Creation of a Chihuahuan Desert Bi-National Wetland:

A Feasibility Assessment

Report prepared for the Chihuahuan Desert Program,
World Wildlife Fund

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Table of contents

Environmental Assessment of the Rio Grande/Rio Bravo

The Rio Grande is the fifth longest river in North America (Schmandt, 2002). It stretches southward 1,800 miles from southern Colorado to the Gulf of Mexico passing through 3 US states and 5 Mexican states, and delimits the international boundary from El Paso, TX to the Gulf of Mexico. The river is a very important natural resource for both the United States and Mexico in terms of industry, agriculture, domestic and public water supply, recreation, and wildlife habitat; however, along its journey, factors such as high salt content, sediment loads, inconsistent water flow and inputs of various other pollutants have made the Rio Grande unsafe for human and aquatic life.

The river's water is mostly supplied by the snowmelt of the San Juan Mountains of Colorado and the Sangre de Cristo Mountains of northern New Mexico. Historically, the floodplains of the river in central New Mexico used to stretch out 8 miles wide when flooding of the Rio Grande occurred during spring and early summer. This flooding would result in the shifting of the natural course of the river and damage to riverside farmlands and communities. There would also be periods as long as 3 months where no water would flow through the river. These occurrences would create boundary disputes between the U.S. and Mexico because of the constantly shifting river and its unreliability to supply water. In the 1900's, The Rio Grande Project called for the river to be dammed, straightened, and diverted so that there would be a more consistent supply of water for irrigation (King & Maitland 2003). During 1934 and 1938, in order to create and stabilize a border between the US and Mexico in the El Paso-Juarez region, the International Boundary and Water Commission (IBWC) completed the Rio Grande Rectification Project between El Paso and the mouth of Little Box Canyon below Fort Quitman, Texas. The rectification project was bounded by parallel levees throughout the El Paso-Cd. Juarez valley that ultimately reduced the length of the Rio Grande in the region from 155 miles to 88 miles (Reinhardt, 1937). Thus the floodplain was cut off from the rest of the river.

In 1907, Mearns described the river: *"Lines of cottonwood and willow mark the shifting course of the river… The river flats are occupied by dense patches of arrowwood, flanked by tornillo or screwbean and mesquite."* Springtime flood events were essential to maintaining these natural ecosystems of the Rio Grande. Cottonwood forests relied on floods to disperse their seeds in spring (Howe and Knoff, 1991). Native riparian vegetation such as screwbean mesquite, willows and cottonwood trees were once dominant in the area until stressors such as the introduction of invasive salt cedar *(Tamarix spp.*) and damming of the river resulted in largely altered communities.

The loss of native riparian forests and wetland has likely negatively impacted the biological communities in the Rio Grande. For example, Bailey (2001) reported that leaf litter produced by encroaching salt cedar (*Tamarix* spp.) in southwestern streams provides a poorer habitat for local macroinvertebrates and arthropods than that of the cottonwoods. The loss of seasonal flooding has also disrupted fish, mammals and birds communities (Stotz 2000). Changes in fish communities in the middle and lower Rio Grande have occurred due to decreased stream flows, the introduction of exotic species and sediment and chemical pollution (Edwards and Contreras-Balderas, 1991; Edwards, 2001; Cowley, 2006). Similarly, birds and mammals have undergone a severe decline due to human activity as well due the water flow reductions. Stotz (2000) suggested that invasion by exotic plants, loss of native wetland habitats, and human disruptions are some of the primary factors causing these declines.

According to Schmandt (2000), the human population in border communities has doubled every 20 years for the past 40 years. As a result of this increased population and industrialization, the water quality in the river has been impaired due to inadequate sewage treatment, industrial pollution and agricultural inputs. Currently, many communities on both sides of the border utilize only minimal sewage treatment, or no sewage treatment at all. In Cd. Juarez, Mexico only 75% of the municipality has access to wastewater facilities (Garza-Almanza, 2002) and these utilize only primary treatment. For example, the Juarez North Wastewater Treatment Plant in Cd. Juarez, which began operation in 2000, utilizes Advanced Primary Treatment (APT) as their main method for treating waste water (TDSHS, 2005). During APT, mechanical actions, such as screening, are used to separate floating solids from the wastewater, chemicals are added to aid in the settling of finer particles, and disinfection with chlorine occurs (TDSHS, 2005). This primary treated wastewater is then discharged into the Aquas Negras, an irrigation canal parallel to the Rio Grande, which drains into the Rio adjacent to Hudspeth County, TX, USA. Across the border, in El Paso, TX, more advanced secondary and tertiary treatment of wastewater occurs. Advanced treatments are used to remove nutrients like nitrogen or phosphorus, which were not removed during the primary treatments. Ozonization, ion exchange, carbon ascription, reverse osmosis, and electrodialysis are ways that tertiary treatments increase water quality and make safer drinking water (Sanchez-Marre, 1997).

In addition to discharges from wastewater treatment plants, there are also many unserviced colonias in the lower Rio Grande valley which may discharge untreated waste into local water ways. Owens and Niemeyer (2004) found extremely high levels of coliform bacteria, dissolved solids, heavy metals, as well as benzene, which is a known carcinogen, in wastewater canals near a colonia in Tamaulipas, Mexico. Similarly, industrial expansion along the border, including approximately 1,400 maquiladoras or foreign-owned factories, has lead to not only further population growth in the region, but also an increased release of some pollutants into the Rio Grande.

The Rio Grande watershed has been in a severe drought since 1993, exacerbating water quantity and quality problems. Because of the drought the Rio Grande has been experiencing, as well as surface water diversions for agriculture, water is scarce in the channel and cannot be used to dilute incoming pollutant loads from drains and canals and is not available for aquatic habitats during the months of October through March when the river is largely dry in El Paso County.

The Paso del Norte Region, which includes El Paso and Cd. Juarez, is located within the northern Chihuahuan Desert with an average rain fall of 8 inches per year. The area inhabits close to 3 million people. The combined population of Ciudad Juarez and El Paso reported in 2006 was about 2.2 million inhabitants (City of El Paso 2006). Available water is shared between many users and several jurisdictions found across several political boundaries. The population in the region is growing therefore water demand is increasing as well. For agricultural uses El Paso County Water Irrigation District (WID) #1 relies 100% on the Rio Grande, the Elephant Butte Irrigation District relies on the Rio Grande for 87% of its water, and the Distrito de Riego 009 in Juarez obtains 34% of its water from the Rio Grande. As a result of human activities, water is not only scarce but also polluted (Paso del Norte Water Task Force, 2001).

For management purposes, the Texas Commission on Environmental Quality (TCEQ) divides the Rio Grande into segments for which water quality standards must be met. Segments 2308 is downstream of the International Dam in El Paso County (TX), while 2307 is downstream of this segment and flows through Hudspeth County (TX) and the Forgotten Stretch of the Rio Grande. The Texas Surface Water Quality Standards are written by the TCEQ and are designed to sustain and protect aquatic life as well as human health by setting criteria that are able to support and protect desired uses. State water quality standards are dependent on the designated uses, or purpose, for which the body of water is suitable. Classifications for designated uses include public water supply, contact recreation, fish consumption and protection of aquatic life. Recreation can be divided into primary contact, which includes swimming and other activities that potentially involve total body immersion or incidental water exposure, and secondary contact, which includes boating, wading or fishing.

Segment 2307, the Rio Grande below Riverside diversion dam to the Rio Conchos, has a length of 222 miles and is designated for contact recreation use, high aquatic life and public water supply. Segment 2308, which covers 15 miles in El Paso from the International dam to Riverside dam, is designated for a non-contact recreation and for low aquatic life use. Because they have different designated uses, they have different water quality criteria that must be met (e.g. Table 1 and 4).

Table 1: *Selected water quality criteria for the Segment 2307 (Rio Grande from Riverside diversion dam to Rio Conchos) and Segment 2308 (Rio Grande below International dam to Riverside diversion)). (From IBWC, 2004)*

Criteria	Segment 2307	Segment 2308
TDS (mg/L)	1500	1400
Cl (mg/L)	300	250
Fecal coliforms (CFU/100mL)	200	2000
DO (mg/L)	5	3

Both segments exceed many of the protective standards established for salts, nutrients, heavy metals and the presence of fecal coliforms. Salinity can cause the water to become unusable for agriculture, affects aquatic life and increases the costs of water treatment for drinking purposes. Segment 2307 exceeded criteria for both chloride and total dissolved solids with concentrations of 630 mg/L for chloride and 2,082 mg/L for TDS (IBWC, 2004). On average, both segments exceed the standards for bacteria in the water with concentrations of fecal coliforms ranging from 0 to $3x10^6$ CFU per 100mL for segment 2307 and 0 to $3.7x10^5$ CFU per 100mL for segments 2308 (Mendoza et al. 2004). Mendoza et al. (2004) also observed *Helicobacter pylori* contamination at all sites. They suggest that inadequate sewage treatment and the use of wastewater to irrigate agricultural fields in Mexico are likely main sources for fecal contamination.

The International Boundary Water Commission (IBWC) and the United States Geological Survey (USGS) have identified a number of chemicals such as arsenic, chromium, copper, nickel, lead and zinc as exceeding state and/or federal standards (Rios-Arana et al, 2003) in the El Paso region (Table 2 and 3). Most of the metals are present as a result from local industry, maquiladoras, agricultural runoff, as well as storm runoff. In a study done by Mora et al. (2001), examining fish toxicity around the US-

Mexico border region, arsenic and lead concentrations were accumulated from waste discharge from historic hospitals. High levels of lead concentrations were attributed to local industry as well as automobile exhaust and an increase in traffic in the sampled area. Humans were impacted by the increase in contaminant when fish meat was ingested. However, human health issues have also resulted from eating crops that were irrigated with contaminated water (Alam, 2003). Heavy metal contamination is known to cause skin damage, gastrointestinal distress, liver and kidney damages which may later become carcinogenic.

Table 2: *Heavy Metal Concentrations found in Sediments from the Rio Grande (TCEQ).*

	Threshold Effects (TEL) mg/kg	**Concentration (mg/kg)**
Arsenic	5.9	4.2
Copper	35.7	45.3
Cadmium	0.596	0.73
Chromium	37.3	12.9
Lead	35	28.6
Zinc	123.1	55

Table 3: *Heavy Metal Concentration found in Water from the Rio Grande (TCEQ).*

	Screening Level (State 85th Percentile)	**Concentration µg/L**
Arsenic	5	4 – 22
Cadmium	2	
Chromium	2.5	
Copper	5	10
Lead	5	3 – 7
Zinc	20	20 -110

The TCEQ reported in 2002 a nutrient enrichment concern for both segments 2307 and 2308. According to a TNRCC and IBWC report using data from 1998, Segment 2308 exceeds criteria for ammonia and orthophosphorus, while Segment 2307 only just meets the screening levels for total phosphorus (Table 4). Elevated nutrient concentrations, or eutrophication, may stimulate excessive algae growth which reduces aesthetics, can reduce dissolved oxygen levels upon decomposition and can also create shade which prevents sunlight from penetrating the water. This can have cascading impacts on fish and other organisms that are deprived of oxygen and sunlight.

Table 4: *Screening levels (TNRCC 2002) and nutrient concentrations from 1998 in Segment 2307 (Rio Grande from Riverside diversion dam to Rio Conchos) and Segment 2308 (Rio Grande below International dam to Riverside diversion).*

	Screening Level (mg/L)	Segment 2307 (mg/L)	Segment 2308 (mg/L)
Ammonia	0.17	<0.05	0.94
Nitrate + Nitrite	2.76	1.64	2.1
Orthophosphorus	0.5	0.23	0.5

Total Phosphorus	0.8	0.8	0.52

With this data it is clear that wildlife habitat and water quality in the Rio Grande are degraded by reduced water quality and quantity. Since this region depends on the Rio Grande for various uses, a solution must be implemented. It has been suggested that the loss of valuable habitat and water filtration abilities along the Rio Grande in El Paso and Hudspeth counties could potentially be ameliorated by the creation of a wetland. Wetlands offer a variety of ecosystem services such as flood abatement, improving water quality, and providing habitat for a wide variety of organisms, thereby increasing biodiversity. Focusing on water quality, a functioning wetland provides much of the tertiary treatment needed to reduce the level of pollutants traveling to a receiving body. Wetlands have a high capacity to improve water quality and this evidence has resulted in many initiatives to restore or even create wetlands for water quality and wildlife habitat purposes in the region.

Regional Wetlands

Regionally, wetlands are rare but valuable habitats. Historically the Trans-Pecos region consisted of natural wetlands and springs that were used on routes that were frequented by nomadic tribes as well as traders and travelers.

Holloman Lake Wetlands used to be simply a sewage lagoon on the Holloman Air Force Base in Alamogordo, NM. Today, a dike between Lake Holloman and the sewage lagoon is filled with treated wastewater from the base water treatment water plant and has resulted in constructed wetland habitat. Holloman Wetland serves as a sanctuary for birds during winter and migration months (National Audubon Society 2004) and has received a number of awards and other recognitions for the protection of the area (Cram 2001).

Balmorhea State Park, TX is home to San Solomon Springs, which used to feed a large cienega, or desert marsh, that attracted humans for thousands of year. The damming of the spring and creation of a swimming hole destroyed the cienega; however, in 1997, a 3-acre cienega was re-created in the park where wetland plants and birds are now thriving (Patoski, 2005).

Bosque del Apache, located in San Antonio, New Mexico; consists of 7,000 acres of floodplain waters that has been diverted from the Rio Grande to create a wetland managed by the US Fish and Wildlife Service. This wetland is unique in that vegetation growth of various kinds is promoted on the land is designated especially for the wildlife in the refuge. The wetland is home to nearly 32,000 Snow Geese and 14,000 Sandhill Cranes during the winter months (FOBDA 2007).

Cuatro Cienegas is desert ecosystem that is able to support aquatic life and diversity with its naturally occurring springs and wetlands. The park is located in Coahuila, Mexico, in the middle of the Chihuahuan Desert. The different ecosystems, wetlands, desert gardens, and sand dunes in the park help to support at least 77 of plant and animal species' that are found nowhere else on Earth (Natural Conservancy 2007). Local pools and other habitats are top priority of protection in the park; however, irrigation, habitat destruction, and introduction of invasive species are some of the threats to local flora and fauna (Natural Conservancy 2007).

In the El Paso areas, we are fortunate to have two desert wetlands: The Rio Bosque and Keystone. Keystone Heritage Wetland park is a 52 acre park in El Paso's

Upper Valley. The spring-fed wetland is home to over 193 species of birds, including 22 species of rare birds. The wetland is also site to an archaic archaeological site, dating to over 4000 years old. The park is under currently under construction to re-create wetland habitats that were present in the historic Rio Grande floodplain (Keystone Heritage Park 2008).

Rio Bosque Wetlands Park, located in the lower valley of El Paso, TX, is a 372 acre park that receives treated wastewater from the Bustamante Wastewater Treatment Plant. Before the channelization of the Rio Grande, the park lay in the riparian zone of the Rio Grande. Today the park receives water from late October to mid February, but remains largely dry during the summer agricultural irrigation season. Thus, the development of wetland plant communities and wetland functions has been severely limited (Sherrill, 2007). Despite these limitations, the Rio Bosque provides valuable habitat for local birds as well as reptiles and small mammals (Watts et al. 2002). An extensive management plan for the restoration of the Rio Bosque has been developed by Watts et al. (2002). In particular, it provides a list of wetland plant species which may be suitable for wetland creation in the Paso del Norte. A small subset of this list is included in Table 5.

***Table 5**. Selected recommended plant species for revegetation of bank and wetland areas at the Rio Bosque Wetlands Park (for complete list see Watts et al. 2002).*

	Species
Forbs	*Typha domingensis* (Cattail)
Forbs	*Polygonum lapathifolium* (Curltop smartweed)
Forbs	*Suaeda sufrutescens* (Seepweed)
Forbs	*Rumex hymenosephalus* (Dock)
Forbs	*Heliotropium curassavicum* (Salt heliotrope)
Forbs	*Sesuvium verrucosum* (Salt purslane)
Shrubs	*Lycium torreyi* (Wolfberry)
Shrubs	*Salix exigua* (Coyote Willow)
Shrubs	*Tessaria sericea* (Arroweed)
Shrubs	*Baccharis salicifolia* (Seepwillow)
Trees	*Populus deltoids* (Rio Grande Cottonwood)
Trees	*Salix gooddingii* (Godding Willow)

Management Options: Are wetlands the solution?

Can a wetland successfully reduce excess amounts of nutrients, bacteria, and metals, while still being an economically feasible option for the region? Wetlands have been proven to be “natural” water treatment plants and are considered of great value to their ecosystems. But how exactly is it that wetlands “clean” water?

<u>Nutrient Reduction/Uptake</u>

Various studies have found that wetlands reduce nitrogen levels mainly by the process of *denitrification* and phosphorus by the process of *sedimentation*. Denitrification is the process in which bacteria convert nitrates into atmospheric nitrogen under anoxic wetland conditions; wetland denitrification is one of the primary ways in which nitrogen is returned to the atmosphere (Mitsch and Gosselink, 2007). Sedimentation, on the other hand, is a process in which suspended particles settle out of the water column due to reduced rate of flow and gravity. Because phosphorus attached readily to organic matter and inorganic sediments, phosphorus also tends to be reduced by sedimentation. Through this process, phosphorus retention is one of the most important attributes of wetlands (Mitsch and Gosselink, 2007). In addition to these two processes, excess nutrients are also taken up by plants and soil microbes. Mitsch et al. (2005) found that in their created wetlands in Ohio, nitrate concentrations were reduced by 35% on average after flowing through the wetland cells, while orthophosphorus declined by 70%. However, they found no effect of the wetland on total phosphorus, which seemed to be exported from the wetlands attached to suspended sediments.

The role of plants in the reduction of nutrients is critical and has been recorded in several studies. The maximum potential rate of removal by plants has been shown to be 1000 to 3000 kg N/ha/yr and 60 to 100 kg P/ha/yr (Verhoven et al, 2006) depending on several factors such as plant species, nutrient load amounts, and soil type . It is important to differentiate between various plant species because some are more efficient at up taking and retaining nutrients than others. For instance, when compared to other four species, bur reed was found to be the most efficient plant species for nitrate uptake and retention. On the other hand, soft rush was found to be the most efficient species for phosphorus uptake and retention (Table 6; Kao et al, 2003). Therefore, vegetation selection is of utmost importance to the success of a wetland.

In the Chihuahuan Desert, an appropriate option may be an emergent aquatic wetland because it can withstand dry periods and many emergent aquatic plants are native to our region. Some examples of emergent wetland plants native to our region include are listed on Table 5. The plants listed are also able to withstand high salinity levels, which is suitable for the sediment in the arid environment.

Table 6. *Plant efficiency of nitrogen (N) and phosphorus (P) retention (Kao et al, 2003).*

Rank	Species	N retention (g N m^{-2})	Species	P retention (g P m^{-2})
1	*S. americanum* (bur reed)	9.7	*J. effuses* (soft rush)	1.3
2	*J. effuses* (soft rush)	9.3	*S. americanum* (bur reed)	0.9
3	*S. cyperinus* (wool grass)	4.1	*C. Canadensis* (blue joint grass)	0.49
4	*C. canadensis* (blue joint grass)	4.7	*S. cyperinus* (wool grass)	0.46
5	*P. arundinacea* (reed canary grass)	3.3	*P. arundinacea* (reed canary grass)	0.2

There are other factors that influence the rate of nutrient uptake by wetlands. These factors include soil type, conditions promoting denitrification (i.e. sufficient amounts of available organic carbon), water depth, surface area, shoreline complexity, and pollutant loadings (Klapproth et al, 2000). For instance, one study showed that while nitrate was efficiently absorbed in shallow waters, phosphorus was more readily absorbed in deep waters (Hansson et al, 2005). In terms of a wetland's surface area, several studies have arrived to the conclusion that the correct size of a wetland with the purpose of improving water quality and providing flood control has to be anywhere from 2% to 7% of the catchments' size (Table 7; Verhoeven et al. 2006, Mistch & Gosselink 2000).

Table 7. *Different size wetlands and their efficiency in removing nutrients (Verhoven et al, 2006).*

CATCHMENT	**CATCHMENT SIZE (km^2)**	**REMOVAL BY WETLANDS (%)**	**WETLAND AREA (% OF TOTAL)**
1	882	43	5
2	224	6	0.4
3	1900	7	0.6

<u>Bacterial removal in wetlands.</u>

Bacteria can enter the Rio Grande via improperly treated wastewater, leaky septic systems, landfills, use of wastewater or manure to fertilize crops and domestic animals (Kelly 2001). Numerous biological, physical and chemical parameters are involved in the retention and removal of bacteria in wastewater treatment systems, including temperature, pH, moisture content, organic matter levels and bacterial species (Stevik et al., 2004).

Quinonez-Diaz et al. (2001) observed a reduction in levels of fecal coliforms, *Giardia* cysts and enteric viruses as water flowed through created wetlands. They suggest that sedimentation of microorganisms and cysts adsorbed to sediment are likely primary mechanism whereby microbes are removed in created wetlands. In a survey of 60 constructed wetlands with emergent vegetation around the world, Vymazal (2005) summarized the importance of using plants in order to reduce bacterial levels in wetlands. As water flow through both planted and unplanted systems, the amount of bacteria in the water column declined (Figure 2). These constructed wetlands were efficient at removing different kind of bacteria such as fecal coliform, fecal streptococci, total coliforms, and *Clostridium perfringis* from the water column with 65-99% efficiency. Hydraulic loading rate and hydraulic residence time were 2 of the primary factors affecting wetland bacterial removal efficiency.

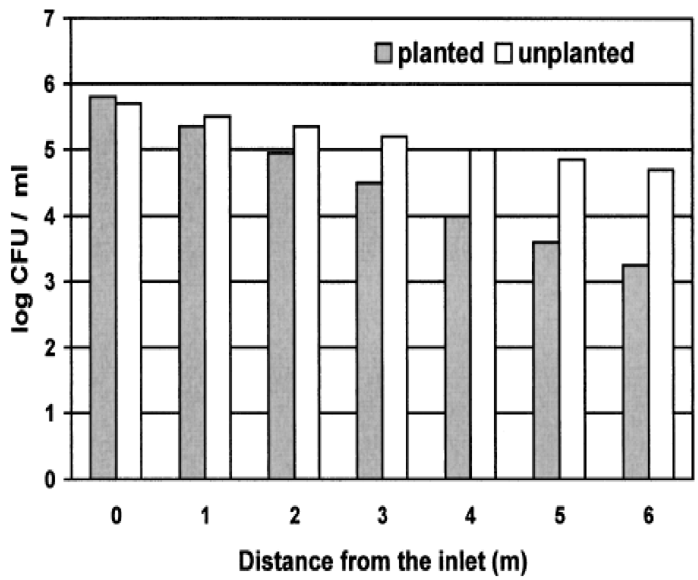

Figure 2. *Relationship between E. coli numbers and the distance from the inlet of a planted and unplanted constructed wetland. (Vymazal 2005).*

Table 7. *Bacterial removal efficiency of free water surface wetlands (Vymazal et al., 1998).*

Bacteria	Inflow (CFU/100mL)	Outflow (CFU/100mL)	Removal (%)
Fecal coliform	4.77 x 106	4.29 x 104	85.6
Fecal streptococci	3.31 x 104	1.44 x 103	84
Total coliforms	8.13 x 105	2.96 x 1065	65.1
Clostridium perfringins	5118	12	99.0

Heavy metal removal by plants

In the Rio Grande near El Paso, there has been unsafe levels of arsenic (As), copper (Cu), cadmium (Cd), chromium (Cr), lead (Pb), and zinc (Zn) in the water and the sediment (Rios-Arana 2003). Heavy metals can be removed from the water by wetlands through various mechanisms which include sedimentation, adsorption, precipitation, anion and cation exchange, and uptake by plants and micro-organisms.

A study by Yang et al. (2006) to test the long term efficiency and stability of a wetland used for treating wastewater of a Pb/Zn mine in the South of China showed that wetlands are capable of removing heavy metals from the water. They found that the accumulation of the metals was greatest at the surface of the sediment and increased towards the outlet of the wetland (Figure 3). The wetland as a whole, including plant and sediment uptake, was able to reduce the concentration of Pb by 99.04%, of Zn by 97.3%, and of Cd by 94.0%; it also reduced the pH from 8.23 to 7.67 and the suspended solids by 98.95%. Similarly, Ye et al. (2003) found that, in a microcosm experiment, the concentrations of As were reduced by 67%, while Selenium (Se) and Boron (B) were reduced by 79% and 57% respectively. This study also showed that these metals concentrated in the sediment, with 63% of the Se, 51% of As, and 36% of B, while only 2-4% accumulated in the plants. When looking at the distribution of the metals in the plant tissue, Yang et al. (2006) found that most of the accumulation was belowground, in the rhizomes and roots. This was also true for a study by Weiss et al. (2006), and one by Windham et al. (2003), where they both found that metals accumulate in the roots and rhizomes more than they do in the leaves, stems, or shoots (Figure 4). While uptake of contaminants is a beneficial function of wetland plants, it is possible that these plant tissues could be ingested by birds, small mammals, or other herbivores and thus the metals would bioaccumulate up the food chain. This is an important concern that must be taken into consideration when building and managing a wetland.

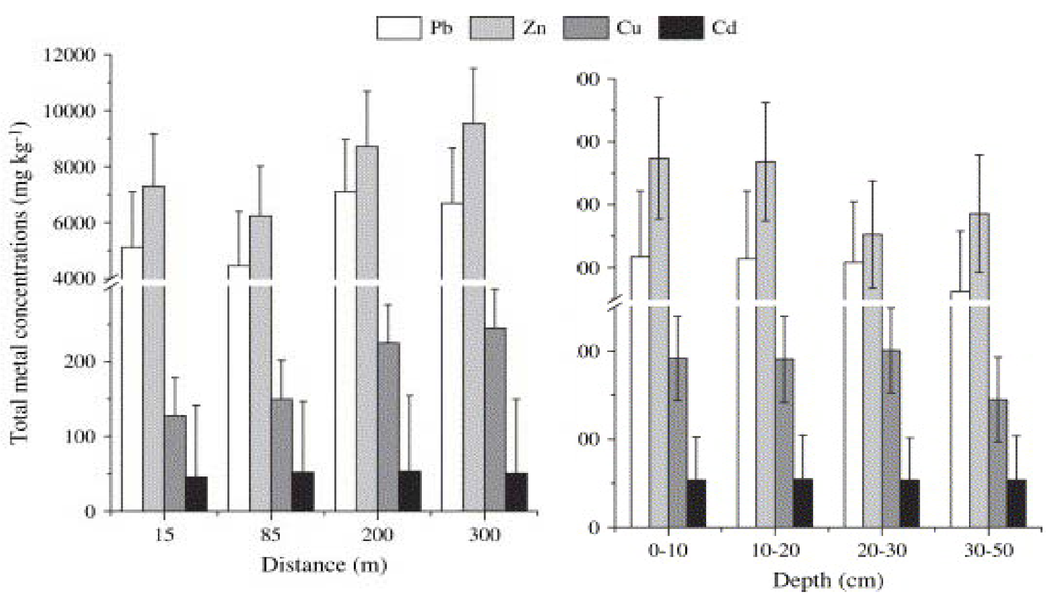

***Figure 3.** Accumulation of concentrations by plants at various distances and depths. (Weiss et al. 2006).*

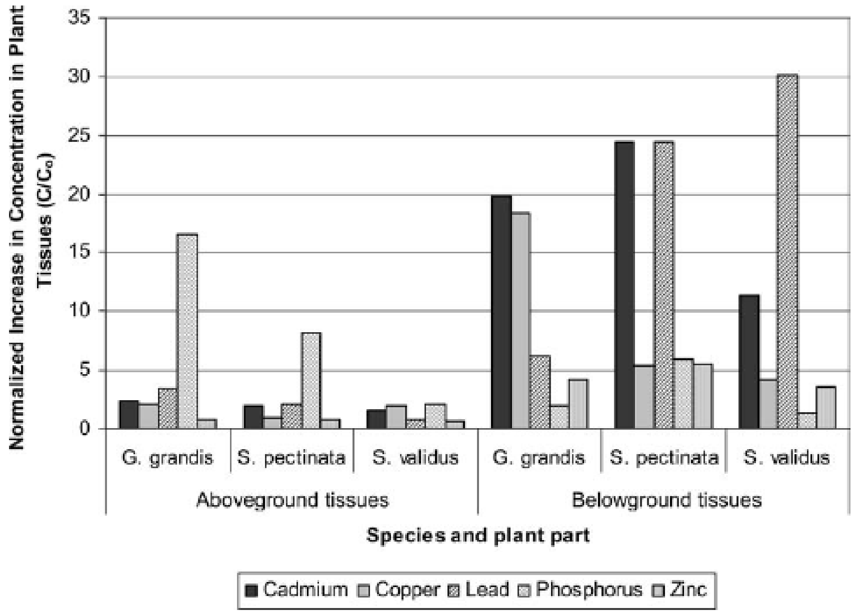

Figure 4. *Bioaccumulation of concentration in plants above and below ground. (Weiss et al. 2006).*

Created Wetlands Case Studies

Case Study: New River Wetlands Project

The New River originates in Mexico and flows into the United States through California, near the Mexicali-Calexico border, and ends at the Salton Sea. The river gets both sewage and agricultural input from both sides of the border, which increases the levels of nutrients, heavy metals, pesticides, and bacteria in the water. In order to see if a wetland could enhance the quality of the water, two pilot wetlands were built and monitored for three years.

After the three years, data from both sites indicated that after water flowed through the pilot wetlands, the percentage of dissolved oxygen increased, while total nitrogen (TN), total phosphorus (TP), selenium (Se), and the concentration of fecal coliform bacteria decreased in both wetlands (Table 8). Aside from the obvious improvement of the water quality, the wetlands also provided a habitat for plants, fish, wildlife and migrating waterfowl, and provided recreational benefits. Due to these large improvements in water quality, a large scale wetland was approved and began construction in November 2006.

Table 8. *Changes in selected water chemistry variables at the inlet and outlet of 2 sites at the New River wetlands. Site 1 is on the left, site 2 on the right.*

	INLET	OUTLET	Change
DO	7.92	10.95	+28%
TN	5.8	3.5	-40%
TP	1.95	0.57	-71%
Se	0.007	0.005	-29%
Fecal Coliform	1998	76	-96%

	INLET	OUTLET	Change
DO	3.67	10.83	+66%
TN	0.9	0.9	0
TP	1.59	0.73	-54%
Se	0.011	0.008	-27%
Fecal Coliform	151664	274	-99%

(New River 2001)

Case Study: Oletangy Research Park

Mitsch et al. (2005) looked at the efficiency of two 1-ha experimental wetlands at The Oletangy River Wetland Research Park in Ohio over a 10 year period. The two wetlands differed in that wetland 1 was planted with over 2400 plant propagules of 13 different species, and wetland 2 remained unplanted to see the differences between a wetland with natural colonization and a planted wetland.

Both wetlands received the same amount and quality of water, for the same periods of time. In 2003, there was a flood pulsing study where artificial floods were introduced to both wetlands. During this study, they found that both nitrate (NO_3) and total phosphorus levels declined as water flowed through the wetland cells (Table 9; Mitsch et al. 2005). Aside from looking at the difference between a wetland with natural colonization and a planted wetland, they were looking at the time it takes for wetland functions to develop and the ability of the wetland to improve water quality.

After the 10 year period, Mitsch et al. (2005) came to the following conclusions: created wetlands can develop into healthy ecosystems quite fast if they have the proper hydrologic conditions and plant propagules are continually introduced. They also found that planting does have an effect on the functioning of created wetlands since differences in plant composition and productivity led to differences in water quality and carbon accumulation in the wetlands. With regards to the soil, they found that hydric soils can develop in 2-3 years after the creation of a wetland. They also saw that sometimes changes in water quality are due directly to plant cover, but other changes can occur over longer periods of time due to sediment accumulation, and soil and redox changes. Looking at water quality, they concluded that wetlands can be effective sinks for nutrients for many years if they are managed correctly and not overloaded; higher biodiversity can actually lead to lower productivity of plants and changes in the food web and water quality; and finally, floods have significant influences on water and gaseous fluxes from wetlands.

Table 9. *Concentrations and percent change of selected variables at the inflow and outflow of Oletangy Park experimental wetlands during flood pulsing experiments in 2003 (Mitsch et al. 2005).*

	Pulse Flood				**Non-pulse flood**		
	Inflow	**Outflow**	**% Change**		**Inflow**	**Outflow**	**% Change**
NO_3 (mg/L)	4.17	2.88	-31		4.48	2.01	-55
TP (µg/L)	54	47	-13		103	44	-57

Case Study: Rio Bosque Wetland Park

Currently we are using the Rio Bosque Wetlands Park as a local case study of a created desert wetland and its role in reducing nutrient levels. Water chemistry data has been collected from 2005 until 2007 from the Rio Bosque Wetlands Park. With this information we can analyze nutrient level inter- and intra-annually.

The park is 372 acres and is enclosed by irrigation canals and drains on three sides. Treated wastewater is delivered to the wetland cells of the Rio Bosque from the Roberto Bustamante Wastewater Treatment Plant during the months of October to February, when it is not being used for irrigated agriculture. Water entering the park at the inflow is delivered through water delivery gates 2, 3 and 4 into wetlands Cells 1 and 2. Water exits Cell 2 at Gate 6, whereas water from Cell 1 evaporates over time.

Results indicate that the effect of the wetland cells on water quality varies from year to year. During the 2005-06 season there was a decrease in total phosphorus and ammonia, while the amount of nitrate increased from the inflow to the outflow of the wetland (Table 10). In 2006-07, we observed an increase in phosphorus, but decreases in both nitrate and ammonia (Table 11). We are currently completing studies to determine why this wetland varies in nutrient removal efficiency. It is likely that internal loading of nutrients is occurring from the sediments. In addition, uptake of nutrients by algae, which are the only primary producers present in the wetlands during the winter likely varies as a function of climate and water clarity. A wetland with aquatic plants and water present during the growing season is more likely to be an effective sink of nutrients from the water column.

The University of Texas at El Paso (UTEP) and its partners are working to guide and shape the recovery of the wetland park to promote native river-valley plant communities (Watts et al. 2002). Understanding the ability of a desert wetland to remove nutrient from the water column through uptake by primary producers or sediment transformations is key to justifying the protection and creation of other similar wetland sites.

Table 10. *Concentrations and percent change of selected variables at the inflow and outflow of the Rio Bosque Wetland Park for the 2005-06 season.*

	Inlet	Outlet	%change
TP (µg/L)	5531	3500	-37
NO_3 (µg/L)	2806	5745	+51
NH_3 (µg/L)	4844	1395	-71
DO	71%	79%	+10

Table 11*. Rio Concentrations and percent change of selected variables at the inflow and outflow of the Rio Bosque Wetland Park for the 2006-07 season.*

	Inlet	Outlet	% change
TP (µg/L)	4047	5261	+23
NO_3 (µg/L)	5454	3964	-28
NH_3 (µg/L)	9469	6048	-36
DO	88%	107%	+18

Policies and Laws to Help Protect and Restore the Rio Grande

In order to build a wetland, several laws and regulations regarding water quality, water management, water rights and land acquisition must be taken into consideration. Some of these regulations and programs were as follows: the Clean Water Act (CWA), Rivers and Harbors Act of 1899, and the Endangered Species, Mitigation Banking, Wetlands Reserve Program, Conservation Innovation Grants (CIG), Farm Bill of 2002 Wetlands Reserve Program, the Texas Wetlands Reserve Program and North American Wetlands Conservation Act of 1989. Because there is the intent to make this a bi-national project, the Border Environmental Cooperation Commission (BECC) and the North American Development Bank (NADB) will also be considered.

<u>Chemical, physical and biological integrity of US Waters</u>

The primary federal law regarding water quality is the Clean Water Act which is a 1977 amendment to the Federal Water Pollution Control Act of 1972. This act regulates all waters of the US, their tributaries and any wetlands adjacent to them. The objective of this act is the restoration and maintenance of the chemical, physical and biological integrity of and waters of the US.

There are several sections of the CWA which pertain to wetland creation:

Section 101 states that the goal of the CWA is to maintain the physical, chemical and biological integrity of the Nation's waters by reducing the discharge of pollutants, constructing publicly owned waste treatment works, and undertaking research to develop programs and technologies to reduced point and non-point source pollutant recharge.

Title III describes standards and enforcements. In particular, section 319 deals with non-point source pollution management program. This section requires states to identify non-point source pollutants and develop management strategies to address these problems.

Title IV deals with permits and licenses; section 401 deals with water quality. Each state must certify compliance of federal permits of licenses with state water quality requirements and other applicable laws. In Texas the agency which sets state water quality standards is the Texas Commission on Environmental Quality (TCEQ)

Section 404 establishes programs for permitting the discharge of dredged or fill material into the Nation's waters. In this section the USACOE must evaluate potential impacts of discharge on physical and chemical characteristics of the aquatic ecosystem as well as special or critical characteristics of disposal following factors such as living communities, human uses or threatened and endangered species.

An act that indirectly deals with water quality is section 10 of the Rivers and Harbors Act of 1899 that states that the navigability of the waters of the US cannot be obstructed. For example, if the wetland were to be built in a navigable waterway then a weir could not be used nor a dam be built to pool water.

The legal precedent for applying the CWA to wetlands is seen through the following court cases: United States v. Riverside Bayview Homes, 474 U.S. 121(1985), United States v. Byrd, 609 F.2d 1204 (7th Cir. 1979), Avoyelles Sportsmen's League v. Marsh, 715 F.2d 897 (5th Cir. 1983) and United States v. Leslie Salt [1990 Decision]. However, there are situations in which the CWA does not apply to wetlands. For example, the CWA does not apply to wetlands that are designed solely to treat waste water, nor does it apply to isolated wetlands.

The CWA states that we must protect the physical, chemical, and biological integrity of the Nation's waters. Therefore, not only must water quality be taken into consideration but biological life in the area must also be protected. The Endangered Species Act states that all federal agencies must develop and complete programs to conserve threatened and endangered species. The objective of the act is to ensure that the actions of government, corporations or individuals do not jeopardize the existence of any listed species or negatively modify a critical habitat.

For instance, the Rio Grande silvery minnow once inhabited most of the Rio Grande, but today occurs only in the middle Rio Grande upstream of Elephant Butte Reservoir, New Mexico **(**USFW, 2006). Modification of the riparian habitat and river channel, as well as decreased flows, contributed to the eradication of this species. The silvery minnow has been replaced by the plains minnow, because of its ability to adjust and thrive in a modified habitat (Cowley 2006). However, with water quality improvements and habitat management plans, endangered species such as the Silvery Minnow may return. In 2007, the USFW proposed re-introducing the silvery minnow downstream of Little Box Canyon, which is downstream of the Rio Grande Project, near Big Bend National Park; improvements in water quality may help any potential re-establishment of this endangered species.

<u>Management of water across borders</u>

The Paso del Norte region along the United States-Mexico border and near the Texas-New Mexico border incorporates three levels of water management at the interstate, international and national levels. Many of these are concerned with how much water is delivered to whom and when.

At the interstate level, between New Mexico and Texas, water management is regulated by the Pecos River Compact and the 1938 Rio Grande Compact. The Pecos Compact states that New Mexico must not completely deplete the flow of the Pecos River before it reaches the Texas border. The 1938 Rio Grande Compact was signed by Colorado, New Mexico and Texas, and requires that Colorado delivers water to New Mexico based on annual runoff rates. The compact provides schedules of deliveries and in some circumstances regulates storage (The Rio Grande Compact, 1938).

Water management at the international level is regulated by several treaties, compacts, and agreements which have been made between the US and Mexico. After years of drought in the El Paso-Cd. Juarez region, Mexico claimed their right to water of the Rio Grande. At the Rio Grande Convention in 1906 it was agreed that the US shall give Mexico a total of 60,000 acre feet of water per year according to the schedule in Table1, with the majority of water received during the irrigation season (March-October). There are allowances in the Rio Grande Convention to reduce the amount delivered in the case of extreme drought.

Table 10. *Summary of the amount of water Mexico receives each month*

	Acre feet per month
January	0
February	1,090
March	5,460
April	12,000
May	12,000
June	12,000
July	8,180
August	4,370
September	3,270
October	1,090
November	540
December	0
	60,000 Acre Feet

(*Rio Grande Convention, 1906)*

The Water Treaty of 1944 was written in order divide the water flowing from Ft. Quitman to the Gulf of Mexico between Mexico and the United States. Under this treaty, Mexico and the US are allotted a certain proportion of the water flowing into the Rio Grande on either side of the border. For example, the US is allotted all the water from the Pecos, while the US and Mexico must split the amount flowing in from the Rio Conchos in a one-third: two-thirds split.

The La Paz Agreement signed in 1983 establishes joint cooperation for the protection and improvement of the environment along the border. Article 5 of the agreement states that the parties shall coordinate their efforts to address environmental problems in conformity with their national legislation as well as with any bi-national agreements in place. According to Article 6 of the same agreement, addressing environmental issues can be achieved through such means as environmental monitoring and impact assessment. Under Article 8 each party must have a national coordinator that should be aware of all projects and in the case of the US it is the US Environmental Protection Agency and for Mexico it is the Secretaría de Desarrollo Urbano y Ecología, through the Subsecretaría de Ecología. (La Paz Agreement, 1983)

The Border XXII Program is another program designed to promote environmental restoration and protection along the US-Mexico border. The mission statement of the Border Program is that restoration should be obtained through sustainable development. The Border Program defines “sustainable development,” as a development that is both socially and economically conservation based, that emphasizes the protection and sustainable use of resources. The Program also stresses the need to address both current and future impacts of human actions, to foster public participation, to achieve concrete results while still maintaining a long term vision (Border 2012 Program, 2002).

Water Rights

At the national level in the United States water management is regulated by state law whereas, in Mexico, it is regulated by federal laws. In Mexico, water is delivered based on water availability and during times of shortage all users have their allocations reduced. In the United States, water is allocated on a seniority based system, where senior appropriators are given priority.

Currently, in the United States, most surface water bodies are fully appropriated. Meaning that the water is already accounted for by owners, any new needs must be met by transferring water rights among users. There are several means of obtaining water. These means include: purchasing, leasing, donation, passive use of water restoration and improvement of farm efficiency. Purchasing of land with water rights is the most straightforward option, while leasing of water rights from land owners is a second option. Passive use of water for restoration is the use of water without affecting quantity, timing or quality available to farmers. For example, restoration of habitat within existing agricultural drains could meet water quality improvement and habitat goals without further depleting the system. However, the likelihood of drought impacting water delivery in drains may necessitate having some water rights that could be utilized as needed (King & Maitland, 2003). The improvement of farm efficiency is a method of obtaining water by encouraging farmers to use more efficient irrigation practices and any water conserved could then be used for other uses, such as environmental uses. For example, in Hudspeth County, conversion to drip irrigation may reduce water use and allow for management of soil salinity (King & Maitland, 2003). In some areas environmental pools have been created and consist of water, land or money that can be used for environmental restoration. One such pool exists in Las Cruces, NM where the parking lot of the downtown K-mart was designated water rights but since the water was not needed it was placed in a conservation pool (King & Maitland, 2003). Unfortunately, there is no legal framework in place to easily allow the water rights owner to transfer their water to environmental uses. King and Maitland (2003) identify this as a primary barrier preventing aquatic and riparian habitat restoration in the region.

Wetland Creation and Land Acquisition Programs

Mitigation Banking

The *Federal Guidance on the Establishment, Use and Operation of Mitigation Banks* (*1995 Banking Guidance*) (EPA, 2006) is used to provide direction for the implementation of mitigation banks to provide compensatory mitigation for adverse impacts to wetlands and other aquatic resources that are authorized under Section 404 of the CWA and Section 10 of the Rivers and Harbors Act of 1899 (Zirschky et al., 2006). Compensatory mitigation is the restoration, creation, or replacement, of aquatic habitats, such as wetlands, to compensate for the unavoidable loss or damage of these habitats during development. For example, the Rio Bosque Wetlands in southeast El Paso, TX were constructed as mitigation for impacts from irrigation canal construction and maintenance along the Rio Grande (Watts et al. 2002). A wetlands mitigation bank is a wetland area that has been restored or created and set aside to compensate for future wetland losses. Mitigation banks are usually “third-party” compensatory mitigation, due to the fact that responsibility for design, construction, monitoring, and ecological success of the mitigation site rests on a party other than the permittee (EPA, 2006). The value of the mitigation bank, and the value of the impacted wetland, are expressed by credits that quantify the wetland functions created or lost, respectively. These credits can be purchased by developers in place of compensatory mitigation. A mitigation bank will identify the number of credits that are available for sale, and perform ecological assessments to ensure that those credits provide the necessary ecological functions (EPA, 2006).

Mitigation banking may be key to the creation of wetlands in the region. In 2001 the population along the border regions of Mexico and United States was estimated at 7.0 million, and is estimated to increase to about 13.8 million by the year 2025 (Lopez, 2006). With the expansion of the El Paso urban area, including more border crossings, wastewater treatment plants and other constructions along the Rio Grande, there will be an increased likelihood of a need for mitigation as riverine riparian habitats are destroyed.

Farm Bill 2002 Wetlands Reserve Program

The Wetland Reserve Program (WRP), authorized under the Farm Bill 2002, is a voluntary program that offers landowners the opportunity to protect, restore, and enhance wetlands on their property in exchange for financial incentives. The eligible land must have been originally a wetland or can be an existing wetland, and must be restorable and suitable for wildlife benefits. The land available can include naturally conditioned farmed wetlands, farmed wetlands, and previously converted cropland. The WRP has three enrollment options: the Permanent Easement, the 30-Year Easement, and the Restoration Cost-share Agreement.

Under a Permanent Easement, the USDA pays 100% of the cost of restoring the wetland, and offers a payment to the owner that equals the lowest of the agricultural value, an established cap or an amount offered by the landowner. The 30-Year Easement payments are 75% of what would be paid for a permanent easement, and the USDA pays up to 75% of the cost for restoration. The Restoration Cost-Share Agreement is a 10 year agreement to restore damaged or lost wetland habitats. Under this option, the USDA pays 75 percent of the restoration cost activity. Under the 30-Year Easement partnerships between the landowners and other agencies or organizations are encouraged to provide extra incentive payments to decrease the landowner’s share of the costs (NRCS, 2006).

Texas Wetland Reserve Program

The Texas WRP has more than 27,000 acres in the WRP. In Hudspeth County, there are 9 wetlands enrolled in the program, and, although the total acreage is unknown there has been a total payment of $91,000 to farmers in the county.

Conservation Innovation Grants (CIG)

The Conservation Innovation Grant (CIG), also a program under Farm Bill 2002, is a voluntary program intended to encourage the development and adoption of new conservation approaches and technologies in an agricultural setting. Constructing a bi-national wetland to enhance the quality of water along the U.S.-Mexico border could be viewed as a novel project being that there is currently no project of this type in the region that offers the chance to clean water and naturally enhance wildlife (such as bird migrations). The CIG requires a 50-50 match between the agency and the applicant, and has both National and State funding components. In the state of Texas, the Texas NRCS awards grants to eligible government or non-government organizations or individuals (NRCS, 2006).

North American Wetland Conservation Act of 1989

The North American Wetlands Conservation Act (NAWCA) funds wetland acquisition and restoration projects in the U.S., Canada, and Mexico to protect habitats for migratory species, especially birds. Federal funding must be matched one-to-one with non-federal sources, including non-profit organizations, state funds, or landowner contributions. The NAWCA offers a 10-year agreement or a 5-year demonstration project agreement (Texas Parks and Wildlife, 2000). This is an applicable act to the Paso del Norte region because in addition to being located in an international border, we occur along a major migratory bird route. On the US-Canadian border there are about 3000 acres of wetland (US Fish & Wildlife Service 2008).

Other programs that will support the construction of wetlands are the following:

- Challenge Cost Share Program
- Conservation Contract Program
- Environmental Quality Incentives Program
- Partners for Fish and Wildlife Program (PFW)
- Wildlife Habitat Incentives Program (WHIP)
- Matching Aid to Restore States Habitat Program (MARSH)
- Wetland Habitat Alliance of Texas (WHAT)
- TxDOT – Three wetland banks

Border Environment Cooperation Commission (BECC) and North American Development Bank (NADB)

The BECC and NADB are bi-national agreements under the North American Free Trade Agreement (NAFTA) to help improve environmental infrastructure along the border region between the US and Mexico. The BECC identifies projects related to water pollution, wastewater treatment, and solid waste management and, then the NADB works with BECC to help find and obtain funding (Liverman et al, 1999). According to Liverman et al (1999), since its beginning in 1995, the BECC filed more than 150 proposals, and by early 1999, 27 had been certified (12 in Mexico, and 15 in the U.S). By spring of 1999, seven certified projects under BECC had NADB loans and/or grants approved and closed with five of those projects under construction (Liverman et al, 1999).

Other organizations and programs associated with the conservation and restoration of wetlands in México include:

- Comision Nacional de Areas Naturales Protegidas (CONANP)
- Secretaría de Medio Ambiente, Recursos Naturales y Pesca (SEMARNAP)
- Comision Nacional del Agua (CONAGUA)
- Instituto Nacional de Ecología (INE)
- Procuraduría Federal de Protección al Ambiente (PROFEPA)

Is a bi-national wetland economically feasible?

Wetlands can provide services such as flood abatement, water quality improvement, and serving as habitat for wildlife in the area (Zedler 2003). Wetland size and location promote different services. Large wetlands support greater biodiversity; small wetlands can harbor small and rare native species; upstream wetlands can only trap few nutrients; and downstream wetlands can remove up to 80% of nitrates (Zedler 2003). A wetland along the Rio Grande would function to improve water quality in ways such as trapping nutrients and increasing sediment deposition. It would also support biodiversity by harboring small and rare native species such as the yellow-breasted chat, the painted bunting, and the blue grosbeak. The region is located along the migratory route for neo-continental birds, and existing wetlands in the region serve as stopovers for these and many other species.

Sometimes it is hard for society to see services provided by ecosystems in a monetary sense. However, a study by Constanza et al. (1997) has assigned monetary values to ecosystem services, including the services provided by wetlands. This study addressed the many services that a community can benefit from a healthy wetland, including: wastewater treatment, habitat refuge, and recreation. In total, healthy wetlands can provide added value of $14,785 ha/yr (Table 11)

Table 11. *Services and monetary values of a wetland. (Constanza et al., 1997).*

Service	**Value ($/ha/yr)**
Disturbance regulation	$4539
Waste Water Treatment	$4177
Water Supply	$3800
Cultural	$881
Recreation	$574
Habitat/Refuge	$304
Food Production	$256
Gas Regulation	$133
Raw Materials	$106
Water Regulation	$15
Approx Total Value	**$14,785/ha/yr**

Constructing a wetland costs money. To begin with, King and Maitland (2003) estimate that the legal costs alone can vary depending on the size of the wetland and can range from $10,000 to $100,000. The Tres Rios Project and the New River Project are two case studies in which construction and planning of wetlands were aided by a pilot study.

The Tres Rios Project in Phoenix, Arizona started with a feasibility study that cost $3.6 million. Pilot wetlands were constructed to determine optimum design configurations for flood control, water quality improvement and habitat availability. Over the three years of the feasibility study, the pilot wetland (4.85 Ha) was effective in achieving these goals. Now, with funding from the Army Corps of Engineers and a local governmental sponsor, the project is expanding to a full scale system with 800 acres with a total cost of $82 million along the Salt and Gila Rivers (EPA 2004). The project uses 16 separate wetland basins to evaluate different designs and parameters (Cole 1998). If we assume a wetland is worth $14,785 ha/yr (Costanza et al. 1997), the full scale Tres Rios Project could end up paying for itself in ecosystem services in 17 years.

Similarly, the New River Wetland in California began as a 3 year feasibility study and was highly successful in improving water quality (see Case Study earlier in this report). A full scale wetland project is now under construction and the final wetland will be 22.3 hectares, approximately half of which will be dikes or channels (i.e. not wetland area). The cost of constructing each hectare will be approximately 30,000 to 40,000 dollars (C. Rodriguez, US Bureau of Reclamation, pers. comm.). According to Costanza et al's (1997) estimates of wetland value, this wetland could end up paying itself in 2 to 3 years and subsequently provide an income of $14,785 ha/yr in ecosystem services to the region.

Mexico has shown a growing interest in and dedication to the restoration and conservation of its wetlands. Since 2001, the budget for wetland programs in Mexico has increased by 100% (Figure 5). In 2004, Mexico, with the support of Comision Nacional de Areas Naturales Protegidas (CONANP) hosted the World Wetlands Day along with the 1st International Migratory Birds Conference. They were chosen among many other countries because of they have designated 51 wetland sites for protection, more than any other country. The director of CONANP has said wetlands represent 25% of the Gross National Product (GNP) in Mexico.

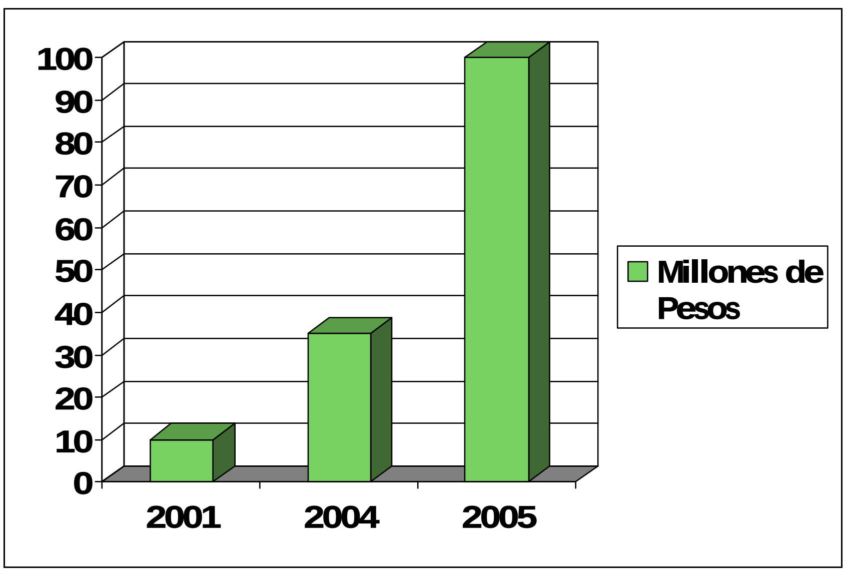

Figure 5. *Increased financial support for wetland programs in Mexico (CONANP 2005).*

Wetland creation can be expensive; however, an interested community can contribute to the reduction of expenses while reaping its benefits. Monitoring and maintaining the wetland could be done in cooperation with local educational institutions, including universities, colleges and high schools. In addition, the wetland could serve as an outside classroom for all levels of education. Citizens and the community would benefit from volunteering and learning in a natural environment. Properly managed, ecotourism, can also have a substantial monetary input in the value of this wetland. Birdwatchers can stop and observe native species of the area, drivers can stop and rest in a natural environment and hike around the wetland. Because of the innovative concept of a “green cleaning machine”, an entrance fee to the park will not prevent for visitors to stop and enter (Mathis & Matisoff 2004).

Regional Perspective

Although the Rio Rectification Project, which extends from El Paso through Fort Quitman, TX to Little Box Canyon reduced the length of the Rio Grande from 155 miles to 88 miles (Reinhardt, 1937), the construction of more than 465 miles of drains, 457 miles of laterals and 139 miles of canals (USBR) has increased the total length of all waterways in the region by more than four-fold. For irrigation, water is diverted from the Rio Grande into canals that take the water to the fields for irrigation; water percolates and gets into subsurface drain systems that take the water to a main drain which returns the flow to the river. King and Maitland (2003) suggest that many drains in the region may be ideal for wetland and riparian habitat restoration because they are heavily vegetated, the flow velocity is less than the river and it would not lead to an increase in water depletion. A primary concern, however, would be that they may dry out during the drought season, but because a wetland only needs to be inundated with water long enough to promote wetland or aquatic processes these drains may still function to serve as a working wetland.

Both water quality and quantity are of major concern in Hudspeth County. The water in the canals and drains of the Hudspeth County Conservation and Reclamation District (HCCRD) is generally considered to be of poorer quality than areas upstream. With respect to water availability, Hudspeth County lies outside the Rio Grande Project, and therefore has water rights inferior to those upstream, which can be a disadvantage during times of drought. HHCRD has no legal right to waters of the Rio Grande, only rental rights to surplus water of the Rio Grande Project (King and Maitland, 2003). King and Maitland (2003) reported that the drains in Hudspeth County were the least suitable for restoration because (1) they have very high levels of salinity, the water clarity is bad, and since the origin is agricultural, the water may contain herbicides; (2) the drains are kept clear of vegetation to increase the flow and flush out the salts, a wetland would have to deal with high levels of salinity; and (3) there is only flow in the drains during irrigation season. However, downstream of Balluco Arroyo, and the inflow of the Hudspeth Main canal into the Rio Grande, there is many miles of the river within the Rio Grande Project, which ends at Little Box canyon, that is rectified but not used for agricultural purposes.

To determine whether nutrient levels in the drains, canals, and the Rio Grande in the region could be improved by a wetland, we visited 23 sites in El Paso and Hudspeth Counties on a seasonal basis over a one-year period (Fall 2006-7). On the West Side of El Paso, 5 sites were sampled; the Rio Grande (upstream of all sample locations), the Nemexas Drain, the Montoya Drain, and the Rio Grande up- and downstream of the Montoya Drain. In the Lower Valley of El Paso, 5 sites were sampled; the Rio Grande at Rio Bosque, the Riverside Canal up- and downstream of the Bustamante WWTP input, and the Franklin Drain and Canal. In Hudspeth County 13 sites are sampled; 3 sites along the Rio Grande, 5 canals, and 5 drains. In Fall 2007, we also determined contamination by fecal coliforms in drains, canals and the Rio, and also in 6 stormwater retention ponds in west El Paso.

Based on the seasonal data collected from the different sampling sites, drains contained the lowest amounts of nutrients, especially when compared to canals. Canals contained higher nutrients than both drains and the Rio Grande sampled. On average, total phosphorus (TP) did not exceed the screening levels set by TCEQ (0.8 mg/L), however, higher than permitted levels were noted in the canals in Hudspeth County (Tornillo Canal and Hudspeth Port of Entry Canal) (Figure 10). Nitrate screening levels were never exceeded, and were under the standards (2.76 mg/L). Ammonia levels exceeded the standard (0.17 mg/L) on average on all sampling dates and in various sample locations, but most occurred during both Fall seasons (2006 & 2007). Nutrient concentrations were likely higher in canals in part because some canals receive input directly from WWTP's, whereas lower nutrient levels in the drains may indicate that nutrients have been captured by the plants and microorganisms inhabiting the agricultural fields through which the water has recently passed. TP levels increased as water flowed downstream through El Paso, lower TP concentrations are found at Riverside Canal, and are at its highest at Hudspeth Main Canal (Figure 10). Phosphorus levels then begin to fall as the water flows further downstream. Nitrate levels also show a decrease in concentration as the water flows downstream past El Paso County. Despite the fact that the nutrient levels of waters in El Paso and Hudspeth Counties do not consistently exceed protective standards for phosphorus and nitrates, the screening levels set by the TCEQ are relatively high, as compared to other sites in the nation, thus efforts to improve nutrient water quality would likely benefit regional water resource quality.

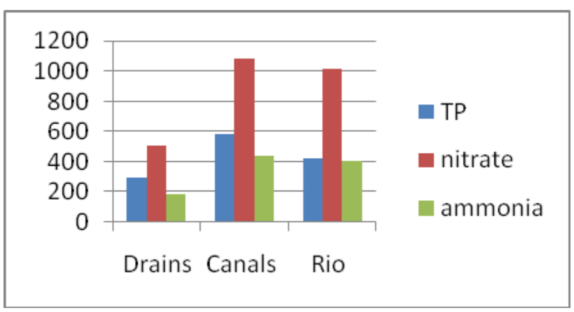

Figure 6. *Average of nutrients sampled in Hudspeth County during Fall 2006.*

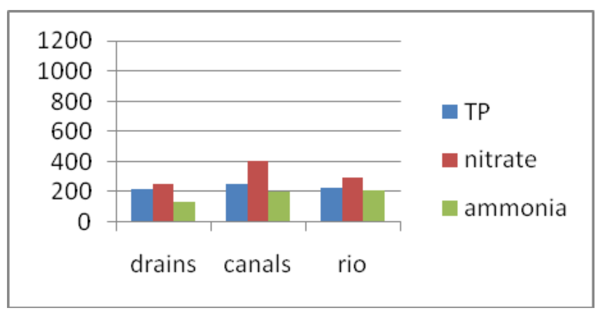

Figure 7. *Average of nutrients sampled in Hudspeth County during Spring 2007.*

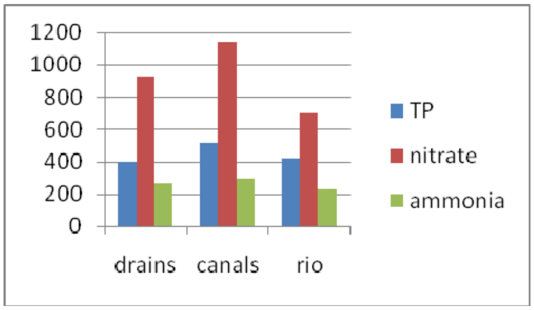

Figure 8. *Average of nutrients sampled in Hudspeth County during Summer 2007.*

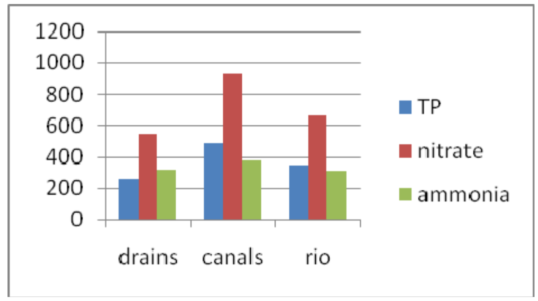

Figure 9. *Average of nutrients in Hudspeth County during Fall 2007.*

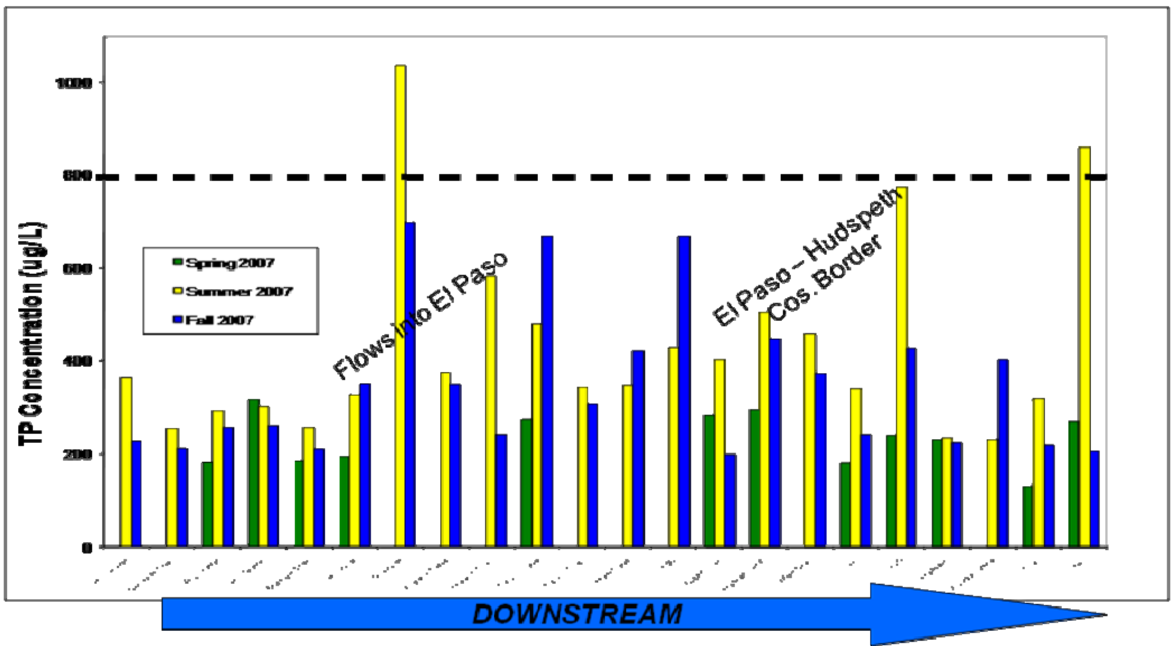

Figure 10. *Total Phosphorus is more likely to exceed TCEQ Standards in Summer, and after these waters receive inputs from the cities of El Paso and Ciudad Juarez, Mexico.The dashed line irepresents thes TCEQ Screening Levels to Protect Aquatic Life Uses(EPA Segment 2307 in Hudspeth County)*

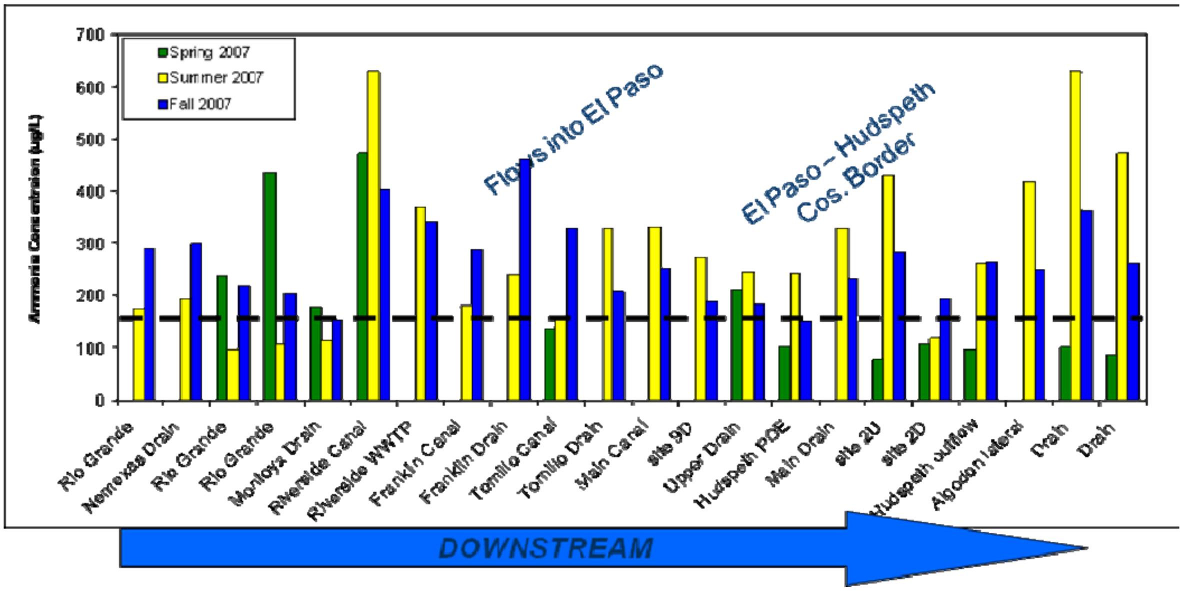

Figure 11. *Ammonia levels consistently exceed protective standards in El Paso County waters.*

Chloride levels, an important component of salinity in regional waterbodies, increased as water travels downstream (Figure 12). While the was a slightly higher Cl concentration in the drains, this comparison was not significant for Summer 2007 data (Figure 13).

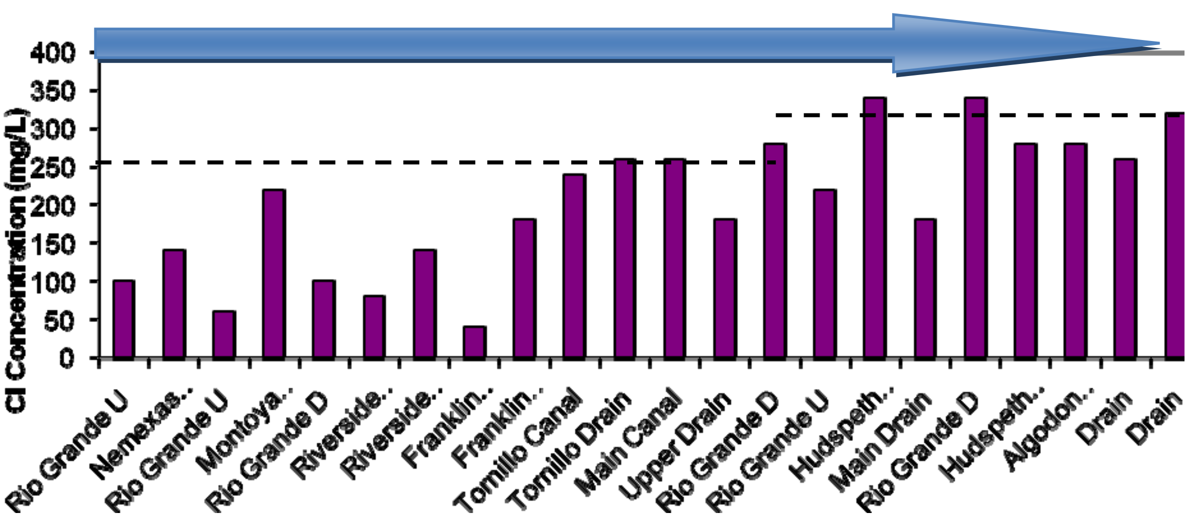

Figure 12. *Chloride levels exceed protective standards at several sites in and near Hudspeth County in Summer 2007.*

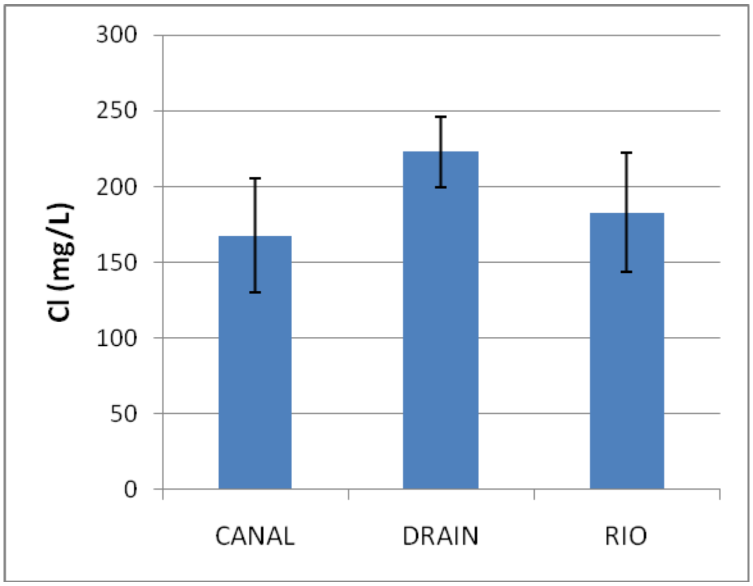

Figure 13. Comparison of Chloride levels in canal, drain and rio sites; July 2006 .

On average, *E. coli* levels exceed Texas Commission of Environmental Quality (TCEQ) Screening Levels for El Paso County (200 CFU/mL) in the Rio Grande and storm water retention ponds, while canals and drains are generally lower than this standard (Figure 14). The highest levels of fecal coliforms were found in the Aguas Negras canal in Juarez, Mexico, where we were unable to dilute the sample sufficiently to get an accurate reading.

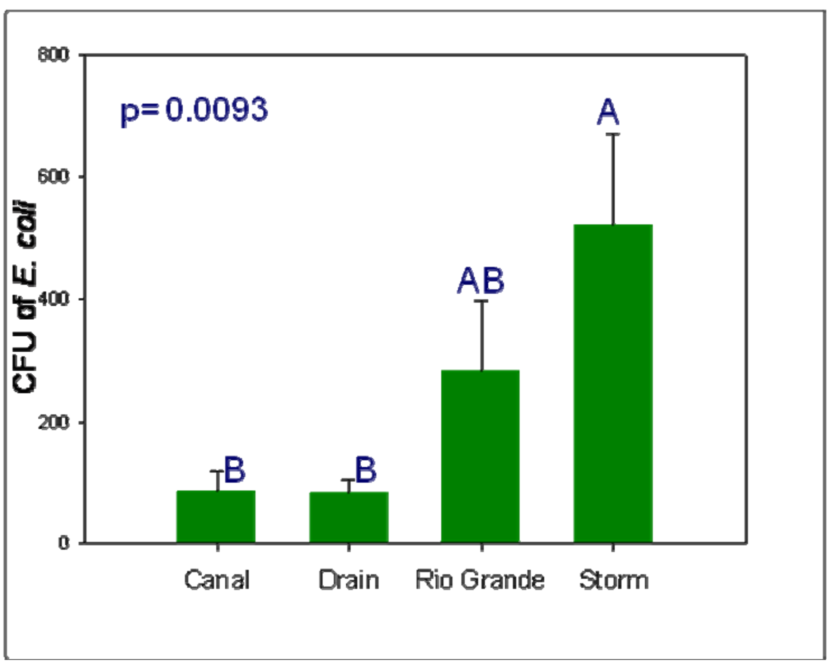

***Figure 14.** Agricultural canals and drains had a significantly lower CFU count than the storm water retention ponds (Tukey HSD, $p<0.05$) .*

We are also using Geographical Information Systems (GIS) to identify potential wetland sites. By using GIS we are able to view the topography, drain inflow, arroyos or springs, and soils to indicate the best location of the wetland. By using the natural topography of the land, we could see an ideal location where there may have been past wetlands (Appendix A and B).

Challenges and Solutions

Aside from the challenges we would encounter by using Hudspeth Co drains, there are challenges to be faced by created wetlands in general. If a wetland is constructed, there are several issues that have to be monitored while the wetland is in use or considered before construction:

1) Release of greenhouse gases. Wetlands are known to be net carbon sinks due to their relatively high primary productivity (Gorham et al. 1991). Although wetlands are important sinks of CO_2 as they sequester organic matter, the release of CH_4 and N_2O may be a concern for radiative forcing and the greenhouse effect. (e.g. Brix et al. 2001, Groffman et al 2000). The function of wetlands as a source of greenhouse gases may be a concern with wetland creation. However, wetlands that exist over a long period of time (>100 years), have been shown to produce less greenhouse gases (Brix et al. 2001), thus long-term investment in and commitment to wetland restoration must be a priority.

2) Invasion by tolerant exotic species. Controlling invasion by exotic invasive species of plants and animals that are more tolerant than native species, which could out-compete more desirable species and dominate the wetland community may be an important concern (Moore et al. 1999, Lovich & Gouvenain 1998, Levine & Stromberg 2001). For example, at the Rio Bosque Wetland Park in El Paso, TX, the water delivery channels must be continually maintained to reduce the build-up of tumbleweed and salt cedar.

3) Bioaccumulation of toxic contaminants in plants and other organisms could cause a decrease in the performance of the wetland. Water-borne contaminants are taken up by primary producers such as algae, which may then be consumed by small invertebrates, thus making them available for larger organisms that feed on them, and so on. If this were to happen, the structure and function of the wetland could be negatively affected. Some plants and animals are more tolerant to contaminants than others and they could out-compete more desirable, sensitive taxa and take over the wetland. Aside from this change in structure of the wetland, if toxicants aren't controlled they could affect the natural resistance of the organisms in the wetland to diseases or changes in the environment, which could lead to a decrease in the population (Paveglio 2007). Some solutions to bioaccumulation could be to monitor the levels of toxicants that enter the wetland to ensure that the health of the wetland won't be jeopardized; another possibility could be to remove the contaminated biomass or sediment so that it won't be available for uptake and that way it won't accumulate up the food chain; the last possibility would be to regulate the discharge of this toxicants so that they won't end up in the water in the first place (Nelson et al. 2000, Polonsky and Clements 1999, Garcia-Hernandez et al. 2000).

4) Salinity. In order for the salt to be flushed out of the system, there needs to be a high flow, but if the retention time of the water in the wetland is too low, then the plants won't be able to uptake as much nutrients and contaminants as they could normally. The drains of Hudspeth Co have very high levels of salt, and according to Nielsen et al. (2003), high salinity can reduce emergence of zooplankton and aquatic plants in the water. According

to our preliminary conductivity measurements done in Hudspeth Co (10-13-2006), the salinity in the drains is double the salinity of the Rio Grande, and both Hudspeth and Riverside Canals (Table 12). Some possible solutions to high salinity are increasing the flow so that it flushes out the salts, or acquiring an additional low salinity water source apart from the drains to dilute the water and decrease the overall salinity of the water.

Table 12*.Conductivity measurements in Hudspeth County drains, canals and Rio Grande (October 2006).*

Sites	Conductivity
Hudspeth Canals	1.763
Rio Grande	1.87
Hudspeth Drains	4.400

5) Improvement in water quality. Nutrient concentrations were likely higher in canals in part because canals receive input directly from WWTP's, whereas lower nutrient levels in the drains may indicate that nutrients have been captured by the plants and microorganisms inhabiting the agricultural fields through which the water has recently passed. TP levels increase as water flows downstream through El Paso, lower TP concentrations are found at Riverside Canal, and are at its highest at Hudspeth Main Canal. Phosphorus levels then begin to fall as the water flows further downstream. Nitrate levels also show a decrease in concentration as the water flows downstream past El Paso County. Phosphorus levels do not exceed the screening levels set by TCEQ (0.5 mg/L) but are very close. Nitrate levels are under the standards (3.5 mg/L). Ammonia levels exceed the standard (.16 mg/L) in various sample locations.

6) Seasonal flows. There is only flow in the drains during agricultural seasons; however, a wetland is defined as, "land that is saturated with water long enough to promote wetland or aquatic processes as indicated by poorly drained soils, hydrophytic vegetation, and various kinds of biological activity adapted to a wet environment (National Wetland Working Group 1988)." So having water in the wetland only seasonally is not a problem as long as when there is water the wetland still functions properly.

7) Depth to water table. Habitat restoration will need to take into consideration the depth of the groundwater table. In Hudspeth County in particular, drains are established very deep into the soil into order to achieve their function.

8) Selecting a location.
Identifying former and current wetland sites would greatly facilitate the likelihood of locating a wetland which will function properly. For example, created wetlands may be more successful in landscapes that are saturated with water, or impervious to water infiltration. To this end, we have established a GIS of the Rio Grande corridor in El Paso and Hudspeth Counties (Appendix A) and used remote sensing to identify areas along the corridor that remain flooded both inter- and intra-annually (Figure 15 and Appendix B). In addition, wetlands must be located such that they receive water of sufficient quality and quantity, and ideally, so that they provide important habitat in wildlife corridors and flyways

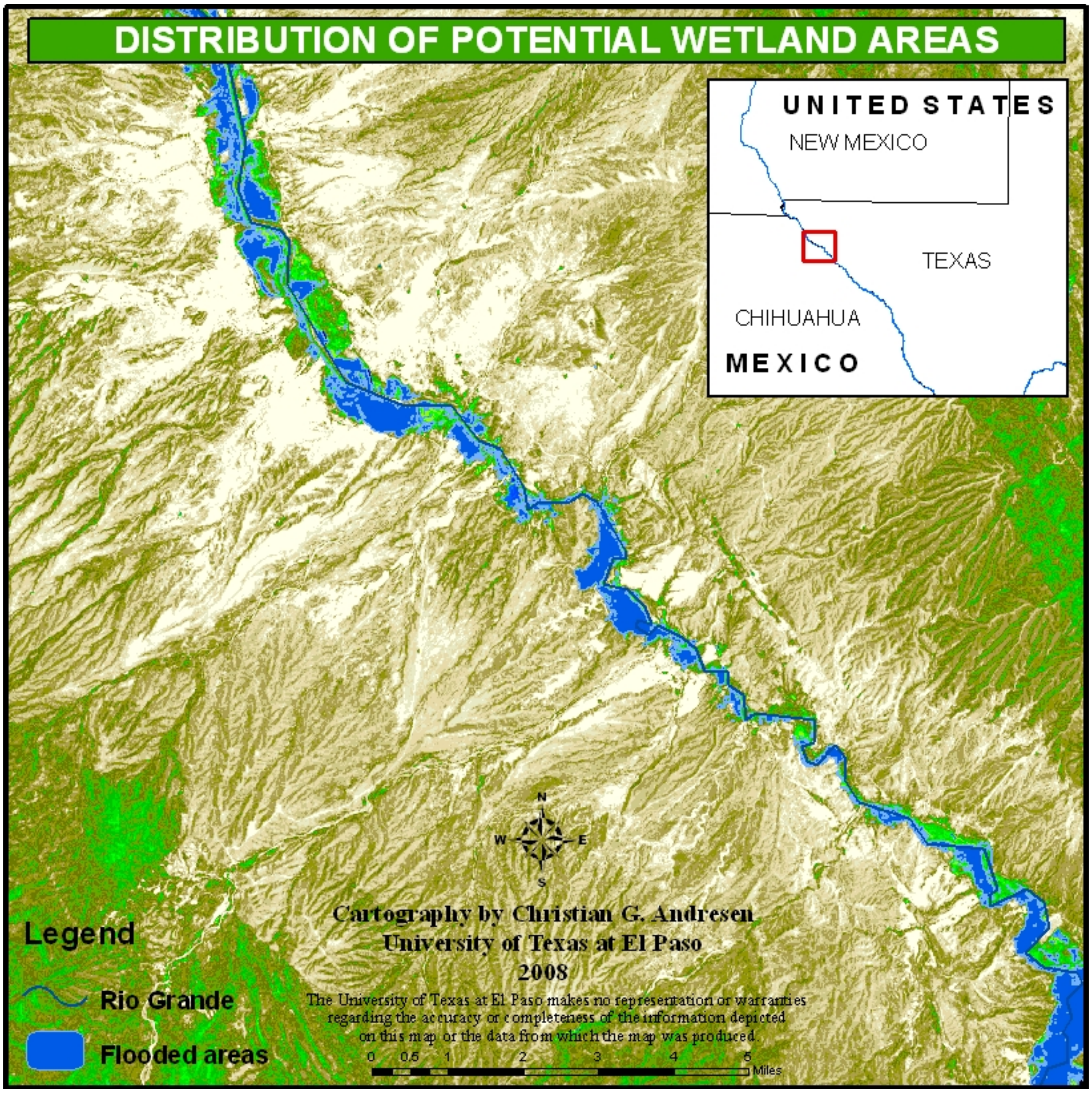

Figure 15. *Distribution of flooded areas along the study area in Hudspeth County (see Appendix B for more details).*

Are there any alternatives to building a wetland that would also be able to treat the agricultural return flows or improve water quality in the Rio Grande? Could we use wetlands to treat stormwater? In the El Paso region, stormwater tends to have significantly lower levels of nitrates ($p=0.0043$), phosphorus (not significant) and conductivity ($p<0.0001$), but significantly higher levels of fecal coliforms ($p=0.0093$) than canals, drains and the Rio Grande (Lougheed, unpubl. data). However, since the region does not receive vast amounts of precipitation, the storm water supply would likely be even more limited than that in drains, and creation of wetland functions in these mostly dry environments would be impossible. In particular, many of the stormwater ponds in the region do not connect with the Rio Grande except in times of exceptional rainfall. According to Davies et al. (2000), stormwater can contain sediment, solid and sanitary waste, phosphorus and nitrogen from fertilizers, pesticides, oil and grease, and chemicals from construction and road runoff.

Would it be better if we spent money on improving existing Waste Water Treatment Plants (WWTP) in Mexico or to incorporate a joint Mexico-United States WWTP? Treating stormwater or municipal inputs from Mexico addresses only municipal pollutants and will not reduce the quantity of agricultural pollutants which are also important when discussing water quality. And, a wetland has advantages over a WWTP in that they provide habitats for the increasing amount of birds, plants, and other organisms in the environment.

Other challenges that must be looked at involve local, regional, national & international policy. King and Maitland (2003) report that, "river restoration and instream flows should be a beneficial use of water"; however, there is no administrative framework in place for allocating and delivering water for restoration purposes. Could irrigation districts develop a policy regarding having or creating a class of water specifically for environmental use?

The benefits of a cross-border collaboration in or near the Chihuahuan Desert Transboundary Corridor, include ecological, political, economic, and socio and cultural benefits (WWF, 2004). Ecological benefits include the improved management & protection of shared resources, such as the Rio Grande, and improve success of restoration efforts. For example, the eradication of exotic species (i.e. *Tamarix* spp.) would likely be a more successful effort if teams from both sides of the border were working together. Political and economic benefits would include the development of mechanisms to ensure joint responses to border problems. By collaborating, the funds available for wetland creation may be greater and more people would be able to provide their expertise into design, maintenance and oversight. In particular, there is a need for an international coalition or agency to ensure that both sides of the border are benefiting from the wetland. By working together on a collaborative project, it would show cooperation between the bordering countries and increase goodwill and understanding of the two cultures along the border.

Some other challenges in creating a wetland include the acquisition of money, land, and water rights. Uncertainties include:

- Would downstream users be willing to pay for the wetland, since they will be benefiting from its water filtering and flood control services?
- Would El Paso residents pay for a wetland that could be an hour's drive away?
- Would we be eligible to receive any endowments or water from environmental pools to use in the wetland?
- If land is not privately donated, who will buy the land for the wetland? In Texas, land ownership is very important, and many landowners might not be willing to sell, so we must look at benefits or incentives for the land owners to persuade them to sell.
- Where would we acquire water rights to supplement the flow? Water rights as well as water in general are also challenges in the creating of our wetland. Drain water may not be our best choice because of the high salinity and low nutrient content, so we may have to get another source of water for the wetland. Regional conversion of agricultural to urban land may make water rights available.

The next step in the construction of the wetland is to get the community involved. If we are able to get people better educated and informed about wetlands, what they do and why they are useful, we would not only increase awareness of wetlands but overall environmental awareness. For example, it may be helpful if researchers or volunteers would go to local schools or offer tours of existing wetlands, such as the Rio Bosque, to help familiarize the community of what a wetland is. If people are more environmentally aware of the existing problems, then they would be more willing to pay or vote on issues that would benefit the natural environment as well as doing serving a practical purpose, cleaning the water. By doing so, we could then get funds and partners to aid in the development and construction of the wetland.

Before a full scale wetland is constructed, a small pilot wetland is advisable. By studying a pilot wetland and how it meets our design objectives, including water quality improvements and provision of habitat, we would could optimize financial resources and time because pilot projects are less expensive, a smaller amount of land, water and construction time are needed. Pilot wetlands also provide us a way to establish a research and monitoring program, while testing the sustainability of wetland functions. Two examples where pilot wetlands were constructed before the full scale wetlands are the Tres Rios and New River Project wetlands. Here smaller scale wetlands were constructed in order to view the impacts of the wetland on the area as well as to get insight to see if the wetland would remove the desired nutrients and to identify any potential problems. For example, in the New River Project wetland, which receives agricultural and waste from the Salton Sea, the pilot wetland helped managers discover that the wetland was uptaking some undesired nutrients like selenium (C. Rodriguez, US Bureau of Reclamation, pers. Comm.). Because a pilot wetland has a lesser cost than a large-scale wetland, people may be more willing to spend a smaller amount of money and actually see what the wetland does before agreeing to something that they might not know about. When the pilot wetland at Tres Rios was completed, the voters of these areas agreed to give $3,600,000 into the construction of a wetland that consists of around 12 acres (EPA 2004).

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Appendix A:
GEOGRAPHICAL INFORMATION SYSTEMS DATA AQUISISITION REPORT

INTRODUCTION

Geographical Information Systems (GIS) technologies provide powerful tools for the spatial analysis and visualization of the distribution of wetlands and riparian areas in the West Texas and the Northern Chihuahua region. Delineation and mapping of these critical habitats along the middle Rio Grande may allow the development of better management strategies to protect and restore these critical areas. To this end, we created a GIS database with hydrological, geological, topographical, biological, and political information for the study area.

DATA & METHODS

Project area

This project focuses on the Chihuahuan desert region of South New Mexico, West Texas, and North Chihuahua (see figure 1). This area was selected because of the economical, geographical, and biological importance. It embraces the sister cities of El Paso and Ciudad Juarez, which is the biggest metropolitan border city in the world.

Data collection

The data used in this analysis was obtained through several agencies and organizations in the United States, and Mexico. The data was adapted to the needs of the project; it was reviewed, processed, and incorporated into the WWF GIS project database.

Hydrology represents a key element for this geographical study. Therefore, we used ArcHydro, an ArcGIS data model for water resources in order to understand the water networks of the region and help to understand water dynamics. The ArcHydro modeling for the study area was accomplished using the USGS Digital Elevation Models, which serve as the tridimensional platform for the analysis. The software used in this study was ArcGIS 9.0, along with the ArcHydro modeling tool.

Figure A1. *Map depicting the GIS study area.*

RESULTS & DISCUSSION

The digital geographical data that comprises the project database includes biological, hydrological, geological, and political information for the study area. The data base files are summarized in Table B1. Land ownership data from Hudspeth Co. was acquired in a non-digital format due to the rustic data management of this County. Also, soil information for Hudspeth Co. was incomplete. The soil information available for this County lacks spatial distribution and only a table of soil types was acquired.

Table A1. *WWF wetland feasibility project database vector files.*

Subject	File
Biology	Mexican soils
	Mexican vegetation
	US National wetland inventory shapefiles
	Land cover/use (US and MX)
	Flooded area (Remote Sensing analysis)
Hydrology	ArcHydro modeling files
	El Paso drains and canals
	Hudspeth drains and canals
	Mexican aquifers
	Mexican irrigation districts
	Mexican drains and canals
	Rio Grande
	River inputs from USA (IBWC)
	River inputs from Mexico
	Texas hydrology
Political boundaries	Counties of Texas
	Counties of Chihuahua
	El Paso land ownership
	El Paso streets
	Juarez parcels
	Mexican localities
	US and MX states
	US and MX roads
Geology	El Paso Co. soils
	Hudspeth soils (metadata only)
	Texas soils

The hydrologic modeling files are summarized in Table B2. Figure B2 represents a portion of the hydrological files for the study area.

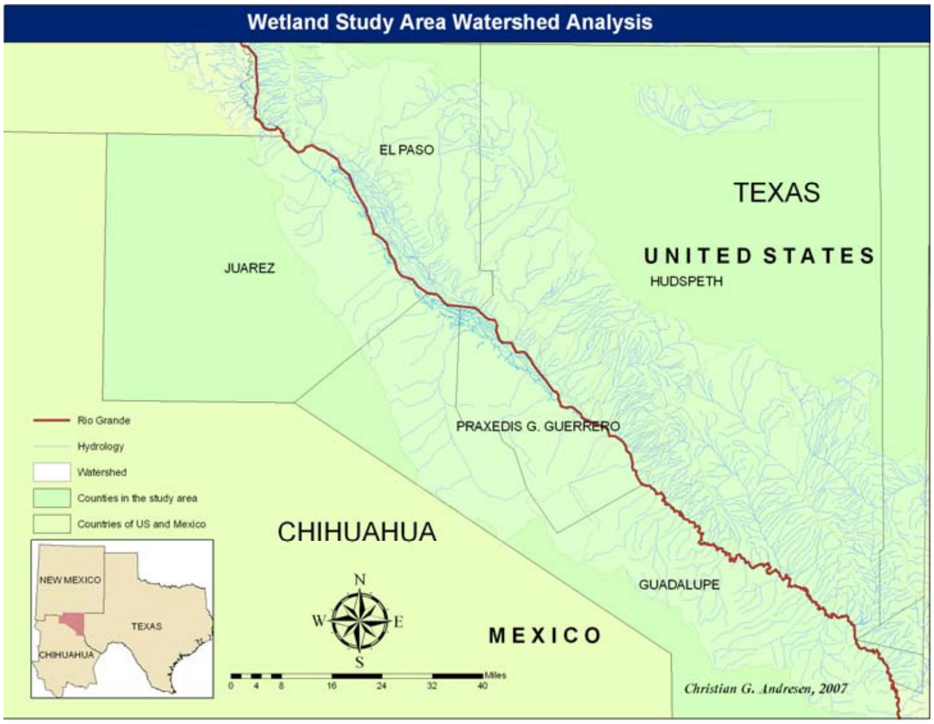


Figure A2. *Hydrology map of the study area derived from the ArcHydro modeling files.*

Table A2. *Hydrologic modeling files*

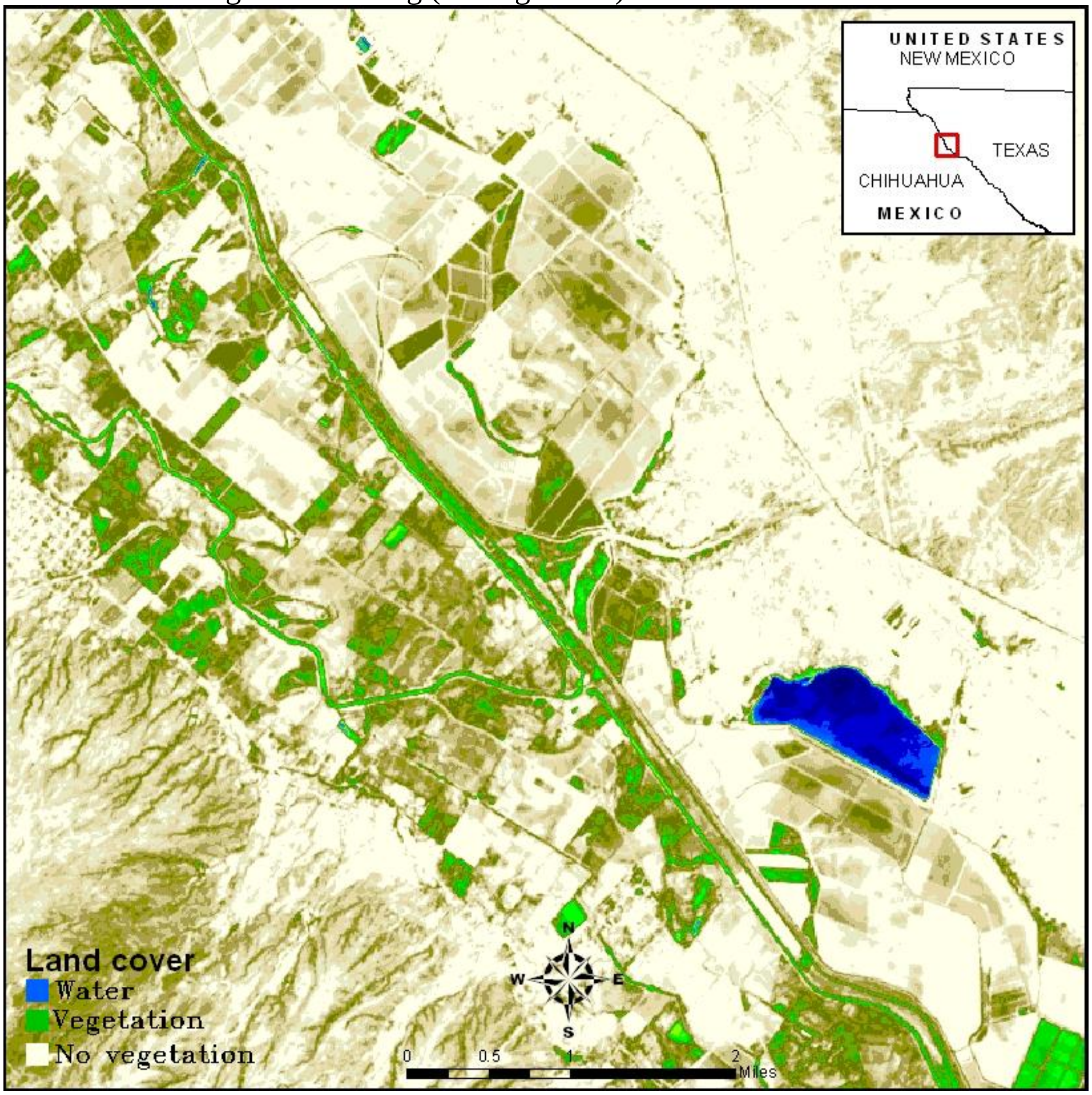
Modeling files	Description
Hydro-edge	Lines that represent a hydrological features (stream, arroyo, etc).
Hydro-junction	Point of strategic hydrological interest such as an outlet of a watershed.
Hydro-network	Geometric network tracing water movement trough streams.
Monitoring point	Points along the model suggesting monitoring sites.
Water body	Water feature.
Watershed	Subdivision of a basin into drainage areas.

The topology and satellite imagery collected through different sources comprised the raster files of the wetland feasibility project (see Table B3). The resolution of this imagery ranges from 0.3 m to 60 m. The land cover/use map and Normalized difference Vegetation Index (NDVI) where derived from the ASTER imagery.

Table A3. *Database Raster files.*

File	Resolution (m)
Region Topographic map (US only)	2
Region Digital Elevation Model DEM (US only)	30
El Paso County true color raster image	0.3
Hudspeth County true color raster image (2005)	2
Land cover/use classification (US & MX)	15
Normalize Difference Vegetation Index (NDVI)	15
Hudspeth region ASTER multispectral imagery (08/22/2000)	15, 30, 60
Hudspeth region ASTER multispectral imagery (03/26/2004)	15, 30, 60
Hudspeth region ASTER multispectral imagery (07/16/2004)	15, 30, 60
Hudspeth region ASTER multispectral imagery (11/01/2005)	15, 30, 60
Hudspeth region ASTER multispectral imagery (04/20/2007)	15, 30, 60
Hudspeth region ASTER multispectral imagery (05/22/2007)	15, 30, 60

Land cover map was obtained from ASTER images using an unsupervised K-means classification. The classes from the output where assigned to a land cover type by image visualization and ground truthing (see Figure B3).



FigureAB3. *A section of the land cover map for the study area.*

CONCLUSION

We developed a geographic database to support the WWF wetland feasibility study. Nevertheless, it is important to note that this database should be updated to incorporate new data and improve pre-existing information. One of the most important challenges was the compilation of the data. The collaboration from agencies from the U.S. and Mexico played a vital role in the database assemblage.

Appendix B:

ASSESMENT OF TEMPORAL AND SPATIAL DISTRIBUTION OF CRITICAL WETLANDS ALONG THE MIDDLE RIO GRANDE

INTRODUCTION

Combining GIS with remote sensing allowed us able to incorporate geographical and spatial information into our wetland feasibility research and monitoring activities, from site selection to data analysis and modeling, in order to support important geographical decisions. This project aims to understand intra- and inter-annual distribution of flooded riparian areas, which could potentially be restored as critical wetland habitat. This would provide baseline data for further research and monitoring of these critical habitats.

METHODS

Project area

This project focuses on the Chihuahuan desert region of west Texas and north Chihuahua (see Figure C1). This area was selected to accomplish the project objective because of the presence of wetlands and riparian habitats along the Rio Grande. Wetlands are the most important habitats in this ecosystem formed on the majority as a result of river oxbows and land depressions adjacent to the river.

Figure B1. *Location of study area. Green box depicts the boundaries of the imagery used in the wetland assessment.*

Imagery

The wetland assessment was conducted using ENVI 4.4 software. The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) imagery was used in the wetland assessment, and was acquired through NASA's ASTER imagery database (http://asterweb.jpl.nasa.gov/). The ASTER images used in this study were selected because of their geographical boundaries that coincide with the study area, the absence of cloud cover, which improves the analysis, and the season of the year which are spring and summer. The ASTER imagery selected for the study was AST07 Surface Reflectance

VNIR/SWIR because these pre-processed images are at-sensor radiance corrected for the atmospheric transmission improving image accuracy, and they are formally validated for scientific publications. We completed all subsequent analysis on 2 images from 2004, in order to look at intra-annual variation, and one image from 2007, to allow for inter-annual comparisons. For imagery detail see Table C1.

Table B1. *ASTER imagery used for the wetland assessment.*

Season	Date	Imagery
Spring `04	03/26/2004	AST_07XT_00303262004175115_20080216052942_28739
Summer `04	07/16/2004	AST_07XT_00307162004175054_20080216053152_29740
Spring `07	04/20/2007	AST_07XT_00304202007175121_20080223004008_13090

Preprocessing
The imagery was geographically registered using ground control points of an ASTER orthorectified image providing a true scale and distortion-free imagery. The registered imagery bands were stacked to a pixel size of 15m in order to provide the same resolution for the VNIR and SWIR ASTER bands, and to give a better insight for the classification process. After stacking, the imagery was spatially resized to focus on the project area, excluding unnecessary data.

Classification
This study focuses on the remote recognition of water extent across seasons and across years. Water areas were identified using ground-truthed data and imagery visualization. The images where analyzed with a supervised maximum likelihood classification using Regions of Interest (ROIs) as the samples of spectral classes for the classification.

Accuracy assessment
After completing the wetland classification and mapping, we undertook an accuracy test to ascertain the validity of the resulting map. We used a Confusion Matrix to show the accuracy of a classification result by comparing a classification result with ground truth regions of interest (ROIs). Two methods where used to assess accuracy: (1) Field wetland confirmation of a sub-sample of mapped wetlands, recording land cover and other observations (photos); and (2) Digital visualization of the VNIR_Band3N (0.76 - 0.86 of wavelength) which is the most representative for water.

Post-classification
The classes obtained from the supervised classification were "sieve" and "clump" to achieve spatial coherency. Then, the classes were exported as vector files to correct errors of commission (i.e. wet areas mapped by the classification process that are not wet areas; also known as false positives). This step was accomplished using ArcGIS v9.2.

Spatial Analysis
The water-covered areas of the three classifications (spring`04 & `07, and summer `04) were spatially analyzed for shared, unique and total water-covered area using ArcGIS v9.2.

Normalized Difference Vegetation Index

We created a Normalized Difference Vegetation Index (NDVI) as part of the ancillary data in this study. The index provides an estimation of photosynthetic activity along the study area with the goal of identifying vegetation cover in wetlands. NDVI is defined by the following equation:

$$NDVI = \frac{\rho_{NIR} - \rho_{RED}}{\rho_{NIR} + \rho_{RED}}$$

This method is one of the oldest, most well known, and most frequently used for vegetation indices. The combination of its normalized difference formulation and use of the highest absorption and reflectance regions of chlorophyll make it robust over a wide range of conditions.

RESULTS

Over 2,000 Ha of flooded area were mapped along a 52 mile stretch of river (Table C2). An even distribution of flooded areas was observed along the riparian areas of the Rio Grande, and none were observed outside the river valley (see figure C2). Substantially more flooded area was observed in the Spring, most notably after a rainfall event in Spring 2004 (Table C2, Figure C3, Figure C4). There was a low total flooded area in Summer 2004, due in part to the fact that there had been no rainfall for several weeks prior to the image. More flooded area would be expected in summer after large rainfall events.

Table B2. *Remotely sensed areas of flooded land and the accuracy of the assessment using a Confusion Matrix.*

Season	Area (Ha)	Accuracy (%)
Spring `04	1552	97.24
Summer `04	37	76.06
Spring `07	1375	98.8
		Total accuracy = 90.7
Net potential flood area	2032	

The low accuracy of summer 2004 classification (76%) was due to the relatively low water area that was present during this season that made it harder to correctly assign it. We decided to err in the side of inclusion to decrease the likelihood of overlooking possible wetland areas,

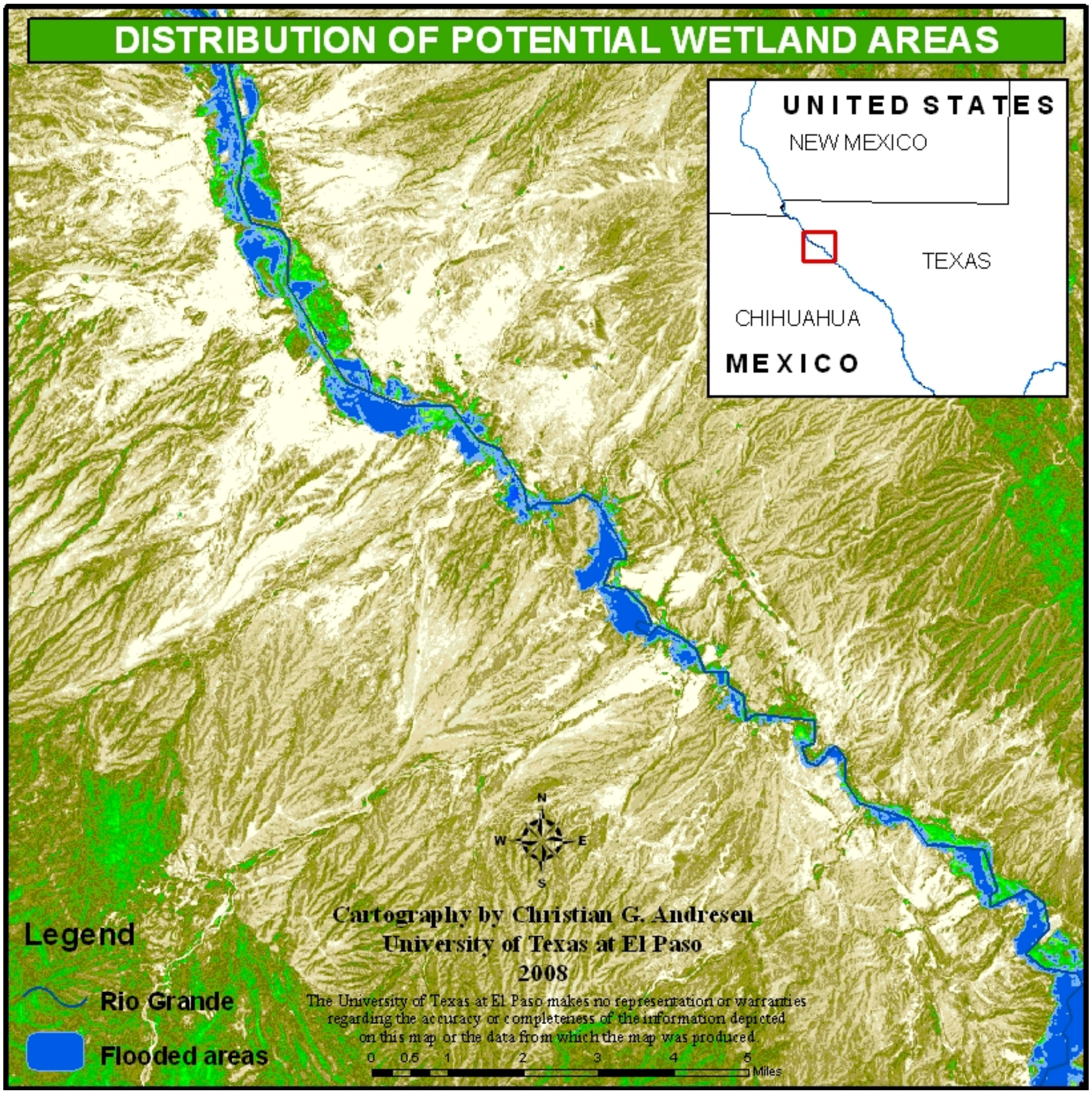


Figure B2. *Distribution of flooded areas along the study area*

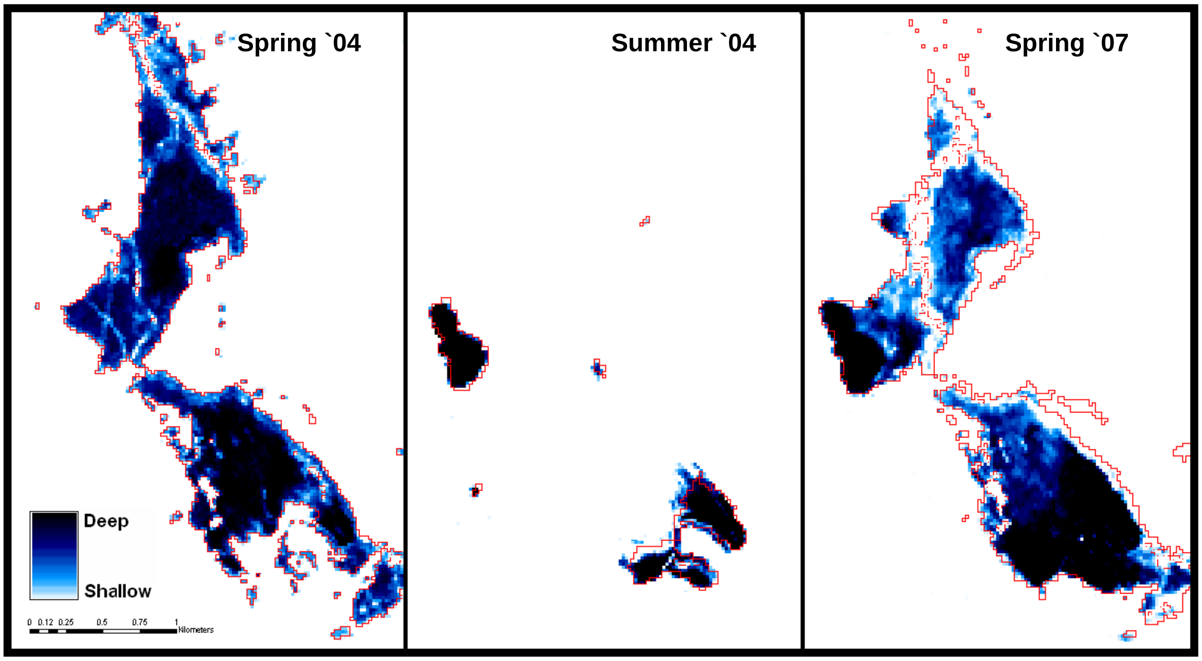


Figure B3. *Comparison of the variation in the extent of flooding in a subset area.*

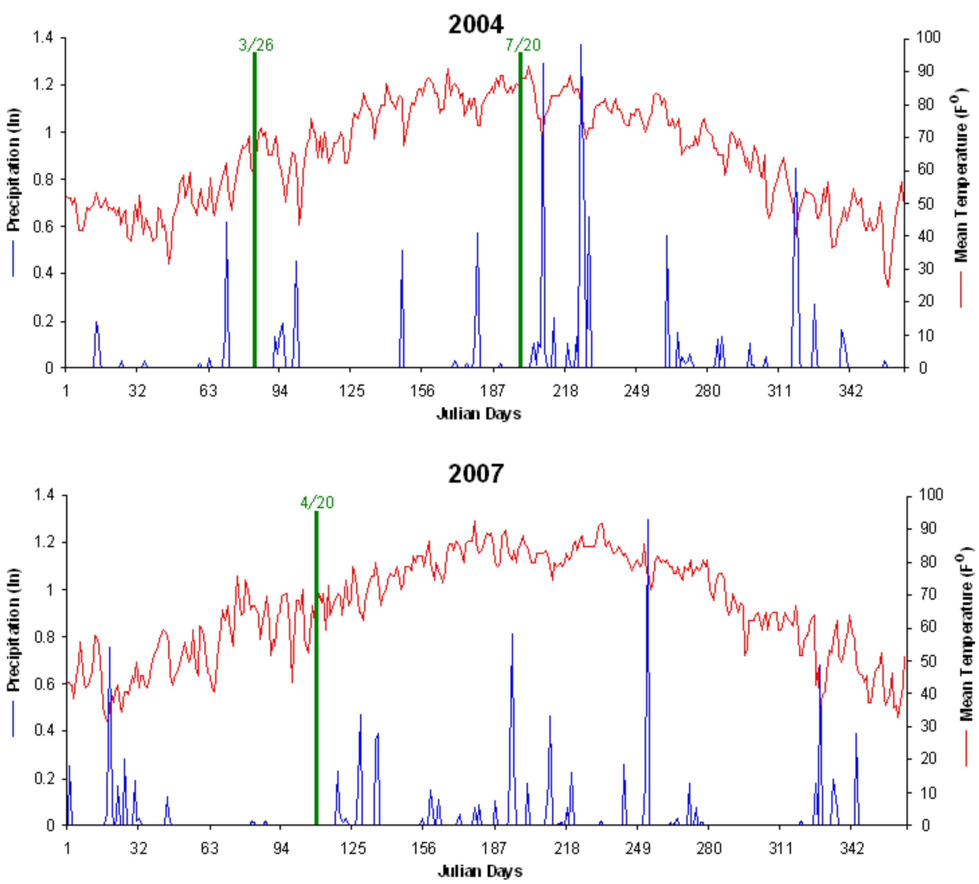


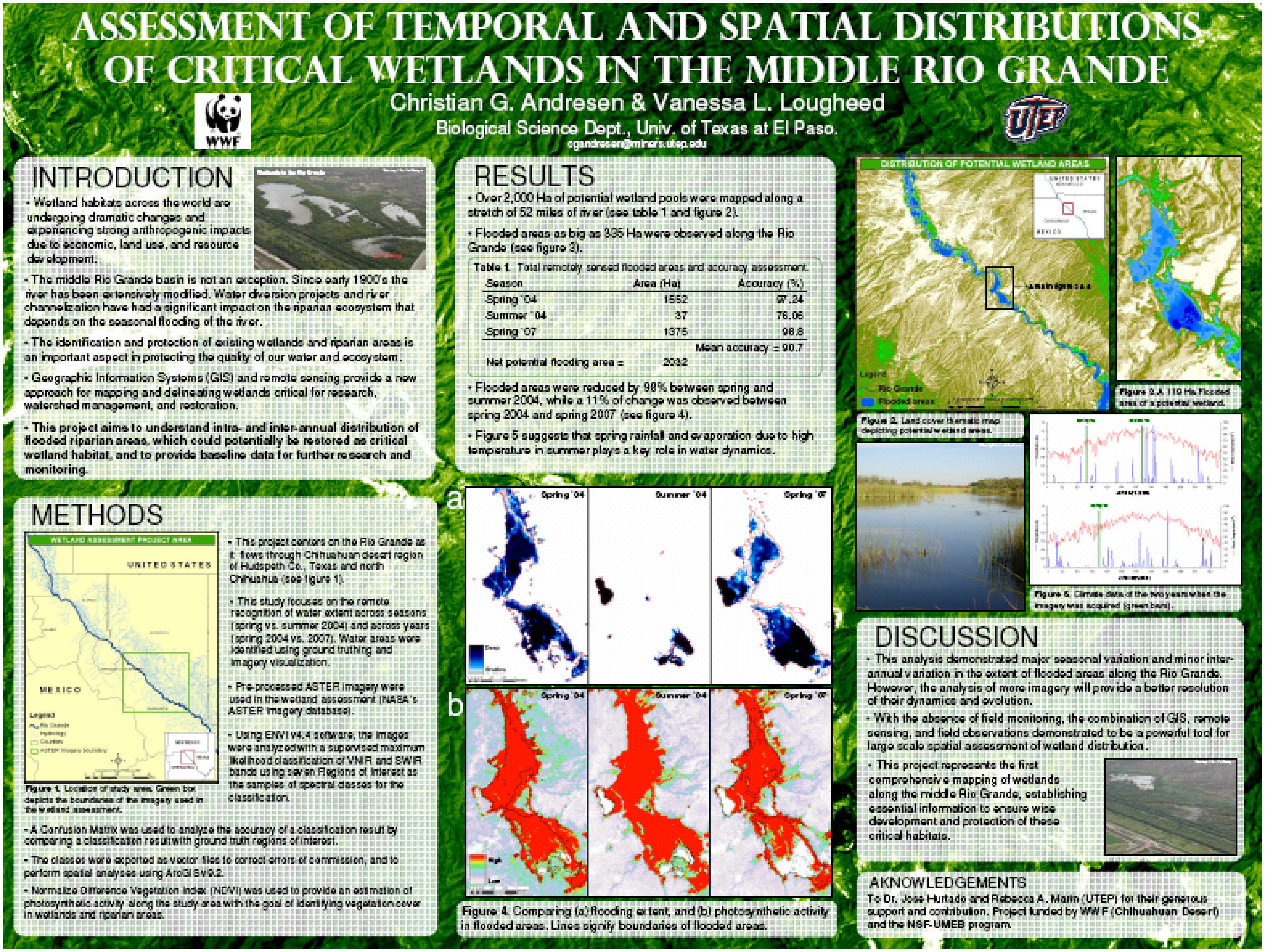
Figure B4. *Precipitation and temperature in the 2 study years. Dates of imagery are indicated in green.*

DISCUSSION

This project represents the first comprehensive mapping of wetlands and flooded areas along the middle Rio Grande, establishing essential information to ensure wise development and protection of these critical habitats. This analysis demonstrated major seasonal variation and minor inter-annual variation in the extent of flooded areas along the Rio Grande. However, the analysis of more imagery, over a broader range of environmental conditions and inter-annual variability will provide a better resolution of their dynamics and evolution. With the absence of field monitoring, the combination of GIS, remote sensing, and field observations demonstrated to be a powerful tool for large scale spatial assessment of wetland distribution.

Appendix C.

Posters presented by UTEP students based on the WWF Wetland Feasibility Project (Society of Wetland Scientists National Meeting; May 24-30, 2008, Washington, DC).


ASSESSMENT OF TEMPORAL AND SPATIAL DISTRIBUTIONS OF CRITICAL WETLANDS IN THE MIDDLE RIO GRANDE
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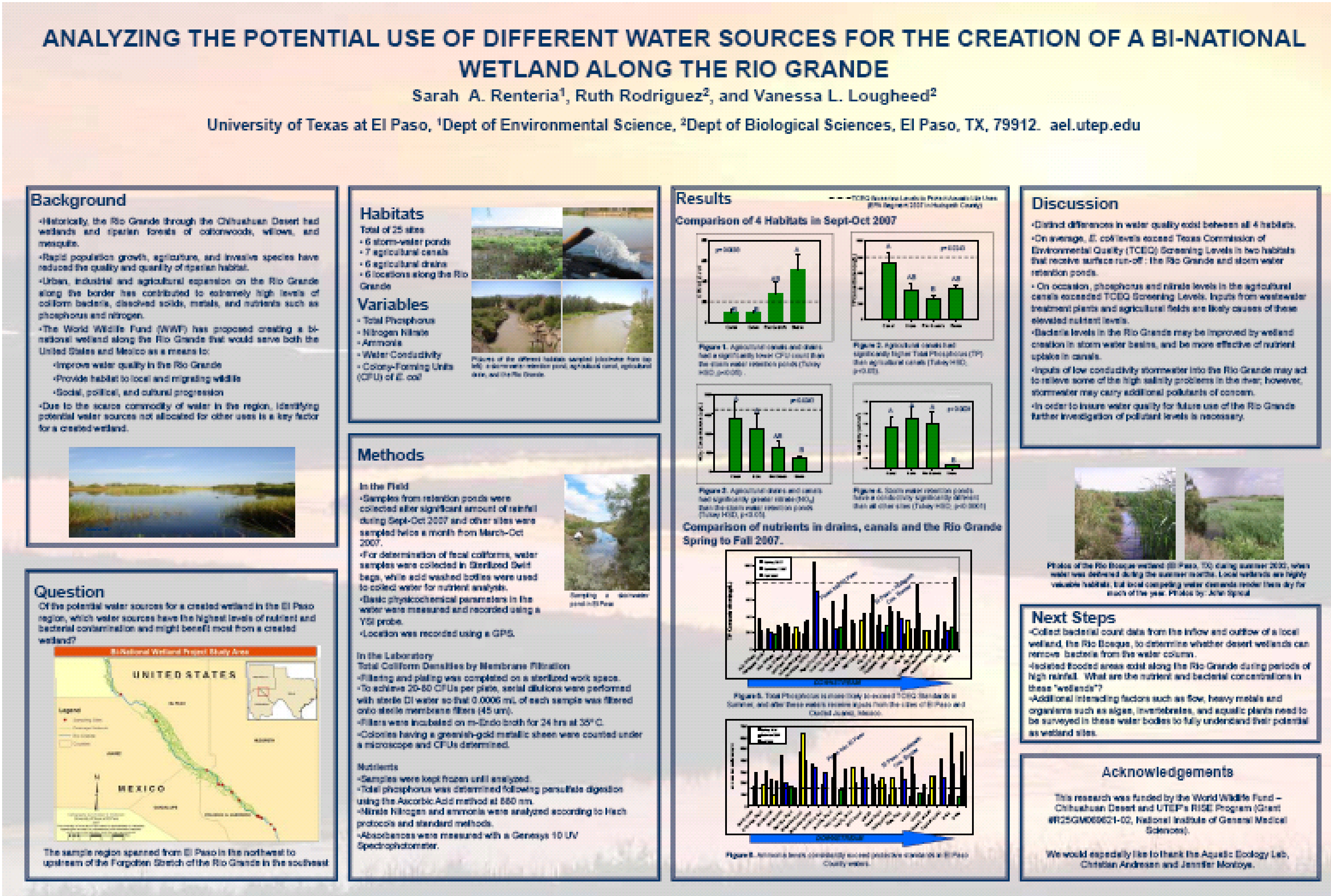
WWF
INTRODUCTION
• Wetland habitats across the world are undergoing dramatic changes and experiencing strong anthropogenic impacts due to economic, land use, and resource development.
• The middle Rio Grande basin is not an exception. Since early 1900's the river has been extensively modified. Water diversion projects and river channelization have had a significant impact on the riparian ecosystem that depends on the seasonal flooding of the river.
• The identification and protection of existing wetlands and riparian areas is an important aspect in protecting the quality of our water and ecosystem.
• Geographic Information Systems (GIS) and remote sensing provide a new approach for mapping and delineating wetlands critical for research, watershed management, and restoration.
• This project aims to understand intra- and inter-annual distribution of flooded riparian areas, which could potentially be restored as critical wetland habitat, and to provide baseline data for further research and monitoring.
METHODS
WETLAND ASSESSMENT PROJECT AREA
UNITED STATES
MEXICO
Legend
Figure 1. Location of study area. Green box depicts the boundaries of the imagery used in the wetland assessment.
• This project centers on the Rio Grande as it flows through Chihuahuan desert region of Hudspeth Co., Texas and north Chihuahua (see figure 1).
• This study focuses on the remote recognition of water extent across seasons (spring vs. summer 2004) and across years (spring 2004 vs. 2007). Water areas were identified using ground truthing and imagery visualization.
• Pre-processed ASTER imagery were used in the wetland assessment (NASA's ASTER imagery database).
• Using ENVI v4.4 software, the images were analyzed with a supervised maximum likelihood classification of VNIR and SWIR bands using seven Regions of Interest as the samples of spectral classes for the classification.
• A Confusion Matrix was used to analyze the accuracy of a classification result by comparing a classification result with ground truth regions of interest.
• The classes were exported as vector files to correct errors of commission, and to perform spatial analyses using ArcGIS v9.2.
• Normalize Difference Vegetation Index (NDVI) was used to provide an estimation of photosynthetic activity along the study area with the goal of identifying vegetation cover in wetlands and riparian areas.
RESULTS
• Over 2,000 Ha of potential wetland pools were mapped along a stretch of 52 miles of river (see table 1 and figure 2).
• Flooded areas as big as 335 Ha were observed along the Rio Grande (see figure 3).
Table 1. Total remotely sensed flooded areas and accuracy assessment.
Season | Area (Ha) | Accuracy (%)
Spring '04 | 1552 | 97.24
Summer '04 | 37 | 76.06
Spring '07 | 1375 | 98.8
Mean accuracy = 90.7
Net potential flooding area = 2032
• Flooded areas were reduced by 98% between spring and summer 2004, while a 11% of change was observed between spring 2004 and spring 2007 (see figure 4).
• Figure 5 suggests that spring rainfall and evaporation due to high temperature in summer plays a key role in water dynamics.
a
Spring '04
Summer '04
Spring '07
Deep
Shallow
b
High
Low
Figure 4. Comparing (a) flooding extent, and (b) photosynthetic activity in flooded areas. Lines signify boundaries of flooded areas.
DISTRIBUTION OF POTENTIAL WETLAND AREAS
UNITED STATES
MEXICO
Legend
Rio Grande
Flooded areas
Figure 2. Land cover thematic map depicting potential wetland areas.
Figure 3. A 119 Ha Flooded area of a potential wetland.
Figure 5. Climate data of the two years when the imagery was acquired (green bars).
DISCUSSION
• This analysis demonstrated major seasonal variation and minor inter-annual variation in the extent of flooded areas along the Rio Grande. However, the analysis of more imagery will provide a better resolution of their dynamics and evolution.
• With the absence of field monitoring, the combination of GIS, remote sensing, and field observations demonstrated to be a powerful tool for large scale spatial assessment of wetland distribution.
• This project represents the first comprehensive mapping of wetlands along the middle Rio Grande, establishing essential information to ensure wise development and protection of these critical habitats.
AKNOWLEDGEMENTS
To Dr. Jose Hurtado and Rebecca A. Marin (UTEP) for their generous support and contribution. Project funded by WWF (Chihuahuan Desert) and the NSF-UMEB program.



ANALYZING THE POTENTIAL USE OF DIFFERENT WATER SOURCES FOR THE CREATION OF A BI-NATIONAL WETLAND ALONG THE RIO GRANDE
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Background
Question
Habitats
Total of 25 sites
• 6 storm-water ponds
• 7 agricultural canals
• 6 agricultural drains
• 6 locations along the Rio Grande
Variables
• Total Phosphorus
• Nitrogen Nitrate
• Ammonia
• Water Conductivity
• Colony-Forming Units (CFU) of E. coli
Methods
Results
Comparison of 4 Habitats in Sept-Oct 2007
Comparison of nutrients in drains, canals and the Rio Grande Spring to Fall 2007.
Discussion
Next Steps
Acknowledgements
UNITED STATES
MEXICO