12-2001

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Repository Citation

Aaron, Patti, "The Suitability of reclaimed agricultural lands along the lower Colorado River for native Riparian habitat restoration" (2001). *UNLV Theses, Dissertations, Professional Papers, and Capstones*. 289.
https://digitalscholarship.unlv.edu/thesesdissertations/289

THE SUITABILITY OF RECLAIMED AGRICULTURAL LANDS ALONG THE LOWER COLORADO RIVER FOR NATIVE RIPARIAN HABITAT RESTORATION

ABSTRACT

The purpose of this paper is to determine the suitability of agricultural lands for use in native riparian restoration efforts under development for the Lower Colorado River Multi-Species Conservation Program. Assuming these fields are productive for crops, would they be productive for cottonwood-willow restoration? There are two aspects to consider: (1) the edaphic conditions required for three major LCR agricultural crops; alfalfa, cotton, and wheat, and (2) whether those conditions are consistent with the conditions required for the restoration of native LCR riparian habitat, primarily Fremont cottonwood *(Populus fremontii)* and Goodding willow *(Salix gooddingii)*. Using the case study research approach for nine proposed conservation areas, the edaphic factors considered include: (a) depth to groundwater, (b) soil moisture, (c) salinity, (d) pH, and (e) soil texture.

As a result of this study, one conservation area was found to be suitable for cottonwood-willow restoration. However, the edaphic conditions evaluated represent only a gross winnowing of the data. There is a need for more refined data to more accurately assess the suitability of the other proposed conservation areas.

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A senior thesis completed in partial fulfillment of a
Bachelor of Arts Degree in Environmental Studies
University of Nevada, Las Vegas
December 2001

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I. INTRODUCTION

The lower Colorado River (LCR) provides water to the arid Southwest for a variety of uses, including irrigation and municipal use, and generation of hydroelectric power for 25 million people in three southwestern states: Nevada, Arizona, and California (USBR, 1996). Historically, the LCR was characterized by Fremont cottonwood-Goodding willow dominated riparian ecosystems. However, over 80% of this habitat has been lost since pre-Euroamerican settlement times (Swift, 1984; Tellman *et al.*, 1997).

Cottonwood-willow forests support conditions for a diverse understory of herbaceous plants. A rich riparian ecosystem of this type provides habitat essential to the maintenance and enhancement of threatened and endangered species along the LCR (Busch & Smith, 1995).

Early in 1994, the U.S. Fish and Wildlife Service (FWS) designated critical habitat for four listed endangered native fishes, i.e. Colorado pike minnow, razorback sucker, bonytail chub, and humpback chub, in the mainstem and major tributaries within the Colorado River basin. In response, a number of federal, regional, state, and local stakeholders formed a partnership to create a Multi-Species Conservation Program to balance the water use needs of the lower Colorado River region and Endangered Species Act (ESA) compliance requirements. Part of this program involves proposed conservation areas for native riparian vegetation restoration on agricultural lands.

There are many agricultural lands along the LCR. Current restoration research suggests these cultivated fields provide an economical strategy for revegetation of cottonwood and willow. Such lands do not require extensive site preparation due to level surfaces free of heavy vegetation from past agricultural use, existing irrigation infrastructure, and lower salinity levels as a result of past irrigation practices (Raulston, 2001).

The purpose of this study is to determine whether agricultural lands located within nine proposed conservation areas are suitable for use in native riparian restoration efforts along the lower Colorado River. There are two aspects to consider: (1) the edaphic conditions required for three major LCR agricultural crops; alfalfa, cotton, and small grain, and (2) whether those conditions are consistent with the conditions required for the restoration of native LCR riparian habitat, primarily Fremont cottonwood *(Populus fremontii)* and Goodding willow *(Salix gooddingii)*.

In order to determine suitability, a case study research approach (Yin, 1984) was used to evaluate the conditions for agricultural crops grown in, and adjacent to, nine proposed conservation areas along the LCR. Edaphic conditions, i.e. the physical and chemical properties of soil that influence plant growth, are comprised of a number of factors. For the purposes of this study, the edaphic factors considered include: (a) depth to water table, (b) soil moisture (water holding capacity), (c) salinity, (d) pH, and (e) soil texture (Anderson, 1988; Pinkney, 1992; Raulston, 2001).

If the edaphic conditions for the three major crops grown in these areas fall within the same ranges as the native species, then the fields can be considered more suitable. If the edaphic conditions for the three major crops do not fall within the same ranges as the native species, then the fields can be considered less suitable.

The remainder of this thesis is organized as follows: Section II reviews the relevant literature on species issues, groundwater and soil issues, and water and soil quality issues; Section III presents the method; Section IV describe the data; Section V presents background information on the proposed conservation areas; Section VI discusses the findings; and Section VII offers concluding remarks. A list of acronyms used throughout this paper are in Appendix D.

II. LITERATURE REVIEW

The literature contains a broad range of topics related to the question of whether the proposed conservation area agricultural lands along the LCR are suitable for native species restoration. Three general categories are relevant to this paper: (A) species issues, (B) groundwater and soil issues, and (C) water and soil quality issues.

(A) Species Issues

Historically, the LCR was characterized by Fremont cottonwood-Goodding willow dominated riparian ecosystems. However, over 80% of this habitat has been lost since pre-Euroamerican settlement times (Swift, 1984; Tellman *et al.*, 1997).

Cottonwood-willow forests support conditions for a diverse understory of herbaceous plants. A rich riparian ecosystem of this type provides habitat essential to the maintenance and enhancement of threatened and endangered species along the LCR.

The general topics covered in this category are (i) habitat restoration and enhancement; (ii) cottonwood-willow requisites, the effects of past water management practices, and future mitigation; and (iii) crop requisites.

(i) Habitat restoration and enhancement

The issue of habitat restoration and enhancement receives support from a variety of sources, including federal, state, and local funding. For example, the U.S. Department of Agriculture administers the Wildlife Habitat Incentives Program and Conservation Reserve Program to help land owners improve fish and wildlife habitat on their private lands (USDA, 2001). Congress passed the Conservation Security Act of 2001 which will provide financial incentives to help farmers and ranchers find viable solutions to a variety of environmental concerns, including wetland and wildlife habitat restoration and enhancement (CalSAWG, 2001b). The Arizona Partners for Fish and Wildlife Program provides technical and financial assistance to private land owners for the improvement of fish and wildlife habitat on their property (UA, 2001). The California Sustainable Agriculture Working Group is a network of diverse groups dedicated to promoting sustainable systems, which includes habitat preservation (CalSAWG, 2001a).

(ii) Cottonwood-Willow

Cottonwood-willow stands represent pioneer species that support high biodiversity in riparian zones. These communities are often more diverse than those supported by adjacent dominant riparian species (Busch & Smith, 1995; Stromberg *et al.*, 1996). Restoration research suggests successful cottonwood/willow revegetation provides favorable conditions for successional herbaceous species development (Pinkney, 1992; Stromberg, 1993).

Recovery of this type of riparian habitat is vital to the success of current efforts to stabilize and enhance populations of several endangered and threatened species dependent upon these communities, e.g. the southwestern willow flycatcher, the western yellow-billed cuckoo, and the occult little brown bat (FWS, 1997). Restoration efforts have been hampered in the past by factors unique to this geographic area. Some of these factors include, but are not limited to, lack of available water sources, highly saline soils, unsuitable groundwater table levels, the spread of salt cedar, and fire (Stromberg, 1993; Busch & Smith, 1995; Raulston, 2001).

Both Fremont cottonwood and Goodding willow are classified as phreatophytes (Busch *et al.*, 1992b). A phreatophyte is a plant that is dependent on groundwater, obtaining its water supply from the zone of saturation, either directly or through the associated capillary fringe (Robinson, 1958; Busch *et al.,* 1992b). Little & Jones (1980) define a phreatophyte as a perennial plant which derives its water from a more or less permanent, subsurface water supply. It is thus not dependent upon annual rainfall for survival. Obligate phreatophytes are plants that must be in contact with groundwater at all times, while facultative phreatophytes can utilize moisture from unsaturated soils, in addition to groundwater (Busch *et al.,* 1992b). Smith *et al.* (1998) further refine the definition of arid-adapted obligate phreatophytes to plants in contact with a phreatic surface, which implies a perennial groundwater source.

When the distinction between obligate and facultative phreatophytes was made in the literature reviewed for this paper, cottonwoods were usually designated as facultatives and willows as obligates (Stromberg *et al.*, 1996; Horton *et al.*, 2001). However, as a result of plant water absorption research conducted on the LCR and the Bill Williams River, Busch *et al.* (1992b) and Smith *et al.* (1998) consider both Fremont cottonwood and Goodding willow to be obligate phreatophytes. Both species showed evidence of absolute groundwater usage, regardless of condition changes. Further studies, along the San Pedro River, revealed both species were capable of utilizing some precipitation-derived soil moisture. This suggests some adaptive-related flexibility when survival conditions are marginal (Snyder & Williams, 2000).

In response to an increase of population and land use in the Southwest the U.S. Bureau of Reclamation (USBR) initiated a series of projects in the early 20th century that transformed the Colorado River into what is seen today; an extensively managed water delivery system. The Colorado River basin is separated into two USBR management regions, the Upper Colorado River Region and the Lower Colorado River Region. The

Lower Colorado River Region begins at Lee Ferry, 15.5 miles downstream of Glen Canyon Dam, in the north, and continues to the Southern International Boundary (SIB) with Mexico in the south. Management of the lower Colorado River provides: (1) river regulation, improvement of navigation, and flood control, (2) irrigation and domestic uses, including the satisfaction of present perfected water rights (collectively known as the “Law of the River”), and (3) hydroelectric power for 25 million people in three southwestern states: Nevada, Arizona, and California (USBR, 1996). The modifications, management, and associated uses of the LCR have resulted in detrimental effects on the ecosystems, habitats, and native species of the region (SAIC/Jones & Stokes, 2001a).

There are two major factors attributed to the decline of riparian habitat along the LCR: (1) extensive water management practices, and (2) the introduction of non-native species; primarily salt cedar *(Tamarix ramossisima* and *T. aphylla).*

(1) A 1699 expedition led by Father Kino, an Italian Jesuit priest, reported dense cottonwood-willow groves 3 miles wide at the junction of the Gila and Colorado Rivers. Soldiers and scientists began keeping records in the same area in the late 1840s. They reported abundant and impenetrable thickets of willows and cottonwoods. An 1852 boundary survey also mentioned dense forests of cottonwood-willow that filled the river’s floodplain (Busch *et al.*, 1992a).

The river’s navigability was being explored in the mid-to-late 1800s. Steamboat travel became a popular mode of transportation. Cottonwoods and willows were the primary source of fuel for powering the vessels and were readily accessible in those early years. Steamboat use from 1855 to 1890, and the resultant need for fuel, caused widespread reduction of cottonwood-willow communities along the river. Toward the end of the steamboat period, the populations of suitable trees had been reduced to the point that steamers planning long trips on the river had to take on wood to ensure an adequate supply (Busch *et al.*, 1992a).

Agricultural activities began along the LCR in the early 1900s. Major floods in 1905 and 1907 devastated these early farming efforts. Public pressure was placed on the federal government to control the river for human use (Busch *et al.,* 1992a).

The first water management structure constructed on the Colorado River, Laguna Dam, was built in 1907 (CH2MHill, 1999). Continued political pressure, often prompted by flood events, led to a series of USBR-initiated projects that transformed the Colorado River into what is seen today; an extensively managed water delivery system.

Annual floods affected new settlements and irrigated agricultural lands along the LCR. The growing human population perceived the natural course of events along the river as a travesty in need of control, a mindset indicative of the Modernist Project. Unfortunately for the riparian habitat, what was considered devastating by humans was the exact flow regime required for native recruitment of cottonwood and willow seedlings and enhancement of juvenile and mature trees and the vegetative understory they supported (Stromberg, 1993).

Two major actions had dramatic effects on the remaining cottonwood-willow riparian communities. First, when the Hoover Dam was completed in 1935, it essentially stopped all threats of floods. The rich alluvial soils downstream encouraged an expansion of farming. Also, the creation of Lake Mead and other lakes formed behind other dams inundated thousands of acres of riparian habitat. Today, ten dams and hundreds of miles of bankline stabilization manage the flow of the river and contain the water in a disciplined course (Busch *et al.,* 1992a). Without floods, the life-cycle of cottonwoods and willows was irreversibly changed (Ohmart *et al.*, 1988).

(2) Salt cedar has established a dramatic presence along the LCR over the last few decades, replacing many native Fremont cottonwood-Goodding willow forests (Sala *et al.,* 1996; Cleverly *et al.,* 1997; Smith *et al.,* 1998). Although a study of saltcedar is outside of the scope of this paper, much of the literature reviewed addresses this invasive non-native shrub and its increasing dominance in the Southwest (Busch *et al.*, 1992b; Busch & Smith, 1995; Sala *et al.*, 1996; Cleverly *et al.*, 1997; Smith *et al.*, 1998; Shafroth *et al.,* 2000; Horton *et al.,* 2001).

Salt cedar, an exotic non-native, spread into the lower Colorado River basin from the Gila River. In 1894, Mearns estimated close to 450,000 acres of riparian vegetation in the lower Colorado River floodplain. As of 1986, total riparian vegetation was reported at about 100,000 acres. About 40 percent of the remaining area was pure salt cedar stands, and additional 43 percent consisted of native plants mixed with salt cedar, and only 0.7 percent was designated as mature cottonwood-willow habitat (Anderson and Ohmart, 1982).

A number of resilient qualities enable saltcedar to adapt and survive conditions cottonwood and willow cannot. It is a facultative phreatophyte able to operate at low plant-water potentials with good water-use efficiency and to send roots through unsaturated soils to the water table, making it more drought-tolerant than cottonwood or willow (Cleverly *et al.,* 1997; Shafroth *et al.,* 2000). It is highly tolerant of saline conditions (Sala *et al.,* 1996). The seedlings exhibit a rapid growth rate and are tolerant of both desiccation and inundation (Sala *et al.*, 1996). It shows efficient recovery from wildfire and is relatively free of insect and mammal herbivores (Smith *et al.*, 1998).

The Lower Colorado River Multi-Species Conservation Program (MSCP) is a partnership of Federal, state, tribal, and other public and private stakeholders, including various water and power agencies, with an interest in managing the water and related resources of the Lower Colorado Basin. The partnership was formed in response to the need to balance the legal issues of LCR water resources and the conservation of threatened and endangered species and their habitats in compliance with the federal and California Endangered Species Acts (ESA and CESA respectively). In August 1995, the Department of Interior and the states of Arizona, California, and Nevada entered into a Memorandum of Agreement to initiate development of a MSCP that will:

1. Conserve habitat and work toward the recovery of threatened and endangered species, and reduce the likelihood of additional species listings under the Endangered Species Act,
2. Accommodate current water diversions and power production and optimize opportunities for future water and power development, and
3. Provide the basis for Federal ESA and California ESA compliance via incidental take authorizations resulting from the implementation of the first two purposes.

The program area covers the mainstream of the LCR, the historical flood plain, and reservoirs. The MSCP will prepare all environmental compliance documents required by the National Environmental Policy Act (NEPA), the ESA, the CESA, and the California Environmental Quality Act (CEQA) (LCRMSCP, 1999).

The MSCP has adopted a habitat-based approach to the conservation of covered species. Conservation areas have been proposed based on MSCP goals: (1) protection of existing habitat, (2) enhancement of existing habitat, (3) restoration to create new habitat, (4) management of habitat to maintain and preserve ecological functions, (5) avoidance and minimization of direct impacts on individuals and populations of covered species, and (6) population enhancement measures that directly or indirectly increase population levels of covered species (SAIC/Jones & Stokes, 2001b). Nine of these proposed conservation areas are the focus of this study.

(iii) Crops

Agricultural irrigation began along the LCR in the early 1900s and is a predominant determinant in present-day river operations (Busch *et al.*, 1992a). Over 21,000 acres of land were classified as agricultural in the year 2000 along the LCR (USBR, 2001).

The single most limiting factor for crop production in the arid Southwest is water, with salinity being the second most limiting factor.

(B) Groundwater and Soil Water Issues

This category covers (i) depth to groundwater and soil moisture, and (ii) groundwater level requirements for cottonwoods and willows at various stages of growth; i.e. seedlings, saplings and juvenile trees, mature trees, and root development.

(i) Depth to Groundwater and Soil Moisture

Depth to groundwater and available soil moisture are significant factors in determining the biological diversity, structural and spatial patterns and species recruitment and composition of riparian plant communities (Robinson, 1958; Busch *et* *al.,* 1992b; Richter, 1993). Hydrologic variation has significant effect on riparian plant community structure and function (Busch & Smith, 1995). Riparian species on the LCR collect into community patterns along moisture and salinity gradients (Busch & Smith, 1995; Stromberg *et al.*, 1996).

A number of studies have observed cottonwood-willow to be indicators of a shallow water table (Busch *et al.*, 1992b; Richter, 1993; Briggs, 1996). Cottonwood and willow are sensitive to the depth to groundwater, require continuous access to a relatively shallow water table, and the capillary fringe, and have poor tolerance to water stress (Busch & Smith, 1995; Smith *et al.,* 1998; Shafroth *et al.*, 2000).

Pinkney (1992) found soil moisture of about 10% near the soil surface in naturally occurring LCR cottonwood-willow stands. Moisture increased with depth to 40% at 1.2 m. Busch & Smith (1995) observed soil moisture content was higher for the active floodplain soils along the Bill Williams River than along the flood-restricted LCR. Soil moisture of about 4% was reported along the LCR resulting from depressed floodplain water tables, lack of moisture replenishment by flooding, low precipitation, and high potential evapotranspiration. Cottonwood recruitment was not successful under these conditions.

(ii) Groundwater Level Requirements

Naturally occurring Southwestern cottonwood-willow forests are generally found where the depth to groundwater is about 1.0 to 3.0 m (Stromberg *et al.,* 1991; Busch *et al.,* 1992a; Horton *et al.,* 2001). Goodding willow is generally found at sites with shallower groundwater than Fremont cottonwood, suggesting more shallow rooting depths (Stromberg *et al.*, 1991; Busch *et al.*, 1992a) and is more sensitive to groundwater level changes than Fremont cottonwood (Horton *et al.*, 2001).

On the LCR, Pinkney (1992) found the highest survival rates, for both natural and planted cottonwood and willow, with groundwater levels from 0.6 to 2.5 m. Anderson (1988) found naturally occurring LCR cottonwood-willow stands had a mean depth to groundwater of 1.8 m.

Fremont cottonwood and Goodding willow seedlings naturally establish in a dynamic floodplain environment with coarse soils and high moisture availability where developing roots can match the rate of retreating water levels (Fenner *et al.*, 1984; Stromberg *et al.*, 1991; Briggs, 1996). While direct contact with groundwater is not necessary for seedling survival, high capillary fringe soil moisture is required. A moist seedbed on the soil surface is needed during the time of seed viability, which ranges from one to five weeks. Moist conditions must persist until the seedling roots grow to depths with readily available moisture (Fenner *et al.*, 1984; Cooper *et al.*, 1999; Horton *et al.*, 2001). Fenner *et al.* (1984) reported annual soil moisture fluctuations in Arizona's Gila River cottonwood-willow forests of 8 to 23% at 0.4 m below the soil surface and a constant 10% at 0.6 m deep. In a sandy-loam soil, soil moisture of 10% can support a relatively high germination rate (Fenner *et al.*, 1984).

In a study of the impacts of flood flows on the Hassayampa River riparian forests in Arizona, Fremont cottonwood seedlings naturally established on the floodplains in areas ranging from 0.2 to 1.0 m above the water table. The most successful seedling recruitment was observed at 0.2 to 0.4 m above the water table. The seedlings found from 0.5 to 1.0 m above the water table had a higher mortality rate (Stromberg *et al.*, 1991).

Studies in the same area found Goodding willow tends to establish on sites closer to the stream, with a shallower water table than Fremont cottonwood (Stromberg, 1993).

Other influential factors for seedling survival include soil texture (Mahoney & Rood, 1991); soil type and soil profile stratigraphy, as they affect moisture-holding capacity, capillary rise, formation of perched water tables, and lateral water movement (Stromberg, 1998); soil fertility and length of growing season (Segelquist *et al.,* 1993); climate, e.g. rainfall and evaporative stresses (Stromberg, 1998); and population factors, e.g. stand density, stand age, and acclimation to site conditions (Stromberg, 1998).

The very hydrologic events that create ideal conditions for seedling germination also contribute to higher mortality rates in subsequent age classes (Stromberg *et al.,* 1991; Busch & Smith, 1995). For example, young cottonwoods past their first growing season are tolerant of periodic, short-term inundation, i.e. less than one growing season, but are highly susceptible to being scoured away or buried with sediment by more vigorous flood events (Rood & Mahoney, 1990; Busch *et al.,* 1992a, Shrader, 2000).

In a study of riparian vegetation on the Hassayampa River Preserve, Fremont cottonwood, Goodding willow saplings and pole stands had a mean depth to groundwater of 0.71 m and 1.31 m respectively (Table 1) (Richter, 1993). In the same area, Stromberg *et al.* (1996) found Fremont cottonwood and Goodding willow juveniles grew where depth to groundwater averaged less than 1.0 m. The range for cottonwood was 0.4 to 1.4 m and the range for willow was 0.25 to 1.0 m (Table 1).

Along Colorado's Yampa River, Cooper *et al.* (1999) observed 4-year old Fremont cottonwoods with roots reaching to the lowest summer groundwater depth of 2.5 m.

Mature cottonwood and willow trees with well-developed root systems are more likely to survive under conditions seedlings and juveniles are unable to tolerate (Briggs, 1996). However, these phreatophytes are still quite sensitive to drought-stress (Rood & Mahoney, 1990).

Mature Fremont cottonwood and Goodding willow saplings on the Hassayampa River Preserve had a mean depth to groundwater of 2.20 m (Table 1) (Richter, 1993). In the same area Stromberg *et al.* (1996) found mature Fremont cottonwood grew where depth to groundwater averaged less than 3.0 m. The range for cottonwood was 0.4 to 2.6 m and the range for Goodding willow was 0.5 to 2.3 m (Table 1). Studies along the LCR have also found that mature Fremont cottonwood and Goodding willow typically grow where the water table is less than 3.0 m (Busch *et al.,* 1992b; Raulston, 2001).

On the Hassayampa River Preserve, Stromberg *et al.* (1991) found trees aged from about five to 20 years dominating the 0.5 to 1.75 m depth to groundwater range. Young trees (ca. 10 years) ranged from 0.7 to 1.3 m above the water table. Mature trees (ca. 40 years) ranged from 2.0 to 3.2 m above the water table (Stromberg *et al.,* 1991; Stromberg *et al.,* 1996). It is suggested the decline in groundwater levels over the years is the result of human use. The rate of decline was not stated (Stromberg, 1991). It was observed that relative abundance of cottonwood to willow favored willows as the depth to groundwater increased (Stromberg, 1991). While both species are sensitive to groundwater level, willows are slightly more tolerant of changes (Busch *et al.,* 1992b; Briggs, 1996).

Table 1. Depth to Groundwater by Structure Type for Naturally Occurring Trees

Vegetation Type	Mean Depth to Water Table (m)	Location	Source
Cottonwood-Willow Saplings	0.71	Hassayampa River	Richter 1993
	0.8	Hassayampa River	Stromberg *et al.* 1991
	0.7	San Pedro River	Stromberg *et al.* 1996
Cottonwood-Willow Juveniles	1.31	Hassayampa River	Richter 1993
	1.0	Hassayampa River	Stromberg *et al.* 1991
	1.0	San Pedro River	Stromberg *et al.* 1996
Cottonwood-Willow Mature	2.2	Hassayampa River	Richter 1993
	2.6	Hassayampa River	Stromberg *et al.* 1991
	1.9	San Pedro River	Stromberg *et al.* 1996

The structure of developing root systems is determined by site-specific soil type and groundwater conditions, (Groeneveld & Griepentrog, 1985; Scott *et al.,* 1999). Variable growth forms and functional architecture are probably more related to site-specific hydrologic and soil conditions, than to genetic characteristics of the species (Pinkney, 1992; Snyder & Williams, 2000). Fenner *et al.* (1984) suggest a declining water table tends to promote root growth to greater depth, as opposed to a static water table, which would cause a shallow root system to develop.

Shafroth *et al.* (2000) suggest that a change in groundwater depth relative to previous conditions or patterns is more important than absolute depth to the water table. This is due to the influence of groundwater history on root architecture (Shafroth *et al.,* 2000). Root architecture has been shown to be a function of soil moisture conditions and water table depth in cottonwood and willow (Sprackling & Read, 1979, as cited in Shafroth *et al.,* 2000).

Scott *et al.* (1999) suggest trees established with the influence of a stable water table are more sensitive to groundwater declines than trees that developed with a more variable water table environment.

(C) Water and Soil Quality Issues

Literature regarding (i) salinity and (ii) soil texture are covered in this category.

(i) Salinity

Salinity has long been recognized as one of the major problems of the Colorado River. Salinity concentration progressively increases downstream as a result of two processes, (1) salt loading, i.e. the addition of soluble salt to the river, and (2) salt concentration, caused by a reduction in the volume of river water as a result of evaporation, transpiration, and withdrawal (Ghassemi *et al.*, 1995).

Man and nature each contribute approximately equally to salinity levels in the river. Salts in arid regions like the Southwest, naturally accumulate through a lack of leaching and evaporation. Natural contribution occurs as water washes into streams and rivers after it passes through ancient marine deposits where soluble salts accumulate due to lack of leaching and restricted drainage (Chapman, 1975; Ghassemi *et al.*, 1995; Briggs, 1996). The river picks up over 8 million tons of salt per year as it flows through the seven basin states (Hedlund, 1984; Ghassemi *et al.*, 1995). Agricultural irrigation, municipal and industrial water uses, and reservoir evaporation account for the remaining salt accumulation (Jonez, 1984; Ghassemi *et al.*, 1995). Historically, annual spring floods leached out excess salts (Briggs, 1996).

High soil and water salinity pose a problem along the LCR. High levels of salts have direct effects on plant growth. For example, there is a reduction of osmotic potential of the soil solution which reduces the amount of water available to the plant. Soil salinity can indirectly affect plant growth through the inhibition of soil biological processes. High concentrations of sodium ions can negatively impact the physical characteristics of a soil, indirectly affecting plant health, e.g. stunted growth and thicker, smaller leaves (Poljakoff-Mayber & Lerner, 1994). Sodic soils readily lose their structure and become impermeable, further reducing the amount of water available for plant use. (Dudley, 1994; Szabolcs, 1994; Briggs, 1996).

The effects of salinity on plants depends not only on the tolerance of the plant species to salinity, but also on numerous other factors, including climate, amount of soil water, salt composition, soil texture, and stage of development (Briggs, 1996). Plants become stressed in a saline environment because of a reduction in water availability due to the increase in the osmotic potential of the soil and the effects of high concentrations of ions (Busch *et al.*, 1992b).

(ii) Soil Texture

Characteristic ecosystems, such as cottonwood-willow communities, have characteristic soils with a range of similar properties. For example, a representative soil series is a group of soils developed from the same kind of parent material, by the same genetic combination of processes, and whose horizons are quite similar in their arrangement and general characteristics (Colinvaux, 1986).

Soil texture largely determines the ability of the soil to hold water and make it available to plants. Coarse textured soils have low available water capacity and moderately fine to fine textured soils have high available water capacity (SCS, 1980; SCS, 1986).

III. METHOD

To determine whether agricultural lands along the LCR can be used to restore native riparian habitat requires the use of the case study research method. Yin (1984) defines the case study research method as an empirical inquiry that investigates a contemporary phenomenon within its real-life context in which multiple sources of evidence are used. This thesis requires an examination of key edaphic conditions as recommended by Anderson (1988), Pinkney (1992), and Raulston (2001).

Edaphic factors considered for this study include: (a) depth to groundwater, (b) soil moisture, (c) salinity, (d) pH, and (e) soil texture (Anderson, 1988; Pinkney, 1992; Raulston, 2001). The edaphic requirements for cottonwood, willow, alfalfa, cotton, and wheat, a representative small grain were compiled through a literature review. Data collected about the proposed sites are then compared with ranges obtained from the literature.

The next section presents background information on data collected for nine conservation areas and key edaphic conditions in the literature.

IV. DATA

Nine proposed conservation areas, and agricultural lands adjacent to them, were examined. Key variables were identified and compared for each site. Multiples sources of evidence were collected and evaluated. Identical and/or comparable data sources were used in all cases.

Data were collected for five edaphic condition comparisons for cottonwood-willow (naturally occurring and restored) and three major crops grown in the proposed MSCP conservation areas and adjacent lands, i.e. alfalfa, cotton, and small grain, and for each of the nine proposed conservation areas, including data obtained from soil series and crop budgets developed with Geographic Information System (GIS). This section summarizes the edaphic condition comparisons and background information on the proposed conservation area conditions is presented in the following section.

Anderson (1988) conducted a study to determine the overall suitability of the lower Colorado River for the growth of cottonwood and willow. The most significant variables were determined to be depth to water table, soil types, electroconductivity, and pH. Pinkney (1992) determined some of the important factors to consider when developing a lower Colorado River riparian vegetation establishment plan to be groundwater and soil moisture, soil profile features and characteristics, irrigation or supplemental watering, soil salinity, and fertilizers. Raulston (2001) sampled depth to groundwater, soil texture, and electroconductivity in a study on planting techniques for lower Colorado River restoration projects.

All of the data collected were compiled into five categories of edaphic conditions for cottonwood, willow, alfalfa, cotton, and small grain: (a) depth to groundwater

(Table 2), (b) soil moisture (Table 3), (c) salinity (Tables 4 and 5), (d) pH (Table 6), and (e) soil texture (Table 7) (Anderson, 1988; Pinkney, 1992; Raulston, 2001)

Depth to groundwater is a factor of primary importance to the success of cottonwood-willow restoration. All crops along the LCR are irrigated, so root depth is not a factor considered in the literature reviewed thus far (Busch *et al.*, 1992b; Stromberg *et al.,* 1996; CalFlora, 2001; NRCS, 2001) (Table 2).

Table 2. Range of Depth to Groundwater* Conditions (meter)

Vegetation Type	Minimum	Maximum
Cottonwood	0.2	3.0
Willow	0.1	2.5
Alfalfa	0.6	n/a
Cotton	0.4	n/a
Small Grain	0.4	n/a

*Cottonwood and willow data are for naturally occurring stands. Alfalfa, cotton, and small grain data are for irrigated crops.

The capillary fringe in soil can extend 3 to 4 feet above the water table. Cottonwood and willow have similar requirements for soil moisture as alfalfa and cotton (Brady, 1990; CalFlora, 2001; NRCS, 2001) (Table 3).

Table 3. Range of Soil Moisture Conditions

Vegetation Type	Minimum	Maximum
Cottonwood	medium	high
Willow	medium	high
Alfalfa	high	high
Cotton	medium	high
Small Grain	low	low

Salinity levels are another major issue of concern along the LCR. High temperatures and low humidity promote high levels of evaporation. The evaporative process conducts water to the surface and deposits salts in the upper crust of the soil. Cottonwood, willow, and alfalfa fall within the same salinity ranges. Cotton and small grain are more saline tolerant after the seedling stage (Francois, 1982; Francois & Maas, 1984; Ayers, 1985; Anderson, 1988; Shafroth *et al.*, 1995; Silvertooth, 1997 and 1998; CalFlora, 2001; NRCS, 2001) (Tables 4 and 5).

Table 4. Range of Soil Electroconductivity*/Salinity Conditions (dS m^{-1})

Vegetation Type	Minimum	Maximum
Cottonwood	0.0	<2.0
Willow	0.0	<2.0
Alfalfa	0.0	<2.0
Cotton	1.3	7.4
Small Grain	0.0	<4.5

*Electroconductivity is a function of salinity concentration

Table 5. Plant Sensitivity to Saline Conditions (dS m^{-1})

Plant Sensitivity	Ideal EC
Very sensitive	0.0-2.0
Sensitive	2.0-4.0
Tolerant	4.0-8.0
Very tolerant	8.0-16.0

pH expresses the acidity or alkalinity of soil and water (SCS, 1980). Cottonwood and alfalfa tolerate the same range of pH. Willow is less tolerant, and cotton and small grain are more tolerant (CalFlora, 2001; NRCS, 2001; Silvertooth, 2001) (Table 6).

Table 6. Range of Soil Reaction Conditions (pH)

Vegetation Type	Minimum	Maximum
Cottonwood	6.0	8.5
Willow	6.0	7.4
Alfalfa	6.0	8.5
Cotton	4.0	8.0
Small Grain	5.5	8.0

Soil texture is a description of relative proportions of sand, silt, and clay particles. Coarse is the equivalent of sand, medium is the equivalent of loamy sand, and fine is the equivalent of sandy loam (SCS, 1980; Brady, 1990; NRCS, 2001) (Table 7).

Table 7. Range of Soil Texture Conditions

Vegetation Type	Minimum	Maximum
Cottonwood	fine	coarse
Willow	medium	coarse
Alfalfa	fine	medium
Cotton	fine	medium
Small Grain	fine	coarse

(ii) Proposed Conservation Areas

CH2MHill (1999) developed a series of ecological restoration concepts for the lower Colorado River which were further refined by SAIC/Jones & Stokes (2001a) in the Phase 1 draft of proposed conservation areas for the MSCP. Information obtained from Ogden (1999 and 2000) and Colorado River Indian Tribes (2000) was included in the SAIC/Jones & Stokes (2001a) report. Crop budget source data for the proposed conservation areas and the agricultural lands adjacent to them were obtained from the Lower Colorado River Accounting System, using GIS technology to analyze the crop budgets for each site (Martinez, 2001; Milikin, 2001; SAIC/Jones & Stokes, 2001b). Background information on the proposed conservation areas and relevant data collected are presented in the next section.

V. BACKGROUND INFORMATION ON PROPOSED CONSERVATION AREAS

This section presents background information, including (i) proposed conservation area site descriptions, (ii) crop budget data, and (iii) soil series data.

(i) Proposed Conservation Area Site Descriptions

Nine conservation areas proposed by SAIC/Jones & Stokes (2001a and 2001b) were examined for this study. Site maps are located in Appendix F. Conservation area location is described by River Mile. Within the U.S. Bureau of Reclamation River Miles (RM) are numbered along the thalweg, i.e. the center of the waterway channel, of the LCR channel south to north starting with RM 0.0 at the Southern International Border with Mexico (Holden *et al.,* 1986). Appendix F, Figure 1-1, shows the all of the proposed areas along the LCR. Land ownership, including associated water rights, ranges from large blocks of federal, tribal, and private lands to smaller units of state and local agency ownership (Shrader, 2000). Criteria considered when designating areas for proposed conservation efforts include: habitat occupied by endangered and threatened species vs. other species, flood plain sites close to the river, large blocks of habitat, up to 3,000 contiguous acres (a minimum of 100 acre block required for Southwestern willow flycatcher utilization), dispersal of habitat along the entire LCR corridor, and contiguous to the riparian corridor, occupied habitat and/or large habitat blocks (Shrader, 2000).

(1) Long Lake Conservation Area

This proposed conservation area is located between RM 255 and 252 on the Arizona side of the LCR (Appendix F, Figure D-5). The total project area is approximately 1,320 acres and primarily is located on the Fort Mojave Indian Reservation. The conservation area contains mostly open land, some of which was formerly used for agriculture. The open land supports native vegetation including cottonwood, willow, mesquite, and non-native saltcedar (CH2MHill, 1999; SAIC/Jones & Stokes, 2001a and 2001b).

(2) Ahakhav Tribal Preserve Conservation Area

This proposed conservation area is located between RM 175 and 169 on the Arizona side of the LCR (Appendix F, Figure D-6). The total project area is approximately 1,010 acres. It is located in the Ahakhav Tribal Preserve, which currently supports a native plant nursery that grows riparian tree species for restoration purposes. Included in the area is Deer Island, which was part of an oxbow that was dredged by USBR. The oxbow channel was closed off on the east side of the island to form a backwater and increase habitat quality for fish and wildlife (Ogden, 1999; CRIT, 2000; SAIC/Jones & Stokes, 2001a and 2001b).

(3) Mohave and Deer Tail Backwaters Conservation Area

This proposed conservation area is located between RM 169 and 166 on both sides of the LCR (Appendix F, Figure D-7). The total project area is approximately 800 acres. To date, Colorado River Indian Tribes (CRIT) has revegetated 140 acres with native cottonwood and willow and 110 acres with mesquite within the concept area. If implemented, this option would augment the existing restored areas of the Ahakav Tribal Preserve Conservation Area, creating a large continuous strip of restored habitat (CRIT, 2000; SAIC/Jones & Stokes, 2001a and 2001b).

(4) A7 Backwater Conservation Area

This proposed conservation area is located between RM 121 and 117 on the Arizona side of the LCR (Appendix F, Figure D-8). The total project area is approximately 1,490 acres and consists of agricultural lands currently in production and abandoned agricultural lands (SAIC/Jones & Stokes, 2001a and 2001b).

(5) Swendt Slough Conservation Area

This proposed conservation area is located between RM 111.5 and 110 on the Arizona side of the LCR (Appendix F, Figure D-11). The total project area is approximately 190 acres and consists of the relict Swendt Slough and former floodplain with undeveloped, heavily vegetated lands (SAIC/Jones & Stokes, 2001a and 2001b).

(6) BLM Agricultural Leases within PVID Conservation Area

This proposed conservation area is located between RM 106.6 and 102 on the California side of the LCR (Appendix F, Figure D-13). The total project area is approximately 2,200 acres and is on lands managed by the Bureau of Land Management (BLM) as agricultural leases to growers within the Palo Verde Irrigation District (PVID). The area consists primarily of agricultural lands with some undeveloped lands (SAIC/Jones & Stokes, 2001a and 2001b).

(7) Palo Verde Oxbow Enhancement Conservation Area

This proposed conservation area is located between RM 101.5 and 100 on the California side of the LCR (Appendix F, Figure D-14). The total project area is approximately 1,560 acres and consists of active agricultural lands and undeveloped lands in the Imperial County Oxbow Lake Park. The Palo Verde oxbow was isolated from the mainstem of the LCR by the realignment of the river in the 1960s. Inlet and outlet structures were installed by USBR to provide flow through the oxbow, and dredging has been conducted to clear some areas overgrown with marsh vegetation (Ogden, 1999; SAIC/Jones & Stokes, 2001a and 2001b).

(8) Cibola Restoration Concept Conservation Area

This proposed conservation area is located between RM 96 and 88 on the California side of the LCR (Appendix F, Figure D-16). The total project area is approximately 230 acres and is located on Cibola National Wildlife Refuge (CNWR) lands. It includes portions of the CNWR Island Unit and the old river channel (CH2MHill, 1999; SAIC/Jones & Stokes, 2001a and 2001b).

(9) Limitrophe BLM Habitat Restoration Conservation Area

This proposed conservation area is located between RM 8 and 0 on the Arizona, United States side of the LCR (Appendix F, Figure D-19). The total project area is approximately 1,000 acres and is located on lands owned by the BLM currently in agricultural production (SAIC/Jones & Stokes, 2001a and 2001b).

(ii) Crop Budget Data

Maps of the nine proposed MSCP conservation areas (Jones & Stokes, 2001a) are used to determine the location and boundaries of the conservation areas and the agricultural buffer zones around those areas. The buffer zones were designated and used solely for the purposes of this research effort; therefore the boundaries are fairly arbitrary and are not, in the true sense, buffering anything. The boundaries were drawn with the idea of encompassing enough of the area adjacent to the conservation areas to get a good representation of crops grown in those general areas. The varied nature and sizes of the proposed conservation areas made the use of a specific formula impractical. For example, some proposed areas have very little surrounding agriculture, while others are located within extensive agricultural regions. The proposed conservation areas and buffer zone boundaries were then digitized (Martinez, 2001). An example of these digitized boundaries is in Appendix E.

Source data were collected for the Lower Colorado River Accounting System (LCRAS), as part of USBR's compliance for federal consumptive water use accounting requirements. Remote sensing, field surveys, and GIS processes are used to identify and map crops and open water along the LCR from Hoover Dam to the SIB with Mexico (USBR, 2001). This information is used to compute and project irrigation water consumption values.

For the purpose of this study, GIS analysis of LCRAS source data was used to determine crop budgets for the year 2000, e.g. crop type and acres grown. This data was used to determine which crops were grown in the proposed conservation areas and the buffer zones (Milikin, 2001). The crops reported were alfalfa, bermuda grass, cotton, crucifers, field grain, legume vegetables, lettuce, melons, small grain, small vegetables, and Sudan grass. (Appendix A). Table 8 shows a summary of the crop data for all the proposed conservation areas. The data for each individual conservation area are in Appendix A.

Table 8. Crop Budget Summary of Conservation and Buffer Zone Areas (acres)

Crop Type	Conservation Areas (CA)	% of CA Total	% of CA+Buffer Total	Buffer	% of Buffer Total	% of CA+Buffer Total	CA+Buffer Total
Alfalfa	2,333.71	41	15	13,292.41	43	85	15,626.12
Bermuda	88.88	2	13	614.93	2	87	703.81
Cotton	1,892.99	34	26	5,404.30	17	74	7,297.29
Crucifers	181.17	3	16	933.62	3	84	1,114.79
Field Grain	18.33	0	11	150.36	0	89	168.69
Legumes	48.98	1	11	405.10	1	89	454.08
Lettuce	218.53	4	8	2,600.42	8	92	2,818.95
Melons	39.70	1	3	1,096.08	4	97	1,135.78
Small Grain	531.60	9	12	4,040.08	13	88	4,571.68
Small Vegetables	53.58	1	23	182.74	1	77	236.32
Sudan	230.86	4	9	2,202.21	7	91	2,433.07
Total	**5,638.33**	**100**	**15**	**30,922.25**	**100**	**85**	**36,560.58**

Source: Milikin, 2001

Alfalfa, cotton, and small grain, i.e. wheat, represented 84% of the crops grown in eight of the nine proposed conservation areas (Swendt Slough Conservation Area has no existing agriculture) and 73% of the crops grown in the buffer zones adjacent to all nine proposed conservation areas (Table 9). Edaphic conditions data for only the three major crops were included to keep the scope of this project manageable.

Table 9. Percentage of Three Major Crops in Conservation and Buffer Zone Areas

Crop Type	% CA Total	% BZ Total
Alfalfa	41	43
Cotton	34	17
Small Grain	9	13
Total	**84**	**73**

All three major crops were grown in three of the proposed conservation areas. Two major crops were grown in two proposed conservation areas and only one major crop was grown in the remaining two areas. For active fields within the proposed conservation areas, the percentage of alfalfa crops ranged from 3 to 89%, cotton crops ranged from 12 to 46%, and small grain crops ranged from 3 to 53% (Table 10). Table 11 shows the crops grown in the buffer zones.

(1) Long Lake Conservation Area

The three crops evaluated account for 66% of the crops grown in the proposed conservation area: 54% alfalfa, 12% cotton, and 0% small grain. Those three crops account for 75% of the crops grown in the adjacent buffer zone: 53% alfalfa, 22% cotton, and 0% small grain.

(2) Ahakhav Tribal Preserve Conservation Area

The three crops evaluated account for 89% of the crops grown in the proposed conservation area: 89% alfalfa, 0% cotton, and 0% small grain. Those three crops account for 96% of the crops grown in the adjacent buffer zone: 87% alfalfa, 0% cotton, and 9% small grain.

(3) Mohave and Deer Tail Backwaters Conservation Area

The three crops evaluated account for 63% of the crops grown in the proposed conservation area: 63% alfalfa, 0% cotton, and 0% small grain. Those three crops account for 92% of the crops grown in the adjacent buffer zone: 82% alfalfa, 0% cotton, and 10% small grain.

(4) A7 Backwater Conservation Area

The three crops evaluated account for 86% of the crops grown in the proposed conservation area: 40% alfalfa, 46% cotton, and 0% small grain. Those three crops account for 93% of the crops grown in the adjacent buffer zone: 57% alfalfa, 23% cotton, and 13% small grain.

(5) Swendt Slough Conservation Area

This proposed conservation area is not reported as agricultural land. Those three crops account for 83% of the crops grown in the adjacent buffer zone: 50% alfalfa, 33% cotton, and 0% small grain.

(6) BLM Agricultural Leases within PVID Conservation Area

The three crops evaluated account for 100% of the crops grown in the proposed conservation area: 43% alfalfa, 54% cotton, and 3% small grain. Those three crops account for 78% of the crops grown in the adjacent buffer zone: 53% alfalfa, 18% cotton, and 7% small grain.

(7) Palo Verde Oxbow Enhancement Conservation Area

The three crops evaluated account for 99% of the crops grown in the proposed conservation area: 61% alfalfa, 26% cotton, and 12% small grain. Those three crops account for 78% of the crops grown in the adjacent buffer zone: 53% alfalfa, 18% cotton, and 7% small grain.

(8) Cibola Restoration Concept Conservation Area

The three crops evaluated account for 76% of the crops grown in the proposed conservation area: 23% alfalfa, 0% cotton, and 53% small grain. Those three crops account for 100% of the crops grown in the adjacent buffer zone: 8% alfalfa, 0% cotton, and 92% small grain.

(9) Limitrophe BLM Habitat Restoration Conservation Area

The three crops evaluated account for 58% of the crops grown in the proposed conservation area: 3% alfalfa, 25% cotton, and 30% small grain. Those three crops account for 47% of the crops grown in the adjacent buffer zone: 1% alfalfa, 12% cotton, and 34% small grain.

Table 10. Major Crops Grown in Proposed Conservation Areas by Percent (%)

Conservation Area	Alfalfa	Cotton	Small Grain	Other Crops
Long Lake	54	12	0	44
Ahakhav Tribal Preserve	89	0	0	11
Mohave and Deer Tail Backwaters	63	0	0	37
A7 Backwater	40	46	0	14
Swendt Slough*	0	0	0	0
BLM Agricultural Leases w/in PVID	43	54	3	0
Palo Verde Oxbow Enhancement	61	26	12	1
Cibola Restoration Concept	23	0	53	24
Limitrophe BLM Habitat Restoration	3	25	30	42

*The proposed Swendt Slough Conservation Area is not designated as agricultural land. However, there is agricultural land in the buffer zone.

Source: Milikin, 2001

Table 11. Major Crops Grown in Buffer Zones by Percent (%)

Conservation Area	Alfalfa	Cotton	Small Grain	Other Crops
Long Lake	53	22	0	25
Ahakhav Tribal Preserve	87	0	9	4
Mohave and Deer Tail Backwaters	82	0	10	8
A7 Backwater	57	23	13	93
Swendt Slough*	50	33	0	83
BLM Agricultural Leases w/in PVID	53	18	7	22
Palo Verde Oxbow Enhancement	53	18	7	22
Cibola Restoration Concept	8	0	92	100
Limitrophe BLM Habitat Restoration	1	12	34	0

Source: Milikin, 2001

(iii) Soil Series

Soils data from Natural Resources Conservation Service (NRCS), formerly known as the Soil Conservation Service (SCS), Soil Surveys were then overlaid by hand on maps of proposed MSCP conservation areas and surrounding agricultural lands (Jones & Stokes, 2001) to determine if there were detectible patterns relating to the crops grown in each area and the soil suitability for cottonwood-willow. The purpose of this exercise was not precision, but to get a general idea of patterns and factors, if present, and to guide further data collection and analysis.

Sixteen soil series were identified when NRCS soil survey data were overlaid on maps of the proposed conservation areas and buffer zones: Agualt, Carrizo, Chuckawalla, Cibola, Gadsden, Gilman, Glenbar, Gunsight, Holtville, Indio, Kofa, Lagunita, Ripley, Rositas, Superstition, and Vint (Appendix B). Table 12 shows the ten soil series found within the proposed conservation areas among the overall 16 soil series.

Table 12. Proposed Conservation Areas Soil Series

Conservation Area	Agualt	Gadsden	Gilman	Glenbar	Holtville	Indio	Lagunita	Ripley	Rositas	Vint
Long Lake		X				X			X	X
Ahakhav Tribal Preserve	X						X			
Mohave and Deer Tail Backwaters	X		X	X			X			X
A7 Backwater		X				X	X	X		
Swendt Slough						X	X	X		
BLM Agricultural Leases w/in PVID						X	X	X		
Palo Verde Oxbow Enhancement						X	X	X		
Cibola Restoration Concept					X	X	X	X		
Limitrophe BLM Habitat Restoration		X						X		

Sources: SCS, 1980; SCS, 1983; SCS, 1986

Data from the soil series found in the proposed conservation areas and the areas immediately adjacent to them were compiled, including depth, clay percentage, permeability, available water capacity, pH, and salinity.

Among the 16 soil series identified for the proposed conservation areas and buffer zones, only the Gilman Series lists cottonwood and willow as species that naturally occur on that soil. Table 13 shows the native vegetation found for each soil series.

Table 13. Naturally Occurring Vegetation by Soil Series

Vegetation	Carrizo	Cibola	Gadsden	Gilman	Glenbar	Gunsight	Holtville	Indio	Kofa	Lagunita	Ripley	Vint
Desert Scrub	X	X	X	X	X	X	X	X	X	X	X	X
Mesquite				X	X		X			X		X
Arrowweed				X	X							
Salt Cedar				X			X					
Cottonwood-Willow				X								

Sources: SCS, 1980; SCS, 1983; SCS, 1986

The SCS soil factors evaluated for the purpose of this paper; clay percentage, permeability, available water capacity, pH, and salinity; varied from series to series. They also varied within each series, depending on the location of the soil series. For example, the ranges for the Gadsden Series variables in the Long Lake Conservation Area are different than the ranges for the same variables in the Limitrophe BLM Habitat Restoration Conservation Area (Appendix C).

As previously mentioned, the Gilman Series was the only one that listed naturally occurring cottonwood-willow. For the purpose of this study, factors from each series were compared to the Gilman Series by depth and given a score of 0 to 5 depending on how many of the five factors matched, i.e. 0 = no matching factors, 5 = all factors matched. The factors compared were clay percentage, permeability, available water capacity, pH, and salinity. When compared to the Gilman Series, the Agualt, Cibola, Gadsden, Glenbar, Gunsight, some Indio, some Kofa, some Lagunita, and Ripley Series had four and five factors that corresponded positively when compared to the same Gilman Series factors (Appendix C). Table 14 shows the soil series and locations with the most similarity to the Gilman Series. Table 15 shows the soil series and locations with the least similarity to the Gilman Series.

Table 14. Soil Series Most Likely to Support Cottonwood-Willow (as compared to Gilman Series)

Conservation Area	Gilman	Agualt	Carrizo	Chuch-awalla	Cibola	Gadsden	Glenbar	Gunsight	Holtville	Indio	Kofa	Lagunita	Ripley	Rositas	Superstition	Vint
Long Lake						PCA				PCA	BZ					
Ahakhav Tribal Preserve	BZ	PCA		BZ	BZ	BZ	BZ	BZ			BZ		BZ			BZ
Mohave and Deer Tail Backwaters	PCA	PCA			BZ		PCA									PCA
A7 Backwater													PCA			
Swendt Slough													PCA			
BLM Agricultural Leases w/in PVID												PCA	PCA			
Palo Verde Oxbow Enhancement													PCA			
Cibola Restoration Concept													PCA			
Limitrophe BLM Habitat Restoration											BZ		PCA			

PCA = Proposed Conservation Area
BZ = Buffer Zone

Sources: SCS, 1980; SCS, 1983; SCS, 1986

Table 15. Soil Series Least Likely to Support Cottonwood-Willow (as compared to Gilman Series)

Conservation Area	Gilman	Agualt	Carrizo	Chuchawalla	Cibola	Gadsden	Glenbar	Gunsight	Holtville	Indio	Kofa	Lagunita	Ripley	Rositas	Superstition	Vint
Long Lake									BZ		BZ		BZ	PCA		PCA
Ahakhav Tribal Preserve			BZ						BZ			PCA BZ				BZ
Mohave and Deer Tail Backwaters			BZ									PCA			BZ	PCA
A7 Backwater						PCA				PCA		PCA				
Swendt Slough										BZ		PCA				
BLM Agricultural Leases w/in PVID										PCA		PCA				
Palo Verde Oxbow Enhancement										PCA		PCA				
Cibola Restoration Concept									PCA	PCA		PCA				
Limitrophe BLM Habitat Restoration						PCA			BZ	BZ		BZ		BZ	BZ	

PCA = Proposed Conservation Area
BZ = Buffer Zone

Sources: SCS, 1980; SCS, 1983; SCS, 1986

VI. DISCUSSION

This section discusses (A) the suitability of the nine proposed conservation areas for restoration and (B) the limitations of the data.

(A) Suitability of Proposed Conservation Areas for Cottonwood-Willow Restoration

When considering these results, it must be kept in mind that this first look at the suitability of the proposed conservation areas for habitat restoration is an exercise in the gross winnowing of the data. With that disclaimer stated, this study found one proposed conservation area, the Swendt Slough Conservation Area, appears to be clearly suitable for cottonwood-willow restoration. Two of the areas, Ahakhav Tribal Preserve Conservation Area and Cibola Restoration Concept Conservation Area, do not appear to be suitable for cottonwood-willow restoration. The remaining areas had mixed results. The results are summarized in Table 16. All of the proposed conservation areas require further study.

Table 16. Summary of Edaphic Conditions by Proposed Conservation Area

Conservation Area	Depth to Groundwater	Soil Moisture	Salinity (EC)	pH	Soil Texture	Conditions Match
Long Lake	mixed	mixed	no	yes	no	**mixed**
Ahakhav Tribal Preserve	no	no	no	no	mixed	**no**
Mohave and Deer Tail BW	no	yes	mixed	yes	mixed	**mixed**
A7 Backwater	no	yes	no	yes	no	**mixed**
Swendt Slough	yes	yes	mixed	yes	yes	**yes**
BLM Ag Leases w/in PVID	no	mixed	mixed	yes	mixed	**mixed**
Palo Verde Oxbow Enhancement	no	mixed	mixed	yes	mixed	**mixed**
Cibola Restoration Concept	no	no	no	no	no	**no**
Limitrophe BLM Habitat Restoration	no	no	mixed	mixed	no	**mixed**

(1) Long Lake Conservation Area

This proposed conservation area had mixed results when edaphic conditions were compared. Further study is necessary to determine the area’s suitability.

(2) Ahakhav Tribal Preserve Conservation Area

This proposed conservation area does not appear to be suitable for restoration when edaphic conditions were compared. However, the lands found in the buffer zone contain the Gilman Series and several similar soil series and are well suited to restoration.

(3) Mohave and Deer Tail Backwaters Conservation Area

This proposed conservation area had mixed results when edaphic conditions were compared. It contains both the Gilman Series which is highly suitable for cottonwood-willow and the Vint Series, which is poorly suited for restoration. Further study is necessary to determine the area’s suitability.

(4) A7 Backwater Conservation Area

This proposed conservation area had mixed results when edaphic conditions were compared. Favorable and unfavorable soil series each comprise about half of the proposed conservation area. Further study is necessary to determine the area’s suitability.

(5) Swendt Slough Conservation Area

This proposed conservation area appeared to be suitable for restoration when edaphic conditions were compared.

(6) BLM Agricultural Leases within PVID Conservation Area

This proposed conservation area had mixed results when edaphic conditions were compared.

(7) Palo Verde Oxbow Enhancement Conservation Area

This proposed conservation area had mixed results when edaphic conditions were compared. Further study is necessary to determine the area’s suitability.

(8) Cibola Restoration Concept Conservation Area

This proposed conservation area does not appear to be suitable for restoration when edaphic conditions were compared.

(9) Limitrophe BLM Habitat Restoration Conservation Area

This proposed conservation area had mixed results when edaphic conditions were compared. Further study is necessary to determine the area’s suitability.

(B) Limitations of the Data

The original purpose of this study was to obtain some idea of the suitability of the proposed conservation areas for cottonwood-willow restoration. This information will then be used to prioritize in-depth on-site tests of edaphic conditions. Many edaphic factors contribute to the overall suitability of a site. Those outside of the scope of this study need to be considered in addition to the results found here. They include soil structure, including access, slope, and aspect; capillary fringe water holding capacity; seasonal groundwater fluctuations; porosity/percolation; and cation exchange capacity (CEC); seasonal water table and capillary fringe fluctuations; and fertilizers, herbicides, and pest control methods used in the normal course of crop production (Anderson, 1988; Pinkney, 1992; Shrader, 2000; Raulston, 2001).

There are other relevant factors to consider, as well. Federal and non-federal lands with existing habitat values need to be evaluated and ranked for acquisition or protection. The criteria would be based on their biological and physical attributes and how stable their habitat values are. Engineering feasibility, proximity to other habitat, water consumption, land ownership and associated water rights, and land costs all need to be considered (Shrader, 2000).

VII. CONCLUSION

This study is a snapshot of the progress made thus far on a project I am doing for the U.S. Bureau of Reclamation. Clearly, further study is warranted and is in process. As stated in the discussion, other edaphic conditions are being considered, and all of the crops grown along the LCR will be included in the final report. Additionally, on-site interviews with farmers and agricultural agents are planned in the next few months (Spring 2002). On-site tests are critical in the preparatory stages of the planned restoration.

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26 November 2001.

ACKNOWLEDGMENTS

Let me begin with a hearty *Thank You* to the many people who have freely shared their expertise and resources with me.

Special thanks to my advisors, Helen Neill and Tom Shrader, for all their guidance.

Thank you to Krys Stave, for teaching me about research, and Paul Richett, for teaching me about environmental law and compliance. The lessons learned in their classes are evident on every page of this thesis.

Thanks to Jim Deacon and Tom Burke, for the many doors they have opened for me.

Thanks to Jim Aaron, Lesley Argo, and Marguerite McClurg, for proofing the draft.

Finally, mere words cannot express my depth of gratitude for the unwavering support of my husband, son, and mom. I dedicate the completion of this thesis and my degree to you.