9.29	1
6/18/2009	22.01	48	6/18/2009	22.19	48
7/28/2009	22.28	40	7/28/2009	22.00	40
9/4/2009	22.20	38	9/4/2009	22.00	38
10/21/2009	22.01	47	10/21/2009	17.52	47
Total Irrigation (cm)		132.52	Total Irrigation (cm)		126.47
Rainfall (cm)[2]		1.12	Rainfall (cm)[2]		1.12
Estimated Reference Evapotranspiration (cm)[2]		216.34	Estimated Reference Evapotranspiration (cm)[2]		216.34
Irrigation and Precipitation/ET_0		0.618	Irrigation and Precipitation/ET_0		0.590

1 Days since previous irrigation event (rainfall not included).
2 Data from US Fish and Wildlife Service Cibola weather station, available: http://www.wrcc.dri.edu/cgi-bin/rawMAIN.pl?azACBL.

Table 4. ANOVA linear modeling results after three growing seasons (October 2009 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 Average Height[4]	POFR Stems/ m^2
Main Effects		**p Values[5]**					
Sprinklers		<0.0001	<0.0001	0.058	0.331	0.192	0.576
Seed Treatment		0.617	0.483	0.014	0.409	0.120	0.066
Surface Irrigation Method		<0.001	<0.001	0.623	0.360	0.254	0.070
Plot Position		<0.001	<0.001	0.200	0.394	0.261	0.008
Seeding Rate PLS/m^2		0.598	0.334	0.152	0.851	0.795	0.980
Interactions							
Sprinklers*Seed Treatment		0.389	0.395	0.182	0.413	0.228	0.966
Sprinklers*Surface Irrigation Method		0.032	0.051	0.663	0.343	0.231	0.136
Seed Treatment* Surface Irrigation Method		0.969	0.974	0.128	0.394	0.222	0.963
Sprinklers*Seed Treatment*Surface Irrigation Method		0.801	0.826	0.117	0.398	0.331	0.438
		Means and Significant Differences[6]					
Sprinklers	No Sprinklers	0.860 A	0.877 A	0.003A	0.000 A	251 A	12.80 A
	Sprinklers	0. 547 B	0.553 B	0.000 A	0.001 A	218 A	11.05 A
Seed Treatment	Un-cleaned Hydroseed	0.739 A	0.760 A	0.004 A	0.000 A	214 A	17.30 A
	Cleaned Hydroseed	0.679 A	0.685 A	0.000 B	0.001 A	270 A	9.12 B
	Cleaned Broadcast	0.679 A	0.701 A	0.000 B	0.000 A	219 A	9.35 AB
Surface Irrigation Method	Border-strip	0.601 B	0.604 B	0.001 A	0.000 A	220 A	8.98 A
	Furrow	0.806 A	0.826 A	0.002 A	0.001 A	248 A	14.88 A
Plot Position		0.537 B	0.562 B	0.003 A	0.001 A	219 A	5.35 B
	Block 1						
	Block 2	0.776 A	0.778 A	0.000 A	0.000 A	222 A	11.52 AB
	Block 3	0.796 A	0.805 A	0.001 A	0.000 A	262 A	11.90 A
Seeding Rate, PLS/m^2							
Correlation Relationship[7]	direct		0.334	0.151	0.851		
	inverse	0.598				0.924	0.980

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 5. 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]	G/S[3] Crown Cover	S/F[4] Crown Cover	TARA Canopy Cover5	G/S Canopy Cover	S/F Canopy Cover	TARA Stems/ m^2	TARA Average Height[6]
Main Effects		**p Values[7]**							
Sprinklers		0.018	<0.0001	0.449	0.017	0.008	0.695	<0.0001	0.452
Seed Treatment		0.889	0.090	0.637	0.751	0.476	0.611	0.274	0.763
Surface Irrigation Method		0.201	<0.001	0.451	0.904	0.033	0.507	0.863	0.318
Plot Position		<0.001	0.426	0.937	0.021	0.051	0.575	0.665	0.002
Seeding Rate, PLS/m^2		0.588	0.906	0.988	0.549	0.887	0.376	0.792	0.313
Interactions									
Sprinklers*Seed Treatment		0.716	0.433	0.821	0.811	0.626	0.960	0.996	0.869
Sprinklers*Surface Irrigation Method		0.129	0.168	0.797	0.567	0.512	0.050	0.348	0.068
Seed Treatment* Surface Irrigation Method		0.511	0.524	0.822	0.989	0.889	0.889	0.425	0.975
Sprinklers*Seed Treatment*Surface Irrigation Method		0.780	0.202	0.937	0.288	0.569	0.223	0.565	0.375
		Means and Significant Differences[8]							
Sprinklers	No Sprinklers	0.064 A	0.068 B	0.002 A	0.448 A	0.518 B	0.024 A	19.77 A	68.21 A
	Sprinklers	0.183 A	0.237 A	0.004 A	0.292 B	0.712 A	0.021 A	5.89 B	74.80 A
Seed Treatment	Un-cleaned Hydroseed	0.134 A	0.105 B	0.005 A	0.383 A	0.566 A	0.028 A	12.13 A	72.99 A
	Cleaned Hydroseed	0.128 A	0.161 AB	0.003 A	0.391 A	0.611 A	0.024 A	16.09 A	74.87 A
	Cleaned Broadcast	0.107 A	0.191 A	0.001 A	0.336 A	0.668 A	0.016 A	10.28 A	66.67 A
Surface Irrigation Method	Border-Strip	0.154 A	0.214 A	0.004 A	0.374 A	0.691 A	0.026 A	13.07 A	75.92 A
	Furrow	0.092 A	0.091 B	0.002 A	0.366 A	0.540 B	0.019 A	12.59 A	67.10 A
Plot Position	Block 1	0.276 A	0.179 A	0.004 A	0.498 A	0.736 A	0.018 A	14.24 A	94.74 A
	Block 2	0.059 B	0.130 A	0.003 A	0.287 B	0.576 AB	0.030 A	13.10 A	70.19 B
	Block 3	0.033 B	0.147 A	0.003 A	0. 325 B	0.534 B	0.020 A	11.17 A	49.59 B
Seeding Rate, PLS/m^2									
Correlation Relationship[9]	direct	0.588	0.906						
	inverse			0.988	0.549	0.887	0.376	0.792	0.313

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 G/S is for combined grasses and sedges.
4 Code is for combined shrubs and forbs (S/F) excluding TARA.
5 Canopy cover is the total canopy cover of the given vegetation type, including crown cover.
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 6. ANOVA modeling results for Fremont cottonwood and saltcedar growth rates for the 2007 small-scale field study plots during the 2009 growing season.

Results		POFR[1] Growth Rate[2], cm/day	TARA Growth Rate, cm/day
Main Effects		**p Values[3]**	
Irrigation Treatment		0.001	0.868
Surface Irrigation Method		0.013	0.514
Fremont Cottonwood Crown Cover[5]		0.033	0.060
Fremont Cottonwood Stem Density		0.003	0.478
Saltcedar Crown Cover		0.688	0.802
Saltcedar Stem Density		0.001	0.098
Initial Tree Height[6]		<0.0001	0.014
Irrigation Treatment[7]		**Means and Significant Differences[4]**	
A		0.165 B	0.046 A
B		0.237 A	0.049 A
Surface Irrigation Method			
Border-Strip		0.226 A	0.051 A
Furrow		0.176 B	0.044 A
POFR Crown Cover			
0-25		0.351 AB	0.083 A
25.5-50		0.206 A	0.060 A
50.5-75		0.112 B	0.024 B
75.5-100		0.136 AB	0.0021 B
POFR Density, stems/m^2			
1-11.4		0.216 A	0.039 A
11.5-23.4		0.204 A	0.058 A
23.5-35.4		0.149 B	0.045 A
35.5-47.4		0.236 A	0.046 A
TARA Crown Cover			
0-14.4%		0.181 A	0.054 A
14.5-28.4%		0.223 A	0.041 A
28.5-42.4%		0.197 A	0.043 A
42.5-56.4%		0.181 A	0.051 A
TARA Density, stems/m^2			
1-10.4		0.252 A	0.030 B
10.5-20.4		0.221 A	0.051 AB
20.5-30.4		0.224 A	0.039 AB
30.5-40		0.107 B	0.069 A
Initial Tree Height, cm			
Correlation Relationship[8]	direct	<0.0001	0.014
	inverse		

1 Codes are for Fremont cottonwood (POFR) and saltcedar (TARA).
2 Growth rate between May, 2009 and October, 2009 surveys.
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 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.
6 Height as measured during May 2009 surveys.
7 Codes indicated shallow, frequent irrigation (A) or deep, infrequent irrigation (B).
8 Relationships denote a direct or inverse correlation between treatments and respective seeding rates.

Table 7. Applied water summary for 2009 growing season, 2008 plots, Block A3.

Block A3		
Date	**Irrigation Depth (cm)**	**Elapsed Time (days)[1]**
3/19/2009	7.02	—
3/30/2009	7.04	11
4/10/2009	6.98	11
4/22/2009	6.99	12
4/30/2009	7.01	8
5/11/2009	7.01	11
6/1/2009	7.01	21
6/15/2009	7.01	14
6/24/2009	7.02	9
7/1/2009	7.01	7
7/9/2009	7.02	8
7/16/2009	7.00	7
7/24/2009	7.01	8
7/30/2009	7.01	6
8/5/2009	5.47	6
8/12/2009	7.00	7
8/14/2009	6.00	2
8/20/2009	7.00	6
8/27/2009	6.63	7
9/4/2009	6.60	8
9/11/2009	5.67	7
9/17/2009	5.26	6
10/2/2009	5.97	15
10/22/2009	6.23	20
Total Irrigation (cm)		159.96
Rainfall (cm)[2]		1.12
Estimated Reference Evapotranspiration (cm)[2]		216.34
Irrigation and Precipitation/ET_0		0.745

1 Days since previous irrigation event (rainfall not included).
2 Data from US Fish and Wildlife Service Cibola weather station, available: http://www.wrcc.dri.edu/cgi-bin/rawMAIN.pl?azACBL.

Table 8. Applied water summary for 2009 growing season, 2008 plots Block B3.

Block B3		
Date	**Irrigation depth (cm)**	**Elapsed Time (days)[1]**
3/19/2009	22.30	—
4/22/2009	14.11	34
4/23/2009	9.07	1
6/15/2009	22.48	53
7/13/2009	22.06	28
8/12/2009	13.32	30
8/13/2009	8.75	1
9/11/2009	16.01	29
10/22/2009	17.88	41
Total Irrigation (cm)		145.97
Rainfall (cm)[2]		1.12
Estimated Reference Evapotranspiration (cm)[2]		216.34
Irrigation and Precipitation/ET_0		0.679

1 Days since previous irrigation event (rainfall not included).
2 Data from US Fish and Wildlife Service Cibola weather station, available: http://www.wrcc.dri.edu/cgi-bin/rawMAIN.pl?azACBL.

Table 9. 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/m^2	SAGO Average Height	TARA Crown Cover	G/S Crown Cover	S/F Crown Cover	TARA Canopy Cover	G/S Canopy Cover	S/F Canopy Cover	TARA Stems/m^2	TARA Average Height
Main Effects		**p Values[4]**											
Seed Treatment		0.377	0.043	0.020	0.671	0.090	0.608	0.358	0.495	0.855	0.277	0.951	0.500
Surface Irrigation Method		0.107	0.019	0.426	0.283	0.830	0.708	0.220	0.947	0.552	0.530	0.765	0.890
Seeding Rate PLS/m^2		0.672	0.753	0.473	0.710	0.242	0.204	0.801	0.210	0.984	0.463	0.379	0.590
Interaction													
Seed Treatment* Surface Irrigation Method		0.790	0.743	0.443	0.343	0.172	0.740	0.405	0.069	0.112	0.682	0.773	0.767
Seed Treatment		**Means and Significant Differences[5]**											
Un-cleaned Hydroseed		0.115 A	0.276 A	11.18 A	84.9 A	0.358 A	0.033 A	0.430 A	0.741 A	0.412 A	0.674 A	31.05 A	52.6 A
Cleaned Broadcast		0.056 A	0.114 B	1.65 B	70.4 A	0.522 A	0.053 A	0.340 A	0.812 A	0.386 A	0.560 A	60.61 A	47.0 A
Surface Irrigation Method													
Border-strip		0.034 A	0.106 B	5.09 A	60.2 A	0.431 A	0.050 A	0.441 A	0.774 A	0.360 A	0.646 A	31.82 A	50.3 A
Furrow		0.138 A	0.283 A	7.75 A	95.2 A	0.449 A	0.037 A	0.328 A	0.780 A	0.438 A	0.587 A	39.84 A	49.3 A
Interactions													
Broadcast, Border		0.071 A	0.198 B	1.61 B	37.7 A	0.454 AB	0.082 A	0.449 A	0.716 A	0.458 A	0.570 A	30.64 A	46.4 A
Broadcast, Furrow		0.116 A	0.213 AB	1.69 B	103.2 A	0.591 A	0.023 A	0.244 A	0.651 A	0.315 A	0.549 A	30.59 A	47.6 A
Hydroseed, Border		0.071 A	0.198 AB	8.57 AB	82.7 A	0.409 AB	0.017 A	0.449 A	0.832 A	0.263 A	0.723 A	33.01 A	54.2 A
Hydroseed, Furrow		0.159 A	0.353 A	13.80 A	87.1 A	0.308 B	0.050 A	0.411 A	0.651 A	0.562 A	0.625 A	29.10 A	50.9 A
Seeding Rate, PLS/m^2													
Correlation Relationship[6]	direct		0.753	0.473	0.710	0.241				0.984		0.379	0.590
	inverse	0.672					0.740	0.801	0.210		0.463		

1 Codes are for Goodding's willow (SAGO), saltcedar (TARA), combined grasses and sedges (G/S), 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 10. ANOVA modeling results for Goodding's willow and saltcedar growth rates for the 2008 small-scale field study plots during the 2009 growing season.

Results		SAGO[1] Growth Rate[2], cm/day	TARA Growth Rate, cm/day
Main Effects		**p Values[3]**	
Irrigation Treatment		0.897	0.002
Surface Irrigation Method		0.871	0.553
Goodding's Willow Crown Cover[5]		0.008	0.009
Goodding's Willow Stem Density		<0.005	0.092
Saltcedar Crown Cover		0.822	0.504
Saltcedar Stem Density		0.0.743	0.033
Initial Tree Height[6]		<0.0001	<0.0001
Irrigation Treatment[7]		**Means and Significant Differences[4]**	
	A	0.256 A	0.071 B
	B	0.248 A	0.134 A
Surface Irrigation Method			
	Border-strip	0.249 A	0.108 A
	Furrow	0.255 A	0.098 A
Goodding's Willow Crown Cover			
	0-10%	0.163 B	0.124 AB
	10.01-20%	0.183 B	0.137 A
	20.01-30%	0.410 A	0.047 B
Goodding's Willow Stem Density, stems/m^2			
	0-10	0.360 A	0.113 A
	10.01-20	0.240 B	0.067 A
	20.01-30	0.156 B	0.129 A
Saltcedar Crown Cover			
	0-30	--	0.143 A
	30.01-60%	0.261 A	0.080 A
	60.01-90%	0.243 A	0.085 A
Saltcedar Stem Density, stems/m^2			
	0-9.30	0.261 A	0.109 AB
	9.31-18.60	0.231 A	0.080 B
	18.61-27.90	0.264 A	0.120 A
Initial Tree Height, cm			
Correlation Relationship[6]	direct	<0.0001	<0.0001
	inverse		

1 Codes are for Goodding's willow (SAGO) and saltcedar (TARA).
2 Growth rate between May, 2009 and October, 2009 surveys.
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 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.
6 Height as measured during May 2008 surveys.
7 Codes indicated shallow, frequent irrigation (A) or deep, infrequent irrigation (B).
8 Relationships denote a direct or inverse correlation between treatments and respective seeding rates.

Table 11. 2009 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.
Surface Irrigation Method	Furrow	Furrows on 1.02 m spacing.
Seeding Rate	540 PLS/m^2	Target seeding rate of 540 PLS/m^2, actual seeding rate of 579 PLS/m^2 estimated by hydroseed application duration.
	1,080 PLS/m^2	Target seeding rate of 1,080 PLS/m^2, actual seeding rate of 1,150 PLS/m^2 estimated by hydroseed application duration.
	1,600 PLS/m^2	Target seeding rate of 1,600 PLS/m^2, actual seeding rate of 1,685 PLS/m^2 estimated by hydroseed application duration.

Table 12. Applied water summary for 2009 growing season, 2009 Goodding's willow plots.

Northern Plots		
Date	**Irrigation depth (cm)**	**Elapsed Time (days)[1]**
6/6/2009	11.96	—
6/9/2009	6.79	3
6/11/2009	10.19	2
6/15/2009	9.04	4
6/18/2009	9.65	3
6/24/2009	9.24	6
6/26/2009	10.13	2
6/29/2009	9.94	3
7/1/2009	8.41	2
7/3/2009	8.81	2
7/7/2009	10.45	4
7/9/2009	8.91	2
7/13/2009	9.38	4
7/16/2009	8.70	3
7/22/2009	9.78	6
7/24/2009	9.46	2
7/28/2009	9.08	4
7/31/2009	7.87	3
8/5/2009	8.38	5
8/12/2009	8.71	7
8/14/2009	7.50	2
8/18/2009	8.06	4
8/20/2009	7.61	2
8/22/2009	8.11	2
8/27/2009	8.35	5
9/1/2009	8.34	5
9/4/2009	8.06	3
9/8/2009	7.13	4
9/11/2009	6.52	3
9/17/2009	7.35	6
9/21/2009	7.60	4
10/2/2009	7.39	11
10/8/2009	7.41	6
10/21/2009	7.18	13
Total Irrigation (cm)		291.48
Rainfall (cm)[2]		1.09
Estimated Reference Evapotranspiration (cm)[2]		135.28
Irrigation and Rainfall/ET_o		2.16

1 Days since previous irrigation event (rainfall not included).
2 Data from US Fish and Wildlife Service Cibola weather station, available: http://www.wrcc.dri.edu/cgi-bin/rawMAIN.pl?azACBL.

Table 13. 2009 Goodding's willow small-scale study result averages and significant differences for Goodding's willow (SAGO), saltcedar (TARA), grasses and sedges (G/S), and shrubs and forbs (S/F) per plot.[1]

Seeding Rate, PLS/m^2	Crown Cover				Canopy Cover			
	SAGO	TARA	G/S	S/F	SAGO	TARA	G/S	S/F
579	0.08 A	0.12 A	0.10 B	0.69 A	0.14 A	0.23 A	0.25 A	0.93 A
1150	0.11 A	0.16 A	0.18 AB	0.53 AB	0.18 A	0.28 A	0.28 A	0.92 A
1685	0.23 A	0.11 A	0.23 A	0.43 B	0.36 A	0.21 A	0.36 A	0.87 A

1 Numbers show arithmetic means, letters denote significant differences at p=0.05 each column.

Table 14. 2009 Goodding's willow small-scale study result averages and significant differences for Goodding's willow (SAGO) density and percent establishment, and saltcedar (TARA) density.[1]

Seeding Rate, PLS/m^2	SAGO Stems/m^2	Percent SAGO Establishment	TARA Stems/m^2
579	12.0 A	2.2 A	4.7 A
1150	13.8 A	1.3 A	6.2 A
1685	29.9 B	1.8 A	6.2 A

1 Numbers show arithmetic means, letters denote significant differences at p=0.05 each column.

Table 15. Number of functioning soil volumetric water content sensors by year for 2007 study plots.

Irrigation Block	2008			2009		
	15 cm bgs	46 cm bgs	91 cm bgs	15 cm bgs	46 cm bgs	91 cm bgs
A1	3	9	9	2	9	9
A2	3	9	9	3	9	9
B1	2	9	8	3	9	8
B2	5	9	9	0	9	7

Table 16. Field conductivity meter-measured groundwater specific conductance for Field 51 piezometers monitoring during the 2009 growing season.

Piezometer	Specific Conductance (EC), dS/m					
	3/30/2009	4/27/2009	6/1/2009	7/16/2009	9/4/2009	10/11/2009
PZ-SAGO N	1.6	1.8	1.6	1.6	1.5	1.8
PZ-SAGO S	1.5	1.8	1.9	1.9	2.2	2.5
PZ-SSN	--	2.7	2.1	4.0	1.8	1.8
PZ-SSC	2.0	2.7	2.2	--	2.0	2.0
PZ-SE	--	--	--	2.4	2.1	1.6
PZ-SW	--	--	--	1.1	3.0	3.2
PZ-NW	--	--	--	2.4	3.0	2.7
PZ-C	--	--	--	2.0	2.6	2.7
Mean	**1.7**	**2.3**	**2.0**	**2.2**	**2.3**	**2.3**
Irrigation Water	1.0	--	1.0	--	--	--

Table 17. Laboratory results for major cations and anions for Field 51 piezometers monitored during the 2009 growing season.

Location	Date	Ca mg/L	Mg mg/L	K mg/L	Na mg/L	Cl Mg/L	Fl mg/L	NO3- mg/L	Sulfate mg/L
PZ - SSN	4/27/2009	480	110	19	240	200	ND	ND	450
	10/11/2009	140	61	9.3	220	50	ND	ND	250
PZ - SSC	4/27/2009	200	70	17	210	220	ND	ND	400
	10/11/2009	160	58	20	240	210	ND	ND	380
PZ – SAGO N	4/27/2009	200	76	15	220	140	0.57	ND	340
	10/11/2009	130	68	13	200	160	ND	ND	350
PZ – SAGO S	4/27/2009	180	65	8.8	170	150	0.58	ND	410
	10/11/2009	170	76	9.3	260	220	ND	ND	500

Table 18. Laboratory results for alkalinity, specific conductivity (EC), and total dissolved solids (TDS) for Field 51 piezometers monitored during the 2009 growing season.

Location	Date	Bicarbonate mg/L	Carbonate mg/L	Hydroxide mg/L	Total Alkalinity mg/L	EC dS/m	TDS mg/L
PZ - SSN	4/27/2009	400	ND	ND	400	2.7	1,200
	10/11/2009	340	ND	ND	340	2.3	1,200
PZ - SSC	4/27/2009	360	ND	ND	360	2.7	1,300
	10/11/2009	340	ND	ND	340	2.3	1,300
PZ - SAGON	4/27/2009	380	ND	ND	380	1.8	1,000
	10/11/2009	300	ND	ND	300	2.1	1,100
PZ - SAGOS	4/27/2009	320	ND	ND	320	1.8	1,000
	10/11/2009	310	ND	ND	310	2.7	1,500

Table 19. Decrease in total soil water between 3/1/08 and 10/31/08 by depth interval, location and irrigation block.

Irrigation Block	ΔS South 0-30 cm	ΔS South 30-69 cm	ΔS South 69-165 cm	ΔS South All	ΔS North 0-30 cm	ΔS North 30-69 cm	ΔS North 69-165 cm	ΔS North All
	cm	cm	cm	cm	cm	cm	cm	cm
Shallow Block A	-59.81	-16.57	-15.08	-91.47	-57.13	-8.36	-12.59	-78.08
Deep Block B	-52.41	-9.51	-11.46	-73.38	-58.29	-13.77	-10.46	-82.53

Table 20. Decrease in total soil water between 3/1/09 and 10/11/09 by depth interval, location and irrigation block.

Irrigation Block	ΔS South 0-30 cm	ΔS South 30-69 cm	ΔS South 69-165 cm	ΔS South All	ΔS North 0-30 cm	ΔS North 30-69 cm	ΔS North 69-165 cm	ΔS North All
	cm	cm	cm	cm	cm	cm	cm	cm
Shallow Block A	-54.46	-4.11	-4.61	-63.19	-33.27	-2.84	-1.47	-37.58
Deep Block B	NA[1]	-7.31	-9.85	NA[1]	-34.62	-10.48	-4.74	-49.83

1 Due to loss of 15 cm bgs sensors in Block B2 (south).

FIGURES

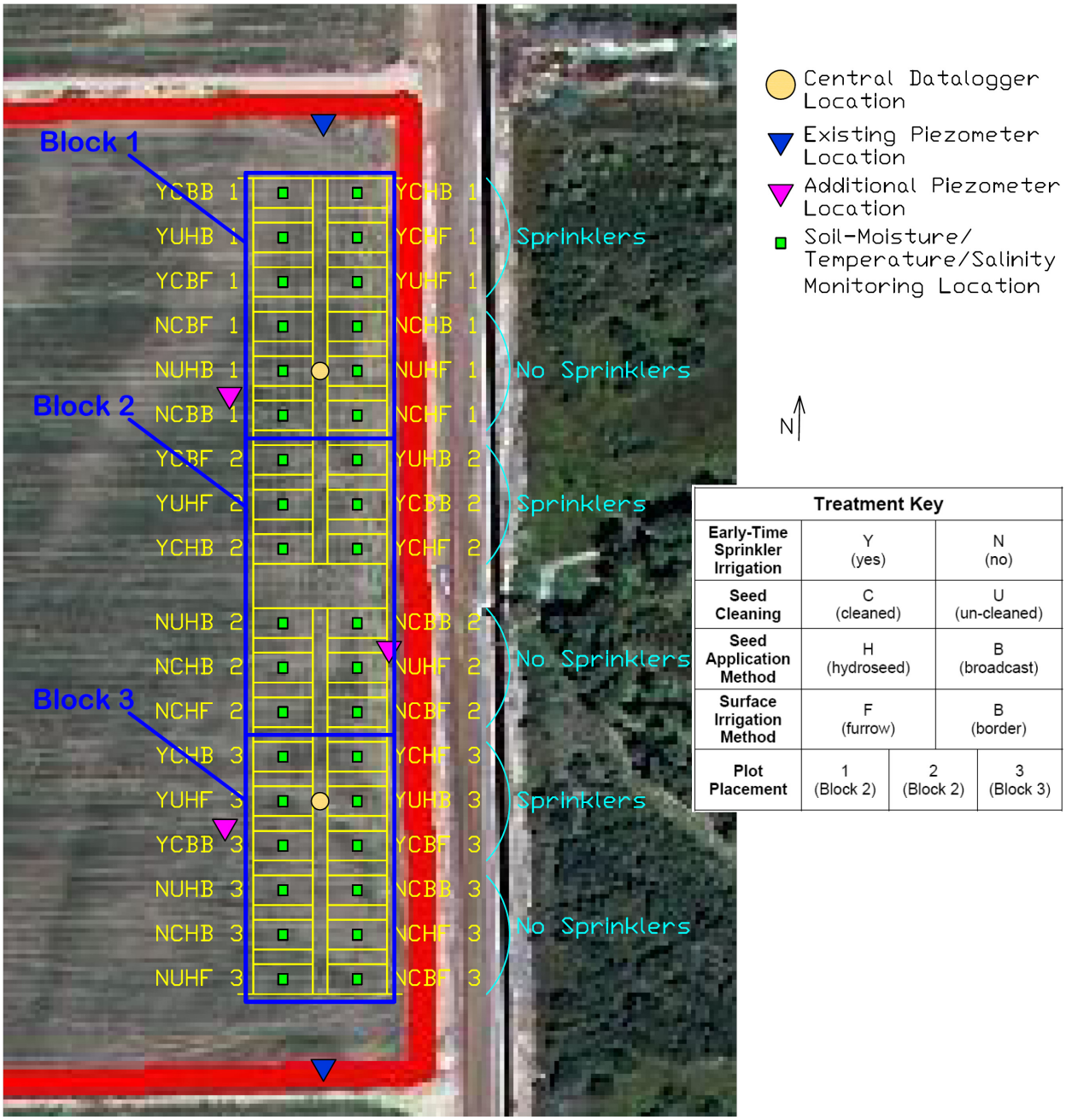
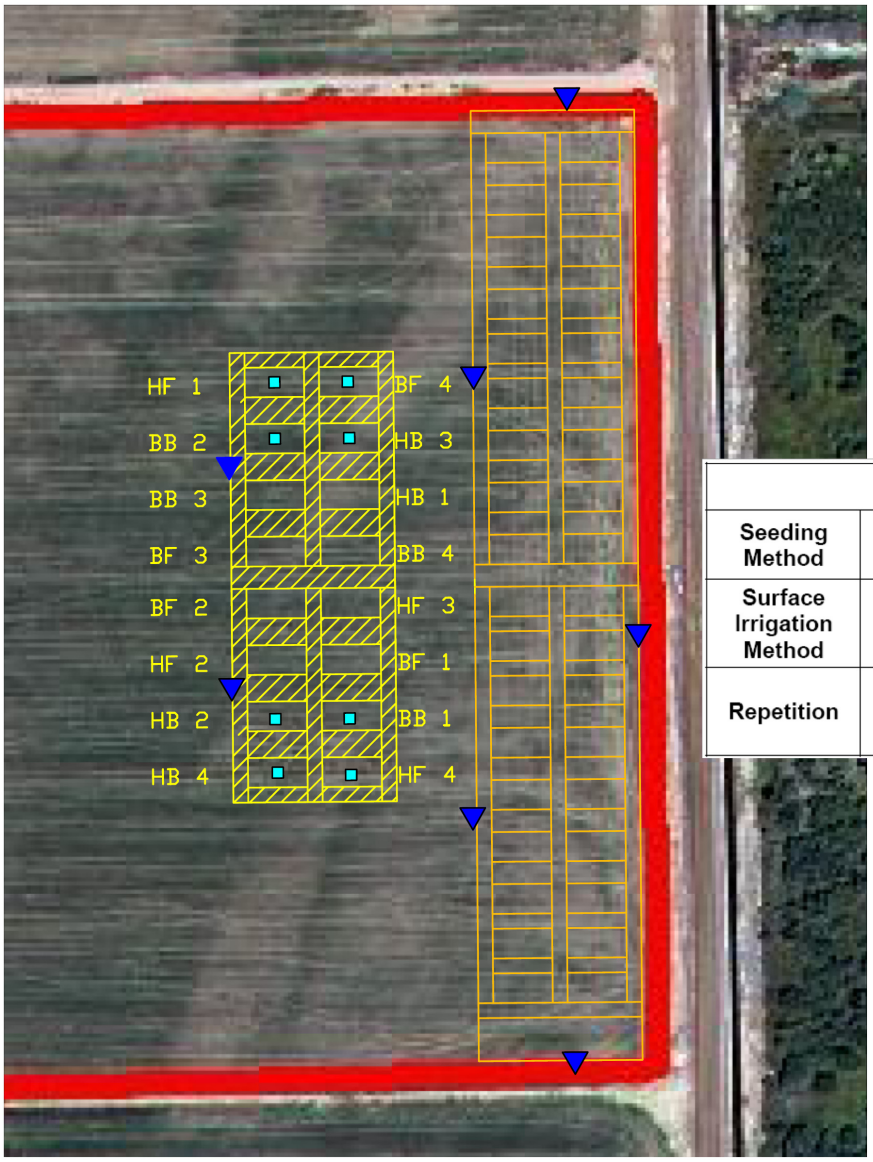


Figure 1. Layout and treatments for 2007 small-scale field study plots at Cibola NWR Field 51.



Treatment Key				
Seeding Method	B (Broadcast Cleaned)		U (Hydroseed Un-cleaned)	
Surface Irrigation Method	F (furrow)		B (border)	
Repetition	1	2	3	4

Figure 2. Layout and treatments for 2008 small-scale field study plots at Cibola NWR Field 51.

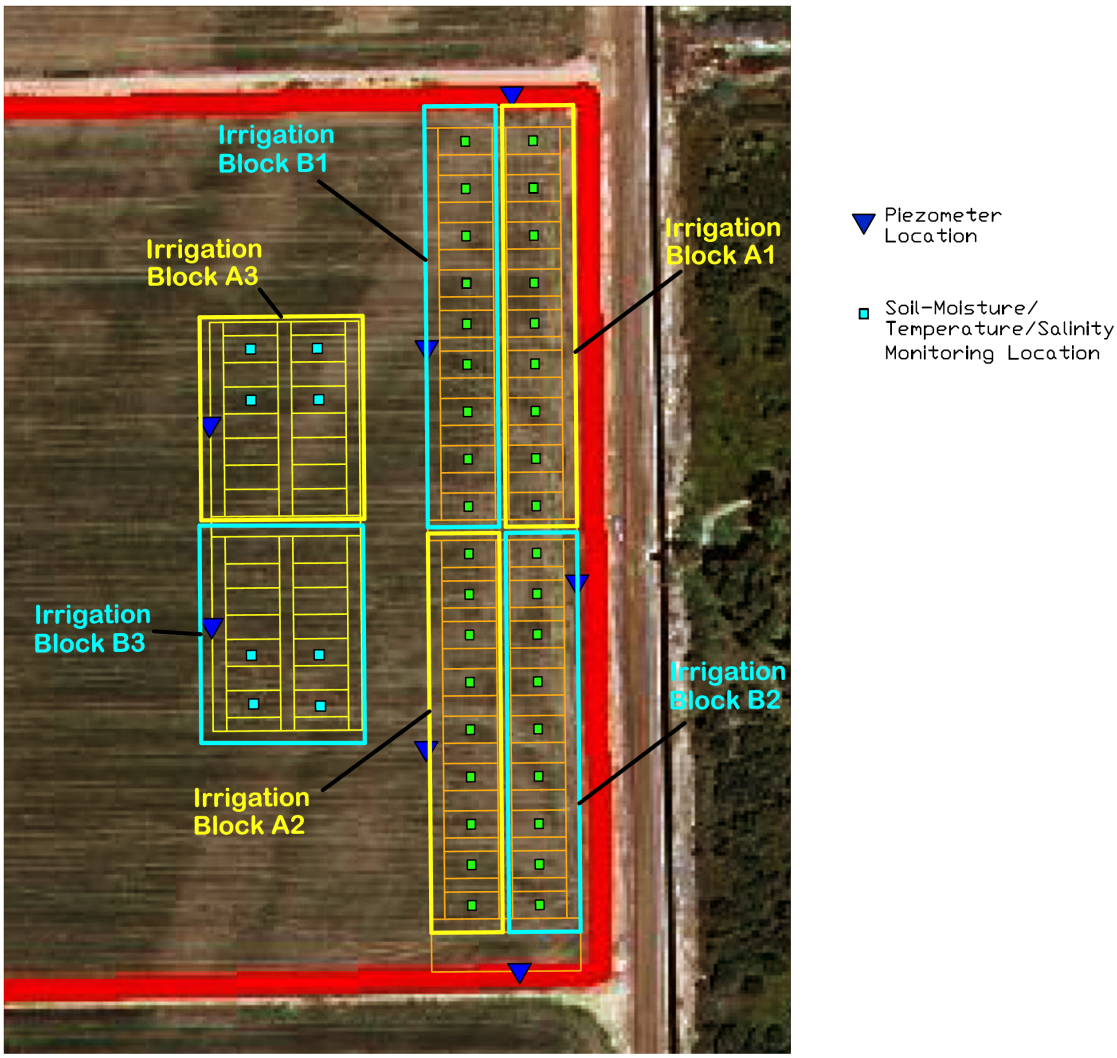


Figure 3. 2009 growing season irrigation block layout for 2007 and 2008 small-scale field study plots at Cibola NWR Field 51.

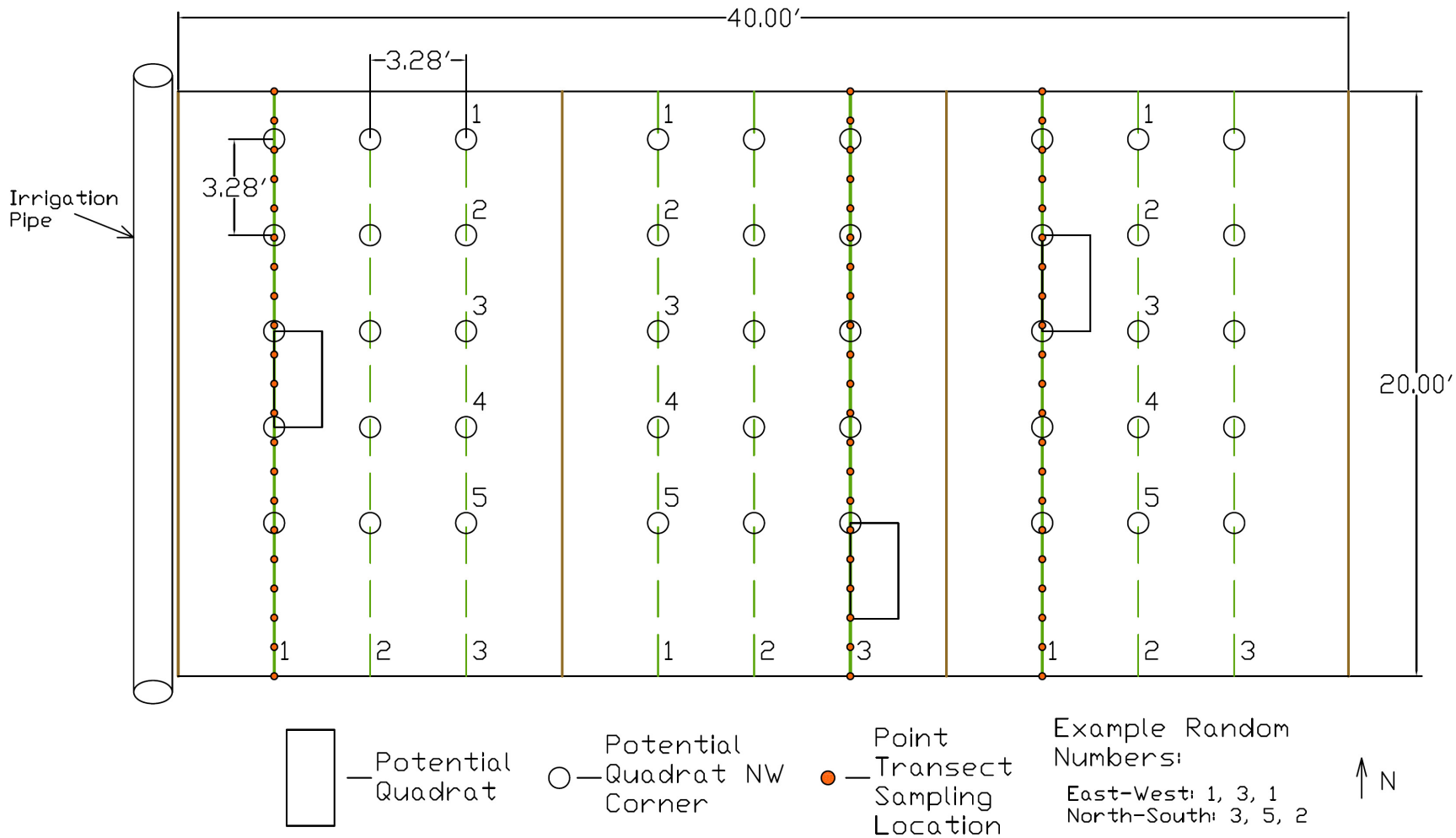


Figure 4. Example vegetation monitoring schematic for small-scale field study plots at Cibola NWR Field 51.

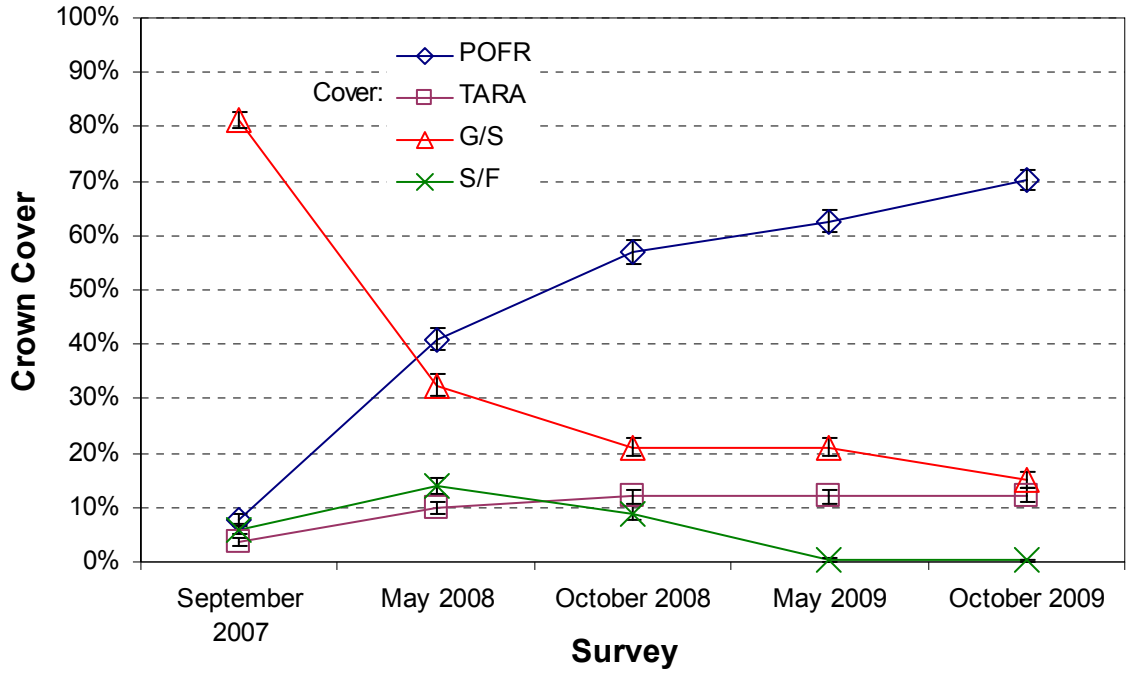


Figure 5. Vegetation crown cover trends for Fremont cottonwood (POFR), saltcedar (TARA), grasses and sedges (G/S), and shrubs and forbs (S/F) in 2007 study plots.

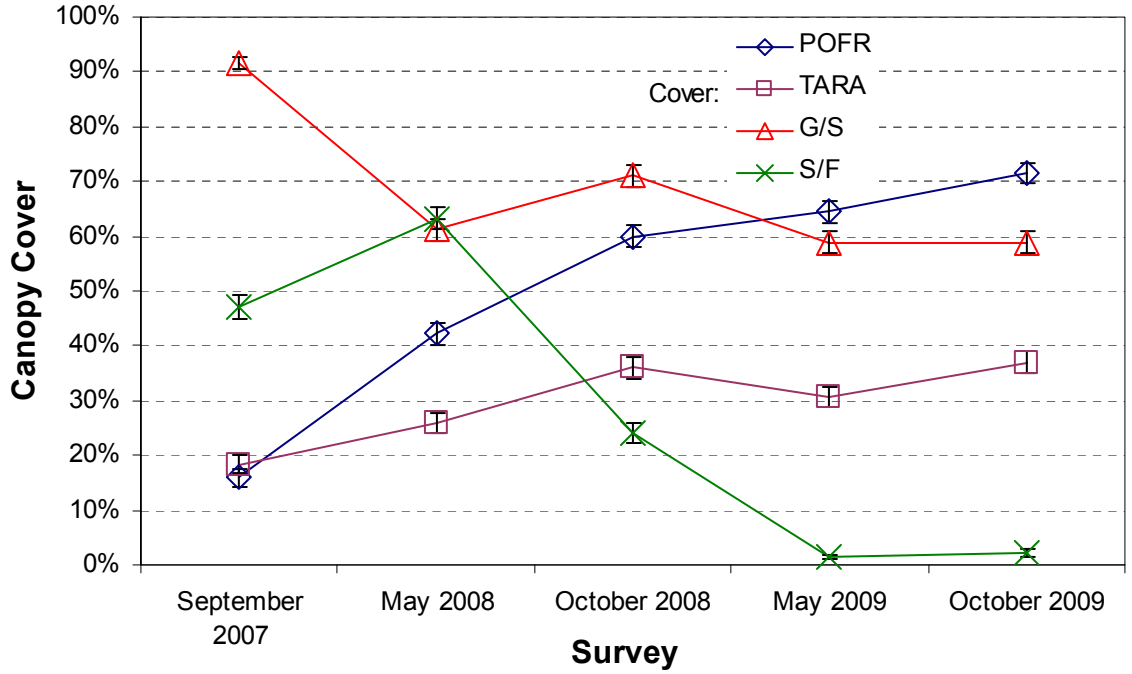


Figure 6. Vegetation canopy cover trends for Fremont cottonwood (POFR), saltcedar (TARA), grasses and sedges (G/S), and shrubs and forbs (S/F) in 2007 study plots.

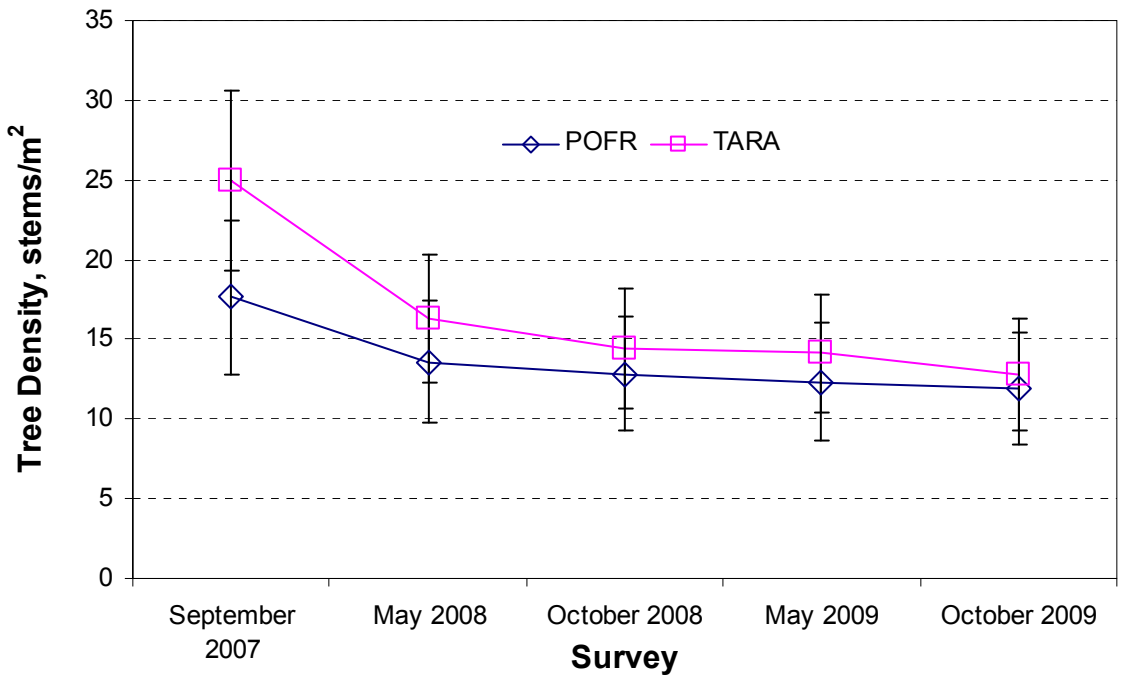


Figure 7. Fremont cottonwood (POFR) and saltcedar (TARA) tree density trends in 2007 small-scale study plots.

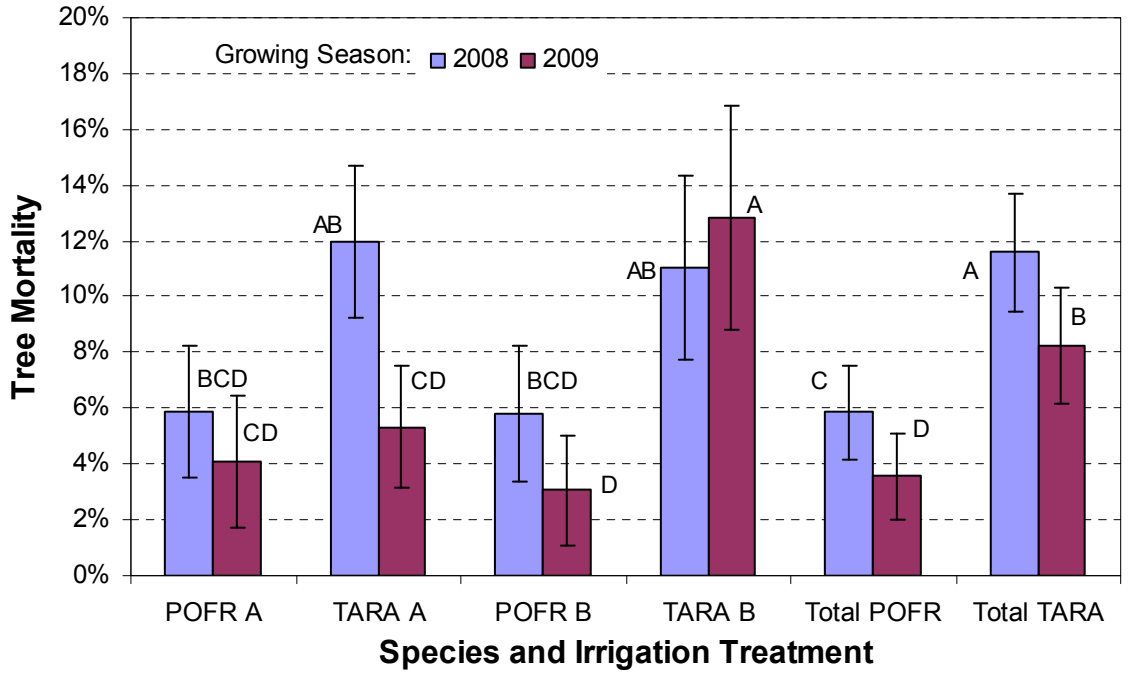


Figure 8. Fremont cottonwood (POFR) and saltcedar (TARA) mortality rates versus irrigation method and growing season in 2007 study plots for all heights combined. Letters indicate significant differences across all columns (Student's t-test, α=0.05).

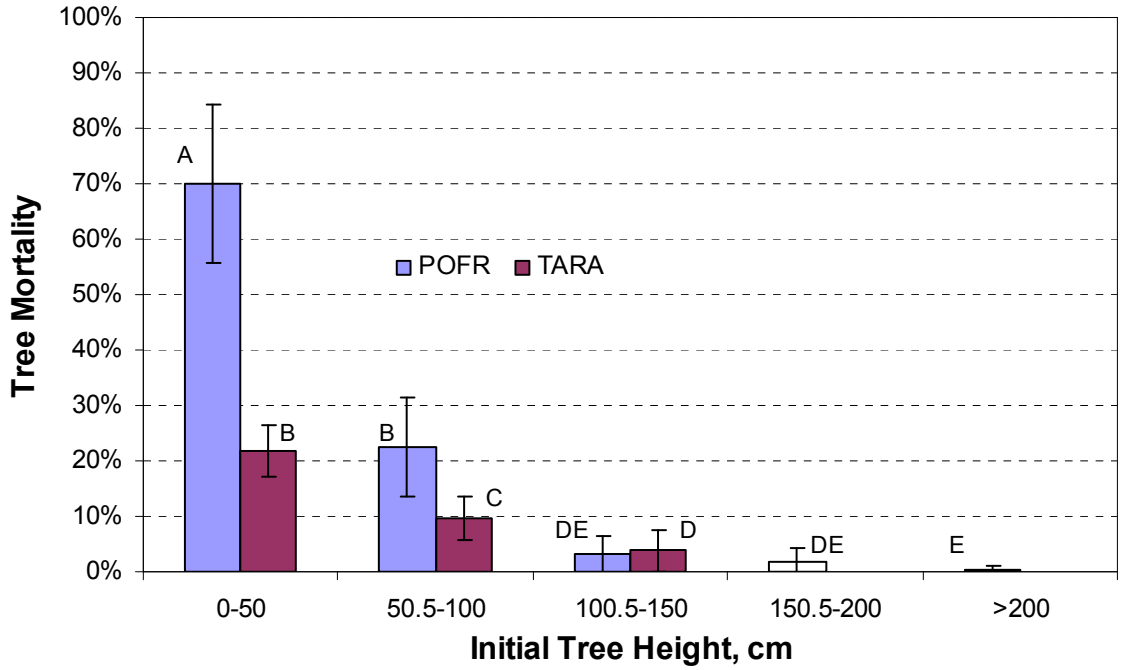


Figure 9. Fremont cottonwood (POFR) and saltcedar (TARA) mortality rates (combined irrigation treatments) versus initial tree height (May 2009) in 2007 study plots during the 2009 growing season. Letters indicate significant differences across all columns (Student's t-test, α=0.05).

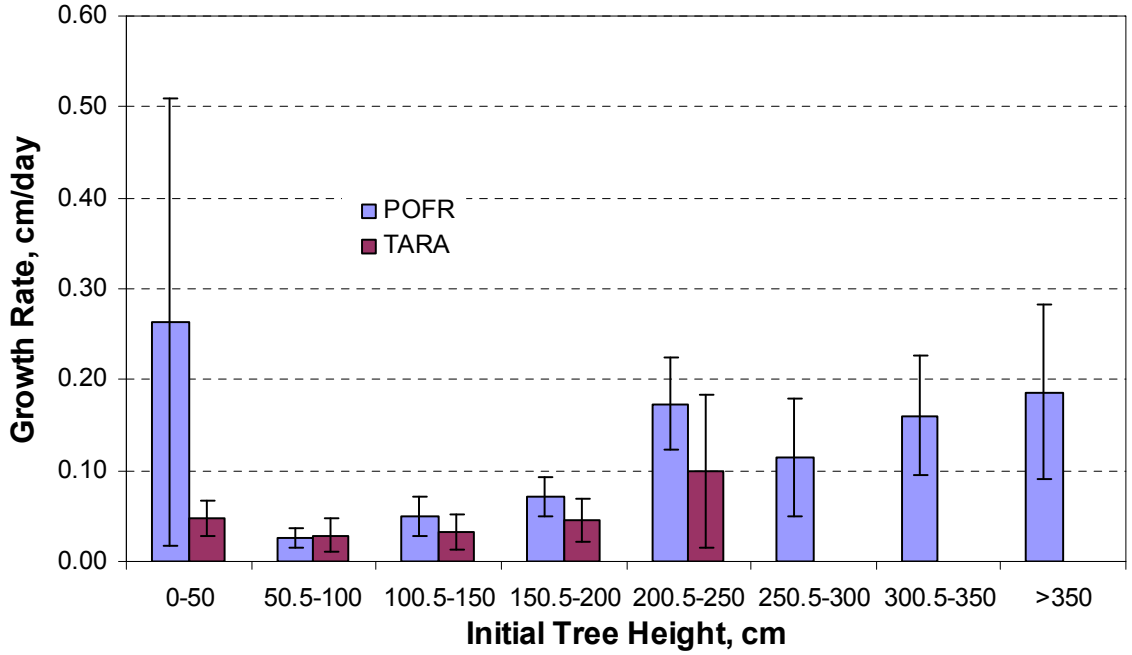


Figure 10. Fremont cottonwood (POFR) and saltcedar (TARA) growth rate versus initial height (May 2009) in 2007 study plots during the 2009 growing season, A blocks only. * indicates significant differences between paired columns (Student's t-test, α=0.05).

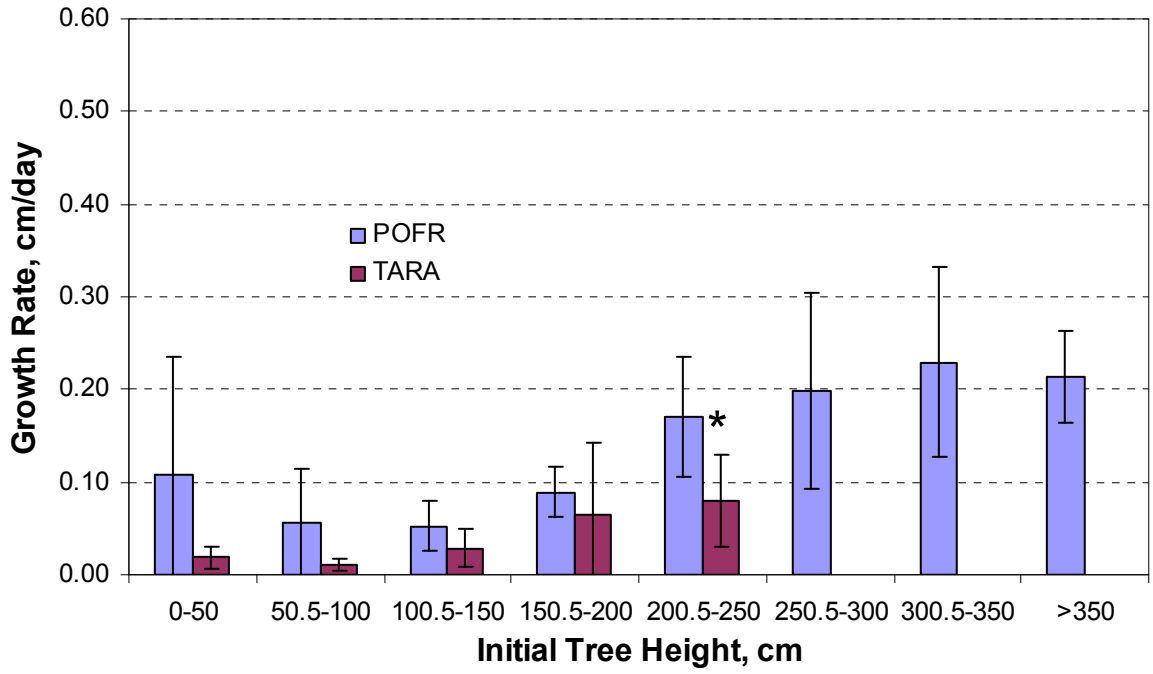


Figure 11. Fremont cottonwood (POFR) and saltcedar (TARA) growth rate versus initial height (May 2009) in 2007 study plots during the 2009 growing season, B blocks only. * indicates significant differences between paired columns (Student's t-test, α=0.05).

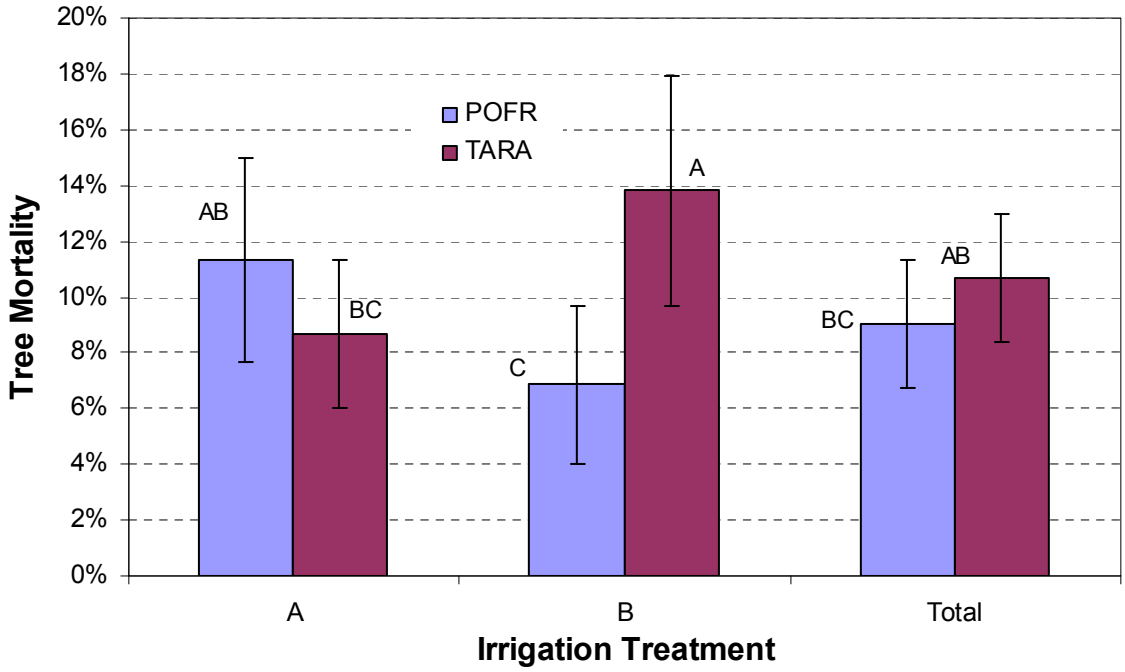


Figure 12. Fremont cottonwood (POFR) and saltcedar (TARA) mortality rates versus irrigation method in 2007 study plots between the fall 2008 and fall 2009 surveys for all heights combined. Letters indicate significant differences across all columns (Student's t-test, α=0.05).

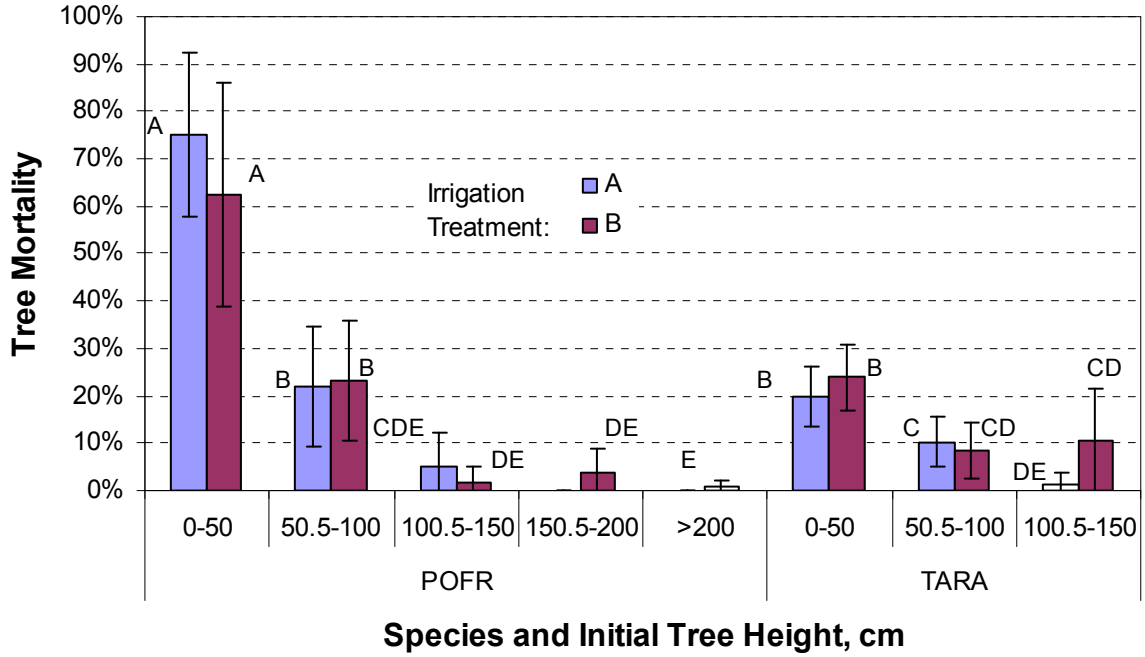


Figure 13. Fremont cottonwood (POFR) and saltcedar (TARA) mortality rates versus initial height (May 2009) and irrigation method in 2007 study plots during the 2009 growing season. Letters indicate significant differences across all columns (Student's t-test, α=0.05).

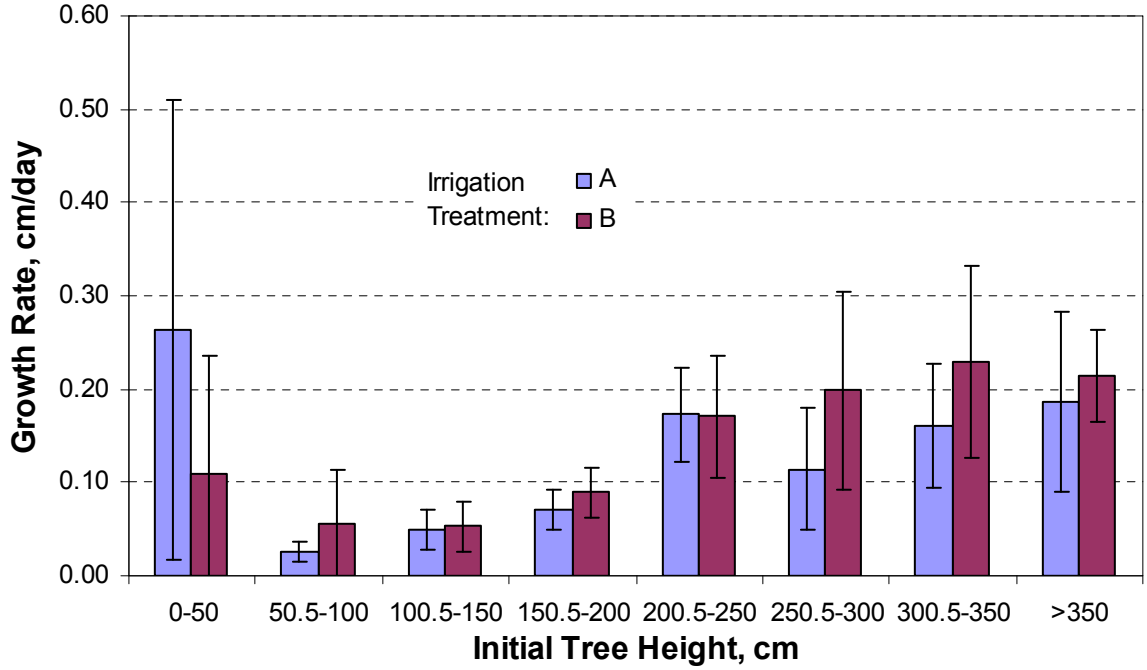


Figure 14. Fremont cottonwood growth rate versus initial height (May 2009) and irrigation method in 2007 study plots during the 2009 growing season. * indicates significant differences between paired columns (Student's t-test, α=0.05).

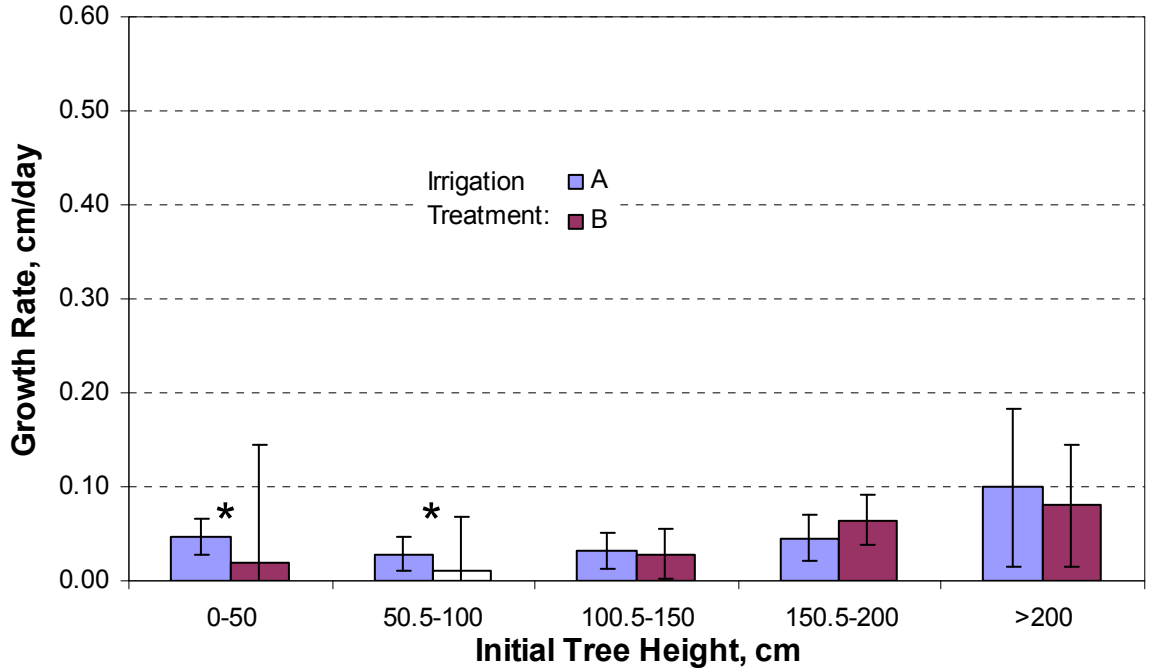


Figure 15. Saltcedar growth rate versus initial height (May 2009) and irrigation method in 2007 study plots during the 2009 growing season. * indicates significant differences between paired columns (Student's t-test, α=0.05).

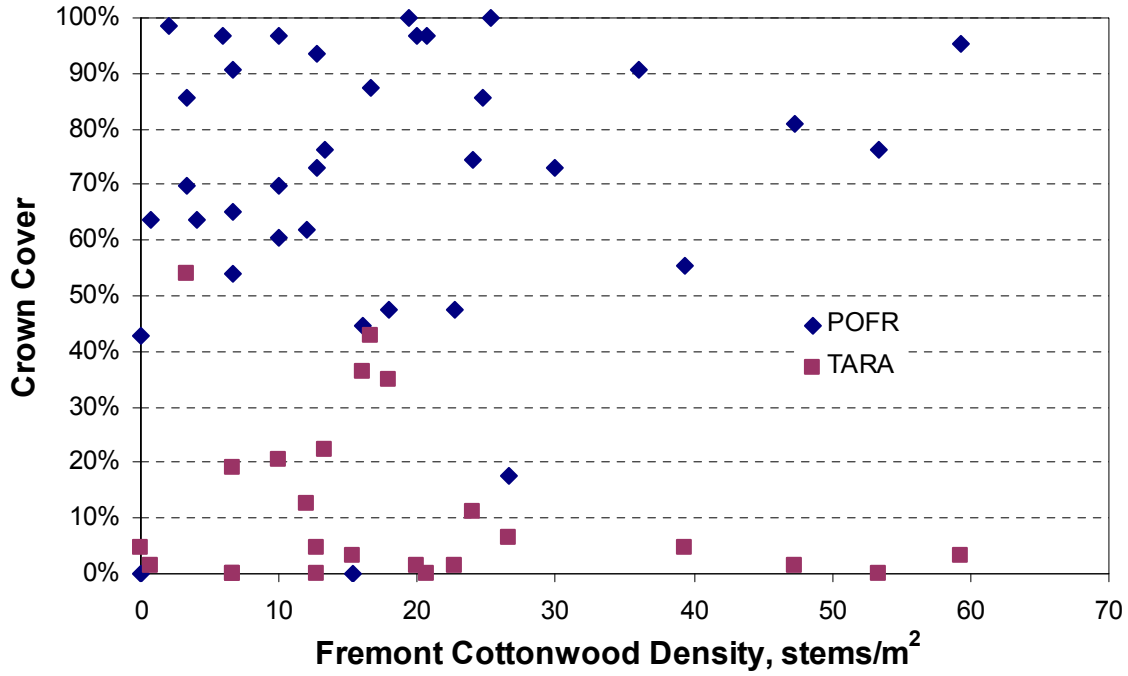


Figure 16. Fremont cottonwood (POFR) and Saltcedar (TARA) crown cover after three growing seasons (October 2009) versus Fremont cottonwood stem density after the first growing season (September 2007).

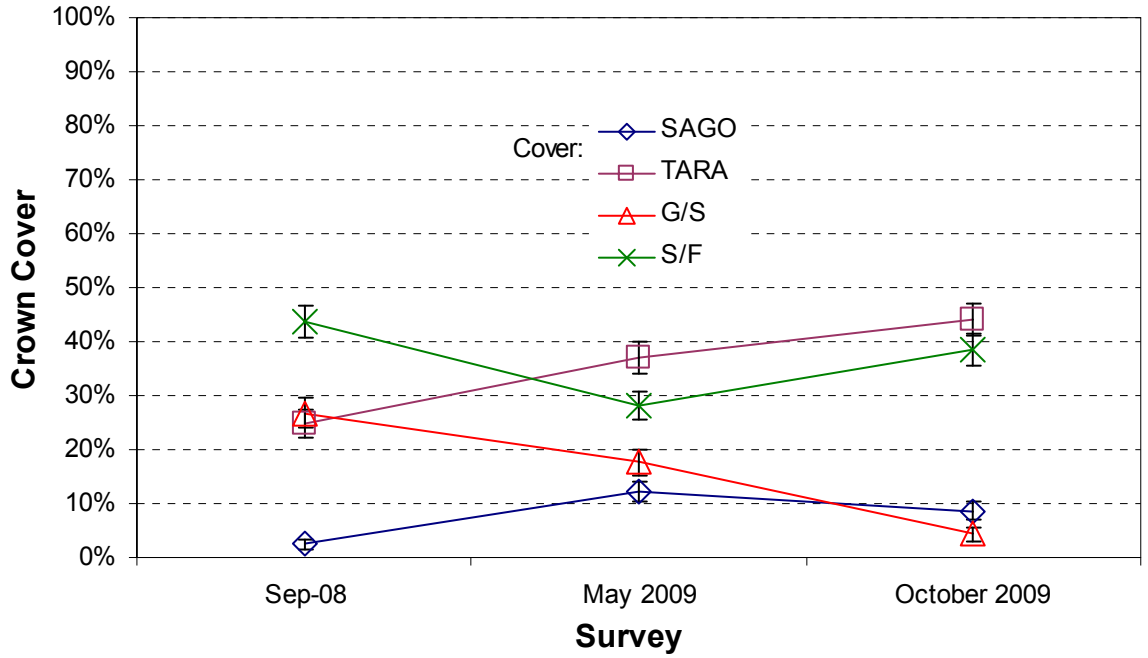


Figure 17. Vegetation crown cover trends for Goodding's willow (SAGO), saltcedar (TARA), grasses and sedges (G/S), and shrubs and forbs (S/F) in 2008 study plots.

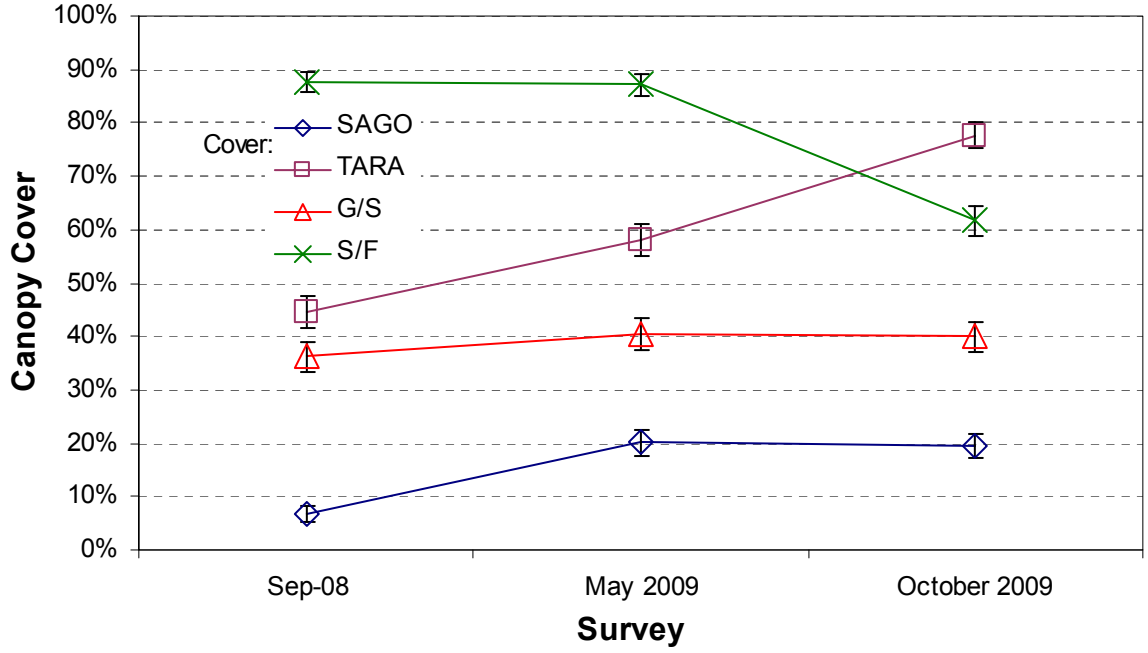


Figure 18. Vegetation canopy cover trends for Goodding's willow (SAGO), saltcedar (TARA), grasses and sedges (G/S), and shrubs and forbs (S/F) in 2008 study plots.

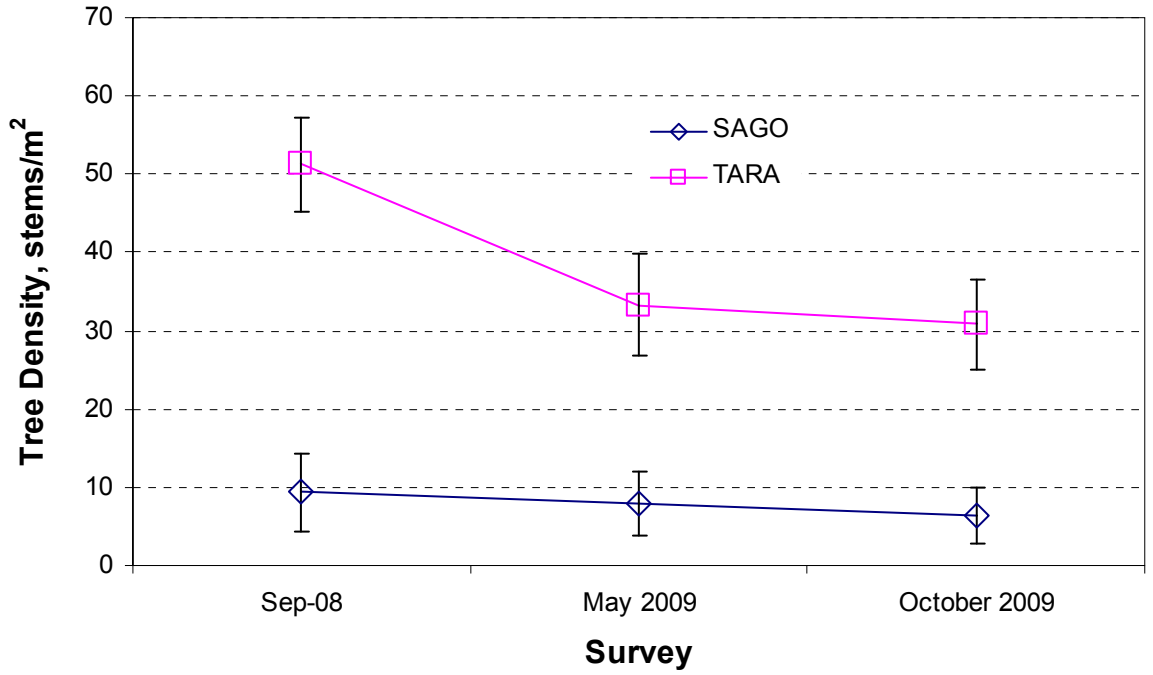


Figure 19. Goodding's willow (SAGO) and saltcedar (TARA) tree density trends in 2008 small-scale study plots.

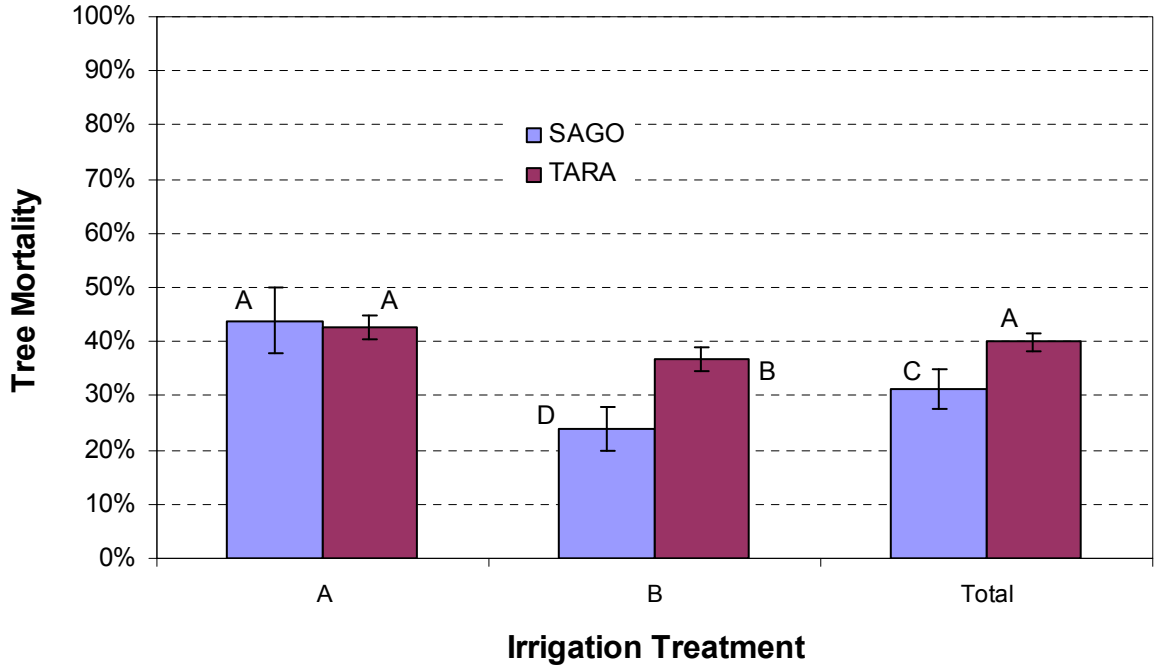


Figure 20. Goodding's willow (SAGO) and saltcedar (TARA) mortality rates versus irrigation method in 2008 study plots between the fall 2008 and fall 2009 surveys for all heights combined using quadrat data. Letters indicate significant differences across all columns (Student's t-test, α=0.05).

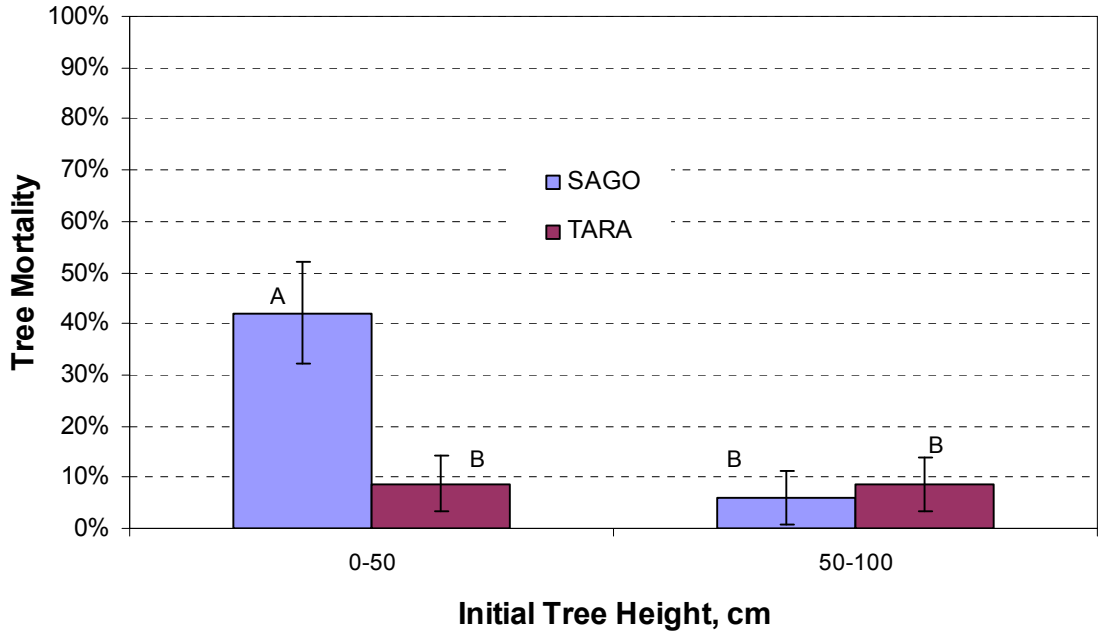


Figure 21. Goodding's willow (SAGO) and saltcedar (TARA) mortality rates (combined irrigation treatments) by initial tree height (May 2009) in 2008 study plots during the 2009 growing season. Letters indicate significant differences across all columns (Student's t-test, α=0.05).

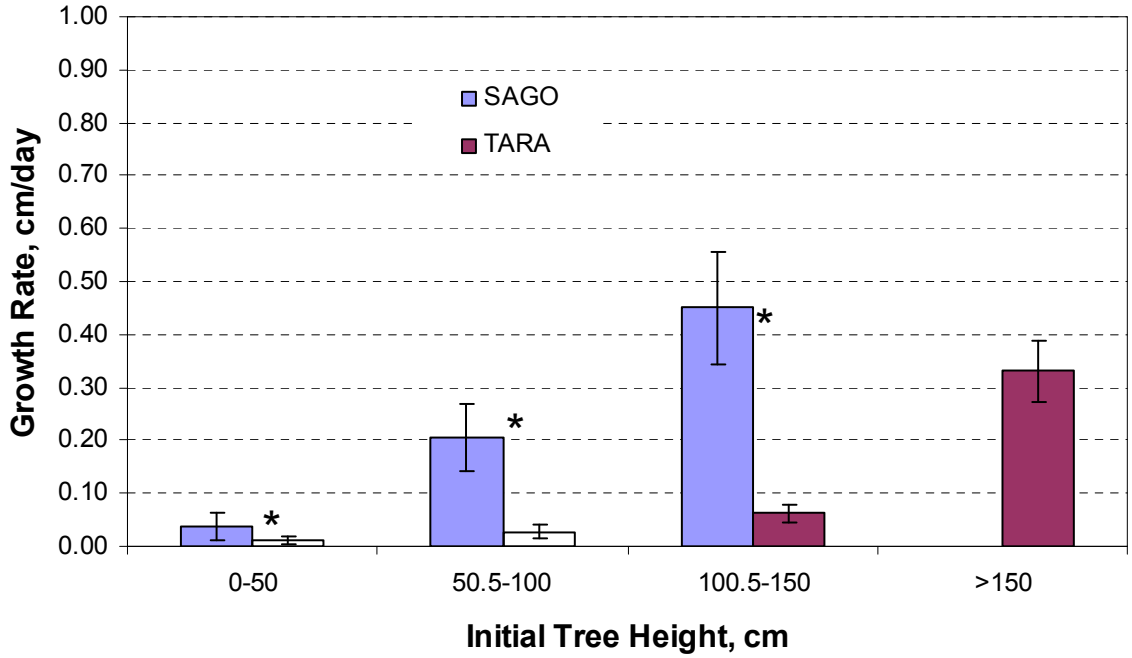


Figure 22. Goodding's willow (SAGO) and saltcedar (TARA) growth rate versus initial height (May 2009) in 2008 study plots during the 2009 growing season, A blocks only. * indicates significant differences between paired columns (Student's t-test, α=0.05).

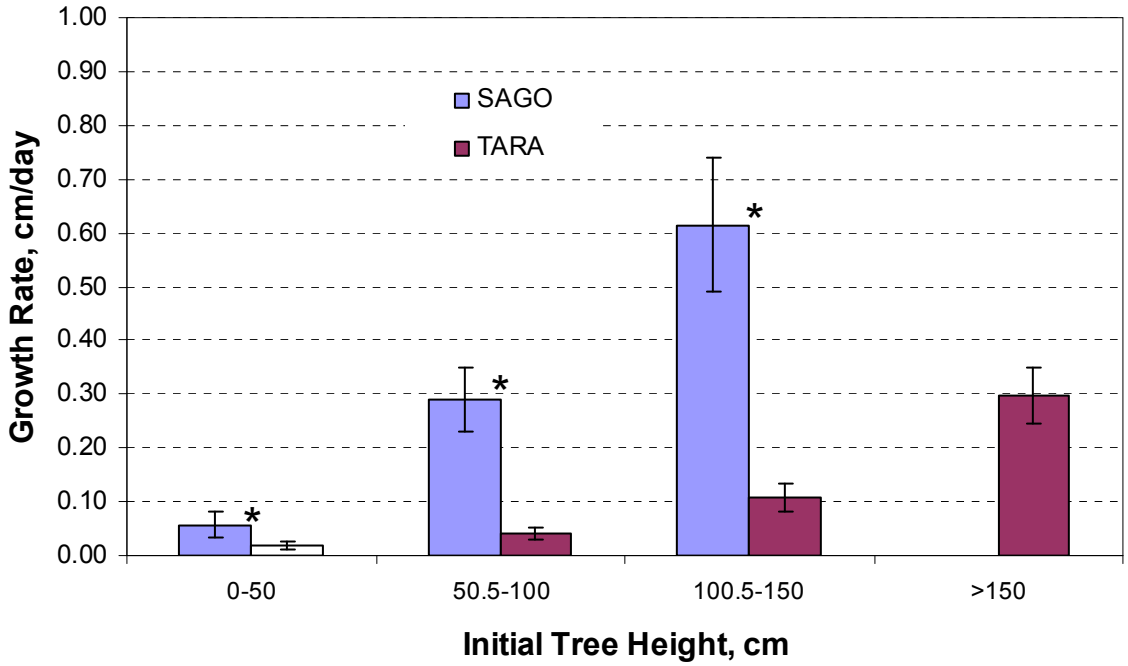


Figure 23. Goodding's willow (SAGO) and saltcedar (TARA) growth rate versus initial height (May 2009) in 2008 study plots during the 2009 growing season, B blocks only. * indicates significant differences between paired columns (Student's t-test, α=0.05).

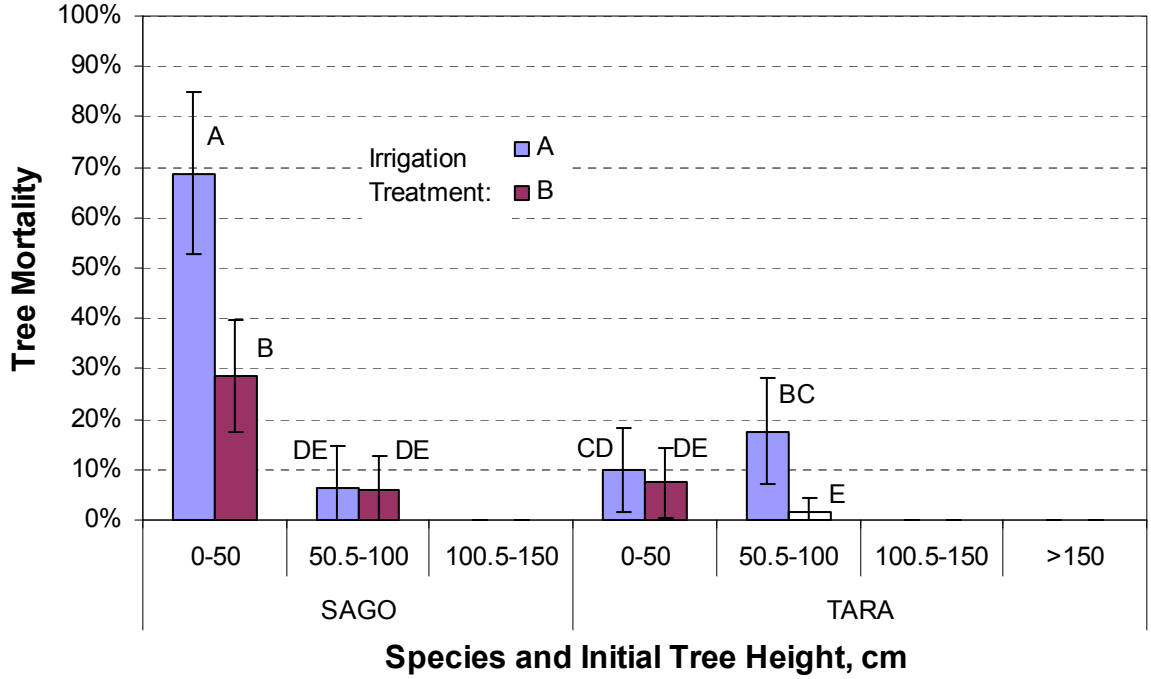


Figure 24. Goodding's willow (SAGO) and saltcedar (TARA) mortality rates versus initial tree height (May 2009) and irrigation method in 2008 study plots during the 2009 growing season. Letters indicate significant differences across all columns (Student's t-test, α=0.05).

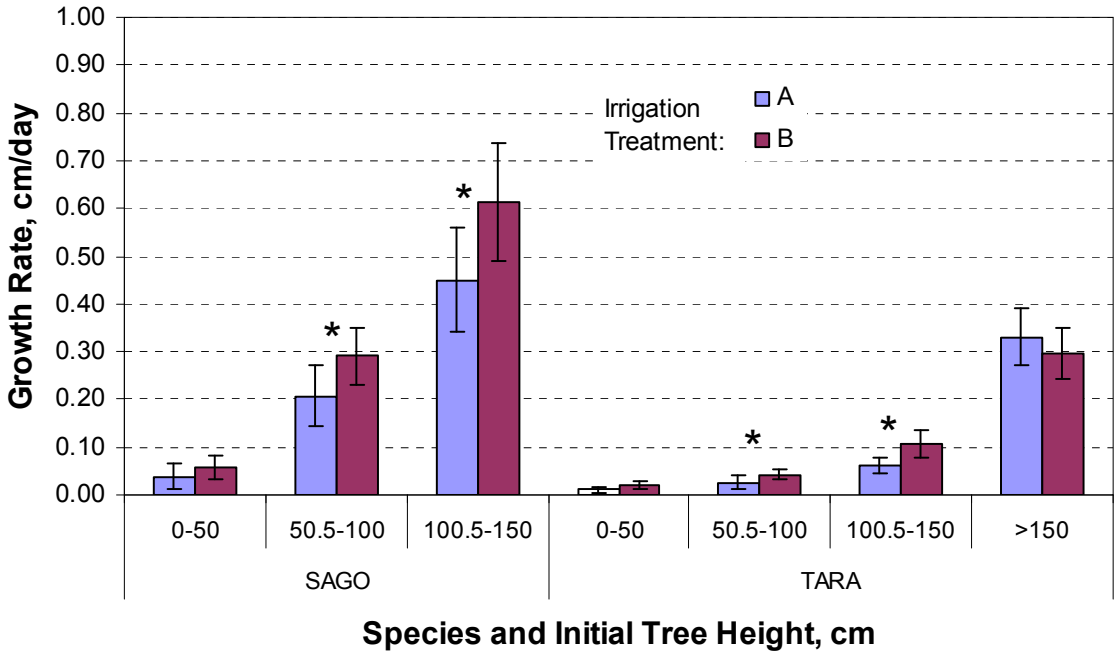


Figure 25. Goodding's willow (SAGO) and saltcedar (TARA) growth rates versus initial tree height (May 2009) and irrigation method in 2008 study plots during the 2009 growing season. * indicates significant differences between paired columns (Student's t-test, α=0.05).

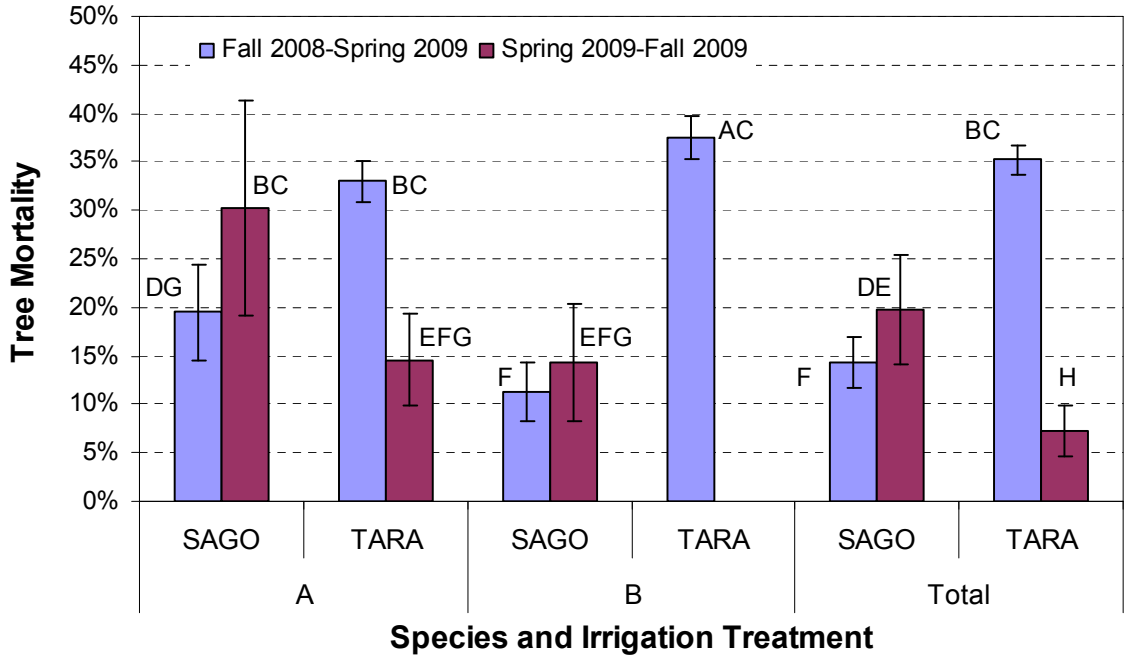


Figure 26. Goodding's willow (SAGO) and saltcedar (TARA) mortality rates versus irrigation method in 2008 study plots over the 2008-2009 winter and the 2009 growing seasons for all heights combined. Letters indicate significant differences across all columns (Student's t-test, α=0.05).

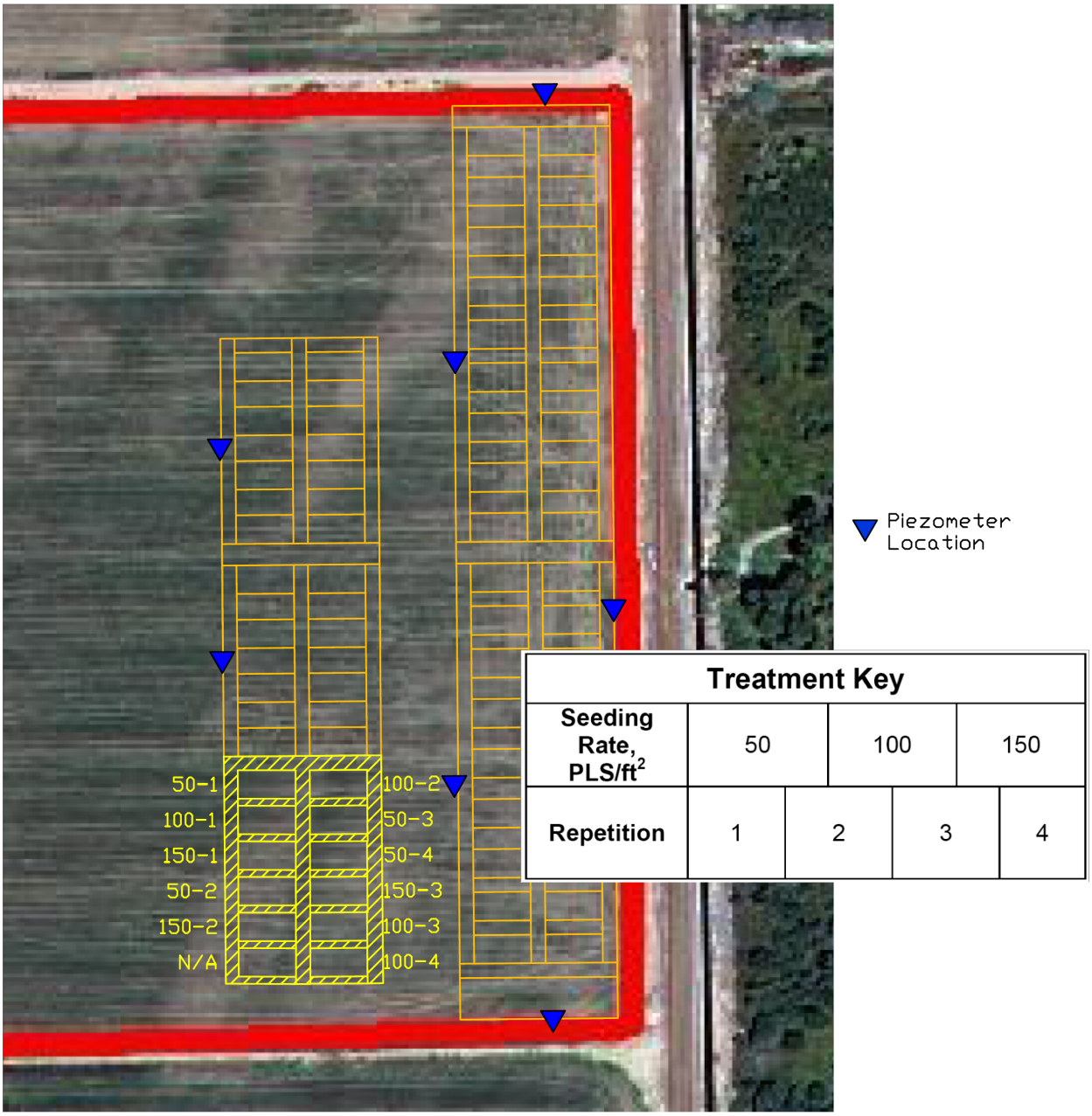


Figure 27. Layout and treatments for 2009 small-scale field study plots at Cibola NWR Field 51.

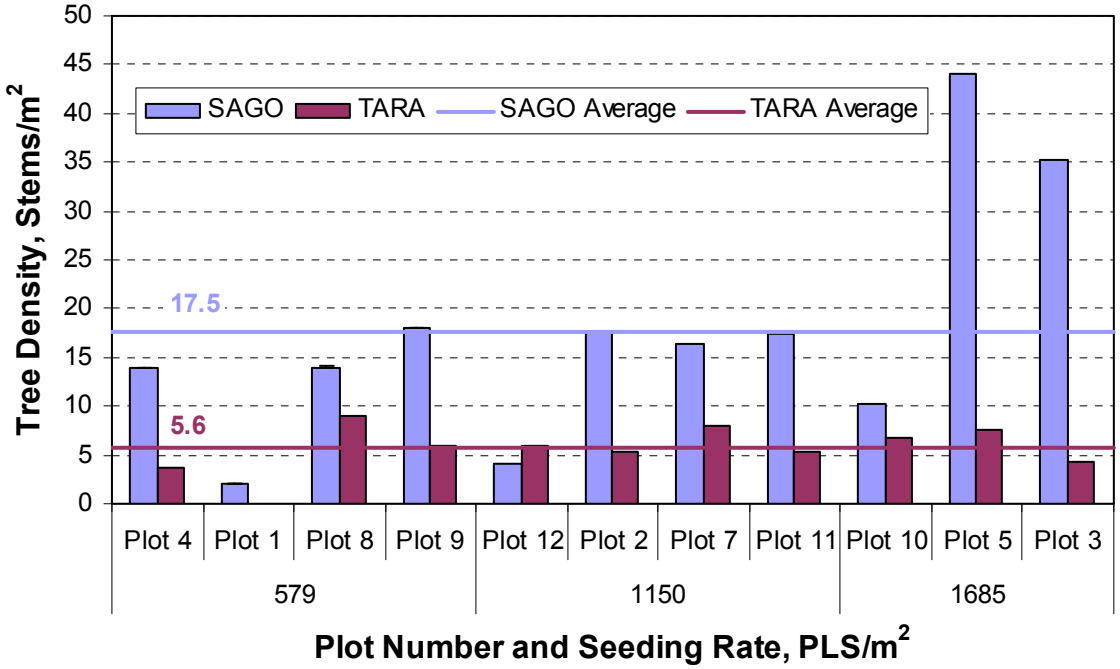


Figure 28. Average (per plot) stem density of Goodding's willow (SAGO) and saltcedar (TARA) in 2009 Goodding's willow small-scale field studies after one growing season.

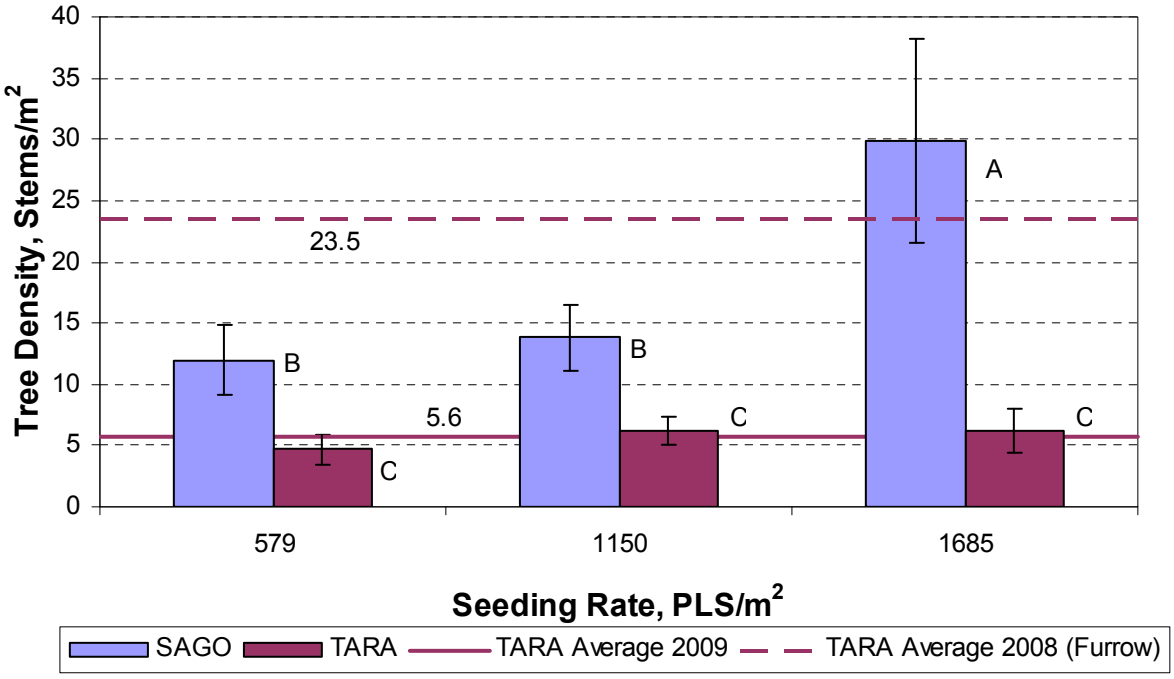


Figure 29. Average (per treatment) tree density of Goodding's willow (SAGO) and saltcedar (TARA) in 2009 Goodding's willow small-scale field studies after one growing season. Letters indicate significant differences across all columns (Student's t-test, α=0.05).

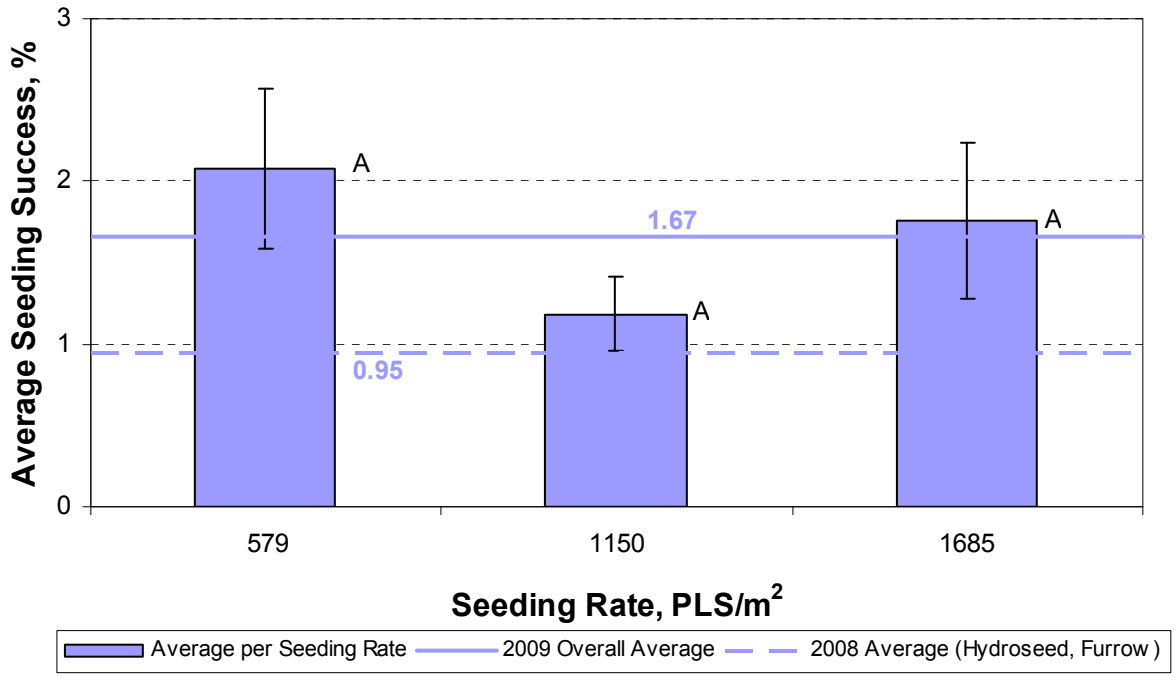


Figure 30. Average (per treatment) establishment of Goodding's willow after one growing season in 2009 Goodding's willow small-scale field studies. Letters indicate significant differences across columns (Student's t-test, α=0.05).

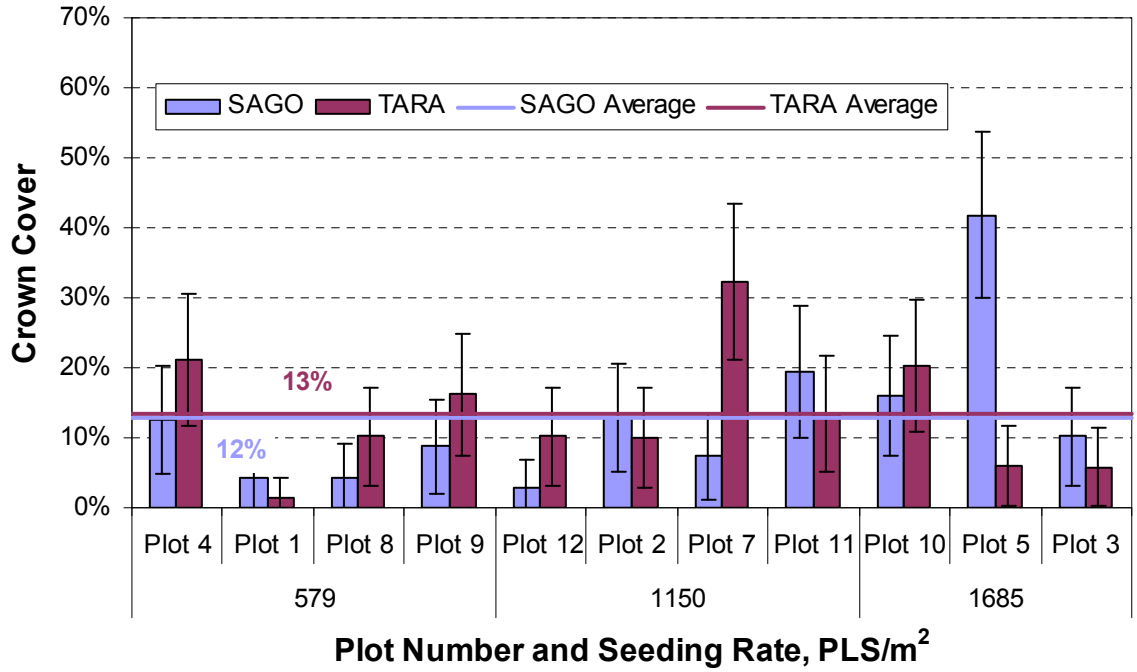


Figure 31. Average (per plot) crown cover of Goodding's willow (SAGO) and saltcedar in 2009 Goodding's willow small-scale field studies after one growing season.

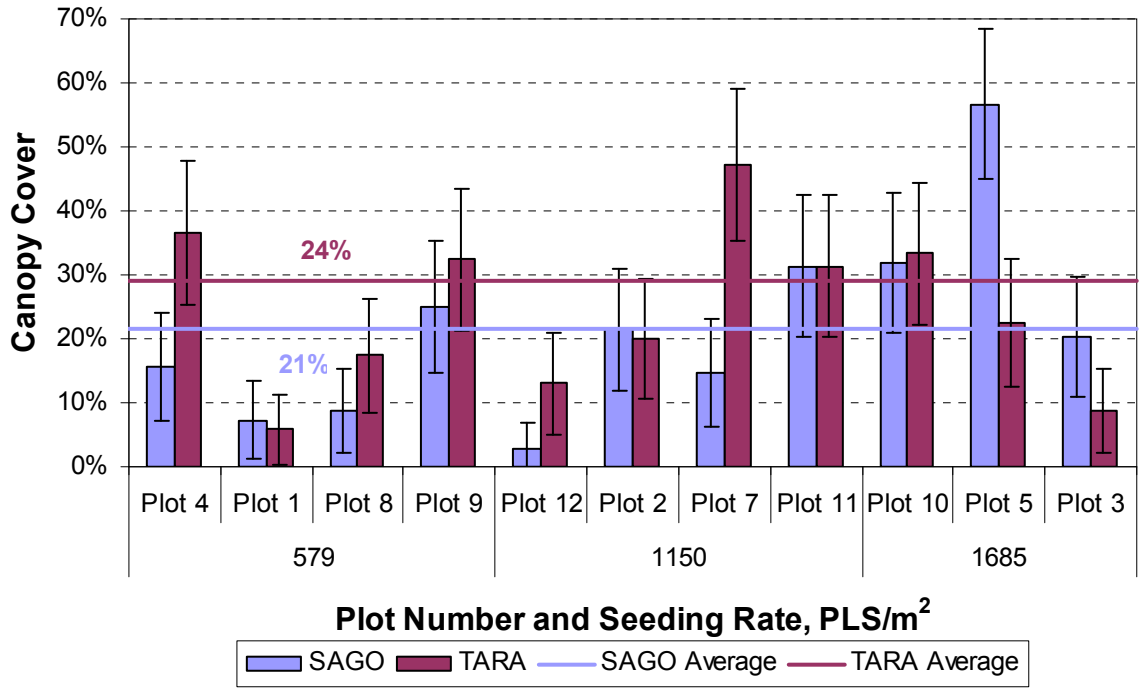


Figure 32. Average (per plot) canopy cover of Goodding's willow (SAGO) and saltcedar in 2009 Goodding's willow small-scale field studies after one growing season.

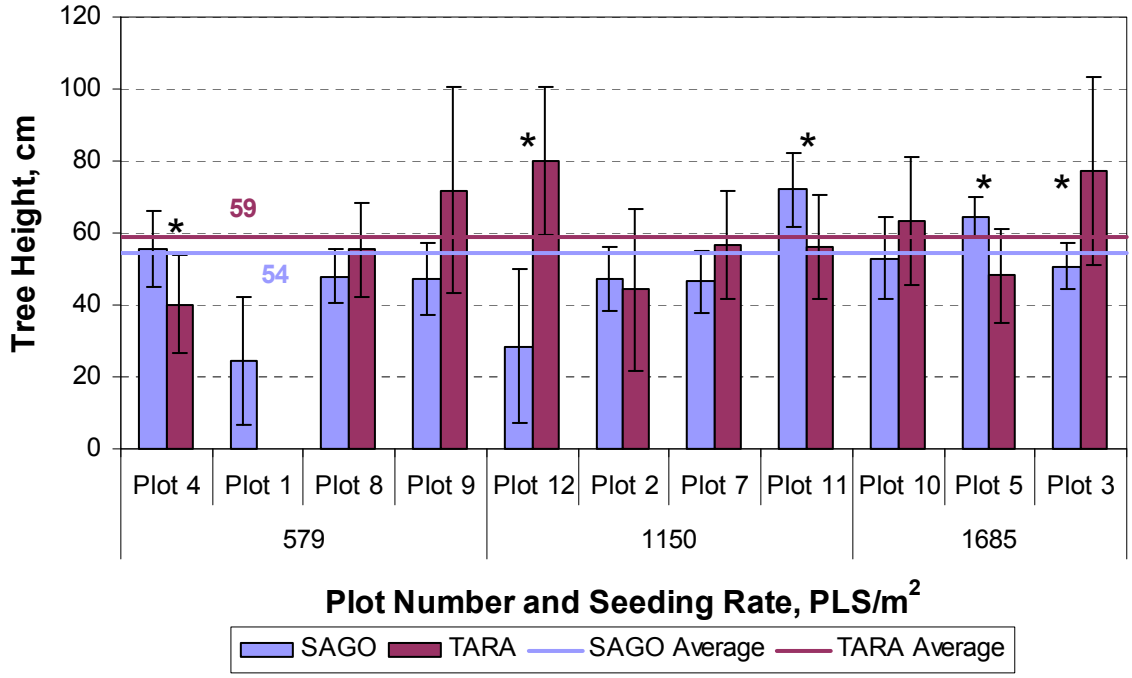


Figure 33. Average (per plot) height of Goodding's willow (SAGO) and saltcedar in 2009 Goodding's willow small-scale field studies after one growing season. * indicates significant differences between paired columns (Student's t-test, α=0.05).

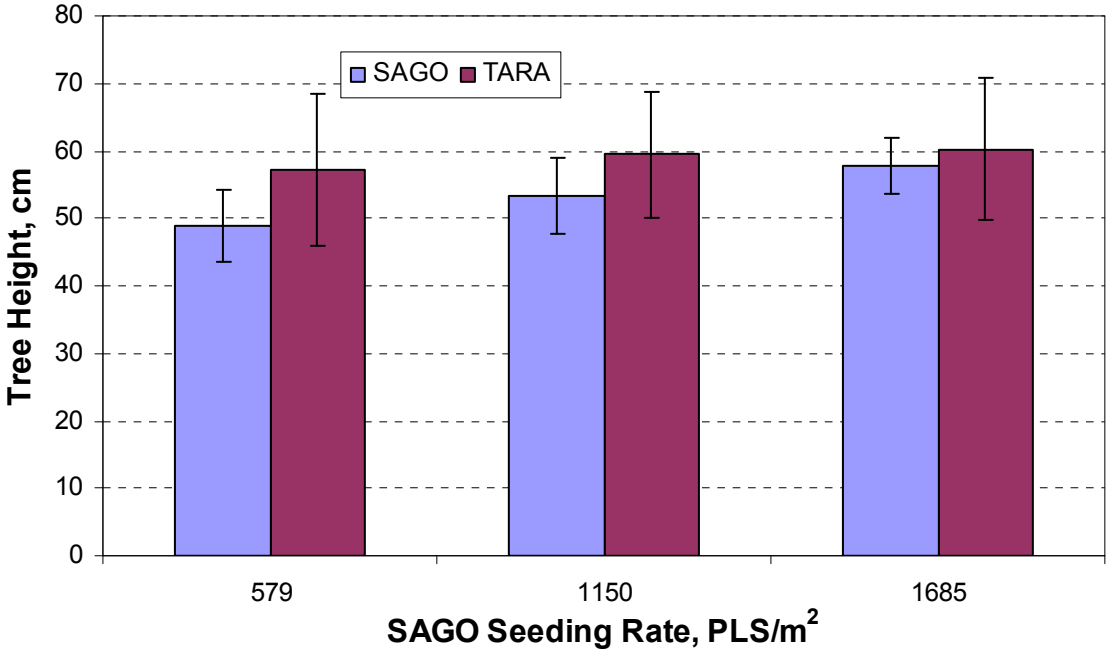


Figure 34. Average (per treatment) height of Goodding's willow (SAGO) and saltcedar in 2009 Goodding's willow small-scale field studies after one growing season. No significant differences were observed between paired columns at α=0.05.

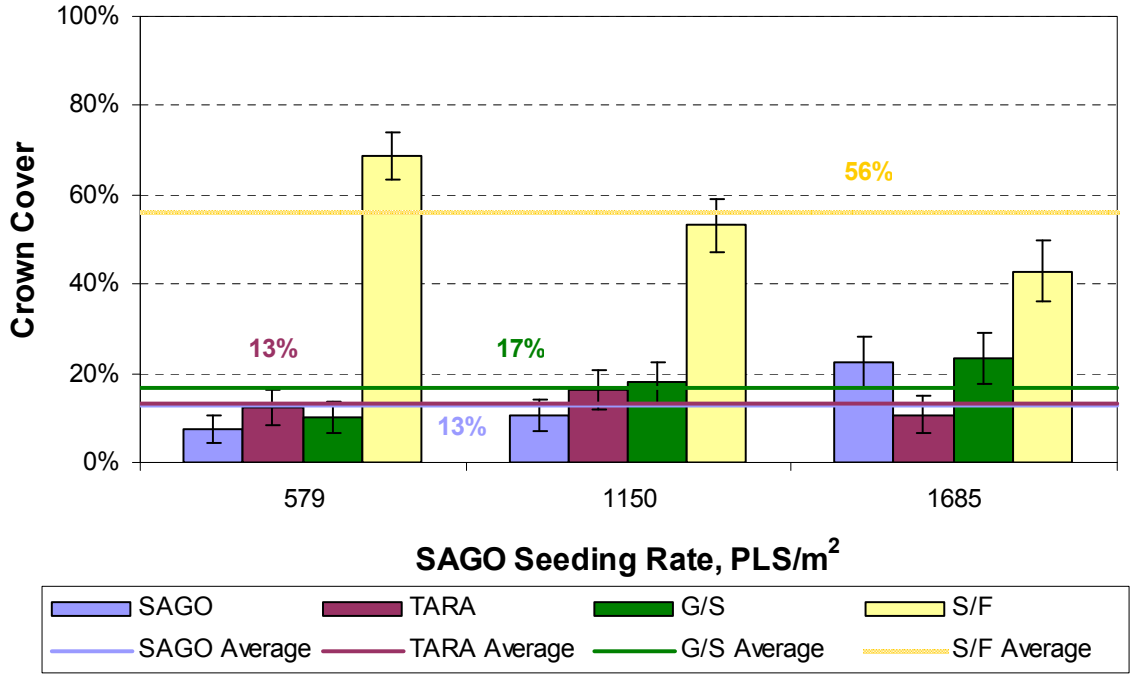


Figure 35. Average (per treatment) crown cover of Goodding's willow (SAGO), saltcedar (TARA), grass and sedges (G/S), and shrubs and forbs (S/F) in 2009 Goodding's willow small-scale field studies after one growing season.

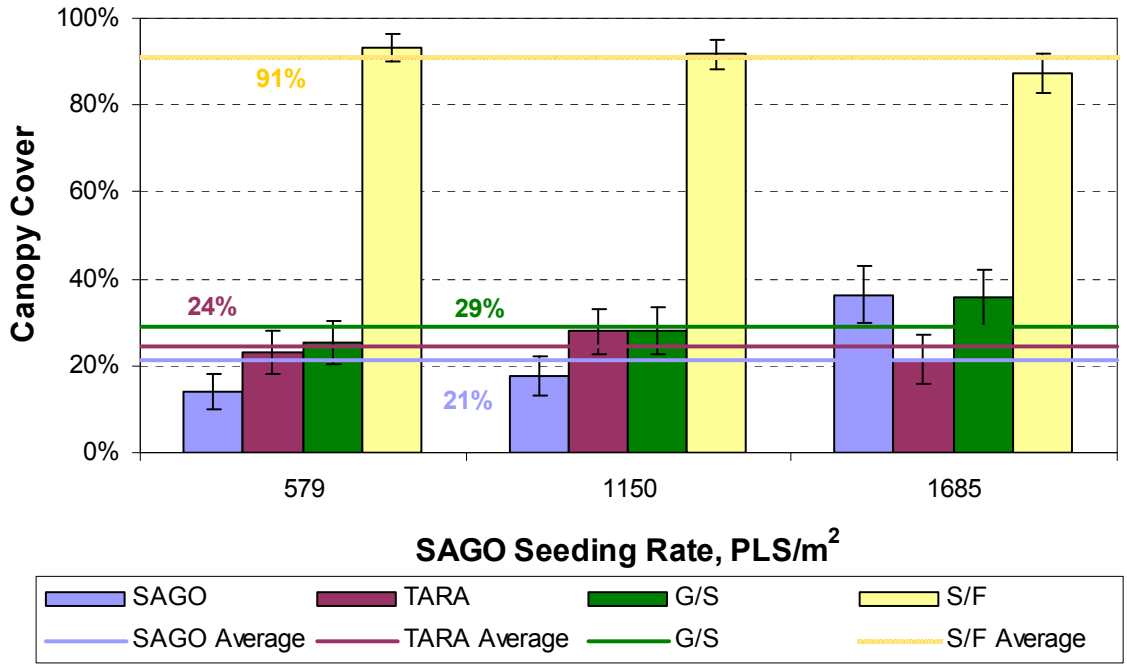


Figure 36. Average (per treatment) canopy cover of Goodding's willow (SAGO), saltcedar (TARA), grass and sedges (G/S), and shrubs and forbs (S/F) in 2009 Goodding's willow small-scale field studies after one growing season.

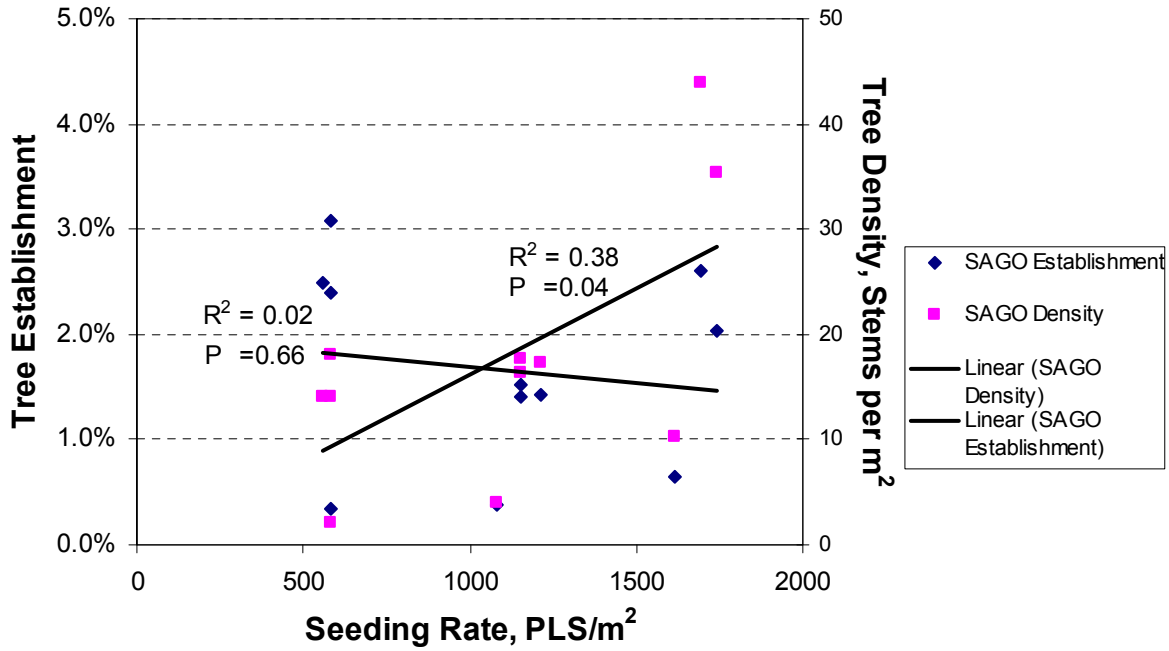


Figure 37. Goodding's willow tree establishment after one growing season versus seeding rate in 2009 Goodding's willow small-scale field studies.

Figure 38. Well point piezometer and soil instrumentation locations for small-scale field studies at Cibola NWR Field 51.

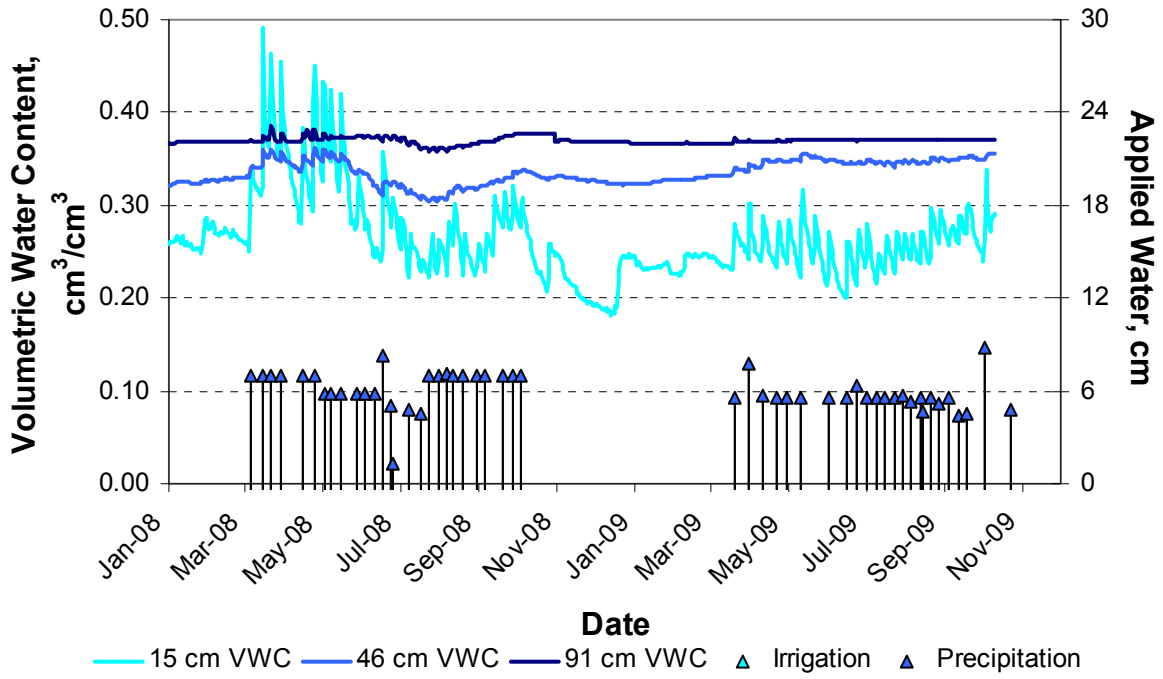


Figure 39. Average volumetric water content and applied water for small-scale field study plots in irrigation block A1.

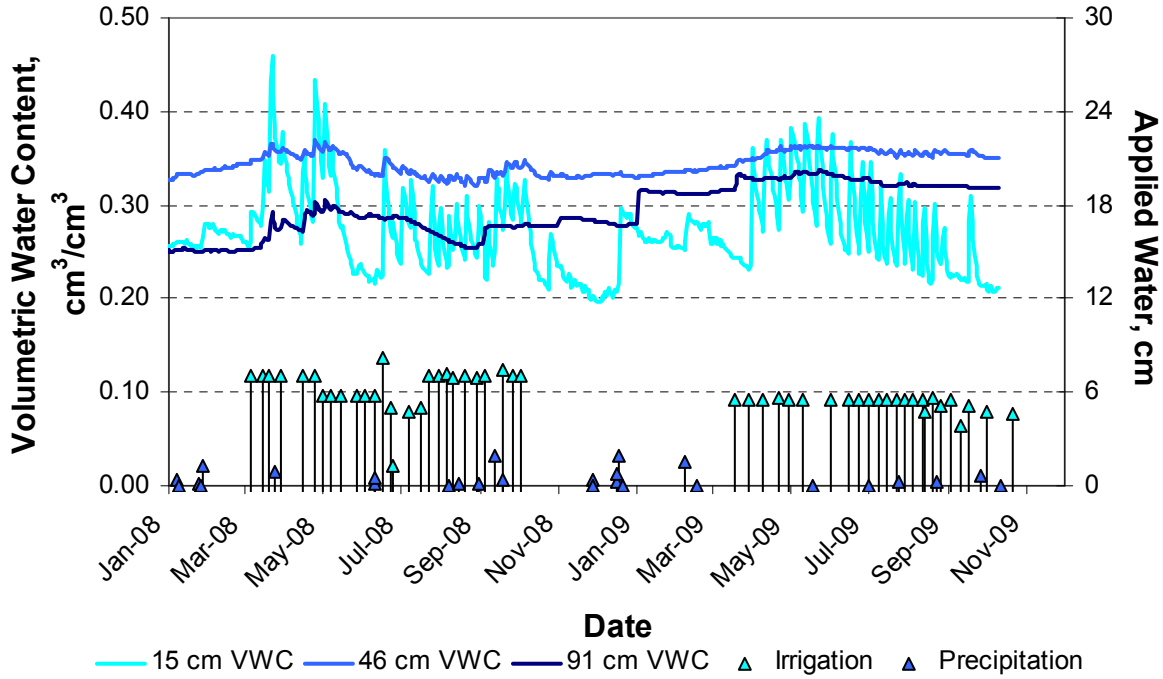


Figure 40. Average volumetric water content and applied water for small-scale field study plots in irrigation block A2.

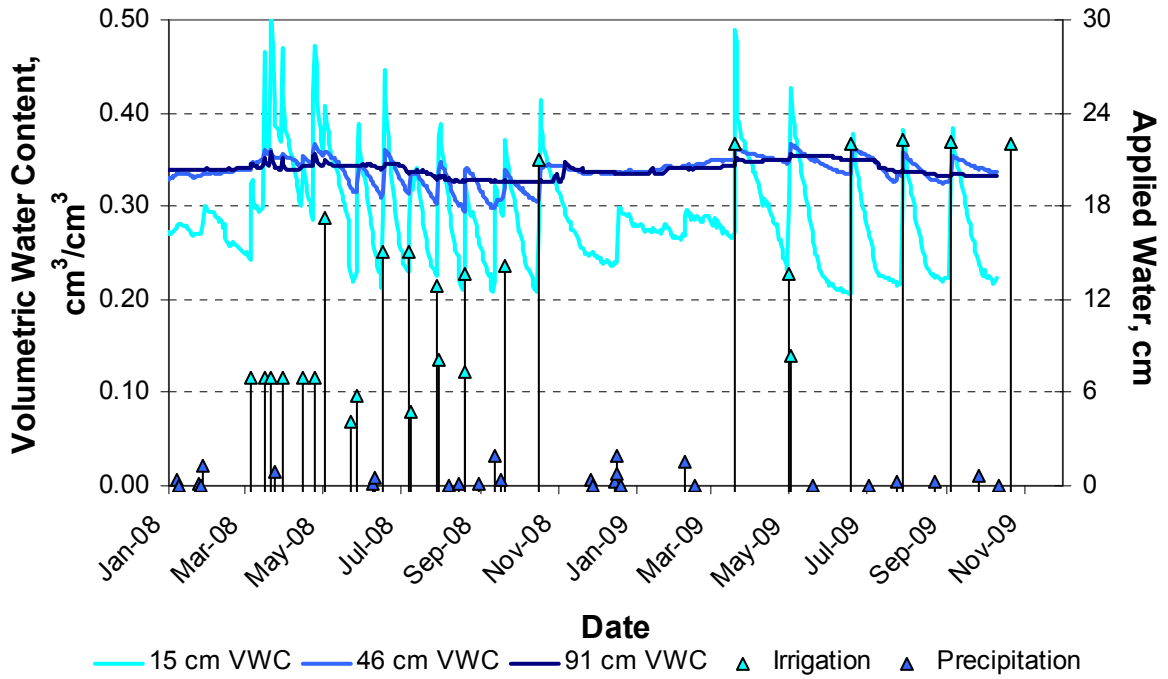


Figure 41. Average volumetric water content and applied water for small-scale field study plots in irrigation block B1.

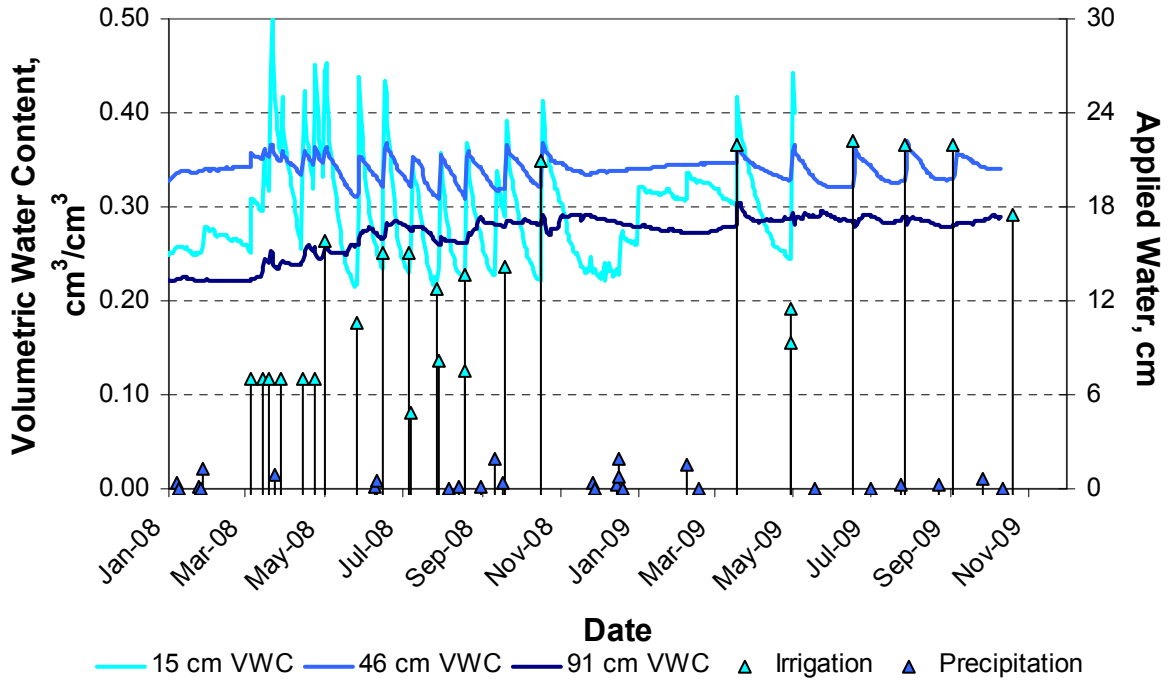


Figure 42. Average volumetric water content and applied water for small-scale field study plots in irrigation block B2.

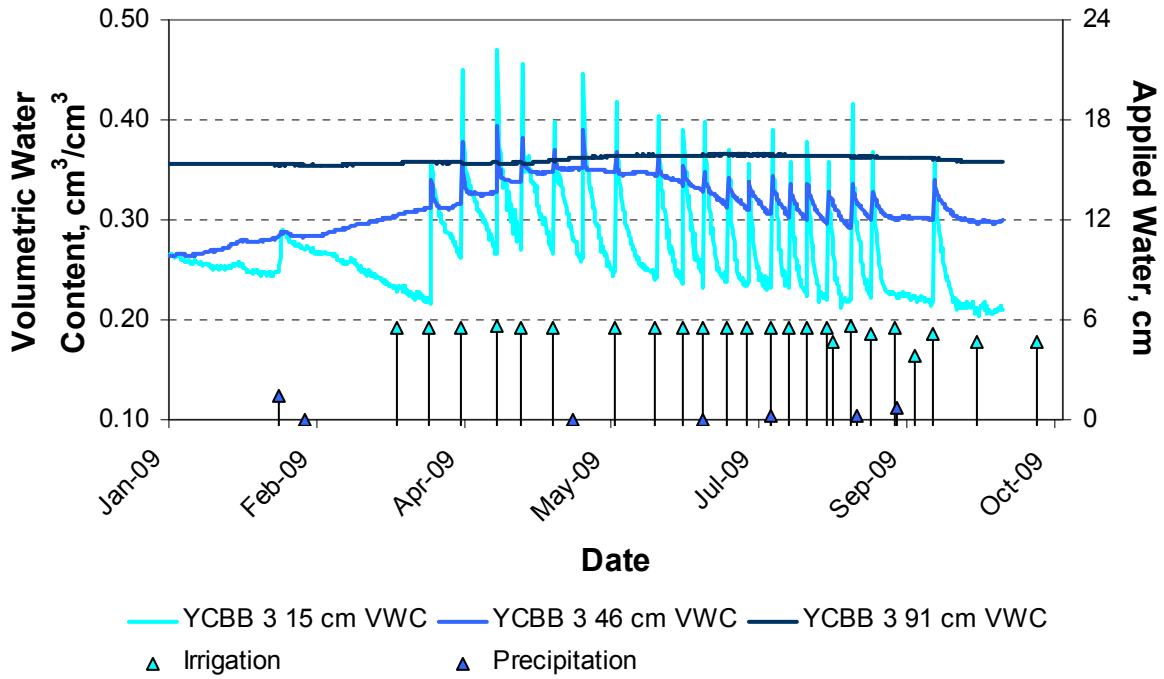


Figure 43. Volumetric water content and applied water for small-scale field study plot YCBB 1, in irrigation block A2.

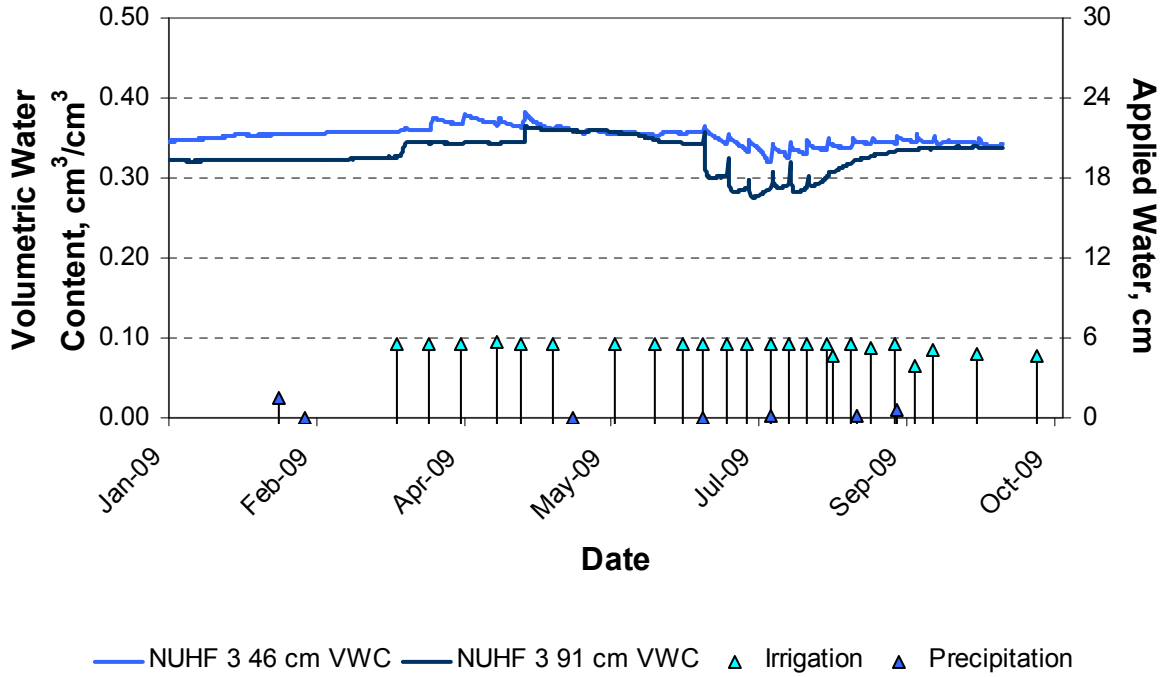


Figure 44. Volumetric water content and applied water for small-scale field study plot NUHF 3, in irrigation block A2.

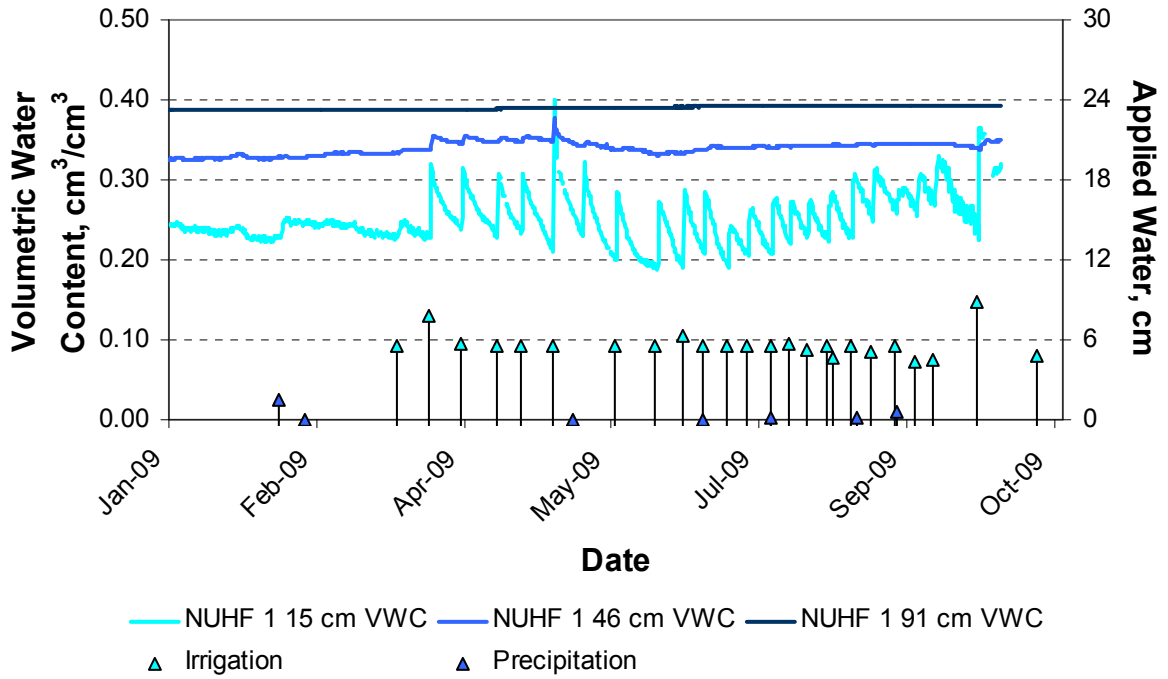


Figure 45. Volumetric water content and applied water for small-scale field study plot NUHF 1, in irrigation block A1.

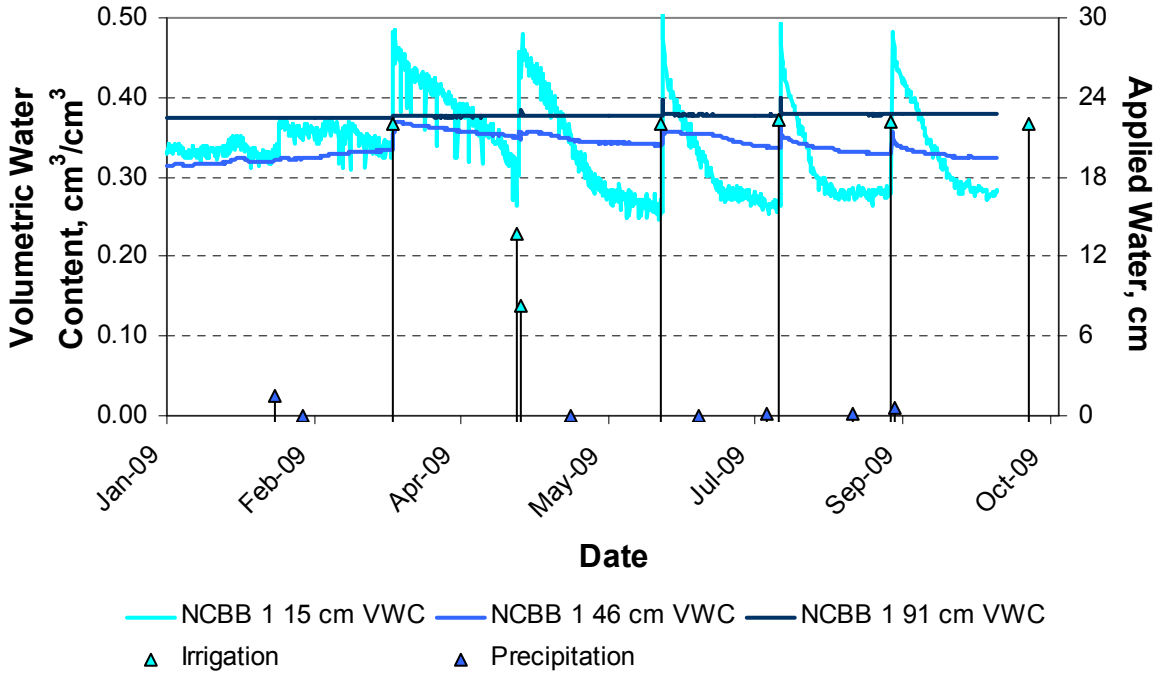


Figure 46. Volumetric water content and applied water for small-scale field study plot NCBB 1, in irrigation block B1.

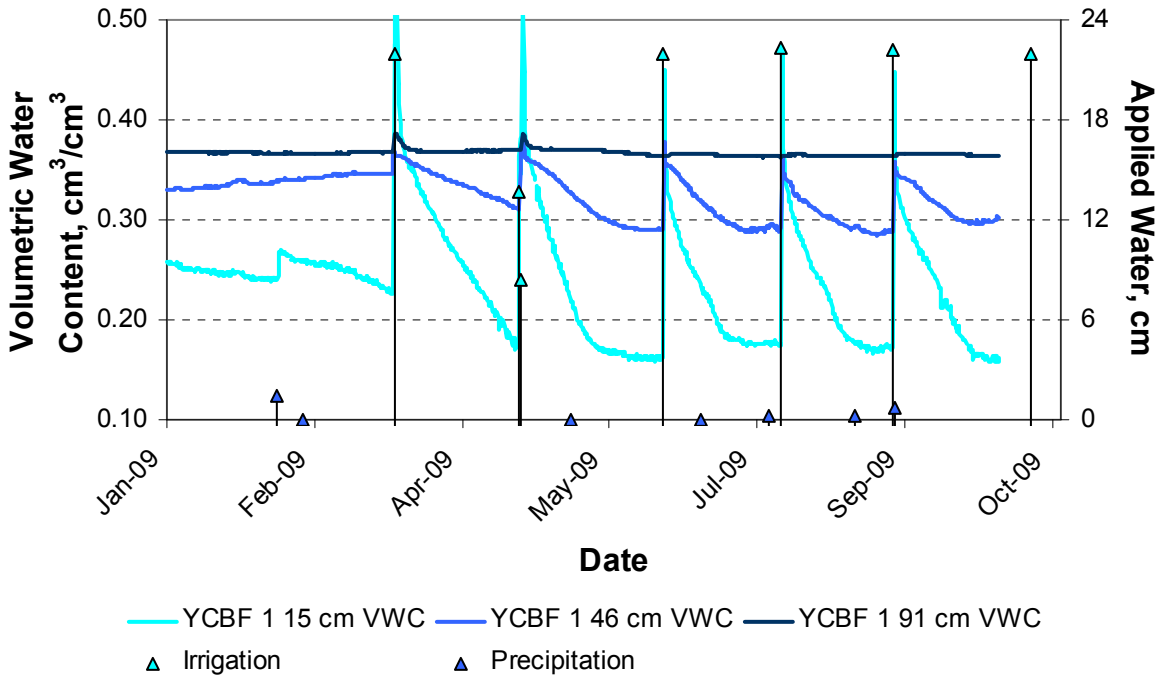


Figure 47. Volumetric water content and applied water for small-scale field study plot YCBF 1, in irrigation block B1.

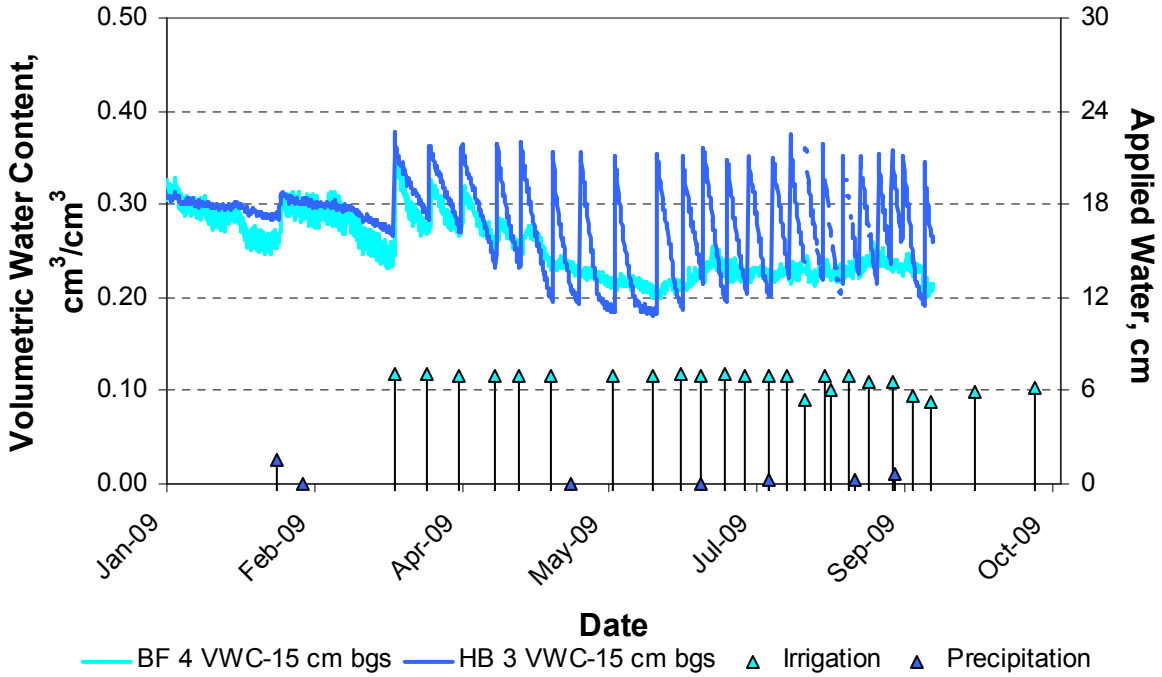


Figure 48. Volumetric water content and applied water for 2008 small-scale field study plots in irrigation block A3.

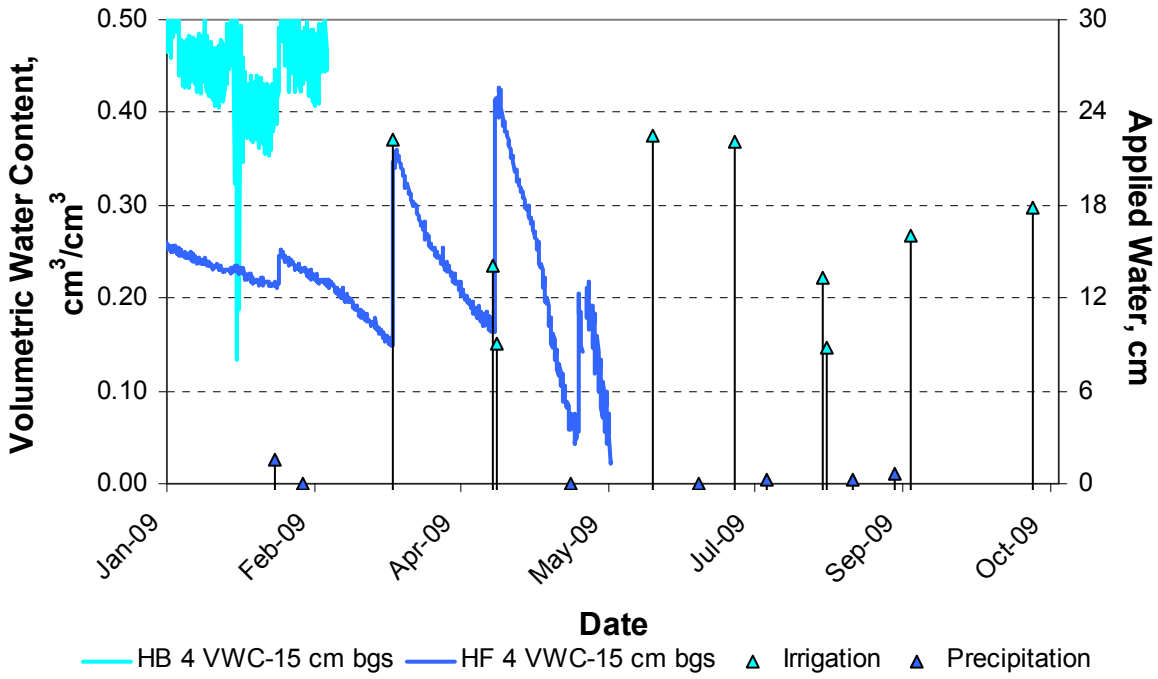


Figure 49. Volumetric water content and applied water for 2008 small-scale field study plots in irrigation block B3.

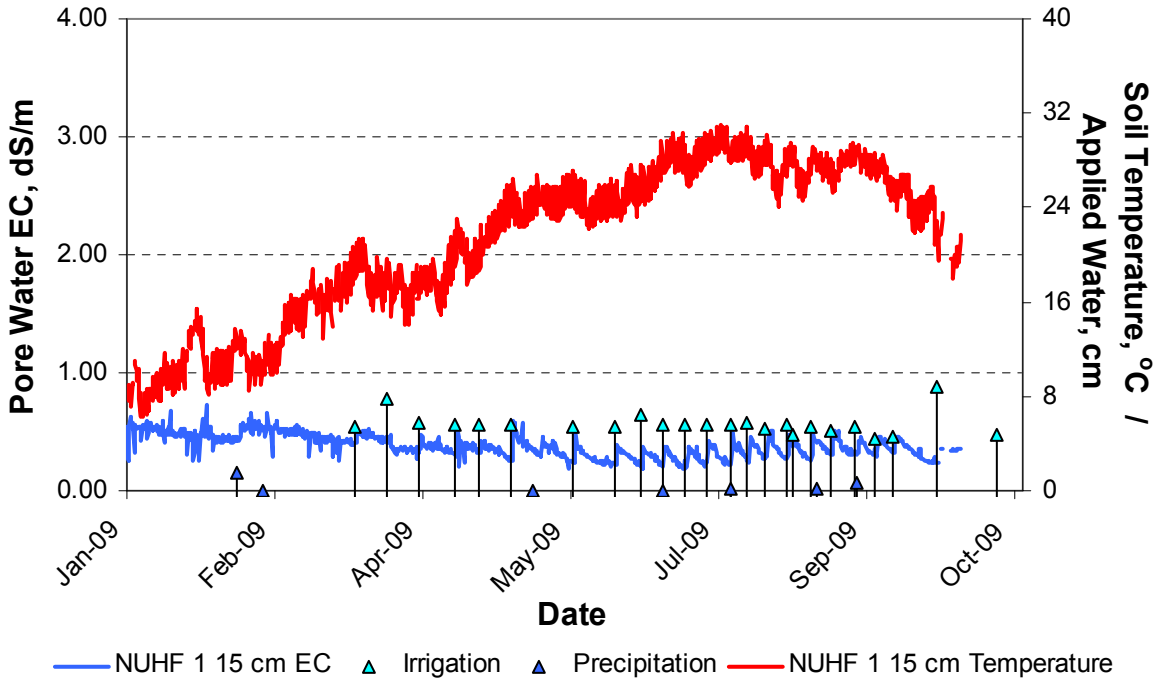


Figure 50. Pore water electrical conductivity (EC), soil temperature, and applied water for 2007 small-scale field study plot NUHF 1, in irrigation block A1.

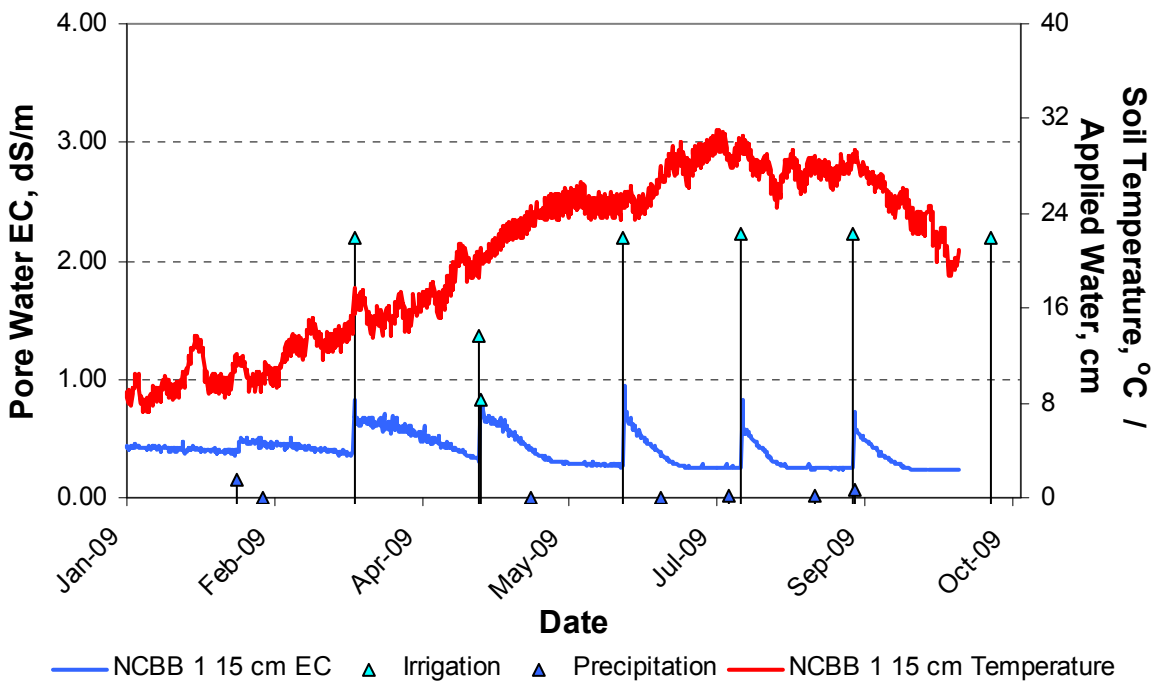


Figure 51. Pore water electrical conductivity (EC), soil temperature, and applied water for 2007 small-scale field study plot NUHF 1, in irrigation block A1.

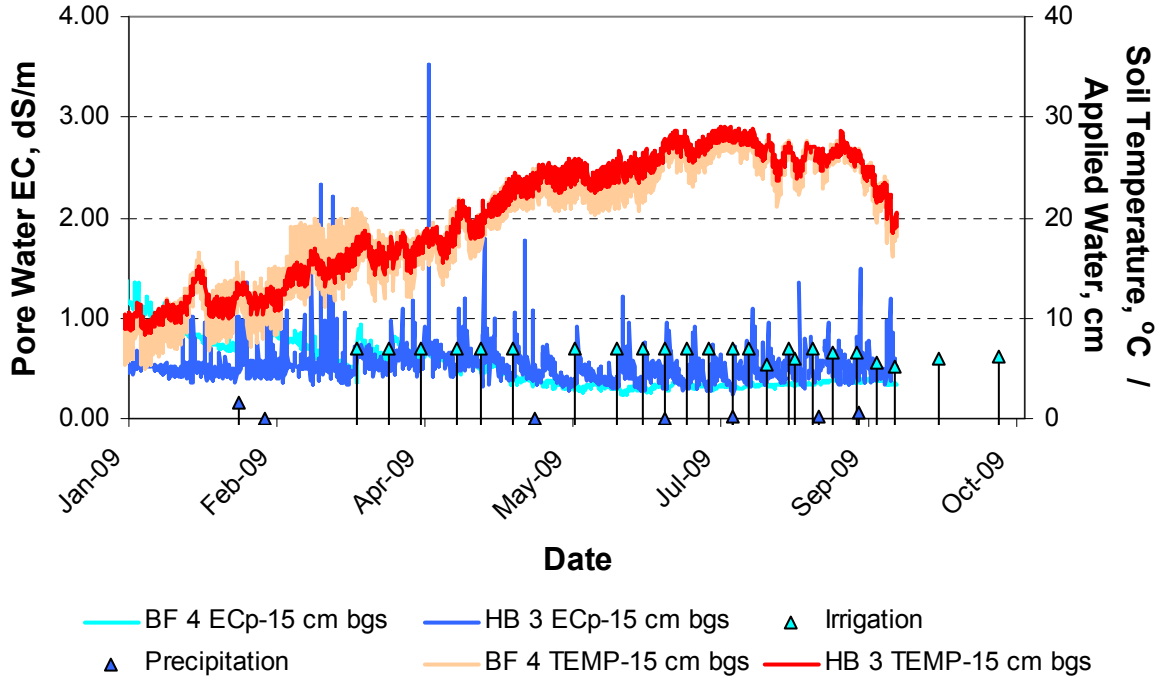


Figure 52. Pore water electrical conductivity (EC), soil temperature, and applied water for 2008 small-scale field study plots in irrigation block A3.

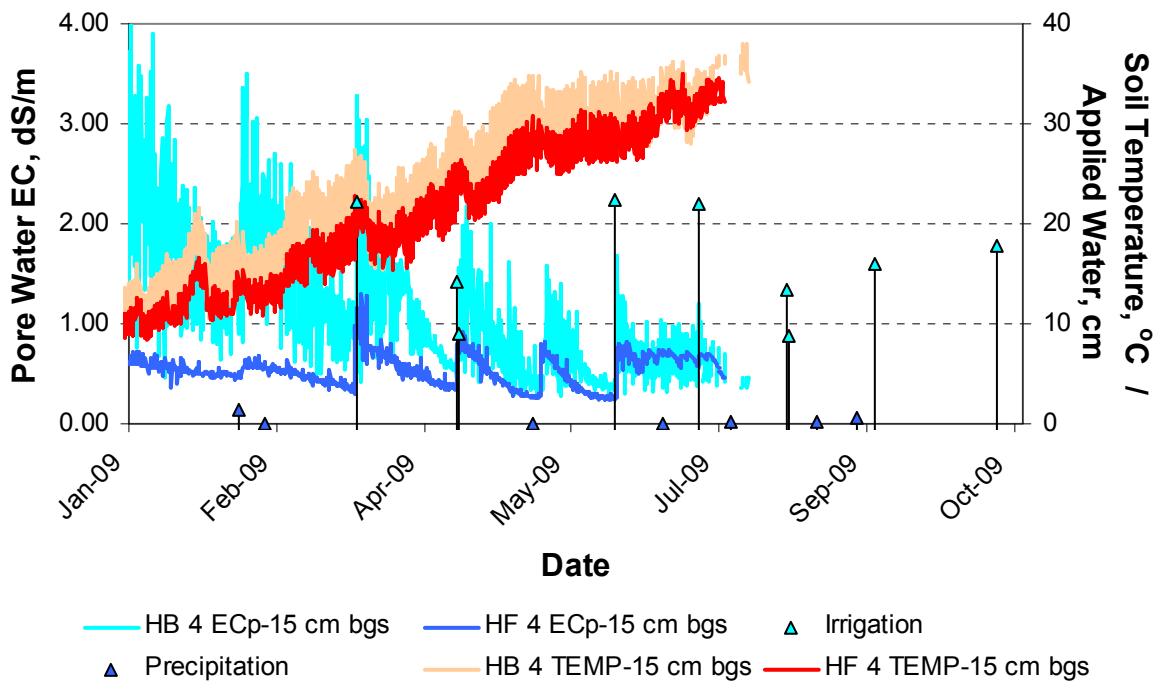


Figure 53. Pore water electrical conductivity (EC), soil temperature, and applied water for 2008 small-scale field study plots in irrigation block B3.

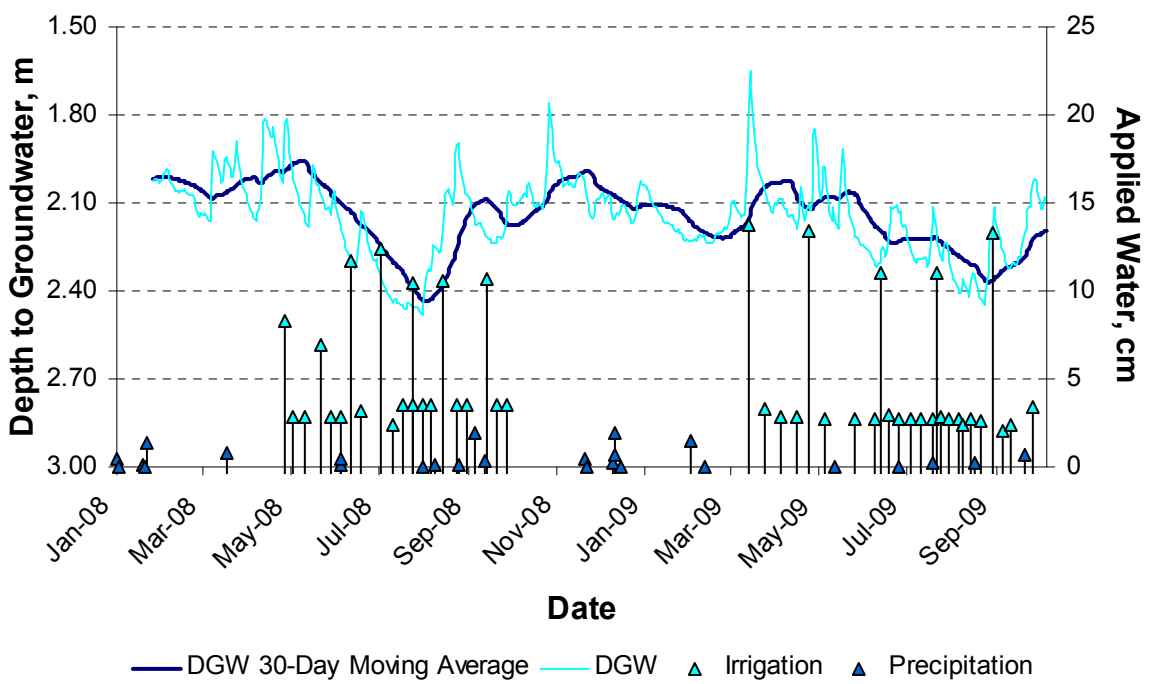


Figure 54. Average depth to groundwater and applied water for the 2007 small-scale study plot area. Depth to groundwater is the average for piezometers PZ-NE, PZ-SSN, and PZ-SSC, and applied water is the total volume applied to 2007 plots divided by the total area of the 2007 small-scale study plots.

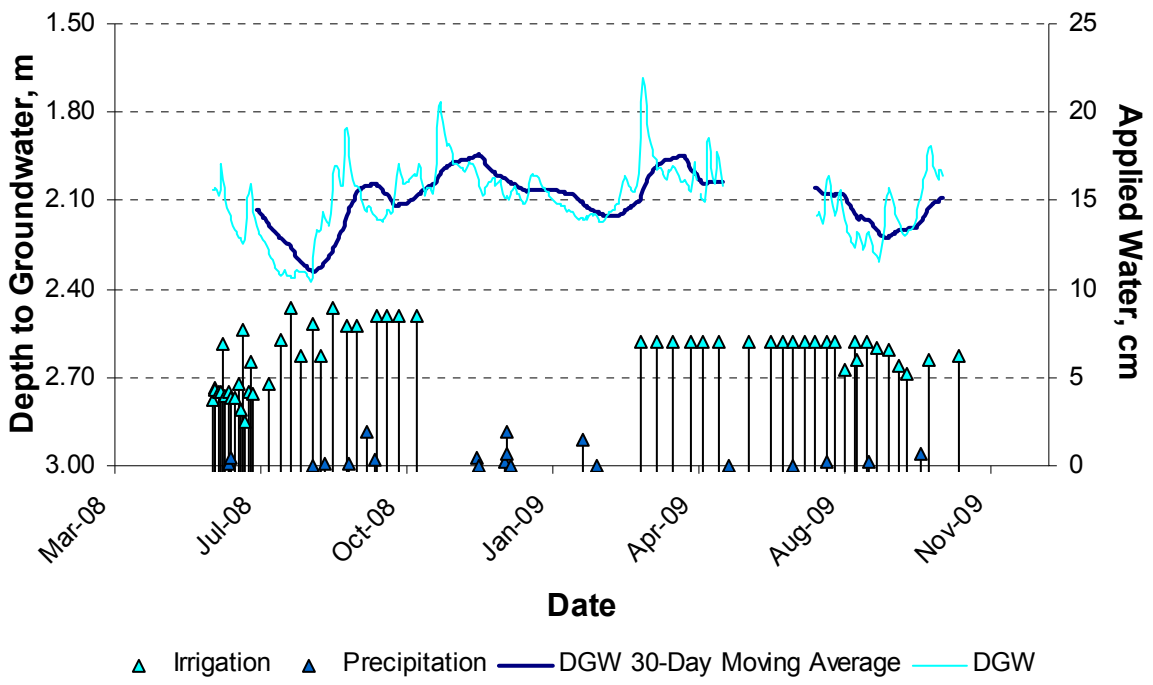


Figure 55. Depth to groundwater and applied water for the 2008 small-scale study plots in irrigation Block A3. Depth to groundwater is from PZ-SAGON, and applied water is the volume applied to Block A3 divided by the area of Block A3.

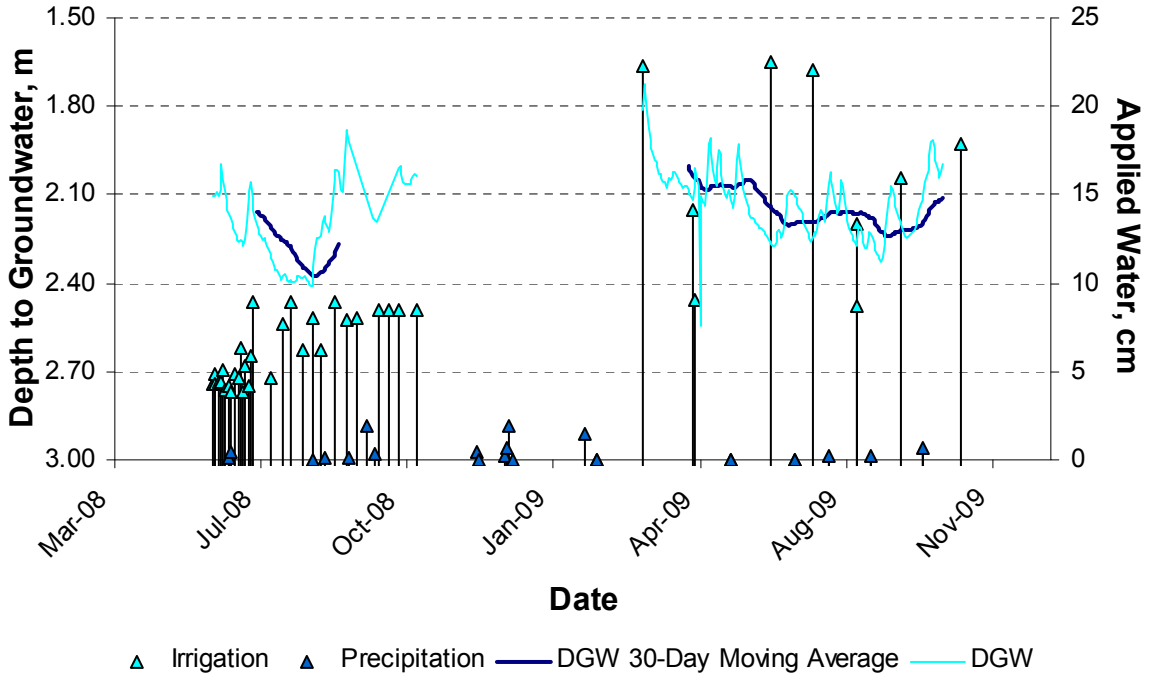


Figure 56. Depth to groundwater and applied water for the 2008 small-scale study plots in irrigation Block B3. Depth to groundwater is from PZ-SAGON, and applied water is the volume applied to Block B3 divided by the area of Block B3.

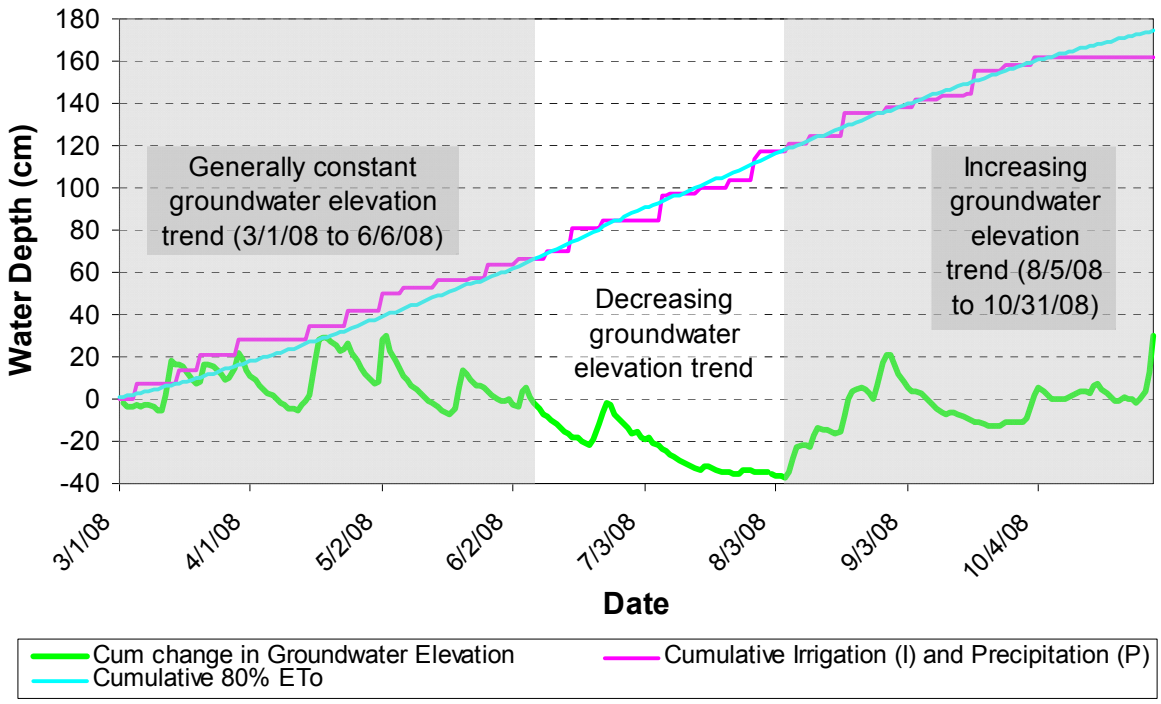


Figure 57. Cumulative groundwater elevation change and applied water during for 2007 small-scale study plots between March 1, 2008 and October 31, 2008.

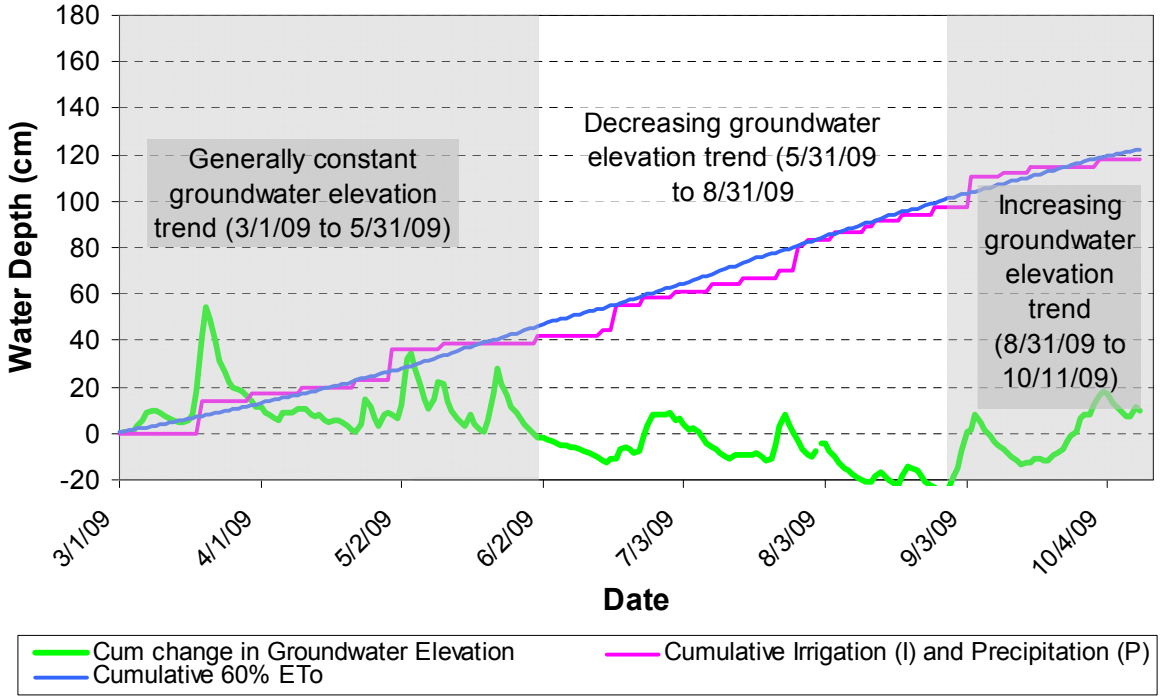


Figure 58. Cumulative groundwater elevation change and applied water during for 2007 small-scale study plots between March 1, 2009 and October 11, 2009.