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Managing Riparian Succession and Stabilizing Native Plant assemblages in The Middle Rio Grande State Park

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Abstract

Anthropogenic alterations of hydro geomorphological conditions of the Rio Grande River have changed the processes that have created the mosaic of riparian habitats valuable for ecosystem functioning, wildlife, and enjoyment by residents. These changes have created conditions that have increased the frequency of historically unprecedented disturbances such as fire and aggressive invasion of exotic species. Restoration activities and planning efforts have begun to reverse these effects, yet large areas of the Middle Rio Grande State Park, commonly called the Bosque, are still being affected by ecosystem changes. Studies of the Rio Grande and other Riparian corridors suggest that lack of overbank stream flows, reduced channel mobility, and disconnection of the river hydrology from floodplain hydrology are causing senescence of cottonwood forests and other riparian plant communities. The objective of this research is to create and execute a methodology that can quantify the statistical distribution of plant species within the Bosque relative to elevation (species elevational distributions). This is

necessary to identify whether a community/population is in decline/expanding, through age determination of new stands surveyed in the field relative to their elevational distribution. Ultimately this paper seeks to find a methodology to discern the realized niche of plant communities at specific sites within the Bosque that can be statistically quantified and spatially mapped in GIS to guide site plans and restoration activities. This methodology seeks to addresses the question of what specific areas would be appropriate for upland or riparian community restoration, as well as determining the most ecologically effective way to implement restoration in terms of agency goals.

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Chapter 1

Introduction

Cultural Landscape Background:

Current environmental realities are the result of a long history of human settlement, management strategies, cultural conflicts, and changing societal environmental awareness. The cultural and environmental perspectives driving restoration of the Bosque's ecosystems have developed and changed over time in response to land use practices, research, and political and legal trends and challenges.

The impacts of cultural land use of the Rio Grande have been occurring for thousands of years, and historic settlement of the area and practices still influence legal precedence to this day. Beginning with hunter gatherer native Americans that lived in the area 11,000 to 15000 years ago at the end of the last ice, age people began to use the areas resources for hunting and gathering. (Crawford 22). Subsequent sedentary agricultural settlement of the valley by pueblo native Americans has been occurring for the last 2000 years. Their influence on the land ranged from clearing land for agriculture, using high river flows to irrigate fields, and constructing small scale diversions. The descendants of some of these peoples living in current pueblo communities have paramount water rights of the Rio Grande to this day.

The trend of subsistence agriculture using flood irrigation from the Rio Grande continued with the settlement of the Spanish in the 16th century. These communities began alteration of the valley by clearing more land for agriculture and diverting water through newly constructed acequias, a system of irrigation canals. Land was increasingly being converted to agriculture, from 73,600 acres in 1700, to 100,400 acres in 1800 (Stafford et al. 1938) Some domestic animals and plants were introduced to the landscape, but human impact on the valley was still constrained by the flooding river and its everchanging plant communities of wetlands, cottonwoods, willows and grasslands.

In the 1800s Anglo settlement in the middle Rio Grande increased and with it came an expansion of commodity agriculture, commercial livestock grazing, and timber harvesting. These land uses began to change the environmental and cultural landscape. The increase development of agricultural land further increased, to 125,000 acres in 1880 (Crawford 1993. pg. 25). The exploitation of the Rio Grande watershed by the livestock and timber industries created widespread erosion that substantially increased the amount of sediment to an already high sediment load system. During this time, the number of domestic livestock increased to over 2000,000 sheep, more than 150,000 cattle, and 50,000 other domestic animals such as horses and mules on rangelands within the Rio Grande watershed (Crawford 1993 pg. 25). During the first part of the 19th century, these conditions resulted in an abnormally high rate of aggradation of the bed of the river and its subsequent flooding of valley communities. These floods and the associated increasing in salination of soils reduced the productivity of commercial and noncommercial agriculture, creating the need for flood control and water management. The federal government authorized the Rio Grande project in 1905 to create irrigation systems and resulted in the construction of Elephant Butte Reservoir in 1916. Even with these new interventions the river still produced intense spring flows, and exhibited high mobility across the valley floor, thus maintaining its mosaic of natural habitats to a major degree. This limiting the spatial extent of economic development by threatening real estate development and farming.

The river retained its dominance of the valley until the New Mexico State Legislature formed the Middle Rio Grande Conservancy District (MRGCD) in 1923, with the authority and intent to reduce flooding, increase agricultural acreage by draining wetlands, and to construct irrigation works. Following the creation of the MRGCD, numerous water diversion and storage dams and levees were built, with the intention of reducing the mobility of the river.

Dams constructed by the MRGCD reduced peak flows and channel side drains lowered the water table. The excess material from dredging was used to create the levee system that restricted high flows to within the floodway. Direct dredging was also used to straighten the river to a restricted channel. The increased channelization of the river was aided by the installation of Jetty Jacks in the 1950's by the Army Corps of Engineers. These interventions were large steel barricades constructed to catch debris and sediment that stabilized the banks of the river, making them less susceptible to erosion. This resulted in a decrease in peak flows as well as altering the sediment regime of the river. An end to the free-flowing river and seasonal flooding was brought about with the completion of Cochiti Dam in 1973.

Changes in Hydrology and Geomorphology

The reduction in peak flows has had the most notable effect on river behavior and ecosystem dynamics. These reduction of post Cochiti closure flows increased exponentially with the magnitude of flood events. A comparison of flood discharge exceedance probabilities is shown for pre-Cochiti and post-Cochiti periods in Figure 1 and Figure 2. Examples in reductions from the Cochiti gauge show a reduction in 2-year event flows from 6400 cfs.(cubic feet per second) to 4,480 cfs., a decrease in 30 percent, and a reduction of 100-year event from 28,700 cuffs. to 12800 cfs., a decrease of 55 percent. A more extreme example of reductions is the decrease of the 100-year flow at the San Marcial gauge. The flows at this gauge have witnessed a 70 percent reduction pf the 100-year flood event. In the Albuquerque reach, which is where this study is located, the current 100-year peak flow is 12,600 cfs, which was a 10-year event before the construction of Cochiti damn, and the 2-year event has had a reduction from 7,090 to 5,410 cfs. (Mustetter Engineering). Cochiti Dam essentially attenuated the extremes flow ranges, reducing the probability of low and high flows. The authors of the report "Summary of the Geomorphology of the Middle Rio Grande" from which this data was taken, state how the reductions in peak flows alone would have result in the reduction of flood inundation and its associated ecological processes. Essentially what they suggest is that just the reduction in peak flows would have caused a reduction in the conditions necessary for the development of riparian plant community development, aside from the effects of channelization.

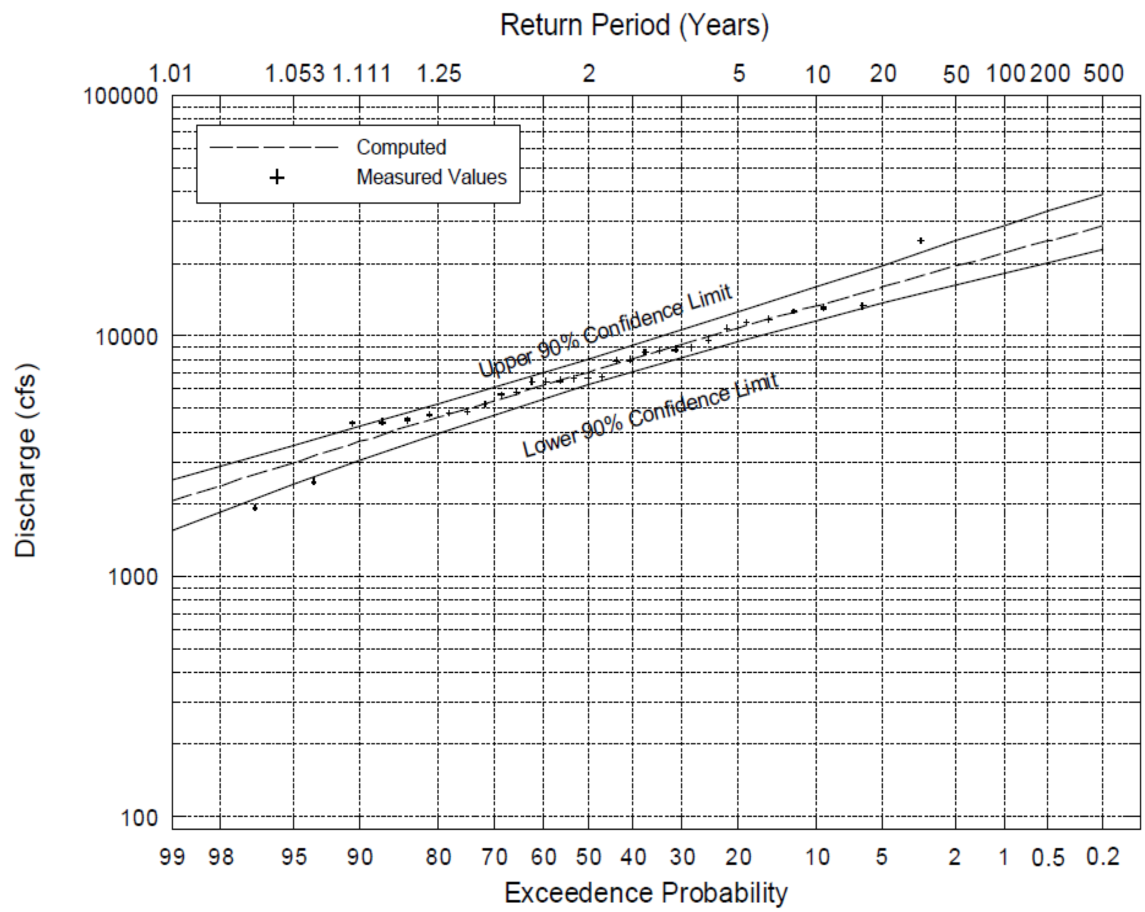

Figure 3.7. Pre-Cochiti flood-frequency curve for the Albuquerque gage, based on the period of record between 1942 and 1973.

3.11 Mussetter Engineering, Inc.

Figure 1.

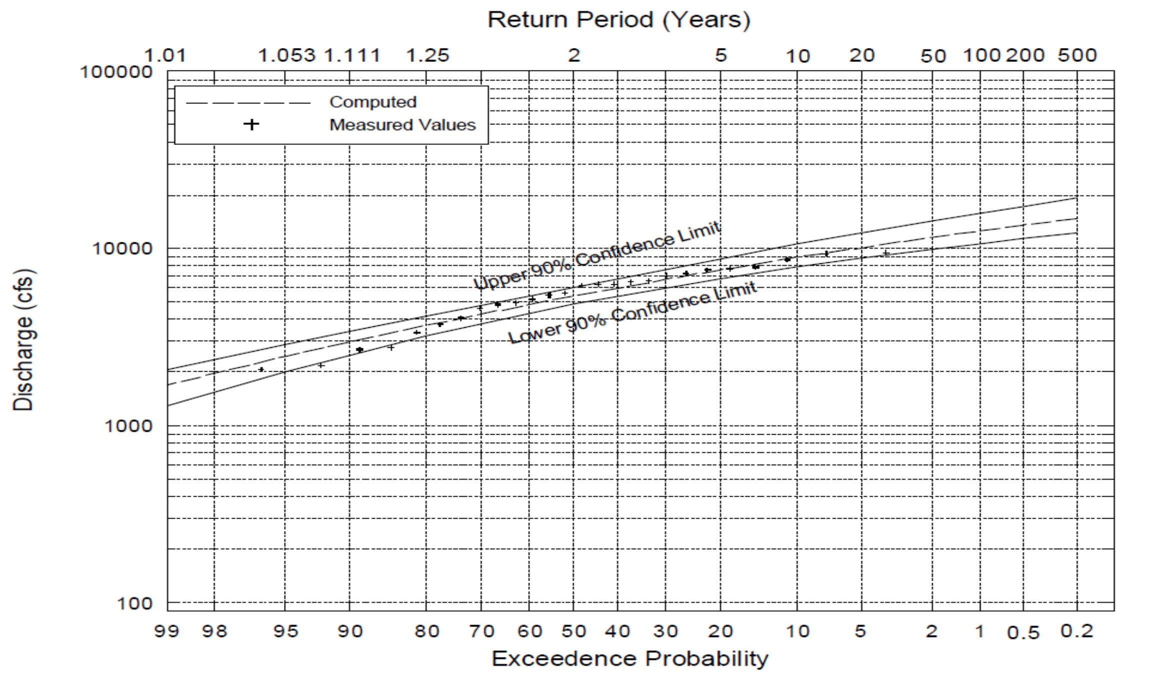

Figure 3.13. Post-Cochiti flood-frequency curve for the Albuquerque gage, based on the period of record between 1974 and 1999.

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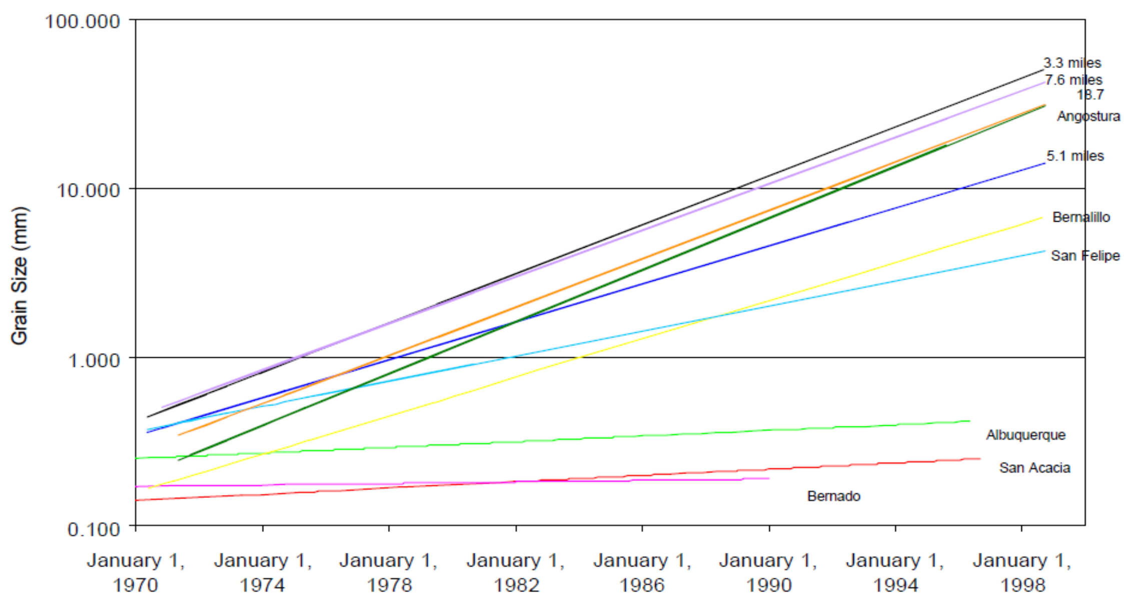
Figure 2.

Table 3.1. Peak flow hydrology (cfs).

	Return Period (yrs)					
	2-	5-	10-	20-	50-	100-
Cochiti (1926-1999)						
Pre-1973	6,400	11,200	14,900	18,700	24,200	28,700
Post-1973	4,480	6,830	8,350	9,770	11,500	12,800
San Felipe (1927-1999)						
Pre-1973	8,370	13,800	17,800	22,000	27,700	32,300
Post-1973	5,560	7,430	8,560	9,580	10,800	11,700
Albuquerque (1942-1999)						
Pre-1973	7,090	10,800	13,400	16,000	19,500	22,200
Post-1973	5,410	7,600	8,940	10,100	11,600	12,600
Bernardo (1937-1964)						
Pre-1973	5,180	10,200	14,300	18,800	25,400	30,900
Post-1973						
San Acacia (1936-1969)						
Pre-1973	9,510	14,700	18,400	22,100	27,300	31,400
Post-1973						
San Marcial (1925-1991)						
Pre-1973	5,680	11,900	17,300	23,600	33,200	41,500
Post-1973	4,160	6,290	7,610	8,810	10,300	11,300

Figure 3.

Other morphological changes caused by Cochiti Damn include coarsening of bed material and the progressive coarsening downstream with time (Mustetter Engineering). Sediment transport of the Rio Grande has also changed in post development conditions. The Rio Grande has a naturally high sediment concentration, one of the highest in the world, as much as 200,000 PPM. Post Cochiti conditions however have caused reductions from as much as 24,000 PPM in the 50's, to as low as 5,000 PPM during current times. (Baird, 1998). These changes have "affected the channel width, channel cross section, the ability of the river to laterally migrate, the capacity of the channel and its tendency to overbank, sediment storage and bar morphology, and bed composition" (Mustetter Engineering). The river has decreased in width in the Middle Rio Grande because of channel straightening, maintain a static geometry, and the bed of the river has degraded an average 7.5 feet between Angostura and Bernalillo. (Mustetter Engineering)



re 3.41. Regression lines showing changes of the D_{50} of the bed material between 1970 and 1998 for gage locations and other identified USBR range lines within the project reach of the Rio Grande. Data collected after 1992 represent averages of 3 samples taken on the range line.

Figure 4.

Research has shown that the size of the riparian zone, mainly the development of cottonwood forests, is directly related to peak flows and channel mobility, followed by times of relative geomorphological stability. The paper "Extreme Floods, Channel Change, And Riparian Forests Along Ephemeral Stream," (Friedman, Lee, 2002) studies similar high sediment load, highly mobile rivers in southeastern Colorado, and examines the development of Riparian forests after large flood events and the corresponding channel widening and post-flood channel narrowing. There is evidence and historical accounts that the period before Cochiti was one of large flood events and channel avulsions that resulted from a combination of natural and anthropogenic factors. Land use disturbances such as erosion caused by timber and grazing interests, increased runoff and sediment input of the river increasing channel mobilization. This would have created the environment necessary for largescale riparian recruitment, that was shortly followed by restriction of flows and channelization that would have protected new riparian stands, artificially freezing the successional clock at a certain period. This would suggest that the size of our current late successional stage riparian gallery forests is a relic of these events and possibly larger in spatial extent than in the pre-development period.

Changes in Riparian Ecology

The restriction of flows and other channel modifications removed conditions under which cottonwoods, willows, wetlands, and marshes regenerated with. The increased absence of saturated soils during seasonal floods corresponding with the release of seeds from riparian plants prohibits plant recruitment, and the retreating groundwater depth has begun to cause death of riparian tree stands (Catron et al, 2008). The presumed age for valley cottonwoods is between 150-200 years. The confined river channel between the levees, containing the mostly non-regenerating, single age stand cottonwood gallery forest, with the increasing invasion of exotic species such as Siberian elm, Russian olive, and Salt cedar, has now became the prominent riparian landscape during the majority of the 19th and early 20th century (Catron et al). This landscape became socially normalized, and for all its beauty, is a historically unnatural and unsustainable landscape.

The non- regenerative native riparian plant communities and aggressive invasion of exotic trees species have also caused an increase of fire occurrence in the riparian corridor. The unprecedented fires were historically rare and are caused by the lack of litter decomposition resulting from decreased soil moisture, increased fuel density from exotic tree species, and a reduction in natural restrictions to fire movement by wetlands and open areas. These fires are not only a threat to human settlements that abut the riparian corridor, but can also destroy what native plant cover exists. Research suggests that if these dynamics continue, the native riparian plant communities will continue to decline (Catron et al, 2008)

Under historic conditions, climate and vegetation of the Rio Grande Watershed were the dominant factors shaping the floodplain characteristics. Before major anthropogenic alterations to the river system, the Rio Grande was perennial, with an aggrading bed composed of sand. Watershed characteristics caused the river to migrate laterally across the valley bottom, caused by a process called avulsion, in which the bed would aggrade and after a flood event, move from its higher elevation to a lower elevation creating a shifting mosaic of dynamic depositional environments. (Ritter 236)

Changes in climate and its resulting effect on vegetation resulted in variable timing, intensity, and location of these flood events. Flood levels also created fluctuations in groundwater levels in areas next to the river. Direct and indirect effects of flooding such as removal of plants by floodwaters and alterations of substrates, provided heterogeneous sites for the development of vegetation communities that can start, end, or change the course of succession, or changing of plant communities from one to another. (Franz et al. 1978)

How these riparian plant communities organized themselves is through their evolutionary adaptation to reduce competition through niche differentiation. (Whittaker 1965, 1970, Franz et al 1778) This is the process by which species respond to environmental conditions and form normal distributions along environmental gradients. In this instance, the environmental gradients would be attributes related to flooding, (Whittaker 1960, Whittaker and Nearing 1964) which was the historical driving force behind community dynamics in the riparian corridor. These attributes include flood depth and duration, soil conditions (moisture, salinity), and mechanical disturbance, (removal from floods etc.). These can prove difficult to quantify simultaneously. Studies have shown a holistic way to describe and quantify how plants respond to these individual attributes in riparian plant communities is through how they respond to elevation or microtopography, smaller scale changes in landscape position. (Franz et al.1977) With the assumption that the probability of flooding become less likely with an increase in elevation, and that the effects of flooding become less influential as elevation increases, species then sort themselves along the elevational gradient in response to flood attributes. (Franz et al. 1977) In the Rio Grande bank and bed scouring, and channel avulsion from floodwaters created these microtopographic gradients that included a range of soil moisture, and groundwater conditions that cottonwoods, willows, and other wetland species responded to accordingly. Specifically, in the case of Cottonwoods, (Taylor et al) low elevation and bare soil that exhibit a flood drawdown rate of no greater than 2 cm/day is crucial for the germination of seedlings, that must be timed with the natural fall of seeds from nearby trees.   In areas where elevation prohibited the river from exerting its influence, upland communities were interspersed with riparian vegetation that continued upward into the adjoining mesas.

These conditions drove the dynamic structure of the Bosque, which was historically a mosaic of riparian and upland plant communities that existed on the terraces and mesas above the floodplain such as grassland and shrub lands. The movement of the river channel and its transportation of sediment created variable locations of riparian vegetation within the valley in which new stands were created one season, and possibly destroyed in the next season's high flows, creating stands of variable age. When riparian trees grew enough to hold soil in spring floods, they created interspersed groves of cottonwoods that grew to large stands attaining later successional stages (Crawford 1993, pg. 19). These stands historically exhibited low average age and age diversity. These stands of Cottonwood (*Populus deltoides va.*, *wizlenzii*) and Willow (*Salix* sp.) were interspersed with grasslands, small lakes and marshes and were associated with understory shrubs species in the shade or near canopy edges. Coyote willow (*Salix exigua*) occurred in thick groves near the river while taller willow species such as Salix *goodingii* and Salix *amygdaloides* grew in the understory of taller cottonwoods along with New Mexico Olive (*Forestiera pubescens*), *Bacharis sp*., False indigo bush (*Amorpha fruticosa*), wolfberry (*Lycium sp*), and mesquite (*Prospis sp*.) (Crawford 28).

Widespread wetlands that occurred in shallow water areas and abandoned channel locations contained cattails, sedges (*carex* sp., *Eleocharis* sp), rush (Juncus sp.), *Equieseitum* sp., buttercup (Ranunculus *cymbalaria*), pepperwort (*Marsilea mucrontata*) and mosquito fern (*Azolla mexicana*). Cottonwoods and willows also grew on the edges of these wetlands while a floating plant community of algae and duckweed grew in deeper water, with submerged shallow water species of chara, water-milfoil (*Myriophyllum spicatum*), and hornwort (*Cerotaphyllum demersum*) (Crawford 1993, pg. 28)

Wet meadows occurred in areas where the water table existed near ground elevation that exhibited high soil salinity in which sedges, rushes, salt grass (Distichlis stricta) and yerba mansa (Anemopsis californica) grew (Crawford. 1993, pg. 28).

As high peak flows, sediment yield, and their associated effects of channel mobility were reduced, the environmental gradients necessary for these riparian communities largely ceased, and the floodway has become hydrologically disconnected from the river. These factors have led to the decline in riparian plant communities within the Bosque.

Chapter 2

Developing Awareness and Changing Perspectives

Socio-Political Responses and Management Developments

These ecological changes became apparent to the public and resource managers at an alarming rate in the 1990's. Restoration of the riparian zone in the Middle Rio Grande Valley was catapulted into public discourse with the listing of the Rio Grande silvery minnow and the southwestern willow flycatcher. Increased concerns about the decline of the "Bosque", which was publicly valued for its continuous cottonwood gallery forest, and increasing awareness of the invasion of exotic species also became central to planning efforts and public discourse. These introductory concerns stemmed from the proceeding decades' increasing awareness of water scarcity and legal delegation of priority water rights. Conflicts between agricultural and municipal water acquisition created a will to support water conservation awareness. An increased understanding of limitations of groundwater resources as relating to municipal development and its connection to surface water resources all converged as prominent issues during the 1990's.

A landmark date for the beginning of Bosque restoration was 1991, as awareness for the declining Cottonwood forests increased and a Congressional appointment of the Rio Grande Bosque Conservation Committee was developed with the support and input from the public. The group consisted of a citizen committee to study the factors contributing to the decline of the Riparian forest. This resulted in the creation of the Biological Interagency Team that helped to bring about the "Middle Rio Grande Ecosystem: Bosque Biological Management Plan" written by Cliff Crawford in 1993, which has been a central document guiding restoration since, containing 21 recommendations that have since been central in guiding restoration. (Robert 2005. pg.9)

To implement the Biological Management Plan, congress funded the U.S. Fish and Wildlife Service to create a committee, the Middle Rio Grande Bosque Initiative, to guide the implementation of the plan which sought to "enhance, and restore biological values by addressing ecological functions within the Middle Rio Grande. Participation in BIG (Bosque Improvement Group) was non-exclusive group and included engineers, scientists, educators, administrators, tribal members, historians, farmers, private landowners, and others concerned with the health and preservation of the middle Rio Grande Ecosystem." (Robert 2005 pg. 9).

As BIG gained momentum, there was an increasing acceptability of the concept of ecosystem approach (a central concept in the biological management plan) to resource managers. Just as this breakthrough in the collective understanding of society and agency culture was gaining acceptance, the realities that constricted restoration and preservation of the river were becoming increasingly apparent. Legal battles between environmental groups, state water managers, tribal governments, the federal government, state water compacts and local municipalities highlighted the water deficit in the state water budget. During this time groundwater rights were not connected to surface water rights, and the relationship of surface water and groundwater was poorly understood. It became apparent that the aquifer was as not as big as expected at a time of increasing demand. There was an increase in unmonitored digging of wells and municipalities began increasing pumping of aquifer water for unmanaged growth. These issues began to create increased awareness of water shortages and the strained administration of water resources. It became understood that the river was the most significant contributor to groundwater recharge in the valley, and that the pumping of shallow groundwater reduced groundwater levels and river flows (Robert 2005 pg.18 pg. 33).

With the listing of the silvery minnow on the endangered species list in 1994, there was an increased litigation of water rights. This included conflicts between farmers and resource managers during times of scarcity during which water managers were federally required to deliver instream flows for the minnow, as well as the juggling of water from different sources to provide for the need but not violate interstate compacts. Restoration in the 1990s was shaped not only by the changing geomorphological realities of the river system, the deficit of water, and by a host of such legal, political, and cultural conflicts.

During this time, the scarcity of river water and tensions between user groups was so high that there was a need for the creation of a state water plan. The “white paper”, or Water Management Strategy for the Middle Rio Grande Valley was being written in 1996, which was an interagency plan to deliver water for critical reaches of the silvery minnow and at the same time allow for other water users including district irrigators (Roberts 2005, pg32) This plan represented diverse interests within the valley. Conflicts between urban and agricultural interests became a cultural battle, as well as the racial and class conflicts inherent in these interests. The tension was so high, a representative of the U.S. bureau of Reclamation was cited on record stating, “You’d have thought we were negotiating peace in Bosnia…..” (Rob Leustheuser, Albuquerque Office, U.S. Bureau of Reclamation, personal communication, November 26, 1996. (Roberts 2005Pg.32))

In 2005 Cliff Crawford wrote in the preface to the “Review of Bosque Restoration” how demographic pressures and increasing water demand threatened the Bosque, and introduced the idea of ecosystem shifts as resource availability change.

Crawford states how successful functioning of the ecosystem depended on its access to river water and the hydraulic linkage of the landscape to that water and the aquifers beneath (Crawford 1993 pg.11) He became increasingly convinced that restoration needed to be planned with current resource availability, instead of struggling to re-create and environment for which the resources no longer existed to maintain it.

The 21 recommendations of the plan focus on sustaining biological quality, diversity and abundance of species, environmental and ecological processes that sustain them as well as ecosystem integrity of the Bosque, river and floodplain. Ultimately the goal was to create "… a capacity of the ecosystem to return to an organizing, self-correcting condition, following a major disturbance". "One is to carefully alter the ecosystem by making it resemble, in structure and function, that of the pre-regulation past. Think of this as a form of restoration in which the resulting mosaic of largely native vegetation enhances biodiversity, conserves the basins water, and reduces the intensity of Bosque fires within the confines of the levee system." (Crawford 2005, pg. 12)

Crawford's statement and the 21 recommendations contradict each other in that to have a functioning, self-correcting and organizing ecosystem, changes in the driving force, structure, function, and disturbance regime will reflect an ecological reality that differs from the pre-regulation past. The disturbance regime has shifted from what was historically prominent so the ecosystem must also change to reflect this. Given the reality of constraints, preservation of the Bosque, an ecosystem produced by largescale floods and channel migration, needs to be rethought in terms of scale and organization to reflect the force that the river exerts on the landscape, not to be an anthropological imposition of an idealized relic landscape that does not reflect hydrogeomorphic realties.

Studies of long term absence of largescale floods within riparian forests in semi-arid area show how a decrease in channel mobility can cause a reduction in the size of cottonwood forests and an increase in upland plant communities, grasslands. The previously mentioned study by Friedman and Lee studies how riparian plant communities develop in the decades of channel narrowing after short term channel widening caused by extreme floods. The study also shows that if no significant floods occur, riparian forests begin to senesce into grasslands within a 150-200-year period.

Changing Restoration Perspectives

Restoration goals seek to mimic historical ecological processes in hopes of providing the substrate and hydrological conditions that native riparian vegetation needs to develop. Hydro geomorphological constraints limit the spatial effectiveness of these restoration activities in the Middle Rio Grande State Park, and some ecologists recognize that current conditions cannot support riparian habitats within the full extent of the Bosque. (Crawford 2005) To reverse these effects management organizations such as the Army Corps of Engineers, Middle Rio Grande Conservancy District, Albuquerque Open Space Division, and environmental groups have been creating restoration plans and implementing them as funding, political will, and environmental constraints allow.

Restoration activities including bank lowering, back channel creation, river management strategies and flood modeling that enable substantial amounts of overbanking and spring peak flows have allowed for some areas of extensive riparian plant community regeneration. Yet the alteration of geomorphological and hydrological processes, competition from exotic species, and a long history of land use disturbance, inhibit the Bosque's ability to return to natural stable state of a mosaic of native plant communities including riparian habitats such as cottonwood forests, wetlands, shrub lands and grasslands. Riparian Restoration activities in the Albuquerque reach of the Rio Grande have had difficulty in restoring self-sustaining riparian plant communities in the full extent of the area between the levees because hydro geomorphological constraints, as well as politically and socially framed goals and expectations that may not reflect realistic environmental conditions.

Direct and indirect effects of floods such as removal of plants by floodwaters and alterations of substrates provided a heterogeneous template for the development of vegetation communities that can start, end, or change the course of succession, or changing of plant communities from one to another. Restoration goals seek to mimic these processes in hopes of providing the substrate and hydrological conditions that native riparian vegetation need to develop. Hydro geomorphological constraints limit the spatial effectiveness of these restoration activities in the Middle Rio Grande State Park, and some ecologists recognize that current conditions cannot support riparian habitats within the full extent of the Bosque. (Crawford 2005)

The Bosque was historically a mosaic of riparian and upland plant communities, including savannas comprised of upland plants that existed on the terraces and mesas above the floodplain such as grassland and shrub lands. Restorations are increasingly seeing these plant communities are useful tools in meeting management goals of reducing fire hazard, combating the spread of exotic species, reducing evapotranspiration rates, and re-creating native plant assemblages. A description of successful riparian restoration that would allow for temporal shifts or succession of native plant communities enabled by restoration efforts would include the developments of wetlands and willow shrub lands, aggrading and later becoming cottonwood forests, or scouring of banks creating wetlands that dry and become meadows as the river shifts locations. This paper suggests restoration methodologies should include dynamics of natural successional pathways that rivers in semi-arid landscapes exhibit in response to reduced flows. This would allow the for naturally occurring scenario of the decline in size of riparian plant communities, the expansion of grassland or savanna areas, essentially acknowledging and deliberately managing the terrestrialization of the Bosque. (Friedman, Lee, 2010)

A Framework for Managing a Changing Landscape

There are a myriad of restoration activities being performed that have been the result of research and planning being carried out in the Middle Rio Grande by the Army Corps, of Engineers, the Middle Rio Grande Conservancy, the U.S. Fish and Wildlife, as well as other agencies. The most intensive restoration activities have specific riparian target communities, with other activities including removal of exotic species and sowing of seed for passive development of other vegetation such as grasses, shrubs and herbs. The location of riparian restoration efforts such as backchannels, swales, and bank lowering are determined using hydrological models that show where overbanking would occur at different flow scenarios and model the depth and duration of inundation such as the Flo 2d program (Tetra Tech 2002). These models have geospatial outputs that are used to locate some restoration activities This modelling essentially delineates the theoretical area where overbanking could a possibility for the development of riparian habitat. Beyond these areas riparian plant communities would theoretically not be self-sustaining. It is in these outlying areas that overbanking theoretically would occur in very rare events (unless of largescale floods such as 100 yr. flood) and that groundwater would not exist at sufficient levels that riparian areas would eventually senesce, and upland plant communities would expand and eventually replace the riparian plants.

Studies have shown that there is a linear relationship between flood probability and elevation in valley bottom floodplains in which, as elevation increases flood probability decreases. This relationship is determined by the hydrogeological conditions of the watershed including climate, vegetation, soils, and land-use. General river morphology of bottomland alluvial floodplains is such that the riparian areas contain the active channel, at the locally lowest elevation, and towards increasing elevations, the floodplain and its terraces (Ritter et al. 2002). This results in fluvial landforms that exhibit small to largescale changes in topography that effect abiotic conditions such as soils, groundwater, disturbance, and flood inundation intensity and duration. Riparian and upland plant species respond to this environmental gradient containing topography and resource availability through their adaptations. (Franz et al. 1977)

“Species distribution in the floodplain can be viewed as the outcome of a stochastic process in which species compete for favorable microsites for establishment. Species with specialized physiological and structural or life history adaptations, germinate and survive with higher probability than the species without such adaptations as the frequency, depth, and duration of flooding increases. Life history strategies, especially the timing and modes of seed dispersal, germination requirements, and seedling growth rates may be as important as physiological and structural mechanisms of flood tolerance in maintaining separation in this stochastic process, although the latter have received far greater attention" (Franz 1977, pg. 178)

Through the process of evolution, these adaptations result in plant community organization in which species reduce competition through niche differentiation. (Whittaker 1965, 1970) Species responses to resources and competition with other plants result in their individual grouping into their niches, which is their statistical occupation in space determined by responses to axes that represent abiotic and biotic factors. (Franz 179) In this instance, this is displayed through bell shaped curves that overlap and have populations centers along the gradient of topography and resources. (Franz 178). In the riparian setting the main factor driving abiotic and abiotic conditions is flood stage, and as previously stated, flood probability generally decreases with increasing elevation, creating a gradient of flood probability, its associated resource gradients, maintained by the topographical gradient. According to studies by Franz et al. 1977, species sort themselves out in statistically predictable manner along this topographic gradient.

In the middle Rio Grande modification of flood regime and other watershed changes have altered this gradient, with problematic yet predictable responses of declining native plant communities. With peak flow levels generally attenuated through reservoir operations and other management strategies, recent historic activities resulted in a general homogenization of floodplain topography. The restriction of channel mobilization and its associated production of a diverse microtopographic gradients have reduced the environments associated resource gradients. This has resulted in the reduction of riparian plant communities over the last 80 years, and despite restoration and management strategies to offset these changes, the alteration of geomorphic and topographic dynamics has been a hurdle for restoration along the Bosque in the area between the levees in some areas.

The senescence of cottonwood forests and reduction of wetlands is a major restoration problem that managers seek to mitigate, but because of previously mentioned constraints, historic natural hydro-geomorphic conditions cannot be fully restored in the Rio Grande. With the reduction of peak flows and sediment transport caused by upstream damming and its accompanied reduction in channel mobility, amplified by decades of bank stabilization, areas of the topographic gradient that riparian species once occupied have become smaller with the subsequent reduction of riparian plant communities. In other similar non-modified watersheds containing cottonwood forests with long term reduction flows and channel mobility, the natural response of plant communities is a reduction in the area of riparian species and an expansion of upland plant communities, in particular grasslands and shrub lands. In agreement with the late Cliff Crawford's later research, this dynamic should be used as a tool to expand the mosaic of native plant communities within the Bosque, as well as aid in meeting management goals. Yet the creation of more areas of strictly upland species and the reality of the senescence of riparian communities is resisted by managers and community members.

To quantifiably discern the new realized niche of riparian species and the theoretical niche of expanding upland species which can be represented spatially, a restoration site planning/ evaluation method that uses the correlation between elevation with plant species distributions should be used. This model developed by Franz et al (1977), uses the statistical distribution of species along the topographic gradient, species elevational distributions, to predict how plant species will respond to changes in flood probability. In their study plant species surveys were taken along multiple transects that ran perpendicular to the river, that also corresponded to river cross sections, with the elevation of each surveyed plant individual taken. Elevational benchmarks were made at the lowest elevation of each transect, with survey equipment being set up at 50m intervals. At each of these intervals the species and elevation of all trees were taken to the nearest 3mm, within 10m along a line away from each side of the transect. The number of species at each transect was compiled along the mean of the elevational frequency of each species, and its standard deviation. The data from this study showed that most species populations did respond predictably, forming bell shaped curves along the topographic axis, showing how species exhibit niche differentiation and their subsequent organization into coherent plant communities. (Whittaker 1965, 1970)

Chapter 3

Methodology and Objectives

Objectives

The main goals of this research are to A.) create and execute a methodology that can quantify the statistical distribution of plant species within the Bosque relative to elevation (species elevational distributions) B.) Identify whether a community/population is in decline/expanding, through age determination of new stands surveyed in the field relative to their elevational distribution. C.) Ultimately this paper seeks to find a methodology to discern the realized niche of plant species at specific sites within the Bosque that can be statistically quantified and spatially mapped in GIS to guide site plans and restoration activities. This methodology seeks to addresses the question of what specific areas would be appropriate for terrestrial community restoration, what the plant community structure and composition should be, as well as determining the most ecologically effective way to implement restoration in terms of agency goals. Alternative cost and labor sharing programs will also be explored.

Methodology:

The conditions for restoration management vary widely along the Rio Grande, such as channel incision in some areas and flooding in other areas. Species elevational distribution analysis is a consistent and widely applicable method for studying plant species distributions and planning for restoration. With the relationship between elevation, flooding, and plant species distributions being theoretically predictable, data should reveal discrete areas, (realized niche represented by normal distributions) of riparian regeneration, and areas of senescence in which riparian vegetation in not regenerating. This study proposes taking plant surveys like that of Franz et. al. (1977), along 5 transects running perpendicular to the Rio Grande and analyzing species elevational distributions, with the addition of spatializing the data in GIS for site planning and evaluation.

The site of the study is located just north of central on the east side of the river, between the active channel and the levee in the Middle Rio Grande state park, approximately .25 miles square miles in area. The site has been subject to some restoration efforts, including areas of significant bank lowering and back channel excavation. The vegetation is a mixture of mature cottonwood forest with little to no understory, open areas with grass species including *Sporobolus* sp., and other grasses such as *Sorghastrum nutans*, willow thickets at lower elevations near the river with wetland plants in their understory, and areas of young cottonwood stands, as well as significant stands of invasive trees.

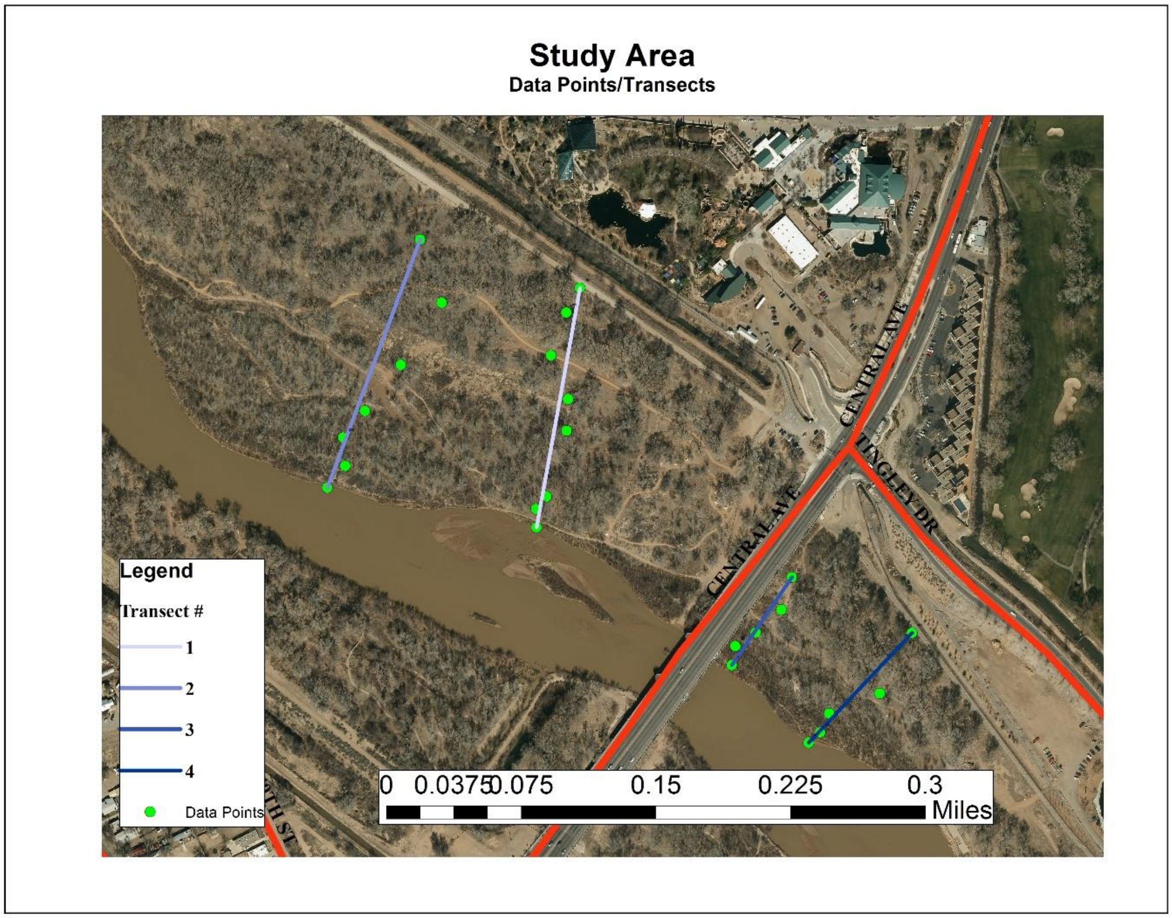


Figure 5.

<u>Vegetation Survey:</u>

Four transects were taken on the site, approximately 500 feet apart. Each transect begins just outside the active river channel, and extends away from the river towards the levy. Each transect was chosen to have a variety of vegetation types and approximately equally spaced along a .25-mile-long running parallel to the river. Each cross transect began nearest the river, with rebar stake driven into to the ground to hold a tape measure at one end and another stake at the other end of the transect was driven to delineate a sub transect. Starting from the first stake which was generally the southernmost, all plants that encountered the tape measure were counted and identified in chronological order, and data was collected in a notebook. From a stake delineating the approximate center of each sub transect to once again hold the tape measure, distances of 50 to 200 feet were then measured to the center of each preceding cross-transect, where the line intersect method was again used. This process was repeated between 4-10 times a transect until the riverside levee was reached, depending on the width of the riparian area. Using the tabular format of the BEMP (Bosque Ecological Monitoring Project) species list for the middle Rio Grande, each species encountered was listed in excel in numerical order beginning with its plant code, botanical name, common name, growth type, native or exotic status, and perennial or annual growth habits. All cottonwood individuals were measured by their diameter to discern relative age, whether recently germinated or mature.

Elevation survey:

One elevation was taken at each cross transect, with the assumption that elevation within the cross transect varied less than .5 feet. Elevations were determined with the help of the Survey Office of Albuquerque. Using GIS Survey receivers and a data collector, the base unit was set up at the parking lot area just north of Central Avenue and Tingly Dr, and relative elevation was determined using the nearest permanent monument/benchmark that was located underneath the Central bridge at the southwestern location. After the receiver was calibrated to the permanent benchmark, we proceeded to take the elevation at the center point of all the cross transects. Beginning with transect 1, the receiver was held at the center of cross transect 1, which was collected as elevation point 100. Each successive cross transect was collected as 101, 102… etc. Each following transect was collected in sequential order, transect 2 cross transects collected as 200, 201,..etc, transect 3 cross transects collected as300, 301,..transect 4 cross transects collected as 400, 401 and so on. After the data was collected, The Survey Office provided data points with their X, Y, and Z values in tabular form.

Species elevational Distribution

After the location and elevation data were received and transcribed into and excel sheet, the elevations for each cross transect were then entered into the last column of each cross transect. All data from the transects were then combined into a single sheet, and then sorted by species in alphabetical order into species groups. Once the data was sorted by species the average elevation and its standard deviation was calculated. The total number of observances, wetland status, average elevation and standard deviation of each identifies species was also compiled. Standard deviations were not calculated for species with less than 5 observations, Histograms and normal distribution curves were then created for each species to analyze individual distributions. General trends in distribution of plant communities were analyzed through grouping all plants species by their USDA wetland indicator status. This allows the average elevation of community types to be analyzed. The National Wetland Indicator Status Ratings are as follows and taken from the US Army Corps of Engineers “National Wetland Plant List Indicator Rating Definitions”. (Lichvar et al 2012)

OBL (Obligate Wetland Plants)-Almost always occur in wetlands, With Few exceptions, these plants (herbaceous and woody) are found in standing water or seasonally saturated soils (14 or more consecutive days) near the water’s surface

FACW (Facultative Wetland Plants)-Usually occur in wetlands, but may occur in non-wetlands. These plants predominately occur in hydric soils, often in geomorphic settings where the water saturates the soils or floods the soil surface at least seasonally

FAC (Facultative Plants)-Occur in wetlands and non-wetlands. These plants grow in hydric, mesic, and xeric habitats. The occurrence of these plants in different habitats represents responses to a variety of environmental variables other than just hydrology, such as shade tolerance, soil pH, and elevation, and they have a wide tolerance of soil moisture conditions.

FACU (Facultative Upland Plants)-Usually occur in non-wetlands, but may occur in wetlands. These plants predominately occur on drier or more mesic sites in geomorphic settings where water rarely saturates the soils or floods the soil seasonally

UPL (Upland Plants)-Almost never occur in wetlands. These plants occupy mesic to xeric non-wetland habitats. They Almost never occur in standing water or saturated soils. Typical growth forms include herbaceous, shrubs, woody vines, and trees.

Chapter 4

Results and Discussion

In terms of overall plant community distributions, the data suggests the communities do sort themselves out along the topographic gradient. Figure 6. shows the range of the averages for each wetlaand indicator groups. Obligate wetland species occur at the lowest elevations, with communities of decreasing hydrophytic characteristics occurring in successive higher elevations.

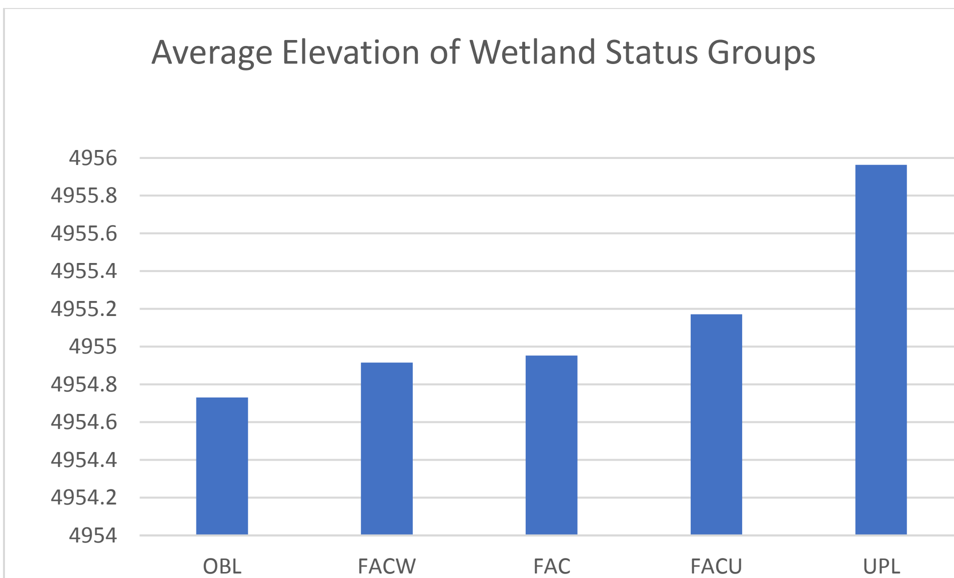


Figure 6.

A deviation from this trend does occur on an individual species level. This trend may result from higher elevations near the river at Transect #1 in general. Riparian plants near the river at this site that can access groundwater due to their proximity to the channel. Research suggests that groundwater availability decreases with distance away from the river. Results such as this may also be due to the dynamic morphology of the river and the persistence of human effects on the river such as channel and bank stabilization. In general, the floodplain structure also differs from that of the Franz et al (1977) study. Their river system studied was a more typical of a river channel with a floodplain that has a consistent increase in elevation away from the river. The current morphology of the Rio Grande is unique because of channelization and anthropogenic factors that froze the river at an elevation above the surrounding floodplain. Pre-regulation conditions of a braided river also differ from the Franz study in that The Rio Grande exhibited widescale spatial variability of features caused by river avulsions such as side channels, oxbows, and abandoned channels that create a more irregular topography. These factors coupled with groundwater dynamics appear to be the some of the causes of this deviation from the trend. Deviations may also be caused by relic dynamics, such as plant facilitated by cottonwood shade that were established during pre-regulation conditions.

Other than these deviations from the overall trend, plants (OBL and FACW groups) that require inundation, soil and moisture conditions driven by the availability of floodwaters exist at lower elevations and have average elevations of 4954.73 and 4954.916088 respectively. Plants in the FAC community group has an average elevation of 4954.95, the FACU group has an average elevation of 4955.17, and the UPL group has an average elevation of 4955.96.

In the study area lower elevations which contained the majority of OBL and FACW plants mainly existed in sites that experienced restoration techniques such as bank lowering or backchannel creation. These areas contained most obligate wetland plants and displayed the majority of the regenerative riparian community. As elevation increases, riparian plants do occur, but these are species that seem to not have as strict water requirements or special recruitment requirements such as Salix exigua. Plants in mid-level elevations also appear to be plants that are typical of late secondary riparian succession, or plants that establish themselves once soil is stabilized by pioneer riparian species. In the higher elevations plants in the facultative upland group (FACU) and upland group (UPL) are dominant.

A significant factor in the ecosystem is the ubiquitous presence of mature Populus deltoids ssp. Wislenzii, commonly known as cottonwood, which are a hallmark of the landscape. The study area is once again in the “bosque”, which means forest in Spanish, and refers in this instance mainly to cottonwoods. These stands presumably were established during largescale floods and geomorphic events during the beginning of the 19^{th} century before flood control was enabled by the construction of Cochiti Dam. These stands are considered senescent, or non-regenerative. Once again restoration and environmental awareness are centered around this species, and managers are attempting to maintain the current gallery forest structure. Despite their visual dominance in the landscape, cottonwoods only accounted for 3% of the overall sample, and less than half are regenerative individuals, which only occur in the lower elevations near the river, created by restoration efforts.

The wetland indicator status can be thought of as categories of plants that range from hydric to xeric, with plants experiencing total submersion for prolonged periods, to plants submerged seasonally, to plants that can tolerate a wide array of soil moisture and sunlight requirements, to plants that grow in dry soils rarely saturated by water. Another way to think of these categories is a temporal sense, in which each group responds to disturbance at a time during the flood cycle. Plants in each group are evolved to thrive to the varying conditions of disturbance. In the case of the Rio Grande, this is varying flood stages or lack thereof. These groups respond to floods cyclically and result in the mosaic of plant communities in the landscape. Obligate plants occupy the area at or near a stable water level, facultative wetland plants are evolved to occupy and stabilize areas subject to prolonged flooding, and once these areas are stabilized they are made available to facultative plants that can survive long periods without saturation, some periods of high flows, and other diverse conditions. As in the Franz et al study, migration or avulsing of the channel such as in the Rio Grande, after periods lacking floods, communities then shift to facultative upland and upland which are mesic to xeric plants occupying geomorphically stable and drier terrace areas. This assumes a pattern of succession in which an area is flooded, colonized by riparian plants, and then stabilized by terrestrial plants as the channel moves away and water becomes unavailable. This pattern is exhibited in the study, “largescale floods” in which landscape change is quantified over time through aerial photography and stream gauge data.

If the pattern observed in the Friedmen et al (2002) study is assumed to be comparable to conditions of the Rio Grande which for the most part they are, sharing a braided stream type with high sediment loads, and extreme channel mobility followed by prolongued periods that lack extreme floods, then the same directional trend of the landscape moving forward in time away from riparian communities to upland communite would presumably follow.

Fig. 8. Bottomland forest dynamics on the Colorado Piedmont (modified from Friedman et al. [1997]).

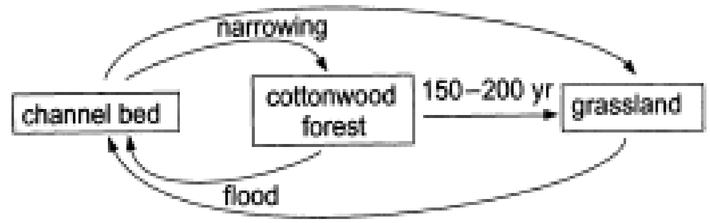


Figure 7. (“Extreme Floods, Channel Change and Riparian Forests Along Ephemeral Streams.” Friedman et al. 2002)

The following figure provides a breakdown of community types by wetland indicator status. The largest group is the facultative upland, followed by the facultative, with the third largest group being the facultative wetland. What this shows is that 32%, much of the sample population consists of non-riparian plants. Assuming a directional change after massive flooding, followed by a period lacking substantial floods, or a persistence of current conditions, the plant community groups shown below would be increasing towards the xeric end of the spectrum. In the Franz et all study this is a natural process of succession. In the instance of the Rio Grande this dynamic of riparian habitat decline is caused by anthropogenic alteration of the hydro-geomorphic regime. In these current conditions, managers are struggling to maintain the relic riparian forest structure against the reality of environmental conditions.

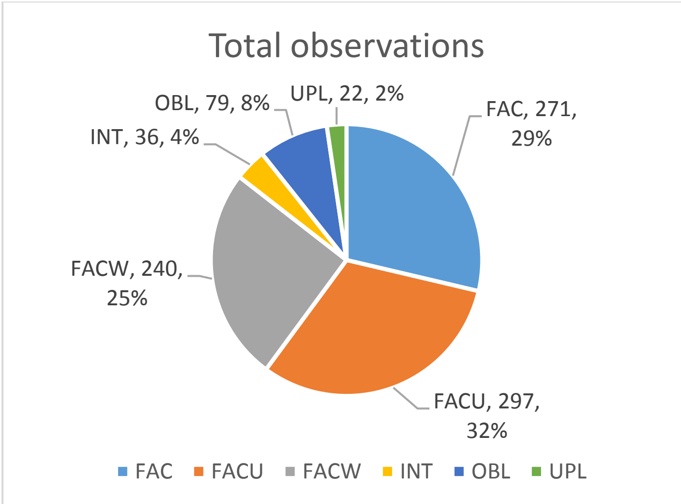


Figure 8.

The following table is a summary of the results of field data collection. The individual species observations were used to create the wetland indicator groupings for community analysis and spatial analysis.

Summary of Collected Data

Species	Total Observations	Wetland Status	Average elevation	Standard deviation
Ambrosia sp.	118	FAC	4955.356273	0.643497269
Apocynum cannabinum	20	FAC	4955.3983	0.448485695
Baccharis salicifolia	1	FAC	4954.46611	0.659955681
Chloracantha spinosa	17	FAC	4954.5819	
Elaeagnus angustifolia	4	FAC	4955.5555	
Elymus canadensis	1	FAC	4953.536	
Forestiera pubescens var. pubescens	1	FAC	4954.299435	0.431232753
Lycium torreyi	4	FAC	4954.601147	0.328019958
rhus trilobata	1	FAC	4955.01454	0.592416718
Senecio flaccidus	8	FAC	4959.49215	
solanum rastrum	3	FAC	4955.711225	
Solidago Altissima ssp. Gilvocanescens	4	FAC	4955.4725	

Sorghum halepense (L.) Pers.	32	FAC	4956.068852	0.271481506
Sphaeralcea angustifolia	35	FAC	4955.3671	0.02541609
Sporobolus airoides	22	FAC	4953.906217	0.276643431
Elymus longifolius	33	FACU	4954.6427	
Helianthus annuus	5	FACU	4955.74024	
Morus alba	4	FACU	4953.6549	
Oenothera pallida	4	FACU	4956.162129	2.494528119
Robinia pseudoacacia	9	FACU	4955.5555	
Salsola tragus	36	FACU	4954.987575	
Solanum elaeagnifolium	28	FACU	4955.706676	0.330010222
Sorghastrum nutans (L.) Nash	76	FACU	4956.1469	
Sporobolus cryptandrus	101	FACU	4954.5819	
Sporobolus flexuosus	1	FACU	4954.53976	0.939677873
Amorpha fruticosa	16	FACW	4955.1575	
Equisetum laevigatum	18	FACW	4955.270122	0.063850798
Euthamia occidentalis	13	FACW	4955.3918	
Juncus sp.	4	FACW	4954.486675	0.769265761
Muhlenbergia asperifolia	100	FACW	4954.85726	
Salix amygdaloides	1	FACW	4954.36106	0.39392736
Salix exigua	83	FACW	4954.486675	2.25632343
Salix gooddingii	5	FACW	4955.693938	
Convolvulus arvensis	5	INT	4962.009029	0.5523399
Kochia scoparia	21	INT	4955.547409	0.324172002
Saccharum ravennae (L.)	10	INT	4954.9815	
Carex sp.	54	OBL	4954.3066	
Populus deltoides ssp. wislizenii	25	OBL	4955.154291	0.644114164
Aristida purpurea	2	UPL	4955.885955	0.277140452
Atriplex canescens	1	UPL	4957.886377	3.450642633
Dimorphocarpa wislizeni	2	UPL	4955.2719	
Pleuraphis jamesii	1	UPL	4956.152974	2.283055316
Sporobolus contractus	7	UPL		

Ulmus pumila	4	UPL	4955.340425	
xanthisma spiulosum	5	UPL	*4955.2431*	
Verbascum thapsus	*1*		4963.3376	

Table 1.

Chapter 5

Recommendations

What the data in this study shows is a quantifiable distribution and shifting of plant communities relative to elevation. Elevation is an easily measurable proxy for soil moisture, flood probability, and soil conditions. Not only does this provide data on how individual plant species respond to an environmental gradient, but it provides a framework for understanding the physical location of existing plant community types relative to landscape position. The landscape is currently subject to anthropogenic forces that are creating largescale community shifts such as fire, invasion and removal of exotic tree stands, as well as the natural process of riparian senescence exhibited as cottonwood die off, that is cause by human alteration of the hydraulic regime. What is left are small to largescale areas that are blank slates for plant community development. Current restoration strategies consist replacing what was there prior to disturbance, which in most cases is an already declining mature riparian forest. This study suggests using species elevational surveys to prescribe plant communities to these areas that are supported by data showing what is growing and reproducing in the landscape, not replacing non-regenerative stands.

Using the average and standard deviation from plant surveys, the realized niche of communities and individual species can be determined. These values exist as elevational ranges that have spatial parameters that can be used for restoration planning. This is providing a quantitative framework for implementing the ideas for Cliff Crawford's "Landscape alteration". In his proposal which he deemed radical in the late 1990s, and whose ideas are still controversial realistic reactions to present conditions, he discusses the necessity of a shift in community structure to more closely resembles the mosaic structure of the historic wider floodplain. The main tenants of his proposal can be summarized from this paragraph from the introduction to his paper.

"We present this picture in more detail below. It amounts to a restoration of the Rio Grande's riparian zone between the levees—an action that will both diminish the potential for frequent and intense Bosque wildfires and reduce water loss due to evapotranspiration (ET). The operation will involve the removal of most of the Bosque's invasive trees, and some senescent native species as well. It will also create savanna-like woodland patches that can retain or be planted with an understory of native grasses and shrubs, and perhaps small numbers of widely spaced individual trees or groves useful for animals moving between patchy woodlands. This combination of tree reduction and increased open space will reduce overall ET in the altered landscape and increase water in its shallow aquifer." (Crawford 2005 pg. 1)

Cliff Crawford wrote this paper in his later years when he realized that environmental and societal constraints would never allow the riparian system to be restored to pre-regulation conditions. Instead he argues for an implementation of a restoration plan that is essentially a functional restoration of that system on a smaller scale that is proportional to available resources and processes. This falls in line with a statement from the Bosque Biological Management Plan, which has been the paramount restoration document for the last 30 years. These ideas fall in line with the original intent of the Management Plan. Just to reinstate how appropriate this idea fits into the overall framework of the plan, it is important to restate Crawford's own ideas from the original plan.

". Ultimately the goal was to create "… a capacity of the ecosystem to return to an organizing, self-correcting condition, following a major disturbance". "One is to carefully alter the ecosystem by making it resemble, in structure and function, that of the pre-regulation past. Think of this as a form of restoration in which the resulting mosaic of largely native vegetation enhances biodiversity, conserves the basins water, and reduces the intensity of Bosque fires within the confines of the levee system." (Crawford 2005. pg.12)

Written 10 years after the management plan, this excerpt stresses the importance of changing the way we think and manage the riparian corridor which we all love, is needed by wildlife, and performs ecosystem functions. These ideas juxtaposed paint a clear picture that managers must not seek to appease societal nostalgia instead of implementing landscape wide strategies that are aimed to create a functional ecosystem, even if it differs from the one known in the recent past, which some studies suggest is to some degree a relic of human disturbance. Therefore, quantitative research based restoration planning must be implemented, because the ecosystem is irreversibly changing whether managers want to realize it or not, and the change is going to be to a smaller riparian community. This can either be realized and deliberate restoration of upland native plant communities can be restored in their place, which is part of the natural process of succession, or managers can continue to treat the Bosque as an ad-hoc garden, planting species that cannot develop into self-organizing communities that are regenerative self-correcting in response to disturbance.

This study proposes that using the elevational distribution of plant species and communities is a way to plan for and implement the terrestrialization and aridification of the Bosque, while still providing for statistically driven spatial planning for riparian plant communities. The data has shown communities display a separation along the elevational gradient, which is a proxy for flood stage and disturbance, and that having normal distributions 50% of their population will be within the first and third quartile of their mean. This is what this research suggests is the realized niche of the species or plant community. To create prescriptive restoration maps in GIS, the gathered data is used to create spatial ranges for plants on a community level using the national wetland indicator status groups.

This is accomplished in ARCMAP using raster data digital elevation maps (DEM) for the area. The elevation ranges of wetland species indicator groups have numerical parameters, therefore a DEM can be reclassified to show these display these ranges. This is done using the raster calculator tool, in which the spatial areas of the DEM are selected with the input values of the 1st quartile and 3rd quartile of the species groups to produce output files that can show the expected range of all the wetland status indicator groups over a study area.

The following maps represent the ranges of data observed in the field for each wetland status indicator group between the first and third quartile of the data set. These ranges show the geographic areas where certain plant groups are regenerating and thriving, or where their realized niche is.

Obligate Wetland Species

The following is a map showing the elevational ranges of the obligate wetland species. As defined from the Army Corps of Engineers wetland classification, these plants almost always occur in wetlands, with few exceptions. They are (herbaceous and woody) are found in standing water or seasonally saturated soils (14 or more consecutive days) near the water's surface. These plants were found in the lowest elevations of the survey. This group's spatial extent is likely to be strongly reduced by overlaying groundwater depth data. Areas further away from the river may experience high flows during the spring but drawdown may be rapid and not likely able to support wetland vegetation. The actual area of community restoration recommendation would be smaller than that of the GIS output because of groundwater restrictions. The current theoretical extent or restoration recommendation area of the obligate group is 14.7% of the total study area.

Species	Observations	Wetland Indicator Group	Average Elevation
Carex sp.	54	OBL	4954.3066
Populus deltoides ssp. wislizenii	25	OBL	4954.53976

Table 2.

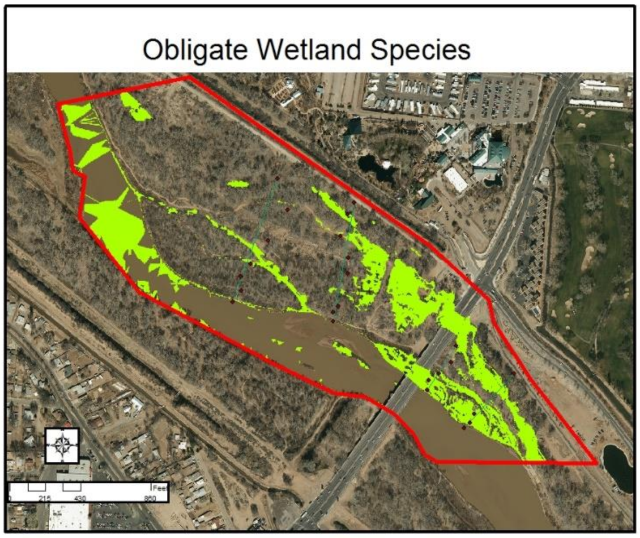


Figure 9.

Facultative Wetland Plants

The facultative wetland species mainly occur in wetlands, but may occur in non-wetlands. These plants predominately occupy hydric soils, often in environments where the water saturates the soils or floods the soil surface at least seasonally. Data from the survey shows that these plants occur on a slightly higher range of the topographic gradient than obligate wetland species. The spatial extent of this group is likely to be different than what the elevational distribution data suggests as result of plants near the river at higher elevations having access to shallow groundwater and soil moisture. This group could likely occupy a greater extent of higher elevations near the river and possibly a reduction in areas further away from the river. Clonal reproduction in some species such as *Salix exigua* also increases its resource range by not strictly relying on specific geomorphic settings for reproduction. The current theoretical extent or restoration recommendation area of the facultative wetland group is 14.8% of the total study area

Table 3.

Species	Observations	Wetland Indicator Group	Average Elevation
Amorpha fruticosa	16	FACW	4955.1575
Equisetum laevigatum	18	FACW	4955.270122
Euthamia occidentalis	13	FACW	4955.3918
Juncus sp.	4	FACW	4954.486675
Muhlenbergia asperifolia	100	FACW	4954.85726
Salix amygdaloides	1	FACW	4954.36106
Salix exigua	83	FACW	4954.486675
Salix gooddingii	5	FACW	4955.693938

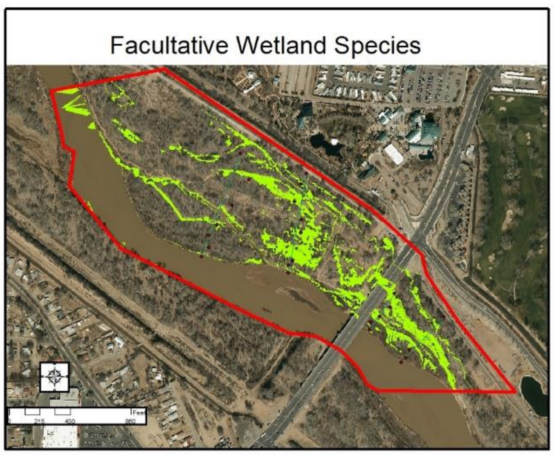


Figure 10.

Facultative Species

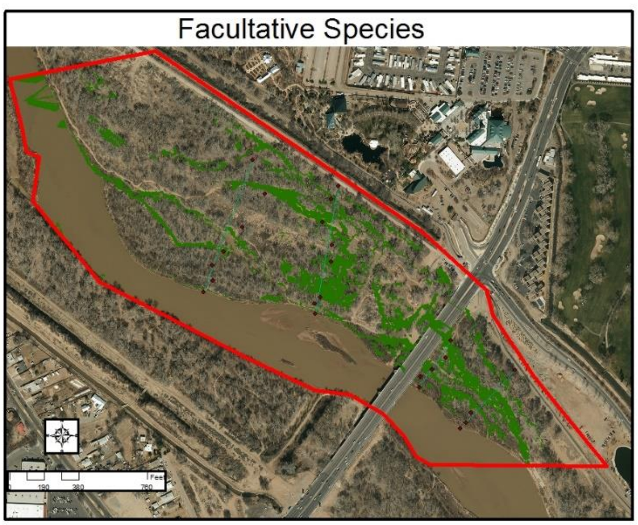
The facultative plants occur in wetlands and non-wetlands. These plants grow in a range of hydric, mesic, and xeric environments. These species exist in a range different habitats. Their ability to occur un such a range represents adaptations to a variety of environmental variables other than hydrology (Lichvar et al 2012). They can occupy variable conditions of shade tolerance, soil pH, and elevation, and have a wide tolerance of soil moisture conditions. The plants observed during the vegetation survey are typical of shrub understory of middle age cottonwood stands and herbaceous species growing in the shade, that would not typically be found in upland environments. This elevational range also displays and increase in open areas. This group is dominated by grasses such as *Elymnus canadensis, Sporobolus airoides,* and *Sorgham halapense* and shows and increasing dominance of grasses with elevation and aridity. The shrub understory with herbaceous groundcover may be relics from facilitation during the time when the cottonwood overstory was established. It is uncertain whether this group will persist in this range as cottonwood canopy declines. There is a possibility that there would be a reduction in the shrub/herbaceous species and an increase in grass species as well as more xeric herbaceous species. It is important to note that the shrub and herbaceous species in this group may be abundant in the Facultative wetland group and be present in the Wetland range. What this group possibly represents are the transition areas between riparian and uplands plant communities. The current theoretical extent or restoration recommendation area of the facultative

Species	Total Observations	Wetland Status	Average elevation
Ambrosia sp.	118	FAC	4955.356273
Apocynum cannabinum	20	FAC	4955.3983
Baccharis salicifolia	1	FAC	4954.46611
Chloracantha spinosa	17	FAC	4954.5819
Elaeagnus angustifolia	4	FAC	4955.5555

Elymus canadensis	1	FAC	4953.536
Forestiera pubescens var. pubescens	1	FAC	4954.299435
Lycium torreyi	4	FAC	4954.601147
rhus trilobata	1	FAC	4955.01454
solanum rastrum	3	FAC	4955.711225
Solidago Altissima ssp. Gilvocanescens	4	FAC	4955.4725
Sorghum halepense (L.) Pers.	32	FAC	4956.068852
Sphaeralcea angustifolia	35	FAC	4955.3671
Sporobolus airoides	22	FAC	4953.906217

group is 17.9% of the total study area

Table 4.



____ Figure 11.

Facultative Upland Species

The facultative upland group mainly occurs in non-wetlands, but may occur in wetlands. These plants occur on drier or more mesic sites in environments where water rarely saturates the soils (Lichvar et al 2012). The increasing aridity of higher elevations not subject to seasonal flooding drives an increase in the abundance of grasses. This group as well as some of those from the facultative group, represent the terrestrialization of the Bosque in the absence of largescale flooding. The ranges of the environmental gradient and spatial extent of these species parallels the shift from riparian forest to open grassland species shown in the Friedman and Lee paper in the absence of flooding after 150-200 years. Once again flooding does occur in some of the elevations these species occupy, but does not result in the development of riparian vegetation possibly due to rapid drawdown and hydraulic disconnection from the water table and the lack of geomorphic alteration of topography and soils. High Flows that reach these elevations rarely alter topography and soils. The current theoretical extent or restoration recommendation area of the facultative upland group is 22.51% of the total study area.

Species	Observations	Wetland Status	Average Elevation
Elymus longifolius	33	FACU	4954.6427
Helianthus annuus	5	FACU	4955.74024
Morus alba	4	FACU	4953.6549
Oenothera pallida	4	FACU	4956.162129
Robinia pseudoacacia	9	FACU	4955.5555
Salsola tragus	36	FACU	4954.987575
Solanum elaeagnifolium	28	FACU	4955.706676
Sorghastrum nutans (L.) Nash	76	FACU	4956.1469
Sporobolus cryptandrus	101	FACU	4954.5819
Sporobolus flexuosus	1	FACU	4954.53976

Table 5.

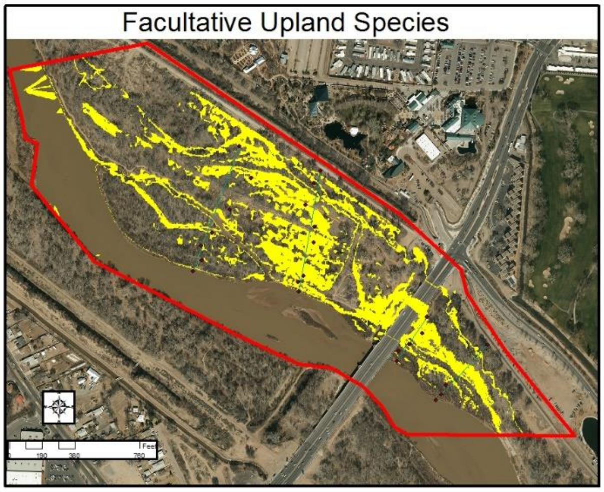


Figure 12.

Upland Species

Upland species almost never occur in wetlands. These plants occupy mesic to xeric non-wetland habitats (Lichvar et al 2012). These species almost never occur in standing water or saturated soils. The species that occur in these ranges and have the spatial output representing survey data display species that typically exist in on adjoining mesas and terraces. The suggested dominance of the spatial output of this group further displays an increase in aridity and terrestrialization of the floodway. These species often occur with those in the facultative upland group. The upland group and facultative upland group represent species that make up the savanna open areas that Cliff Crawford recommended being incorporated into restoration planning to reduce evapotranspiration, aid in controlling massive fires, and establish widescale native plant assemblages that are adapted to the static and arid geomorphic setting of the floodway. The apparent dominance of this group is a result of the geomorphic constraints and management strategies during the early to mid-19th century to reduce peak flows and reduce channel mobility. Many of the sites that currently occupy this elevational range are dominated by invasive species and have yet to undergo restoration efforts. The current theoretical extent or restoration recommendation area of the upland group is 30% of the total study area.

Species	Observations	Wetland Status	Average Elevation
Aristida purpurea	2	UPL	4955.885955
Atriplex canescens	1	UPL	4957.886377
Dimorphocarpa wislizeni	2	UPL	4955.2719
Pleuraphis jamesii	1	UPL	4956.152974
Sporobolus contractus	7	UPL	4955.2719
Ulmus pumila	4	UPL	4955.340425
xanthisma spiulosum	5	UPL	*4955.2431*

Table 6.

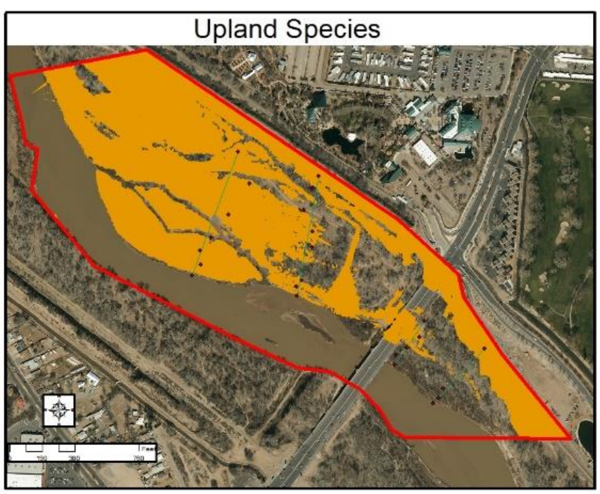


Figure 13.

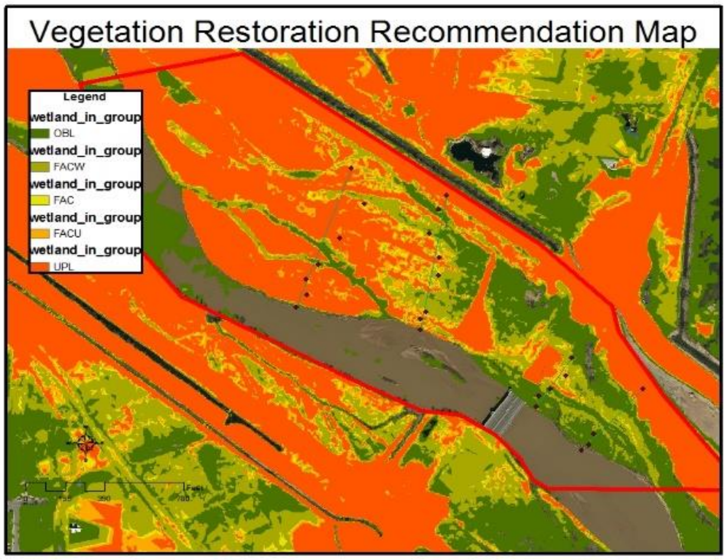
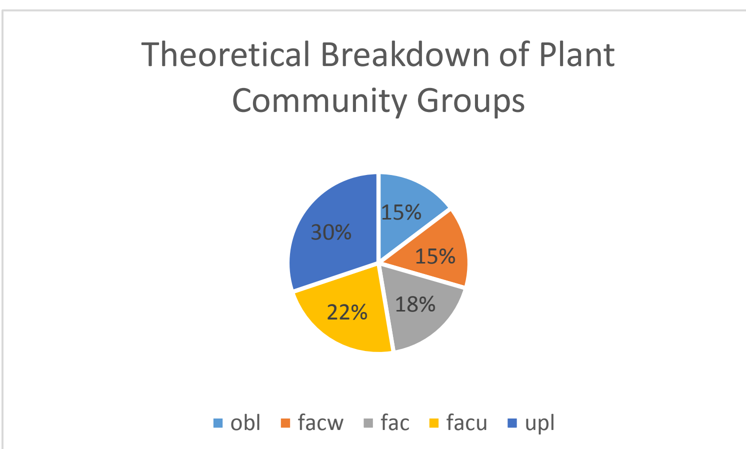


Figure 14.

Figure 15.



The assumption that plant species sort themselves out along a topographic gradient proved itself to be quantitatively valid with some explainable variation. An observational analysis of this data in GIS on a large scale also supports the assumption with some exceptions. The effects of soil moisture conductivity, groundwater level, and the dynamic variation of land forms from the historic movement of the river, create exceptions to the trend. The assumption once again is that wetland status of species increases with a decrease in elevation and that with an increase in elevation, the more likely it is that upland species will be dominant. The aforementioned possible causes of variation to the trend occur in higher elevation areas near the river. This is where riparian species have access to soil moisture due to soil conductivity and shallow groundwater. Another area of substantial deviation from the trend is low areas far away from the channel in which upland plants are dominant, possibly due to the lack of available groundwater and soil moisture. Some of these areas do experience seasonal flooding, as a result of water management to mimic the natural hydrograph of the river, but the lower groundwater depths possibly create a rapid drawdown that is not able to support widescale riparian development. On a geospatial level, mapping could filter out these results by adding a groundwater layer and quarrying known ranges of soil moisture requirement in these areas. Figure represents what a restoration recommendation map would look like encompassing all the wetland status indicator groups, that would result in the mosaic of upland and riparian plant communities that once existed across the wider historic floodplain on a smaller scale. The implementation of such as map would have substantial visual changes to the landscape of the Bosque that would include large open grassland areas.

Conclusion

If a methodology such as the one proposed were to be an accepted management strategy, planning for the changing ecology of the Bosque would involve a substantial public information process. Residents of the Middle Rio Grande Valley react very strongly towards threats to the health of the beloved Bosque, and the changes that are occurring in response to the negative hydraulic and geomorphic management strategies are not well understood amidst the broader public. There is a public understanding that the mature cottonwood gallery forest is an original functioning ecosystem that should remain in perpetuity. Even amongst natural resource managers, ideas suggesting substantial change to the Bosque are met with resistance. This study does not propose the removal of any native vegetation stands. It is intended to understand the natural changes in vegetation communities, quantify their ranges as a function of elevation, and provide recommendations as to where specific plant communities should be restored in the event of disturbances. These circumstances that maps such as the ones created in this study would be intended for use could be disturbances such as fires, revegetation after invasive stand removal, or largescale cottonwood die off because of declining groundwater or natural stand death. The plant species observed and listed in this study are in no way a complete inventory of species in total or in community groups. What the study shows is a decrease in the range of riparian species due to lack of geomorphic conditions allowing for their regeneration, and an overall reduction in the spatial extent if available moisture from groundwater or flooding. If managers seek to increase the range of riparian plant comminutes, what this study shows is that restoration activities such as bank lowering and backchannel creation near the channel where they can be connected to shallow groundwater resources are successful. Back channel creation further away from the channel that are inundated from high flows that experience a more rapid drawdown appear to be less successful.

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