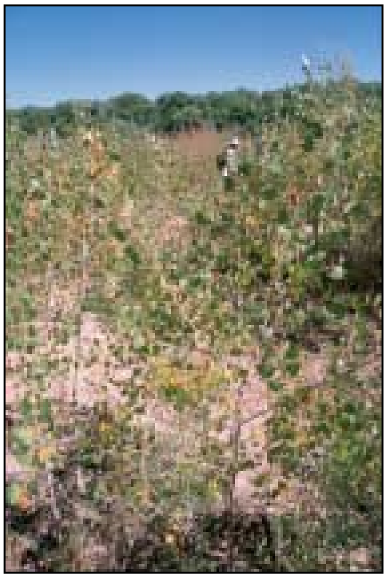
The Albuquerque Overbank Project

A Model for Large River Riparian Restoration in the Southwest



Natural Heritage New Mexico

U.S. Department of the Interior Bureau of Reclamation

The University of New Mexico

2004

The Albuquerque Overbank Project
A Model for Large River Riparian Restoration in the Southwest[1]

Esteban Muldavin, Clifford S. Crawford, and Nancy Umbreit[2]

SUMMARY

The Albuquerque Overbank Project (AOP) was a five-year pilot riparian restoration project implemented in the Albuquerque reach of the Rio Grande to evaluate the efficacy of using site clearing of exotic shrubs, bank lowering and overbank flooding to reestablish Rio Grande cottonwoods and a native riparian vegetation community. While the Rio Grande has been highly modified over the past century, many of the essential elements of functionality and biodiversity are still extant, and our goal was to take advantage of those remaining attributes in river-aided restoration and to do so in a cost effective manner. On an existing depositional point bar adjacent to the main channel, exotic Russian olive (*Elaeagnus angustifolia*) was removed, a portion of the bar lowered approximately 1 m within reach of typical spring runoff events, and a micro-topography of channels and islands constructed to aid the establishment of native cottonwoods, willows, and an assemblage of shrubs, grasses, and forbs. The cost of the manipulation was approximately $12,350/ ha ($5,000/ac).

In 1998, 1999, and 2001, the site flooded during peak discharges between 85 and 113 cms (3,000 and 4,000 cfs) during the months of May and June. After the initial 1998 flood, there was a large germination event of Rio Grande cottonwoods (*Populus deltoides* ssp. *wislizeni*) that resulted in the establishment of 10,070 saplings/ha (4,077/acre) by the end of 1998. Through a process of self-thinning due to shading and minor amounts of beaver damage, the numbers were reduced to 4,650 stems/ha (1,881/acre) by the end of 2002. No significant recruitment of cottonwoods occurred in subsequent floods. The highest densities of cottonwoods occurred in and along the constructed channels, and to a moderate degree on the island between the channels. Lowest densities in lower channel areas characterized by deposits of clay sediments, or high salinities, and on an elevated terrace where Russian olive had been removed, but the site had not been flooded. In addition, sites composed primarily of fill material from the excavation of the bar had lower cottonwood recruitment. Exotic trees and shrubs such as Russian olive and salt cedar (*Tamarix ramosissima*) had ongoing recruitment during the project period and were approaching densities of 1,353 stems/ha by the end of 2002, but cottonwoods still dominated the site. The vegetation diversity was very high with 89 species of shrubs, grasses, and forbs detected over the five years, and native species outnumbering exotic species three to one. Canopy cover of grasses and forbs went from 20% in the first growing season of 1998 to a peak 83% in 2001, and then declined with the drought to 42% in 2002.

The outcome suggests that the AOP site can be a useful model for large river riparian restoration utilizing bar lowering followed by overbank flooding and low-intensity management. Restoration success, though, may be dependent on the timing and duration of flooding, the design of the constructed floodplain, soil conditions, the availability of seed sources, and the subsequent adaptive management strategies implemented. Accordingly, we would recommend that additional AOP-style restoration sites be initiated in other segments of the Middle Rio Grande to further refine overbank flooding prescriptions. But the success of AOP in itself is encouraging for the prospects of multi-agency cooperation in restoring many of the compositional, structural, and functional qualities of the riparian landscape that once dominated the Middle Rio Grande Valley.

---

[1] Submitted in partial fulfillment of Coop Agreement G-FC-40-1989-0 between the Bureau of Reclamation, Albuquerque Area Office and the University of New Mexico, New Mexico Natural Heritage Program.
[2] Esteban Muldavin is the ecologist for the New Mexico Natural Heritage Program; Cliff Crawford is Professor Emeritus in the Biology Department, University of New Mexico, and Nancy Umbreit is an Environmental Protection Specialist for the Bureau of Reclamation, Albuquerque Area Office.

TABLE OF CONTENTS

Introduction 1
The historical context for a river-aided restoration approach 2
Study Area 3
Site selection, location and preparation 3
Climate and hydrology 3
Methods 7
Site Preparation 7
Groundwater Measurements 7
Soils and Geomorphology 10
Biological monitoring 10
Results 11
Flooding and geomorphology 11
Groundwater dynamics 15
Tree establishment and growth 18
Vegetation diversity and dynamics 27
Discussion 31
Overbank flooding capacity 31
Tree recruitment 31
Biodiversity trends 32
The Future 33
Literature Cited 34
Appendix A. Albuquerque Overbank Project (AOP) Vegetation Summary Tables 35
Appendix B. Albuquerque Overbank Project (AOP) Plant species list. 49

List of Figures

Figure 1. Location of the Albuquerque Overbank Project 4
Figure 2. Site design for the Albuquerque Overbank Project. 4
Figure 3. Average yearly precipitation over the course of the AOP project 5
Figure 4. Discharge profile of the Rio Grande through Albuquerque, NM 6
Figure 5. AOP site treatment. 8
Figure 6. Albuquerque Overbank Project contour map and grid system 9
Figure 7. Paired photos from 1998 and 1999 12
Figure 8. AOP bankline changes 1998 through 2002 13
Figure 9. A groundwater well at the end of Line B 13
Figure 10. Bank erosion along the lower bankline through time. 14
Figure 11. The transport of the large snag during the 2001 flood 14
Figure 12. Monthly AOP groundwater well depths between 1999 and 2000. 16
Figure 13. Piezometric heads from 7/29/98 to 8/13/1998 17
Figure 14. An example of piezometric heads in late spring at AOP 17
Figure 15. Changes in stand structures of cottonwood and Gooding's willow 20
Figure 16. Changes in stand structures of Russian olive and saltcedar 21
Figure 17. Changes in stand structures of Siberian elm 22
Figure 18. AOP cottonwood reproduction 24
Figure 19. AOP tree distribution in 2002 by microsite type 25
Figure 20. AOP 2000 tree census counts by species. 26
Figure 21. Vegetation patch composition change 1998-2002 at the AOP. 28
Figure 22. Herbaceous cover on the AOP. 29
Figure 23. Shrub cover on the AOP. 30
Figure 24. Yearly peak discharges of the Rio Grande at Albuquerque, NM. 31
Figure 25. Young Russian olives 31
Figure 26. A new emergent wetland and riparian community 32

List of Tables

Table 1. Climate summary for Los Lunas 3 SSW, NM (Station 295150) 5
Table 2. Correlations between AOP groundwater depths 15
Table 3. Seasonal variation in AOP groundwater depths 16
Table 4. AOP tree densities (stems/ha) by species and year on the lowered river bar 19
Table 5. AOP tree densities (stems/ha) by species and year on the unflooded upper terrace. ... 19
Table 6. Electromagnetic meter (EM) horizontal readings and electrical conductivies (EC) 25
Table 7. AOP flooded bar average vegetation percent cover by year and lifeform 28
Table 8. AOP cumulative species richness 1998-2002 28

INTRODUCTION

Historically, overbank flooding resulting from late spring snowmelt enhanced cottonwood and willow seedling establishment along rivers and streams in the semi-arid Southwest of North America. Temporal and spatial patterns of establishment were influenced by elements of the flow regime (e.g., its timing, duration, frequency, and magnitude) before, during, and after periods of inundation. However, during the past century in particular, this complex sequence of fluvial and biological processes was interrupted by anthropogenic activities that changed the appearance and ecological dynamics of earlier riparian forests along rivers such as the Colorado and Rio Grande. Current regulation in the 260-km "Middle Rio Grande" (MRG) reach between Cochiti and Elephant Butte reservoirs in New Mexico lowers peak flows and, in the upper two-thirds of the reach, degrades channel beds (Crawford et al. 1993). Snowmelt runoff now produces only infrequent overbank flooding, with far-reaching effects on the MRG riparian zone. Of foremost concern is that, in the absence of overbank flooding, suitable habitat for native Rio Grande cottonwood *(Populus deltoides* ssp. *wislizeni*) reproduction and establishment has become severely limited, and, conversely, exotic trees, shrubs, and herbaceous species that do not require flooding have aggressively entered the ecosystem, displacing natives throughout the river corridor.

In this context, how to restore some level of the previous composition and function to the riparian zone is a frequently asked question by environmentally concerned citizens, managing agencies, and scientists in the region. We address the question here by describing a five-year pilot restoration effort known as the Albuquerque Overbank Project (AOP) that has produced positive results using the current attributes of the Middle Rio Grande flow regime in combination with direct site manipulation. The AOP focused on a river-aided treatment of an existing depositional point bar adjacent to the main channel where exotic Russian olive (*Elaeagnus angustifolia*) was removed, a portion of the bar lowered within reach of typical spring runoff events, and a micro-topography of channels and islands constructed to potentially aid the establishment of native cottonwoods, willows, and a predominantly native assemblage of shrubs, grasses, and forbs. One of the key objectives was to determine if such manipulation could be conducted in a cost-effective way in comparison to highly intensive restoration techniques such as site clearing followed by pole plantings. That is, could the river itself be used as a tool to lower the cost and the intensity of a restoration effort, including the post-restoration management phase, while enhancing success over other methods?

This was a multi-agency collaboration involving the Bureau of Reclamation (Reclamation), Albuquerque Open Space, the Middle Rio Grande Conservancy District, the Fish and Wildlife Service, and the University of New Mexico Biology Department 's New Mexico Natural Heritage Program (NMNHP) and the Bosque Ecosystem Monitoring Program (BEMP). It required only a six-month planning effort from the initiation of the idea to the day manipulation was begun, and may serve as a model for how institutions that often have different mandates can find ways to work in an efficient and timely way to accomplish a common goal.

The historical context for a river-aided restoration approach

Climate and basin geology were the main determinants of the Rio Grande flow regime during most of the Holocene (Crawford et al. 1993). Described as a wide, relatively shallow and braided river north of the present border between Mexico and the United States, the river was subject to flood-generated avulsion, which induced new channel formation across the often wide floodplain. This would have isolated old riparian cottonwood and willow (*Salix* spp.) communities and produced others along newly formed channels, creating a patchwork of uneven-aged stands of those native trees. When humans began to settle in the floodplain and to modify the riparian forest, or "bosque," by clearing and agriculture, they, too, experienced the flooding. Serious human alteration of basin hydrology and river flows began in the nineteenth century, with livestock grazing, extensive logging, and increased agriculture in northern watersheds (Crawford et al. 1996; Scurlock 1998). These activities led sequentially to increased sediment runoff, aggraded riverbeds, heavy flooding, and waterlogged soils in the middle valley. Yet, despite eventual flood control, floodplain drainage, and improved irrigation systems, damaging floods continued into the early 1940s.

Following the severe floods of 1941 and 1942, extensive channel modifications were instigated by the Army Corps of Engineers (ACOE) to control flows (REFS). The river was straightened and channelized between two parallel levees, creating a narrow active floodplain. In addition, large iron riprap known as Kellner jetty-jacks were installed to create and stabilize the banks and to protect the newly created levies. These devices collected sediment that in turn became a seedbed for the establishment of Rio Grande cottonwood. The result was the transformation of what was by that time a relatively denuded riparian zone into a nearly continuous, even-aged gallery forest along a restricted channel along with significantly reduced area of point and island sand bars (Crawford et al. 1993).

While native cottonwoods and willows still dominate portions of the riparian zone, saltcedar (*Tamarix ramosissima*), Russian olive, and other exotic woody species now compete with them both as monotypic stands and as significant understory components. An added problem for the native trees is that their requirements for seedling establishment (wet unshaded soil in May and June) are more restrictive than are the conditions that recruit the major non-native species. Moreover, relatively high water tables and adequate soil moisture during the growing season are needed for optimal water uptake and nutrient cycling by older stands of cottonwoods and willows. Neither of these conditions is guaranteed by the present flow regime.

The AOP was implemented in the context of this very constrained river ecosystem, but with an aim towards contributing to our understanding of how to do restoration using the best attributes of the remaining natural processes and biotic components. For while the Rio Grande has been highly modified over the past century, many of the essential elements of functionality and biodiversity are still extant, albeit in differing degrees and proportions. Hence, we felt there were still opportunities to utilize the available water and an understanding of the natural capacity for the ecosystem to regenerate itself to effect successful restoration in the Middle Rio Grande.

STUDY AREA

Site selection, location and preparation

Project planning began in the fall of 1997 with scoping for an appropriate site. Criteria for selecting a site were as follows: 1) be roughly five to fifteen acres in size and adjacent to the main channel; 2) not receive heavy public use, and in particular, not be a target for vandals; 3) be dominated by non-native vegetation; 4) have a moderate bank height and sediment volume, and hydrogically disconnected from the current floodplain, but with the potential to be reconnected without removing inordinate amounts of material; 5) have an area where the soil material (sediment) from the bank lowering could be properly placed to meet state water quality standards; 6) would not be detrimental to any infrastructure nearby, e.g., the levee system and; 7) avoided nearby landscape features such as arroyos that might influence the selected site by filling the design channels.

The site chosen was the lower end of a point bar located half way between the Bridge Street and Rio Bravo bridges along the west bank of the Rio Grande in south Albuquerque (Figures 1 and 2). The river at this location was a shifting sandy bed at approximately 2 m (6.6 ft) below bankfull discharge. The point bar as a whole forced a localized narrowing (75 m; 250 ft) and deepening of the river channel at the upper end and then opened up again at the lower end to approximately 125 m (410 ft). The restoration site was approximately 1.6 ha (4 acres) and elliptical in shape. At the bar's southern end was a lower, unvegetated sand bar located out of the main channel that provided room for moving material and extending the bar downriver, but at a lower elevation.

Climate and hydrology

With respect to precipitation, the AOP site is located in a semi-arid zone where annual precipitation ranges from 138 to 477 mm (5.42 to 18.8 in) around a mean of 252 mm (9.92 in) as reported at Los Lunas, NM, 15 miles to the south along the river corridor (Table 1). About 50% of the precipitation arrives during the four-month summer "monsoon" season (June-September). During the project period, precipitation was above normal between 1998 and 2000, but dipped significantly below normal in 2001 and 2002 as extreme drought took hold throughout New Mexico (Figure 3).

Similarly, river discharges were essentially normal from 1998 through 2000 with peak releases from Cochiti Reservoir, 50 miles up stream, occurring in the late spring following snowmelt (Figure 4). Beginning in 2001, releases began a downward trend (except for a small spike in early spring of 2001) in response to drought conditions that continued through 2002. For a review of the history of climate and discharges within the reach, see Crawford et al. 1993.

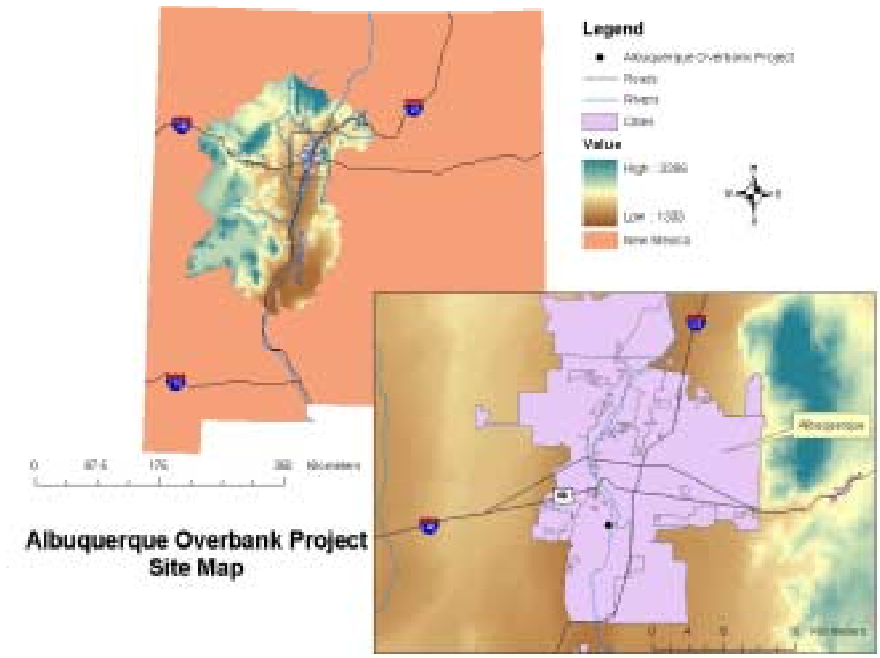


Figure 1. Location of the Albuquerque Overbank Project along the Albuquerque reach of the Middle Rio Grande (map courtesy of Ortiz, Shah, and Vinson, 2002).

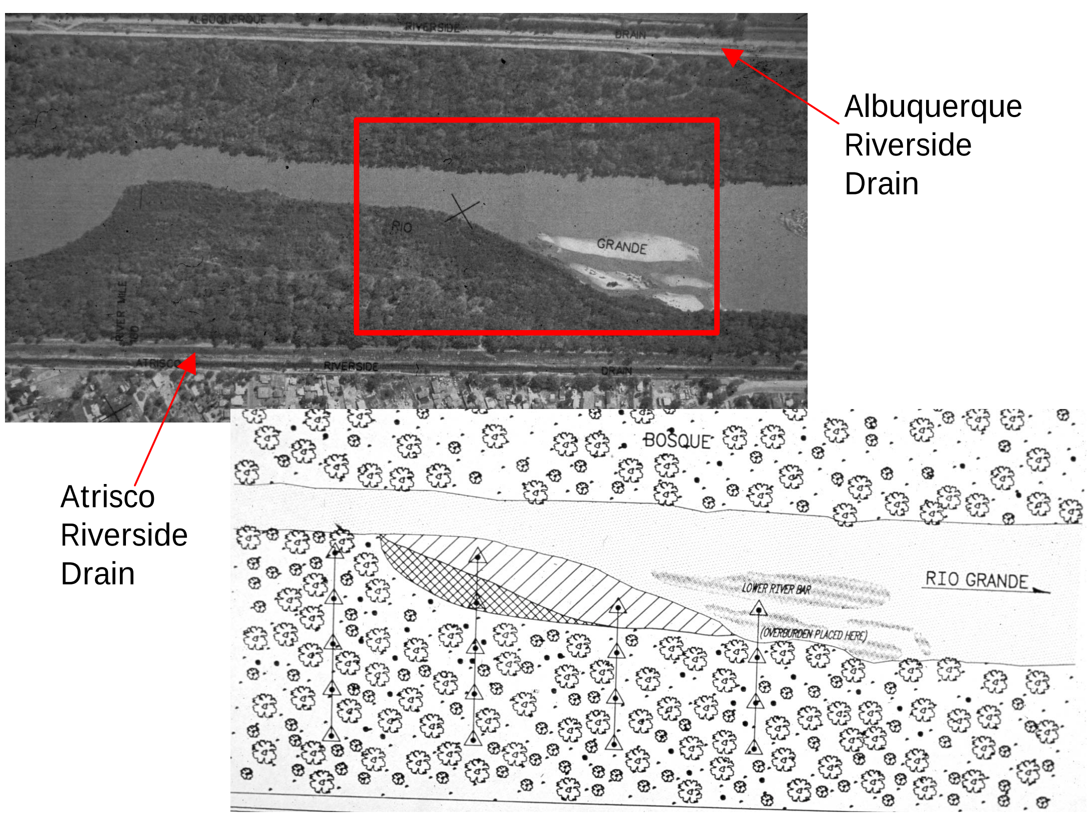


Figure 2. Site design for the Albuquerque Overbank Project showing the area to be lowered (right diagonal hatching), and the cleared, but not lowered terrace (cross hatching). Note the constriction of the channel around the upper end point and then the widening at the location of treatment area. The triangles represent the approximate locations of groundwater wells installed along transects from the river's edge into the cottonwood forest.

Table 1. Climate summary for Los Lunas 3 SSW, NM (Station 295150), located approximately 15 miles south of the AOP site, and the nearest valley bottom weather station. (source: Western Regional Climate Center web page http://www.wrcc.dri.edu/).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average Max. Temperature (F)	51.6	58.9	66.1	73.3	81.4	90.2	92.5	90.0	84.1	73.8	59.0	51.3	72.9
Average Min. Temperature (F)	19.0	23.6	29.5	36.0	44.6	53.2	59.8	58.7	50.5	37.8	25.5	19.1	38.2
Average Total Precipitation (in.)	0.46	0.42	0.55	0.52	0.57	0.59	1.36	1.74	1.49	1.08	0.63	0.51	9.92

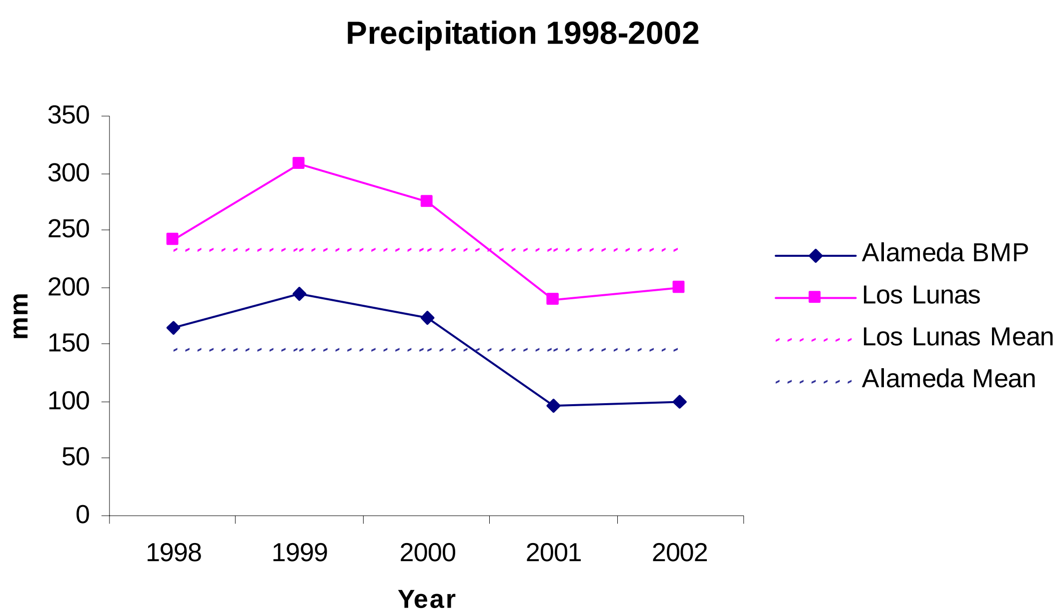


Figure 3. Average yearly precipitation over the course of the AOP project as reported at Los Lunas 3, SSW (Station 295150), and from the Alameda Bosque Ecosystem Monitoring Program site.

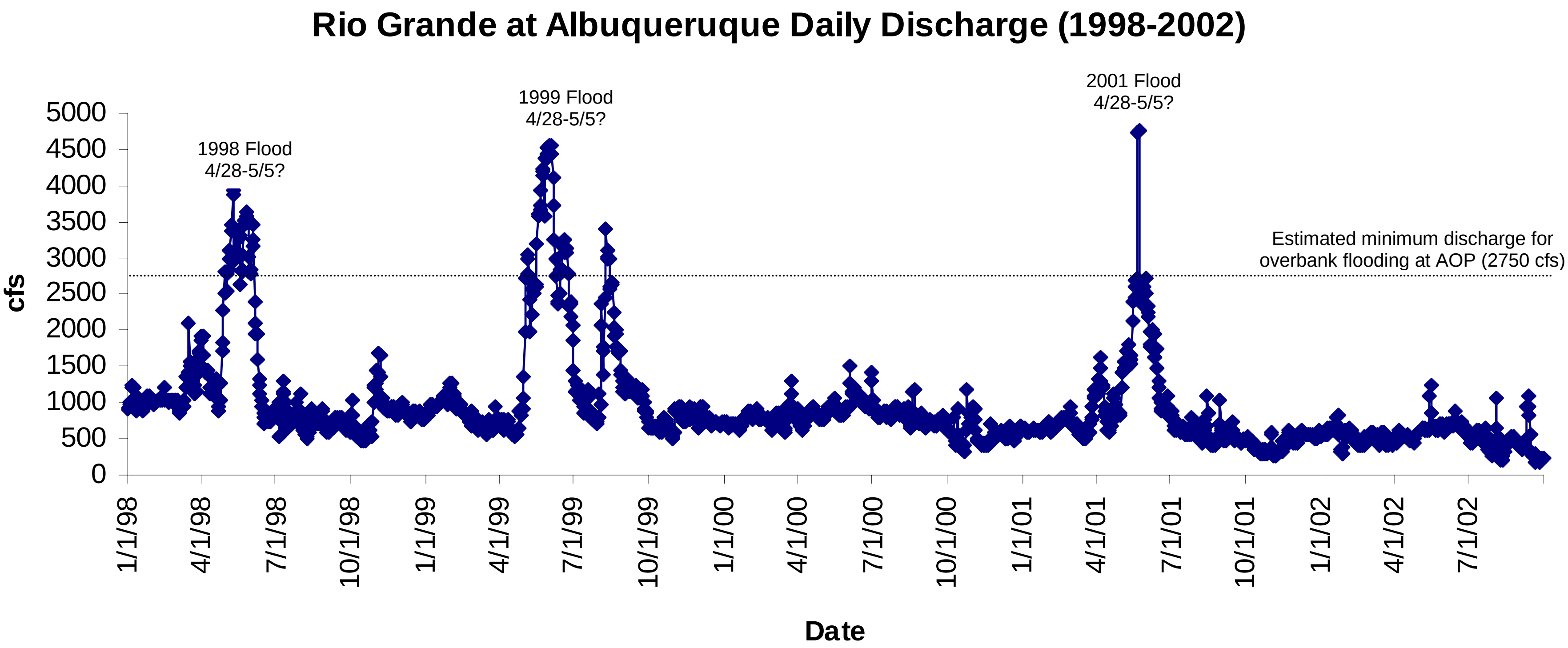


Figure 4. Discharge profile of the Rio Grande through Albuquerque, NM during the project period. Estimated minimum discharge for overbank flooding at AOP based on models of Kolk and Umbreit, personal communication, 2000 (data from http://waterdata.usgs.gov/nm/ Gage 08330000).

METHODS

Site Preparation

In March 1998, mechanical treatment was initiated using Bureau of Reclamation equipment and operators. A monotypic Russian olive stand was cleared and root-plowed along a length of approximately 200 m (700 ft). The vegetative materials were pushed towards the northern portion of the bar as the clearing progressed. A strip, approximately 75 m by 100 m (200 ft by 300 ft), was utilized to stockpile the vegetative materials until the City of Albuquerque Open Space hauled, shredded, and disposed it off site.

Following clearing, 2.4 acres of that acreage was lowered approximately 0.66 m (2 ft) using land-based equipment to allow for flooding during spring runoff events (Figure 5). Soil material from the lowering was moved to the lower bar area, and the entire area blended and leveled to a height approximately 0.5 m (1.5 ft) above the channel bed. Then artificial channels and intervening island bars were excavated into the new bar to mimic the conditions that might be found on a natural bar following flooding, and that would create possible microhabitats for successful cottonwood regeneration. An area of about one acre of cleared terrace was not lowered, and hence, not subject to overbank flooding under normal circumstances. This "upper terrace" served as a comparative site representative of the more standard restoration practices of exotic removals without flooding (but typically followed by cottonwood pole plantings). The total amount of material moved was approximately 6,100 m^3 (8,000 yds^3). All work was performed in dry weather and without entering the active channel, at a cost of approximately $5,000/acre (both equipment and labor).

Groundwater Measurements

Four equidistant transect lines of shallow groundwater wells were established to study the dynamics of the cleared area relative to the uncleared forest to the west and north (Figures 2 & 6). Lines were situated perpendicular to the river and wells (2 in inside diameter pvc or metal, sieved at bottom meter) were hand-augered to depths of ~1 m below the water table (low in late winter). Lines were ~140 m apart and designated as A-D, north to south. Wells on a line were numbered 1-5 (or 4) from east to west and placed 38 m apart. Lines A and B each initially contained five wells; lines C and D each had four. Wells B5 and D4 were lost to bank erosion within a few months. Well A5 was vandalized after two years and made inoperable.

Well depths were measured using a Solinst water-level meter intermittently beginning January 1998, and then on a monthly basis beginning in May 1999. Pressure transducers wired to data loggers were installed in wells A2, A5, C1, C4, D1, and D3 in late July 1998 to record two weeks of daily water table fluctuations. A UNM research team similarly instrumented wells C3 and C4 in 2000 in conjunction with a large evapotranspiration study that included part of the AOP site.

Figure 5. AOP site treatment was begun in March 1998 with the clearing of a Russian olive stand and the lowering of the bar by approximately 0.66 m (two ft) (A). Materials were moved onto an adjacent sandbar downstream (B). Channels and low-lying islands were excavated into the new bar to create microhabitats for cottonwood regeneration (C and D).

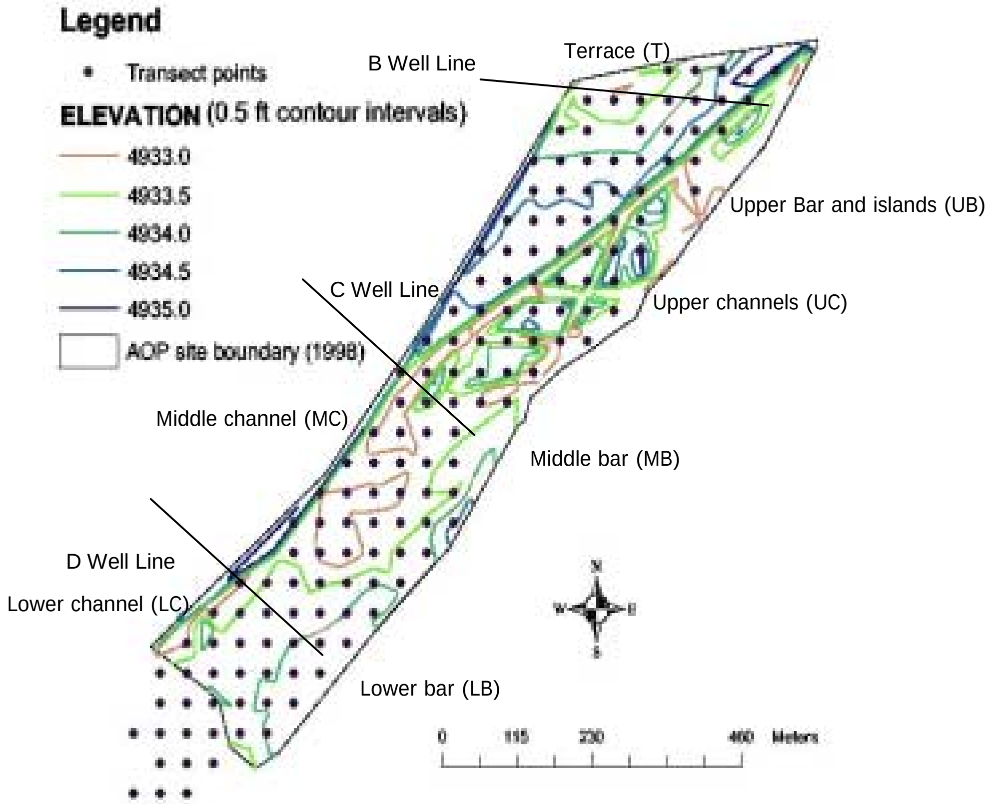


Figure 6. Albuquerque Overbank Project contour map and grid system of monitoring points based on a 1998 survey by the U.S. Bureau of Reclamation. The approximate location of the water well lines and landform sites are also indicated (derived from drawing by J. Shah).

Soils and Geomorphology

Following bank lowering, a professional topographic survey was conducted across the bar and a half-foot-interval contour map developed for the project area (Figure 6). The bank line was mapped for erosion annually prior to the spring runoff using a hand-held Trimble GeoExplorer GPS with a precision of approximately one meter (3.3 ft). Using the survey and the bankline maps, Ortiz, Shah, and Vinson (2002) calculated bankline sediment losses over the period.

Reclamation's Environmental Research Laboratory[3] in Denver, CO conducted a soil salinity and texture study of selected AOP sites in 1999. Soil profiles were described from eight bore samples locations representing various types of microhabitats on the bar and terrace. Texture, electrical conductivity and paste pHs were laboratory-determined at selected depth intervals and compared among sites. In addition, the US Fish and Wildlife Service conducted rapid salinity surveys on a yearly basis using an electromagnetic meter (EM).[4] The EM meter measurements were calibrated against the Reclamation laborator values by regression.

Biological monitoring

To monitor tree recruitment and vegetation composition and abundance, a grid system of one-meter quadrats was established across the site at 12.5 m intervals (Figure 6). The grid system was oriented in the cardinal directions and was installed from a random starting point using GPS at the same time as the topographic survey was conducted. A total of 150 quadrats were established across the site. In 1998 and 1999 all tree regeneration was recorded by height classes and the percent cover of vegetation by major growth form estimated in 10% cover classes (shrubs, grasses, and forbs). In 2000, the system was refined to estimate cover on a species basis for all species, and the tree counts expanded to a full census on the 12.5 by 12.5 grid squares. Voucher specimens were collected for all but the most common species, identified, and deposited in the UNM Herbarium.[5] The vegetation was mapped in broad categories in 1998 and 1999.

Ellis (2001) conducted surveys of surface arthropod, bird, and beaver activity on the treated areas and in the adjacent forest for a year between June 2000 through June 2001. These included pitfall traps for the arthropods, monthly area searches and point counts for birds, and quadrats to measure beaver browsing of tree saplings.

---

[3] Soil study conducted by Joe Brummer, Reclamation Soil Scientist.
[4] Salinity surveys conducted by Gina Dello-Russo, Biologist, Bosque del Apache National Wildlife Refuge.
[5] Botanical voucher identifications by Yvonne Chauvin, New Mexico Natural Heritage Program.

RESULTS

Flooding and geomorphology

Overbank flooding of various extents and durations ocurred at AOP in 1998, 1999, and 2001 (Figure 4). The first flood occurred from late May into early June, 1998 as peak discharges exceeded 4,000 cfs (113 cms) upstream at the Albuquereque gauge at Central Avenue. Based on *post facto* backwater modeling of water and vegetation elevations, overbank flooding at AOP occurred at between 2,750 and 3,000 cfs (79 and 85 cms). This is well below the design estimate of 5,000 cfs[6]. Flooding lasted at least 10 days and inundated all of the constructed channel areas, and either flooded or saturated most of the elevated island and bar surfaces (Figure 7). The site flooded again in 1999 on several occasions from late May into late June. By then, vegetation cover was high enough to helped stabilize the site and modify flood-water dispersal. There was no flooding in 2000, despite above-normal precipitation, but during the drought year of 2001, a short-duration flood of two days occurred in mid May that inundated the entire constructed bar surface. Throughout the study period, the upper cleared terrace was never flooded, although a lower depression along the northern edge became saturated at peak discharge.

During the floods some geomorphic changes occurred, particularly along the bar bankline (Figure 8). The first flood event immediately eroded away a constructed island and the upper portion of the main new channel, leaving the outermost groundwater well along Line B orphaned in the river (Figure 9). There was also ongoing erosion along the entire bank that was accelerated during the flood of 2001 by the removal of a large snag (Figures 10 & 11). Ortiz, Follstad and Vinson (2002) estimated total sediment losses over the five-year record of bankline sediment loss at 3,360 m^3 to 4,000 m^3. But while this material was being removed, deposition was occurring at the downstream end of the bar below the new point where the snag came to rest in the 2001 flood. This increased the width of the bar significantly in this area, providing new sites for vegetation establishment, including trees. In general, bank erosion from 2001 to 2002 was negligible, perhaps as a function of low discharges during this drought period, the armoring of the bank by vegetation, and possibly adjacent channel adjustment as the new bar altered the river's width-depth ratio.

[6] Personal communication 2003, Robert Padillia and Nancy Umbreit, Bureau of Reclamation, Albuquerque Area Office.

Upper bar

Lower bar

1998 (3,000 cfs) 1999 (4,200 cfs)

Figure 7. Paired photos from 1998 and 1999 at the upper and lower portions of the AOP bar, respectively, show the extent of spring overbank flooding and subsequent vegetation establishment.

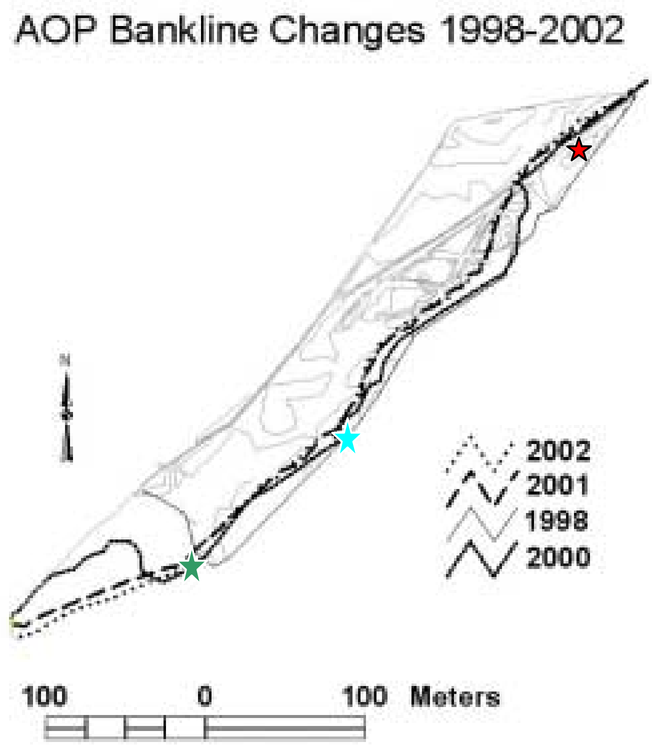


Figure 8. AOP bankline changes 1998 through 2002 as measured with a hand-held GPS. The red star indicates the location of the orphaned groundwater well in Figure 9. The blue star is the location of the large snag in Figure 11 prior to the flood of 2001; the green star is it location after the flood (Figure 26).

Figure 9. A groundwater well at the end of Line B was orphaned in the river by bank erosion in the first flood of 1998 (photo taken May 22).

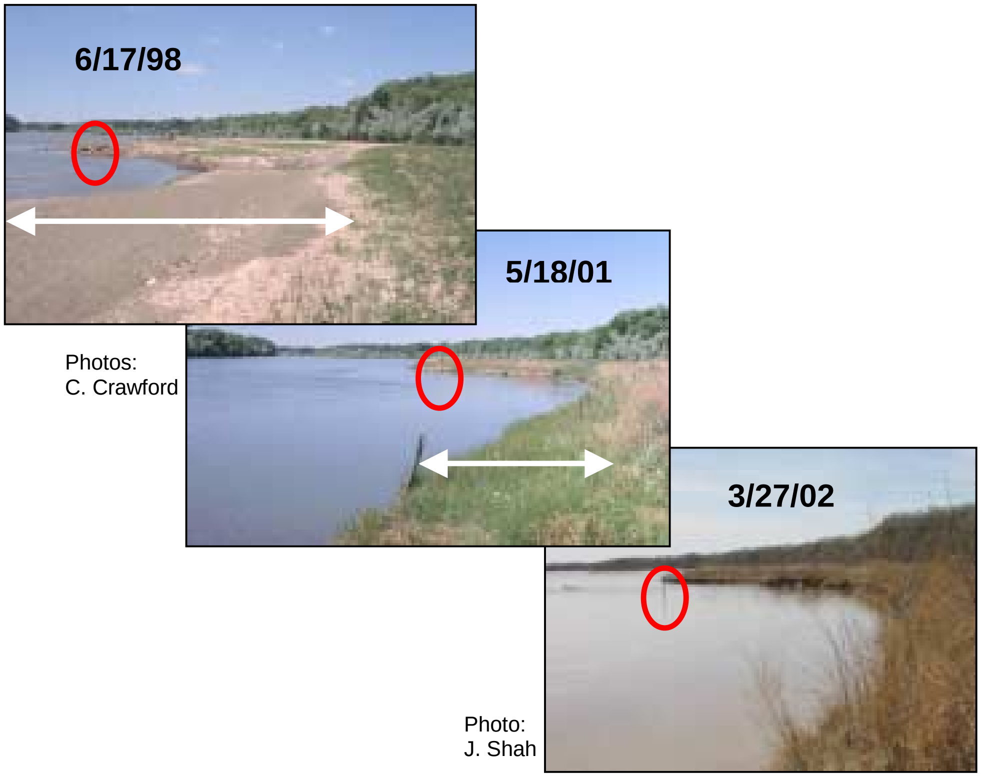


Figure 10. Bank erosion along the lower bankline through time. Note the increasing isolation of the circled groundwater well.

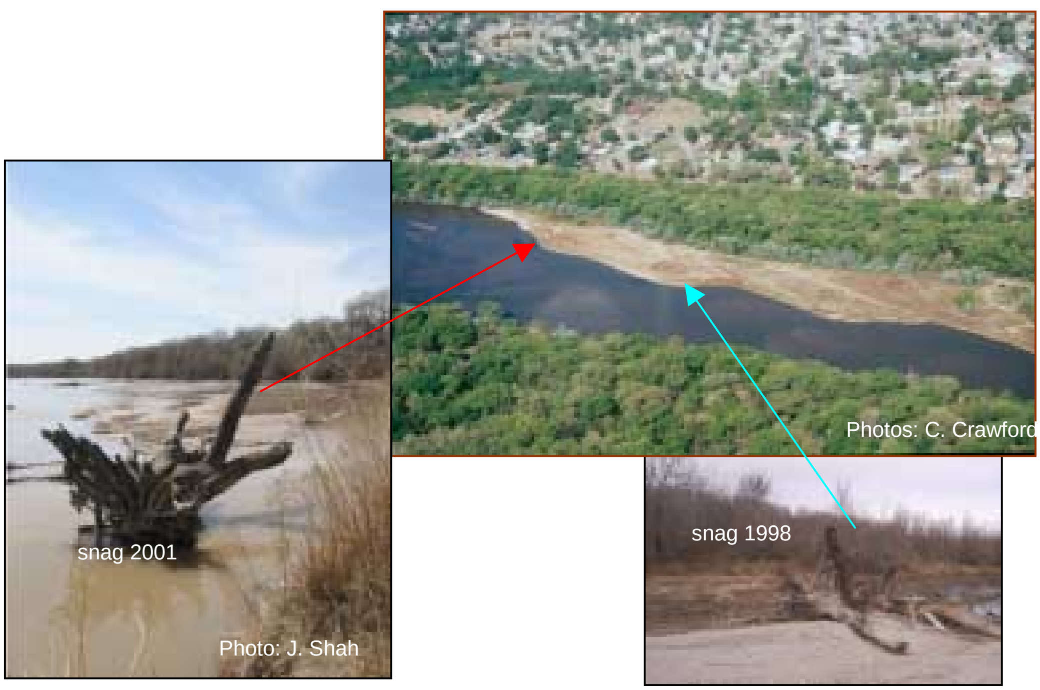


Figure 11. The transport of the large snag during the 2001 flood from mid bar to point just at the lower end.

Groundwater dynamics

Groundwater levels correlated well with river discharge (Table 2). Wells nearest the river (10 m to 30 m) were more responsive to changes in flows over the years, while those further away (75 m or more) in the mature forest responded more slowly, with smaller peak heights (Figure 12; Table 3). While peak levels are important for creating wet soils during cottonwood germination events in the spring, base flows throughout the year are important for maintenance. Overall, base flow depths remained more or less constant though the 2000 and 2001 water years, but there is a suggestion of decline of some 25 cm during the extreme drought of 2002.

Data on daily well responses is limited. In 1998, continuous measurements conducted at one pair of wells, one near the water (D3) and one in the adjacent forest (D1), during the six-week peak growth period in summer clearly showed the daily effects of established forest vegetation on water levels (Figure 13). While the forest well showed the classic dip in water depth at the height of the day as a function of evapotranspiration, the bar, even with the development of significant herbaceous vegetation, showed little diurnal response (almost all the response is due to discharge). In 2001, we began peiziometric monitoring from the C4 well in a vegetated area of the bar and a supplemental well within the adjacent forest (Figure 14). During a representative month over the a three-year period from 2001 through 2003 there was a hint of the development of a diurnal response on the vegetated bar, but, in general, vegetation water use effects on groundwater still appeared to be minimal relative to the forest.

Table 2. Correlations between AOP groundwater depths (cm) with the mean 24-hr Rio Grande discharge (cfs) and stage (cm) at the Central Avenue gauge between May 6 and September 23, 1999 (n=23). Note that discharge and stage are from USGS records and are not corrected for normality.

Well	Elevation (ft)	Condition	r^2
A1	4935.3	Discharge	0.43
A1	4935.3	Stage	0.43
A4	4932.9	Discharge	0.88
A4	4932.9	Stage	0.90
C1	4935.0	Discharge	0.76
C1	4935.0	Stage	0.79
C4	4934.3	Discharge	0.71
C4	4934.3	Stage	0.96

Table 3. Seasonal variation in AOP groundwater depths (cm) between May 6 and September 23, 1999.

	Groundwater depth			
Well	$\bar{x}$ ±	SE	Range	Diff.
A1	234 ±	8	207-241	34
A4	32 ±	4	1-66	65
C1	194 ±	5	178-207	29
C4	47 ±	6	6-90	84

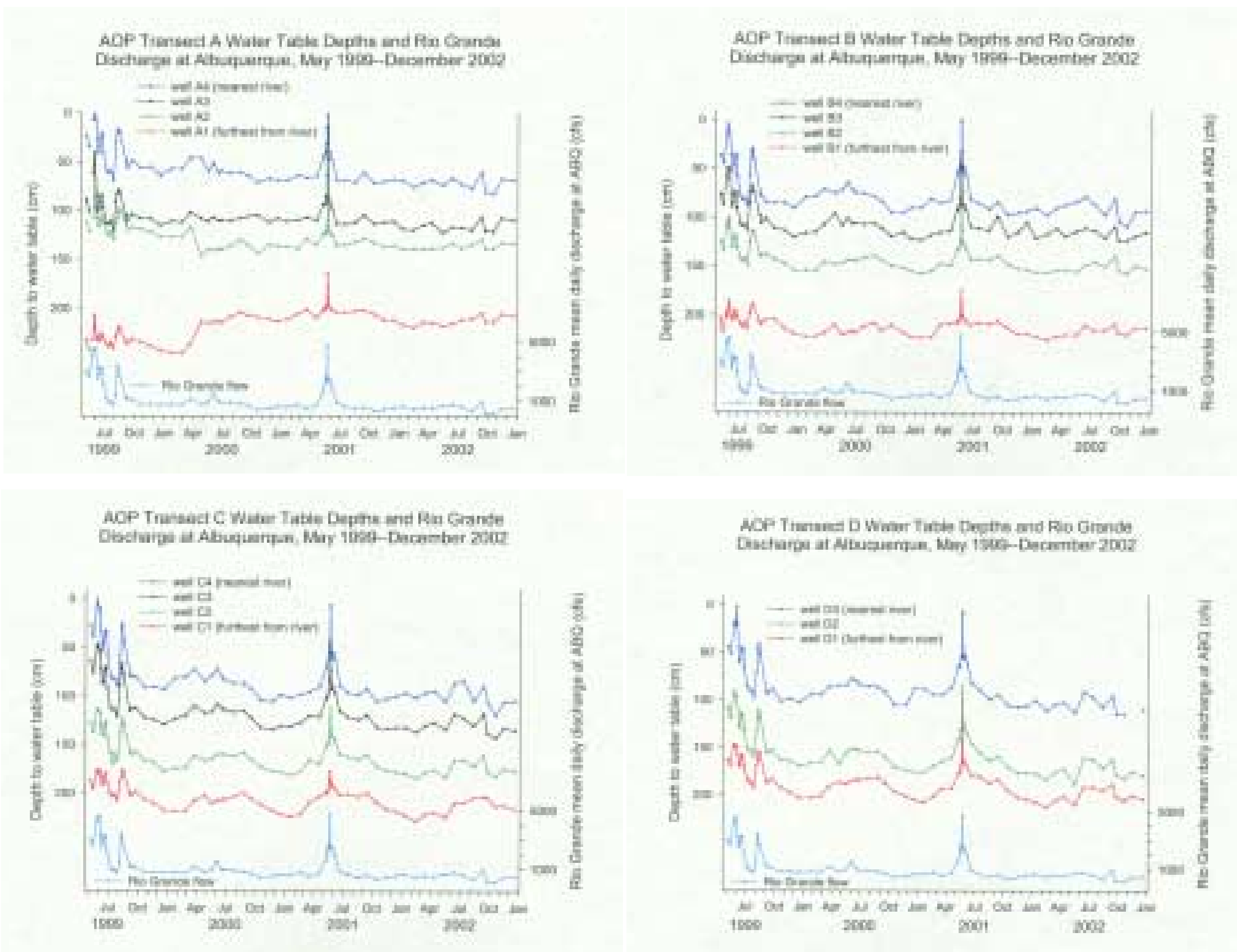


Figure 12. Monthly AOP groundwater well depths between 1999 and 2000.

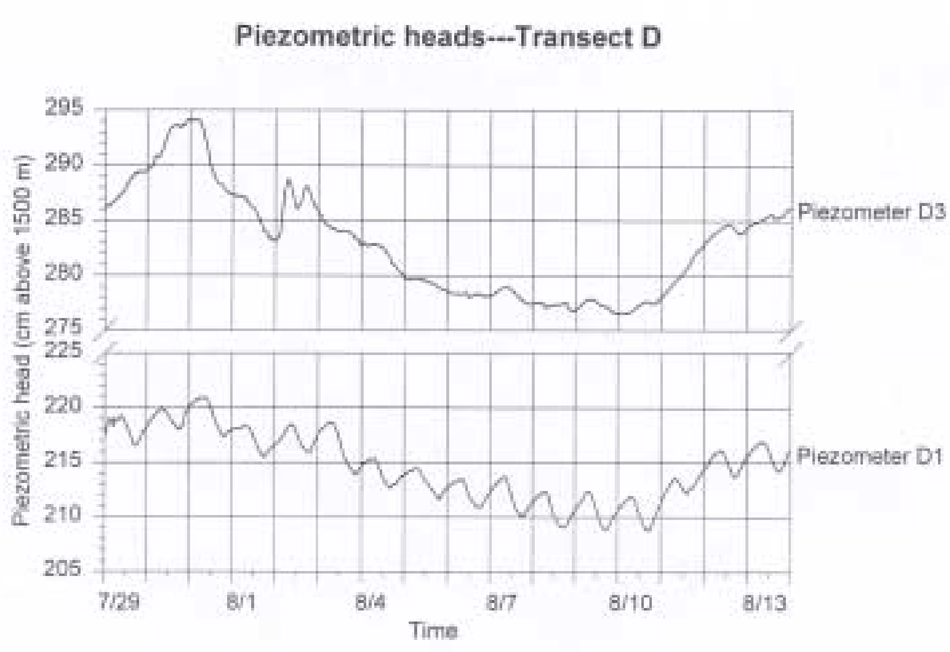


Figure 13. Piezometric heads from 7/29/98 to 8/13/1998 at wells D3 near the river and D1 in the adjacent forest.

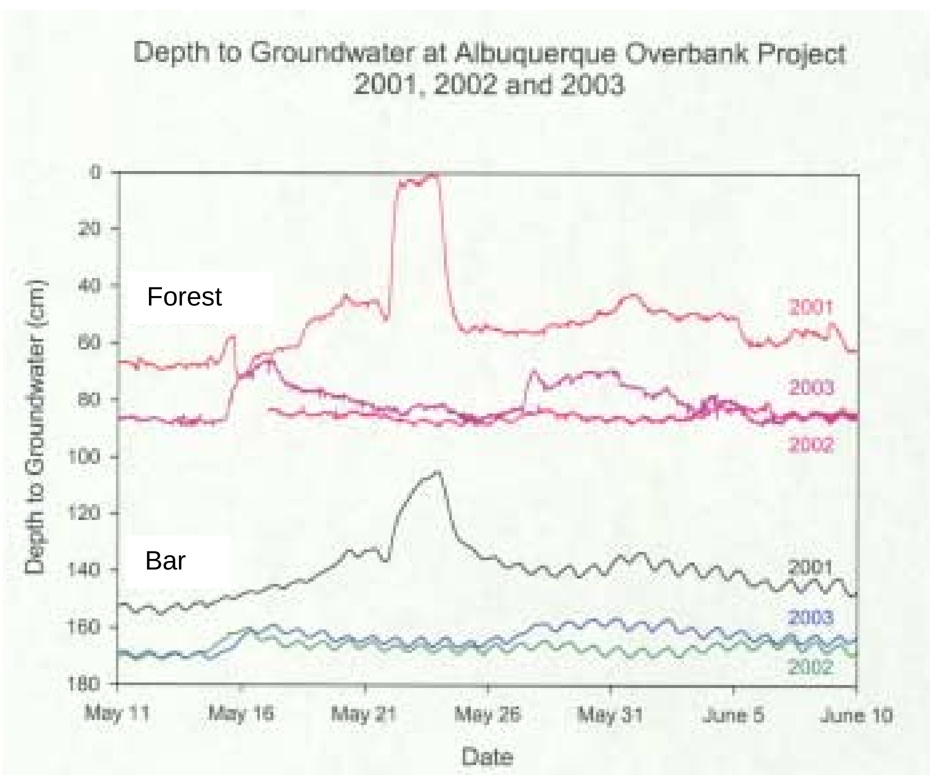


Figure 14. An example of piezometric heads in late spring at AOP bar C4 well near the river and a supplemental well in the adjacent forest.

Tree establishment and growth

The initial overbank flooding of May 1998 generated ideal conditions for cottonwood germination. By the end of the growing season, young cottonwood seedling densities on the flooded bar were over 164,000/ha (Table 4). Of these, about 10,000/ha became established by the end of 1999. While 1999 had above-normal rainfall (Figure 3), successful cottonwood establishment was probably predicated on roots reaching the groundwater in the first two growing seasons (in this case approximately 0.5 m to 1 m below the surface). Numbers continued to decline through the ensuing years, but by the end of the fifth growing season in 2002 there were still 4650/ha, comprising 75% of the total tree population on the flooded site. By that time, the cottonwoods had also developed a definite size-class structure (Figure 15), mostly through shade self-thinning and occasional beaver herbivory (see Ellis 2001). By 2002, many cottonwoods were well over three meters tall. Despite flooding in the spring of 1999 and 2001, there were no additional significant germination and establishment events after 1998. Those individuals in the smallest size classes in 2002 represented trees that had been repeatedly browsed by beavers, not new establishments. Gooding's willow (*Salix goodingii*), although not detected until 2000, has become established and maintained among the cottonwoods through 2002.

Non-native trees also reproduced on the flooded bar following the 1998 flooding, but their densities were considerably lower. Initial Russian olive densities were only around 1000/ha, and some of that could be attributed to resprouting of remnant root systems. After a decline in 1999, numbers began to increase with new seedlings and saplings being recorded in 2000 and 2001 (Figure 16). Unlike cottonwood, Russian olive appears to have ongoing recruitment. Saltcedar had a high number of germinations in 1998 relative to Russian olive, but these numbers declined quickly, and by 2000 there were only scattered individuals around the bar. Since then, their numbers fluctuated, but were generally on the rise, with many individuals growing to over three meters tall. Siberian elm (*Ulmus pumila*), while absent early on, has become established in low numbers, and as typical for the species, recruitment is ongoing (Figure 17). Overall, by the end of 2002, exotics constituted 22% of the trees on the treated and flooded bar.

The unflooded upper terrace had a different outcome (Table 5). Cottonwood reproduction was minimal--simply root-plowing without lowering and flooding the bar did not create a suitable environment for germination and establishment. Those cottonwood establishments that did occur were toward the north end of the terrace where elevations decline towards a moist swale. Some of the individuals also represented root sprouts off a nearby stand of mature trees. On the other hand, despite the efforts to remove all Russian olive from the terrace, numbers rose over the years and by 2002 approached pre-treatment densities. This was mostly sexual reproduction, but sprouting from remnant root systems was also possible. Siberian elm and saltcedar have also invaded the terrace, although saltcedar numbers remain relatively low. By 2002, while the terrace occupied over a third of the treated acreage, it accounted for only 26% of the tree density and most of these were exotics (86%).

Table 4. AOP tree densities (stems/ha) by species and year on the lowered and flooded river bar.

	Year				
	1998	1999	2000	2001	2002
Native Species					
Rio Grande cottonwood	164888	10070	5864	5872	4650
Goodding's willow	0	0	177	192	122
Non-native					
Russian olive	1058	673	486	537	616
Saltcedar	15840	5064	22	739	439
Siberian elm		0	161	177	298
All Trees	181785	15808	6710	7518	6125

Table 5. AOP tree densities (stems/ha) by species and year on the unflooded upper terrace.

	Year				
	1998	1999	2000	2001	2002
Native Species					
Rio Grande cottonwood	26	795	147	281	301
Goodding's willow	0	0	1	48	45
Non-native					
Russian olive	26	795	424	763	915
Saltcedar	0	52	24	24	24
Siberian elm	0	0	131	373	784
All Trees	52	1642	772	1604	2168

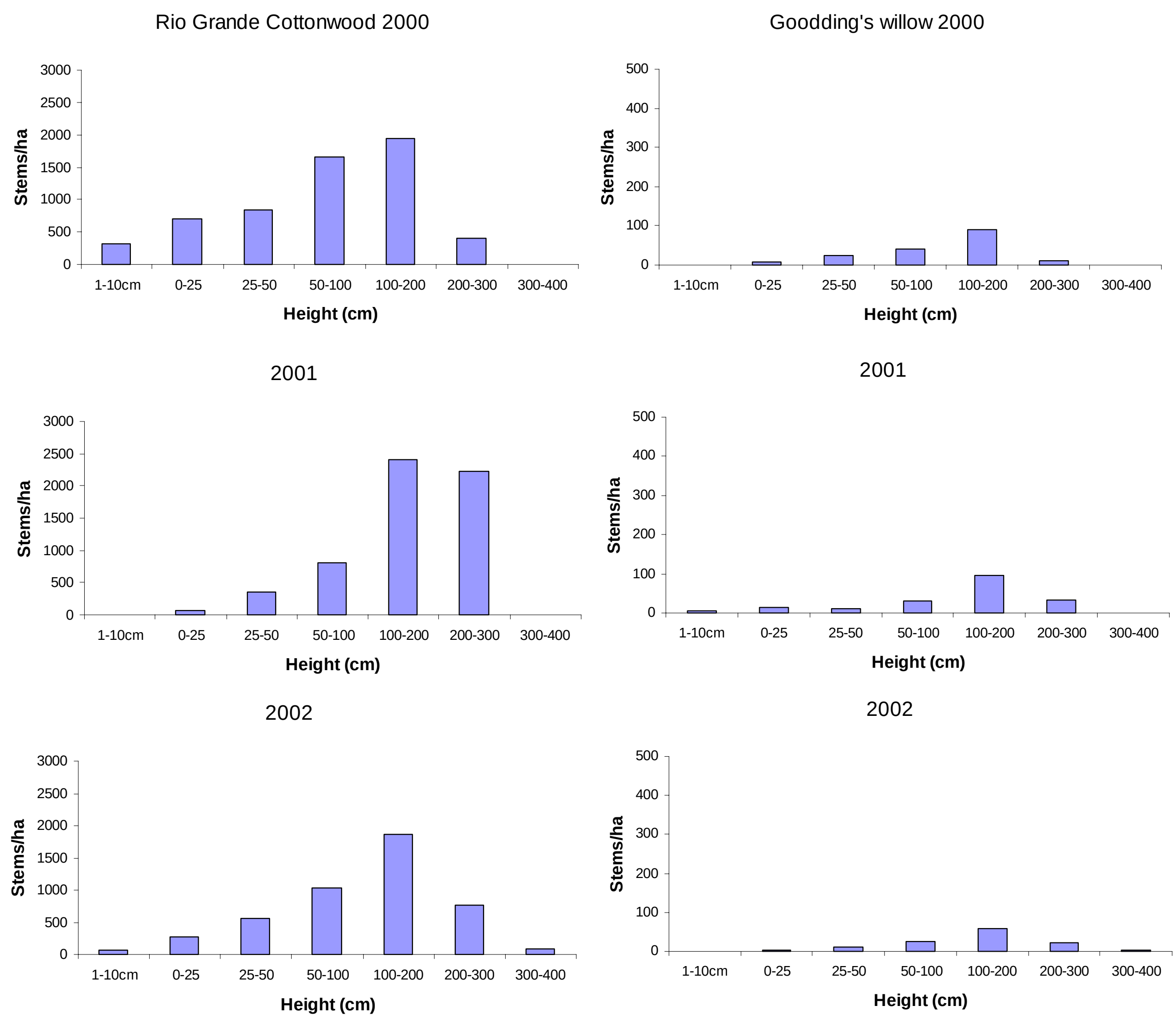


Figure 15. Changes in stand structures of cottonwood and Gooding's willow on the flooded bar between 2000 and 2002.

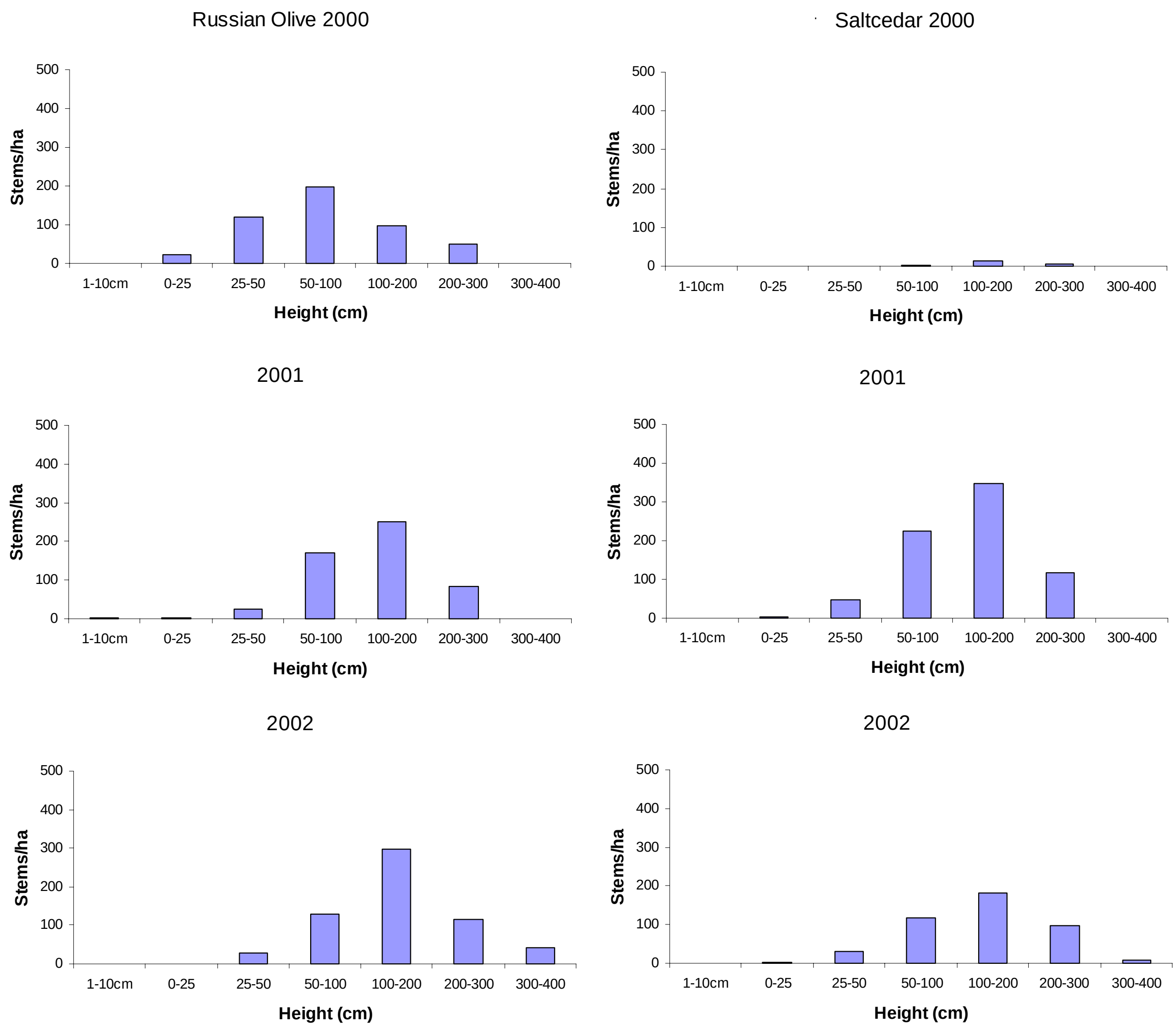


Figure 16. Changes in stand structures of Russian olive and saltcedar on the flooded bar between 2000 and 2002.

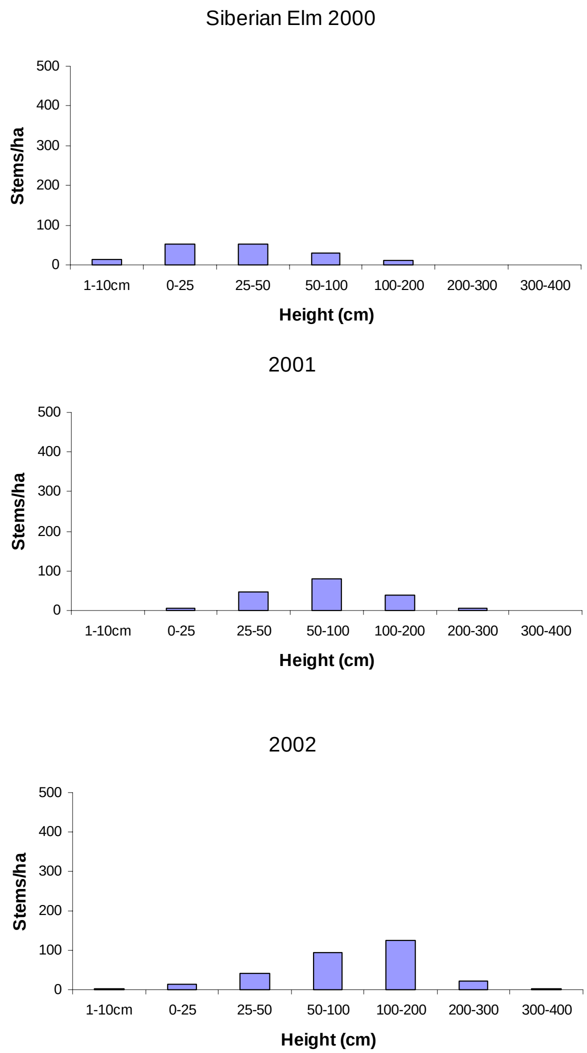


Figure 17. Changes in stand structures of Siberian elm on the flooded bar between 2000 and 2002.

Recruitment was not only different between the upper cleared terrace and the flooded bar, but also among microsites within the bar (Figures 18 and 19). Cottonwood recruitment was highest in and along the middle and upper channels artificially created during the bar construction. The small islands created between the channels of the upper and middle portion of the bar also had moderate native reproduction, but declined towards the lower end. Yet, even at the lower end of the bar cottonwood densities still approached 1000 stems/ha, representing good potential for the establishment of a cottonwood forest overstory. In contrast, cottonwood recruitment along the lower back channel was minimal despite receiving sustained floodwaters.

The differential in reproduction success appears to be correlated to several factors. In general, the highest recruitment was in areas with the lowest salinities as measured in 1999 (Table 6; Figure 20). Salinities in sites with low establishment were approaching the known tolerance limits for cottonwoods[7]. The exception was in the lower channel where salinities remained low while reproduction was nearly absent. Substrate differences may have played a role here. Deposition during flood events followed a gradient of increasingly fine surficial soil textures from the upper end to the lower end of the main channel as clays increased from 5% to near 20%. The middle channel site had the highest reproduction and a moderate clay fraction at 15%. It also was situated where the channel widened into what is essentially an outwash plain across the lower bar. Hence, floodwaters entering the middle channel area were slowed and spread out, coarse sediments were dropped, and silt and clay-laden waters carried through to the lower channel and bar area. It is in the initial sandy deposition areas that the densest stands of cottonwoods became established. In contrast, the lower channel with its finer textured surface deposition has remained essentially barren over the five-year course of the study. Similarly, the upper and middle bar islands with their moderate reproduction also had finer textures due to differential deposition, but the fine textured surface was shallower than the lower bar/channel area (18 cm versus 45 cm ; 7 in versus 18 in).

Besides texture and salinity, the effects on the soil structure of the mechanical treatment itself may have a played a role. The flooded areas with the lowest cottonwood establishment, the lower bar and channel, were also the sites that received significant amounts of fill material from the excavation and lowering of the bar, and as result the soil columns are highly disrupted. In contrast, while middle and upper portions of the bar were scraped and lowered, the remainder of the soil column remained more or less intact. While still relatively young, these soils exhibit incipient structure that may be important to the establishment of cottonwood seedlings.

Depth to the groundwater may also be important. Our groundwater wells indicate that the water table was generally within 0.5 m and 1.0 m of the surface throughout the year, but the locations of the wells were generally in elevated bar areas out of the channels. Hence, the depth to the water table was likely 0.25 m to 0.50 m shallower in the channels, and in the upper channel nearest the river subsurface flows often saturated the soils in the channels or caused ponding. But there is likely a balance between prolonged anoxic conditions created by saturation and the advantage gained by less distance to travel for seedlings to get established in contact with the groundwater.

The establishment patterns of the exotic species were somewhat different (Figure 18 and 19). Russian olive densities were highest along the upper channels and on the intervening constructed islands, and on the middle bar. Densities were relatively low in the middle channel

[7] Personal communication 1999, Joseph Brummer, Bureau of Reclamation soil scientist, Denver, CO.

outwash area where cottonwoods were highest. Furthermore, much of the ongoing recruitment and growth of Russian olive was along the bankline of the river. This is in keeping with the establishment of Russian olive along much of the bank edge of the Albuquerque reach of the Rio Grande. Saltcedar establishment was more constrained. Most seedlings have become established on drier, more saline sites of the middle and lower bar, but also intermixed among the cottonwoods of the middle channel area. Siberian elms were scattered throughout all habitats of the bar.

a)

b)

c)

d)

Figure 18. AOP cottonwood reproduction was most prolific along the upper (a) and mid channels (b). Russian olives were also abundant along the upper channel and scattered on lower bar (c). The lower channel area was nearly barren of both cottonwoods and Russian olives (d).

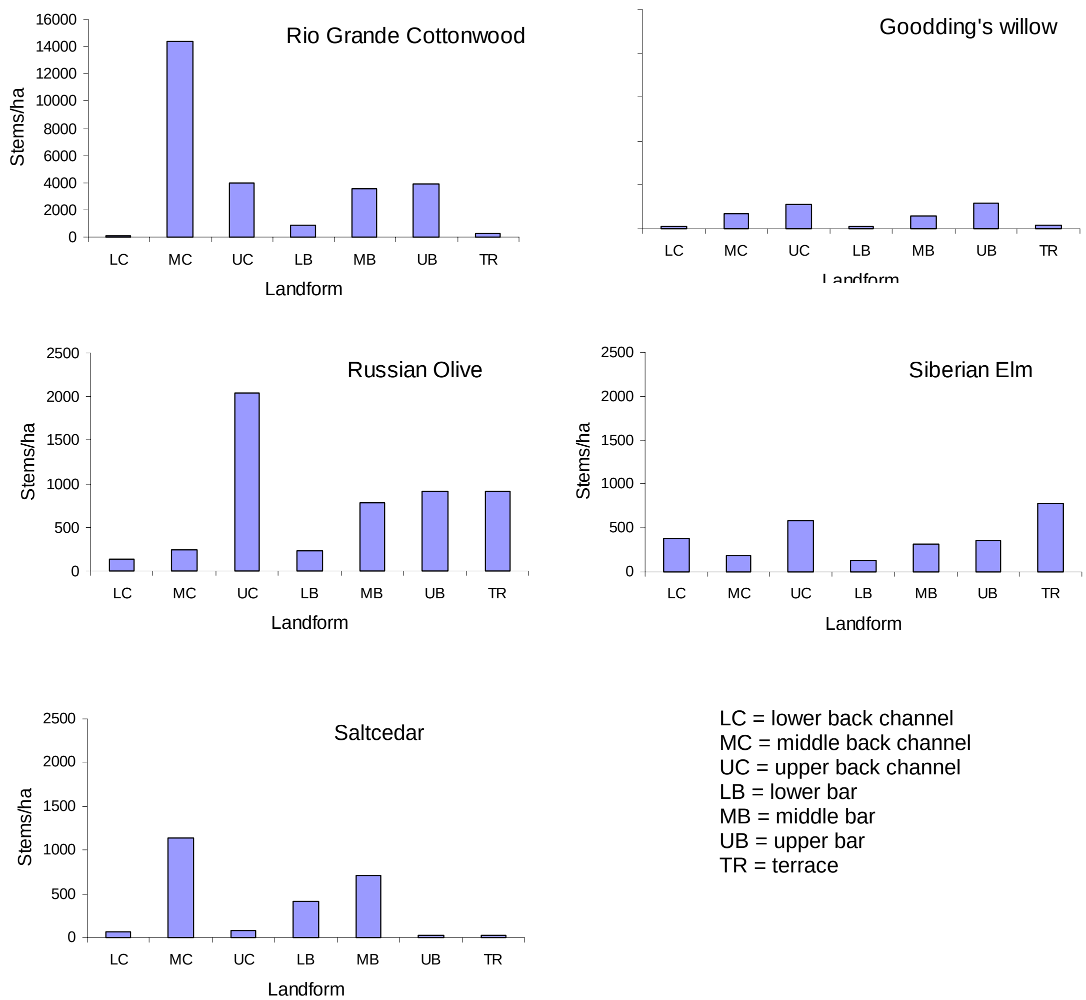


Figure 19. AOP tree distribution in 2002 by microsite type. See Figure 22 for microsite locations.

Table 6. Electromagnetic meter (EM) horizontal readings and electrical conductivies (EC) averaged over 0 to 75 cm depths for selected sites on the AOP bar (source: Joseph Brummer, Bureau of Reclamation and Gina Dello-Russo, FWS).

Site	Em_h mS/m	EC_e dS/m
1 - Lower Bar	16.8	1.45
2 - Mid-channel	13.0	0.46
3 - Upper Bar	16.2	1.42
4 - Upper Channel	9.8	0.43
5 - Upper Terrace	36.7	2.31
6 - Lower Channel	5.9	0.38

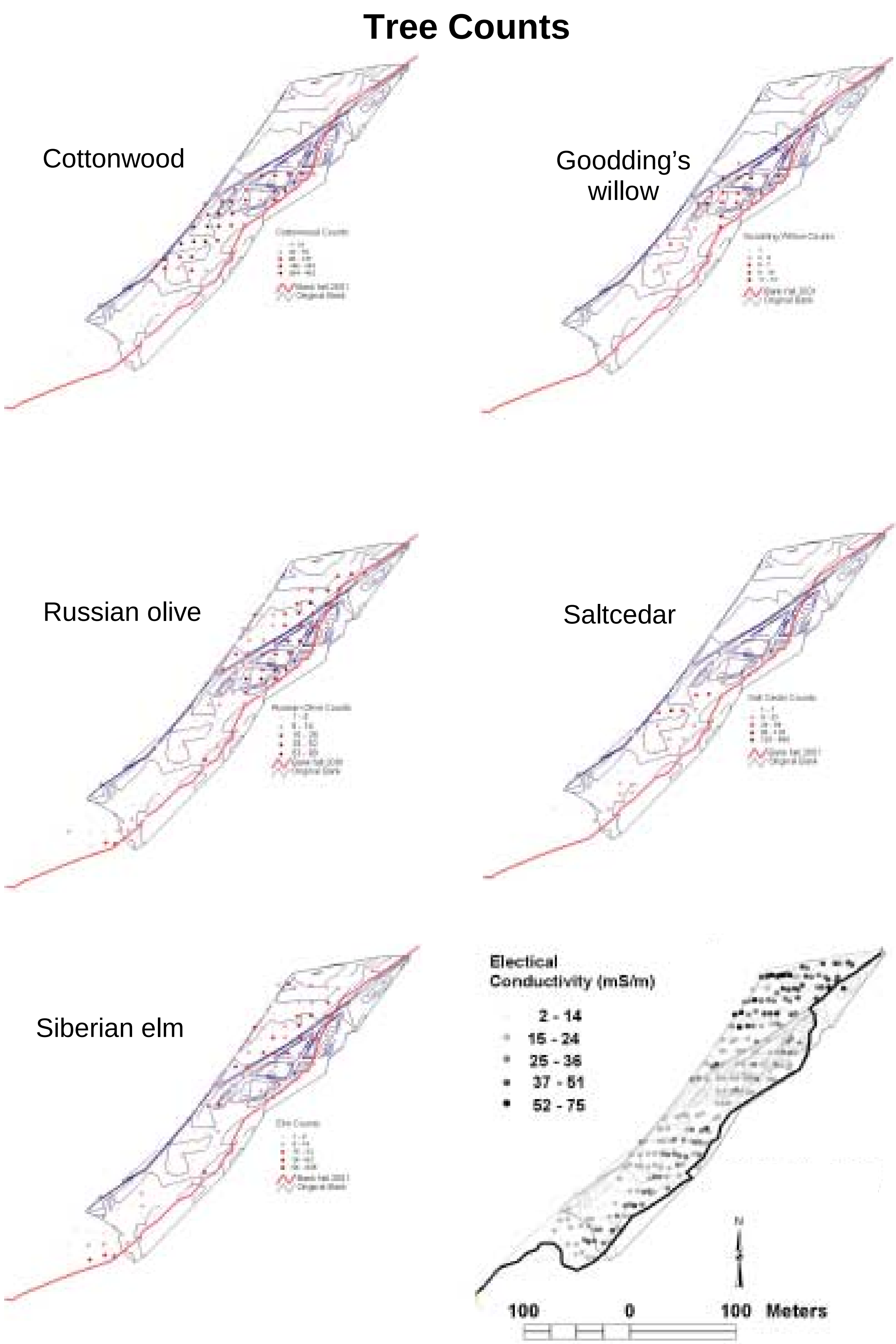


Figure 20. AOP 2000 tree census counts by species across the sampling grid in relation to estimated salinity measured as horizontal electrical conductivity by an electromagnetic meter.

Vegetation diversity and dynamics

While trees were becoming established on the bar, the site was also undergoing significant changes in terms of overall vegetation cover. Beginning with bare ground after the 1998 flood, the site was quickly occupied by annual forbs and some grasses by the end of the first growing season (Table 7). Sunflowers (*Helianthus petiolaris*) dominated the unflooded terrace, while horseweed (*Conyza canadensis*) and rough cocklebur (*Xanthium strumarium*) were prevalent on the bar along with sedges (*Carex* spp.) and rushes (*Juncus* spp.) in the channel (Figure 21). In the second year, perennial grasses began to take hold on the bar and forb abundance declined. Meanwhile, the biennial and exotic sweet clover (*Meliotis officinalis*) filled the upper the terrace.

By 2000, over 60 species of shrubs, forbs and grasses had become established on the bar (Appendix A summary tables; Appendix B species list). Native grasses and forbs outnumbered exotic species by over two to one (Figure 22). During 2002, there was a surge in forb cover led by the establishment of sweet clover on the bar along with sunflowers, western goldentop (*Euthamia occidentalis*), white heath aster (*Symphyotrichum ericoides*), cocklebur, and cuman ragweed (*Ambrosia psilostachya*). Grass cover was dominated by native scratchgrass (*Muhlenbergia asperifolia*), witchgrass (*Panicum capillare*), and thin paspalum (*Paspalum setaceum*), along with the exotic Johnsongrass (*Sorghum halepense*). While shrubs had not been very prevalent in 1998 and 1999, sandbar willows (*Salix exigua*) by 2002 approached 5% cover and shrubby Russian olives 2%. On the terrace, overall species richness was lower (34 species), but natives still prevailed over exotics (Figure 23). Sweet clover remained the dominant, but cuman ragweed, western goldentop, and bindweed (*Convolvulus arvensis*) were becoming prevalent by 2002.

In 2001, despite the declines in annual precipitation, forb and grass cover remained high and natives were continuing to increase relative to exotics. On the bar, sweet clover and sunflowers declined while horseweed, western goldentop, cocklebur, white heath aster, and cuman ragweed remained high or increased. Grass cover increased as well, led by scratchgrass and saltgrass (*Distichlis spicata*). Wetland indicators were also on the rise, particularly in the upper channel. These included Emory sedge (*Carex emoryi*), bull rush (*Schoenoplectus pungens*), Indiangrass (*Sorghastrum nutans*), Indian ricegrass (*Leersia oryzoides*), field horsetail *(Equisetum arvense*), and Indianhemp (*Apocynum cannabinum*). On the terrace, while sweet clover also declined, Russian thistle (*Salsola tragus*), green molly (*Kochia americana*), and bindweed were on the rise in contrast to the bar.

Continued drought conditions in 2002 appeared to depress grass and forb cover. On the bars, the biannual sweet clover was gone and horseweed had fallen from 5% to less than 0.25%. On the terrace, green molly and Russian thistle also declined significantly, but bindweed became more prevalent. The trend of natives over exotics was still maintained. Overall, the cumulative species richness on the bar was 89 species, of which 66% were natives, and on the terrace there were 52 species recorded between 2000 and 2002 with 73% natives (Table 8).

Table 7. AOP flooded bar average vegetation percent cover by year and lifeform.

	Year				
Lifeform	1998	1999	2000	2001	2002
Trees			6.41	9.91	15.69
Shrubs			4.89	7.91	11.25
Graminoids	4.21	17.19	14.51	21.93	17.75
Forbs	15.24	9.35	68.21	60.75	24.58

Table 8. AOP cumulative species richness 1998-2002 on the unflooded terrace and flooded bar.

Origin	Terrace	Bar	Total
Native	40	67	68
Exotic	12	22	22
Total	52	89	90

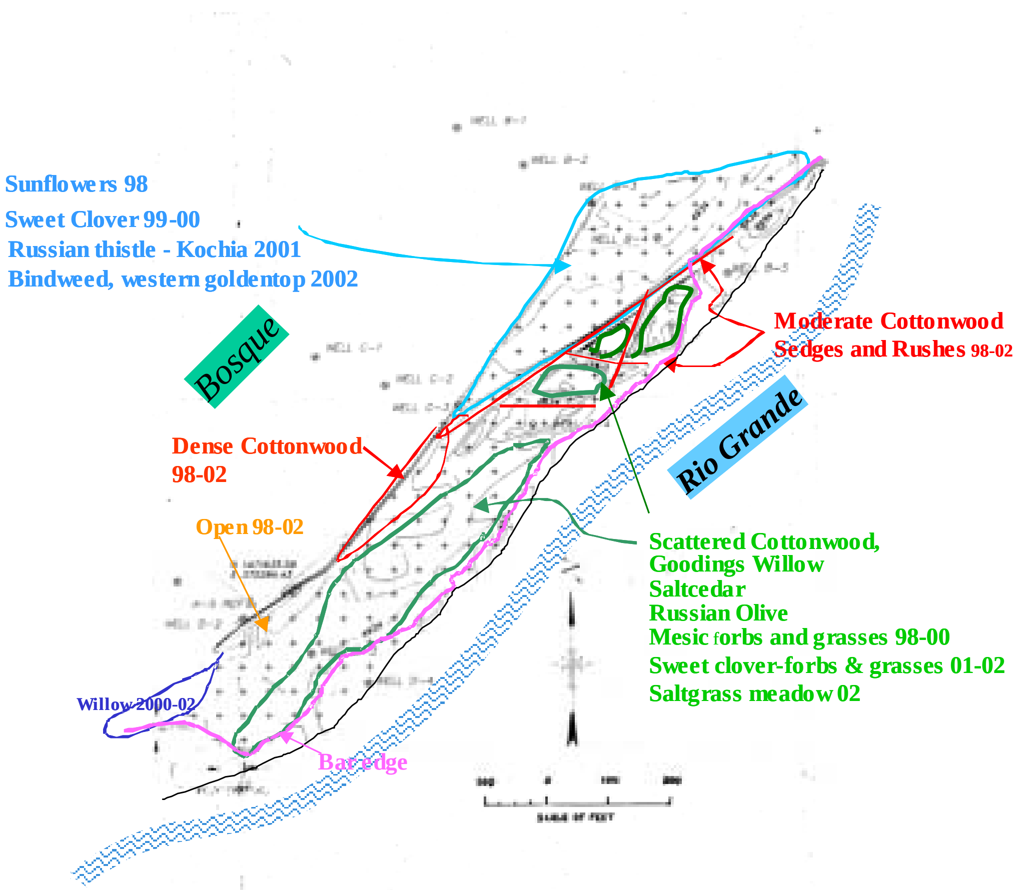
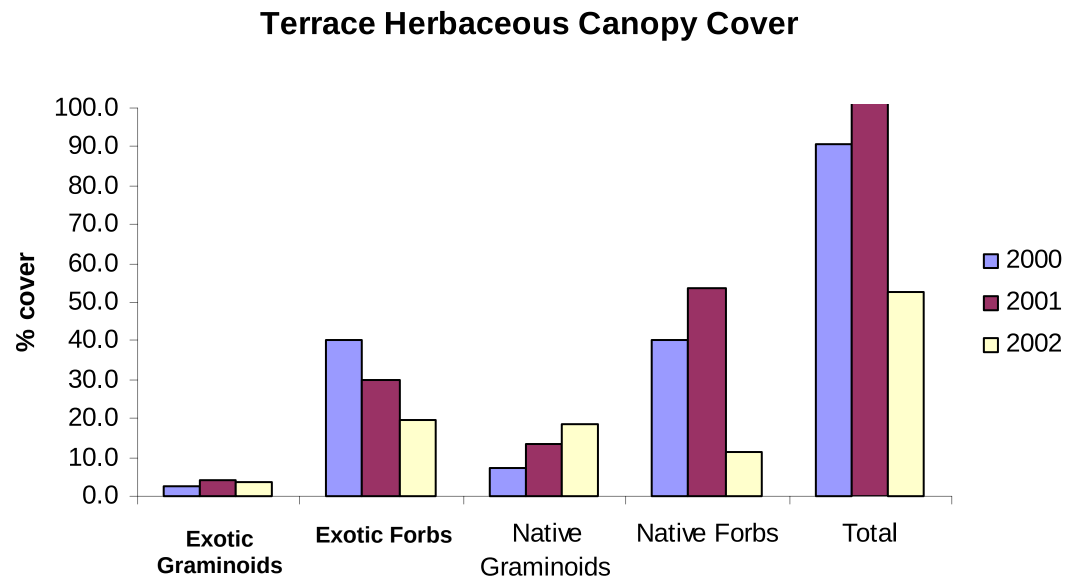


Figure 21. Vegetation patch composition change 1998-2002 at the AOP.



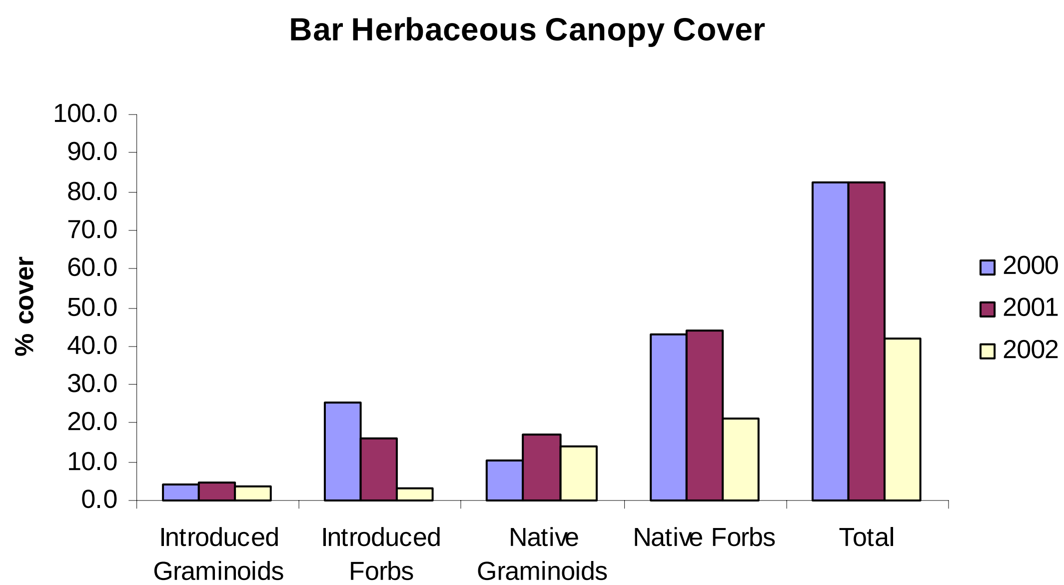
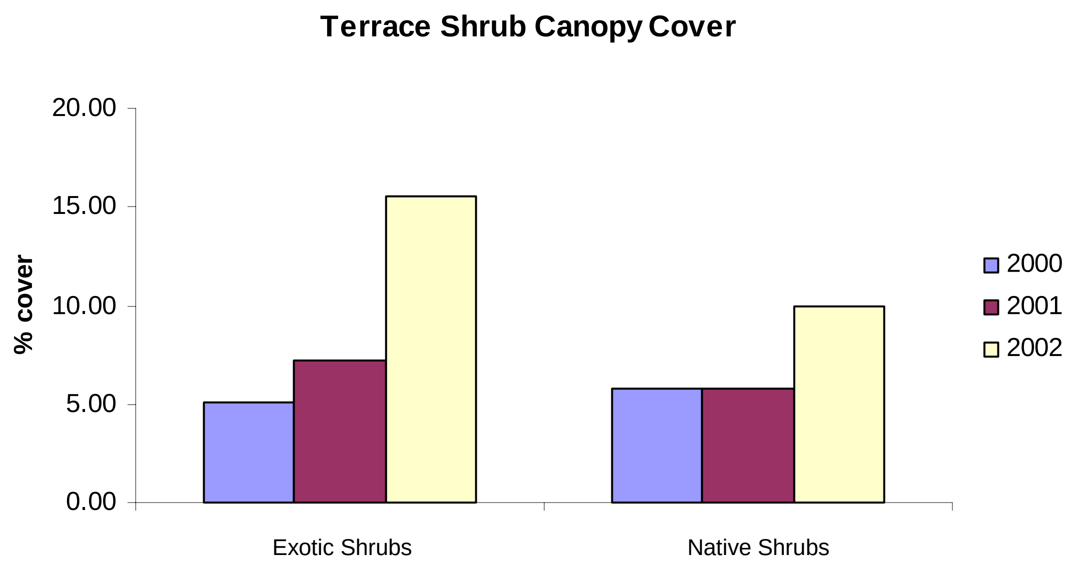


Figure 22. Herbaceous cover on the AOP unflooded terrace and flooded bar by operational functional groups from 2000 through 2002.



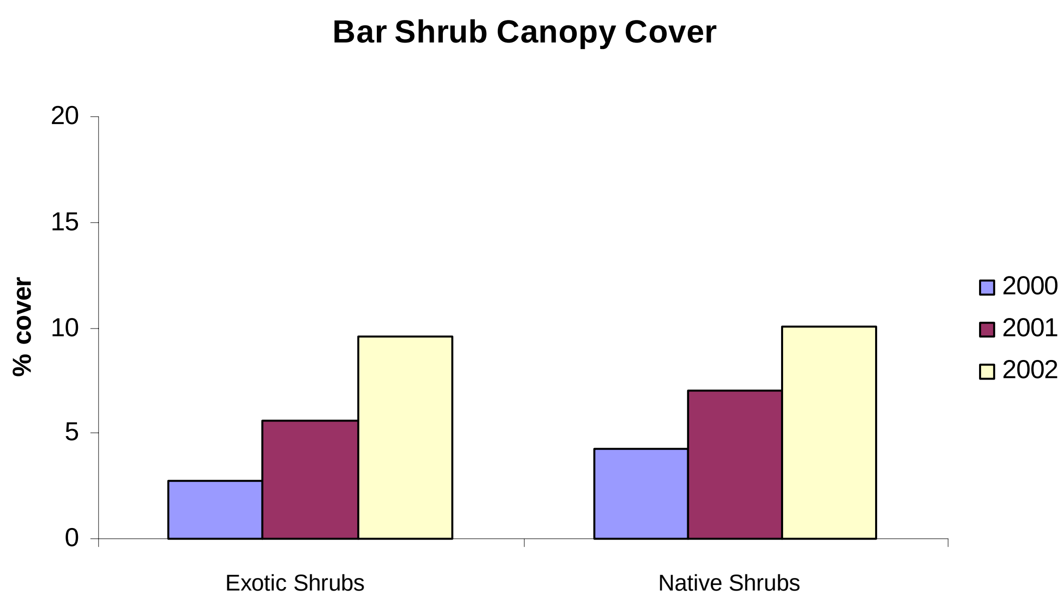


Figure 23. Shrub cover on the AOP unflooded terrace and flooded between 2000 and 2002 stratified by native and non-natives.

Overbank flooding capacity

While the design flood for AOP was estimated at 5,000 cfs, flooding actually took place at a much lower level between 2,750 to 3,000 cfs. This is well within the norm for historical peak discharges on the Rio Grande, even in the post-Cochiti Dam period after 1972 (Figure 24). This is encouraging because it suggests that overbank flooding for restoration can be accomplished without having to request exceptionally high targeted releases. Hence, planning can focus on the timing of releases and their duration, rather than the amounts.

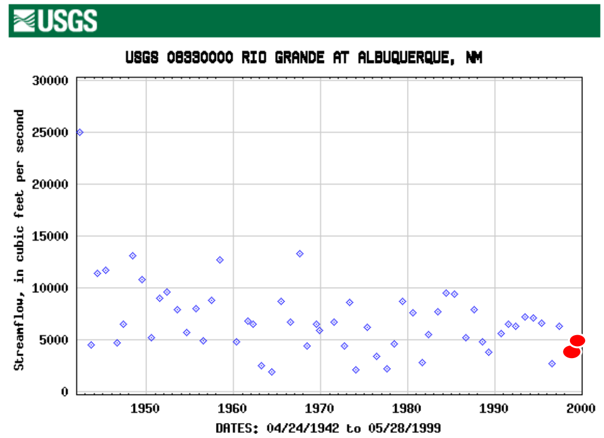


Figure 24. Yearly peak discharges of the Rio Grande at Albuquerque, NM. Red dots represent the 1998 and 1999 discharges that caused overbank flooding at AOP.

Tree recruitment

Clearly, the use of overbank flooding to propagate cottonwoods was highly successful at AOP. Increased recruitment appeared well-correlated with sandier soil texture and less clays, lower salinities, and shallower depths to the water table. The construction of backwater channels and small islands also enhanced reproduction by slowing floodwaters and creating optimal microsites for establishment. In contrast, on the adjacent cleared terrace site that was not lowered or flooded, reproduction was negligible. In addition, the best establishment rates seemed to occur where the structure of the soil column was maintained and minimally disturbed, i.e., areas primarily composed of fill material derived from the mechanical excavation had less recruitment. Overall, while cottonwood stands on the bar have self-thinned and have been browsed differentially by beavers, we suggest that densities are likely to remain sufficient to produce a new forest canopy over at least 80% of the bar.

Concerns have been raised with respect to the continued increases in Russian olive, saltcedar, and other exotic trees on the site. Recent experiments suggest that when conditions allow cottonwood establishment, it can out-compete saltcedar (Sher et al. 2000), and perhaps other species. But because upwards of 25% of the tree density was attributed to exotics by 2002, an early intervention management strategy was adopted before they grew to a size where they would be difficult and expensive to remove. Accordingly, in 2003 the exotics were spot-treated with herbicide and left as standing dead (Figure 25). Since Russian olive and


Figure 25. Young Russian olives were spot-treated with herbicide and left standing dead before they could attain tree size.

saltcedar do not require flooding for successful germination and establishment, they are likely to reestablish on the bar, but the expectation is that densities will be relatively low and that most trees will persist as sub-canopy elements rather than dominants.

There were events of significant bank erosion during high discharges, but under the low-flow regime of recent drought years, bank loss has been minimal. Conversely, there has been deposition at the distal end of the bar, particularly behind the large snag that was moved downstream in the 2001 flood. On this site, cottonwood regeneration has been excellent and a new wetland and riparian community has been established (Figure 26). This suggests that large woody debris could be important in the dynamics of the system. We are currently monitoring this new community to see if it will be sustained when normal post-drought flows return to the river.

Figure 26. A new emergent wetland and riparian community with abundant cottonwood regeneration has developed below a large stump snag that moved to the lower end of the AOP bar in the 2001 flood.

Biodiversity trends

Using overbank flooding significantly enhanced local biodiversity. The cumulative plant species richness of 89 species on the manipulated and flooded bar was significantly higher than that reported by Milford and Muldavin (2004) for willow-dominated bars adjacent to the restoration site (38 species from 1998-2002), and elsewhere in the Albuquerque reach (50 +/- 15 over the same period). The upper terrace richness of 52 species was also above the 25 species found in an adjacent Russian olive stand and the average of 31 (+/- 8) for Russian olive bars in the Albuquerque reach (Milford and Muldavin 2004). The increased overall species richness may reflect disturbance effects from the initial manipulation that are not present in established willow or Russian olive bars. Regardless, species diversity, particularly on the flooded bar, was far higher than that found in the adjacent forests where the average richness was 10 (+/- 5) species. Furthermore, the flooded site was persistently dominated by native trees, shrubs and forbs throughout the period of study, suggesting that as succession proceeds and the site matures, natives may prevail.

Among animals, Ellis (2001) showed a similar pattern for arthropod diversity in the single year of her study at the AOP site where carabid beetle and ant diversity were from 35% to 75% higher on the bar than on the terrace, or in the adjacent forest. In addition, bird species diversity was enriched significantly by adding the flooded bar to the system, particularly in the fall. Overall, this points to the important contribution that flooded, restored sites can make to the Rio Grande ecosystem, not only in terms of cottonwood regeneration, but also in overall biodiversity. On a community basis, the site is developing into an intricate mosaic of young cottonwood stands, wetlands, wet meadows, salt grass meadows, and open ground with their various constituent animal communities. Moreover, it is the high richness and productivity of the overbank flooding site that suggest that merely clearing and following up with cottonwood pole planting without flooding will leave out the majority of the biodiversity potential in the restoration of the Middle Rio Grande ecosystem.

THE FUTURE

Our results suggest that the AOP site can be a useful model for large river riparian restoration in that it has an abundance of young native trees, grasses, and forbs, and a diversity of habitats--all initiated by overbank flooding followed by low-intensity management. Restoration success, though, may be dependent on the timing and duration of flooding, the design of constructed floodplain, soil conditions, the availability of seed sources, and the subsequent adaptive management strategies implemented. Accordingly, we would recommend that additional AOP-style restoration sites be initiated in other segments the Middle Rio Grande to further refine overbank flooding prescriptions. But the success of AOP in itself is encouraging for the prospects of restoring many of the compositional, structural, and functional qualities of the riparian landscape of the Middle Rio Grande Valley.

ACKNOWLEDGEMENTS

Many people made this project possible. Robert Padilla of Reclamation was key in the development of the site design and implementation. Ondrea Linderoth-Hummel of Albuquerque Open Space provided assistance in the design and manipulation of the site. Sterling Grogan and Dave Gensler of MRGCD provided the site along with support for installation of water wells. Gina Dello-Russo of the FWS Bosque del Apache Refuge conducted electromagnetic (EM) surveys for salinity on the site on a yearly basis. Jim Thibault and Jennifer Schutz of the UNM Biology Department provided the groundwater analysis used in this study. Kim, Donnie, & Tom Eichorst as well as David Gilroy (UNM), and Suzanne De Veogie (Reclamation) kindly assisted in groundwater well depth measurements. Elizabeth Milford, Yvonne Chauvin, Amanda Browder, Kyleb Wild, Stacey Sekscienski, Sarah Wood, and Paul Arbetan from Natural Heritage New Mexico of the UNM Biology Department helped design, install, and read the vegetation monitoring system.

LITERATURE CITED

Crawford, C. S., A. C. Cully, R. Leutheuser, M. S. Sifuentes, L. H. White, and J. P. Wilber. 1993. Middle Rio Grande ecosystem: bosque biological management plan. Biological Interagency Team, U.S. Fish and Wildlife Service, Albuquerque, NM. 291 + maps.

Crawford, C.S., L.M. Ellis, and M.C. Moles, Jr., 1998. The middle Rio Grande Bosque: an endangered ecosystem. New Mexico Journal of Science 36:277-299.

Ellis, L. M. 2001. Short-term response of woody plants to fire in a Rio Grande riparian forest, Central New Mexico, USA. *Biological Conservation* 97(2): 159-170.

Milford E. and E. Muldavin. 2004. River Bars of the Middle Rio Grande: a *c*omparative study of plant and arthropod diversity Final Report, Rio Grande Bosque Initiative, U.S. Fish and Wildlife Service, Albuquerque, NM.

Ortiz, R. J. Follstad Shah, and D. Vinson. 2002. Albuquerque Overbank Project: Geomorphic evaluation of a practical flood restoration experiment in a regulated-hydrograph alluvial river. Unpublished class report, Earth and Planetary Sciences 516, University of New Mexico, Albuquerque, NM.

Scurlock, D. 1998. From the Rio to the Sierra: an environmental history of the middle Rio Grande basin. Gen. Tech. Report RMRS-GTR-5. USDA Forest Service, Rocky Mountain Research Station, Fort Collins, CO.

Appendix A. Albuquerque Overbank Project (AOP) Vegetation Summary Tables

Table A1. Frequency (Freq) and relative percent cover (Cov) on the lower bar (lb) site at AOP from 2000 through 2002.

				2000		2001		2002	
P	LF	Species Name	Common Name	Freq	Cov	Freq	Cov	Freq	Cov
lb	Tree	Elaeagnus angustifolia	Russian olive	(2)	0.30	(4)	3.05	(5)	6.95
lb	Tree	Populus deltoides ssp. wislizenii	Rio Grande cottonwood	(3)	0.13	(4)	1.37	(3)	0.95
lb	Tree	Ulmus pumila	Siberian elm					(2)	0.16
lb	Shrub	Salix exigua	coyote willow	(1)	0.25	(2)	1.37	(2)	0.89
lb	Shrub	Tamarix ramosissima	saltcedar	(3)	1.20	(3)	3.47	(4)	5.11
lb	Grass	Agrostis gigantea	redtop	(2)	0.85	(1)	1.58		
lb	Grass	Carex emoryi	Emory's sedge	(2)	0.25	(2)	1.84	(2)	0.53
lb	Grass	Carex spp.	sedge					(1)	0.03
lb	Grass	Cyperus odoratus	fragrant flatsedge	(3)	0.23	(2)	0.13	(2)	0.16
lb	Grass	Distichlis spicata	inland saltgrass	(3)	2.10	(4)	6.74	(4)	4.16
lb	Grass	Echinochloa crus-galli	barnyardgrass			(3)	0.63	(2)	0.08
lb	Grass	Eleocharis palustris	common spikerush	(2)	0.15				
lb	Grass	Eragrostis pectinacea	tufted lovegrass	(1)	0.15	(2)	0.68		
lb	Grass	Leptochloa fascicularis	Bearded sprangletop	(1)	0.10				
lb	Grass	Muhlenbergia asperifolia	alkali muhly	(3)	3.50	(2)	4.74	(2)	5.00
lb	Grass	Panicum capillare	witchgrass					(1)	0.79
lb	Grass	Panicum obtusum	vine mesquite	(1)	0.10	(1)	1.05	(2)	0.37
lb	Grass	Paspalum distichum	knotgrass			(4)	0.42		
lb	Grass	Schoenoplectus pungens	common threesquare			(1)	0.01	(2)	0.03
lb	Grass	Sorghastrum nutans	Indiangrass	(1)	0.15				
lb	Grass	Sorghum halepense	johnsongrass	(2)	0.80	(4)	1.26	(4)	3.00
lb	Grass	Sporobolus airoides	alkali sacaton			(1)	0.53		
lb	Grass	Sporobolus compositus var. compositus	tall dropseed	(1)	0.15	(3)	0.37	(4)	0.79
lb	Grass	Sporobolus contractus	spike dropseed					(1)	0.16
lb	Grass	Sporobolus cryptandrus	sand dropseed	(1)	0.03	(1)	0.03		
lb	Forb	Ambrosia psilostachya	Cuman ragweed	(9)	4.88	(10)	7.84	(7)	4.66
lb	Forb	Calibrachoa parviflora	seaside petunia			(1)	0.00		
lb	Forb	Chamaesyce serpyllifolia	thymeleaf sandmat	(1)	0.35			(4)	0.11
lb	Forb	Convolvulus arvensis	field bindweed			(1)	0.11	(4)	0.79
lb	Forb	Conyza canadensis	Canadian horseweed	(4)	1.75	(14)	5.92		
lb	Forb	Euthamia occidentalis	western goldenrod	(7)	8.75	(8)	11.11	(4)	0.48
lb	Forb	Gaura parviflora	velvetweed					(1)	0.11
lb	Forb	Helianthus petiolaris	prairie sunflower	(19)	41.65	(14)	13.63	(2)	0.03

				2000		2001		2002	
P	LF	Species Name	Common Name	Freq	Cov	Freq	Cov	Freq	Cov
Ib	Forb	Lactuca tatarica var. pulchella	blue lettuce	(1)	0.10				
Ib	Forb	Melilotus officinalis	yellow sweetclover	(17)	25.90	(10)	19.47	(2)	1.58
Ib	Forb	Salsola tragus	prickly Russian thistle			(1)	0.05		
Ib	Forb	Symphyotrichum ericoides	heath aster	(1)	0.10	(1)	0.26	(1)	3.68
Ib	Forb	Symphyotrichum praealtum	willowleaf aster			(1)	0.21		
Ib	Forb	Xanthium strumarium	rough cocklebur	(4)	0.90	(2)	0.53		

Table A2. Frequency (Freq) and relative percent cover (Cov) in the lower channel (lb) site at AOP from 2000 through 2002.

				2000		2001		2002	
P	LF	Species Name	Common Name	Freq	Cov	Freq	Cov	Freq	Cov
lc	Tree	Elaeagnus angustifolia	Russian olive	(1)	1.18	(1)	2.50	(1)	3.75
lc	Tree	Ulmus pumila	Siberian elm	(1)	0.12	(1)	1.25	(1)	0.20
lc	Shrub	Salix exigua	coyote willow	(3)	12.94	(3)	12.00	(4)	9.75
lc	Shrub	Tamarix ramosissima	saltcedar					(1)	0.01
lc	Grass	Carex emoryi	Emory's sedge			(1)	0.03		
lc	Grass	Cynodon dactylon	bermudagrass			(2)	0.30	(1)	0.05
lc	Grass	Cyperus odoratus	fragrant flatsedge			(5)	0.60	(5)	0.12
lc	Grass	Distichlis spicata	inland saltgrass	(1)	0.06	(3)	0.80	(3)	0.38
lc	Grass	Echinochloa crus-galli	barnyardgrass	(1)	0.06	(1)	0.03	(2)	0.08
lc	Grass	Eragrostis pectinacea	tufted lovegrass			(8)	2.81		
lc	Grass	Muhlenbergia asperifolia	alkali muhly	(2)	0.89	(3)	3.80	(3)	0.80
lc	Grass	Muhlenbergia racemosa	marsh muhly	(1)	0.12	(1)	0.25		
lc	Grass	Panicum capillare	witchgrass	(1)	0.06				
lc	Grass	Paspalum distichum	knotgrass			(1)	0.10	(1)	0.05
lc	Grass	Paspalum setaceum	thin paspalum	(2)	0.12				
lc	Grass	Polypogon monspeliensis	annual rabbitsfoot grass	(1)	0.41	(1)	0.10		
lc	Grass	Schoenoplectus pungens	common threesquare	(1)	0.06	(1)	0.05	(1)	0.10
lc	Grass	Sorghastrum nutans	Indiangrass			(1)	1.00		
lc	Grass	Sorghum halepense	johnsongrass			(3)	0.25	(1)	0.05
lc	Grass	Sporobolus airoides	alkali sacaton			(2)	1.00	(1)	0.20
lc	Grass	Sporobolus compositus var. compositus	tall dropseed			(1)	0.05	(1)	1.25
lc	Grass	Sporobolus contractus	spike dropseed					(2)	0.40
lc	Grass	Sporobolus cryptandrus	sand dropseed	(1)	0.06			(2)	0.03
lc	Forb	Ambrosia psilostachya	Cuman ragweed	(8)	2.27	(5)	5.65	(4)	0.26
lc	Forb	Asclepias subverticillata	whorled milkweed			(1)	0.10		
lc	Forb	Chamaesyce serpyllifolia	thymeleaf sandmat			(3)	0.18	(5)	0.40
lc	Forb	Conyza canadensis	Canadian horseweed	(3)	0.32	(9)	1.95	(1)	0.20
lc	Forb	Euthamia occidentalis	western goldenrod	(3)	3.00	(3)	4.60		
lc	Forb	Grindelia nuda var. nuda	curlytop gumweed			(1)	0.05		
lc	Forb	Helianthus petiolaris	prairie sunflower	(11)	9.33	(8)	5.75	(1)	0.01
lc	Forb	Lactuca tatarica var. pulchella	blue lettuce	(1)	0.12				
lc	Forb	Machaeranthera canescens	hoary aster			(4)	2.00	(1)	0.03
lc	Forb	Machaeranthera canescens ssp. glabra	hoary tansyaster			(2)	0.25		
lc	Forb	Melilotus officinalis	yellow sweetclover	(8)	5.89	(8)	3.53	(1)	0.05
lc	Forb	Oenothera elata ssp. hirsutissima	Hooker's eveningprimrose	(1)	1.76	(2)	2.50	(1)	0.05

P	LF	Species Name	Common Name	2000 Freq	2000 Cov	2001 Freq	2001 Cov	2002 Freq	2002 Cov
Ic	Forb	Portulaca oleracea	common purslane					(2)	0.02
Ic	Forb	Salsola tragus	prickly Russian thistle	(3)	1.94	(6)	6.31	(10)	1.16
Ic	Forb	Solanum elaeagnifolium	silverleaf nightshade					(1)	0.03
Ic	Forb	Symphyotrichum ericoides	heath aster			(1)	0.10		
Ic	Forb	Tribulus terrestris	puncturevine			(1)	0.03	(1)	0.03
Ic	Forb	Ulmus pumila - yng regen	Siberian elm			(1)	0.20		
Ic	Forb	Xanthium strumarium	rough cocklebur	(2)	0.24	(3)	1.55	(1)	0.01
Ic	Forb	Xanthium strumarium var. canadense	Canada cocklebur	(2)	0.35	(1)	0.01		
Ic	Forb	Xanthium strumarium var. glabratum	rough cocklebur	(1)	0.41				

Table A3. Frequency (Freq) and relative percent cover (Cov) on the middle bar (mb) site at AOP from 2000 through 2002.

				2000		2001		2002	
P	LF	Species Name	Common Name	Freq	Cov	Freq	Cov	Freq	Cov
mb	Tree	Elaeagnus angustifolia	Russian olive	(1)	0.88	(3)	1.19	(4)	6.56
mb	Tree	Populus deltoides ssp. wislizenii	Rio Grande cottonwood	(6)	2.00	(7)	2.63	(8)	5.25
mb	Tree	Salix gooddingii	Goodding's willow	(3)	0.15	(3)	0.44	(1)	0.25
mb	Tree	Ulmus pumila	Siberian elm			(1)	0.06	(2)	0.69
mb	Shrub	Baccharis salicina	false willow					(1)	0.25
mb	Shrub	Salix exigua	coyote willow	(5)	1.24	(9)	5.06	(12)	16.38
mb	Shrub	Tamarix ramosissima	saltcedar	(3)	0.47	(1)	0.03	(2)	0.34
mb	Grass	Agrostis gigantea	redtop	(4)	1.18	(4)	3.19	(4)	1.31
mb	Grass	Bromus carinatus	California brome					(1)	0.19
mb	Grass	Carex emoryi	Emory's sedge	(5)	6.18	(8)	7.38	(9)	15.81
mb	Grass	Cyperus odoratus	fragrant flatsedge	(1)	0.59	(1)	0.13	(2)	0.25
mb	Grass	Distichlis spicata	inland saltgrass			(2)	3.75	(2)	1.69
mb	Grass	Echinochloa crus-galli	barnyardgrass	(3)	0.94	(1)	0.06	(1)	0.06
mb	Grass	Eleocharis palustris	common spikerush	(2)	0.82	(2)	0.07	(1)	0.06
mb	Grass	Elymus canadensis	Canada wildrye	(1)	0.06			(1)	0.13
mb	Grass	Elymus elymoides	bottlebrush squirreltail	(2)	0.18				
mb	Grass	Hordeum jubatum	foxtail barley			(2)	0.22		
mb	Grass	Leersia oryzoides	rice cutgrass			(4)	2.13		
mb	Grass	Muhlenbergia asperifolia	alkali muhly	(4)	0.94	(2)	0.56	(3)	1.25
mb	Grass	Panicum capillare	witchgrass	(3)	0.88				
mb	Grass	Panicum obtusum	vine mesquite	(1)	0.35	(1)	0.06	(2)	1.88
mb	Grass	Paspalum distichum	knotgrass			(7)	12.31	(5)	8.38
mb	Grass	Paspalum setaceum	thin paspalum	(7)	10.41	(1)	0.75	(1)	0.31
mb	Grass	Poa compressa	Canada bluegrass			(1)	0.63	(1)	1.25
mb	Grass	Schoenoplectus pungens	common threesquare	(5)	0.42	(7)	3.69	(5)	1.44
mb	Grass	Sorghastrum nutans	Indiangrass			(2)	0.75	(1)	0.13
mb	Grass	Sorghum halepense	johnsongrass	(1)	0.29			(1)	0.13
mb	Grass	Sporobolus compositus var. compositus	tall dropseed					(1)	0.75
mb	Forb	Ambrosia psilostachya	Cuman ragweed	(3)	7.41	(5)	3.50	(8)	6.00
mb	Forb	Apocynum cannabinum	Indianhemp	(2)	0.59	(2)	2.88	(5)	3.56
mb	Forb	Chamaesyce serpyllifolia	thymeleaf sandmat	(3)	0.71	(2)	0.04	(2)	1.57
mb	Forb	Convolvulus arvensis	field bindweed			(3)	0.88	(3)	9.69
mb	Forb	Conyza canadensis	Canadian horseweed			(5)	7.38	(3)	0.50
mb	Forb	Equisetum laevigatum	smooth horsetail	(2)	0.36	(4)	0.22	(4)	0.57
mb	Forb	Erigeron philadelphicus	Philadelphia fleabane	(1)	0.18				

P	LF	Species Name	Common Name	2000 Freq	2000 Cov	2001 Freq	2001 Cov	2002 Freq	2002 Cov
mb	Forb	Euthamia occidentalis	western goldenrod	(13)	36.76	(14)	35.81	(13)	15.63
mb	Forb	Gaura parviflora	velvetweed					(1)	0.19
mb	Forb	Grindelia nuda var. aphanactis	curlytop gumweed					(1)	0.56
mb	Forb	Helianthus petiolaris	prairie sunflower	(9)	12.24	(5)	1.00	(2)	0.07
mb	Forb	Lactuca serriola	prickly lettuce					(1)	0.13
mb	Forb	Lactuca tatarica var. pulchella	blue lettuce	(1)	0.18	(1)	0.06	(1)	1.25
mb	Forb	Melilotus officinalis	yellow sweetclover	(14)	34.88	(10)	30.56	(3)	0.26
mb	Forb	Oenothera elata ssp. hirsutissima	Hooker's eveningprimrose					(1)	0.13
mb	Forb	Plantago major	common plantain	(3)	0.59	(1)	0.06		
mb	Forb	Polygonum lapathifolium	curlytop knotweed	(2)	0.13				
mb	Forb	Polygonum spp.	knotweed			(1)	0.25	(1)	0.31
mb	Forb	Solidago canadensis	Canada goldenrod	(1)	0.06				
mb	Forb	Sonchus asper	spiny sowthistle			(1)	0.01		
mb	Forb	Symphyotrichum ericoides	heath aster	(3)	0.82	(1)	0.06	(2)	0.44
mb	Forb	Symphyotrichum praealtum	willowleaf aster	(1)	0.71	(3)	0.44	(2)	0.25
mb	Forb	Teucrium canadense var. occidentale	western germander	(5)	3.35	(5)	2.88	(4)	1.88
mb	Forb	Xanthium strumarium	rough cocklebur	(9)	8.47	(5)	8.19	(1)	0.13
mb	Forb	Xanthium strumarium var. canadense	Canada cocklebur			(7)	5.50	(3)	0.31

Table A4. Frequency (Freq) and relative percent cover (Cov) in the middle channel (mc) site at AOP from 2000 through 2002.

				2000		2001		2002	
P	LF	Species Name	Common Name	Freq	Cov	Freq	Cov	Freq	Cov
mc	Tree	Elaeagnus angustifolia	Russian olive	(2)	5.10	(3)	5.75	(5)	7.45
mc	Tree	Populus deltoides ssp. wislizenii	Rio Grande cottonwood	(12)	14.85	(16)	15.60	(16)	21.50
mc	Tree	Salix gooddingii	Goodding's willow	(2)	0.20	(1)	0.05	(1)	0.15
mc	Tree	Ulmus pumila	Siberian elm			(2)	0.03	(2)	0.03
mc	Shrub	Baccharis salicina	false willow	(1)	0.60	(1)	0.30	(3)	1.20
mc	Shrub	Salix exigua	coyote willow	(10)	4.35	(13)	9.55	(14)	14.55
mc	Shrub	Tamarix ramosissima	saltcedar	(6)	0.86	(5)	0.55	(6)	0.60
mc	Grass	Agrostis gigantea	redtop			(1)	0.30	(1)	0.05
mc	Grass	Bromus carinatus	California brome	(1)	0.05	(1)	0.25		
mc	Grass	Carex emoryi	Emory's sedge	(2)	0.30	(4)	0.25	(3)	0.26
mc	Grass	Cenchrus spinifex	sandbur					(1)	0.03
mc	Grass	Cyperus odoratus	fragrant flatsedge	(4)	0.30	(1)	0.05	(2)	0.16
mc	Grass	Echinochloa crus-galli	barnyardgrass	(3)	0.80	(2)	1.40	(1)	0.05
mc	Grass	Elymus canadensis	Canada wildrye	(1)	0.03	(1)	0.03	(2)	0.13
mc	Grass	Elymus elymoides	bottlebrush squirreltail	(1)	0.15				
mc	Grass	Elymus x pseudorepens	false quackgrass					(1)	0.05
mc	Grass	Hordeum jubatum	foxtail barley			(5)	0.35		
mc	Grass	Leersia oryzoides	rice cutgrass			(1)	0.05		
mc	Grass	Muhlenbergia asperifolia	alkali muhly	(4)	0.73	(6)	3.70	(9)	3.88
mc	Grass	Panicum capillare	witchgrass	(7)	0.68	(1)	0.15		
mc	Grass	Panicum obtusum	vine mesquite	(1)	0.10	(3)	0.20		
mc	Grass	Paspalum distichum	knotgrass			(2)	0.30	(2)	0.55
mc	Grass	Schoenoplectus pungens	common threesquare			(1)	0.03		
mc	Grass	Sorghastrum nutans	Indiangrass			(2)	0.30		
mc	Grass	Sorghum halepense	johnsongrass	(5)	9.25	(4)	9.80	(4)	8.65
mc	Grass	Sporobolus airoides	alkali sacaton	(1)	0.15	(1)	0.15		
mc	Grass	Sporobolus compositus var. compositus	tall dropseed			(2)	0.20	(3)	1.20
mc	Grass	Sporobolus contractus	spike dropseed	(1)	0.15	(2)	0.65	(3)	0.95
mc	Forb	Ambrosia acanthicarpa	flatspine burr ragweed	(4)	0.48	(2)	0.26		
mc	Forb	Ambrosia psilostachya	Cuman ragweed	(5)	0.78	(5)	1.16	(9)	2.40
mc	Forb	Apocynum cannabinum	Indianhemp	(3)	0.28	(2)	0.45	(3)	0.50
mc	Forb	Asclepias speciosa	showy milkweed			(1)	0.05	(1)	0.10
mc	Forb	Bidens frondosa	devil's beggartick	(4)	0.78	(4)	0.09	(2)	0.08
mc	Forb	Chamaesyce serpyllifolia	thymeleaf sandmat	(6)	1.06	(3)	0.16	(4)	0.26
mc	Forb	Conyza canadensis	Canadian horseweed	(6)	0.70	(16)	10.08	(3)	0.20

				2000		2001		2002	
P	LF	Species Name	Common Name	Freq	Cov	Freq	Cov	Freq	Cov
mc	Forb	Elaeagnus angustifolia - yng regen	Russian olive			(1)	0.03		
mc	Forb	Equisetum laevigatum	smooth horsetail	(3)	0.11	(7)	0.21	(7)	0.46
mc	Forb	Erigeron philadelphicus	Philadelphia fleabane	(1)	0.01				
mc	Forb	Euthamia occidentalis	western goldenrod	(11)	13.25	(11)	18.30	(11)	13.90
mc	Forb	Grindelia nuda var. aphanactis	curlytop gumweed	(1)	0.25			(1)	0.95
mc	Forb	Grindelia nuda var. nuda	curlytop gumweed	(1)	0.05	(1)	0.15	(1)	0.15
mc	Forb	Helianthus petiolaris	prairie sunflower	(7)	3.50	(3)	0.83	(1)	0.03
mc	Forb	Lactuca serriola	prickly lettuce			(2)	0.15	(2)	0.01
mc	Forb	Melilotus officinalis	yellow sweetclover	(13)	18.40	(10)	12.20	(2)	0.01
mc	Forb	Oenothera elata ssp. hirsutissima	Hooker's eveningprimrose					(5)	2.05
mc	Forb	Plantago major	common plantain	(2)	0.40	(1)	0.05		
mc	Forb	Polygonum lapathifolium	curlytop knotweed	(4)	0.41				
mc	Forb	Pseudognaphalium stramineum	cottonbatting cudweed	(1)	0.25				
mc	Forb	Solidago canadensis	Canada goldenrod	(2)	0.40	(2)	0.20	(4)	1.10
mc	Forb	Sonchus asper	spiny sowthistle			(2)	0.10		
mc	Forb	Symphyotrichum ericoides	heath aster	(4)	0.35	(3)	1.15	(4)	0.65
mc	Forb	Symphyotrichum praealtum	willowleaf aster	(1)	0.35	(1)	0.05	(1)	0.05
mc	Forb	Teucrium canadense var. occidentale	western germander	(1)	0.01			(1)	0.05
mc	Forb	Verbena bracteata	bigbract verbena	(1)	0.05	(1)	0.05		
mc	Forb	Xanthium strumarium	rough cocklebur	(12)	3.35	(5)	2.70	(1)	0.03
mc	Forb	Xanthium strumarium var. canadense	Canada cocklebur	(1)	0.05	(11)	5.45	(4)	0.09
mc	Forb	Xanthium strumarium var. glabratum	rough cocklebur	(2)	0.10	(3)	0.15		

Table A5. Frequency (Freq) and relative percent cover (Cov) on the terrace (t) site at AOP from 2000 through 2002.

				2000		2001		2002	
P	LF	Species Name	Common Name	Freq	Cov	Freq	Cov	Freq	Cov
t								(1)	0.06
t	Tree	Elaeagnus angustifolia	Russian olive	(5)	5.26	(6)	7.20	(9)	15.71
t	Tree	Populus deltoides	eastern cottonwood	(3)	8.00	(3)	8.00		
t	Tree	Populus deltoides ssp. wislizenii	Rio Grande cottonwood	(2)	1.77	(2)	2.23	(5)	6.09
t	Tree	Ulmus pumila	Siberian elm			(2)	0.20	(2)	0.29
t	Shrub	Salix exigua	coyote willow	(10)	5.97	(8)	5.94	(9)	10.23
t	Grass	Carex emoryi	Emory's sedge	(6)	0.49	(4)	0.26	(2)	0.17
t	Grass	Cynodon dactylon	bermudagrass					(4)	1.06
t	Grass	Cyperus odoratus	fragrant flatsedge			(1)	0.03		
t	Grass	Distichlis spicata	inland saltgrass	(1)	1.00	(4)	2.40	(5)	3.71
t	Grass	Elymus canadensis	Canada wildrye	(2)	0.17	(1)	0.29	(2)	0.20
t	Grass	Elymus x pseudorepens	false quackgrass	(1)	0.14	(3)	0.23	(4)	1.60
t	Grass	Hordeum jubatum	foxtail barley	(1)	0.43				
t	Grass	Muhlenbergia asperifolia	alkali muhly	(7)	1.37	(9)	3.20	(12)	4.51
t	Grass	Panicum capillare	witchgrass	(1)	0.01	(1)	0.06		
t	Grass	Panicum obtusum	vine mesquite	(4)	1.97	(9)	5.46	(10)	6.34
t	Grass	Pascopyrum smithii	western wheatgrass	(1)	0.03				
t	Grass	Paspalum setaceum	thin paspalum	(2)	1.06	(1)	1.43	(1)	0.29
t	Grass	Poa compressa	Canada bluegrass			(1)	0.06		
t	Grass	Schoenoplectus pungens	common threesquare	(3)	0.20	(3)	0.15	(1)	0.11
t	Grass	Sorghastrum nutans	Indiangrass	(2)	0.31	(2)	0.06	(1)	0.06
t	Grass	Sorghum halepense	johnsongrass	(8)	2.77	(10)	4.43	(13)	7.06
t	Grass	Sporobolus airoides	alkali sacaton	(1)	0.00	(1)	0.14		
t	Grass	Sporobolus compositus var. compositus	tall dropseed	(3)	0.19	(4)	0.34	(6)	1.63
t	Grass	Sporobolus cryptandrus	sand dropseed					(3)	0.29
t	Forb	Ambrosia psilostachya	Cuman ragweed	(22)	27.17	(23)	18.73	(16)	1.49
t	Forb	Apocynum cannabinum	Indianhemp	(1)	0.09	(2)	0.09	(2)	0.11
t	Forb	Asclepias speciosa	showy milkweed					(1)	0.03
t	Forb	Bidens frondosa	devil's beggartick			(1)	0.29		
t	Forb	Chamaesyce serpyllifolia	thymeleaf sandmat	(2)	0.09	(5)	0.29	(7)	0.12
t	Forb	Chloracantha spinosa	spiny chloracantha	(2)	0.40	(2)	0.57	(3)	0.40
t	Forb	Convolvulus arvensis	field bindweed	(16)	6.91	(19)	8.26	(24)	19.27
t	Forb	Conyza canadensis	Canadian horseweed	(2)	0.14	(22)	14.23	(1)	0.71
t	Forb	Equisetum laevigatum	smooth horsetail	(4)	0.08	(5)	0.09	(5)	0.09
t	Forb	Erigeron philadelphicus	Philadelphia fleabane	(1)	0.03				

P	LF	Species Name	Common Name	2000 Freq	2000 Cov	2001 Freq	2001 Cov	2002 Freq	2002 Cov
t	Forb	Euthamia occidentalis	western goldenrod	(13)	4.23	(15)	9.57	(11)	5.75
t	Forb	Gaura parviflora	velvetweed	(1)	0.11	(8)	1.91	(1)	0.03
t	Forb	Helianthus petiolaris	prairie sunflower	(21)	7.64	(15)	6.54		
t	Forb	Kochia scoparia	common kochia	(2)	2.00	(7)	8.63	(5)	0.30
t	Forb	Lactuca serriola	prickly lettuce			(1)	0.03		
t	Forb	Machaeranthera canescens	hoary aster			(3)	0.94	(1)	0.26
t	Forb	Machaeranthera canescens ssp. glabra	hoary tansyaster			(7)	0.37	(1)	0.11
t	Forb	Melilotus officinalis	yellow sweetclover	(25)	32.10	(11)	4.97	(4)	0.02
t	Forb	Oenothera elata ssp. hirsutissima	Hooker's eveningprimrose	(1)	0.57				
t	Forb	Physalis longifolia	longleaf groundcherry	(1)	0.01				
t	Forb	Salsola tragus	prickly Russian thistle	(3)	0.60	(7)	8.89	(2)	0.51
t	Forb	Sonchus asper	spiny sowthistle			(1)	0.00		
t	Forb	Symphyotrichum ericoides	heath aster	(3)	0.63	(4)	0.74	(4)	0.94
t	Forb	Symphyotrichum praealtum	willowleaf aster	(3)	0.23	(5)	0.57	(3)	1.34
t	Forb	Teucrium canadense var. occidentale	western germander	(2)	0.06			(1)	0.11
t	Forb	Tribulus terrestris	puncturevine					(1)	0.03
t	Forb	Xanthium strumarium var. canadense	Canada cocklebur			(1)	0.01		
t	Forb	Xanthium strumarium var. glabratum	rough cocklebur			(1)	0.01		

Table A6. Frequency (Freq) and relative percent cover (Cov) on the upper bar (ub) site at AOP from 2000 through 2002.

				2000		2001		2002	
P	LF	Species Name	Common Name	Freq	Cov	Freq	Cov	Freq	Cov
ub								(1)	2.22
ub	Tree	Elaeagnus angustifolia	Russian olive	(4)	1.94	(5)	7.39	(5)	11.00
ub	Tree	Populus deltoides ssp. wislizenii	Rio Grande cottonwood	(4)	1.68	(4)	2.56	(4)	3.11
ub	Tree	Salix gooddingii	Goodding's willow	(2)	0.78	(2)	0.33	(2)	0.78
ub	Tree	Ulmus pumila	Siberian elm	(1)	0.11	(1)	0.11	(2)	0.18
ub	Shrub	Baccharis salicina	false willow	(1)	0.22	(1)	0.22	(1)	0.22
ub	Shrub	Salix exigua	coyote willow	(3)	3.89	(3)	10.56	(3)	7.44
ub	Shrub	Tamarix ramosissima	saltcedar	(3)	0.50	(2)	0.12	(2)	0.23
ub	Grass	Agrostis gigantea	redtop	(1)	0.33	(2)	0.56	(2)	0.56
ub	Grass	Bromus carinatus	California brome			(1)	0.11		
ub	Grass	Carex emoryi	Emory's sedge	(2)	1.12	(3)	5.22	(4)	2.22
ub	Grass	Cenchrus spinifex	sandbur			(1)	0.11		
ub	Grass	Distichlis spicata	inland saltgrass	(2)	1.68	(1)	0.56		
ub	Grass	Echinochloa crus-galli	barnyardgrass	(1)	0.01	(1)	0.11		
ub	Grass	Eleocharis palustris	common spikerush	(1)	0.56				
ub	Grass	Elymus canadensis	Canada wildrye			(1)	0.11	(2)	3.67
ub	Grass	Elymus elymoides	bottlebrush squirreltail	(3)	0.72				
ub	Grass	Hordeum jubatum	foxtail barley			(2)	0.67	(2)	0.12
ub	Grass	Juncus torreyi	Torrey's rush			(1)	0.06		
ub	Grass	Muhlenbergia asperifolia	alkali muhly	(2)	2.44	(5)	3.11	(4)	3.33
ub	Grass	Panicum capillare	witchgrass	(5)	2.26	(2)	1.22	(1)	0.11
ub	Grass	Panicum obtusum	vine mesquite	(2)	0.17	(1)	0.56	(1)	0.11
ub	Grass	Paspalum distichum	knotgrass			(1)	0.11	(1)	1.11
ub	Grass	Schoenoplectus pungens	common threesquare	(4)	1.47	(5)	6.56	(4)	1.96
ub	Grass	Sorghastrum nutans	Indiangrass	(1)	0.44	(1)	0.44		
ub	Grass	Sporobolus compositus var. compositus	tall dropseed	(3)	0.67	(5)	3.06	(5)	5.78
ub	Forb	Ambrosia psilostachya	Cuman ragweed	(6)	25.89	(8)	20.44	(8)	5.46
ub	Forb	Asclepias subverticillata	whorled milkweed			(1)	0.11	(1)	0.22
ub	Forb	Bidens frondosa	devil's beggartick	(3)	0.36	(1)	0.06	(1)	0.56
ub	Forb	Chamaesyce serpyllifolia	thymeleaf sandmat	(5)	1.72	(1)	0.06		
ub	Forb	Convolvulus arvensis	field bindweed	(3)	0.44	(4)	0.61	(3)	2.00
ub	Forb	Conyza canadensis	Canadian horseweed	(3)	1.89	(3)	0.67	(1)	0.22
ub	Forb	Equisetum laevigatum	smooth horsetail	(3)	1.13	(5)	0.31	(6)	0.47
ub	Forb	Erigeron philadelphicus	Philadelphia fleabane	(1)	0.02				
ub	Forb	Euthamia occidentalis	western goldenrod	(6)	11.56	(6)	18.89	(7)	17.44

P	LF	Species Name	Common Name	2000 Freq	2000 Cov	2001 Freq	2001 Cov	2002 Freq	2002 Cov
ub	Forb	Helianthus petiolaris	prairie sunflower	(6)	3.39	(1)	0.33		
ub	Forb	Lactuca tatarica var. pulchella	blue lettuce					(2)	0.44
ub	Forb	Lycopus americanus	American bugleweed					(1)	0.11
ub	Forb	Melilotus officinalis	yellow sweetclover	(8)	24.11	(4)	5.22		
ub	Forb	Oenothera elata ssp. hirsutissima	Hooker's eveningprimrose	(1)	0.00			(2)	1.33
ub	Forb	Plantago major	common plantain	(1)	0.22	(1)	0.22		
ub	Forb	Polygonum lapathifolium	curlytop knotweed	(1)	0.11				
ub	Forb	Pseudognaphalium stramineum	cottonbatting cudweed	(2)	0.33				
ub	Forb	Solidago canadensis	Canada goldenrod	(1)	0.22	(1)	0.11		
ub	Forb	Sonchus asper	spiny sowthistle	(1)	0.11	(1)	0.11		
ub	Forb	Symphyotrichum ericoides	heath aster	(1)	0.22	(4)	1.00	(4)	5.11
ub	Forb	Symphyotrichum praealtum	willowleaf aster	(2)	1.12	(2)	1.44	(3)	1.44
ub	Forb	Taraxacum officinale	common dandelion	(1)	0.33	(1)	0.33	(1)	0.67
ub	Forb	Teucrium canadense var. occidentale	western germander	(2)	0.79	(3)	1.67	(3)	1.12
ub	Forb	Xanthium strumarium	rough cocklebur			(2)	3.89	(1)	0.01
ub	Forb	Xanthium strumarium var. canadense	Canada cocklebur			(1)	0.06		

Table A7. Frequency (Freq) and relative percent cover (Cov) in the upper channel (uc) site at AOP from 2000 through 2002.

				2000		2001		2002	
P	LF	Species Name	Common Name	Freq	Cov	Freq	Cov	Freq	Cov
uc				(1)	0.18			(1)	2.27
uc	Tree	Elaeagnus angustifolia	Russian olive	(5)	3.00	(5)	10.55	(5)	20.00
uc	Tree	Populus deltoides ssp. wislizenii	Rio Grande cottonwood	(7)	3.36	(7)	6.00	(7)	9.55
uc	Tree	Salix gooddingii	Goodding's willow	(4)	0.65	(5)	1.65	(5)	2.41
uc	Tree	Ulmus pumila	Siberian elm			(1)	0.01	(1)	0.01
uc	Shrub	Baccharis salicina	false willow	(1)	0.09	(1)	0.09	(1)	1.36
uc	Shrub	Salix exigua	coyote willow	(5)	1.73	(8)	3.18	(8)	7.73
uc	Shrub	Tamarix ramosissima	saltcedar	(4)	0.38	(4)	0.33	(3)	0.11
uc	Grass	Agrostis gigantea	redtop	(2)	0.36	(1)	0.01	(2)	0.65
uc	Grass	Bromus carinatus	California brome			(1)	0.09	(1)	0.27
uc	Grass	Carex emoryi	Emory's sedge	(2)	0.41	(5)	2.73	(4)	1.09
uc	Grass	Cyperus odoratus	fragrant flatsedge	(2)	0.64	(1)	0.09	(2)	0.14
uc	Grass	Echinochloa crus-galli	barnyardgrass	(3)	5.18	(2)	1.36	(1)	0.01
uc	Grass	Eleocharis palustris	common spikerush	(3)	1.45	(1)	0.09	(1)	0.09
uc	Grass	Elymus canadensis	Canada wildrye	(1)	0.05	(3)	1.18	(5)	1.82
uc	Grass	Elymus elymoides	bottlebrush squirreltail					(1)	0.09
uc	Grass	Elymus x pseudorepens	false quackgrass					(1)	0.27
uc	Grass	Eragrostis pectinacea	tufted lovegrass			(1)	0.27		
uc	Grass	Festuca arundinaceae	tall fescue or K-31	(2)	0.45			(1)	0.91
uc	Grass	Hordeum jubatum	foxtail barley			(2)	0.18		
uc	Grass	Juncus torreyi	Torrey's rush	(1)	0.73				
uc	Grass	Leersia oryzoides	rice cutgrass					(1)	0.27
uc	Grass	Muhlenbergia asperifolia	alkali muhly	(3)	6.09	(4)	6.18	(7)	8.09
uc	Grass	Panicum capillare	witchgrass	(7)	15.32	(4)	0.91		
uc	Grass	Panicum hallii	Hall's panicgrass	(1)	0.09				
uc	Grass	Paspalum distichum	knotgrass					(2)	0.64
uc	Grass	Polypogon monspeliensis	annual rabbitsfoot grass	(2)	1.00	(2)	1.82		
uc	Grass	Schoenoplectus pungens	common threesquare	(8)	2.20	(9)	8.11	(6)	2.92
uc	Grass	Sorghastrum nutans	Indiangrass	(2)	0.82	(3)	4.45	(2)	0.36
uc	Grass	Sorghum halepense	johnsongrass	(2)	1.45	(2)	5.00	(3)	4.27
uc	Grass	Sporobolus airoides	alkali sacaton			(1)	0.45		
uc	Grass	Sporobolus compositus var. compositus	tall dropseed	(1)	0.73	(1)	0.27	(2)	4.18
uc	Grass	Sporobolus cryptandrus	sand dropseed					(1)	0.09
uc	Forb	Ambrosia psilostachya	Cuman ragweed	(3)	9.55	(8)	6.82	(8)	9.09
uc	Forb	Apocynum cannabinum	Indianhemp	(1)	0.14	(2)	0.18	(1)	0.01

				2000		2001		2002	
P	LF	Species Name	Common Name	Freq	Cov	Freq	Cov	Freq	Cov
uc	Forb	Asclepias speciosa	showy milkweed					(1)	0.01
uc	Forb	Bidens frondosa	devil's beggartick	(4)	1.00	(2)	3.27		
uc	Forb	Centaurium arizonicum	arizona centaury	(1)	0.91				
uc	Forb	Chamaesyce serpyllifolia	thymeleaf sandmat	(4)	0.73	(2)	0.27	(1)	0.18
uc	Forb	Convolvulus arvensis	field bindweed			(1)	0.18	(1)	1.82
uc	Forb	Conyza canadensis	Canadian horseweed	(4)	0.68	(1)	0.91	(3)	0.45
uc	Forb	Dimorphocarpa wislizeni	spectacle pod	(1)	0.09				
uc	Forb	Equisetum laevigatum	smooth horsetail	(4)	0.42	(8)	0.65	(9)	1.21
uc	Forb	Euthamia occidentalis	western goldenrod	(5)	8.00	(8)	26.73	(9)	29.59
uc	Forb	Gaura parviflora	velvetweed	(1)	0.27				
uc	Forb	Helianthus petiolaris	prairie sunflower	(3)	0.55	(1)	0.18		
uc	Forb	Kochia scoparia	common kochia	(1)	0.09				
uc	Forb	Lactuca serriola	prickly lettuce			(2)	0.36		
uc	Forb	Lactuca tatarica var. pulchella	blue lettuce			(1)	0.18	(1)	0.45
uc	Forb	Lycopus americanus	American bugleweed			(1)	0.09	(1)	0.05
uc	Forb	Melilotus officinalis	yellow sweetclover	(10)	45.09	(8)	14.27		
uc	Forb	Oenothera elata ssp. hirsutissima	Hooker's eveningprimrose					(2)	0.23
uc	Forb	Plantago major	common plantain			(3)	0.36	(2)	1.55
uc	Forb	Polygonum lapathifolium	curlytop knotweed	(3)	1.05				
uc	Forb	Pseudognaphalium stramineum	cottonbatting cudweed	(2)	0.18	(1)	0.18	(3)	0.92
uc	Forb	Ratibida tagetes	green prairie coneflower					(1)	0.01
uc	Forb	Rumex pulcher	fiddle dock			(1)	0.09	(1)	0.18
uc	Forb	Rumex spp.	dock	(1)	0.09				
uc	Forb	Sonchus asper	spiny sowthistle					(1)	0.01
uc	Forb	Symphyotrichum ericoides	heath aster	(5)	7.82	(5)	8.82	(6)	4.91
uc	Forb	Symphyotrichum praealtum	willowleaf aster	(2)	2.91	(3)	0.91	(4)	4.73
uc	Forb	Typha latifolia	broadleaf cattail			(1)	0.45		
uc	Forb	Xanthium strumarium	rough cocklebur	(4)	1.18	(3)	1.36	(2)	0.10
uc	Forb	Xanthium strumarium var. canadense	Canada cocklebur			(4)	4.18	(1)	0.09
uc	Forb	Xanthium strumarium var. glabratum	rough cocklebur			(2)	0.23		

APPENDIX B. ALBUQUERQUE OVERBANK PROJECT (AOP) PLANT SPECIES LIST.

Table B1. List of all plant species recorded at Albuquerque Overbank Project 20009-2002. LF=lifeform; NHNM Code is the Natural Heritage New Mexico database code for the species; A/P refers to annual /perennial; Wetland status is that according to the PLANTS database; Freq= frequency or the number of quadrats the species was recorded in from 2000 through 2002.

LF	NHNM Code	Scientific Name	Common Name	A/P	Origin	Wetland Status	Family	Freq
Tees	ELAANG	Elaeagnus angustifolia	Russian olive	P	Introduced	FACW-	Elaeagnaceae	81
	POPDELW	Populus deltoides ssp. wislizenii	Rio Grande cottonwood	P	Native	NI (OBL)	Salicaceae	123
	SALGOO	Salix gooddingii	Gooding's willow	P	Native	OBL	Salicaceae	31
	ULMPUM	Ulmus pumila	Siberian elm	P	Introduced	NI (UPL)	Ulmaceae	52
Shrubs	BACSAL	Baccharis salicina	false willow	P	Native		Asteraceae	12
	SALEXI	Salix exigua	coyote willow	P	Native	OBL	Salicaceae	135
	TAMRAM	Tamarix ramosissima	saltcedar	P	Introduced	NI (FACW)	Tamaricaceae	52
Grasses	AGRGIG	Agrostis gigantea	redtop	P	Introduced	FACW+	Poaceae	27
	BROCAR	Bromus carinatus	California brome	P	Native	NI (FACU)	Poaceae	6
	CAREMO	Carex emoryi	Emory's sedge	P	Native	NI (FAC)	Cyperaceae	70
	CAREX	Carex spp.	sedge		Native		Cyperaceae	1
	CENSPI	Cenchrus spinifex	sandbur	P	Native	NI (UPL)	Poaceae	2
	CYNDAC	Cynodon dactylon	bermudagrass	P	Introduced	FACU (FACW)	Poaceae	7
	CYPODO	Cyperus odoratus	fragrant flatsedge	P	Native		Cyperaceae	34
	DISSPI	Distichlis spicata	inland saltgrass	P	Native	FACW	Poaceae	35
	ECHCRU	Echinochloa crus-galli	barnyardgrass	A	Introduced	FACW- (FACW)	Poaceae	28
	ELEPAL	Eleocharis palustris	common spikerush	P	Native	OBL	Cyperaceae	13
	ELYCAN	Elymus canadensis	Canada wildrye	P	Native	FAC (FACW)	Poaceae	23
	ELYELY	Elymus elymoides	bottlebrush squirreltail	P	Native	NI (FACU)	Poaceae	7
	ELYPSE	Elymus x pseudorepens	false quackgrass	P	Native	NI (FAC)	Poaceae	10
	ERAPEC	Eragrostis pectinacea	tufted lovegrass	A	Native		Poaceae	12
	FESARU	Festuca arundinaceae	tall fescue or K-31	P	Introduced	NA (FAC)	Poaceae	3
	HORJUB	Hordeum jubatum	foxtail barley	P	Native	NI (FAC)	Poaceae	14
	JUNTOR	Juncus torreyi	Torrey's rush	P	Native	FACW (OBL)	Juncaceae	2
	LEEORY	Leersia oryzoides	rice cutgrass	P	Native	OBL	Poaceae	6
	LEPFAS	Leptochloa fascicularis	Bearded sprangletop	A	Native		Poaceae	1
	MUHASP	Muhlenbergia asperifolia	alkali muhly	P	Native	OBL	Poaceae	96
	MUHRAC	Muhlenbergia racemosa	marsh muhly	P	Native	FACW	Poaceae	2
	PANCAP	Panicum capillare	witchgrass	A	Native	FAC	Poaceae	34
	PANHAL	Panicum hallii	Hall's panicgrass	P	Native	FACU	Poaceae	1
	PANOBT	Panicum obtusum	vine mesquite	P	Native	FAC (FACW)	Poaceae	39

LF	NHNM Code	Scientific Name	Common Name	A/P	Origin	Wetland Status	Family	Freq
	PASDIS	Paspalum distichum	knotgrass	P	Native	OBL	Poaceae	26
	PASSET	Paspalum setaceum	thin paspalum	P	Native		Poaceae	15
	PASSMI	Pascopyrum smithii	western wheatgrass		Native	NI (FACU)	Poaceae	1
	POACOM	Poa compressa	Canada bluegrass	P	Introduced	FACU	Poaceae	3
	POLMON	Polypogon monspeliensis	annual rabbitsfoot grass	A	Introduced	FACW+ (OBL)	Poaceae	6
	SCHPUN	Schoenoplectus pungens	common threesquare	P	Native	OBL	Cyperaceae	67
	SORHAL	Sorghum halepense	johnsongrass	P	Introduced	FACU+	Poaceae	67
	SORNUT	Sorghastrum nutans	Indiangrass	P	Native	NI (FACW)	Poaceae	21
	SPOAIR	Sporobolus airoides	alkali sacaton	P	Native	FAC	Poaceae	9
	SPOCOMC	Sporobolus compositus var. compositus	tall dropseed	P	Native	NI (UPL)	Poaceae	46
	SPOCON	Sporobolus contractus	spike dropseed	P	Native	NI (UPL)	Poaceae	9
	SPOCRY	Sporobolus cryptandrus	sand dropseed	P	Native	FACU- (FAC)	Poaceae	9
Forbs	AMBACA	Ambrosia acanthicarpa	flatspine burr ragweed	A	Native		Asteraceae	6
	AMBPSI	Ambrosia psilostachya	Cuman ragweed	P	Native	FAC	Asteraceae	180
	APOCAN	Apocynum cannabinum	Indianhemp	P	Native	FAC+ (FACW)	Apocynaceae	26
	ASCSPE	Asclepias speciosa	showy milkweed	P	Native	FACW-	Asclepiadaceae	4
	ASCSUB	Asclepias subverticillata	whorled milkweed	P	Native	FACU	Asclepiadaceae	3
	BIDFRO	Bidens frondosa	devil's beggartick	A	Native	FACW	Asteraceae	22
	CALPAR	Calibrachoa parviflora	seaside petunia		Native	FACW	Solanaceae	1
	CENARI	Centaurium arizonicum	arizona centaury		Native		Gentianaceae	1
	CHASER2	Chamaesyce serpyllifolia	thymeleaf sandmat	A	Native	NI (FACU)	Euphorbiaceae	60
	CHLSPI	Chloracantha spinosa	spiny chloracantha	P	Native	FACW	Asteraceae	7
	CONARV	Convolvulus arvensis	field bindweed	P	Introduced	NI (UPL)	Convolvulaceae	82
	CONCAN	Conyza canadensis	Canadian horseweed	A	Native	FACU (FAC)	Asteraceae	104
	DIMWIS	Dimorphocarpa wislizeni	spectacle pod	P	Native	NI (UPL)	Brassicaceae	1
	EQULAE	Equisetum laevigatum	smooth horsetail	P	Native	FACW	Equisetaceae	76
	ERIPHI	Erigeron philadelphicus	Philadelphia fleabane	P	Native		Asteraceae	4
	EUTOCC	Euthamia occidentalis	western goldenrod	P	Native	FACW	Asteraceae	178
	GAUPAR	Gaura parviflora	velvetweed	B	Native	NI (FACU)	Onagraceae	13
	GRINUDA	Grindelia nuda var. aphanactis	curlytop gumweed	P	Native		Asteraceae	3
	GRINUDN	Grindelia nuda var. nuda	curlytop gumweed	P	Native		Asteraceae	4
	HELPET	Helianthus petiolaris	prairie sunflower	A	Native	NI (UPL)	Asteraceae	129
	KOCSCO	Kochia scoparia	common kochia	A	Introduced	FAC	Chenopodiaceae	15
	LACSER	Lactuca serriola	prickly lettuce	B	Introduced	FAC	Asteraceae	8
	LACTATP	Lactuca tatarica var. pulchella	blue lettuce	P	Native	NI (FAC)	Asteraceae	9
	LYCAME	Lycopus americanus	American bugleweed	P	Native	OBL	Lamiaceae	3
	MACCAN	Machaeranthera canescens	hoary aster	P	Native	FAC	Asteraceae	9

LF	NHNM Code	Scientific Name	Common Name	A/P	Origin	Wetland Status	Family	Freq
	MACCANG	Machaeranthera canescens ssp. glabra	hoary tansyaster	P	Native		Asteraceae	10
	MELOFF	Melilotus officinalis	yellow sweetclover	B	Introduced	FACU+	Fabaceae	168
	OENELAH	Oenothera elata ssp. hirsutissima	Hooker's eveningprimrose	P	Native	FACW	Onagraceae	16
	PHYLON	Physalis longifolia	longleaf groundcherry	P	Native	NI (FACU)	Solanaceae	1
	PLAMAJ	Plantago major	common plantain	P	Introduced	FACW	Plantaginaceae	14
	POLLAP	Polygonum lapathifolium	curlytop knotweed	A	Native	OBL	Polygonaceae	10
	POLYGO	Polygonum spp.	knotweed			FACW	Polygonaceae	2
	POROLE	Portulaca oleracea	common purslane	A	Native	FAC	Portulacaceae	2
	PSESTR	Pseudognaphalium stramineum	cottonbatting cudweed	B	Native	FAC	Asteraceae	9
	RATTAG	Ratibida tagetes	green prairie coneflower	P	Native	NI (FACU)	Asteraceae	1
	RUMEX	Rumex spp.	dock				Polygonaceae	1
	RUMPUL	Rumex pulcher	fiddle dock		Introduced		Polygonaceae	2
	SALTRA	Salsola tragus	prickly Russian thistle	A	Introduced		Chenopodiaceae	32
	SOLCAN	Solidago canadensis	Canada goldenrod	P	Native	FACU (FAC)	Asteraceae	11
	SOLELA	Solanum elaeagnifolium	silverleaf nightshade	P	Native	NI (FACU)	Solanaceae	1
	SONASP	Sonchus asper	spiny sowthistle	A	Introduced	NI (FACW)	Asteraceae	7
	SYMERI	Symphyotrichum ericoides	heath aster	P	Native	FACU	Asteraceae	57
	SYMPRA	Symphyotrichum praealtum	willowleaf aster		Native	FACW-	Asteraceae	37
	TAROFF	Taraxacum officinale	common dandelion	P	Introduced	FACU	Asteraceae	3
	TEUCANO	Teucrium canadense var. occidentale	western germander	P	Native		Lamiaceae	27
	TRITER	Tribulus terrestris	puncturevine	A	Introduced	NI (UPL)	Zygophyllaceae	3
	TYPLAT	Typha latifolia	broadleaf cattail	P	Native	OBL	Typhaceae	1
	VERBRA	Verbena bracteata	bigbract verbena	P	Native	FAC	Verbenaceae	2
	XANSTR	Xanthium strumarium	rough cocklebur	A	Native	NI (FACW)	Asteraceae	57
	XANSTRC	Xanthium strumarium var. canadense	Canada cocklebur	A	Native	NI (FACW)	Asteraceae	38
	XANSTRG	Xanthium strumarium var. glabratum	rough cocklebur	A	Native		Asteraceae	10