Conceptual Restoration Plan
Active Floodplain of the Rio Grande
San Acacia to San Marcial, NM

Volume 1 of 4

Phase I. Data Collection and Analysis

Phase II. Specific River Issues

Phase III. Concepts and Strategies for River Restoration Activities

Final Draft Report

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Save Our Bosque Task Force

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Conceptual Restoration Plan for the Active Floodplain of the Middle Rio Grande – San Acacia to San Marcial

Phase I. Data Collection and Analysis

Phase I Introduction

This document presents the compiled information to support a conceptual floodplain restoration plan for the Middle Rio Grande reach from San Acacia to San Marcial. It discusses the Phase I effort of six phases that include:

I. Data Collection and Analysis
II. Specific River Issues
III. Development of the Restoration Concepts and Strategies
IV. Development of the Restoration Plan for the Riparian Corridor
V. Preparation of the Monitoring Plan
VI. General Instructions and Information

At the end of Phase I, an analysis of specific river issues 'Phase II' is presented that will guide the restoration plan. The information compiled in Phase I will provide the basis for investigating and resolving specific river restoration issues. It should be noted that Phase I data collection and analysis represents a compilation of existing data, mapping and information. No new field studies were conducted. This final report constitutes Phase I and II of the six phase restoration plan. Please note that Figures for Phase I were placed in Appendix A and the figures for Phase II are located within the report text. A bibliography of related literature is presented in Appendix I. Following the publication of the Phase II Draft Report, review comments were received and responses to the comments were prepared. These are presented in Appendix J.

The overall goal of the project is to develop a comprehensive river and floodplain restoration plan for the Rio Grande reach from San Acacia to San Marcial. The restoration planning process is designed to be inclusive involving close coordination with the project Oversight Committee. It is the intent of the Tetra Tech ISG project team to coordinate this effort with the various federal and state agencies as well as local entities and individual stakeholders. At the first Oversight Committee meeting on June 6, 2002, committee members offered the following specific goals and objectives:

- Restore channel function, form, and processes.
- Maintain cottonwood bosque and re-establish cottonwood regeneration.
- Address floodplain structural encroachment.
- Recognize historic uses in restoration planning.
- Integrate adaptive management into the restoration design.
- Restore a mosaic of native riparian vegetation.
- Enhance channel conveyance capacity to pass high flows safely.
- Notify and seek feedback of landowners regarding conservation easements.
- Address potential for water salvage.

Phase I Scope of Work

The Phase I scope of work was divided into four general categories and 16 individual tasks that were distributed with the project schedule at the first Oversight Committee meeting. The first category includes project administration and coordination with the Oversight Committee. Specific tasks are to compile existing reference materials including GIS mapping. The remaining three categories include a review of historical information, fluvial geomorphology and habitat analysis.

Coordination

1. Coordinate First Oversight Committee Meeting
2. Prepare a Working Bibliography
3. GIS Base Maps

Review of Historical Information

4. Compile Historical Maps and Aerial Photos
5. Comparative Analysis of Historical Geomorphic and Vegetative Changes
6. Compile Historic Hydrographs for USGS Gages
7. Coordinate Oversight Committee Review

Fluvial Geomorphology

8. Bed Slope Analysis
9. Bed Load, Suspended Load and Wash Load Analysis
10. Geologic, Geomorphic and Sediment Yield Analysis
11. Delineate Subreaches
12. Analyze Bed Aggradation/Degradation Trends
13. Analyze Overbank Flooding and Flood Frequency
14. Display Results on GIS Mapping

Habitat Analysis

15. Vegetation Classification and Mapping
16. Wildlife Inventory

These four categories encompass the key elements of any river restoration plan, hydrology, geomorphology, biological resources, and water resource development.

The Focus of this Document

The focus of this report is to present a concise description of the data bases that will be used to examine the specific river issues. It will also present information that will support the restoration plan including a historical reconstruction of the river and riparian ecosystem evolution. It is intended that this will be a working document to help integrate the Oversight Committee into the restoration planning process.

The primary uses for this document are:

- Provide a working document to pursue the specific restoration related issues and activities.
- Create a historical understanding of the channel changes and trends.
- Compile databases for analyses in Phase II tasks.
- Identify any existing data or information deficiencies.
- Create a framework with which to coordinate the response of the Oversight Committee.

Restoration Vision

The general approach to this project is to create riparian restoration opportunities by establishing favorable hydrogeomorphic conditions in the San Acacia – San Marcial reach. Such opportunities may take the form of providing a greater range of flow regimes, returning to a higher level of river dynamic behavior, removing constraints on channel processes such as invasive vegetation, expanding the active floodplain, increasing channel floodplain connectivity, physical reformation of the channel geometry, enhancement of the riparian system and management of the sediment load.

One restoration vision statement proposed by members of the Save Our Bosque Task Force is:

A riparian ecosystem that functions as natural as possible within the confines of 21st Century infrastructure and political limitations while respecting the traditional customs and cultures of the citizens of Socorro County.

There will be an opportunity to revise or rework this vision statement after the second Oversight Committee meeting. Other vision statements will be considered. This vision statement may evolve over time, but it identifies one of the key elements in the restoration plan, "a naturally functioning riparian ecosystem." As this project grows, the concepts of a naturally function river system will be explored. The river restoration vision will integrate a historical perspective, technical and physical limitations, potential to mimic form and process, possible irrecoverable losses, system dynamics, reversal of geomorphic trends and long term channel maintenance.

Establishing a vision enables us to set goals with high standards. Whereas practical limitations such as funding or available water may preclude obtaining some goals, it is also recognized that values change over time and what may be an insurmountable obstacle to restoration today may become a reachable goal in the future. For that reason, while system wide restoration may not be the guiding precept, it is critical not to limit future system wide restoration opportunities by designing a plan that may adversely affect a system wide restoration approach. Restoration sustainability within reasonable maintenance budgets is also an important objective. Practically speaking, not all restoration objectives will be achieved. Failure of some restoration components is likely and an adaptive management strategy will be necessary to mitigate some of the restoration shortcomings.

Restoration Issues

An email memo was distributed to the Oversight Committee during the week of June 10th requesting a list of issues related to potential restoration activities in the reach from San Acacia to San Marcial. From the responses, a list of restoration issues has been compiled and is broken down into categories associated with administrative/legal, hydrologic, geomorphic, biological and ecological topics. This list contains only those issues and objectives that have been identified by members of the Oversight Committee either through email correspondence or verbally at the Oversight Committee meeting. Tetra Tech ISG has not contributed to this list. This list is by no means all encompassing and additional issues will be raised as the project proceeds.

Administrative/Legal:

- Private landowner rights and wishes.
- Communication and planning between water management agencies.
- Environmental education for the general public.
- Provide a useful tool for Bosque management.
- Tie together various small projects with this restoration effort.
- Create a model plan for other restoration projects in the Middle Rio Grande.
- Bring together different area entities and provide input to various water management issues.
- Limited funding.
- Integrate restoration projects across private and government lands.
- Keep investigation independent of the ESA project.
- Residents of the valley driving restoration not endangered species.
- Address floodplain encroachment with structures.
- Level of management required to maintain restoration activities.

Hydrologic

- In drought years, water may be inadequate for flows south of San Acacia.
- River and riparian restoration must consider flow intermittency.
- Shallow aquifer hydrology must be understood to sustain restoration projects.
- Habitat restoration projects must include depletion analysis to insure Rio Grande Compact deliveries.
- Understand the inter-connectivity between the river and LFCC with respect to seepage and flow characteristics.
- Understand the surface/groundwater interaction.

Geomorphic/Hydraulic

- Restoration plans should consider the future disposition of the Low Flow Conveyance Channel (LFCC).

- Restoration plans should consider the Bureau of Reclamation’s plan to shift the river channel and LFCC to the west near San Marcial.
- Investigations related to the San Acacia diversion dam may result in operational constrains that could effect restoration activities.
- Levee rehabilitation in the San Acacia reach may require that some MRGCD bosque land will have to be reserved for levee project mitigation.
- Levee integrity must be maintained with habitat restoration projects.
- Potential future operations of the Low Flow Conveyance Canal.
- San Marcial Railroad Bridge conveyance capacity.

Biological

- Enhance habitat for the endangered species.
- Restoration removal of exotic vegetation should consider habitat enhancement for the southwestern willow flycatcher.
- The restoration plan should consider the Armendaris Ranch proposed Rio Grande silvery minnow habitat project using tailwater from Bosque del Apache NWR.

Ecological

- Removal of non-native vegetation; restoration of native vegetation.
- Alleviate stress on agricultural community to provide suitable wildlife habitat.
- Fire management for old growth cottonwood/willow bosque.
- Determine how historic flow regimes and groundwater levels affect vegetation.
- Types of habitats that are possible within existing flow regimes.

It should be noted that the Low Flow Conveyance Canal future operation scenarios and its possible relocation will not be addressed in this restoration plan.

Review of Historical Information

The Concept of Restoration from a Historical Perspective

The concept of river 'restoration' implies returning the river and its riparian environment to a form that reflects some previous time in history. In other river restoration projects this could be construed to mean a complete reconstruction of the river to a 'pre-human impact' point in time. The difficulty with applying this 'overhaul' concept to the Middle Rio Grande is that pre-European history in the river valley dates to about 1540 when the Spanish arrived by which time established pueblo communities along the river had already altered the floodplain. Early recorded observations on diversity and composition of floodplain vegetation did not reflect a pre-human floodplain condition. Whereas pre-nineteenth century observations of the channel morphology reflect minimal impact by humans, floodplain vegetation composition was already substantially disturbed by human impact.

A riparian and floodplain restoration plan for the San Acacia to San Marcial reach of the Middle Rio Grande will focus on river ecosystem and river process enhancement rather than attempting to restore the river to a known or prescribed historical condition. Based on the current river condition that involves severe channel narrowing, a limited areal floodplain and extensive invasion by non-native vegetation, any restoration activity will be a step towards a pre-historical environment.

Floodplain restoration planning will be constrained by the west side levee system. Other constraints that may limit the scope of restoration activities include water availability, land ownership and funding. Within these constraints, the restoration vision and plan for the San Acacia to San Marcial reach may fall short of a perception of the pre-historic river and floodplain. Within the limited areal extent of the floodplain, the restoration plan will attempt to restore the forms and processes that mimic the historic hydrogeomorphic interaction of the river and floodplain with the objective to increase aquatic and terrestrial habitat diversity. In this context, the restoration plan will take on a limited historic perspective.

It should be noted that the distribution and composition of plant communities in the Middle Rio Grande basin has not been significantly affected by climate change since the arrival of the Spanish. Scurlock (1998) states that the climate of the basin was relatively static during the past six centuries although the average temperature between 1450 and 1850 was slightly cooler than the post-1850 period. Even without climatic variation, the hydrologic record has been punctuated by extended drought and wet periods that accentuated the seasonal fluctuations in discharge.

To provide a background for the restoration plan, the environmental history of the Middle Rio Grande and specifically the San Acacia to San Marcial reach are reviewed in the following sections.

The Evolving Rio Grande Channel and Floodplain – A Brief Overview

A number of authors have compiled literature on historic observations of the Middle Rio Grande including Scurlock (1998), Marshall and Walt (1984), Horgan (1984), Crawford et al. (1993), Stotz (2000) and Tetra Tech (2002). These five documents have extensive historical descriptions and thorough reference lists. The historical perspective for this project will be largely drawn from these secondary sources rather than attempt to recover the primary documents. The three topics that are addressed in this section are:

- Channel morphology and the relationship to human occupation;
- Historical flows;
- Evolution of vegetation composition and areal distribution.

Channel Morphology and Human Occupation

The Rio Grande was the lure of prehistoric occupation in central New Mexico and in turn, human occupation had significant impact on the evolution of the channel morphology. For that reason, these two subjects are discussed in unison. Hopefully this amalgamation of human history and channel development will lend insight into the potential for restoration needs and concepts.

The climatic variation over the North American continent associated with the episodic ice ages was a key factor in the Rio Grande morphology since its birth about 5 million years ago. A series of ancestral basins were gradually joined together to create the Rio Grande valley (tectonic rift system). This valley has been filling with alluvium and fluvial sediments as the rift developed. There have been at least three major cycles of downcutting and backfilling in response to glacial episodes (Crawford et al., 1993; Hawley, 1975). Superimposed on the long term glacial trends are periods of high sediment loading from upstream watersheds that have resulted in channel avulsion and migration across the valley. During extended periods of low sediment yield, channel entrenchment occurred and floodplain terraces were created.

The concept of dynamic equilibrium as it relates to sediment delivery and bed slope may not appropriately describe the San Acacia South reach, in part because of the high variable nature of the sediment loads from the Rio Salado and Rio Puerco. Although dynamic equilibrium does not infer a static state of bed adjustment, there were continual major adjustments to bed slope resulting in channel avulsions and major changes in channel morphology. ‘Dynamic equilibrium’ may be a poor choice to describe the long term fluvial geomorphology of this reach. In response to land use and water resource development during the past 125 years, much of the Middle Rio Grande from Albuquerque to San Marcial has been aggrading and is not considered to be in ‘dynamic equilibrium’.

Prior to the 14th century, the channel morphology in the San Acacia South reach can be deduced from inference only, often from a geological perspective. Following the comments made in Crawford et al. (1993), the San Acacia – San Marcial reach was aggrading over the long term, slightly sinuous, braided at flows less than bankfull discharge and it was probably perennial as will be discussed later. The nature of the braided channel at lower flows included numerous sand bars and large sand macroforms. In response to high sediment loads from upstream tributaries, the river became choked with long-scale sand waves and shifted or avulsed its channel, migrating across the valley. The wetlands/marsh complex on the Bosque del Apache NWR (BOR, 1918 Maps) for example, is evidence of the historic nature of channel migration.

Most discussions of channel morphology begin with human use and development of the land and water related resources. The Rio Grande waters fostered the development of advanced civilization in the desert environment of central New Mexico (Marshall and Walt, 1984). The Rio Grande Valley was a travel corridor and center of habitation from the earliest human occupation of New Mexico beginning 11,000 to 15,000 years ago (Crawford et al., 1993). In the central Rio Abajo region (roughly San Acacia to San Marcial), most of the prehistoric settlements are located on the entire eastern portion of the valley which is flanked by elevated cobble benches overlooking the river (Marshall and Walt, 1984). Evidence of the Paleoindian in the riverine environment has essentially been lost (Marshall and Walt, 1984). The Archaic sequence begins 5500 to 4800 B.C. but the sites in the study region date only from 4800 to 3200 B.C. The appearance of maize occurs in the Armijo phase of the Archaic period from 1800 to 800 B.C. (Marshall and Walt, 1984). It is generally speculated that early nomadic hunters/gatherers leading up to about 400 A.D. may have burned some of the cottonwood bosque to drive out game (Crawford et al., 1993).

Marshal and Walt (1984) relate that the San Marcial Phase of historic occupation of the Rio Grande Valley spans the period from 300 to 800 A.D. and represents the earliest manifestation of sedentary riverine adaption in the Rio Abajo region. This distribution of sites indicate that occupation during the San Marcial Phase was restricted to the area from Black Mesa to Elephant Butte. This is regarded as an early stage of Puebloan development and all known sites are located adjacent to the river. It was estimated that 120 rooms occupied the riverside area, but the population density was considered low (Marshal and Walt, 1984).

The Tajo Phase corresponds with the Pueblo I period 800 – 1000 A.D. (Marshall and Walt, 1984). During this phase, there were an estimated 500-1000 people in the riverine environment representing the first major sedentary occupation. There is a shift from upland to lowland riverside sites during this period which are clustered around the Rio Salado confluence (Marshall and Walt, 1984).

The population along the river during the Elmendorf Phase, extending from 950 to 1300 A.D., appears to have increased only slightly to 1,000 to 1,500 individuals, but the population gathered into apartment complex villages (Marshall and Walt, 1984). Almost all the village sites are located on the east side of the river. There was a decided preference for the eastern margin of the river. This may been because the river, occupying one third to half of the river valley, may have been located on the western portion of the floodplain, leaving the eastern portion filled with marshes, wetlands and a more accessible potable water supply. Early in this period, 75 percent of the population was concentrated into five village centers. Throughout the period, there was a gradual increase in the number of rooms from 252 to 443 (Marshall and Walt, 1984). Communal activities included the development of irrigation works.

Significant human impact on the floodplain probably began with the first major population increase in the valley around 1350 A.D. Prior to this time, agricultural activities that may have begun around 400 A.D. probably had minimal impact (Crawford, et al., 1993.) The Piro Phase spans the period from 1300 A.D. to Spanish contact in 1540 A.D. This Phase is characterized by a dramatic increase in population, community coalescence into large plaza villages and the expansion into riverside areas (Marshall and Walt, 1984).

A substantial portion of the Piro population appears to have been concentrated into three large southern pueblos. The expansion into larger apartment complexes during this period was most significant in the Bosque del Apache/Milligan Gulch area. San Pascual, the largest pueblo, was estimated to have 1,500 rooms for a population of about 2,000 people. This was the ancestral Piro capital and was located on the east bench above the river. It extended over 30,000 square meters that was organized around four plazas (Marshall and Walt, 1984). Marshall and Walt (1984) surmise that the river hydrology and potential for extensive irrigation was the cause for the southern migration and nucleation into villages. The population in this area reached 7,500 people (Marshall and Walt, 1984). The lack of a tributary near the San Pascual community and other pueblos in this area is a clear indication that the population was dependant on the river for both domestic and irrigation water. This meant that either the eastside wetlands and marshes were sources of potable water throughout the year or that the during the low flow season, there was always sufficient flow in the river to support this large population throughout this period.

From the Spanish contact in 1540 to general abandonment of the region in the 1670's, known as the Colonial Piro phase, most of the pueblos were concentrated on the gravel benches and low alluvial banks along the river extending from roughly the Rio Salado to Tiffany Junction (Marshall and Walt, 1984). Elevated settlements were limited to the San Acacia mesas where depression structures may have been used as cisterns for water storage transported from the river below (Marshall and Walt, 1984).

After 1680, the Piro populations abandoned the pueblos and Hispanic farming communities gradually began to be established. Before abandoning the pueblos, most of the remaining Piro communities were situated directly adjacent to the active floodplain. Marshall and Walt (1984) indicate that the inhabitants were not discouraged by continual flooding and often returned to the inundated homesites to rebuild. As irrigation developed with the Spanish influence, water from the river was diverted into acequias by post-and-brush dams out into the river. When the river was low, teams of men and horses would set posts in the river along with horizontal branches and mud to direct the water into the acequias (Marshall and Walt, 1984). Channel avulsions or a major flood could shift the river away from the diversion canals with serious consequences.

Extensive agricultural irrigation in the watershed began about 1400 A.D. As it expanded over the next several centuries, water flow in the river progressively decreased. Culminating with the construction of Cochiti Dam in 1973, water resource development throughout the basin resulted in a system-wide and progressive decrease in mean annual flows and peak flow magnitude, frequency and duration. By the 1890s, irrigation diversion in Colorado had reduced flows in the Middle Rio Grande by 40 to 60 percent. As will be described in more detail later, the long term decrease in water supply has had a number of effects on the channel morphology in the San Acacia – San Marcial reach including aggradation, channel narrowing and a loss of channel/floodplain connectivity. The primary impact on this reach was a severely altered relationship between water discharge and sediment load.

Scurlock (1998) documents the progressive development of agriculture and livestock grazing in the Rio Grande drainage. Most of the soils on the floodplain are relatively deep, moderate to highly permeable sandy loam and are capable of producing high crop yields per acre (Marshall and Walt, 1984). Pueblo irrigation in the late 1500s was not as intensive as the later Spanish systems that used upstream diversion dams with gates. Estimates of the land cultivated in the Middle Rio Grande valley in the 16th century varied between 15,000 and 25,000 acres. This increased by 27,000 acres in the 18th century and there was an estimated 100,000 acres under cultivation in 1850. In 1880 irrigated and cultivated acreage peaked with 95,000 irrigated acres and 125,000 acres in cultivation. By the turn of the century flooding, high groundwater tables and waterlogged land caused a rapid decline in agricultural lands to 32,000 irrigated acres and roughly 50,000 cultivated acres in the Middle Rio Grande Valley (Scurlock, 1998). Through the early 1900s agricultural lands gradually increased and in 1942 although not reaching the levels in 1880, irrigated acreage was roughly 60,000 acres with a total of 118,000 cultivated lands (Scurlock, 1998).

Scurlock (1998) discusses the expansion of livestock grazing impacted vegetative cover and increased erosion. In 1598 Onate brought approximately 6000 livestock animals to mark the beginnings of the livestock grazing in New Mexico. Through the 18th century, livestock numbers grew slowly, but a sharp increase in the mid-1800s led to overgrazing in the watershed. There were almost 400,000 sheep in the Middle Rio Grande valley and surrounding uplands by the 1850s. A similar number of cattle were grazing in the territory by 1880. By 1846, most of the rangeland in valley around the population centers had been overgrazed. There were almost 2,000,000 livestock in the Middle and Upper Rio Grande basins by 1900. This sharp increase in livestock numbers greatly accelerated uplands watershed erosion.

There was an increase in sediment loading to the Middle Rio Grande in that started in the 1700s and accelerated in the late 1800s. The intensive livestock grazing and increasing land use resulted in rill and gully erosion and arroyo incision in the upper watersheds. Scurlock (1998) documents the channel incision of the Rio Puerco during the late 1800s. The Rio Puerco has been the primary source of sediment yield to the Middle Rio Grande in the past 150 years. In the 1870s, the Rio Puerco channel was relatively shallow near Cabezon with a wagon road crossing using large logs laid in the stream bed. By 1877, the stream had incised and there were deep channels, caving banks and falling trees (Scurlock, 1998). The farming and ranching communities along the Rio Puerco had a combined population of about 700 residents but during the decade of the 1870s, the number of sheep and cattle increased to over 100,000 and 9,000 respectively. By the end of the century, the number of sheep exceeded several hundred thousand (Scurlock, 1998). Channel incision was the result of simultaneous deepening and "coalescing of previously discontinuous channels" that was attributed to poor land management (Schumm, 1984). This abusive land use practice combined with above normal precipitation during this period resulted in the accelerated entrenchment of the Rio Puerco (Scurlock, 1998). The sediment loading in the Rio Grande basin streams continued to increase through the early 1900s. The increased sediment load from then tributary systems in conjunction with a decrease in the mainstem Rio Grande flows resulted in channel aggradation.

The Rio Grande valley had been aggrading for the last 20,000 years or so (Leopold et al., 1964; Hawley et al., 1976). In response to the increased sediment delivery to the Rio Grande, Scurlock (1998) reported numerous reported channel avulsions as evidence that the river aggradation had accelerated. At the San Marcial gage, there was a continuous rise in the bed and water surface elevation between 1894 and 1938 of almost 16 feet (Baird, 1998). Throughout this period, in the San Acacia to San Marcial reach, the channel was relatively wide and shallow and flooded frequently. Based on the 1918 BOR maps, the river and open sandbar areas extended over a half mile in some areas (near Lemitar and Bosque del Apache NWR). Channelization work temporarily halted the gradual rise in the bed elevation at San Marcial, but the continued aggradation resulted in a channel bed that was 24 ft higher in 1990 than in 1894.

Typically an aggradational river will have an increasing width-to-depth ratio. The river should be gradually getting wider and shallower. This is not the case in the San Acacia to San Marcial reach, the river has been narrowing over the past eighty years. The factors contributing to channel narrowing are reduced discharge, a decreasing sediment supply and vegetation encroachment on the active channel. The documented channel narrowing corresponds to flow regulation and decreasing peak discharge from 1912 (reservoir construction in Colorado) to 1974 (Cochiti Dam). Channelization and floodplain confinement (west side levee) have also contributed to the narrowing. The San Acacia – San Marcial reach has a constriction at each end between which the river has adjusted its slope in response to varying sediment loads. Baird (1998) presented a figure showing average channel width that has decreased from over 2,000 ft to less than 650 ft for the period from 1918 to 1990 for the San Antonio to San Marcial reach (Figure A.1 in Appendix A). Channel narrowing and an aggradational river are conflicting processes indicating that the river should not be considered in 'dynamic equilibrium'. Changes in the water and sediment balance as well as the future water/sediment discharge relationships need to be understood to design appropriate river restoration activities.

Estimates of channel geometry are not available before the 1800s. Starting in the 1800s, there were a number of observations of channel width and depth throughout the Middle Rio Grande including a few near Socorro (Scurlock,1998). One observation made in the fall of 1846, described the river as "…a rapid stream 120 or 200 ft wide between Lemitar and Socorro". In the early 1850s, the river was noted as "…varying from 200 to 600 yards wide in the Socorro area". These contradictory comments indicate that one difficulty in investigating historical river morphology is that the observations are often not specific either temporally (seasonally) or spatially (wetted channel versus bankfull width). An estimate of width or depth can be misleading because it is not related to peak discharge, bankfull discharge, wetted channel surface, bank to bank width or river constrictions. Estimates of flow depth were usually guesses and did not reflect the thalweg or average depth.

The operation of water resources projects throughout the upstream Rio Grande basin has significantly altered the hydrologic and sediment balance that governs the channel morphology of the San Acacia – San Marcial reach. The projects include a mainstem reservoir and several tributary reservoirs, channelization, levee construction, channel stabilization and diversions. The Rio Grande Reclamation Project was authorized in 1905 to reverse the decrease in irrigated lands after 1880 and to reduce the flooding around the turn of the century. River channel rectification, maintenance, drainage, flood abatement and increase agricultural lands were goals of the reclamation projects. Most of the levee system, riverside drainage canals and small diversion dams in the Middle Rio Grande Valley were built in the 1930s (Massong, et al., 2002). The San Acacia diversion dam was built in 1935. The large upstream dams and jetty jack systems were constructed between 1953 and 1973.

Through the middle of the 20th century, reservoir storage and improved land use practice reduced the sediment yield to the Middle Rio Grande. In response, there is a system wide deficit of sediment when compared to the flow regime in early part of the 20th century. Larger bed material sizes and channel incision is evidence that the Middle Rio Grande is now supply limited upstream of San Antonio. The upper portion of the San Acacia South reach is degrading. The lower reach is aggrading, in part, due to the effects of Elephant Butte Reservoir, reduced high flows, and a flatter slope. There is decreased sediment transport as the river approaches the upper end of the reservoir. This will be discussed in more detail in a later section.

The reduction in upstream sediment supply has decreased the channel activity in terms of the number of mobile sand bars, movement of large scale macroforms, changing thalweg location and channel migration across the valley. The loss of sediment load is related to both the decrease in sediment yield from upstream watersheds and a decrease in sediment transport capacity associated with reduced effective discharge. Sandbars are no longer inundated frequently enough or for a long enough duration to remove established vegetation. A less active channel results in sand bars becoming stabilized with vegetation. If sandbars are not reworked before the vegetation has two or three years of growth, inundating the sandbars will not scour the vegetation. Velocities through the vegetation are reduced. Gradually the sandbars vertically accrete with sediment deposition and become attached to banks and islands. Sandbars with vegetation will only erode through the slow process of lateral erosion during low or moderate flows.

This process of channel narrowing due to the altered sediment/water discharge relationship is one of the primary obstacles to self-sustaining channel functions. To be successful, river restoration design must consider how the processes of sandbar erosion will occur in future hydrologic and sediment transport regimes. Flow and sediment regimes that replicate or mimic historic regimes will be investigated. In a later section, the specific river issues effecting channel restoration in the San Acacia to San Marcial reach will be discussed including channel narrowing, aggradation and sediment yield.

Historical Flows

It is surmised that the Middle Rio Grande was a perennial river before human diversion in the 1400s. This statement is supported by Crawford et al. (1993:17). There are several factors that support this assumption. First, historically there were 27 native fish species including six large species that are now extinct. According to the numerous references in both Scurlock (1998) and Crawford et al. (1993) the early Spanish reports were replete with comments on the abundance of fishes including eels, longnose gar, large catfish in excess of 75 lbs and shovelnose sturgeon which persisted until 1874. Secondly, there are a number of accounts in Scurlock (1998) that describe the number of floodplain wetlands, cienegas and marshes throughout the Middle Rio Grande that support the assumption of a higher groundwater table than exists today. In the early 1920s due in part to excessive irrigation, 75 percent of the lands in the Middle Rio Grande valley had a water table that was less than 3 ft below the ground surface (Bureau of Reclamation, 1924). During low flow periods, this high historic groundwater table would have contributed significant seepage flow to the channel and would have likely sustained the river flow during successive dry years. The Low Flow Conveyance Canal now serves as a drain that prevents much of the groundwater supply from reaching the river during low flow periods. The lowering of the groundwater table with long term pumping and drainage throughout the valley has effected downstream low flows. Finally there were large pueblos that were located along the river in the San Acacia to San Marcial reach during the Elmendorf and Piro Phases from about 950 to 1670. A number of these pueblos were continuously occupied during this period while further north some Pueblos were still viable population centers. These pueblo populations required sustained water supplies both for drinking and irrigation.

De Sosa noted in 1591, that a Piro district Pueblo (in the Socorro area) had a large area under irrigation (Simmons, 1992). On February 4, 1583, Espejo’s party ventured on five Piros pueblos below Socorro. Four of these pueblos had about fifty houses with 400 people and the last pueblo had about 100 houses and a population of 800. Further north, ten more pueblos were found on both sides of the river with an estimated 12,000 people (Hammond and Rey, 1966). Improved irrigation methods expanded the food supply to support greater population densities. Consistent and dependable water supply was necessary for these increasing populations. Wozniak (1998) argued that the Piro irrigation probably utilized side channels and marshes, but not the main channel of the

Rio Grande. Pueblos to the east of the river that have been identified by Marshall and Walt (1984) were on the gravel benches above the river and may have relied exclusively on river flows for water.

While it can be argued that prior to human diversion from the river, the San Acacia to San Marcial may have gone dry in short reaches during drought periods, it appears to be unlikely. Spring flooding replenished wetlands, cienegas and marshes and the high groundwater table along the river. Throughout the remainder of the year, the high water table supporting the wetlands and marshes, fed the river at low flows. During drought periods, the late summer and fall base flow in the lower Rio Grande was primarily seepage return flows. The high groundwater storage may have been capable of sustaining a base flow for more than one year even without spring overbank flows. During longer duration drought periods, spring flooding may have occurred on annual basis to replenish groundwater storage.

Drought is defined as a water shortage relative to a need for water in a supply and demand relationship. An arid climate is not an indication that there is a perpetual drought in a desert area. Drought is characterized as any year or period of consecutive years that the average rainfall or streamflow is continuously below a specified threshold level typically below the long term mean value (Kendall and Dracup, 1990). A drought event is composed of three attributes, duration, cumulative deficit (or severity) and magnitude (or average water deficit). The severity is defined as the duration times the magnitude. The concept of a drought depicts a departure from the mean historic hydrologic condition. The high variability of rainfall and flows in the Rio Grande basin results in low flow periods that contribute to a mean hydrologic condition that do not necessarily constitute a drought period.

Scurlock (1998) reports that 52 droughts lasting a year or more (mean length of 4.6 years) and totaling 238 years occurred in a period representing 448 years. In other words, according to Scurlock, droughts occurred more than 50% of the time. This is an inappropriate characterization of drought in the Middle Rio Grande basin. Scurlock is confusing the cyclic nature of the dry periods that contribute to the mean hydrologic condition as drought events. Drought events are departures from the mean not ‘relatively common events’ as suggested by Scurlock (1998). Not all dry periods indicated by tree ring data represent drought periods.

While it is possible that during an extreme pre-historic drought event, short reaches of the Middle Rio Grande may have gone dry, it was unlikely and would have been infrequent. It would have also been very limited in areal extent. Even during very dry years, summer monsoons likely provided flows to support the perennial nature of the river. It is more probable that prior to human impact, the Middle Rio Grande was never completely dry in any given reach. This may not have been the case in the lower Rio Grande in southern New Mexico. Stotz (2000) reports of the river going dry prior to agricultural development in Colorado are all in the lower Rio Grande. In any case, based on early historic descriptions of the river and its environment, the effects of drought on channel morphology, vegetation composition or survival of fish species was clearly shortlived and negligible in the long term. In other words, it is likely flood flows, not drought conditions, shaped the channel and floodplain morphology. Both fauna and flora species in the Middle Rio Grande survived in the presence of highly variable seasonal flow conditions of a perennial stream.

Historical accounts allude to numerous flood events, but prior to the newspaper accounts of floods that began in 1862, the only major flood that can be definitively estimated and dated occurred in the spring of 1928. Prior to 1862, flood descriptions were anecdotal and lacked quantification. The estimate of the 1928 flood is on the order of 100,000 cfs (Scurlock, 1998). Newspaper accounts have large floods with damage occurring in 1865, 1872, 1874 and 1884. Two of these floods (1872 and 1884) reportedly crested at over 100,000 cfs. The 1874 flood was in the range of 45,000 cfs (Scurlock, 1998). Streamflow gaging began in 1889 and notable large spring snowmelt floods occurred in 1903 (18,900 cfs), 1920 (22,500 cfs), 1941 (24,600 cfs) and 1942 (18,400 cfs). Summer and fall storm large floods were noted in 1904 (33,000 cfs), 1929 (24,000 cfs) and 1935 (15,000 cfs).

While destructive flood events can result in channel avulsion and dramatic changes in channel geometry, the role of large, infrequent flood events on channel morphology can be overstated. It is important to a have a full suite of discharges on a sufficiently frequent basis to shape an alluvial river channel. Channel forming flows that occur on a 1 to 2 year return period basis are much more important in sustaining channel geometry and riparian habitat over the long term. The frequency and duration of flows that rework the active channel have been identified as the most important component in the long term maintenance of river function and form (Stanford, 1993). On the same theme, the seasonal variability of flow provides a range of aquatic and riparian habitats that support native species. Long durations of uniform flow can result in a loss of habitat diversity.

Historical Vegetation Composition and Distribution

Some of the changes in floodplain vegetation composition and distribution preceded man’s impact on channel morphology. According to Crawford (1993), there is no documented description of the valley vegetation prior to the Pueblo farming. The prehistoric and historic range of the Rio Grande cottonwood was probably similar to its current range. Scurlock (1998) stated that the riparian cottonwood bosque existed for the past two million years. The floodplain was a continually changing mosaic of cottonwood and willow of varying age groups interspersed with open grass meadows, open sand channel, marshes, savannahs, sparsely vegetated alkali flats and wetlands. The vegetative species in the valley had adapted to a flooding environment with a high ground water table. The age and diversity of plants was spatially distributed in response to channel migration on the floodplain. The riparian zone plant composition was highly influenced by large mobile sandbars, bank erosion, frequent flooding, sediment deposition and beavers.

It is probable that prior to European contact, the Middle Rio Grande had been exposed to a millennia of human occupation with relatively minimal impacts. With the advent of agriculture around 400 A.D. the dynamics and composition of the floodplain vegetation began to change more dramatically. The primary early human impacts were related to farming and burning. It is possible that some forest floodplain areas were intentionally burned to drive out animals while hunting or to clear riparian areas for agricultural use. Intentional fire setting may have had a number of purposes alluded to by Scurlock (1998) including clearing campsites, fighting or defensive measures in battles, signals, relieving insect problems, clearing ditches or creating grasslands. Intentional fires and clearing forest for agriculture changed the vegetation distribution on the floodplain prior to the arrival of the Spanish. According to several of the references in Scurlock (1998) wildfires were common and widespread through early 1700s.

Since agricultural activities pre-dated recorded history, an exact historic reconstruction of the vegetation composition cannot be discerned from the written record. Crawford et al. (1993) indicates that groves of cottonwood trees were discontinuous when the Spanish arrived. The understory shrubs were comprised of New Mexico olive, baccharis, false indigo bush, wolfberry and mesquite species. Coyote willow grew in clearings and along the riverbanks and tree willows were an overstory component of the bosque forest. Flooding sustained wetlands and shallow water marshes in old channels and abandoned meander bends where sedges, rushes, reed, saltgrass and yerba-mansa grew. The groundwater table determined much of the composition and distribution of plant communities on the floodplain (Crawford et. al., 1993). Prior to European exploration, channel migration, flooding and fire created a cyclic process of removal and regeneration of plant communities and age classes in an ever-changing mosaic of cottonwood bosque, marshes, meadows, wetlands and upland floodplain.

Scurlock (1993) and Stotz (2000) provide a number of references relating to the cottonwood bosques and vegetation composition in the Middle Rio Grande Valley. As he traveled upstream from San Marcial in 1853, Espejo reported (as quoted by Scurlock, 1993) "…many cottonwood groves and some patches of white populars for leagues wide." In 1593 Espejo described 2.5 miles of sandy flats on each side of the Rio Grande that were being cultivated by Pueblo Indians. In another reference Scurlock noted that in the reach from San Felipe to Isleta, one of Coronado's party wrote that the river "….flows through a broad valley planted with fields of maize and dotted with cottonwood groves." In the 1620s there were extensive groves of cottonwoods along the Rio Grande in Albuquerque referred as the Bosque Grande de San Francisco Xavier. On the east side of the Rio Grande in the South Valley of Albuquerque, there was an area of cienegas (marshes) and charcos (small lakes). At the southern boundary of the present location of Bosque del Apache NWR, Royal Engineer Nicolas de Lafora noted that there was "plenty of pasture" in the valley all the way to San Acacia along with "swampy ground with a great deal of coarse grass and reeds." Near the Bosque del Apache NWR, Scurlock (1998) relates that Wislizenus in 1846 "…camped in a fine grove of cotton trees near the river." In the 1850s there was an estimated 100,000 acres under cultivation in the valley. By the 1880s, however, agricultural acreage began to decline due to high water tables (water logged lands) and increasing alkalinity.

As early as 1739, the major population centers were experiencing a scarcity of wood and insufficient pasture. The scarcity of wood may have become a concern in the late 1600s. Horgan (1984) noted that in 1681: "It was a hard winter. Snow and sleet storm swept away down the valley. In many a camp firewood was scarce." Scurlock (1998) noted in one of his references that in the 1830s the banks of the Rio Grande were "…now nearly bare throughout the whole range of settlements and the inhabitants are forced to the distant mountains for most of their fuel." Scurlock (1998) wrote that in 1846 Henry Smith Turner reported a "…lack of wood for fuel along the Rio Grande from San Felipe Pueblo and south to almost Socorro…only a few sparse cottonwoods were seen." In the same year, Abert had observed, "…no wood is to be obtained within less than 9 or 10 miles of Albuquerque." There was still wood below Socorro. Turner's army contingent had camped where grass and wood were abundant on the bank and Captain Turner had observed that trees were more abundant than upriver (Scurlock, 1998). Finally, in 1854 W.W.H. Davis wrote that "the only large tract of cottonwoods found along the Middle or Upper Rio Grande was located below Isleta Pueblo on the east side of the river. Wood is exceedingly scarce all over the country. The valleys are generally bare of it." See Scurlock (1998. p. 239).

Watson published a detailed description of vegetation composition in central New Mexico in 1912. Scurlock (1998) relates that Watson did not mention salt cedar or Russian olive as important species, but did indicate that salt cedar was being planted in Albuquerque as an ornamental plant. In the 1918 Bureau of Reclamation map, neither species was present. Scurlock (1998) reports that all five types of the plant communities had undergone changes between 1925 and 1935. Swamps and marshes had disappeared and wet meadows were drying up as a result of water depletions. Cottonwood and willow bosque were decreasing while salt cedar and Russian olive were increasing. Salt cedar and Russian olive were recorded by Van Cleave in the early 1930s and were spreading from the southern reaches of the Middle Rio Grande Valley. Today tamarisk and Russian olive are the dominant species in many floodplain areas.

Tamarisk was introduced to the United States from the Mediterranean to serve as an ornamental and as a windbreak in the early 1800s and was present in Albuquerque in 1908 (Crawford et al., 1993). It 1910 it was reported in Mesilla Park in Southern New Mexico (Crawford et al., 1993). In the Rio Grande Valley it was planted along canals and tributaries for bank stability (Everitt, 1998). There were no significant populations of tamarisk in the Rio Grande Valley until about 1926 when seedlings were planted along the Rio Puerco and Rio Salado drainages. Flooding in 1929 caused the plants to spread quickly and by 1936, salt cedar covered about 2,200 acres in the Bernardo to San Marcial reach (Crawford, et al., 1993). Substantial flooding occurred in 1941 and 1942 and by 1947, over 10,600 acres were dominated by salt cedar in the same reach (Crawford, et al., 1993).

Stotz (2000) attempted to compile the available data to quantify the changes in vegetative composition. She compared land classification in the Socorro floodplain area from 1928 (San Acacia to San Antonio) and 1935 (Bernardo to San Marcial) with 1989 data from Crawford et al. (1993). See Table 1.

Table 1. Composition of the Floodplain Vegetation (Percent)

Habitat Type	1928	1935	1989
Cottonwood Bosque	28.6	17.3	6.6
River Channel	23.1	18.2	8.2
Wetlands/Marsh	3.4	8.6	5.0
Scrub/salt grass	9.4	26.2	32.0
Other (urban, agriculture, range)	35.5	29.7	48.2

While the composition of the floodplain vegetation in Table 1 may not be exact, it should be gleaned that both the cottonwood bosque and the river channel comprise a smaller portion of the study reach floodplain than 70 years ago when the cottonwood bosque constituted about 25 to 30 percent of the floodplain. There was a large bosque in and around Albuquerque and more bosque south of Socorro, but most of the Middle Rio Grande was either channel, salt grass and wetlands or agricultural. The 25 to 30 percent proportion is probably similar to the percentage of total floodplain that the discontinuous cottonwood trees occupied about the time that Spanish arrived on the scene.

Based on the germination requirements for wet substrate and the floodplain erosion during channel migration, the distribution of cottonwood/willow habitat both laterally and longitudinally along the river was highly variable. If the river was migrating from west to east, generally cottonwoods tended to be older farther away from the river to the west. Fire, agricultural activities and river migration (or even bank erosion) altered the distribution of the cottonwoods and willows through the Middle Rio Grande. The structure of older stands, density and understory composition was also variable. As noted by Stotz (2000), Turner in 1846 was camping across from La Joya and he "…encamped immediately on the bank of the river…A few cotton wood trees stand about our present camp." Conversely, camping a few miles upstream of Fra Cristobal, Ferguson about the same time indicated that "(o)ur encampment tonight is at the edge of a large brake, or thicket, or cane grass intermixed with willow twigs and cottonwoods, so thick as to be almost impassable."

Other primary species that made up the historical floodplain habitat in the San Acacia to San Marcial reach included honey mesquite, screwbean mesquite (tornillo), arrowweed, saltbrush, seepweed, sea-blight and salt grass. Needing less moist conditions for germination, mesquite grew on terraces and higher elevations on the floodplain or in areas with dense soils. Finding good grasses for stock forage became a chore because of the heavy traffic along the river corridor. A number of references cited by Stotz (2000) indicated that the riparian grasses were all grazed off.

In summary, throughout the Rio Grande's geologic evolution there was a natural cyclical removal and regeneration of native plant communities through flooding and channel migration across the valley. Flood inundation created wet substrate for seed germination, but high flows also accelerated bank erosion and river migration that removed mature trees. In reaches where the river was stable or had avulsed to the other side of the valley, mature cottonwood groves would remain established for decades. It is apparent that the wetlands, marshes, open scrublands, alkali flats and meadows were a significant portion of the floodplain community when the Spanish arrived.

Our knowledge of the pre-historic "natural" Rio Grande floodplain is only anecdotal. With the stirrings of agriculture in the Rio Grande valley about 1,500 years ago, native vegetation began to be impacted by human activities that also resulted in gradual changes to the channel and floodplain morphology. Vegetation was cleared for cropland. Fires, fuelwood and wood for building materials intensified the vegetation removal. Eventually irrigation systems diverted water from the river and created wetter floodplain areas. Grazing added to the loss of vegetation and ground cover and increased sediment yield. As irrigation diversions increased upstream, decreased flows in the river combined with higher tributary sediment yields created a wider, more active river channel. The channel was braided at less than bankfull discharge.

In terms of restoration goals for this reach, increasing the mosaic of native dominated riparian habitat cottonwood bosque and enhancing river channel dynamics are a primary focus. Based on the historical vegetation composition, the restoration plan will address increasing the cottonwood/willow bosque, creating wetlands, marshes and salt grass meadows and improving river floodplain hydrologic connectivity to support new cottonwood/willow cohorts. In terms of the channel dynamics to minimize vegetation encroachment on the active channel, opportunities to increase width to depth ratio and rework in-channel sandbars will be explored.

Riparian Habitat Changes

Today, the riparian vegetation regenerative processes have been curtailed. Prominently missing in the natural hydrologic cycle are the destructive flows that initiated channel migration and bank erosion to remove the trees. Gone are the flood flows timed with seed dispersal to create the wet substrate in open areas for germination of native riparian plant species. There were three primary factors that altered the vegetation distribution along the river: agriculture, a decrease in flooding and the invasion by non-native plants. To a lesser extent fuelwood cutting and channel narrowing also impacted the riparian vegetation. As noted by Stotz (2000) research indicated that higher grounds dominated by arrowweed and grasses were easily converted to agriculture. Areas around population centers were impacted first. By the mid 1800s, deliberate fires and clearing of cottonwoods had resulted in more timber south of Socorro. Grasses became sparse making forage for travelers difficult to find. The primary changes in riparian habitat before large scale water development in the early 1900s were the reduction of cottonwood/willow habitat, conversion of 100,000 + acres to agricultural (by 1850) and a loss of grass meadows.

The invasion of tamarisk and Russian olive correlated with reduced flood frequency and duration in the Middle Rio Grande. The combination of vegetation encroachment and sediment deposition lead to active channel narrowing or shrinking (reduction in top width). Everitt (1998) argues that although other researchers suggest that channel narrowing is initiated by vegetation establishment, the narrowing process was driven by "…deposition of sediment that the depleted flow could no longer carry overbank." In terms of cause and effect, the invasion of non-native vegetation invasion was the result of a less active channel. Once the vegetation became established, channel stability was enhanced.

Upstream reservoir storage, flow regulation and diversion and channelization all contributed to a less active river channel. The magnitude, frequency and duration of the channel forming discharges quickly and significantly decreased in the early to mid 1900s. The channel narrowing processes can be easily defined. In-channel features such as macroform sand bars and point bars that were remnants of the last high flow event were the primary areas of vegetation establishment. If the flood event was high enough, the upper surface topography of these sandbars may not have been inundated again for several years. Areas that were flooded less frequently in response to flow regulation were prime recruitment areas for salt cedar that out competed the cottonwoods on open sand substrate. One of the primary competition mechanisms was long periods of prodigious seed dispersal that took advantage of summer and fall flood events. If the portions of the channel with salt cedar seedlings were not reworked within a two or three year period after germination, the seedlings could not be removed by subsequent flooding. It has been observed on the Green River, that even when an entire midstream sand bar with three to five feet plants is inundated by flows to a depth of several feet, only the upstream nose of the bar was actually destroyed and experienced plant removal. Along the edges of the bar, the plants were knocked over but not removed and later recovered.

When in-channel sand bars with salt cedar are flooded, slower velocities result in sediment deposition, vertical accretion of the sandbar and eventually attachment to the bank or island. This is the mechanism of channel narrowing and salt cedar contributes to it. Whereas cottonwood bosques were the predominate habitat type prior to the arrival of the Spanish, Crawford et al. (1993) reported the shift to a salt cedar dominated floodplain. In 1918, from San Acacia to San Marcial, there was 18,165 acres of cottonwood-dominated timber and brush. In 1982 and 1989 surveys, the acreages was reduced to 3,823 acres. In the same 1918 mapping there was 48,603 acres of saltgrass meadow in the entire Middle Rio Grande reach from Cochiti to San Marcial and in 1982 and 1989 surveys there was no salt grass meadow indicted.

The increase in salt cedar dominated acreage represented a decrease in the preferred habitat. For example, only white-winged dove showed a preference for salt cedar over other habitats. The only large mammals making use of salt cedar habitat were skunks, raccoons and bobcats (Engel-Wilson and Ohmart (1978). The abundance of many large mammals was impacted by not only the loss of habitat but by other human activities such as hunting including beaver, bear, mountain lions and otter.

Where did the water go?

Scurlock (1998) observed that the climatic regime of over the last six centuries has been relatively stable. The dramatic change in the river hydrology over the last 300 years must be attributed to water resource management. Prior to flow regulation, the seasonal hydrograph in the Middle Rio Grande was dominated by the late spring snowmelt and summer or fall thunderstorm runoff. Significant discharge variability characterized the Middle Rio Grande flows both seasonally and annually. Stream flow records of Middle Rio Grande flows began in 1889 near Embudo, 1895 at the Otowi Bridge gage and 1899 at San Marcial. Prior to this time, diversions in the upper basin and changes in watershed land use were impacting stream flow. While irrigation diversions decreased low flows during the growing season, grazing and logging increased runoff during high flows. In the 1820s, Scurlock (1998) reported that there was an increase in marshes on the floodplain due to excess irrigation waters. In the 1870s, flooding became more frequent due to aggradation of the channel in response to sediment loading from excessive grazing and logging. Prior to the institution of streamflow gaging, there were no major flow regulation projects, so the water management effects on stream flow were more significant at lower flows. The increased runoff only marginally increased the peak flows.

By 1912, two large water resource projects were constructed in Colorado, the Rio Grande Reservoir near the headwaters and the Santa Maria Reservoir on the Clear Creek tributary. Appendix C contains a list of all the water resource projects in the Rio Grande Basin. Combined, they stored almost 100,000 af of water. In 1925, an additional 27,000 af of storage was added with the construction Continental Reservoir on the North Creek tributary, which is also in Colorado. In 1934, three major diversions in New Mexico were constructed by the Middle Rio Grande Conservancy District, Angostura, Isleta and San Acacia. By 1935, El Vado Reservoir was constructed on the Rio Chama with 180,000 af of storage. The construction of these storage and diversion units reduced the peak flows and increased the low flow duration. This is evident in Figure A.2 which displays the flow duration curves for three separate historical periods at the San Marcial, NM stream gage. One of the duration curves in the figure depicts the period from 1899 to 1938. This period began the development of modern water resource projects. The second duration curve represents the period from 1939 to 1973 during which a number of water resource projects were constructed in the basin including seven major storage reservoirs (Platoro, Jemez Canyon, Galisteo, Abiquiu, Heron, and Nambe Falls) and one major transmountain diversion (the San Juan Chama Project, Azotea Tunnel). The final period follows the end of the construction of the major water projects including Cochiti Dam, which was closed in 1975. Comparing the 1899-1938 flow duration curve with the 1939-1973 curve illustrates the progressive redistribution of the high flows to low flow periods. By the time that all of the water resource projects were in place not only was there a reduction in the frequency and magnitude of the higher flows, but also a dramatic increase in the frequency of low flows which was augmented by the transmountain diversion water from the San Juan-Chama project.

Until the late 1930s the peak discharge was relatively unaffected by upstream storage. Table 2 shows a summary of an analysis of USGS gage data. At San Marcial the 2-year flood peak discharge for the period 1899 to 1938 was 11,300 cfs. Generally in semi-arid rivers the bankfull discharge is on the order of a 2 to 5 year return period flood event. Based on the period from 1899 to 1912 (prior to the construction of any major reclamation projects), the average peak mean daily flow (with no data for 1909 and 1911) was 13,460 cfs ranging from 4,070 to 33,000 cfs. Bankfull discharge was probably in the range from 12,000 to 15,000 cfs in the San Marcial Reach with flows greater than 10,000 cfs 7 out of the 12 years. The 33,000 cfs peak discharge event was a fall storm occurring on October 11, 1904. The preceding year the peak flow as 18,900 cfs on June 24, 1903 and the following year the peak discharge was 29,100 cfs on May 24, 1905; both peak flows occurred during the spring runoff season. In a 23-month span, three flood events were greater than 20,000 cfs. For six consecutive years, peak flows exceeded 10,000 cfs and for three consecutive years peaks were greater than 19,000 cfs. For comparison, the 2-year flood for the 1939 to 1973 period was 4,250 cfs, and for the period from 1974 to 1999 it was only 4,160 cfs at San Marcial, only 37% of the 1899 to 1938 period.

This reduction in peak discharge in the Middle Rio Grande has had significant effects on the channel morphology. The channel has narrowed and become less active on the floodplain. Where did all the water go? Upstream of San Acacia, there is 1,750,000 af of storage in the Rio Grande watershed. This is greater than the annual flow at Otowi Bridge, which averages in the range from 1 to 1.2 million af annually. In addition, there are significant diversions at Cochiti, Angostura, Isleta and San Acacia (Socorro Main Canal and the Low Flow Conveyance Canal). Currently, the annual volume of flow at Otowi is 1.029 million af. Correspondingly the mean annual flow at San Marcial is 956,000 af. This 73,000 af reduction in mean annual flow between the two gages includes the San Juan-Chama project that imports up to 110,000 af to the Rio Grande as well as 60,000 af of wastewater discharge from the City of Albuquerque. Approximately 243,000 af per year are lost between Otowi and San Marcial that can be attributed to reservoir and river evaporation, crop consumptive use, evapotranspiration and groundwater recharge.

Table 2. USGS Gage Flood Data

Location	Period	2-yr Flood (cfs)	100-yr Flood (cfs)	Average Annual Volume (acre-ft)
Cochiti	1926-1938	9310	19500	1,073,000
	1939-1973	5480	30500	888,000
	1974-1999	4480	12800	1,074,000
San Acacia	1936-1973	8940	25900	721,000
	1974-1999	6420	17900	985,000
San Marcial	1899-1938	11300	49100	1,015,000
	1938-1973	4250	26300	697,000
	1974-1999	4160	11300	956,000

Revisiting the data at the San Marcial Gage, the estimated 100-year floods have been reduced at San Marcial from 49,100 cfs (1899-1938) to 11,300 cfs (1974-1999). Figures A.3 and A.4 illustrate the variability of flows at this gage over the long term. In Figure A.3 (a cumulative water volume graph) for the period 1899 to about 1942 (ignoring missing data), the slope of line indicates a uniform annual volume of water measured at the San Marcial Gage. By the mid-1940s, the cumulative effect of water storage and losses becomes evident. The slope of the line dramatically decreases until about 1974 (Figure A.4). In 1974 the San Juan-Chama Project began diverting water across the continental divide, offsetting the depletions of the water projects. Interestingly, the slope of the line (also indicated by the average volumes for the periods in Table 2) is about the same as it was at the beginning of the 1900's. The table indicates that the average annual amount passing the gage is only slightly less (~60,000 af/year) than that for the period preceding the construction of the majority of upstream water projects. Future increases in consumptive use will reduce the slope of the water volume curve as was evident before the San-Juan Chama Project.

The cumulative effects of water management activities upstream of San Acacia have been to reduce the total volume of water in the San Acacia South reach and to reduce the spring and summer peak discharge magnitude, frequency and duration. The timing of the peak flows has also been affected. In comparing Figures A.5 and A.6, the effects of storage on the annual hydrographs are apparent. At the turn of century, the mean day of peak discharge occurrence for the spring runoff was approximately May 18. Today, the peak discharge can occur at any time between the first of April and the end of July, but the mean day of occurrence of the peak discharge is later in the month between May 25 and May 30. This stresses the cottonwood/willow bosque regeneration and aquatic species whose reproductive cycles are in tune with the historic peak timings. The effect of storage has been to broaden and flatten the mean annual hydrograph. Cochiti Dam, the mainstem flood control reservoir upstream of Bernalillo, essentially eliminated the flows greater than 7,000 cfs such that the historical 2-year flood event is now the 100-year flood at San Marcial. The reduction of peak flows has resulted in channel incision, channel narrowing, a loss of channel dynamics, a loss of connectivity between the channel and floodplain and a decrease in the frequency and magnitude of overbank flooding.

Understanding Channel Morphology as a Basis for Restoration

The Link between Geology and Sediment Yield

Understanding changes in river morphology requires knowledge of the linkage between the sediment supply, the transport processes and the potential storage locations. Major changes in the Rio Grande channel morphology have occurred over the past 150 years involving channel aggradation and widening in the late 1800s and then channel narrowing in the late 1900s. To track the changes, it is necessary to review the basin geology and sediment yield.

The Middle Rio Grande and its tributaries are located in three physiographic provinces; the Southern Rocky Mountains, the Colorado Plateau, and the Basin and Range. Most of the Middle Rio Grande basin is located in the Colorado Plateau and the Basin and Range provinces. The Colorado Plateau province is situated in the western central portion of the basin and contains the Rio Puerco and Rio Salado drainages. These tributaries drain into the Rio Grande depression in the Basin and Range province. The Colorado Plateau province is characterized by a broad, low relief plateau region with numerous canyons, mesas and buttes in gently deformed Paleozoic, Mesozoic and Cenozoic strata. The topography of the Basin and Range province is predominantly the result of tectonic activity with distinct north-south mountain ranges along the Rio Grande rift valley (Bullard and Wells, 1992).

The Rio Grande rift valley, extending 500 miles from central Colorado through New Mexico, is the major physiographic feature that defines the Rio Grande drainage and controls the location of the river. Seismicity, tectonic uplift, volcanism and extension characterize this rift system, similar to other rift valleys throughout the world. The bordering mountains and blocks are uplifting while the valley bottom is subsiding. According to the literature review by Crawford et al. (1993), the Rio Grande rift has been active for about 18 million years and gave birth to the ancestral Rio Grande about 5 million years ago. The rift valley is a series of depressions or basins. Originally each basin had a drainage and lake. Eventually the lake filled and eroded through the bedrock sills that structured the basins. As these basins combined, the ancestral river segments coalesced into a single river system.

In the Middle Rio Grande valley, the rift trough has filled in some locations with up to 13,000 ft of sediments primarily from the Santa Fe Group (Bullard and Wells, 1992). The Santa Fe Formation consists of a complex sequence of gravel, sand, silt, clay, caliche and volcanic deposits and, in many areas, is overlaid by unconsolidated Quaternary alluvial and thick piedmont detritus. The rift valley is bounded by uplifted blocks that are the result of movement along the major faults. Physiographic features associated with uplifted blocks include mountains, basalt fields, plateaus, mesas, volcanic plugs, calderas and piedmont areas. The filling of the rift trough with tributary sediment was episodic with several cycles of downcutting and backfilling. This filling and trenching process has led to the development of gravel and clay lenses in the valley fill, as well as abandoned river terraces.

According to Hawley (1975) while tectonic activity has been a major factor influencing erosion and deposition on a regional scale, cyclic variations in climate related to glaciation have been the primary factor in filling the valley trough. Increased discharge and river entrenchment corresponds to the waxing glacial periods. During full glacial events, vegetative cover increased and reduced erosion. The aridity during waning glacial periods resulted in decreased vegetation and increased sediment supply to the river system, and the reduced river flows caused aggradation of the valley bottoms. The period of major entrenchment of the Middle Rio Grande occurred from about 11,000 to 22,000 years ago. Hawley (1975) suggests that slow valley bottom aggradation has characterized the last 7,500 years and as evidence offers the encroachment of tributary arroyos onto the river floodplain. In the last 300 years, the river channel has migrated back and forth across the valley, reworking valley fill deposits.

One manifestation of the rift valley volcanism is the Socorro Magma body just north of the Rio Salado. Late Pliocene river sands of the ancestral Rio Grande are displaced 85 m over a distance of 11 km (Ouchi, 1983). The river profile shows a large convexity in the uplifted area between Belen and Socorro. Originally, the rising bulge in the profile was attributed to local aggradation from Rio Puerco and Rio Salado sediments (Ouchi, 1983). This bulge, however, is too large to be explained by sediment deposition. The uplift was estimated to be rising at a rate of 1.8 mm/yr between 1951 and 1980 (Ouchi, 1983). The present rate of uplift is having a negligible effect on the channel morphology in this reach. In comparison to the variability in cross section changes, the 1.8 mm per year of uplift over a twenty-year period is only 0.12 ft. This would not be detected in the variable river cross section plots. The impacts of water resource development on channel morphology are masking the effects of the uplift. Over a 100-year period or more, continued uplift at this rate could have some measurable effect on channel aggradation/degradation.

From Cochiti to Elephant Butte, the eastern boundary of the rift basin is close to the river with the uplift blocks of the mountain ranges (Precambrian, Mesozoic and Paleozoic rock formations) creating coalescing alluvial fans and piedmont surfaces sloping to the river. The tributaries are developed on thick Tertiary rift-fill sediments. The western tributary basins drain Paleozoic and Mesozoic sedimentary formations with volcanic rocks from the Jemez and Albuquerque volcanic fields. Along the west side, there are also terraces that are remnants of the ancestral Rio Grande (Bullard and Wells, 1992).

The geomorphology of the Middle Rio Grande Valley is highlighted by numerous erosional surfaces along the piedmont mountain fronts that include gravel layers over bedrock. The oldest piedmont surfaces and terraces have well-developed soils and thick calcium carbonate horizons (Bullard and Wells, 1992). Younger piedmont surfaces have less soil development and are more permeable.

A number of small tributaries and arroyos have delivered sediment from these erosional surfaces that affect the Rio Grande channel morphology. The Rio Chama, Galisteo Creek and Jemez River contribute sediment loads from upstream of

Albuquerque. Rittenhouse (1944), in a study of sediment sources, estimated that 20 to 40 percent of the channel bed material between Albuquerque and Bernardo came from the Jemez River. Another 2 to 6 percent were delivered from Galisteo Creek, about 1 to 2 percent was derived from the Santa Fe River and roughly 11 to 37% came from the mainstem Rio Grande. Small tributaries delivered the rest of the sediment supply. These include several small arroyos between Albuquerque and Bernardo on both sides of the river.

With respect to the San Acacia to San Marcial reach, the Rio Puerco and Rio Salado currently deliver large quantities of fine sediment to the mainstem Rio Grande. The Arroyo Alamillo, Arroyo de la Parida and several other small arroyos deliver sand and some gravel to the Rio Grande downstream of San Acacia. No significant tributaries enter the Rio Grande between San Acacia and Elephant Butte. The Rio Puerco and Rio Salado are the two major tributaries to the middle Rio Grande that do not have any significant flow regulation structures. While these two tributaries deliver substantial quantities of fine sediment, they contribute only 4% and 1.3% of annual flow volume at San Marcial respectively.

With a drainage of almost 7,294 square miles (~145 miles long), the Rio Puerco is the largest tributary to the Rio Grande constituting 20% of the drainage area at San Marcial. It flows across the Colorado Plateau formations and into the Rio Grande depression. More than 80 percent of the basin is comprised of erodible mudstone, shale and sandy sediments (BOR, 1996). Lower and Middle Tertiary sediments make up another 7 percent. Cretaceous sandstone, shale and coal underlie over 40 percent of the basin. These formations are the primary sources of sands, silts and clays to the Rio Grande downstream of San Acacia. The Rio Puerco has had the fourth highest average annual suspended sediment concentration in the world (Gellis and Pavich, 2001). The Chinle and Abo formations of the upper Paleozoic to Jurassic periods are the source of the red clays that cause the water to appear muddy red during flooding. Scurlock (1998) relates that the arid loamy sands to clayey soils are calcareous and subject to severe erosion when exposed to various land use activities. In the past 3,000 years, the major Rio Puerco channels have been incised and filled three times: but recent surveys indicate that the Rio Puerco is now aggrading (Gellis and Pavich, 2001).

Before about 1885, the Rio Puerco basin channels were relatively small and stable and the floodplain and channel were hydrologically connected. Between 1887 and 1928, an estimated 395,000 acre-ft of sediment were carried out of the basin into the Rio Grande (Schumm, et al, 1988). Suspended sediment concentrations in flows have been measured in excess of 300,000 ppm with 40 percent sand (Nordin, 1963). It was postulated in Schumm, et al. (1988) that abusive land use practices preceding a wetter period at the end of the 19th century triggered the arroyo entrenchment. Further widening of the arroyo and development of a new floodplain is anticipated (Schumm, et al., 1988).

With the construction of Jemez Canyon Dam, Galisteo Dam and Cochiti Dam, approximately 80% of the historical sediment load upstream of Albuquerque is stored. There is an average of 1,800 acre-ft of sediment inflow to Cochiti Reservoir each year

(Lagasse, 1994). The Rio Puerco and Rio Salado tributaries deliver the primary sediment load in the Rio Grande at San Acacia. For a period of record (1965-1977)that overlaps the construction of Cochiti by several years, the average sediment concentration at Bernardo (upstream of the Rio Puerco and Rio Salado confluence) was 2,760 mg/l. Comparably the average sediment concentration at San Acacia was 13,300 mg/l for the period 1946-1978 (Table 3). Prior to 1977, the ratio of the average sediment concentration at San Acacia to Bernardo was 4.81. From 1977 to 1997, the ratio decreased to 3.51 (Baird, 2001). Flow regulation in the upstream Rio Grande basin has impacted the sediment concentration at Bernardo. Land use practice and conservation measures have reduced sediment yield in the Middle Rio Grande drainage and in the Rio Puerco and Rio Salado basins. The percent reduction in sediment yield has been greater in the two tributaries than in the mainstem river. Table 5 shows that the sediment loading from the Rio Puerco and Rio Salado tributaries is the major source of sediment to San Acacia.

In summary, sediment yield is one of the controlling factors of the Rio Grande channel morphology. Sediment yield is primarily a function of the exposed geology with most of the sediment derived from the erodible Santa Fe group to the west of the river. Land use practices such as overgrazing, timber cutting and road construction exacerbated the high sediment yields. Recent soil conservation and flow regulation have reduced sediment loading to the Middle Rio Grande. In response the channel morphology in the San Acacia to San Marcial has been significantly altered.

Table 3. Middle Rio Grande Sediment Load[1]

Gage	Period of Record	Average Sediment Concentration (mg/l)	% of Historic Sediment Supply
Albuquerque	1970-1974	3,750	
	1974-1996	580	15%
Bernardo	1965-1977	2,760	
	1977-1996	740	37%
San Acacia	1946-1978	13,300	
	1978-1997	2,600	20%
San Marcial	1925-1974	12,100	
	1974-1997	3,800	32%

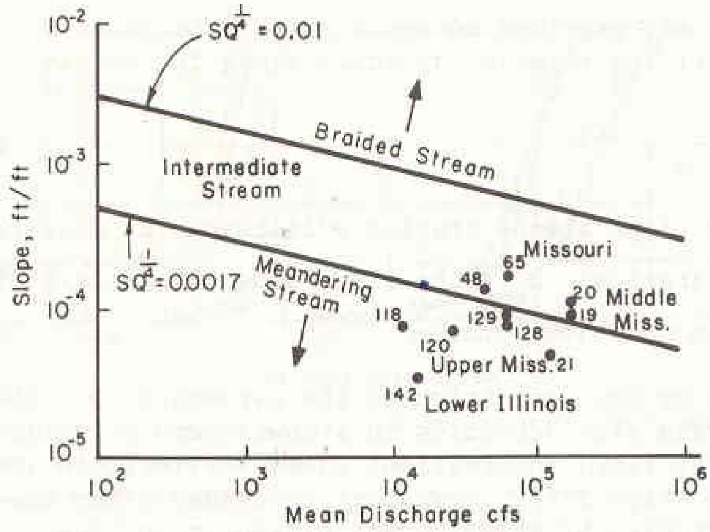
[1]After Baird (2001)

The Link between Sediment Load and Channel Form

The Rio Grande channel morphology is primarily controlled by sediment supply and valley slope. Historically the Middle Rio Grande tributary system provided sufficient sand size and smaller sediments to support a sand bed river. Over geologic time, the ancestral Middle Rio Grande valley was aggrading indicating that there was more sediment being supplied to the valley than the river could transport downstream (Baird, 2001). In this environment the river was very active, reworking the floodplain with reaches of wide, braided channel. Typically, aggradational rivers are braided because the sediment supply exceeds the sediment transport capacity. The threshold relationship (Simons and Senturk, 1977) that delineates between a meandering and braided river is:

$$SQ^{0.25} \geq 0.01$$

where a value greater than 0.01 indicates a braided river (Figure 1 or A.7). The historic Rio Grande approached this value of 0.01 (~0.0094 using an historic mean daily peak discharge of 13,500 cfs for the period 1899 to 1912 at the San Marcial gage and a slope S = 0.00086). The slope is roughly 0.00086 in the San Acacia reach. At low to moderate flows the river had a braided appearance. At bankfull flows, the river took on a multiple channel, slightly meandering planform. An historic channel sinuosity on the order of 1.16 for the San Acacia to San Marcial reach is indicative of a transitional meandering/braided river (Tetra Tech, 2002). Prior to the arrival of the Spanish, the Middle Rio Grande was primarily an anabranching or multiple channel river with slight sinuosity. After a high spring runoff with bankfull discharge, the river took on a braided appearance as the sandbars became exposed.



Identification of Reaches Plotted

19	St. Louis to Chester	Middle Mississippi	118	St. Paul to Redwing	Upper Mississippi
20	Chester to Cape Girardeau		120	La Crosse to Lansing	
21	Ohio River		128	Hannibal to Louisiana	
48	Lower Arkansas River		129	Louisiana to Grafton	
65	Missouri River		142	Lower Illinois River	

Figure 1. Slope – Discharge Relationship, Meandering vs. Braided for Sand Bed River (Simons and Senturk, 1977)

As was previously noted, grazing significantly increased in the mid- to late 1800s, denuding the basins, initiating arroyo incision and substantially increasing the sediment load. Logging and other land use practices in the upper watersheds contributed to the increased sediment yield. Scurlock (1998) documents the Middle Rio Grande bed aggradation after 1850, attributing it to sediment yield as well as to a reduction in river flows. Before the construction of Cochiti Dam, the Rio Grande was aggrading at a rate of 2 ft every 50 years near Albuquerque. The Albuquerque river channel was 6 to 8 ft above the floodplain outside the levees in 1960 (Lagasse, 1994). At San Marcial this aggradation amounted to 9 ft from 1880 to 1924 (Bureau of Reclamation, 1924), roughly 3.5 ft from 1914 to 1926 and 5.4 ft from 1926 to 1936. This aggradation caused the river to widen and avulse its channel in various locations as noted by Scurlock (1998). Reclamation (1924) reported that this aggradation was widespread throughout the valley with 8 ft of aggradation near San Antonio and 7 ft at the Santa Fe Railroad Bridges built in the 1880s, near Isleta.

In recent years, the aggradation trends in the upper San Acacia South reach have been reversed. The upstream sediment supply to San Acacia has decreased by 80% since 1974. Based on 1962 cross sections, channel incision of up to 8 ft has ensued near Escondida Bridge (Massong, et al, 2002). Most of the incision occurred prior to 1990. In the reach from San Acacia to the Escondida Bridge, the channel incision has corresponded to a decreased average width from 1,700 ft in 1918 to 460 ft. in 1999 (Massong, et al., 2002).

Table 3 also indicates the significant decrease in sediment concentration at all the stations following the construction of Cochiti Dam in 1974. The storage of sediment in Cochiti Reservoir as well as the decrease in high flows contributed to the decrease in sediment load downstream. Not all of the decrease in sediment load can be attributed to Cochiti Dam. Changes in land use and soil conservation practices in the tributaries and arroyo watersheds including the Rio Puerco and Rio Salado have also reduced the sediment load delivered to the Rio Grande. Approximately 3 to 5 million tons per year of sediment is now being transported in the San Acacia to San Marcial reach.

Nordin and Culbertson (1961) analyzed bed material size distribution from Otowi Bridge to San Marcial. Their analyses pre-date the construction of Cochiti Dam in 1974. Table 4 presents a summary of Table 265.1 in their paper. Downstream of White Rock Canyon, between Otowi and Cochiti, the Rio Grande was reported to be a sand bed river in 1961. Nordin and Culbertson (1961) noted that below San Felipe there was "…an unlimited supply of sand-sized particles in the bed…available for transport." Also during this time period, there was a slight decrease in the bed material size from Bernalillo to Socorro. Between Belen and Socorro, the sediment contribution of the Rio Puerco and the Rio Salado have a relatively minor effect on the Rio Grande bed material size, but it is obvious that these two tributaries are supplying finer sediment than appears in the upstream riverbed. Most of the fine sediment delivered by the Rio Puerco and Rio Salado is wash load and does not contribute to the bed material size fraction. It should be noted that the Rio Salado also has a coarse size fraction of gravels and cobbles.

In 1965, Nordin and Beverage published a report with additional bed material data covering the period from 1954 to 1962 for the reach from Otowi to Belen. In that report, the D_{50} size for the stations listed in Table 4 from Otowi to Belen were all less than 0.7 mm and became progressively smaller in the downstream direction. They indicated that between Cochiti and San Felipe "…the channel is braided between many bars and islands composed of coarse gravel and cobbles." This comment pre-dated the construction of Cochiti Dam and at that time the reported bed material was sand (Table 4). The winnowing of the sand out of the bed following the construction of Cochiti Dam further exposed the coarse material that was available in the channel

Table 4. Middle Rio Grande Bed Material Size[1]

Location	Number of Samples	Median Diameter (mm)	Standard Deviation (mm)
Otowi	11	1.45	3.0
Cochiti	102	0.44	0.32
San Felipe	102	0.45	0.48
Bernalillo	139	0.29	0.02
Belen	85	0.23	0.06
Socorro	10	0.19	0.03
San Antonio	14	0.20	0.03
San Marcial	9	0.14	0.01

[1] After Nordin and Culbertson, 1961

Table 5 shows that the coarsening of the bed material downstream of Cochiti Dam has now extended to Bernalillo. By 1980, the bed material had significantly coarsened 21 miles downstream of Cochiti Dam (Lagasse, 1994). According to Lagasse's (1994) data, the effects of bed coarsening were still apparent as far as 40 miles downstream of the dam. Today, the bed material is significantly coarser approximately 30 miles downstream of Cochiti Dam to slightly past the Bernalillo bridge. Upstream of Socorro, the Rio Puerco and Rio Salado sediment supply have maintained the fine sand sized bed material in the Rio Grande. This table indicates that these two tributaries have dominated the sediment loading in the mainstem Rio Grande at San Acacia.

The changes in channel and floodplain morphology in the San Acacia to San Marcial reach over the last 24 years is largely attributed to a decreasing sediment supply. While the river had a copious supply of sand-sized sediment, it was aggrading. The wide river had a complex channel with numerous sandbars, was actively reworking the floodplain and was occasionally avulsing the channel to initiate a new sequence of channel migration. Major channel modifications in the San Acacia reach began in the 1930s with the building of the San Acacia diversion dam and a railroad line along the west side of the river. The Low Flow Conveyance Channel was constructed in the 1950s and the floodplain was confined with a levee on the west side. In the study reach, the river channel was straightened, dredged and stabilized with jetty jacks (Massong, 2002).

Table 5. Middle Rio Grande Bed Material Size Past and Present D_{50} (mm)

Location	1961[1]	Present[2]
Otowi	1.45	
Cochiti	0.44	
San Felipe	0.45	11.72
Bernalillo	0.29	2.69
Albuquerque		0.54-0.56
Belen	0.23	0.35
Socorro	0.19	0.21
San Antonio	0.20	0.26
San Marcial	0.14	0.20-0.26

[1] After Nordin and Culbertson, 1961
[2] From the BOR, 2002 (personal communication, T. Massong)

The upstream storage built in the 1950s through 1970s decreased peak flows and the upstream mainstem sediment load in the river. During this period, soil conservation improvements were made in the Rio Puerco and Rio Salado drainages. In response to the reduction in sediment supply (nearly 80% at San Acacia since 1974) and in response to channelization and bank stabilization in the San Acacia to San Marcial reach, the river has become a narrow, single thread channel with a slight sinuous pattern (Figure A.8). Channel narrowing has been exacerbated by tamarisk stabilizing sand bars and banks. In 1918, almost the entire San Acacia reach was wide and braided at low flow. The channel width has decreased by 60% since 1918. Since 1962, the channel depth to thalweg has doubled and the channel bed elevation has degraded 8 to 13 ft (Massong, 2002).

Aggradation/Degradation Trends and Cross Section Variability

Over geologic time, the Middle Rio Grande Valley has been filling with sediments. This was caused by the rift valley floor dropping, rift blocks uplifting, the drainage steepening and extending, and having erosive geologic formations in the basin. In this rift valley environment, the valley floor elevation can go through elongated cycles of aggradation or channel incision depending on long term climatic variation. These long cycles are punctuated by short-term variability associated with volcanic or tectonic activity or human impact such as dam construction and reservoir storage.

The Socorro magma body is an uplift that is affecting the local long-term aggradation trends in the valley. Located just upstream of the Rio Salado, the uplift is decreasing the Rio Grande bed slope upstream and increasing the channel slope downstream. Over the long term, this will affect the channel planform perhaps increasing the sinuosity upstream and causing channel incision and narrowing downstream. The effects of this uplift are being superceded by the impacts of human activity in the valley. Watershed abusive land practices and water resource management in the form of upstream storage and a mainstem dam (Cochiti Dam) have resulted in significant short term effects on channel morphology that are masking the long term trends.

The rapid increase in grazing, logging and other watershed land use in the Rio Grande basin in the mid to late 1800s combined with a sequence of above average rainfall, led to accelerated sediment yield to the river. The increased sediment load combined with a decrease in water discharge resulted in channel aggradation in the San Acacia to San Marcial reach. The most extensive aggradation on record occurred in the period between 1894 and 1938 when the bed elevation at the San Marcial gage rose almost 16 ft (Baird, 1998). By 1990, the bed elevation at San Marcial was 24 ft higher than in 1894 (an average of 0.23 feet per year). Some of this increase in bed elevation was related to the backwater effects associated with high Elephant Butte Reservoir levels. The riverbed was aggrading before Elephant Butte Dam was constructed. From 1895 to 1915, the riverbed at San Marcial rose 4 ft (0.4 feet per year). The effects of the Elephant Butte Reservoir levels can be further ascertained by the 3 feet degradation from 1958 to 1967 when the river channel was dredged through the reservoir delta. About 14 percent of the river aggradation in the San Marcial reach has been attributed to reservoir level backwater effects (BOR, 2002). Figure A.9 shows that the river bed profile is affected by the backwater from Elephant Butte Reservoir all the way to the south boundary of Bosque del Apache NWR. Since the construction of the Elephant Butte Reservoir, the entire valley reach from San Marcial to the reservoir has been aggrading (Figure A.10). The confinement of the river to the east side of floodplain has exacerbated sediment deposition and resulted in the active river floodplain to be perched above the historic river floodplain. The perched floodplain extends from rangeline 9 to rangeline 23. Since 1915 the valley floor at rangeline 12 has risen almost 20 feet.

Prior to the upstream construction of water resource projects, historic peak flows transported a substantial sediment load. The reduction in peak flows discussed in the previous section combined with riverbank stabilization and improved land use practices contributed to the reduction of the sediment load at the San Acacia. According to the Bureau of Reclamation (2002), the sediment concentration in the Rio Grande has averaged 8,000 mg/l over the life of Elephant Butte Reservoir, but the current sediment concentration is only 4,000 mg/l. This decrease in sediment load has initiated channel incision downstream of San Acacia. In the 1980s the sediment concentration averaged only 3,000 mg/l at the San Acacia gage. Prior to 1978, sediment concentrations ranged from 7,300 mg/l to 34,000 mg/l. The sediment concentration at the San Marcial gage is approximately twice the concentration at the San Acacia gage indicating that the intervening reach serves as a supply of sand and smaller sediment to San Marcial. The sediment transport capacity exceeds the upstream supply and sediment is being removed from this reach (Massong, 2002). Figure A.9 shows that since 1962 the reach downstream of San Acacia is incising while the reach upstream of San Marcial is still aggrading.

Figure A.9 depicts the essence of the problem associated with developing sustainable river restoration for the San Acacia to San Marcial reach. Over the past 40 years, sediment is being removed from the upper subreach (San Acacia to the Escondida Bridge). The river channel is incising in this reach. At the lower end of the reach, the river channel is still aggrading from roughly the South Boundary Bosque del Apache

NWR to San Marcial. Overall the channel bed slope in the entire reach is flattening. The sediment being removed from the upper subreach is transported in relative equilibrium through the middle subreach (from roughly Escondida Bridge to the South Boundary) and then is being deposited in the lower reach. The lower subreach appears to be narrowing slightly because of the decrease in sediment load and because of the effects of channel stabilization with vegetation encroachment.

It should be noted that 1962 data in Figures A.9 and A.10 was extracted from digitized aerial photography. If there was water in the channel at the time of the aerial photos, the actual thalweg bed elevation is unknown and had to be estimated. If there was no adjustment made for the water surface in the channel, the thalweg elevation may have been overestimated and the actual channel degradation since 1962 is less than reported. This will have to be confirmed in the Phase II portion of the study.

Figure A.9 indicates that restoration activities planned for the upper reach may not be appropriate for the middle or lower subreaches. In addition, restoration activities in the upper subreach should not be planned in piecemeal fashion ignoring the potential impacts on the middle or lower subreaches. It is probable that the system is approaching an equilibrium slope where the sediment entering this reach is being transported through the entire reach from San Acacia to San Marcial. Some future incision in the upper subreach and aggradation in the lower subreach may still occur but not to the magnitude that occurred from 1962 to 1990. This means either encroaching incision in the downstream direction or channel aggradation from downstream to upstream will further affect the middle subreach. The restoration activities should consider arresting the incision in the upper subreach. Typically channelization has been used to increase channel conveyance efficiency and increase sediment transport capacity in order to limit channel aggradation. In this case, however, channel narrowing is not a desired condition and other options to offset the bed aggradation should be considered.

Channel aggradation and degradation affect cross section geometry. In general, channel incision results in some channel widening as the bed lowers. A channel that is aggrading may lose its conveyance capacity and attack the banks resulting in channel widening. The current trend of channel morphology change throughout most of the San Acacia to San Marcial reach is channel narrowing because of reduced high flows and reduced sediment load.

The plots from over ten years of cross section surveys (all the cross sections in this reach) are presented in Appendix B. While the Figure A.9 shows channel incision in the upper subreach since 1962, the San Acacia lines (SA-Lines) survey plots in Appendix B indicate that the current channel thalweg and most of the cross section elevations are within the range of variability of the last eleven years of surveys. For those cross sections surveyed in both 1991 and 2002 (10 surveys), the thalweg elevation is generally within one foot in both sets of cross sections. In three out of ten cross sections (SA-1210, SA-1218, SA-1221), the 1991 thalweg is actually equal to lower than the 2002 surveyed thalweg. In almost all of the San Acacia surveyed cross sections, the 2002 channel bed is actually higher than previous surveys in the past ten years. A number of SA cross sections are also wider (SA-1212, SA-1215, SA-1221, SA-1231, SA-1252 and SA-1274). It can be concluded that almost all of the channel incision in the upper subreach indicated in Figure A.9 occurred between 1962 and 1990.

In the lower subreach from approximately SO-1560.5 downstream to San Marcial the channel and floodplain are aggrading. Some of the overbank cross sections have aggraded several feet since 1990. Cross-section SO-1566 has aggraded 2 ft for almost 600 ft in the right overbank. Most of the 2002 cross section surveys have higher floodplain elevations than any of the previous surveys.

Understanding and predicting the cross section responses to restoration activities is the key to a planning and designing self-sustaining river system. The channel morphology trends for the three subreaches from San Acacia to San Marcial include:

- A slight channel widening with a relatively stable thalweg profile (or slight incision) in the upstream subreach;
- Channel narrowing in middle and lower subreaches;
- Channel aggradation in the lower subreach.

Keeping an active channel is the key physical process that will eliminate the potential vegetation encroachment. Cross sections SO-1428 through SO-1456 plots display the level of variability necessary to limit vegetation encroachment within the active channel.

Channel Maintenance Flows and Overbank Flooding

The concept of channel forming flows can have several facets related to bed material mobility, maximizing sediment transport (effective discharge) or bankfull discharge. Channel forming flow may be defined as the flow at which the bed material is mobilized and the banks begin to erode. Wolman and Miller (1960) emphasized that a range of flows affects the channel shape, not a single discharge and therefore the importance of destructive large flood events can be overstated.

Bankfull discharge is defined as the flow that fills the channel without overtopping the banks and it is often considered as the dominant or channel-forming discharge for alluvial rivers (Richards, 1982). The channel forming discharge is assigned flow frequency that is in the range of the bankfull discharge return period usually between 1 and 2 years (Richards, 1982). For rivers with regulated flows or incised channels, the bankfull discharge could have a much higher return period. For example, for the Green River in Utah the pre-1963 (date of Flaming Gorge Dam construction) return period bankfull discharge was on the order of 1.5 to 3 years and in the post-1963 period it was as high as 15 years.

It is an oversimplification to assume that the return period for a bankfull discharge is constant over time. Adjustments in channel morphology in response to watershed conditions, climate changes or water resource development can alter the bankfull discharge return period. Reduction in sediment load and peak discharge may result in channel narrowing and incision that may decrease the frequency of bankfull discharge. Channel width will adjust to provide the most efficient discharge under the prevailing sediment supply conditions (Richards, 1982). Other processes may also influence the occurrence of bankfull discharge such as sediment deposition on the floodplain, the creation of natural levees, bank stabilization and vegetation encroachment. Bankfull discharge can vary both spatially and temporally along a river reach.

Overbank discharge in the San Marcial reach was analyzed using the FLO-2D model. To support this effort, a field data collection program for the 1998 peak flow (3,300 cfs) was conducted. The water surface elevation was surveyed for every cross section from Highway 380 to San Marcial on May 28, 1998 just after the peak discharge (flows ranged from 2,200 to 2,500 cfs). During the water surface surveys, the flows were just below bankfull discharge. The water surface elevations were used to calibrate the estimated channel n-values in the model. A flyover video of the river during high flows was made to support the modeling effort. The peak discharge of 3,300 cfs exceeded bankfull discharge in a number of locations in the study reach. The FLO-2D model predicted 633 acres of floodplain inundation. It was estimated that the bankfull discharge in this reach was as low as 2,800 cfs at some cross sections.

The Bureau of Reclamation mapped the 1992 flood inundation for a May peak discharge of 5,200 cfs at San Marcial. FLO-2D was applied and calibrated to the 1992 area of inundation. The Bureau estimated 3,014 acres of flooded overbank area and FLO-2D predicted 3,036 acres (Tetra Tech, 2000). By adjusting the hydraulic conductivity in the infiltration losses, these acreages were computed with a high correlation of the peak discharge at the San Marcial gage (predicted 5,240 cfs vs. measured 5,090 cfs).

A flood frequency analysis was conducted for the San Acacia gage for the periods 1974-1996 and 1987-1996 (Table 6). Cochiti Dam regulated flows for both of these periods of record and therefore the frequency analysis is only valid for flows up to about 8,000 cfs. The 1992 flooding had a return period between 2 and 5 years. Bankfull discharge for much of the middle and lower San Acacia South subreach has a return period of less than 2 years indicating that this portion of the river is functioning with an appropriate alluvial channel-floodplain connectivity. This flood frequency analysis and discussion was updated and expanded in Phase II.

Table 6. San Acacia Peak Discharge Frequency

Frequency	Return Period	1974-1996 Discharge (cfs)	1987-1996 Discharge (cfs)
0.5	2	4530	4590
0.2	5	6430	6190
0.1	10	7610	7140
0.05	20	8670	7990
Average Annual Peak Discharge		4530	4970

Bankfull discharge is variable throughout the San Acacia – San Marcial reach. In the upper reach where the channel has experienced some incision, the bankfull discharge is much greater and more infrequent than the bankfull discharge in the middle and lower subreaches. For this reason, increasing channel-floodplain connectivity to enhance riparian habitat in the upper subreach will be more difficult. It should also be noted that in several reaches between San Acacia and San Marcial, the bed material and bed shear stress relationship is such that at or near bankfull discharge an upper regime plane bed occurs. This significantly reduces the hydraulic roughness in the channel and lowers the water surface elevation. As increasing flows approach bankfull discharge, the water surface elevation can actually decrease with incremental increases in discharge.

In summary, channel forming flows in the range of the bankfull discharge vary throughout the San Acacia – San Marcial reach. Bankfull discharge has a higher magnitude and is less frequent in the upper subreach than the middle and lower subreaches. In the middle and lower subreaches, bankfull discharge has a return period that is less than 2 years based on post-Cochiti flows. This is typical of most alluvial rivers. Maintaining the active channel requires flows that approach the channel forming flows and are also sufficiently frequent to eliminate vegetation encroachment on the active channel bed. Generally, bankfull discharge must occur at least once every three years to avoid channel narrowing associated with vegetation encroachment. Average bankfull discharge in each reach will be estimated for the restoration plan.

Habitat Resources

Vegetation Classification and Mapping

As discussed in the Riparian Habitat Changes section above, there have been various attempts to record and quantify the vegetative communities along the middle Rio Grande over the last decade. Within the last 20 years, there have been two comprehensive vegetation/habitat mapping efforts for the active floodplain of the Rio Grande between San Acacia to San Marcial. The first effort is documented in the Middle Rio Grande Biological Survey by Hink and Ohmart (1984). The fieldwork for this survey was begun on February 1, 1981. Hink and Ohmart used a method of vegetation community classification similar to the Association (sixth level) in the Brown – Lowe-Passe classification system (Brown et al. 1979) and equivalent to Dick-Peddie's (1981) Habitat Type. The results of this survey are three different GIS maps. The first map depicts the vegetation classification according to the text from the Hink and Ohmart (1984) study. This is the most detailed with 111 classifications based on species composition and canopy structure. The vegetative mapping does not cover the area downstream of San Acacia. The second map was created by the USFWS in 2000 based on the Hink and Ohmart study and 1997 aerial photographs. This map updates the Hink and Ohmart study and covers the reach from San Acacia to San Marcial but uses only six major vegetation classifications with a number of subclasses. These classifications use the Association (sixth level) in the Brown-Lowe-Passe classification system (Brown et al. 1979). The third GIS layer created from this study is a wildlife habitats layer depicting six distinct habitat types as related to willow flycatcher habitat suitability.

The second mapping effort is the US Fish and Wildlife Survey (USFWS) National Wetland Inventory maps for the Middle Rio Grande (1989). These 7.5-quad level maps were developed based on aerial photo interpretation using wetland habitat classifications as developed by Cowardin (1979). While these maps provide locations of wetland habitats, the classification system is too general to distinguish vegetative communities and ecological health.

As part of this current study, the University of New Mexico has been contracted to provide GIS layers showing the river channel and riparian corridor of the study area for 1935, 1955 ,1975 and 1992 using digital aerial photographs. The methods and classification system used is not directly comparable to the Hink and Ohmart 1984 and USFWS 2000 vegetation studies. The UNM studies considered a maximum of four categories per study year which were not entirely consistent from year to year. As a result, we will be unable to incorporate this data for direct comparisons

Just upstream of the study area, the Sevilleta Long Term Ecological Research (LTER) Program and the New Mexico Natural Heritage Program have produced a map of vegetative classes within the Sevilleta National Wildlife Refuge (Muldavin and Milne, no date). The classification system includes 13 association-level categories derived from the National Vegetation Classification System (NVCS). This level of aggregation is designed to delineate terrestrial ecological communities over large geographical areas. Such a classification is too broad for distinguishing important riparian communities and is not appropriate for restoration mapping (for example, the entire riparian zone in Sevilleta National Wildlife Refuge is lumped into a category called Rio Grande Riparian Woodland).

The BOR in 2001 developed a Southwestern willow flycatcher habitat suitability map for the riparian corridor between San Acacia and Elephant Butte Reservoir. This information was included in the Programmatic Biological Opinion for the Middle Rio Grande USFWS June 29, 2001. In addition, BOR has collected intensive vegetation data for two seasons in the reach from San Acacia to Elephant Butte in about eight macroplots. Avian nest productivity and point count data has also been collected within these plots. Data is in the process of being compiled and should be ready in early 2003.

There are two vegetation mapping efforts encompassing the study area currently underway. First, the New Mexico Interstate Stream Commission (ISC) is conducting vegetation mapping using IKONOS imagery. This data has been requested but it may not be final or publicly available. Second, the Bureau of Reclamation is planning on taking aerial photographs of the Middle Rio Grande during the summer of 2002. Ground truthing is tentatively scheduled to begin in November 2002. Conversations with Reclamation personnel have indicated that they intend to use the Hink and Ohmart 1984 vegetation community classifications for their survey. This will generate a detailed and accurate map of the area.

In conclusion, the most widely used and referenced vegetation classification system for the study area is the 1984 Hink and Ohmart study. Since the publication of Hink and Ohmart's study, the New Mexico Natural Heritage Program developed the Handbook of Wetland Vegetation Communities of New Mexico to provide a standardized means of classifying wetland and riparian habitat (Muldavin et al., 2000). The classification system has 135 plant communities that occur within 33 plant alliances. While there are a number of reference sites between San Acacia and San Marcial, no formal mapping based on this classification system has been prepared for the study area.

Wildlife Resources

Riparian habitat has high wildlife value because of the diversity and abundance of animal species which rely on the ecosystem for its unique plant community types, hydrologic features, soil, topography and other environmental features that do not exist in contiguous upland habitat (Crawford et al. 1993). Human occupation along the river corridor has altered the floodplain and channel morphology resulting in a significant decline in native plant and animal communities and in increase in exotic species that are more likely to adapt to human induced conditions. For example, over 20 species of vertebrate animals have been extirpated from the Middle Rio Grande basin (Scurlock, 1998) and 21 species that use the river and floodplain habitat have been recorded as sensitive species warranting habitat study (Table 7).

The goal of the Endangered Species Act (ESA) (16 USC §§ 1531-1544 PL 93-205, 1973) is to protect existing sensitive species. It is an key component driving the water and resource management of the Rio Grande system. This has been especially notable over the last decade as the US Fish and Wildlife Service, Bureau of Reclamation, and Army Corps of Engineers have focused Rio Grande management to meet the needs of the endangered Rio Grande silvery minnow (*Hybognathus amarus*) and endangered southwestern willow flycatcher (*Empidonax traillii extimus*).

Table 7 – Special Status Species Potentially Occurring in the Active Floodplain

Common Name	**Scientific Name**	**ESA Listing**	**USFS**	**BLM**	**NM**	**Global Rank**
Mammals						
Occult myotis	*Myotis lucifugus occultus*					G5T3
Hot springs cotton rat	*Sigmodon fulviventer goldmani*					G5T1
New Mexican jumping mouse	*Zapus hudsonius luteus*				T	G5T2
Birds						
Common blackhawk	*Buteogallus anthracinus*				T	G3
Southwestern willow	*Epidonax traillii extimus*	E			E	G5T2
Whooping crane	*Grus americana*	E XN			E	G1
Interior least tern	*Sterna antillarum*	E			E	
Bald eagle	*Haliaeetus leucocephalus*	T PD			T	G4
Bell's vireo	*Vireo bellii*	PS			T	G5
Yellow-billed cuckoo	*Coccyzus americanus*	C				G5
Reptiles						
Big Bend slider	*Trachemys gaigeae*					G3
Fish						
Rio Grande silvery minnow	*Hybognathus amarus*	E			E	G1
Plants						
Ripley milkvetch	*Astragalus ripleyi*				S	G3
Warnock's willow	*Justica warnockii*					G3
Grama grass cactus	*Toumeya papyracantha*				D	G3G4
Great Plains spiranthes	*Spiranthes magnicamporum*					G4
Giant helleborine	*Epipactis gigantea*					G3
Catchfly dentian	*Eustoma exaltatum*					G4G5
Pecos sunflower	*Helianthus paradoxa*				T	
La Jolla prairie clover	*Dalea scariosa*					G4
Parish's alkali grass	*Puccinellia parishii*					G2

Source: CNHP 2002, NMNHP 2002, Crawford et al. (1993).

Notes: E = endangered, T = threatened, PD = proposed for delisting, C = candidate for listing, XN = experimental non-essential population, PS = partial status, S = sensitive, D = dropped list, G1 = critically imperiled, G2 = imperiled, G3 = vulnerable, G4 = apparently secure, G5=demonstrably secure.

Based on species lists maintained by the Bosque del Apache and Sevilleta National Wildlife Refuges over 50 mammal species, 25 amphibian and invertebrate species and over 200 avian species have been observed within the Rio Grande floodplain. Some of these species are opportunistic and can inhabit a variety of habitat types while others are dependent upon certain vegetation communities and site conditions. Desirable community associations for the project area include mature and regenerating cottonwood forest, understory native riparian shrub, marsh and wet meadows, sandbars and shoreline, and riverine habitats. One method to assess the habitat functionality and to monitor the habitat changes over time is to identify certain species that are dependent upon one or two of the habitat types found in the riparian corridor. From a review of the species lists, existing literature, and correspondence with Task Force members there are a number of species that may be suitable for future studies as a way of monitoring key habitat and site conditions. To select appropriate target species, the list was refined based on the data available for specific species such as surveys and document life histories. As expected, this list contains some sensitive species because of the level of research and monitoring that has been dedicated to them. The following lists potentially suitable monitoring species by habitat type. Some species may use more than one habitat type and as a result are listed more than once.

Mature and regenerating cottonwood forest: Rio Grande cottonwood, yellow billed cuckoo, ladder-backed woodpecker (*Picoides nuttallii*), blue grosbeak (*Guiraca caerulea*), ash-throated flycatcher (*Myiarchus crinitus*), and summer tanager (*Piranga rubra).*

Understory native riparian shrub: Coyote willow, southwest willow flycatcher, Gambel's quail (*Callipepla gambelii*), ash-throated flycatcher, and summer tanager.

Marsh and wet meadows: Parish's alkali grass, muskrat (*Ondatra zibethica*), tiger salamander (*Ambystoma tigrinum*)and northern leopard frog (*Rana pipiens*).

Sandbars and shoreline: Spotted sandpiper (*Actitis macularia*), killdeer (*Charadrius vociferous*), interior least tern, piping plover, and snowy plover

Riverine: Rio Grande silvery minnow, beaver (*Castor canadensis*).

Mapping, Data and Photo Resources

Historical Maps and Photos

Historic aerial photographs, maps and digital terrain models of the Rio Grande corridor have been compiled from various sources. A complete set of 1:24,000 scale (7.5 minute) Digital Raster Graphics (DRG's) quadrangle maps have been obtained covering the reach from the San Acacia Diversion Dam to the San Marcial Railroad Bridge. A Mr. SID gray scale mosaic of the 1996 Digital Orthophoto Quarter Quads with a one-meter pixel resolution covering the same reach has also been obtained. The U.S. Fish & Wildlife Service, Region 2, Division of Technical Services office processed and parsed the data for this reach of the river. These comprehensive data sets will be used as 'back drops' for many of the mapping products and displays that will be produced in the succeeding phases of this study.

Several sources of aerial photography and satellite imagery have been identified and/or obtained within the project reach. A summary list of the more significant sets identified to date are presented in Table 8.

Table 8. Available Aerial Photos

Year	Type	Coverage	Scale	Description/Source
1935	B/W	Entire		
1949	B/W	Entire		
1962	B/W	Entire	1:24000	River corridor agg/deg project / unknown for USBR
1972	B/W	Entire	1:24000	River corridor agg/deg support / unknown for USBR
1985	B/W	Entire	1:24000	River corridor agg/deg support / PWT (KPE) for USBR
1992	B/W	Entire	1:24000	River corridor agg/deg support / PWT (KPE) for USBR
1996	Color	BDANWR	1:24000	Scanned 9" x 9" contact prints / unknown for USFWS BDANWR
1997	B/W	South Boundary BDA to SM	1:24000	Tiff/cot digital orthophotos 2' pixel / PWT for USBR
1998	Color	SA to Socorro	1:20000	Tiff digital orthophotos 2' pixel / TRM for COE
2000	Color I/R	Entire	4 meter IKONOS	ERDAS Images / Space Imaging (PWT) for NMISC & MRGCD (licensed data)
2000	B/W	Entire	1:6500	9"x 9" contact prints / TRM for COE
2000	Color	Entire	1:12000	9"x 9" contact prints / TRM for COE

A search for additional aerial photos of the project reach by the Earth Data and Analysis Center (EDAC) of the University of New Mexico produced numerous other photo sets from 1946 through 1999 that contained small sections of the reach. Discussions with the EDAC director revealed, however, that only a 1955 set from the Agricultural Stabilization and Conservation Service included the entire reach.

The "active river" of the complete project reach has been digitized for the years 1935, 1949, 1962, 1972, 1985, and 1992 from the aerial photography. In addition, there is a 1918 data set that has been digitized from hardcopy maps (ground surveyed). These digital depictions will be used in GIS and advanced CADD applications to analyze the migration of the river through time.

Topographic Mapping and DTM Data

Topographic mapping available in the project reach consists of USGS DRG's, USGS digital elevation models (DEM's), detailed digital terrain model (DTM) data, and limited contour mapping. The DRG's and DEM's are only capable of producing 10 and 20 foot contour interval mapping and will be of limited use for this project. The available DTM data is capable of producing 2 foot contour interval mapping and thus will be beneficial for certain aspects of this study. There are three different DTM's within the project reach.

The first, extending from San Acacia to Socorro, was compiled in 1998 using a Light Detection and Ranging (LIDAR) sensor mounted in a fixed wing aircraft. This data set was developed by Eaglescan, Inc through a contract with the Corps of Engineers (COE) and covers the entire floodplain from bluff to bluff with mass point data. The original data was collected at roughly 3-meter post spacing. The COE processed this point data in advanced CADD software (InRoads) and a DTM was created. In addition to the DTM data, natural color digital orthophotos with a 2-foot pixel resolution were produced for this reach. These data sets were delivered to the COE referenced to the New Mexico State Plane Coordinate Grid System (NMSPCGS) NAD 1983 central zone. Elevation data is referenced to NAVD 1988.

The second DTM runs from the Escondida Bridge to the South Boundary of Bosque del Apache NWR. Pacific Western Technology, Inc (PWT) (formerly Koogle & Pouls) created this DTM using traditional photogrammetry in 1997 through a contract with the Corps of Engineers in cooperation with the USBR and USFWS. The DTM covers the width of the aggradation/degradation range lines. PWT used recovered 1:6000 aerial photography from 1992 to compile this DTM. In addition to the DTM data, PWT produced black and white digital orthophotos from 1:24000 aerial photography that also was flown in 1992. These data sets were delivered to the COE referenced to the NMSPCGS NAD 1927 central zone. Elevation data is referenced to NGVD 1929. A copy of this data set has been converted to NMSPCGS NAD 1983 / NAVD 1988.

The third DTM within the project reach extends from the South Boundary of Bosque del Apache NWR to the headwaters of Elephant Butte Reservoir. This DTM was also created using traditional photogrammetry by Pacific Western Technology, Inc in 1997 through a contract with the Bureau of Reclamation. This DTM covers much of the floodplain through the study reach. PWT used 1:6000 aerial photography from 1997 to develop the DTM. In addition to the DTM data, PWT produced black and white digital orthophotos from 1:24000 aerial photography also flown in 1997. These data sets were delivered to the USBR & COE referenced to NMSPCGS NAD 1927 / NGVD 1929. A copy of this data set has been converted to NMSPCGS NAD 1983 / NAVD 1988.

Finally, a brief comment on other available mapping. The Bureau also had 2 foot contour interval graphic files (1”=400’) produced and delivered for this lower reach under the same contract. These contour files represent the only recent detailed contour mapping (produced by a mapping contractor) that is available in the project reach. The 1918 vegetation survey (mapping) covering the Middle Rio Grande from Cochiti to San Marcial is in the process of being obtained.

Sediment Data

Sediment data collected in the reach between San Acacia Dam and the San Marcial Railroad Bridge includes bed material samples, suspended sediment samples and bedload samples. There are two data sources. During the 12-year period from 1978 to 1989, the USGS collected suspended sediment samples and hydraulic data at San Marcial in one month intervals, a total of 79 samples. The Bureau of Reclamation used the data to compute total load and bed material load using the Modified Einstein Procedure (Samad, 1993). The second sediment database was collected for the Bureau of Reclamation either by the Reclamation staff or their contractor, Tetra Tech ISG. A list of the collected sediment data showing the reach, date of collection, type of data collected, and cross section number is presented with the cross section data in Appendix B.

The Reclamation sediment load data were collected in the San Acacia South reach each year from 1995 to 1999 and 2002. Bed material samples were collected with each reach of cross section survey lines. The number of cross sections where bed material was sampled in each set of lines varied from 4 to 15. Suspended sediment samples were collected in 1997 at 13 cross sections. According to the records bedload samples have not been collected in the SA reach.

Sediment data were collected in the Socorro (SO-Lines) reach at least once each year from 1989 through 2002, except 2000. Bed material samples were collected each year at 3 to 18 cross sections. Suspended sediment samples were collected in eleven of the years at 1 to 8 cross sections. Bedload samples were collected at 1 to 3 cross sections during six years. Cross sections SO-1414, SO-1437.9, and 1470.5 have been used for total load calculations. Most of the available sediment load data has been collected at these three cross sections. Total load calculations determine the amount of sediment passing a cross section based on the Modified Einstein equation. Total loads have been calculated at these cross sections seven times between 1992 and 1999. Total sediment load measurements have also been collected at EB-10, just downstream of the San Marcial gage. Bed material and suspended sediment samples were collected in 1992 and 1993 at the Lemitar Jack site for three cross sections. Only suspended sediment samples were collected in 1991. A complete list of all sediment load and bed material sample data and the sites at which they were collected is presented in Appendix B.

Cross Section Data

Cross-section surveys have been conducted by the Bureau of Reclamation and Tetra Tech ISG in the San Acacia – San Marcial reach since 1987. This data is archived at Reclamation's Albuquerque office. Copies of the data collected by Tetra Tech are also archived at the Tetra Tech ISG Albuquerque office. Comparative analysis of the cross section surveys is presented in Appendix B. A brief analysis of the cross section data is presented in the section on cross section variability.

Geographic Information System Maps and Base Data

Geographic Information System (GIS) and CADD base maps will be used as one of the primary tools for displaying and analyzing information in this project. All GIS data and files will be projected to UTM Zone 13 NAD 83 and provided as ArcGIS (ArcView) shapefiles. All CADD files depicting "plan" information will be referenced to the NMSPCGS NAD 83 / NGVD 88. There will be various CADD files in AutoCAD and Microstation formats produced during the course of the project. As outlined in a previous section, several different images have been obtained that will provide backdrops to map products as well as information that can be digitized into GIS themes. The base maps for displaying this information will be generated at a scale of at least 1:24,000.

Base data has been or will be converted to ArcGIS (ArcView) polygon, polyline, or point themes. This includes land parcel and ownership data, public land surveys, Hink and Ohmart vegetation surveys, surveys of the active Rio Grande channel and the DRG files that have been provided by the USFWS. Floodplain terrace polygons also have been provided as ArcView shapefiles by the USBR. The University of New Mexico Civil Engineering Department (UNM) will be providing additional GIS base data depicting soils, geology, hydrography, land use trend data and vegetation classifications. Additional detail on the vegetation mapping and classification is provided in this report under the Habitat Resources section.

GIS & CADD databases are presently being prepared in conjunction with FLO-2D model results to determine area of inundation as a function of other floodplain attributes such as vegetation and property ownership. This effort and the resulting maps will ultimately support the development of the restoration plan. The FLO-2D model processor program MAPPER has been developed to utilize this DTM database and generate GIS ArcView compatible shape files of the FLO-2D results. In addition, advanced CADD applications, such as InRoads, will be used to post process the FLO-2D results and produce maps and files that will assist in the development of restoration concepts through the project reach.

Additional GIS data sets that have been identified but not yet obtained include;

- 1995 – 2000 Southwestern Willow Flycatcher Survey (USBR)
- Southwestern Willow Flycatcher Habitat Suitability Maps (1:24,000 2000 USBR)
- 1995 – 2000 Bald Eagle Surveys (USBR)

- 1995 – 2000 Sensitive Bird Surveys (Yellow-Billed Cuckoo, Bell's vireo and others) (USBR)
- 4500' Full Pool Elephant Butte Reservoir (USBR)
- IKONOS Vegetation (original imagery - 4M resolution-CIR) (NMISC/MRGCD)
  - GIS classification (in ArcView as shapefiles) interpreted from the IKONOS satellite imagery MRGCD and NMISC acquired in July and August of 2000. 90% obtained between July 23 -25.
  - Extents of the imagery: Otowi Bridge to Elephant Butte. Original imagery is 4 band (RGB& IR) & is 4-meter pixel resolution.
  - Paul Nevell from EDAC did the riparian classification (8 classes identified). The extent of ground truthing was not known. It was estimated that the classification for the riparian corridor is ~ 80% accurate.
- 1935 & 1989 National Wetland Inventory Maps:
  - Lateral Extent: Terrace to terrace, except for missing photography on 10% of the geologic floodplain. Photography: 1935 and 1989, respectively.
  - Classification: NWI/Cowardin et al. 1979; "Riparian" (Forested or Shrub, and then prime species); "Agricultural" (with cropland, orchard, tilled land, mixed); and "Range" (upland, not otherwise classified).
  - Mapped by: 1989 photography mapped by NWI contractors, 1935 photography mapped by Mid-continent Ecological Science Center (Formerly NERC), Ft Collins.
  - Availability: Paper maps (NWI overlaid on topo sheet base) of the 1989 coverage are available from USFWS/NWI sources. USFWS also published these in bound folio with some background information and summaries (Roelle, 1994).
  - The USFWS Ecological Services office has prepared Arc/Info datasets of both the 1935 and 1989 coverages. These files will be acquired from the COE or the USFWS for use in this project.

Federal Geographic Data Committee (FGDC) compliant metadata has been produced or will be produced (where source citations and information is available) for the various geospatial data sets anticipated to be used in the course of this project. An example of the functionality of the CADD and GIS maps (scale, resolution, and data) that will be used in this study is shown in Figure A.12.

Phase I. Summary

Phase I of the conceptual restoration plan for the Middle Rio Grande reach from San Acacia to San Marcial involved an investigation of the existing data and published information on the river and riparian ecosystem. The intent was to compile a database and library of reference material to support future conceptual restoration designs. One of the purposes of the Phase I investigation was to explore river restoration from a historical perspective by reviewing the evolution of the Middle Rio Grande river considering hydrology, morphology and vegetation composition. Understanding channel morphology and the changes that occurred in response to water and related land resource development would serve as a basis for exploring restoration opportunities. Such opportunities may take the form of providing a greater range of flow regimes, returning to a higher level of river dynamic behavior, removing constraints on channel processes such as invasive vegetation, expanding the active floodplain, increasing channel floodplain connectivity, physical reformation of the channel geometry, enhancement of the riparian system and management of the sediment loading.

Historically the Rio Grande had a natural cycle of removal and regeneration of native plant communities that occurred with flooding and channel migration. Cottonwood bosques in varying age groups fell victim to channel migration and also to beavers. Woody debris provided coverage and habitat in the river channel. Large flood events filled the valley with ponded water. It is apparent that the wetlands, marshes, open scrublands, alkali flats and meadows were a significant portion of the floodplain community when the Spanish arrived.

With the beginning of agriculture in the Rio Grande valley about 1,500 years ago, the native vegetation composition and distribution was altered. Landscape fragmentation occurred with deliberate fires and cropland clearing. As a result our knowledge of the pre-historic “natural” Rio Grande floodplain is only anecdotal. Increasing populations (both Pueblo and European) and land cultivation was accompanied by expanded irrigation systems that gradually decreased flows in the system. Eventually upstream reservoir storage attenuated flood peaks and the channel morphology was altered. As flooding became infrequent, mistimed and of shorter duration, the riparian vegetation regenerative processes were curtailed. Prominently missing in the river’s hydrologic cycles are the destructive flows that initiated channel migration and bank erosion to remove the trees. Gone are the spring flood flows that created the wet substrate in large open areas for germination of native riparian plant species. In response to decreased flooding and reduced sediment loads, the channel has narrowed and the floodplain has become dominated by non-native salt cedar.

What happened to the Middle Rio Grande was a loss of channel complexity and a loss of channel-floodplain connectivity. The inability of the river to rework the channel on a bi-annual basis supported the development of a monoculture salt cedar riparian system on the floodplain. Both aggradation and degradation in response to reduced sediment loads and decreased peak flows have been documented in the study reach.

These opposing trends indicate that restoration plans must be uniquely designed for each subreach in the San Acacia to San Marcial reach.

To create a mosaic of floodplain vegetation communities and enhance channel processes, channel-forming flows of sufficient magnitude and frequency must occur. The hydrologic relationship between the channel flows and the flooded bottomlands have to be assessed through the response of the system to a range of discharges and sediment loads. Flushing flows are needed to rework the channel and scour sediment and vegetation from low velocity habitats. When peak flows are unsuccessful in creating diverse habitat and complex channel features, then channel narrowing ensues and aquatic habitat is diminished. Infrequent high flows in excess of bankfull discharge may be required to reform the full suite of channel and floodplain features. In the presence of reduced sediment loads, flushing flows can also result in a sediment deficiency and cause incision within a given reach. The key is to have the appropriate balance of sediment and water discharge relationship to sustain an active channel.

The primary restoration goals for this reach are increasing the mosaic of native dominated riparian habitat cottonwood bosque and enhancing river channel dynamics. Restoration of flooded bottomlands habitat and in-channel features can be accomplished through a combination of increased water surface elevations, lowered banks and floodplain, augmented peak flows and reconstructed channels with greater width-to-depth ratio. For restoration sites and reaches to be functional over the long term, channel-forming flows must be available for a prescribed frequency and duration. Sites should also have the ability to be drained.

Based on a final assessment of the historical vegetation composition and an analysis of the existing sediment load and flow regimes, a restoration plan will be formulated that includes improving river-floodplain hydrologic connectivity, increasing the cottonwood/willow bosque and creating wetlands, marshes and salt grass meadows. In terms of the channel dynamics, a flow regime within existing administrative, legal, and physical constraints will be formulated to sustain a prescribed active channel. The restoration plan will optimize the active channel width-to-depth ratio and channel-floodplain connectivity on a reach by reach basis. The plan will consider potential future sediment yield scenarios, the linkage between sediment load and channel form, future aggradation and degradation trends, equilibrium slope, and cross section variability. An adaptive management plan and channel maintenance flows will be proposed.

In Phase II, two important channel morphology and hydrology issues will be addressed. The first issue is the long-term decrease in the sediment load at San Acacia. Higher and more frequent discharge without a corresponding increase in sediment supply would exacerbate channel incision and reduce potential flooding. The second issue in the form of a question is: How much flooding and what frequency of flooding are needed to limit the encroachment of exotic vegetation in the riparian zone?

Conceptual Restoration Plan for the Active Floodplain of the Middle Rio Grande – San Acacia to San Marcial

Phase II. Specific River Issues

Phase II Introduction

To provide a basis for the conceptual restoration plan for the Middle Rio Grande active floodplain in the reach from San Acacia to San Marcial, a number of issues were investigated including flood frequency, sediment loading, channel capacity, areas of high flood potential, restoration components, riparian and aquatic habitat, evapotranspiration, institutional constraints and potential for water salvage. The conceptual restoration plan will include project area components whose design and implementation will be contingent on overcoming obstacles and constraints that may limit the type or the areal extent of the restoration activity.

This report is based on field research, hydrologic analyses, hydraulic modeling and a further review of the literature. Each section of the report addresses a specific river issue including reach delineation, channel conveyance capacity, flood hydrology, channel morphology maintenance flows, long term sediment loading, existing condition or the riparian and aquatic habitat, evapotranspiration, Rio Grande Compact commitments, groundwater impacts, water salvage, and river restoration constraints. The section on the Rio Grande Compact and Related Water Use Issues was prepared by William J. Miller Engineers, Inc. Portions of the data and text on vegetation evapotranspiration were contributed by the University of New Mexico, Department of Civil Engineering under contract to Tetra Tech.

Understanding the issues and resolving the constraints outlined in this Phase II report will lead to the development of specific project area restoration component designs. The restoration component design selection process will be completed in Phase III and will include the development of a matrix evaluation of sites and alternative components and an overall phased restoration strategy. The components will be designed and linked based on consistency of functionality, environmental compatibility and long term maintenance requirements. In this report, the San Acacia to San Marcial reach has been divided into three subreaches based on geomorphic trends. Nine project areas within those subreaches have been outlined. In Phase III the project areas and project components will be ranked and prioritized. The Conceptual Restoration Plan will be finalized in Phase IV and a monitoring program and adaptive management strategy will be developed in Phase V of the project. General instructions and implementation information will be prepared in Phase VI or the project.

Phase II Work Plan

Phase II of this project will examine and analyze specific river issues including channel capacity, areas of inundation, the condition of the riparian and aquatic habitat, water budget, compact commitments and criteria for restoration areas. The projected tasks are presented in the following list.

Channel Capacity
- Determine bankfull discharge by subreach.
- Analyze in-channel maintenance flows.
- Develop a spring flushing flow hydrograph.
- Assess sediment loading for restoration river functions.
- Describe problem areas and subreaches for restoration.

Identify Areas of High Flood Potential
- Identify flood inundation areas.
- High water surface surveys.
- Assess flood frequency and channel forming discharges.

Characterize Condition of Riparian and Aquatic Habitat
- Assessment of habitat value.
- Describe threats.
- GIS mapping of habitat.
- Assess trends and conditions with and without restoration.

Determine Water Budget
- Evaluate ET estimates.
- Determine losses associated with overbank flows.
- Evaluate groundwater/surface water interface.
- Develop a method for determining water salvage.

Rio Grande Compact Commitments
- Describe compact commitments.
- Assess compact limitations on delivery

Establish Criteria for Restoration Areas
- Identify areas for potential restoration on GIS mapping.
- Describe factors contributing to restoration needs.
- Determine restoration criteria and constraints.
- Analyze geomorphic trends for restoration concepts.
- Landownership mapping and constraints.
- Groundwater, salt and other factors.

Subreach Delineation

The San Acacia to San Marcial reach was divided into three subreaches for the purpose of identifying appropriate and compatible restoration activities for the existing channel morphological trends outlined in Phase I of the restoration study. The three subreaches are:

1. *Escondida Reach* - San Acacia Diversion Dam to the Socorro North Diversion Channel (13.5 miles).

2. *San Antonio Reach* - North Socorro Diversion Channel to the North Boundary Bosque del Apache National Wildlife Refuge (18.5 miles).

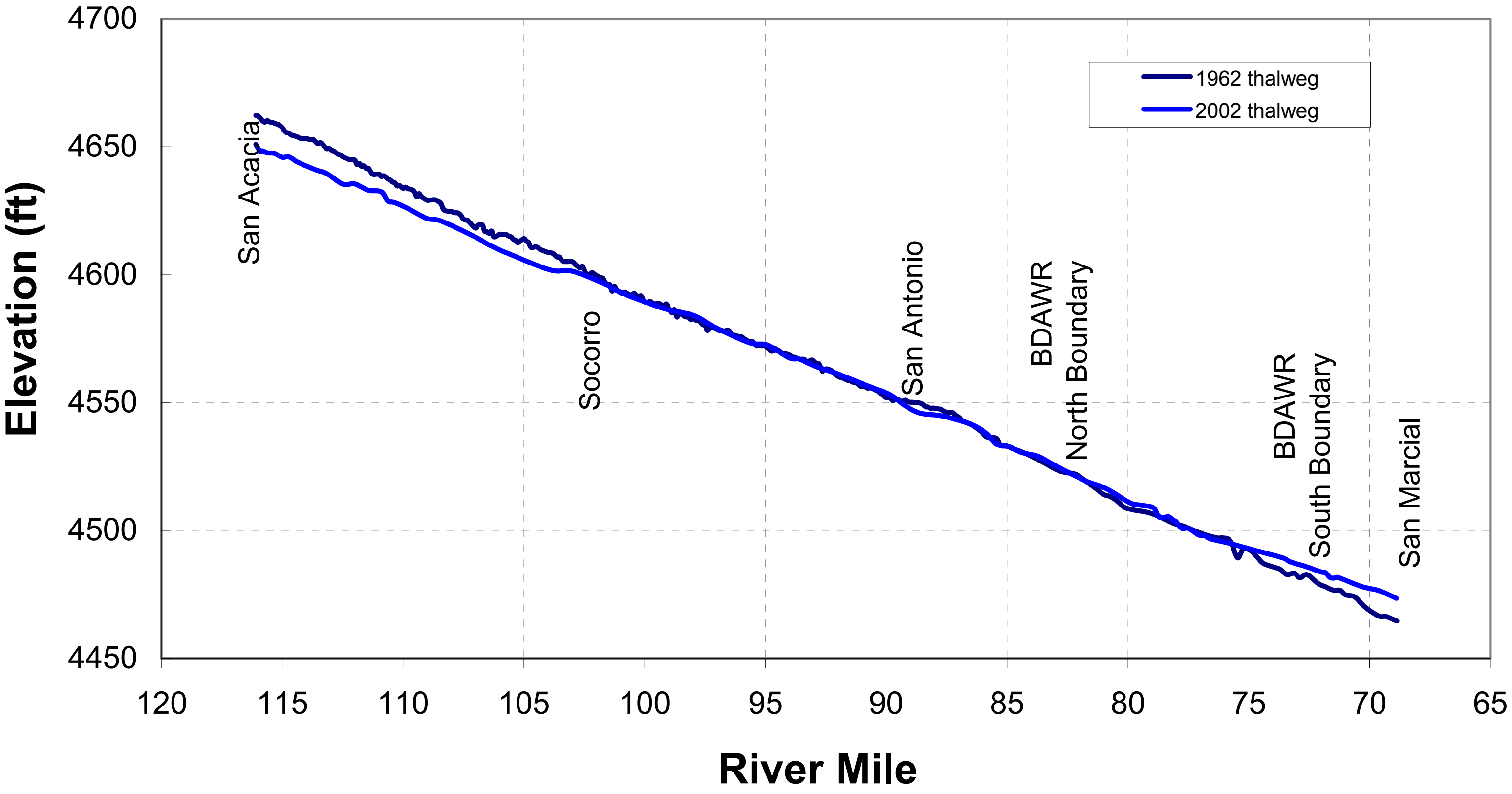
3. *Refuge Reach* - North Boundary Bosque del Apache National Wildlife Refuge to San Marcial Bridge (15.6 miles).

The purpose of this delineation was to address similar channel morphology issues for each subreach. Within each subreach, the river has narrow and wide channel segments, has different stages of an active channel, varying extents of vegetation encroachment and highly variable overbank flooding. Most of the variation has been imposed by river training and maintenance activities including channel relocation and dredging. The entire San Acacia to San Marcial reach has relative uniform sand bed material. The three subreaches were delineated on the basis of potential response to sediment transport capacity.

The river profile in Figure 2 shows the geomorphic trend over the past 40 years. As was discussed at length in the Phase I report, the Escondida subreach channel has incised since 1962, the San Antonio middle subreach has been approximately in equilibrium and the lower Refuge subreach has been aggrading. While the Escondida subreach is not currently displaying any significant incisional pattern and may have reached equilibrium, the lower subreach is expected to continue aggradation. There is a significant break in channel bed slope in the vicinity of river mile 76, just 1.5 miles upstream of the south boundary of Bosque del Apache NWR due to downstream aggradation. It is likely that this aggradation will extend upstream over the long term. For restoration purposes, it is assumed that this general pattern of incision and aggradation will continue but will be moderated. The various subreaches were selected to address the potential channel response to restoration activity. They were not selected on the basis of the existing channel geometry or bed slope.

In each subreach, restoration project components will be developed and may include such projects as channel mowing and disking, creation of overbank side channels, river relocation on the floodplain and exotic vegetation removal. The restoration components will be grouped in project areas that will be ranked and prioritized in Phase III. A preliminary attempt at grouping the project components resulted in nine project areas. For the restoration plan, three subreaches and possibly nine project areas have been delineated.

Figure 2. San Acacia to San Marcial - Thalweg Profile



River Flood Analysis

Flood Frequency Analysis

The purpose of the flood frequency analysis is to estimate the return period floods at San Acacia that can be associated with potential restoration or channel forming flows in the San Acacia to San Marcial reach. Flood frequency return periods are assigned to quantify the discussion of bankfull discharge, channel forming flows, flushing flows and project design floods. Over the last 50 years, there has been a significant change in frequency, duration and magnitude of flooding in the Middle Rio Grande. The Rio Grande channel morphology has evolved with this progressive reduction in flooding. In the San Acacia to San Marcial reach, the existing channel morphology no longer reflects previous flood frequency analyses. For this reason, it is necessary to re-examine the potential flood frequency in this reach.

In 1993, Bullard and Lane conducted a flood frequency study for eleven Rio Grande gaging stations for the Bureau of Reclamation. The results were to be used on future bank protection and sedimentation projects in the Middle Rio Grande. It was determined during the study that the large reservoirs in the system performed traditional flood control for the large flood events; however, an unconventional approach had to be adopted to remove the effects of regulation of the more frequent floods in the Middle Rio Grande. A statistical modeling effort was developed to create a historical record without reservoir regulation effects. At that time, the post-Cochiti (post-1974) record was relatively short (Bullard and Lane (1993) used the historic record through 1989). The approach taken by Bullard and Lane (1993) was to remove the effects of upstream reservoir regulation at each gage and apply statistical and regional smoothing procedures to ensure that the unregulated peak flows at the gages were correlated. The effects of regulation were then re-introduced to the smoothed unregulated peak flow frequency curves to generate the regulated peak flows at the various gages.

There are two major tributaries that enter the mainstem Middle Rio Grande upstream of San Acacia that are unregulated. The Rio Puerco and Rio Salado join the Middle Rio Grande in the 14 mile reach between the Bernardo and San Acacia gages. At the mouth of the Rio Salado and the Rio Puerco, the tributary drainage areas are approximately 1,400 and 5,880 square miles respectively. While the mainstem Rio Grande is regulated by Cochiti Reservoir with other intervening other small arroyos and washes, the unregulated Rio Puerco and Rio Salado add to the difficulty of assessing the flood frequency at San Acacia. Major floods on these tributaries may not be independent. When one tributary is flooding, it is probable that the other tributary may also experience flooding.

At the San Acacia gage, the Bullard and Lane (1993) investigation involved determining the regulated peaks for Cochiti Dam assuming a 2 day travel time. This daily peak flow was then transformed to an unregulated peak using a linear inflow/outflow regressed relationship. The differences between the regulated and unregulated daily peak flows were then added to the regulated gage record at San Acacia which included the Low Flow Conveyance Channel flows and the Socorro Main Canal flows. The regulated flows out of Jemez Dam and the regulated Rio Chama were included in the San Acacia gage analysis by assuming appropriate travel times. The Bullard and Lane (1993) unregulated flow analyses have the following limitations:

- The analysis involving mean daily peak flows underestimate the instantaneous peak flows that may be associated with the Rio Salado and Rio Puerco peak discharge inflows. The occurrence of Rio Salado and Rio Puerco peaks flows may be masked by the regression and smoothing technique used in the analysis.
- A statistical analysis was used to derive the relationships between the gages when in fact, there is high variation between gage discharges.
- Floodwave attenuation with overbank flooding associated with the increased unregulated flows from Cochiti Reservoir was not considered.

By incorporating the recent flow records, an additional 14 years of data can be added to the post-Cochiti gage data base that Bullard and Lane (1993) did not have available for their analysis. This would extend the Bullard and Lane (1993) record from 14 years to 29 years. While the record is doubled, it is still considered to be relatively short for a flood frequency analysis. The reliability of the short record frequency analysis can be tested for sensitivity to high flows by assuming a high flow event for 2003.

There are two other aspects of the frequency analysis for the San Acacia-San Marcial reach that should be mentioned. The record consists of a mixed population of peak flows resulting from snow melt spring runoff and summer convective thunderstorms over the Middle Rio Grande drainage including tributaries. This would have a tendency to decrease the estimated peak flow for a given return period. The effects of upstream storage on peak flows at the San Acacia gage is more pronounced for the snow melt runoff because the Rio Salado and Rio Puerco can deliver potentially large storm flood events (See Table 9). This peak discharge reduction, while punctuated by the construction of major dams such as Cochiti, Jemez and El Vado, has been progressive throughout the 20th century. Diversion dams, urban development and detention basins through the upper Rio Grande drainage have also had an evolving influence. Nevertheless, the importance of Cochiti Dam on moderating peak flows should be considered and therefore the post-Cochiti record is selected for further analysis.

Table 9. Rio Salado and Rio Puerco Flood Frequency Analysis[1]

Probability	Return Period	Rio Salado Q (cfs)	Rio Puerco Q (cfs)
0.5	2	7600	7740
0.1	10	19580	19900
0.02	50	35800	36500
0.01	100	44800	45600
0.002	500	72000	73300

[1] From Bullard and Lane (1993) based on a 1979 Corps of Engineers Study

For these reasons, the frequency analysis was revisited by analyzing different periods at the San Acacia and San Marcial gages using the FREQ/PLOT program (de Roulhac, 1992). Recording of instantaneous peaks were stopped at San Acacia in 1984 and at San Marcial in 1990. For San Acacia, the mean daily peak flows were used for the period from 1984 to 1989. The Corps of Engineers, in communication with the USGS obtained estimates of peak flows after 1990. The frequency analysis therefore includes a mix population of peak discharges and mean daily maximum discharges. This may slightly decrease the estimated return period peak discharge. The pre-Cochiti San Marcial record prior to 1925 is missing 7 years of record. Based on the mobile sand bed at these gages, the recorded peak flows should be considered as estimated discharges.

Following consultation with the Corps of Engineers and the Bureau of Reclamation, it was agreed that the Corps' adjustments for regulated peaks at San Acacia for the period from 1936 to 1974 would be used to represent the entire period of record. The daily peak flows (instead of the instantaneous peak discharge) from 1984 to 1989 were added to the record, but these relatively low discharge data are inconsequential to the derived flood frequency. The September 24, 1929 estimated peak discharge of 60,000 cfs was reduced to 53,400 cfs by the Corps to account for future upstream storage. Although this San Acacia peak discharge was probably a rough estimate, it correlates to the 47,000 cfs peak discharge estimated at San Marcial. A second flood estimated at 60,000 cfs at San Acacia on October 11, 1904 was based on an estimated peak of 50,000 at San Marcial. The 1904 estimated peak flow at the San Acacia gage amounts to little more than an educated guess. It is generally acknowledged that the historical peak of record should only be added to the data base if the actual record exceeds the desired flood event return period. When the data was plotted, this peak discharge appeared as an outlier and was identified as such by the FREQ/PLOT analysis. For these reasons, the 1904 peak was excluded from the database.

The post-Cochiti record (1974-2002) was used to analyze frequent flood events at San Acacia. This data requires no adjustment for upstream flow regulation because the flow regulation is inherent in the record. While it is debatable as to whether the post-Cochiti record of 29 years is sufficiently long enough to assimilate the post-Cochiti effects of flow regulation and provide a reasonable indication of flood frequency, it is notable that during this period, there have been only two flood events (1975: 14,200 cfs and 1980: 14,300 cfs) at San Acacia that exceed the pre-Cochiti 5-year return period flood. This is a clear indication that the Rio Salado and Rio Puerco have not experienced any significant flood events during the post-Cochiti period. This is a factor in determining the lower frequency flood events at San Acacia.

Flood Frequency Results

The FREQ/PLOT frequency analysis results are presented in Tables 10 and 11. A review of the FREQ/PLOT King's table of four plotting paper frequency distributions reveals that the Log Pearson III distribution correlates well with the data for the San Marcial gage record and the San Acacia post-Cochiti record without a skew coefficient. The USGS (personal communication) indicated that a zero skew coefficient was appropriate for these gages. This infers that the combined regulated mainstem flows and unregulated tributary floods as well as the mixed population of snow melt and thunderstorm events are log normally distributed. The other probability distributions (normal, extreme value and log extreme value) were poorly correlated with the data.

The Log Pearson III distribution poorly correlates with the Corps adjusted peak flows for the San Acacia entire record. A significant negative skew is necessary to generate a good fit to the data. It is necessary to graphically fit the data with a best fit distribution curve. The pre-Cochiti record as well as the entire record, require best fit curves. This is due, in part, to the adjustment of the record for the flow regulation on the mainstem Rio Grande and the unregulated Rio Salado and Rio Puerco peaks. The data creates a significant curve that swings upward for the low frequency events.

In comparison, the San Marcial data base for the three selected periods of record was not adjusted. An adjusted unregulated discharge data base was not available. A log normal distribution represents these three periods of record very well. The San Marcial record pre-dates much of the upstream flow regulation and is much longer. For this reason, the less frequent estimates of the return period flows are higher than those projected for San Acacia for the pre-Cochiti record. In reality, floodwave attenuation and the lack of any significant tributary inflows between the two gages, results in actual San Marcial peaks flows that are less than those at San Acacia. Therefore, the two flood frequency analyses for the entire record and pre-Cochiti record are not comparable. The post-Cochiti analysis for the two gages are comparable.

The Bullard and Lane (1993) San Acacia frequency analysis of the regulated flows did not include the 1929 estimated flood event and they did not include any of the San Marcial pre-1925 floods. The first quarter of the century represents a wet period of substantial peak flows. As a result the Bullard and Lane study predicts return period floods that are substantially different from this analysis. Of note is the 2-year and 5-year return period floods of 9,100 cfs and 13,600 cfs for regulated flows. The existing channel morphology in the alluvial reaches (non-incised, non-channelized reaches) between San Acacia and San Marcial reflect post-Cochiti channel forming flows in the range of the 1.25-year (3,700 cfs) to the 2-year (5,700 cfs) return period floods. Overbank flows in this reach initiate in the range from 2,800 cfs to 3,000 cfs.

Table 10. San Acacia and San Marcial Flood Frequency Analysis[1]

Probability	Return Period	Bullard and Lane Analysis (1993)				Pre-Cochiti		Post Cochiti 1974-2002		Entire Record	
		San Acacia[2]		San Marcial[2]							
		Unregulated	Regulated	Unregulated	Regulated	San Acacia 1936-1973	San Marcial 1899-1973[3]	San Acacia	San Marcial	San Acacia	San Marcial
0.8	1.25	-	-	-	-	4600	3460	3700	2630	3750	2990
0.5	2	12200	9100	9860	8570	4830	7180	5660	4170	4140	5810
0.2	5	17700	13600	16700	13600	6750	14300	8480	6160	6280	11500
0.1	10	21100	16500	21600	17100	10600	20200	10400	7350	9740	16600
0.04	25	25200	18800	27900	20300	16100	28800	12800	8710	14200	24600
0.02	50	28100	19800	32700	22100	28300	36100	14600	9610	22800	31900
0.01	100	30800	20800	37300	23800	43600	43900	16400	10400	32500	40400
0.002	500	-	-	-	-	104000	64800	20500	12100	64900	65300

[1] All return period flood discharges are reported in cfs
[2] Bullard and Lane (1993)
[3] Incomplete record prior to 1925 (7 years of missing record)

Table 11. San Acacia Comparative Flood Frequency Analysis[1]

Probability	Return Period	Bullard and Lane Analysis[2]		Pre-Cochiti 1936-1973	Entire Record	Post Cochiti 1974-2002	Post Cochiti 1974-2003[3]
		Unregulated	Regulated				
0.8	1.25	-	-	4600	3750	3700	3700
0.5	2	12200	9100	4830	4140	5660	5780
0.2	5	17700	13600	6750	6280	8480	9020
0.1	10	21100	16500	10600	9740	10400	11400
0.04	25	25200	18800	16100	14200	12800	14600
0.02	50	28100	19800	28300	22800	14600	17100
0.01	100	30800	20800	43600	32500	16400	19800
0.002	500	-		104000	64900	20500	26400

[1] All return period flood discharges are reported in cfs
[2] Bullard and Lane (1993)
[3] 2003 has a imaginary peak of 17,300 cfs (Pre-Cochiti, 10-year flood)

There are several conclusions that can be drawn from this analysis. The pre-Cochiti San Marcial flood frequency is strongly influenced by the large flood events in the early part of the century that is missing from the San Acacia record. There are no major tributaries between San Acacia and San Marcial and generally floodwave attenuation through this reach is pronounced. This is reflected in the post-Cochiti flood frequency analysis of the two gages. The gage record accuracy is also a concern. For example, the 1937 record peak at San Acacia was 18,600 cfs on May 28th. The May 29, 1937 peak at San Marcial was recorded to be 30,000 cfs. Since the peak discharge at the two gages occurred only one day apart and noting that there was no significant snow melt tributary contribution in the intervening reach, it is likely that the San Marcial peak discharge is over estimated because of channel bed sediment deposition. It is reasonable to assume that, except for some intervening summer thunderstorm peak discharge events, flood peaks at San Marcial should be less than those recorded at San Acacia.

The post-Cochiti record clearly defines the effects of upstream storage on flood frequency. The flood magnitude of both the San Acacia and San Marcial gages have significantly diminished. The duration of the peak flow events at San Acacia has been so diminished that the infrequent floods are being severely attenuated before reaching San Marcial. In fact, there is only a slight increase between the 10-year (7,400 cfs) and 100-year (10,400 cfs) post-Cochiti San Marcial return period floods.

The post-Cochiti record of 29 years has no floods greater than 15,000 cfs originating out of the Rio Salado or Rio Puerco drainages. To test the sensitivity of the post-Cochiti San Acacia flood frequency analysis to potential high flows, a 10-year Rio Salado flood of 19,600 cfs is presumed to occur on the last day of July, 2003. This flood event is equivalent to about a 10-year pre-Cochiti flood peak (17,300 cfs) assuming some floodwave attenuation would occur between the Rio Salado mouth and the San Acacia gage. The last column in Table 11 indicates that adding this 10-year event to the flood record would not affect the estimated return period flood up to the 25-year event, but would increase the predicted peak flood for the 50-year through 500-year return period events by about 20%. This increase in flood discharge for the infrequent events due to the addition of only a 10-year flood to the record indicates that the post-Cochiti record is too short to adequately define the frequency of the larger floods.

Flood Frequency Recommendations

For the purposes of a river restoration conceptual plan in the San Acacia to San Marcial reach, it is recommended that the post-Cochiti flood frequency at San Acacia should be used as the benchmark for channel forming flow events and frequent flood events (10-year return period flood and smaller) to reflect the channel morphology evolution in the post-Cochiti period. The 25-year and higher frequency flood events can be taken from the San Acacia total record using the Corps adjusted regulated database. The recommended return period flood events for the San Acacia to San Marcial reach are presented in Table 12. This table suggests a two part frequency curve; one part for flows less than the 10 year flood events that reflect the existing channel morphology and the second portion of the curve for higher flood events associated with the Rio Puerco and Rio Salado flooding that is included in the entire record.

Table 12. Suggested San Acacia Flood Frequency[1]

Probability	Return Period	Bullard and Lane Regulated Analysis[2]	Post Cochiti 1974-2002	Entire Record 1936-2002	Suggested Flood Peak Discharge
0.8	1.25	-	3700	3750	3700
0.5	2	9100	5660	4140	5660
0.2	5	13600	8480	6280	8480
0.1	10	16500	10400	9740	10400
0.04	25	18800	12800	14200	14200
0.02	50	19800	14600	22800	22800
0.01	100	20800	16400	32500	32500
0.002	500	-	20500	64900	64900

[1] All return period flood discharges are reported in cfs
[2] Bullard and Lane (1993)

The Corps of Engineers is currently reviewing and revising their adjusted flood recorded. The analysis may include separation of rainfall flood and snowmelt flood peaks. The recommended flood frequency in Table 12 may be adjusted slightly based on the Corps' revised database.

Spring Restoration Flood Hydrograph – Flushing Flows

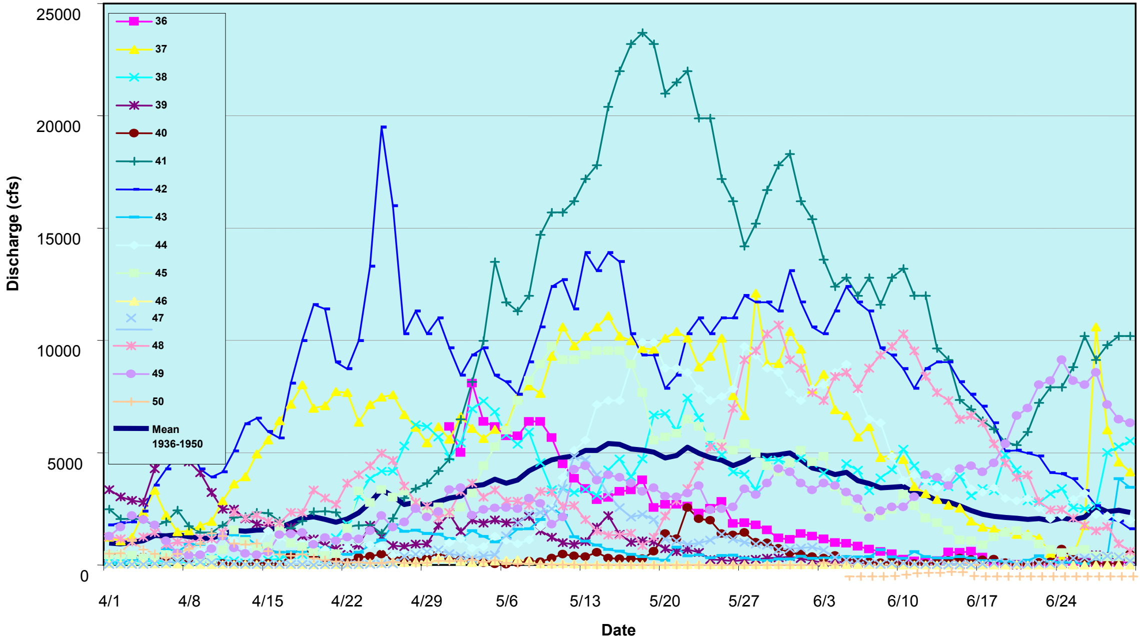
Mimicking the natural hydrograph received the number one recommendation of the Middle Rio Grande Ecosystem: Bosque Biological Management Plan (Crawford, et al., 1993). The importance of the spring hydrograph cannot be overstated. The abundance and diversity of native species in the Rio Grande riparian ecosystem is strongly linked to the river's natural hydrograph. Both the rising and recessional limbs are documented to affect the reproductive strategies of many aquatic and riparian species. The decline of the river functions and biological diversity of the system can be primarily attributed to the reduction in peak flow magnitude, frequency and duration. There are considerable limitations on the existing water resource management system that prevent the opportunity to recreate a historical hydrograph in terms of magnitude and frequency. Structural constraints in the river channel and on the floodplain, as well as the Cochiti Dam outlet works, limit the regulated peak discharge to less than 10,000 cfs. Operational guidelines for Corps dams are mandated in federal law, however, some latitude in making releases is permitted when endorsed by the Rio Grande Compact Commission. Releases from Cochiti and Jemez Canyon dams could be orchestrated to mimic the shape and timing of historic hydrographs. It is possible that releases that do not reflect the spring hydrographs may have a negative effect on aquatic species (Crawford, et al, 1993). Flows should be released to support river restoration efforts and to maintain the maximum channel capacity of 8,000 cfs or more (Crawford, et al, 1993).

Channel forming flows are related to bed material mobility, maximizing sediment transport (effective discharge) or bankfull discharge. Channel forming flow may be defined as the flow at which the bed material is mobilized and the banks begin to erode. Wolman and Miller (1960) emphasized that the channel shape is affected by a range of flows, not just a single peak discharge and therefore the importance of destructive large flood events can be overstated. Bankfull discharge is defined as the flow that fills the channel without overtopping the banks and it is often considered as the dominant or channel-forming discharge for alluvial rivers (Richards, 1982). The channel forming discharge is assigned a flow frequency that is in the range of the bankfull discharge return period usually between 1 and 2 years (Richards, 1982). The post-Cochiti 2-year return period flood is 5,660 cfs as was discussed in the flood frequency section. It is an oversimplification to assume that the return period for a bankfull discharge is constant over time. Adjustments in channel morphology can result in a bankfull discharge that varies both spatially and temporally.

Channel forming flows in the range of the bankfull discharge vary throughout the San Acacia – San Marcial reach. Bankfull discharge has a higher magnitude and is less frequent in the upper Escondida subreach than the middle and lower subreaches. In the middle and lower subreaches, bankfull discharge has a return period that is less than 2 years based on post-Cochiti flows. Maintaining the active channel requires that flows approach the channel forming flows on a sufficiently frequent basis to eliminate vegetation encroachment within the active channel. Generally, bankfull discharge must occur at least once every three years to avoid channel narrowing associated with vegetation encroachment (FLO Engineering, 1995)

The San Acacia mean daily hydrograph for one period prior to the Cochiti Dam closure (1936-1950) is shown in Figure 3. The mean daily peak discharge for this period of record is 5,400 cfs or approximately the post-Cochiti 2-year flood event (5,660 cfs). The mean day of peak discharge of the major flood events for the pre-Cochiti period is approximately May 26. Figure 3, however, indicates that the mean daily discharge may occur from about May 13 to June 1. The spring peak flushing flow should be timed to occur the last two weeks of May and it should reflect the shape of the typical pre-1974 hydrograph in terms of the rising and recessional limbs. This peak discharge timing will encourage regeneration of native riparian vegetation.

Figure 3. San Acacia Spring Hydrographs



The mean annual flow duration for flows above 5,660 cfs (post-Cochiti, 2-yr flood) for the pre-Cochiti period 1936 to 1973 was 9.9 days, or about 10 days. For the post-Cochiti period from 1974 to 2002, the mean annual flow duration of the 2-year flood of 5,660 cfs is 5.8 days or roughly 6 days. The annual duration discharges in this range has decreased, encouraging channel narrowing. For restoration purposes in the San Acacia to San Marcial reach, a spring hydrograph with a peak discharge of 5,660 cfs with a duration of approximately 6 days is recommended (Figure 4). The rate of change in mean hydrograph is 175 cfs/day for the rising limb and 135 cfs/day for the recessional limb. This hydrograph should occur approximately every other year or about 4 times in every 10 years with no more than 2 consecutive years without this spring hydrograph. The suggested hydrograph constitutes a volume of approximately 458,000 acre-ft. It is interesting to note that peak discharges greater than 5,660 cfs at San Acacia have been recorded for months of July thru September for the period from 1974 to 2002. Although the USGS curtailed recording instantaneous peaks at the San Acacia gage after 1984, the summer monsoon season has not generated any large duration flood events in either the Rio Salado or Rio Puerco tributaries to create a significant daily peak during this post-Cochiti era. Figure 4 shows the effects of the drought in the 1950's. Figure 5 indicates the range of the pre-Cochiti hydrograph variation.

Figure 4. San Acacia Mean Annual Hydrographs

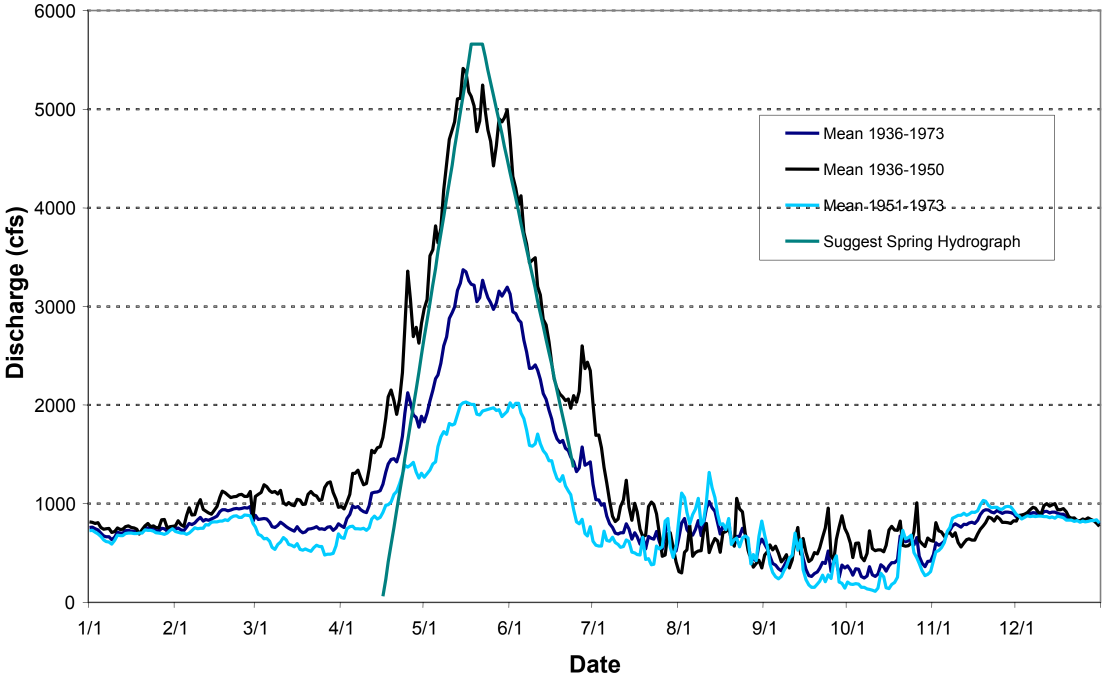
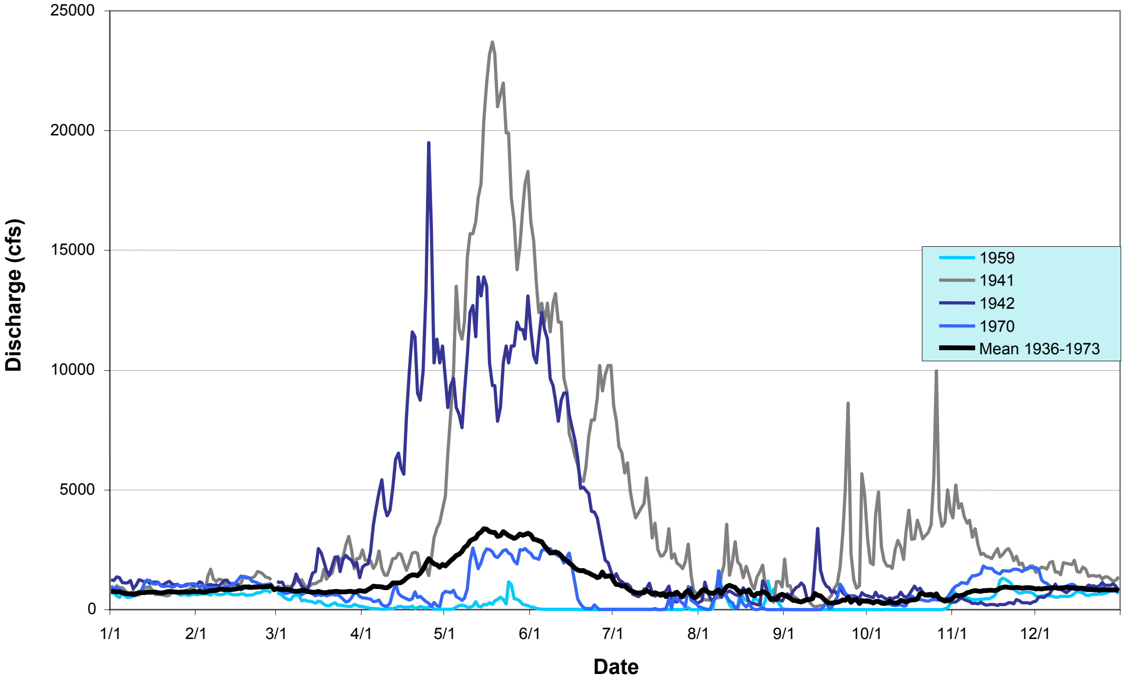


Figure 5. San Acacia Annual Hydrograph Variation



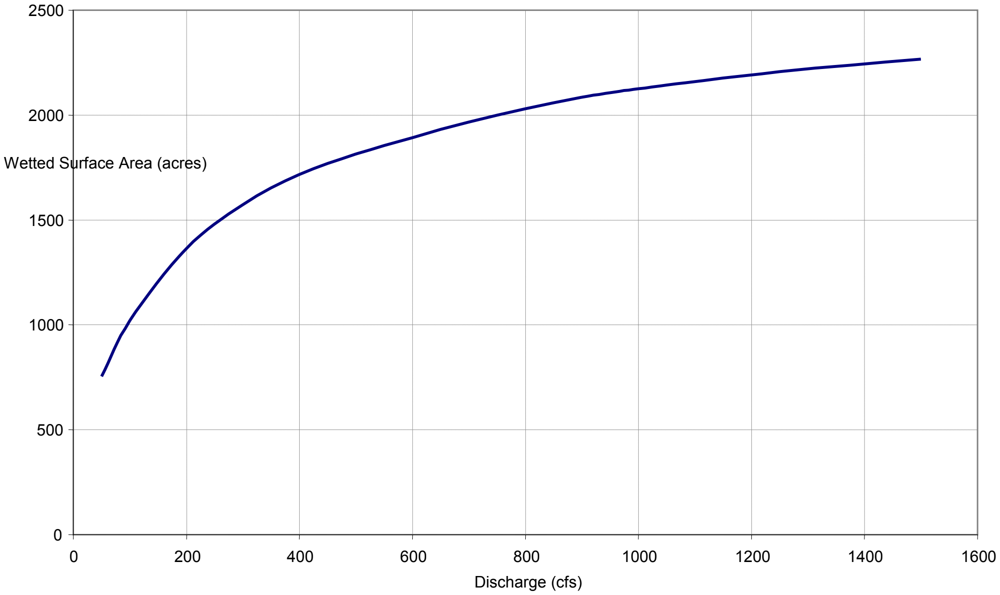
Fall Channel Maintenance Flows

Moderate flows in the fall can provide energy for reworking the channel sand bars. The sand bars are reworked by lateral erosion bars as the small channels move back and forth across the river bed. The sand bars may be positioned one to two feet higher than the water surface and the braided flow paths result in varying angles of attack on the margins of the bars (Photo 1). The small sand bar vertical banks are undermined and collapse into the flow. Lateral erosion may proceed at a rate of a half foot per hour. Often the flow against the bars occurs only for a portion of the day before shifting away from the bar. Seedling growth on the bars can be removed through this bar erosion process.

River discharge in the San Acacia to San Marcial reach increases in late October or early November with the decrease in irrigation diversion. Increased flows may be on the order of 500 cfs to 1,500 cfs depending on the magnitude of the spring runoff and late season irrigation diversion for that given year. The increase in flows may also reflect a decrease in evapotranspiration loss. Figure 4 shows the increase in discharge at the end of the irrigation diversion season in late October. To assess an optimum discharge for the fall maintenance flow, the FLO-2D model was applied to the San Acacia South reach using a range of flows from 50 cfs to 1,500 cfs. The reach was modeled as a rigid bed (no significant change in the channel geometry was expected under these flow conditions) with a constant discharge and no infiltration. Each simulation was conducted until the inflow discharge at San Acacia was observed in the San Marcial output hydrograph for up to 10 hours or more. Figure 6 displays the wetted surface area in the entire channel reach as a function of discharge. This figure indicates that the rate of increase in wetted channel surface area begins to decrease significantly for flows above 500 cfs. Assuming that the wetted surface area reflects the degree to which the channel is being reworked during these moderate fall discharges, the most efficient reworking of the channel occurs for flows in the range of 400 cfs to 800 cfs. Below 400 cfs, about 75% of the channel is wet; above 800 cfs, almost 90 % of the channel is under water. It is recommended that 500 cfs be considered as a target fall channel maintenance flow. Flows of 500 cfs or greater have occurred roughly 39 percent of the time (approximately 23 days) during the months of October and November for the post-1974 period. The target for the fall maintenance flow should be 500 cfs or greater for approximately three weeks on an annual basis. This constitutes a minimum volume of 21,000 acre-ft.

Photo 1. Lateral Erosion of Sand Bars during the Fall

Figure 6. Channel Wetted Surface Area as a Function of Discharge



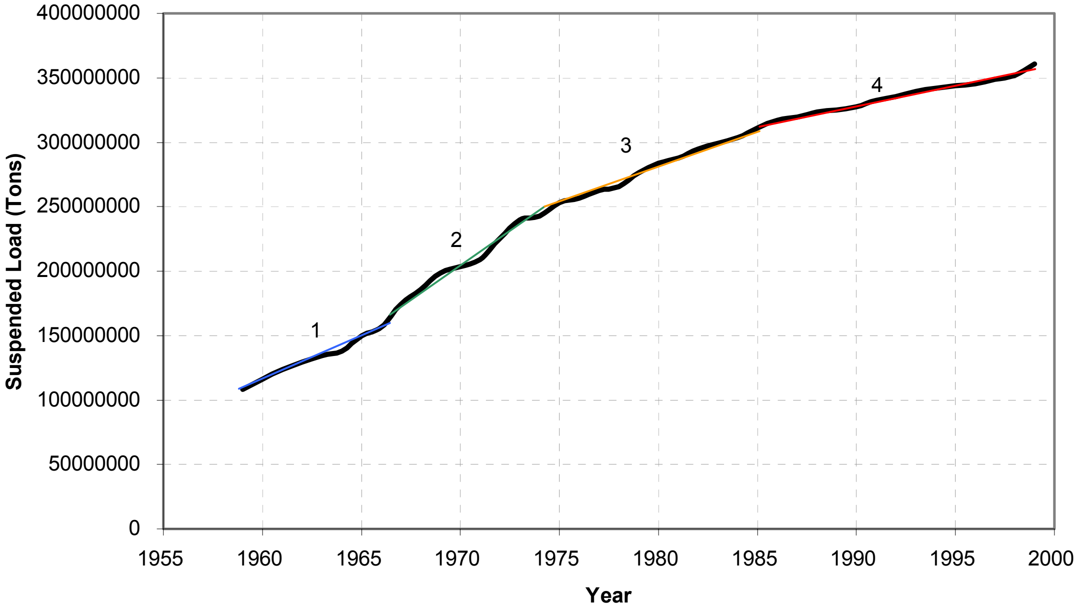
Assessment of Sediment Supply at San Acacia

Long Term Sediment Loading

One of the keys to designing self-sustaining restoration activities in the San Acacia to San Marcial reach is an accurate estimate of long term sediment loading. The success or failure of restoration activities will depend on channel response. Sediment supply will dictate whether the restored channel geometry will be self-sustaining with managed flows or will require continual mechanical maintenance. The current channel response to variations in sediment supply has been limited by bank stabilization due to exotic vegetation. Bank erosion and channel migration are two components of an active wide channel that have been thwarted by the increased density of bank vegetation. The river channel has been progressively narrowing for several decades.

Figure 7 illustrates the progressive decline in sediment supply at San Acacia. This figure is based on the data from a report prepared for the Bureau of Reclamation (Strand, 1996). This figure was divided into periods representing four distinctive periods of sediment loading. From 1966 to 1974, there is a slight increase in the slope of the cumulative suspended sediment load line in Figure 7, indicating an increase in the sediment load at San Acacia over the period from 1959 to 1964. A relatively long dry period from 1950 to 1957 (Norman, 1968) may have been the cause of the lower sediment loads in the early 1960s. It is difficult, however, to separate climatic effects from the water resource development in the upper basin. After 1974, there has been a progressive decrease in the annual sediment load that can be depicted by two periods 1974 to 1985 and 1985 to 1999 (Figure 7). The slope of line segment 4 is significantly less than the slope of the line segment 1 which represents the 1966 to 1974 period.

Figure 7. San Acacia Cumulative Suspended Sediment Load (Tons)

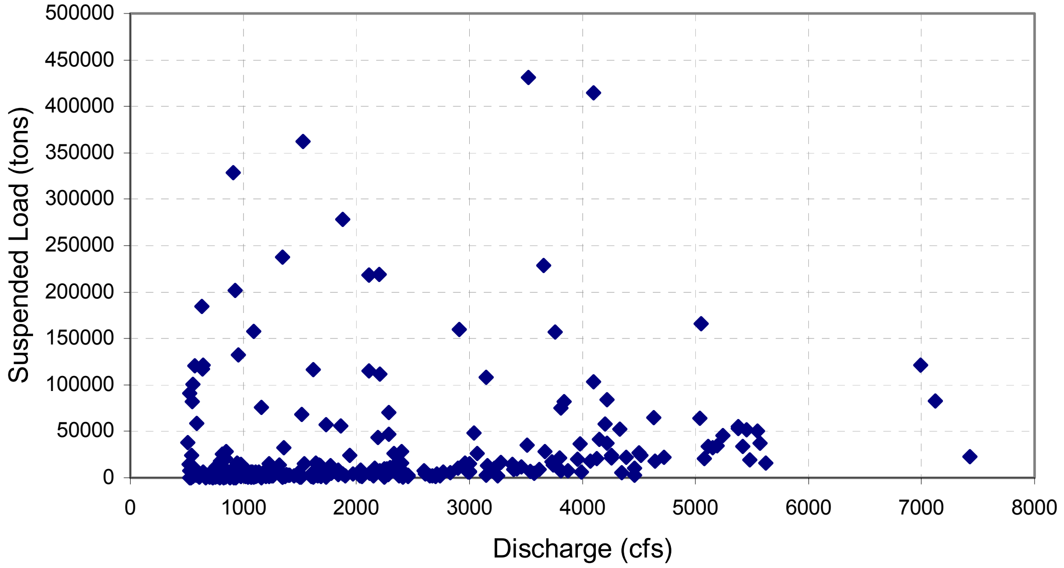


To estimate the long term sediment loading at San Acacia, the following tables were constructed from the available USGS suspended sediment and total load data. This data included the sediment size distribution from which the fine sediment (silt and clay) size fraction could be determined. The suspended sediment load data was regressed as a power function of the discharge to generate a sediment load rating curve. The total load was computed by the USGS using the Modified Einstein procedure and reported in the database. The total load was then regressed as function of the suspended load data. It should be noted that the USGS total load computations were not available for a full range of flows. Most of the USGS total loads were computed for the lower range of discharges which skewed the results such that the mean annual total load was less than the computed mean annual suspended load. Therefore, the total loads in Table 13 were based on the regressed relationship with the suspended load. The mean annual total load (or mean annual suspended load) can be computed using the return period flood event discharges and the corresponding regressed sediment loads as shown in Table 13. The mean annual load is then derived from an equation that incorporates the probability of the return period events over the 100-year period.

It should be noted that there is a significant uncertainty in both estimating historic sediment loading as well as using historical data to project future sediment loads. Estimates of sediment load require measurements of small sediment samples as well as velocity and depth hydraulic measurements to project a total sediment load for a river discharge for a specific instant in time. The only way to overcome the tremendous variation in data is to collect an infinite number of sediment samples and discharge measurements over a long period of time. The closer that the number of samples approaches infinity, the more reliable the data analysis is for projections into the future. The Rio Puerco and Rio Salado contributions of high concentrations of fine sediment create a very difficult data base on which to project long term sediment loads.

The correlation coefficients in the regression equations were generally poor based on the variability of the fine sediment load (silts and clays originating out of the Rio Salado or Rio Puerco). Figure 8 shows a plot of the suspended load versus discharge. To improve the prediction of the sediment supply the data was sorted by periods and discharges less than 500 cfs were discarded. It was assumed that the bed material load for flows less than 500 cfs was not significant to the long term channel morphology.

Figure 8. San Acacia Suspended Load Data



The results in Tables 13 and 14 indicate that the post-Cochiti (1974) sediment load is about 18% of the historical load. This reflects the same magnitude of decrease in the sediment loading at San Acacia that was show in Table 3. Table 15 shows the average annual suspended sediment load for 1974 to 2000 based on the average annual load equation. The estimated average annual suspended sediment load computed from the USGS database compiled by Stand (1996) for the Bureau of Reclamation is presented in Table 16. The average annual suspended sediment load of 5.7 millions tons per year computed using the regression equations in Table 15 compares reasonably well with the measured average annual suspended sediment load of 4.7 millions tons per year shown in Table 16. This indicates that using the post-1974 regression equations should provide a reasonable estimate of the future sediment loading at San Acacia assuming that the watershed and climatic conditions will not appreciably change in the near future.

Table 13. San Acacia Sediment Load Analysis for Discharge > 500 cfs

San Acacia 1946-2000		$Q_s = 1.44426\ Q^{1.27521}$	$Q_T = 2.53737\ Q_s^{0.933311}$	Mean Annual Total Load[1] Q_m (tons/day)
Flood Frequency	Q (cfs)	Suspended Load Q_s (tons/day)	Total Load Q_T (tons/day)	
2-yr	4140	59200	72100	102,000
5-yr	6280	101000	188000	
10-yr	9740	176000	220000	
25-yr	14200	285000	313000	
50-yr	22800	521000	550000	
100-yr	32500	819000	838000	
Mean annual no. of days > 500 cfs = 224 days			Total Load (tons)	22,848,000

[1] $Q_m = 0.015 Q_{s\ 100\text{-yr}} + 0.015\ Q_{s\ 50\text{-yr}} + 0.04\ Q_{s\ 25\text{-yr}} + 0.08\ Q_{s\ 10\text{-yr}} + 0.2\ Q_{s\ 5\text{-yr}} + 0.4\ Q_{s\ 2\text{-yr}}$

Table 14. San Acacia Sediment Load Analysis for Discharge > 500 cfs

San Acacia 1974-2000		$Q_s = 4.00557\, Q^{1.01662}$	$Q_T = 2.5331\, Q_s^{0.934005}$	Mean Annual Total Load[1] Q_m (tons/day)
Flood Frequency	Q (cfs)	Suspended Load Q_s (tons/day)	Total Load Q_T (tons/day)	
2-yr	5660	26200	33900	36,200
5-yr	8480	39500	49700	
10-yr	10400	48600	60400	
25-yr	12800	66700	81100	
50-yr	14600	108000	127000	
100-yr	16400	155000	178000	
Mean annual no. of days > 500 cfs = 197 days			Total Load (tons)	7,131,000

[1] $Q_m = 0.015 Q_{s\ 100\text{-yr}} + 0.015\, Q_{s\ 50\text{-yr}} + 0.04\, Q_{s\ 25\text{-yr}} + 0.08\, Q_{s\ 10\text{-yr}} + 0.2\, Q_{s\ 5\text{-yr}} + 0.4\, Q_{s\ 2\text{-yr}}$

Table 15. San Acacia Suspended Sediment Load Analysis for Discharge > 500 cfs

San Acacia 1974-2000		$Q_s = 4.00557\, Q^{1.01662}$	Mean Annual Suspended Load[1] Q_m (tons/day)
Flood Frequency	Q (cfs)	Suspended Load Q_s (tons/day)	
2-yr	5660	26200	28,900 tons/day
5-yr	8480	39500	
10-yr	10400	48600	
25-yr	12800	66700	
50-yr	14600	108000	
100-yr	16400	155000	
Mean annual no. of days > 500 cfs = 197 days Total Load (tons)			5,693,000 tons

[1] $Q_m = 0.015 Q_{s\ 100\text{-yr}} + 0.015\, Q_{s\ 50\text{-yr}} + 0.04\, Q_{s\ 25\text{-yr}} + 0.08\, Q_{s\ 10\text{-yr}} + 0.2\, Q_{s\ 5\text{-yr}} + 0.4\, Q_{s\ 2\text{-yr}}$

Table 16. Average Suspended Sediment Load[1] (from Stand, 1996)

Gaging Station	Period of Record	Average Annual Suspended Sediment Load (tons)
San Acacia (LFCC + Floodway)	1947-1999	7,053,000
San Acacia (LFCC + Floodway)	1947-1973	9,646,000
San Acacia (LFCC + Floodway)	1974-1999	4,658,000
San Acacia (Floodway)	1959-1973	3,352,000
San Acacia (Floodway)	1974-1999	3,529,000
San Acacia (Floodway)	1959-1999	3,389,000
San Marcial (LFCC + Floodway)	1974-1999	4,281,000
San Marcial (Floodway)	1974-1999	4,090,000

[1] Supplemented with years 1996-1999, partial year data was removed

Table 17 summarizes the sediment loads at the San Acacia and San Marcial gage. The data was filtered to eliminate suspended measurements for small discharges (< 500 cfs) and high sediment load outliers. It was assumed that for flows less than 500 cfs, the bed material load was relatively minor. It should be noted that suspended sediment load associated with small discharges can significantly effect the regression relationship derived from using a least squares fit procedure on a log-log plot of the data. The fine sediment load (wash load) associated with the Rio Salado and Rio Puerco result in highly variable plots with discharge (Figure 8) and generates a regression relationship with a poor correlation coefficient.

As previously discussed, the suspended sediment load after 1974 is only a fraction of the historical sediment load. This is reflected in the San Acacia gage data in Table 15. It can also be gleaned from Tables 16 and 17 that the San Acacia annual sediment load is slightly greater than the San Marcial load for the period from 1974 to 1999. The average water discharge volume is also slightly greater at San Acacia (803,500 acre-ft at San Acacia vs. 753,000 acre-ft at San Marcial). This indicates that there is potential for continued long term sediment storage that can contribute to channel bed aggradation in the lower portion of the reach.

Table 17. Summary of Sediment Load Analyses

Gaging Station	Period of Record	Type of Sediment Load > 500 cfs	No. of Points	No. of Outliers	Mean Annual Load (tons/day)	Mean Annual Load (tons)
San Acacia	1946-2002	Total	582	0	102,000	-
San Acacia	1974-2002	Total	302	3	36,200	7,131,000
San Acacia	1974-2002	Suspended	302	3	28,900	5,693,000
San Acacia	1974-2002	Bed Matl	278	3	10,300	2,029,000
San Marcial	1960-2001	Total	350	0	32,700	-
San Marcial	1974-2001	Total	330	0	20,100	4,261,000
San Marcial	1974-2001	Suspended	330	0	17,100	3,625,000
Young's Eqn	1974-2001	Total	-	-	232,500	-
Samad's Eqn	1974-2001	Total	79	4	174,800	-

Two previous sediment load analyses on the San Marcial sediment data have been conducted. The analysis by Samad (1993) for total load was based on 79 data points for the period 1978 to 1989. Four points from the USGS data set were removed as outliers. The correlation coefficient for this data was 0.90. Obviously this data set was a subset of the entire database which exceeded several hundred sediment measurements. Samad's (1993) selected database has a significantly higher and less realistic correlation coefficient than the poorly correlated data shown in Figure 8. The selected database may skew the results and overpredict the total sediment load on an annual basis. The regression equation was applied to the 11 years of daily flows and resulted in a mean annual total load of 5.4 millions tons. Young's equation was derived by adjusting the total load rating curve at San Marcial based on aggradation/degradation trends in the San Antonio reach (Bureau of Reclamation, 1998). It is not known what database was used to generate Young's equation. It is surmised, however, that Young may have adjusted Samad's total load equation because the exponents of the two equations are very similar.

Based on this analysis, it is reasonable to presume that the estimated sediment load computed from the regression equations can be applied to compute the sediment supply at San Acacia in the FLO-2D model. Of primary interest is the bed material load or sand-sized sediment supply at San Acacia. The fine sediment (silt and clay) is assumed to be wash load that passes through the system. This not entirely true and some fine sediment is found on the channel bars and may actually serve to limit the scour depth. Analyzing the fine sediment load deposition, however, requires 2-dimensional computational hydraulics in the channel that is beyond the scope of the FLO-2D model. The bed material load was computed by applying the sand-size fraction to the suspended load and applying the regression equation for the total load. This would provide an estimate of the total sand-sized sediment load in both the measured and unmeasured zones. The annual bed material load at San Acacia was estimated to be 2.03 million tons per year based on the 1974-2002 database. This supply will be used to estimate the channel bed response to various return period flood events. The bed material load for San Acacia gage used in the FLO-2D model is:

$$Q_{bm} = 4.49\ Q^{0.891}$$

Sediment Load Summary

The sediment load being delivered by the Rio Grande to San Acacia is highly variable based on the erratic sediment loading from the Rio Salado and Rio Puerco tributaries. The post-1974 sediment load to this reach is only a fraction (~30%) of the pre-1973 historic sediment load. During the post-1974 period, there have not been any major floods at San Acacia. Under the discharge and sediment load conditions of the last 25 years, the entire reach appears to be still slightly aggrading (more sediment entering the reach than is leaving it), but most of the sediment deposition is occurring in the Refuge subreach. This is reflected in both the measured load and the regressed sediment load equations. Based on this analysis, approximately 2.0 million tons per year of sand-sized sediment is being supplied to this reach. This analysis ignores the sediment load contributed from tributary arroyos and washes in the reach between San Acacia and San Marcial. While the tributary sediment load can be substantial during a major flood on the tributary, the tributary flooding is too infrequency and the arroyo confluences too few to be considered for sustaining the Rio Grande channel morphology. This is shown by reviewing the changes in channel morphology over the past 30 years. A bed material load regression equation was developed that will be used in the FLO-2D model as the sand-sized sediment supply at San Acacia.

Channel Conveyance Capacity

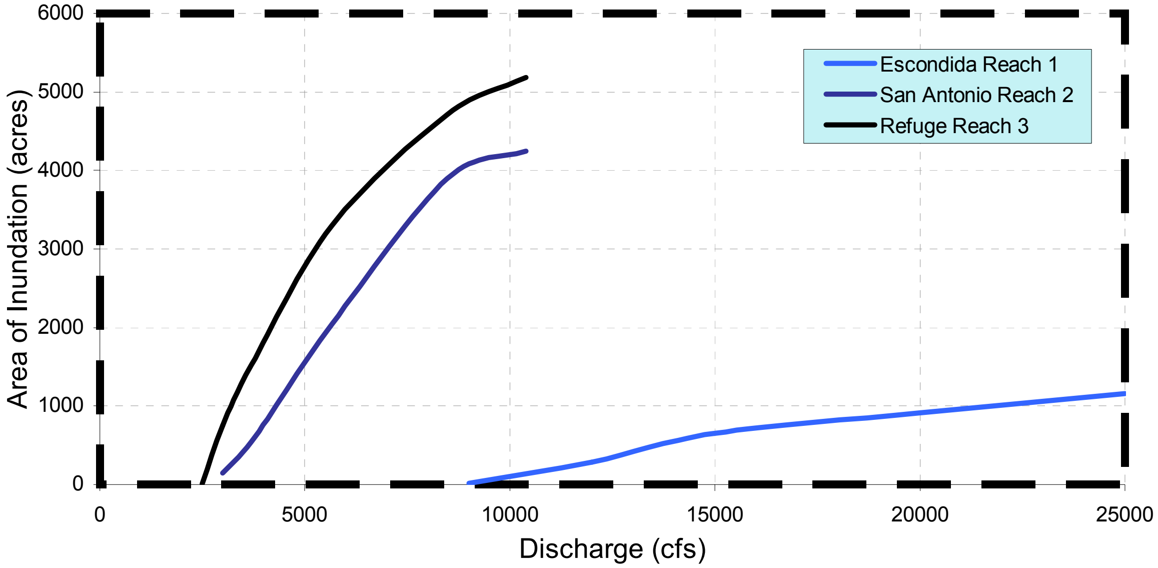
Using the most recent cross section surveys from 2000 and 2001, the FLO-2D Middle Rio Grande model was applied with a series of discharge hydrographs to estimate bankfull discharge. This was accomplished by using San Acacia to San Marcial reach portion of the model. To estimate channel conveyance capacity in the three subreaches, each subreach, Escondida, San Antonio and the Refuge, was individually modeled with unique inflow and outflow points. The same series of discharges related to the 1.25-yr, 2-yr, 5-yr and 10-yr return period flood events were simulated for the San Antonio and Refuge subreaches. Flows greater than the 10-yr flood event are too infrequent for restoration purposes. For the Escondida subreach, flooding does not initiate until a flood of the magnitude of the 10-yr flood is attained. To analyze the overbank flooding potential in the Escondida subreach, a series of arbitrary discharges were used to generate the curve in Figure 9.

In 1998, the FLO-2D model was calibrated in the San Acacia to San Marcial reach using the channel geometry regression relationships. Since 1998, the channel has significantly narrowed and the sand bars have become densely vegetated. While this is true to varying degrees throughout the San Acacia to San Marcial reach, it is prominent in the San Antonio middle subreach. The model was updated with current cross section surveys and the new cross section component. There was no opportunity to recalibrate this model with the new cross section data because bankfull flows were not available to survey high water surface elevations that would reflect the channel changed conditions. For this reason, a calibration to the 1998 high water surface elevations with the existing channel survey data in the model is not appropriate. The channel n-values from the 1998 surveys were generally used with some adjustment for the revised channel geometry.

Bankfull discharge varies through out each subreach based on the relationship between flow area, slope and hydraulic roughness. A bankfull discharge was defined for each of the subreaches as that discharge when some significant flooding initiates. The upper Escondida subreach is incised as indicated in Figure 9. Some minor overbank flooding initiates around 9,000 cfs. Appreciable flooding begins above 10,000 cfs. The 10-year return period flood is approximately 10,400 cfs based on the post-Cochiti Dam record at San Acacia. Bank discharge occurs infrequency in the Escondida subreach that riparian restoration activities associated with overbank flooding have to focus on either raising the bed (grade restoration facility GRF) or lowering the floodplain terrace.

The middle San Antonio subreach experiences more frequent flooding. The flooding initiates just north of the North Boundary of Bosque del Apache National Wildlife Refuge (NWR) at a discharge of about 2,500 cfs. The rate of increase in floodable acreage is essentially uniform until about 9,000 cfs where the incremental increase in flood inundation begins to decrease. This is an area of extensive flooding and the overbank discharge on the floodplain attenuates the channel flood wave significantly. Reworking the riparian areas in this reach will support Bosque regeneration due to the frequency of overbank flooding.

Figure 9. Subreach Area of Inundation



Approximately the last 9.6 miles of channel of the 15.6 miles in the lower Refuge subreach from the North Boundary of Bosque del Apache National Wildlife Refuge to San Marcial Bridge have been channelized. The river transitions from a wide multiple thread channel to a narrow, deep canal-like channel. The prediction of river overbank flooding is difficult in this reach because of the changing bed forms and channel scour that occurs from low flow to high flow. As the channel approaches bankfull discharge, the dune bedforms in lower sediment transport regime transition to plane bed in upper sediment transport regime and the hydraulic roughness decreases substantially. As the bed forms plane out, some of the sand bed also scours and the channel increases its conveyance efficiency and capacity. As a result, overbank flooding is delayed and a rigid bed analysis based on low flow cross section surveys may actually overpredict the flooding in this subreach. The channel begins to flood first in the upper portion of subreach 3, but flooding rapidly occurs throughout the reach. The formation of sediment plugs in this reach can initiate flooding at a lower stage during some years. Flooding initiates between 2,500 and 2,700 cfs in some small overbank floodplain channels.

Figure 9 clearly illustrates the flooding potential difference between the incised Escondida subreach and two lower subreaches. Flooding initiates in the lower San Antonio and Refuge subreaches at one-third the bankfull discharge of the Escondida subreach 1. There is more area of inundation by the same discharge in Refuge subreach 3 than in the San Antonio subreach 2. The Refuge subreach has more potential for habitat restoration on the basis of flooding alone. Between 5,000 cfs and 10,000 cfs, approximately 1,000 more acres are flooded in the Refuge reach than the San Antonio reach for the same discharge. Bankfull discharge is approximately 10,000 cfs for Escondida subreach, 3,000 cfs for the San Antonio subreach 2 and 2,700 cfs for Refuge subreach.

Evapotranspiration Analysis

Restoration activities that increase the flooded area of inundation in the San Acacia to San Marcial reach will increase the total amount of water that is lost to evapotranspiration. Evapotranspiration (ET) includes evaporation from free water surfaces, soils and plant surfaces and transpiration (the water evaporated within plant leaves and passed to the atmosphere through stomates). ET rates are governed by solar radiation and other forms of energy, as well as air and surface temperatures, humidity, wind, air turbulence, plant characteristics and humidity. While the range of free water surface evaporation can be estimated with reasonable confidence, riparian ET is much more difficult to assess. Research at the University of New Mexico (UNM) was designed to quantify ET rates in cottonwood and salt cedar dominated stands. This will assist the effort to determine how bosque riparian restoration activities would affect riparian ET.

A number of proposed restoration components are focused on increasing the overbank flooding to improve the river floodplain hydrologic connectivity. Increased flooding will enhance the bosque floodplain biological dynamics as was discussed at length in the Phase I report. The objective is to increase the flood frequency and duration and expand the area of inundation to support channel and riparian floodplain restoration. It is anticipated that spring flushing flows will also focus on flood timing with cottonwood seed dispersal. Enhanced flooding is proposed to reverse the decline of the native bosque ecosystem.

Restoration activity will include enhanced overbank flooding to support bosque regeneration and would result in an increased in the water surface area and increased evaporation losses. This would be a seasonal condition reflecting the historical spring flooding. Evaporation constitutes the greatest water loss from the system, averaging about one third of the annual depletion (Thibault, et al., 2002). Increased evaporation losses can be evaluated directly from the FLO-2D model that separately tracks the volume of water evaporated from the channel and floodplain free water surface area. The increase in evaporation losses from restoration project conditions over existing conditions can be determined from the results computed by the FLO-2D model.

Evapotranspiration losses from riparian vegetation are subject to significant natural variability and uncertainties. Riparian ET is assumed to be the second largest depletion of annual river flow, averaging about twenty five percent of the total annual depletion (Thibault, et al., 2002). Spatial variability in flooding, consumptive water loss and vegetation density require simultaneous measurements of ET to assess a water budget (Cleverly, et al., 2001). Figure G.1 in Appendix G shows the daily variation (5 mm/day to 11 mm/day) in ET at one of the sites (Albuquerque). Water budgets have produced depletion loss estimates from riparian vegetation ranging from 20 to 50% of the total depletion losses from the river (Dahm, et al., 2002). The research at UNM involved erecting towers equipped with meteorological instruments for determining ET at four sites along the Middle Rio Grande including one at Bosque del Apache National Wildlife Refuge. In addition to the ET towers, each site contains a series of five groundwater wells constructed to the north, east, south, west and near the center of each site. The research and methods for determining ET rates has been documented in a number of publications (Thibault, et al, 2002; Dahm, et al., 2002; Coonrod, et al., 2002; Cleverly, et al., 2001). The ET research data and information is summarized herein to address the potential effects of restoration activities on depletion losses.

The data collected from the sites includes daily corrected ET data (mm/day) over the 2000 and 2001 growing seasons, groundwater depth data at 30 minute intervals for the years 1999 through 2001, streamflow data at various gaging stations and precipitation data from rain gages at the four tower sites. The UNM ET data for the Bosque del Apache Site is presented in Appendix G. Table 18 summarizes the data for the Bosque del Apache salt cedar flooding site.

Table 18. ET data for the Bosque del Apache Salt Cedar Flooding Site

Year	Season (days)	Groundwater Depth (cm)	ET (cm/yr)	ET (mm/day)
1999	183	199 ± 0.3	122	5.4 ± 0.2
2000	233	227 ± 0.1	111	5.0 ± 0.2
2001	214	223 ± 0.2	106	5.0 ± 0.2

Observation of the figures presented in Appendix G, provided by UNM, generally show no correlation between ET and groundwater levels. If further studies and/or continued data collection at the sites yield data from which a reasonable correlation can be determined, ET could be based on daily changes in groundwater levels, groundwater recharge rates or soil properties. The Bosque del Apache site had highly variable groundwater levels that affected both the vegetation type as well as the ET rates. Large fluctuations in groundwater may inhibit native trees while salt cedar can thrive in a dynamic water table environment (Dahm, et al., 2002).

Mature cottonwoods (98 cm/yr) with a closed canopy had smaller ET rates for the growing season compared to dense stands of salt cedar (111-122 cm/yr) and Russian Olives (123 cm/yr) (Dahm, et al, 2002). This is the basis for estimating water salvage associated with eradication of dense salt cedar stands on large tracts of land throughout the San Acacia to San Marcial reach as part of the conceptual restoration plan. Based on a rough estimate of the total riparian zone ET (150 to 250 x 10^6 m^3 per year) provided by Dahm et al. (2002) in the Middle Rio Grande, the savings associated with converting dense stands of salt cedar to cottonwood could result in water salvage in San Acacia to San Marcial reach over the long term could be on the order of 3,000 acre-ft per year. This is comparable to having 25 cfs in the river for two months. These estimates will be refined in the Phase III analysis with the selection of the dense salt cedar acreage to be proposed for eradication in the conceptual restoration plan. Water salvage resulting from salt cedar eradication will be an important facet of the conceptual restoration plan.

It was observed by Dahm, et al. (2002) that the less dense stand of salt cedar that rarely floods at the Sevilleta site had the lowest annual ET of the four sites. This also reflects the greater drought tolerance of salt cedar over cottonwood (Dahm, et al., 2002) If lower ET rates are measured where flooding does not occur as suggested by Dahm et al. (2002), then the proposed enhanced flooding in the San Acacia – San Marcial reach should be complimented by salt cedar removal to offset the potential increase in ET rates that might accompany increased flooding. This infers that when considering replacement of exotic vegetation with native vegetation, a variety of salt grass meadow, willow and other vegetative covers should be considered. Promoting biodiversity will include considerations of site-specific conditions including depth to groundwater, soils, salinity levels and flood frequency to determine the potential for water salvage.

Condition of the Riparian and Aquatic Habitats

A general assessment of the current biological conditions and trends in the San Acacia to San Marcial reach of the Rio Grande riparian corridor is presented. The history of vegetation mapping efforts, general wildlife information and potential for special status species were described in Phase I of the Conceptual Restoration Plan. Components of the biological conditions include riparian and aquatic habitats, federally protected species, and biotic and abiotic factors influencing habitat. Following a description of the current conditions and factors is a discussion of the potential future conditions.

Riparian Habitat

In the San Acacia to San Marcial study reach the habitat diversity has decreased from historic conditions. Enhancing habitat diversity is a restoration objective designed to achieve a mosaic of native vegetation communities. The historic mosaic of vegetation, also termed "native mosaic" is a riparian forest composed of discontinuous cottonwood and willow communities of varying ages. Desirable communities include cottonwood/coyote willow, cottonwood/Goodding's willow, and cottonwood/New Mexico olive (Hink and Ohmart 1984; Muldavin et al. 2000). In the northern portion of the study reach, willows are a minor contribution to the canopy, but become more common south of Bosque del Apache National Wildlife Refuge where they replace cottonwoods as canopy dominants. Historically open areas among the cottonwood and willow communities contained wetlands, marshes, wet meadows and oxbows. Drought resistant grasses and shrubs also covered portions of the floodplain.

Vegetation Classification

Riparian habitat is typically mapped and characterized by dividing the riparian ecosystem into specific vegetation communities, based on plant species, structure, and native or nonnative status. The US Fish and Wildlife Service (FWS) mapped the vegetation and habitats in 2000 based on 1997 aerial photograph data. This represents the most recent comprehensive vegetation survey of the San Acacia to San Marcial reach available. In 1984, Hink and Ohmart had mapped the area, using 111 vegetation classification types. In the 2000 survey, the FWS grouped the 111 vegetation classification types into six major vegetation classifications, with a number of subclasses, based on species composition and canopy structure. These classifications use the sixth level association in the Brown-Lowe-Passe classification system (Brown et al. 1979). The US Bureau of Reclamation (BOR) is preparing an updated survey using the Hink and Ohmart classifications that is expected to be completed in 2003.

Table 19 shows the relationship between the Hink and Ohmart 1984 classification system and the FWS 2000 study. The FWS vegetation classification system is useful because it clearly identifies the major vegetation communities. The subclasses further define canopy structure, understory and vegetation density, allowing for a sufficiently detailed analysis of the riparian habitat. In addition, the data can easily be assimilated with the upcoming BOR survey because the classification system is directly related to the Hink and Ohmart 1984 study classifications. Future monitoring studies should be conducted using the Hink and Ohmart classification system because the level of detail provides valuable site-specific information. If this level of detail is not feasible due to budget or time constraints, vegetation studies should be based on the FWS 2000 classification system. Simpler classification systems would not be useful for monitoring this complex and constantly changing riparian system.

Table 19. Vegetation Classifications and Initial Habitat Assessment Value

Major Plant Community Types (FWS 2000)	Sub-Type	Habitat Assessment Value	Forest Service Mapping Classifications (Hink and Ohmart 1984)
1) Mature cottonwood forest (Bosque) *Structure types I and II*	a) Riparian forest with dense willow understory (*)	High	C/W-SC1
	b) Riparian forest with dense salt cedar and/or Russian olive understory	Medium	C-W/SC1, C/SC1, C/SC-RO1, C/SC-CW1, C/SC-CW-RO1, C-W/SC-RO1
	c) Riparian woodland with sparse understory (r)	Medium	C2
2) Mature willow forest *Structure type I*	a) Riparian willow forest with dense salt cedar understory (*)	High	W/SC1, W-C/SC1
3) Mid-aged cottonwood-willow or salt cedar-Russian olive stands *Structure types III and IV*	a) Mostly dense willow and cottonwood (*)	Medium	W3, C-W3, C/W-SC3, W/C-SC3,
	b) Mixed dense native and exotic riparian stands	Low	C/SC3, W/SC3,C-W/SC3, W-C/SC3, C/SC-W3, C/SC-RO3, C-W/SC-RO3, C/RO-SC3, C-W/SC3, C-W/SC-RO3, SC-RO3, SC-W3
	c) Open mostly native and/or exotic riparian stands (r)	High native / Low exotic	C/SC4, C-W/SC4, W4, SC4
	d) Dense exotic riparian stands	Low	ro/sc3
	e) Open exotic riparian stands	Low	ro/sc4,ro4,ro-c/sc4,ro-sc4
4) Monotypic salt cedar stands	a) Overstory salt cedar	Low	OSC
	b) Intermediate salt cedar	Low	ISC
	c) Understory salt cedar	Low	USC, DSC/USC, SC5
5) Young successional stage stands *Structure types V and VI*	a) Young mostly dense cottonwood/willow (*)	High	C5, C/W5, W/C5, W5, W-C5, C/W-SC5, C-SC5, W-SC5, C-RO5, C-RO/SC5, C-RO-SC5, W/C-SC5, C-SC-W5, C-W-SC5, W-C-SC5, W-C/SC5, C-W/SC5
	b) Young mixed dense cottonwood, willow, salt cedar, and/or Russian olive	Medium	C/SC5, C/RO5, C-SC-RO5, C/SC-RO5, C/RO-SC5, W/SC5, C/SC-W5, C-RO/SC5
	c) Young mostly dense salt cedar and/or Russian olive	Low	SC/C5, SC/W5, SC-W5, RO5, SC-RO5, RO-SC5, SC-C-W5, SC/W-C5, RO-SC-C5,
	d) Sparse young growth, river bars or openings (r)	Low	C-W6, W6, W-C6, W/SC6, W-SC6, C/SC6, C/SC-RO6, C-SC-RO6, C-RO-SC6, SC6, C-SC6, SC-RO6, SC-W6,SC-W-C6, W-SC-C6, RO6, SC-RO-C6, RO-SC-C6, C-SC-W6, SC-RO-W6, DSC, DC1, OP, OP6, OP-SC5,OP-SC6,
6) Wetlands and waters	a) Emergent marsh (*)	High	CAT6, CAT-H20
	b) Open water	High	RIVER, DSC/OVERFLOW, PONDED WATER, ROAD/CANAL
	c) Dead flooded salt cedar	Low	DSC-CAT6, CAT-DSC6
	d) Wet meadow (*)	High	MDW-CAT6, W/MDW6, DSC/MDW

Note: Please refer to the 1984 Hink and Ohmart study for vegetation classification definitions; due to the number of abbreviations used, the information was not included. (*): special habitat feature; (r): area with natural regeneration potential.

Riparian Habitat Value

Based on the FWS 2000 survey data, a general assessment was made of riparian habitat values within the San Acacia to San Marcial reach. A habitat value of high, medium, or low was assigned to each of the vegetation community sub-types used by FWS (Table 19). The factors used to assign habitat value were based on the amount of structure and species diversity present and whether the sub-type was composed of native or nonnative plants. Habitat value was determined based on desired conditions. It is documented that some of the nonnative vegetation communities in the reach provide habitat for wildlife, but from a restoration perspective, a nonnative community is not as desirable as a native mosaic. Also, a native mosaic is an indicator of desirable channel morphology, as is discussed under Abiotic Factors in a following section.

- *Structural diversity* was measured by the combination of overstory and understory plants in the same community. For example, a mature cottonwood forest with sparse vegetation or no understory was considered to have low structural diversity, whereas a riparian forest with dense understory vegetation was considered to have high structural diversity. In communities such as wet meadows, where there are few overstory trees, structural diversity was not considered as important to habitat value.

- *Species diversity* was determined by the variety of species in a specific sub-type. Communities containing multiple species were rated as having higher habitat value than monotypic species communities.

- *Native or nonnative* composition was based on the dominant vegetation species in each sub-type. Sub-types with native species as the dominant vegetation were rated as having higher habitat value than nonnative dominated communities.

Table 19 shows the results of the habitat value determination by vegetation community sub-type. Two GIS maps were created depicting the high, medium, and low habitat values in order to provide a general overview of the San Acacia to San Marcial reach. These maps are presented in Appendix D, Maps D.1 and D.2. In addition, two GIS maps, depicting the vegetation classifications by FWS 2000 sub-type, are also included (Maps D.3 and D.4).

A field survey was conducted to examine the general characteristics of high, medium, and low habitat value areas. A number of sites were checked to ensure proper habitat value and to identify any major habitat changes since the FWS 2000 study. High habitat value areas were examined to determine their potential as reference sites for restoration efforts and the need for protection; low habitat value areas were examined for the potential for restoration. The field survey was not comprehensive examination but was an attempt to evaluate the accuracy of the classified habitat value based on the FWS 2000 study and vegetation classification system. In general, the field survey validated assigned habitat assessment values.

Sixty-one percent of the riparian vegetation (12,569 acres) were classified as having low habitat value; medium and high value habitat made up 18 percent (3,657 acres) and 21 percent (4,438 acres) respectively. Most of the low value habitat contained nonnative vegetation as the dominant component of the vegetation community. Areas classified as medium were typically a mix of native and nonnative species, whereas the low value areas contained high densities of salt cedar *(Tamarix ramosissima).* High quality habitat consisted of native woodland habitat; most wetlands were also classified as high quality habitats.

The river channel and the wetlands habitat on the Bosque del Apache NWR is important migratory bird habitat. The riparian forests are valuable to summer migrants such as neotropical and passerine bird species while the shallow waters around open bars are used by migrating shorebirds in the spring and fall. Wintering raptors use the riparian forest as well. Over sixty thousand waterfowl and thirty thousand white geese utilize the Rio Grande in this reach as a migratory corridor with approximately thirty thousand waterfowl and fifteen thousand white geese wintering in the valley. The river serves as roosting habitat for sandhill cranes during the period from October through February. The sandhill cranes forage in the nearby agricultural fields during the day and roost in the wide, open portions of the Rio Grande during the night (Crawford, et al., 1993). Restoration activities that increase and maintain open bars that are vegetated annually with grasses and forbes support the migratory sandhill crane population.

General Habitat Descriptions

The following is a brief description of the general wildlife associated with each of the six major vegetation categories:

- **Mature cottonwood forest (bosque).** Investigators found cottonwood-dominated community types support greater numbers of bird species than nonnative-dominated or monotypic stands of introduced species (BOR 2000). Native woodlands are characterized by an overstory of cottonwood *(Populus deltoides)* and black willow *(Salix nigra)* with understories of New Mexico olive *(Foresteira neomexicana),* screwbean mesquite *(Prosopis pubescens),* and seepwillow *(Baccaris glutinosa).* This vegetation community also includes forests composed of mature cottonwoods with an understory of either sparse or dense Russian olive and/or salt cedar. This vegetation community supports a variety of riparian wildlife species. Along the Rio Grande, cavity nesting birds are generally associated with mature cottonwood forests.

- **Mature willow forest.** This vegetation community is generally composed of mature black willow trees with a dense salt cedar understory. Wildlife associated with this community includes a variety of migratory bird species that nest in dense shrub habitats including species that use monotypic salt cedar stands. This vegetation category occurs in only a small portion (65 acres) of the bosque.

- **Mid-aged cottonwood-willow or salt cedar-Russian olive stands.** This vegetation community contains five sub-types, ranging from native communities of cottonwoods and willows to dense nonnative species communities such as Russian olive.

- **Monotypic salt cedar stands.** Salt cedar stands are communities composed almost exclusively of introduced salt cedar. Hink and Ohmart (1984) found a distinct assemblage of summer resident birds in salt cedar stands that included mockingbird, lark sparrow, western meadowlark, black-throated sparrow, blue-gray gnatcatcher and crissal thrasher (Crawford et al. 1993).

- **Young successional stage stands.** This community generally refers to the early stages of revegetation. This may occur in areas previously disturbed by fire or other vegetation clearing, as well as sandbars and gravel bars. Some sandbars have established stands of cottonwood, coyote willow, salt cedar, and Russian olive. While these vegetated islands provide excellent habitat for many species, others species require the open and dynamic nature of true sandbars. Shallow channels that provide lower velocity, lower sediment, and warmer aquatic habitats than the adjacent river channel often bisect sandbars. Algae formation on bottom substrates of these shallow backwaters is common.

- **Wetlands and waters.** This category includes marshes, wet meadows, and open water habitats. Species commonly associated with marshes include pied-billed grebe, Virginia rail, sora, yellow-headed blackbird, American coot, mallard, marsh wren, song sparrow, swamp sparrow, chorus frog, bullfrog, tiger salamander, muskrat, Great Plains spiranthes, catchfly gentian, Pecos sunflower, and Parish's alkali grass. Wet meadows provide habitat for some rare and declining species including New Mexican jumping mouse, white-faced ibis, long-billed curlew, common black-hawk, and leopard frog (Crawford et al. 1993). Wetlands were historically a significant part of the Middle Rio Grande floodplain biological community commonly the result of flooding and channel migration. Flood control activities have reduced the amount of wetlands in this reach. In 1918 there were an estimated 2,690 acres of marsh and standing water in the Rio Grande floodplain between San Acacia and San Marcial. By 1989, 790 acres of wetlands had been eliminated (Hink and Ohmart 1984). Additional information regarding the historical amount of wetlands is discussed in the Phase I report. The functionality of wetland and riparian systems along the Rio Grande are interconnected, so the degradation of one adversely affects the other.

Existing and Future Riparian Habitat Studies and Projects

- **The Conceptual Restoration Plan for the Rio Grande from San Acacia to San Marcial, New Mexico.** This study plan will support future habitat restoration efforts in the Socorro Valley (approximately 45 river miles). It is being conducted under the auspices of the Save Our Bosque Task Force.

- **Fuels Reduction in the Socorro Valley.** A number of government entities and resource stakeholders are working on establishing protocol for under-story thinning to protect riparian areas from wildfire but maintain quality habitat for wildlife species. The Forest Service Rocky Mountain Research Station is investigating three fuels reduction treatments on wildlife, vegetation, water and soil resources at study sites in Bernalillo, Valencia and Socorro Counties.

- **Riparian Habitat Restoration at Bosque del Apache NWR.** There are a series of research projects on the techniques for reestablishing native riparian habitats following exotic species removal. Work includes replicated studies in exotic species control, plant establishment, survival and growth, intra and inter-species competition.

- **Long Range Restoration Plan for the Active Floodplain on Bosque del Apache NWR.** The refuge is developing a comprehensive restoration plan to develop, prioritize and implement restoration of river and riparian habitats within the refuge boundary (10 river miles).

- **Saltgrass establishment in restored floodplain areas.** Bosque del Apache NWR is monitoring biotic and abiotic factors associated with the reestablishment of a saltgrass meadow that had been overtaken by salt cedar.

- **Vegetation mapping, US Bureau of Reclamation.** BOR is mapping the riparian vegetation from San Acacia to San Marcial, using the 1984 Hink and Ohmart classification system.

- **Intensive vegetation survey.** BOR has collected intensive vegetation data for two seasons in the reach from San Acacia to Elephant Butte in about eight macroplots. BOR has also collected avian nest productivity and point count data within these plots. The data is being compiled and should be ready in early 2003.

- **Revegetation strategies and technology development for restoration of xeric *tamarix* infestation sites.** BOR has an ongoing study to determine appropriate revegetation of areas following the removal of salt cedar. One of the focuses of this study is to determine appropriate native vegetation for areas lacking the soils and hydrology for cottonwood regeneration.

- **Bosque del Apache National Wildlife Refuge (NWR) south end habitat restoration (present and future).** The FWS under the National American Wetlands Conservation Act and non-federal partners are conducting a restoration project. The purpose is to convert 800 acres dominated by monotypic stands of salt cedar to a mosaic of native habitats including a mixture of grassland, wetland, and forests for the purpose of providing migratory and resident wildlife species with quality habitat.

- **BOR River Restoration/River Maintenance Program, Socorro Reach.** The program objectives are to restore areas disturbed by fire, enhance aquatic habitat and riparian vegetation potential on alternate river bars, destabilize river banks to encourage channel widening, remove exotic vegetation, encourage native vegetation, place random woody debris piles to promote bar formation and micro aquatic habitat, and create low terraces, high flow side channels, and wetlands.

- **River Restoration/River Maintenance Program, San Marcial Reach.** The Bureau of Reclamation has a program to remove exotic vegetation and encourage native revegetation, increase the main channel width, create channel avulsions, develop high flow side channels for overbank flooding, inundate cleared areas, and create backwater refugia areas, and wetlands. This program is from river mile 78 to the headwaters of Elephant Butte Reservoir.

- **Corps of Engineers San Acacia Levee Project.** The US Army Corps of Engineers is planning the restoration of the flood control levee in the San Acacia San Marical reach.

- **MRGCD Management Plan.** The Middle Rio Grande Conservancy District is developing a management plan for 150 river miles and approximately 277,760 acres of MRGCD owned or controlled bosque. This plan will be coordinated with other Middle Rio Grande riparian/river plans.

- **MRGCD Goat Vegetation Management Study.** The MRGCD and the Jornada Research Station are investigating the use of goats to remove exotic phreatophytes on 200 acres of bosque in the Escondida Reach.

- **MRG ESA Collaborative Program.** A consortium of agencies and research entities are investigating habitat and river restoration projects to enhance Rio Grande silvery minnow and southwestern willow flycatcher habitat to recover these endangered species.

- **Private Lands Restoration Projects.** A number of entities including the SSWCD, NRCS, and the Task Force are working with private landowners to rehabilitate their lands from exotic dominated to native dominated forests and open meadows.

- **Ongoing monitoring of Bosque del Apache NWR habitat restoration.** FWS has a bio-monitoring program of wetland and riparian habitat restoration.

- **Floodplain Management Program, Save Our Bosque Task Force.** The task force is planning a program that would offer private landowners the option of selling or donating permanent conservation easements on flood prone portions of their lands and partnering with restoration groups to convert nonnative habitat areas to native-dominated habitat areas. This program would be voluntary and would be designed to address flooding and fire hazards to private lands.

Aquatic Habitat

The Middle Rio Grande is considered to be a warm water river (Platania, 1993). It is characterized by warm summer water temperature, low velocity, high turbidity, more pools than riffles, small particle substrate, and a lack of shade and cover (Winger 1981 *In:* BOR 2000). The Rio Grande, from the San Acacia diversion dam to the upstream boundary of the Bosque del Apache NWR, is characterized by a channel of greatly varying width. The active channel areas ranging from 500 ft to over 1,000 ft in width have a low sinuosity, with low sandy banks. The narrow channel reaches (less than 200-ft cross sections) have low sinuosity (BOR 2000). The Rio Grande within the Bosque del Apache NWR maintains a wide, active river channel for about two-thirds of its length. The downstream third of the river changes character abruptly to a straight narrow channel less 200 feet wide. Backwater and island habitat is greatly reduced in this segment of the river and velocities within the active river channel are relatively high (BOR 2000).

Platania (1993) characterized the low flow aquatic habitat in the reach between Bernardo and San Marcial. This reach was identified as warm water, seasonally ephemeral habitat with runs, flats, and shoreline constituting 93 percent of the available habitat. The remaining 7 percent was backwaters (2%) and island habitat (5%). Substrate type was 100 percent sand and silt (Platania, 1991b). The aquatic habitat downstream of the San Acacia diversion dam primarily was composed of runs (47%) and island habitat (32%)(Platania 1993). The aquatic habitat in the Bosque del Apache NWR contained a higher percentage of island habitats that provides important refugia for fish during low flow periods (Platania, 1991a). Within the last five years, however, the channel narrowing and vegetation encroachment has reduced the aquatic habitat in this reach. Future aquatic habitat studies are necessary to quantify the loss of aquatic habitat during low flow conditions.

The Rio Grande provides habitat for a variety of native and nonnative fish species. The BOR has been monitoring the fish population monthly at seven sampling sites between San Acacia and San Marcial. The results of the monitoring from January to November 2002 in the following list indicated that there were 16 different species in this reach of the Rio Grande:

Fish Species Observed in 2002 in Project Area

Common Name	Scientific Name
Gizzard shad	*Dorosoma cepedianum*
Red shiner	*Cyprinella lutrensis*
Common carp	*Cyprinus carpio*
Rio Grande silvery minnow	*Hybognathus amarus*
Fathead minnow	*Pimephales promelas*
Fathead chub	*Platygobio gracilis*
Longnose dace	*Rhinichthys cataractae*
River carpsucker	*Carpiodes carpio*
Channel catfish	*Ictalarus punctatus*
Western mosquitofish	*Gambusia affinis*
White sucker	*Catostomus commersoni*
White bass	*Morone chrysops*
White crappie	*Pomoxis annularis*

Yellow bullhead	*Ameiurus natalis*
Smallmouth buffalo	*Ictiobus bubalus*
Walleye	*Stizostedion vitreum*
Source: BOR 2003	

Aquatic invertebrates make up a large portion of the food for native and nonnative fish species in the reach. The major aquatic invertebrate orders historically occurring in New Mexico are Diptera (flies and midges), Ephemeroptera (mayflies), Plecoptera (stoneflies) and Tricoptera (caddisflies). Chironomid midge larvae are common in freshwater ecosystems and are a significant food source to fish. Members of Tricoptera and Diptera are commonly found in submerged gravel bars, whereas Ephemeroptera can be found in silty conditions and exist in shifting sand habitat. Macroinvertebrates are important components of stream ecosystems as intermediate consumers of plant materials and nutrient recyclers (Crawford et al. 1993).

Existing and Future Aquatic Studies and Projects

- **Rio Grande silvery minnow population monitoring.** The BOR has an ongoing program to monitor fish populations, with a focus on the Rio Grand silvery minnow at seven sites in the San Acacia to San Marcial reach.

- **San Acacia fish passage feasibility study.** The BOR is evaluating the feasibility of providing fish passage for the Rio Grande silvery minnow at the San Acacia diversion dam.

- **BOR River Restoration/River Maintenance Program for the Socorro and San Marcial Reaches.** One of the purposes of this program is to restore habitat for the Rio Grande silvery minnow by creating side channel and backwater refugia areas.

Federally Listed Endangered, Threatened, and Candidate Species

The ecosystems of the middle Rio Grande have been altered by human activities since the development of the early Pueblos. From an ecological perspective, the most dramatic changes have occurred within the last 120 years, resulting in degradation and loss of riparian and aquatic habitat and reduced functionality. Many native plant and animal species are being replaced by exotic species that are better adapted to human induced conditions. It has been estimated that over 20 species of vertebrate animals have been extirpated within the Middle Rio Grande basin alone (Scurlock 1998).

The goal of the federal Endangered Species Act (16 USC §§ 1531-1544 PL 93-205, 1973) is to protect existing rare and sensitive species and the Act has become a primary focus affecting management of the Rio Grande system within the study area. Over the last decade, the FWS, BOR, and Corps of Engineers have implemented Rio Grande resource management to meet the needs of the endangered Rio Grande silvery minnow (*Hybognathus amarus*) and endangered southwestern willow flycatcher (*Empidonax traillii extimus*). This has affected both water resource management and land use management in riparian areas.

In June 2001, FWS issued a programmatic biological opinion on the Middle Rio Grande addressing river management activities as related to the silvery minnow, southwestern willow flycatcher, bald eagle *(Haliaeetus leucocephalus),* interior least tern *(Sterna antillarum)* and the experimental nonessential population of whooping crane *(Grus Americana)* (US Fish and Wildlife Service 2001). The biological opinion outlines how the BOR and Army Corps of Engineers will manage water operations along the Rio Grande (subject to Rio Grande Compact requirements), provides direction on specific river channel maintenance and restoration activities and outlines monitoring requirements. In addition to the bald eagle, least tern, and whooping crane, the yellow-billed cuckoo, a federal candidate for listing, has occurred or is known to occur in the active floodplain between San Acacia and San Marcial. Habitat use by these species is briefly described:

- **Southwestern willow flycatcher *(Epidonax traillii extimus).*** This federally listed endangered bird is a common migrant throughout the bosque, resting and feeding in riparian understory vegetation. The BOR has been conducting willow flycatcher surveys in selected reaches of the Rio Grande since 1995 with more intensive and regular surveys along the San Marcial reach. The BOR also assessed habitat along the Rio Grande, from San Acacia to Elephant Butte Reservoir for willow flycatcher habitat suitability. One of the major factors governing habitat suitability is the presence of water associated with overbank flooding. Most willow flycatcher nests have been consistently within 150 feet of surface water usually the river channel. About 4,330 acres of highly suitable breeding habitat has been identified in the riparian area between San Acacia diversion dam and Elephant Butte Reservoir. In addition, about 2,360 acres of dense salt cedar, have been classified as marginally suitable. About 1,090 acres of sparse stands of riparian vegetation, usually on river bars along high flow channels, have been classified as habitat that could become suitable habitat following additional growth of current seedlings or when native riparian plants are planted (BOR 2000). Maps D.5 and D.6 in Appendix D are GIS maps of the willow flycatcher habitat suitability created by BOR.

- **Yellow-billed cuckoo *(Coccyzus americanus).*** The yellow-billed cuckoo is a candidate for federal listing. Suitable breeding habitat for the cuckoo includes dense willow and cottonwood. Breeding yellow-billed cuckoos were detected mostly in mid-aged and mature classes of riparian habitat during surveys along the Rio Grande (BOR 2000). The BOR has been recording incidental cuckoo observations during its willow flycatcher surveys for several years. These surveys are expected to continue into the future. In addition, during 2002 the BOR conducted a formal yellow-billed cuckoo survey on the Bosque del Apache NWR. The results of this survey are not yet available.

- **Interior least tern *(Sterna antillarum).*** The federally listed endangered interior least tern's breeding areas range from California, South Dakota and Maine to Chiapas, Mexico and the Caribbean. The tern was never common in New Mexico, being a state on the western periphery of its range. In New Mexico, least terns have been observed breeding in the vicinity of Roswell including Bitter Lake NWR in the Pecos River Basin. This is the primary least tern habitat area of the state. Sightings of a single tern were recorded at Bosque del Apache NWR in 1989, 1991, and 1993 (Crawford et al. 1993).

- **Bald eagle *(Haliaeetus leucocephalus).*** The federally listed threatened bald eagle has been consistently found concentrated around the Cochiti, Elephant Butte, and Caballo reservoirs during the winter. The Bosque del Apache NWR conducts an annual count of bald eagles ranging up to 60 individuals in a given year. Key habitat components for bald eagles are trees with large horizontal branches bordering on open areas, especially on the edges of rivers, backwaters or lakes. Eagles often perch on the tallest trees available that have branches overlooking a food source.

- **Rio Grande silvery minnow *(Hybognathus amarus).*** The federally listed endangered Rio Grande silvery minnow was formerly one of the most widespread and abundant species in the Rio Grande. By the 1960s, it had been eliminated from much of its original range. The San Acacia portion of the Rio Grande supports the largest population of this species (USFWS 1999). The San Acacia to San Marcial reach of the Rio Grande is within the designated critical habitat for this species. Relatively good aquatic habitat is in the reach below the San Acacia diversion dam (BOR 2000). In general, the silvery minnow prefers habitat of 4 to 7.8 inches of flow depth, low flow velocities, and silt substrate or occasionally a sandy substrate during spring, summer, and fall (BOR 2000). These conditions are primarily found in pools, backwaters and secondary channels. As described in the aquatic habitat section, backwaters constitute only about two percent of the aquatic habitat in the San Acacia to San Marcial reach. During flows that were not severely reduced, typical habitat consisted of shallow and braided runs over shifting sand substrate (Bestegen and Platania 1991).

- **Whooping Crane (*Grus americana*).** Individuals from an experimental nonessential population of whooping crane were formerly observed in the San Acacia to San Marcial Reach. These whooping cranes were associated with the Idaho flock of Greater sandhill cranes. The whooping cranes had roosted with the much larger flocks of sandhill cranes on sandbars in the Rio Grande within the Bosque del Apache NWR. This experimental population diminished over time until last year when no whooping crane individuals were observed at the Refuge and the population is considered to have died off.

Existing and Future Federally Listed Species Studies and Projects

- See Existing and Future Aquatic Studies and Projects above for a description of the three Rio Grande silvery minnow studies and projects.

- Southwestern willow flycatcher surveys. BOR has been conducting surveys for willow flycatchers since 1995. These surveys have also recorded incidental yellow-billed cuckoo and other bird species. Surveys are expected to continue.

- Yellow-billed cuckoo. BOR conducted a formal yellow-billed cuckoo survey on the Bosque del Apache NWR in 2002. Surveys are expected to continue.

Biotic and Abiotic Factors Influencing Habitat

The composition and functionality of riparian and aquatic habitat is directly related to the biotic and abiotic conditions within the system. An understanding of these conditions provides a roadmap to the likely future trends and what specific functions need to be altered during restoration to achieve desired goals. An effective restoration plan must create biotic and abiotic conditions that support desired habitat and reduce or eliminate the biotic and abiotic conditions that favor other habitat conditions (these conditions termed stressors). The greatest stressors in the study area are regulation of river flows, lack of river-floodplain connection, channelization and invasive species. The following is a description of the primary biotic and abiotic conditions that are important to and that stress the native mosaic and desired aquatic habitat.

Biotic Factors

- **Nonnative plant species.** The predominant biotic factor threatening the native bosque is the invasion of nonnative plants, primarily salt cedar and Russian olive. Colonization of areas disturbed by fires or other clearing without active restoration tends to favor these introduced species. Monotypic stands of salt cedar have already excluded native cottonwood and willow from the canopy in extensive areas. In some areas, dense nonnative vegetation has stabilized riverbanks and trapped sediments, resulting in higher banks. High bank elevations inhibit overbank flooding necessary for native plant regeneration. It is widely accepted that salt cedar has adverse effects on riparian ecosystems. Salt cedar provides lower quality bird habitat than native forests and increases the frequency and extent of fire. A study of the functional equivalency of salt cedar and Fremont cottonwood showed that salt cedar provided some functions similar to native vegetation species (Stromberg 1998). The potential for successful revegetation with native plant species should be investigated prior to removing salt cedar.

- **Limited habitat diversity.** The diversity of habitats in the San Acacia to San Marcial reach has been reduced compared to the desired native mosaic. Open habitats, such as grasslands, wet meadows, and wetlands have been declining for more than a century. Some of this habitat loss can be attributed to the hydrologic disconnection of the river channel and floodplain. The loss of regenerating native riparian forest to monotypic salt cedar stands has reduced habitat diversity. Limited habitat diversity in turn limits wildlife diversity.

- **Nonnative aquatic species.** Nonnative fish species affect native fish populations through predation or displacement from preferred habitat. This is a particular concern during extreme low flow events when the effectiveness of predatory fish, such as the white crappie, is presumed to be enhanced due to lack of pools and small pool size (Bestegen and Platania 1991). Currently, the Rio Grande lacks the extensive backwater pool and side channel areas that historically provided habitat for native fish. These habitat changes have created suitable conditions for nonnative fish species that have been introduced by sportfish stocking or accidentally through bait fish use (BOR 2000).

Abiotic Factors

- **River flow management (reduced seasonal flooding).** The predominant abiotic factor threatening the native riparian vegetation is the lack of seasonal flooding. Ellis et al. (1999) observed that seasonal flooding is an integral component of river-floodplain ecosystems. The hydrologic connection between the channel and the floodplain controls important functional responses in vegetation. The aquatic-terrestrial interaction in unregulated systems drives the transfer of water, nutrients, sediment, particulate organic matter, and organisms. These transfers have important fluxes, both laterally on the floodplain and in the downstream direction. The overbank flood pulse promotes biological productivity and helps to maintain the ecological diversity in riparian ecosystems (Ellis et al. 1999). Cottonwood are adapted to relatively frequent, intense disturbances produced by the energy of flowing water in riparian environments (Osterkamp and Costa 1987 *In:* Scott et al. 1993). Light to moderate flooding favors the establishment and development through deposition of nutrient-rich sediments and increased soil moisture which are vital cottonwood to regenerate. High quality native riparian habitat depends on overbank flooding for sediment deposition (wet substrate) and cottonwood recruitment. In addition, periodic scouring floods are required to create bare moist soils for seed germination (Muldavin et al. 1999). To support seed germination of native species, flooding should occur from mid-May to mid-June. The Escondida subreach channel between San Acacia and the North Socorro diversion dam has been incised to the point that it precludes cottonwood seedlings from becoming established on the floodplain. The only cottonwoods in this reach are on channel sand bars and banks. Where overbank flooding is frequent in the two lower subreaches, dense monotypic stands of salt cedar have overwhelmed the floodplain. Modeling conducted by Auble et al. (1994) showed that a decrease in the variability of flow results in an increase in the relative abundance of extreme cover types. Concomitantly, an increase in the minimum allowable flow results in a decrease in the area occupied by the wettest vegetated cover type (Auble et al. 1994).

Hydrology is the primary factor influencing Middle Rio Grande aquatic habitat. Historically, the Middle Rio Grande had seasonal high variability of flows characterized by spring flooding and low flows in late summer and fall punctuated by summer convective thunderstorms. Low flow periods resulted in major portions of the channel going dry causing fragmentation of aquatic habitat. During extremely dry years, the isolated pools become the last refuge for populations of fish and invertebrates. Native aquatic species have adapted to survive these conditions until high flows reestablish habitat continuity and availability. The introduction of a water regulation infrastructure in the Middle Rio Grande has increased the potential for longer and more frequent periods of low flow and habitat fragmentation. The extent of channel desiccation, due in part to water regulation, has been identified as a factor in the decline and extirpation of several Middle Rio Grande fish species (Bestegen and Platania 1990, 1991; Edwards and Contreras-Balderas 1991; *Federal Register* 1993a).

- **Soil salinity.** High soil salinities can reduce seedling growth in cottonwood, while salt cedar can tolerate higher salinities (Sprenger et al. 2000). High soil salinity is generally the result of an altered flow regime or land uses (e.g. agricultural drainage). In healthy lotic riparian ecosystems annual spring floods remove excess salts (Briggs 1996). Research with seasonal flooding has shown that native vegetation can out-compete exotics in moderate saline soils if other factors, such as rate of groundwater drawdown and soil texture are favorable.

- **Soil type and condition.** In a controlled flow environment with limited overbank flooding, sandy sediment deposited in overbank areas is significantly reduced compared to a natural flooding river system. Cottonwoods and willows grow best in sandy soils (Horton et al. 2001). Another limiting factor may be a paucity of bare moist soils for cottonwood and willow regeneration. Recruitment of cottonwood is essentially restricted to sites that are not only moist and open enough for seedling establishment but also free from lethal scour during subsequent higher flows (Friedman and Scott 1996). In most floodplain areas, overbank velocities are not sufficient to scour seedlings.

- **Fire.** The proliferation of salt cedar has resulted in an accumulation of deciduous litter and woody debris. This accumulation of fuel has promoted an increased frequency and severity of fires (Ellis 2001). The New Mexico State Forestry department (NMFS) has observed that fire intensity and frequency is higher in areas with dense, untreated invasive species undergrowth. Dense stands of salt cedar, in particular, are susceptible to severe fire intensity. In areas where the undergrowth has been cleared to reduce the fuel buildup, the fire frequency has been reduced. In addition, areas where the understory has been reduced either naturally or manually, the fires that do occur are easier to contain. The majority of the larger fires are human induced by agricultural burning, accidents, or arson.

The natural lightening strike fires are generally small (often single cottonwood snags) and are relatively easily extinguished, often naturally. After fires, salt cedar can sprout prolifically, but native riparian trees including cottonwoods, are not well adapted to severe fires. Increasing fire frequency can alter the species composition of the riparian ecosystem (Ellis et al. 1998). In addition, the dense monotypic stands of salt cedar present a fire risk for adjacent native habitat. Clearing vegetation between nonnative and native vegetation communities to reduce fire risk should be considered. The frequency of human caused fires now is less than around five years ago, probably the result of an educational outreach program initiated by the NMSF. The NMFS has a program to educate the public on the dangers of bosque fires. There has more concerted effort by the agencies and land resource stakeholders to reduce bosque fires.

- **Private land use.** Floodplain structures can limit the potential for regulated overbank flooding. Domestic livestock graze on the floodplain. This can be environmentally damaging because it converts riparian woodland to pasture and cattle ingress and egress erodes the riverbank. If properly managed, grazing can be used to maintain habitat and biodiversity. The conversion of bosque to agriculture is essentially complete, however, there some large tracts of private land that could be converted either to agriculture or other domestic uses.

- **Channelization.** Meanders, oxbows, and other slack water components of historic aquatic habitat have been severely reduced, both spatially and temporally (USFWS 1999). This reduces habitat for native fish species, in particular the Rio Grande silvery minnow. Channelization results in less frequent overbank flooding limiting the regeneration of native riparian forest and the formation and hydrologic maintenance of wetland habitats. One of the major factors in natural regeneration is the progression of tree stands from nursery bars to senescent individuals. Channelization and levee construction has other impacts including the loss of flooded bottomlands for fish nursery and cover and reduced input of coarse particulate matter and nutrients from flooded areas.

- **San Acacia Diversion dam.** Habitat below the San Acacia diversion dam is an extremely important refugium for fish during periods of low flow. Due to the channelization of much of the reach, the area below the dam provides some of the only aquatic habitat during low flow. This habitat is not secure, as routing maintenance and repair of diversion dams may alter habitat and substrate conditions (Bestegen and Platania 1991).

Trends and Future Conditions

Without Restoration

Without restoration riparian and aquatic habitat condition would continue to degrade. Native riparian vegetation communities would continue to be converted into nonnative vegetation communities, resulting in changes to wildlife populations. The amount of wetland and wet meadow habitats are likely to be reduced as the amount of overbank flooding continues to decrease, resulting in reduced habitat diversity. Fires in the floodplain are likely to continue to increase in frequency and intensity. Aquatic habitat would continue to lose shallow, low velocity backwater pools and side channels preferred by native fish species. This is likely to result in further loss of native fish species and populations in the reach.

The existing cottonwood-willow riparian forest is largely an ecological legacy of past flooding and flood control activities. These stands may be rapidly senescing and new stands of cottonwood are not being established (Molles et al. 1998). Existing stands of native woodlands are becoming decadent and are being replaced by nonnative species (Sprenger et al. 2002). Without changes in current water resource management, exotic plants, such as salt cedar and Russian olive, may dominate riparian forests within the next 50 to 100 years (Howe and Knopf 1991). This trend toward nonnative vegetation would affect the types of wildlife capable of surviving in the area.

The transformation of native habitats to nonnative vegetation would cause the wildlife species composition to change in the riparian area. Of particular concern is the trend toward monotypic salt cedar stands. Lisa Ellis (1994) observed that bird species richness in cottonwood and salt cedar did not differ during any season, but species composition did vary. A number of obligate riparian species readily used salt cedar, while others were restricted to areas dominated by native vegetation (Ellis 1995). Summer tanagers *(Piranga rubra)* were detected only in native vegetation during this study. Timber gleaners, specifically the white-breasted nuthatch *(Sitta carolinensis),* were never detected in salt cedar (Ellis 1995). Large predatory and omnivorous birds may also be affected by the change, including birds that roost in large cottonwoods and a variety of hole-nesters that use dead snags or dead branches on living trees to build nests (Crawford et al. 1996). Ash-throated flycatchers *(Myiarchus cinerascens)* were observed foraging in salt cedar, but there was no evidence that they were breeding in that habitat (Ellis 1995). Salt cedar stands within 150 feet of water are considered marginally suitable for the southwestern willow flycatcher.

Densities of mammals, including game animals, furbearers, and rodents, have also been shown to be lower in salt cedar than other vegetation types (Engle-Wilson and Ohmart 1978; Hildebrandt and Ohmart 1982). Ellis et al. (1997) found small mammal species richness to be greater in salt cedar than in native cottonwood, however, in the Middle Rio Grande Valley of central New Mexico. This was due to an increase in species that normally inhabit dry upland or grassland habitats, not species typically expected in a riparian area. Factors such as increased salinity, combined with decreased water availability, may enhance the spread of more xeric upland species ultimately facilitating the dispersal of upland rodent species into the floodplain (Ellis et al. 1997). Jakle and Gatz (1985) trapped three to five times more reptiles and amphibians in native vegetation types as in salt cedar along the Gila River near Florence, Arizona. The abundance of ground-dwelling arthropods would not change appreciably if vegetation were to change from native to nonnative stands. The species diversity of ground-dwelling arthropods would, as with canopy arthropods, undergo some change, but the abundance would remain relatively constant.

The incidence and intensity of fires are expected to increase as a result of the accumulation of forest floor litter due to both the extensive litter produced by salt cedar and the lack of flooding to remove forest litter. Without restoration activities, such as the creation of firebreaks and large scale removal of salt cedar stands, fires beginning in salt cedar stands are likely to spread to native vegetation communities. In addition, fire disturbance favors colonization by nonnative vegetation without active restoration efforts.

Without restoration, the channel would continue to narrow, further reducing the aerial distribution of sandy substrate, shallow water habitat. This potential loss of habitat would further strain on the Rio Grande silvery minnow population. Planned FWS and BOR efforts to enhance silvery minnow habitat would offset the effects of channel narrowing. The loss of conveyance capacity associated with channel narrowing would have increasing impacts on the levee system as floodplain inundation increased. Planned levee improvements should be combined with river channel maintenance.

Private land development and grazing will continue to degrade riverbanks and affect river processes and vegetation composition. Without restoration efforts that include coordination with private land owners, riparian and aquatic habitat conditions would be negatively affected. As mentioned previously, proper management of livestock grazing can be a tool for improving habitat diversity and native vegetation conditions.

Private land use, in particular grazing, will continue to degrade riverbanks and affect vegetation composition. Without restoration efforts that include coordination with private land users, riparian and aquatic habitat conditions would be negatively affected. As mentioned previously, proper management of livestock grazing can be a tool for improving habitat diversity and native vegetation conditions.

With Restoration

Restoration efforts in the San Acacia to San Marcial reach would improve riparian and aquatic habitats. The area of native vegetation communities, such as cottonwood forest, saltgrass meadow and wetlands would be increased resulting in improved native wildlife habitat and increased habitat diversity. Wetlands and wet meadow habitats would be protected, enhanced, and in some cases, created through management of exotic vegetation and improved hydrology. Management of riparian vegetation has great potential to be a beneficial tool. There could be a savings in water lost to evapotranspiration from removing nonnative vegetative and thick understory. Removing nonnative vegetation in channels and along banks would enhance dynamic channel behavior (World Wildlife Fund and Alliance for the Rio Grande Heritage 2002). Channel restoration would improve aquatic habitat for native fish species by increasing the available low depth, low velocity habitat in the main channel and increasing the spatial distribution of backwater and side channel habitats. Increased habitat diversity, in particular the creation of new wetlands and saltgrass meadows, would increase the edge effect on the floodplain. Edges between riparian vegetation types and adjacent aquatic, wetland, upland and agricultural areas provide a valuable habitat for wildlife. Edges have long been associated with abundance of wildlife, as well as with species diversity (Crawford et al. 1993).

The distribution and areal extent of native vegetation would increase by replacing nonnative plant communities and with native species. Due to the extensive areas of nonnative species, this change could effect wildlife species composition. As described under the without restoration section above, the abundance of ground-dwelling arthropods would not change appreciably. The diversity and abundance of small mammal species are related to the mosaic of plant community and structural types historically present, including various wetland habitats, interspersed with patches of cottonwood forest of different ages. As a result, restoration would likely protect the native species diversity for small mammals although the overall species richness may not be affected. Native bird diversity would be protected and enhanced through restoration efforts. Riparian obligate species, such as the summer tanager and white-breasted nuthatch have been found exclusively in cottonwood forest habitat.

Channel restoration would create habitat conditions that favor native fish species over nonnative fish species. A channel that is managed to be wider and more active would create more aquatic habitat diversity. A wider channel with additional flow area and increase channel conveyance capacity would reduce the potential impact on the flood control levees. Channel restoration would increase the amount of sandy substrate, shallow water habitats. The preferred habitat for the Rio Grande silvery minnow would be enhanced. Reducing fish dependency on the aquatic habitats found below the diversion dam by creating additional low flow refugia throughout the reach would reduce predation on native fish.

Rio Grande Compact and Related Water Use Issues

Introduction

This section discusses issues related to the allocation and the use of the waters of the Rio Grande stream system with particular focus on the reach between San Acacia and San Marcial. It has been prepared for the planning and analysis of potential stream restoration activities along the Middle Rio Grande. These issues include the development of the Rio Grande Compact of 1938, the New Mexico delivery schedules included in the Compact, and a summary of the use of surface water and associated water rights in the reach. A general discussion is presented on the impact that possible increased depletions in the San Acacia to San Marcial reach may have on the Rio Grande Compact deliveries to Texas.

Rio Grande Compact

The Rio Grande Compact apportions the waters of the Rio Grande north of Ft. Quitman, Texas between the states of Colorado, New Mexico and Texas. This division of the total drainage basin of the Rio Grande was adopted by the Treaty of 1906 between the United States and Mexico and has been used consistently since that time. The adoption of the Compact represented the conclusion (or some might say the suspension) of a lengthy and sometimes contentious debate among the three states and the federal government over the water resources of the basin. The following is a brief history of events that led to the adoption of the 1938 Compact. A more complete discussion of the events that led up to the signing of the Compact may be found elsewhere (Natural Resources Committee, 1938).

History

Water shortages in the Mesilla and El Paso Valleys in the early 1890’s led to the imposition of the embargo of 1896 as well as the United States - Mexico Treaty of 1906. The embargo prevented the development of further irrigation in the basin through the suspension of applications for rights-of-way across public lands. The embargo remained in effect until May 1925. The shortages in the Mesilla and El Paso Valleys were attributed to degradation of river conveyance in the middle valley and increased depletions in the San Luis Valley.

In 1923, the legislatures of Colorado and New Mexico enacted statutes under which the state’s Governors appointed commissioners to study the water supply conditions in the basin and to draft a compact between the states leading to the equitable allocation of the waters of the basin. Representatives from Texas and the United States were appointed later. After the completion of engineering investigations, the Commission concluded a Compact in 1929 that became effective later that year by ratification of the state legislatures and the Congress.

The 1929 Compact appointed commissions from the three states to negotiate a new compact. The principles established in the 1929 Compact became the cornerstone of a new compact agreement that was eventually ratified in 1938. The provisions included those that were concerned with the maintenance of the "status quo" of conditions of water use in the basin. Between 1929 and 1938, however, the Compact Commission conducted studies to determine an equitable apportionment of the waters of the basin.

In October 1935, the State of Texas filed suit in the Supreme Court of the United States against the State of New Mexico and the Middle Rio Grande Conservancy District (MRGCD). Texas contended that New Mexico had violated the compact of 1929 by impairing the water supply to Elephant Butte Reservoir through excessive diversions and through the detrimental increases in the salt content of the water. The Texas action was precipitated by the storage of water in El Vado Reservoir on the Rio Chama in 1935, a year of deficient supply due to several years of below normal runoff in the basin. In 1937, the two states and the MRGCD stipulated that any further proceedings in the lawsuit be held in abeyance to allow additional time for the three states to conclude a permanent compact among the states. It was also stipulated that the general program of water supply and use investigations carried out in 1936 as part of the Rio Grande Joint Investigation were to be continued through 1937.

In December, 1935, the National Resources Committee agreed with the appointed commissioners pursuant to the 1929 Compact to undertake an investigation of 1) the water supply of the basin above Ft. Quitman, 2) the past, present and prospective uses of water and 3) the opportunities for conserving and augmenting the water supply of the basin. These studies were to assist the Compact Commission in reaching an equitable apportionment of the waters of the basin. Pursuant to this agreement, funds were authorized ($400,000) and field work was conducted from April 1936 through July 1937. The final report of the Rio Grande Joint Investigation was submitted to the President Roosevelt in December 1937.

Numerous conferences were held to debate the terms of a permanent compact during the federal agency investigations. The engineer advisors to the compact commissioners worked closely with those performing the Joint Investigation. Preliminary drafts of the report of the Joint Investigation were made available to the representatives of the three states. The final report of the Rio Grande Joint Investigation indicated the sources and quantities of water available, the needs for water, the means for development and use of the water supplies in the basin. The three Compact commissioners and their advisors entered into the negotiations of the new Compact with an adequate understanding of the problems associated with the equitable apportionment of the water of the basin and this led to the signing of the Rio Grande Compact on March 18, 1938.

New Mexico Delivery Schedule

The purpose of the 1929 Compact included the maintenance of the status quo in the use of the waters of the Rio Grande (protect existing uses), as well as the permission for the maximum use and future development of the water from the Rio Grande consistent with the rights of the states. The Rio Grande Joint Investigation collected all pertinent data as to the supply and demands for water in the middle valley. Thus it became possible in 1938 to establish a relationship between the inflow and outflow to the middle valley and what constituted inflow to Elephant Butte Reservoir. These relationships became the basis of the New Mexico delivery schedule incorporated into Article IV of the Compact of 1938.

The data collected by the Rio Grande Joint Investigation showed that the relationship between the amount of water in the Rio Grande above the principle agricultural areas in New Mexico and inflow to Elephant Butte Reservoir was erratic due, in part, to the wide variation in tributary inflow. The engineers found that there was a reasonable relationship between the discharge of the Rio Grande at Otowi and San Marcial when the months of July, August and September were excluded. The original schedule that was incorporated in Article IV of the Compact was based on this partial year relationship.

The New Mexico delivery schedules were based on the Otowi and San Marcial gage record prior to 1930. Data from the period 1930 to 1937 could not be included because the construction of the MRGCD irrigation works impacted the discharge at San Marcial. The subdivision of the basin at San Marcial rather than at the New Mexico-Texas state line was thought to be necessary because the Rio Grande Project was supposed to be operated as a unit. The data used in computing the middle valley schedule were the annual discharges at Otowi and San Marcial reduced by the discharges during the months of July, August and September.

The San Marcial gage was expensive to operate and the mobile bed conditions made it difficult to obtain an accurate discharge record. In 1945, the Commission decided to investigate the possibility of developing a New Mexico delivery schedule without using the San Marcial gage. The delivery schedule would be one that would apply for the entire year. In 1947 the Engineer Advisors developed a year-round delivery schedule based on the Elephant Butte Effective Index Supply, instead of the San Marcial Index Supply. The Elephant Butte Effective Index Supply is defined as the flow of the Rio Grande below Elephant Butte Dam during the calendar year plus the net gain or loss in storage in Elephant Butte Reservoir during the same year.

Figure 10 illustrates the differences between the delivery obligation under the San Marcial Index Supply and under the Elephant Butte Effective Index Supply. This figure shows the New Mexico depletion allowed by the Otowi Index Supply under the two schedules. The Otowi Index Supply is the flow at the Otowi gage corrected for the flow of transmountain water flowing past the gage and for the operation of reservoirs constructed after 1929 in the basin between Otowi and Lobatos. The difference between the two curves at high levels of the Otowi Index Supply represents the net depletion between San Marcial and Elephant Butte Dam including evaporation losses from Elephant Butte Reservoir.

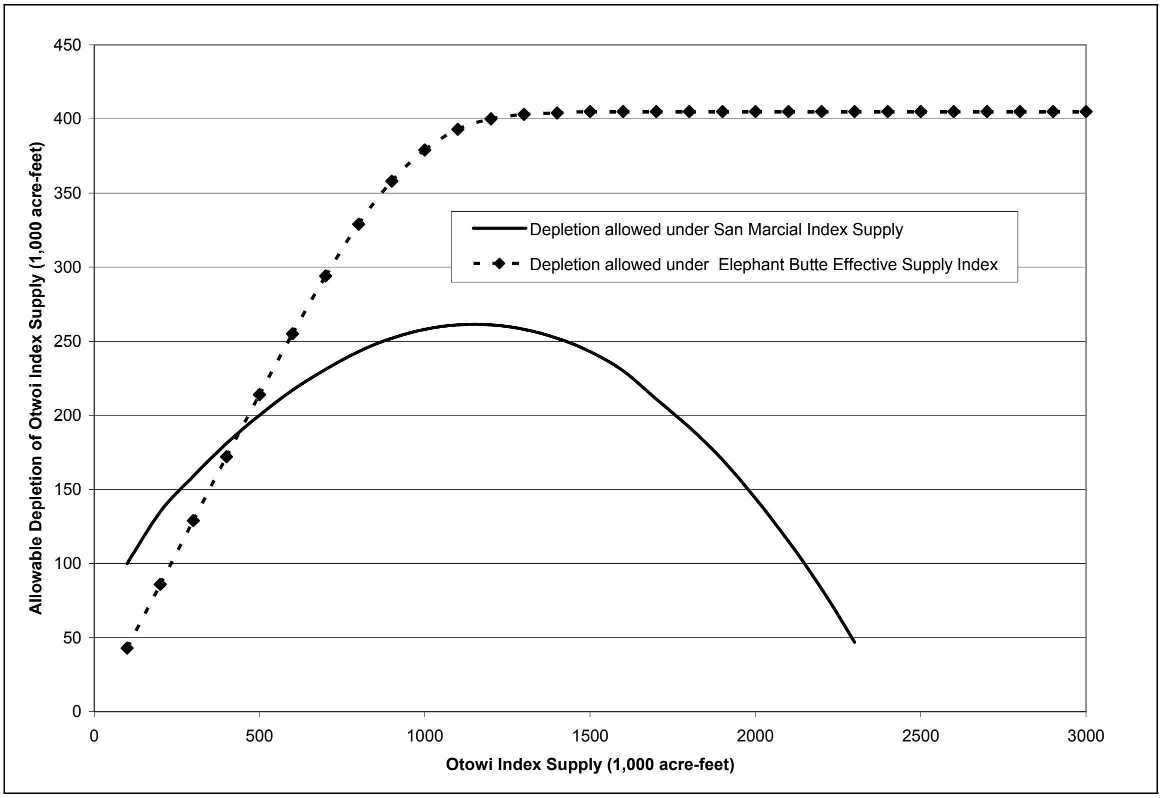


Figure 10. Comparison of Depletions Allowed Under Rio Grande Compact Delivery Schedules

New Mexico Compliance with Delivery Schedule

New Mexico has historically relied on three distinct methods to ensure that the state water delivery remains in compliance with the provisions of the Rio Grande Compact. These methods are administration of groundwater uses, water salvage measures and tributary inflow below the Otowi gage. It is important to recognize that the Compact does not require that the volume of water mandated by the schedule be delivered to Elephant Butte Reservoir each year. Article VI allowed for a system of credits or debits. The New Mexico accrued water debit may not exceed 200,000 acre-feet, except for debits in excess of 200,000 acre-feet caused by the holdover of water in storage in reservoirs constructed in New Mexico after 1929. Furthermore, New Mexico shall not be charged with greater debit in any one year than the sum of 150,000 acre-feet plus the gain in storage for that year. Similarly, in computing the amount of accrued credits and accrued debits, annual credits shall not exceed150,000 acre-feet.

In recognition of the fact that groundwater in the middle Rio Grande basin is in hydrologic connection with the Rio Grande and other related surface water features, the State Engineer issued an administrative order in 1956 that: 1) identified the boundaries of the middle Rio Grande underground water basin, 2) required that all future wells be drilled under a permit obtained from the State Engineer, and 3) required that all impacts of groundwater pumping on the flow of the Rio Grande be offset with the retirement and transfer of valid existing surface water rights. The State is thus reasonably assured that the impacts of new groundwater development after 1956 would not impair the state's ability to deliver water into Elephant Butte Reservoir.

New Mexico has also relied on the implementation of water salvage measures, undertaken in cooperation with the Bureau of Reclamation to reduce the "non-beneficial consumptive use" of water in the middle valley, thereby enhancing the water supply in the middle valley. The principal feature of these measures was the construction and operation of the Low Flow Conveyance Channel between San Acacia and Elephant Butte Reservoir. This facility allowed for the efficient transport of low flows (<1,600 cfs) through the delta at the head of Elephant Butte Reservoir. The facility also salvaged a significant amount of shallow groundwater and continues to function as a drain. The water salvage program also included the mowing of vegetation in the Rio Grande floodway through the middle valley and the removal of salt cedar in the Elephant Butte Reservoir area.

Although not a firm supply, the inflow from tributaries below the Otowi gage has enhanced the available water supply of water users in the middle valley and water delivery to Elephant Butte Reservoir. These tributary inflows below Otowi gage are not accounted in New Mexico's delivery obligation. Principal among these tributaries include the Jemez River (mean annual flow at mouth about 65 cfs), the Rio Puerco (mean annual flow at mouth about 45 cfs) and the Rio Salado (mean annual flow at mouth about 14 cfs).

Large tributary inflows such as the Rio Salado and Rio Puerco that enter the Rio Grande below the major agriculture and domestic use areas are important to analyze. Using 1972 as an example, the combined discharge of the Rio Puerco and Rio Salado was 152,800 acre-ft and the Otowi Index Supply was 474,300 acre-ft. Based on the delivery schedule, 271,100 acre-ft is computed as the water delivery to Elephant Butte. The actual delivery (Elephant Butte Effective Index Supply) was 424,700 acre-ft. The large tributary inflow that year was responsible, in part, for a credit of 153,600 acre-ft that was reduced to 150,000 as per Article VI of the Compact.

Pre-Compact Groundwater Conditions – San Acacia to San Marcial

A review of groundwater conditions that existed on the west side of the river before the 1938 Compact is presented. This review may assist in the analysis of restoration activities in the San Acacia to San Marcial reach and their impact on groundwater levels.

Surveys undertaken at the time of the 1936 Rio Grande Joint Investigation found that groundwater in the Socorro Division moved to the interior drains at a higher gradient than found at other locations within the MRGCD. The investigators attributed this to the fact that the lands in the Socorro Division are located in a relatively narrow section of the middle valley. From San Antonio to the north boundary of the Bosque del Apache, the groundwater moved in a general down-valley direction with little transverse movement. At the time of the 1936 surveys, the Bosque del Apache National Wildlife Refuge lands were undrained and had only limited irrigation. These lands reflected conditions similar to the entire middle valley prior to drainage. Runoff from the Socorro Main Canal South and the San Antonio Riverside Drain discharged to this area creating elevated groundwater levels and vegetation. The water table sloped uniformly southward and had few irregularities.

Comparisons of the 1936 groundwater elevations with those that may have existed before drainage of the middle valley are helpful in understanding the effects that the construction of drainage works had on groundwater levels. The pre-drainage conditions can be represented by data collected in 1926-27 by the Middle Rio Grande Conservancy District (Burkholder, 1928). Figure 11 shows the proportion of land with various depths to groundwater in the Socorro Division for 1926-1927 and 1936. The groundwater levels declined an average of about 2.5 feet over the area surveyed with the construction of drainage works in the area. Figure 12 shows the proportion of land with various depths to groundwater in the Bosque del Apache area for 1926-1927 and 1936. Figure 12 shows little change in groundwater conditions because the area remained undrained in 1936.

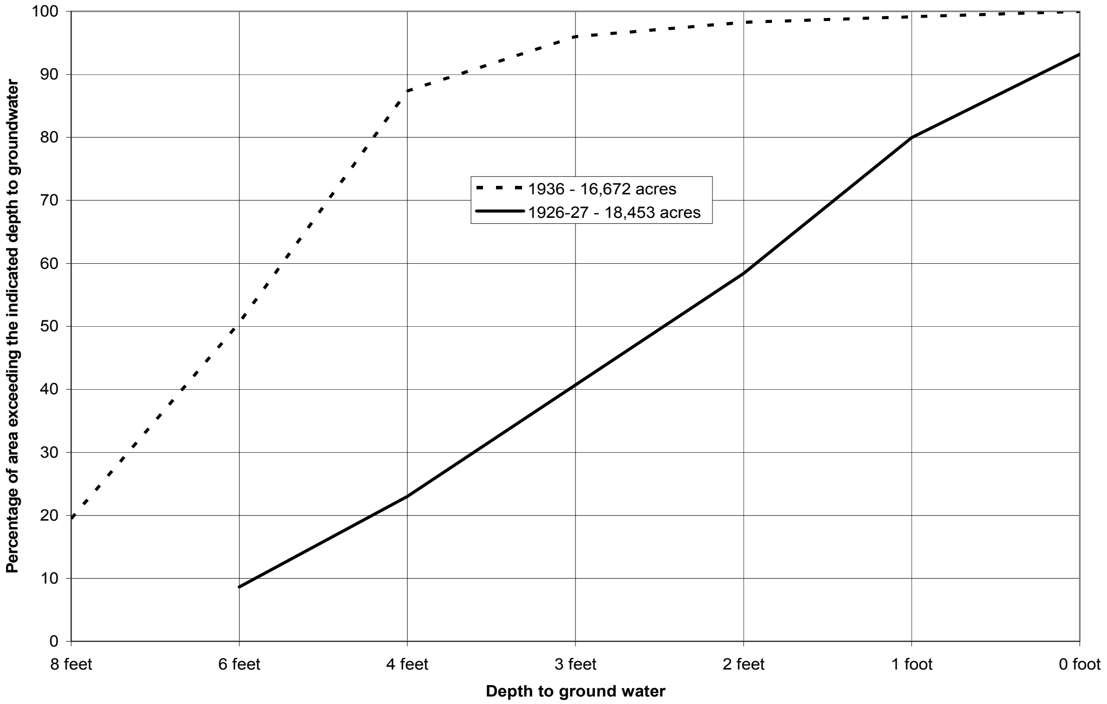


Figure 11. Depth to Groundwater Socorro Division in 1926-27 and 1936

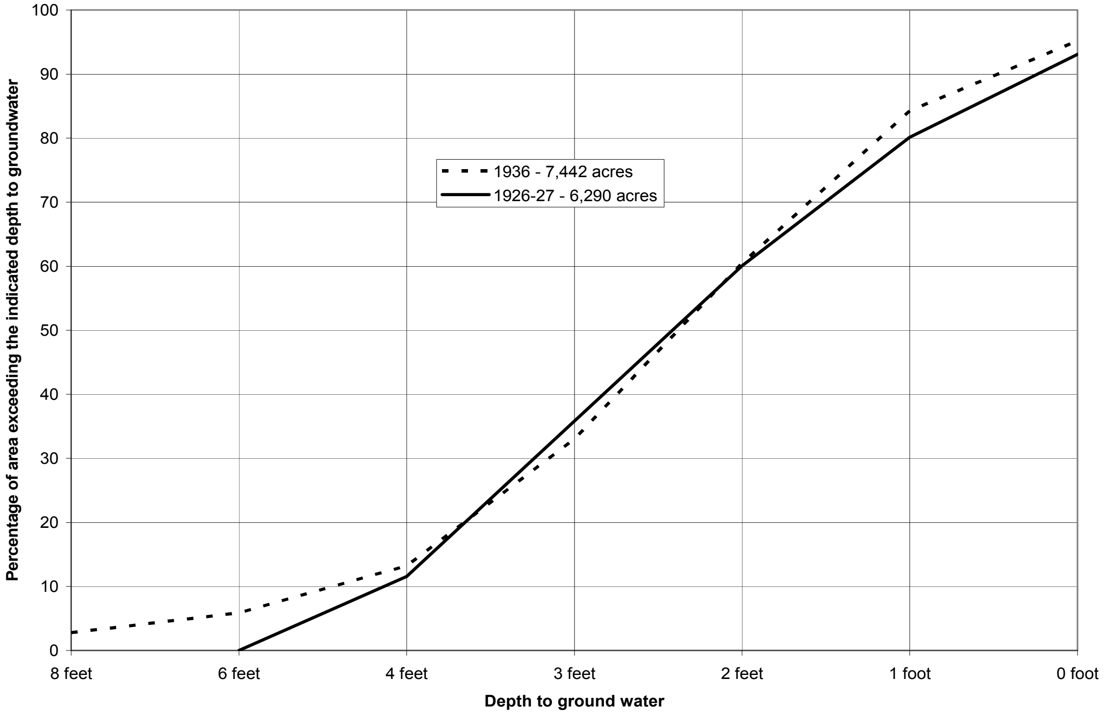


Figure 12. Depth to Groundwater in Bosque del Apache NWR in 1926-27 and 1936

Water Utilization, San Acacia to San Marcial Reach - Surface Water Depletion

Surface water depletion from the San Acacia to San Marcial can be analyzed by comparing the amount of river surface flow entering the reach at San Acacia and the amount departing the reach at San Marcial. The nature and location of surface water gaging stations used in this analysis has changed over the years. Table 20 summarizes the periods of record and locations of the various stream gages used in this analysis.

Figure 13 is a graph of cumulative annual depletions based on a simple inflow and outflow analysis of the reach. The graph demonstrates the reduction in consumptive use resulting from the completion of the Low Flow Conveyance Channel in the early 1950s and the subsequent increase in depletion to about 119,000 acre-feet per year in the late 1970s due to sediment deposition and the loss of the LFCC conveyance capacity. The depletion in the reach has remained relatively constant at about 103,400 acre-feet per year since the LFCC was taken out of service in 1985.

Table 20. Tabulation of Gaging Station Records, San Acacia to San Marcial

Inflow gaging stations:	Period of Record
Rio Grande at San Acacia	1937-1958
Socorro Main Canal North at San Acacia	1937-2000
Rio Grande Conveyance Channel at San Acacia	1959-2000
Rio Grande Floodway at San Acacia	1959-2000
Outflow gaging stations:	
Rio Grande at San Marcial	1937-1951
Rio Grande Conveyance Channel at San Marcial	1952-2000
Rio Grande Floodway at San Marcial	1952-2000

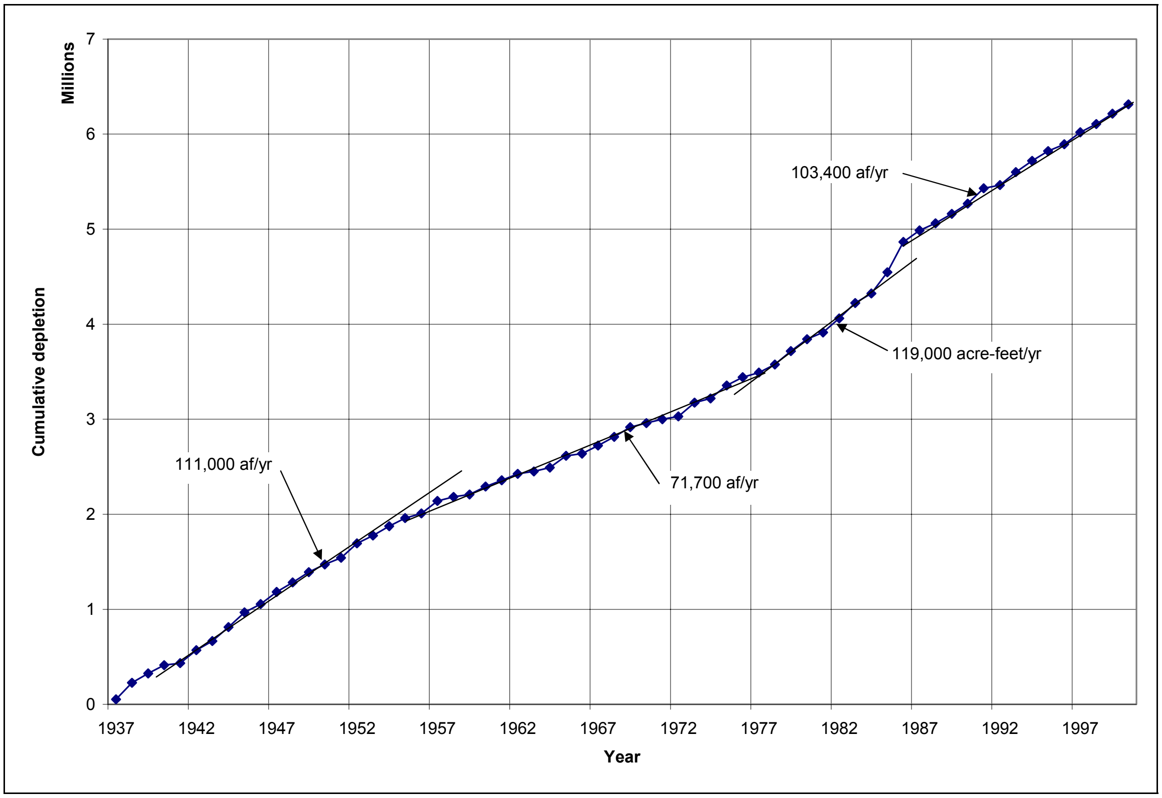


Figure 13. Summary of Gross Depletions, San Acacia to San Marcial

Water Use Infrastructure

Water use infrastructure in the San Acacia to San Marcial reach of the Rio Grande includes surface water diversion structures, wells and drains. Each of these items is briefly discussed in this section.

Surface water diversions

The only diversions from the Rio Grande in the San Acacia to San Marcial reach are located at San Acacia. The Socorro Main Canal North and the LFCC divert water from the Rio Grande at San Acacia Dam. The Socorro Main Canal North delivers irrigation water to lands of the MRGCD Socorro Division and the Bosque del Apache NWR located on the west side of the Rio Grande. The supply of the Socorro Main Canal North is obtained from the Belen Division via the Drain Unit 7 extension as well as by diversion from the Rio Grande. The LFCC, when in operation, diverts water from the river for delivery to Elephant Butte Reservoir. Water is diverted from the LFCC for agricultural use in the Socorro Division, for agricultural and fish and wildlife use at the Bosque del Apache NWR and for return to the river floodway to support low flow silvery minnow habitat. An outfall structure from the LFCC to the Floodway was constructed just north of the Escondido Bridge in 1996 to accommodate sediment transport research flows.

Middle Rio Grande Conservancy District

The irrigated lands of the MRGCD in the Socorro Division are supplied by the Socorro Main Canal North and by diversion from the LFCC at three locations within the Socorro Division. The supply of the Socorro Main Canal at San Acacia is measured, but the downstream diversions from the LFCC are not measured. The MRGCD estimates these LFCC diversions to MRGCD canals to be on the order of 20,000 acre-feet annually. MRGCD also returns an equivalent amount of water back to the LFCC at two locations upstream of Bosque del Apache. The LFCC diversions are located at 1) Escondido, 2) east of Socorro (14.4 miles downstream from the heading), and 3) near the location of the Brown Arroyo discharge to the Floodway. The LFCC diversion near Brown Arroyo also supplies water to the Bosque del Apache NWR via the Socorro Main Canal South.

Table 21 is a tabulation of irrigated acreage for selected crops in the Socorro Division for the 1975-1999 period (URGWOM, 2002). Figure 14 is a plot that relates the water supply of the Socorro Main Canal North at San Acacia with the reported irrigated acreage in the Socorro Division. Note that the per-acre supply of water has generally increased since 1981 and has exceeded 12 acre-feet per acre in recent years. Efforts to maintain low flows for the Rio Grande silvery minnow have caused the MRGCD to increase in Drain Unit 7 and this has resulted in an increased supply of water to the Socorro Division.

Table 21. Tabulation of Selected Crop Acreage in Socorro Division, 1975-1999

Year	Alfalfa	Pasture grass	Hay	Wheat	Corn	Total of irrigated acres	Alfalfa and Pasture as % of Total
1975	6611	1710	178	139	303	10,494	79
1976	5761	1493	520	193	370	10,652	68
1977	6377	1774	389	197	485	10,842	75
1978	6228	1753	650	146	317	10,596	75
1979	5667	1727	426	93	354	9500	78
1980	5305	1967	501	97	315	9658	75
1981	5330	1639	711	88	457	9703	72
1982	5720	1785	581	49	393	9785	77
1983	6079	1840	653	89	405	10,124	78
1984	6020	2047	673	86	400	10,302	78
1985	5801	2241	829	95	403	10,518	76
1986	5153	2389	908	130	496	10,455	72
1987	5122	2240	845	133	476	10,103	73
1988	5171	2262	812	170	512	10,321	72
1989	5675	2569	477	66	481	10,140	81
1990	5165	2516	835	102	104	9744	79
1991	5171	2262	812	170	512	10,321	72
1992	5190	2363	782	165	516	10,355	73
1993	3766	2822	351	364	360	9833	67
1994	5551	2853	480	0	0	9676	87
1995	4206	3153	648	0	0	8949	82
1996	4628	3206	384	117	695	10,216	77
1997	4633	2917	404	164	730	9293	81
1998	4855	2810	259	100	679	9169	84
1999	4806	2809	244	86	693	9100	84

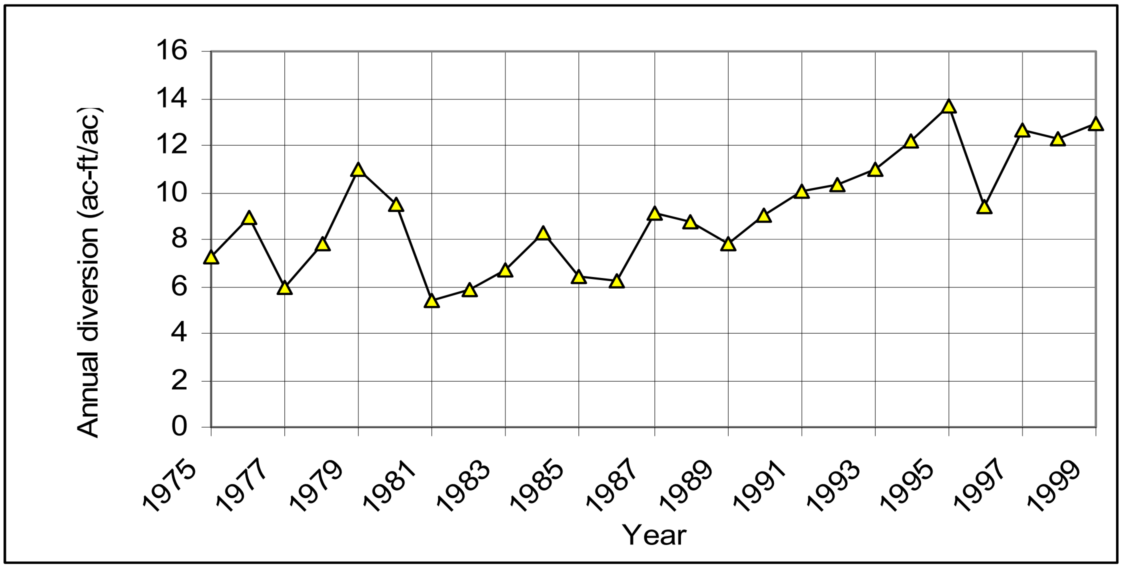


Figure 14. MRGCD Socorro Division Annual Supply per Irrigated Acre
Note: Chart does not include return flows.

Bosque del Apache National Wildlife Refuge

About 12,900 acres of the NWR are located on the Rio Grande floodplain. About 3,800 acres are within the active Rio Grande floodplain between the levee and east side river bluff. Water is diverted to about 8,239 acres of wetlands, farmlands, and riparian forests outside the levee. Crops grown on the refuge include alfalfa, corn, winter wheat, clover and native plants. Water is diverted for use in the Refuge from the LFCC near Brown Arroyo and at the Refuge north boundary and at a location about 4.5 miles upstream of the Refuge south boundary. No diversion data are available for this report.

Water levels in marshes are managed to promote the growth of native marsh plants. Marsh management is rotated (flooding and drying) to allow natural marsh plants to grow. When mature marsh conditions are reached, the cycle is repeated. Wildlife forage grown this way includes smartweed, millets, chufa, bulrush, and sedges.

Rio Grande Low Flow Conveyance Channel

The Low Flow Conveyance Channel was constructed between 1951 and 1959. At the time of its authorization, “the dredging of 20 miles of river channel above the head of Elephant Butte Reservoir,” was recommended (Middle Rio Grande Project, 1950). By the time construction began, Elephant Butte Reservoir had receded to below the ‘narrows’ at the head of the reservoir. From near the south boundary of the Bosque del Apache NWR to the narrows, the river was discontinuous and largely consisted of a broad, diffuse salt cedar wetland. At the time construction began, the Bureau of Reclamation estimated the annual loss of water between San Antonio and the narrows to be about 195,000 acre-feet (Bureau of Reclamation, 1951).

The first phase of the project was the construction of a below grade channel from the narrows to the south end of ‘San Marcial Lake’ where the river channel disappeared. A channel was then excavated from the north end of the ‘lake’ to a river channel heading near the south boundary of the Bosque del Apache NWR. Diversions at this heading began in November 1953. River water was diverted through this heading into San Marcial Lake to allow sediment deposition. Outflow from the grade control structure had smaller sediment concentrations and conveyed to Elephant Butte Reservoir. In 1958, the Conveyance Channel was connected through the sediment deposits in the bed of San Marcial Lake. The ‘lake’ was filled with sediment. At the same time these channels were being built, a 1,000 feet wide floodway was excavated on the east side of the valley paralleling the LFCC. In 1956, the LFCC was extended from its Bosque del Apache terminus to a new heading at San Acacia along with the construction of a parallel 600 foot width cleared river floodway. The completed LFCC was 68 miles long from San Acacia diversion dam to Elephant Butte Reservoir (including a portion within the reservoir). It was designed for a conveyance capacity of 2,000 cfs.

The lower portion of the LFCC near San Marcial began operations in 1954. The completed LFCC was put into service near the end of 1959 and functioned continuously until the late summer of 1974 when loss of conveyance capacity due to sediment deposition required diversion into the river at Tiffany Junction. Over time, sediment deposition in the lower portion of the channel increased to the point to where the delivery of water was impaired. Maintenance work on the LFCC to keep the channel operating continued through the late 1970s and early 1980s. Water diversion into the LFCC at San Acacia was suspended in March 1985 as Elephant Butte Reservoir filled for the first time since 1942. The LCFF has remained out of service since that time, except for sediment transport research diversions in 1997-1999 and 2001, that were returned to the river floodway channel at an outfall constructed about nine miles downstream from San Acacia.

The LFCC continues to operate as a drain to collect water from irrigation return flows, shallow groundwater and water seeping from the river floodway. Generally, during the irrigation season, the LFCC will flow between 200 cfs and 300 cfs from San Acacia and San Marcial.

Drainage System

Drainage of agricultural lands in the reach between San Acacia and San Marcial is accomplished by a series of interior drains that discharge to riverside drains or the Conveyance Channel. North of the narrows at the Escondida Bridge, the San Acacia Drain drains the north end of the Socorro division, followed in downstream order by the Chamisal Drain, the Polvadera Drain and the McAllister Drain. South of the constriction at the Escondida Bridge, the Luis Lopez Drain extends past the City of Socorro and discharges to the riverside drain at San Antonio. The Elmendorf Drain begins south of San Antonio and along with an interior drain, drains Bosque del Apache NWR lands to the south boundary of the Bosque del Apache NWR, where it discharges into the LFCC. The Elmendorf Drain extension drains undeveloped lands south of the Bosque del Apache NWR and discharges to the conveyance Channel at the railroad crossings near Tiffany Junction.

Water Rights

Middle Rio Grande Conservancy District

On November 25, 1930, the MRGCD filed an Application for Permit to Change the Points of Diversion (No. 0620) of 71 old ditches diverting water from the Rio Grande that were located within the boundaries of the District. The Application proposed the abandonment of the 71 old diversion points and the construction of four new permanent diversion dams and two headings. In its Application, the District claimed the right to irrigate a total of 123,267 acres of land, including 80,785 acres for which old irrigation rights are claimed and 42,482 acres of new lands irrigated from water salvaged from the construction of the drainage systems. The Application, that claimed a duty of water of three acre-ft per acre, was approved on January 26, 1931.

The MRGCD claimed that all ditches in existence within the boundaries of the District had perfected water rights and that the MRGCD is the successor in right to divert and distribute water to the lands served by these ditches and that no further water right filings were required.

The MRGCD Official Plan (Burkholder, 1928) included the results of surveys of lands in the Socorro Division. The survey found a total of 5,057 acres of irrigated lands as well as 10,605 acres of non-irrigated lands that included about 10,377 acres of grasses, bosque and "swamp" lands. A total of nine individual ditch headings in the Socorro Division were abandoned and their points of diversion changed to the Socorro Main Canal diversions at San Acacia.

Application No. 1690 was filed by MRGCD on May 27, 1930 for a permit to construct El Vado Dam and related works for the storage and release of water on the Rio Chama as a supplemental supply to the direct diversion for the 123,267 acres claimed under Application No. 0620. Application No. 1690 was considered to be an application for regulation of the flow of water for which old rights were claimed and was not a change in method of use or appropriation. In the 1951 repayment contract between the MRGCD and the United States, the MRGCD conveyed to the United States title to the water rights under permit No. 1690 in 1963; however, the ownership of El Vado Dam and other MRGCD facilities and water rights are the subject of ongoing litigation (*Minnow v. Keyes, 02-2254, 02-2255, 02-2267, U.S. 10th Circuit Court of Appeals*).

Bosque del Apache National Wildlife Refuge

Surface water rights for the Refuge are based on Permit No. 2, granted by the Territorial Engineer on January 4, 1906 to C.H. Elmendorf of the Socorro Company for the appropriation of 97 cfs from the Rio Grande for the purpose of irrigating 6,780 acres of land along the west bank of the Rio Grande within the Bosque del Apache Grant. This permit was transferred to the United States on January 15, 1939. On July 30, 1956, the State Engineer granted License No. 2 to the U.S. Department of the Interior, Fish and Wildlife Service, with a priority date of January 4, 1906, to appropriate 12,417 acre-feet of water per annum from the Rio Grande system for the purpose of protection, production of feed, resting and propagation of wildlife on a total of 4,139 acres within 25 separate tracts on the west side of the Rio Grande in the Bosque del Apache Grant.

On July 10, 1956, the State Engineer issued a Certificate of Construction to the U.S. Department of the Interior, Fish and Wildlife Service, which described the points of diversion for the water supply granted under License No. 2 as:

i. No. 1 diverts from the Socorro Riverside Drain "B" at a point in the SE ¼ NW ¼ of Section 31, T3 S, R1E;

ii. No. 1-b diverts from the Rio Grande, whenever desired for use, at a point in the NE ¼ SE ¼ of Section 31, T3S, R1E.

Points of diversion 1 and 1-b are so designed that 25 cfs may be diverted through either of said diversions into the Socorro Main Canal.

iii. No. 2 diverts from the San Antonio Riverside Drain "B" at a point in the approximate center of the NE ¼ of Section 20, T5S, R1E;

iv. No. 2-b proposed for use when desired from the Rio Grande to the same canal as for No 2.

On May 25, 1983, the State Engineer approved Permit No. 2 for an Alternate Point of Diversion of Surface Waters authorizing the use of the Bureau of Reclamation Conveyance Channel at a point in the SW ¼ SW ¼ Section 16, T5S, R1E. This permit augmented the existing points of diversion of surface water from the Rio Grande in the amount of 12,417 acre-feet of water per annum. The water was designated for protection and propagation of wildlife and growing of feed on 4,139 acres of land with the Bosque del Apache NWR. On February 11, 1999, the State Engineer approved Application No. 2 and RG-1937 et al. ENLGD. This enlarged permit allowed the Fish and Wildlife Service to expand the Refuge water right acreage from 4139 acres to 8239 acres and provided for an additional point of diversion from the LFCC about 4.5 miles upstream of the southern boundary of the Refuge.

In addition to the surface water rights granted to the Fish and Wildlife Service under Permit No. 2, the Service has received permits (RG-1937, RG-1938, RG-1939, and RG-1940) and has drilled 16 wells to divert groundwater to supplement their existing surface water right.

Potential Changes in Depletion Associated with River Restoration Activities

River and floodplain conceptual restoration plans will include an analysis of the potential changes in water depletion or salvage. Changes in consumptive use related to restoration activities in the San Acacia to San Marcial reach could impact the delivery of water to Elephant Butte Reservoir and could affect New Mexico's Compact delivery credit or debit status. Consumptive use impacts of restoration activities should have no impact on water rights above Elephant Butte Dam because no water rights are served by direct diversion from the river below the San Acacia Dam.

The most likely impact from restoration activities in the San Acacia to San Marcial reach would be a change in the evapotranspiration consumptive use. Most of the potential restoration project areas are experiencing significant ET losses associated with riparian vegetation. Net changes in water depletion or salvage would be based upon the "pre-restoration" condition. The reach between San Acacia and San Marcial has experienced significant changes since the signing of the Rio Grande Compact. It was not until after the construction of the LFCC in the 1950s that the Rio Grande channel downstream of the southern end of the Bosque del Apache NWR was confined to the east side of the valley. Over the past forty years, the water depletion downstream of San Antonio has been dependant upon the type and density of vegetation, groundwater levels, and the location of the river channel. It should also be noted that areas on the east side of the river downstream of San Antonio were at one time irrigated. These lands were supplied by the Val Verde Ditch, with water diverted from the Rio Grande about three miles north of the southern boundary of the Bosque del Apache NWR.

Following establishment of a "pre-restoration" or existing condition, the net depletion associated with restoration activities should consider the historic change in depletion. Figure 13 indicates that the gross annual depletion in the San Acacia to San Marcial reach has varied between about 71,000 acre-ft and 119,000 acre-ft. This variation in gross depletion is the result of both natural causes and man's activities. As long as restoration activities result in a gross annual depletion within this range, the net change in depletion or salvage would be within the historical depletion levels experienced in this reach since the Rio Grande Compact of 1938 was signed.

Restoration activities may also result in the increase in groundwater levels in the project area. Higher groundwater levels may increase losses due to increased evaporation or evapotranspiration. Groundwater that is not lost to evaporation or evapotranspiration is considered an increase in groundwater storage. It is not a depletion. This increase in groundwater storage may result in the storage of water that otherwise may have been delivered to Elephant Butte Reservoir, potentially affecting New Mexico's Compact delivery status. The use of groundwater aquifers for the storage of surface water would not invoke or be subject to the storage restrictions on reservoirs constructed after 1929 as provided for in Articles VI and VII of the Compact. The recharge of aquifers through percolation of surface water or the construction of wells for injection of surface water does not mean that these aquifers become storage reservoirs as contemplated by the Compact.

Depending upon the nature of the proposed restoration activity, a water right permit may not be required. If the restoration activity does not involve the diversion of water through man-made works, the jurisdiction of the State Engineer is not invoked. Under this scenario, a proposed restoration activity would not be subject to the requirements of the rules and regulations of the State Engineer involving application, public notice and administrative hearing procedures. It is presumed that the State Engineer as member of the Interstate Stream Commission would be aware of the any potential impacts on water depletion as a result of restoration activities.

The previous discussion on depletions and water rights related to restoration projects has not been formally reviewed by the Office of the State Engineer (OSE) or the New Mexico Interstate Stream Commission (ISC). The assumptions and conclusions in this section may be revised after review comments by OSE or ISC are submitted.

Groundwater/Surface Water Interaction

Groundwater levels and flow paths are important issues in the proposed restoration project. The following discussion includes the historic groundwater levels and overview of current conditions. Raising groundwater levels in the San Acacia to San Marcial reach can enhance river low flow conditions; however, increased groundwater levels may affect agricultural land drainage. The groundwater table data base along the river floodplain is very limited. The following discussion includes an overview of groundwater geology, a brief history of regional groundwater changes, a qualitative assessment of the hydrologic interaction between groundwater and surface water, and potential for reducing river seepage by raising groundwater levels.

Groundwater Geology

The most thorough geological groundwater report detailing the geology and groundwater movement in the Socorro Basin is Scott Anderholm's, "Hydrogeology of the Socorro and La Jencia Basins, Socorro County New Mexico" (1987). Anderholm (1987) indicates that " (t)he principal aquifer system in the Socorro and La Jencia Basins is composed of the Quaternary and Tertiary Santa Fe Group (Poposota and Sierra Ladrones Formations) and Quaternary Deposits." Geological controls confine the shallow alluvial fill (Quaternary deposits) and underlying Sierra Ladrones Formation. A defined boundary between the shallow alluvial fill and the Sierra Ladrones formation is difficult to distinguish since the lithology of the fluvial sediments is very close to that of the underlying fluvial facies of the Sierra Ladrones formation (Anderholm, 1987). Beneath the Sierra Lodrones formation is the Poposota confining bed. The upper portion is composed of playa facies and is believed to be of low conductivity because of the fine sediment sizes found in this formation (Anderholm, 1987).

Figure H.1 (Appendix H) illustrates the confining groups surrounding the principal aquifer system interacting with the Rio Grande (taken from Anderholm, 1987 as modified from Chapin, et al. 1978). As shown in the figure, the alluvial fills to the west are confined by the uplift of the Mesozoic-Paleozoic rocks caused by the uplift of the Lemitar Mountains. To the east, the alluvial fills are confined by Precambrian rocks (Anderholm, 1987). This indicates that groundwater in the shallow alluvial fill in the Socorro basin is analogous to water contained in a 'bathtub' with confining units and geologic controls on both sides. There is a stratification of soil layers in the shallow alluvial fill that is 3-dimenional in nature. Discontinuous layers of silt and clay separate the shallow alluvial aquifer from the deeper Santa Fe Group aquifer (Crawford, et al. 1993). These layers are known to be as thick as 15 ft in the vicinity of the Albuquerque Basin's Floodplain (Thorn et al. 1993).

Mountain front recharge is a significant component to the groundwater system in the San Acacia to San Marcial reach. Recharge from the east is caused by the infiltration of runoff from rainfall (Anderholm, 1987). Estimates by Jack Dewey as described by Glen Hearne, quantify this recharge amount to the Socorro Basin at 1,600 acre-ft per year

(Anderholm, 1987). Anderholm concludes that the water budget in the basin indicates that groundwater inflow is about 53,000 acre-ft greater than groundwater outflow, assuming no storage in the system (1987).

Change in the Groundwater Levels

Groundwater levels in the entire Middle Rio Grande Valley, including the San Acacia to San Marcial reach have declined considerably in the past 100 to 200 years. Historical accounts show that the valley was water logged from over irrigation and poor irrigation practices at the turn of the 19th to 20th century. In fact, as early as 1820, farmers in the Middle Rio Grande Valley noted the formation of cienegas and esteros on the floodplain from excess irrigation (Wozniak, 1987). Total irrigated acreage in the Middle Rio Grande Valley dropped from 124,800 acres to 45,000 acres from waterlogging and alkali conditions (Berry and Lewis, 1997). The primary reasons originally cited by the Berry and Lewis (1997) study included:

> "1) Increased use upstream caused less water to flow into the middle Rio Grande, thus increasing the silt and raising the water stream elevation.
>
> 2) The unregulated construction of ditches and use of water since colonial times effected raising the water table of the agricultural lands along the valley. (1990)"

Crawford et al. (1993) describes the effect of the aggrading channel: "The riverbed was continuing to rise in response to increased sediment deposition in the river, thereby draining to the lower terrain; water was being distributed throughout the valley for irrigated agriculture, enhancing groundwater recharge; and irrigation return flows could not drain into the elevated river channel." In 1925, the Middle Rio Grande Conservancy District (MRGCD) was formed and included approximately 277,760 acres (Scurlock, 1988). Berry and Lewis site the MRGCD Official Plan (1928) indicating that bank stabilization and the construction of bridges, and railroads levees that resulted river channelization consequently raised the water level and increased percolation into the already waterlogged valley (1990). The MRCCD Plan (1928) stated that all over the valley roughly 72% of farmland had a water table within 0.0 to 4.0 ft of the land surface, making the land nearly impossible to farm (Berry and Lewis, 1990). Average depth to the water table was 2.37 ft (Bloodgood, 1930).

MRGCD's mission over the next 50 years besides agricultural water delivery was to mitigate flooding by construction of dams, levees, and drainage canals (Scurlock, 1988). The chief engineer for MRGCD wanted a "consolidated ditch system that would control water logging" and subsequently, by 1935, MRGCD constructed 340 miles of riverside drains (Berry and Lewis, 1990). In addition to alleviating waterlogged agricultural lands, the drains served to augment the water supply with reclaimed water to MRGCD farmland (Berry and Lewis, 1990).

Groundwater levels in the shallow alluvial fill throughout the Rio Grande Valley have significantly declined over the past century. Both the drainage infrastructure and increased pumping for domestic water supply and agriculture contributed to the decline in the groundwater levels. The MRGCD's rigid irrigation and drainage infrastructure system lowered the water table by 5 ft or more in 70% of the valley (Shah, 1991). Theis (1938) conducted a study in 1936 that indicated that after completion of the drains, groundwater levels dropped by approximately 3 ft. Following the cessation of operation in 1985, the Low Flow Conveyance Channel began to function as a deep drain for the shallow alluvial fill (Ong et al. 1991). It is also noted by Crawford et al. (1993) that groundwater extraction increased significantly during the past century. Individual domestic wells, the city of Albuquerque, and Kirtland Air Force base (to a lesser extent) were cited as the primary extractors of groundwater in the Albuquerque area. (Crawford et al. 1993). In some areas of the Rio Grande Valley pumping has been sufficient to reverse the groundwater gradient away from the river (Crawford et al. 1993). In the north Socorro area, groundwater levels are 0.0 to 8.0 ft below the ground surface (U.S. Bureau of Reclamation, 1977) and 4.0 to 11.0 ft below the ground surface near Bosque del Apache NWR (Crawford et al. 1993). See also Figures 11 and 12 in the previous section. This is a significant change from 0.0 to 4.0 ft range of depth to groundwater before MRGCD implemented the drainage system.

Hydrologic Connection Between Surface Water and Groundwater

The hydrologic connection between surface water and shallow alluvial fill groundwater in the Rio Grande Valley is well established (Crawford, et al., 1993). The Rio Grande contributes more water to the groundwater system than any other source (Bullard and Wells, 1992). Crawford et al. (1993) state that, "(g)roundwater flows from north to south through the through the Middle Rio Grande Valley along the axis of the connected ground-water basins." Inside these interconnected basins, groundwater gradients are positive towards the river from adjacent mountains and plateaus (U.S. Bureau of Reclamation, 1977). Well data supports this regional observation (for miles away from the river on either side of the valley); however, within a mile or so of the river the Rio Grande acts as a groundwater recharge source rather than a drain.

Groundwater movement in the San Acacia to San Marcial reach and its strong connection with the river requires a brief discussion of the two surface water channels. Moving south from San Acacia, river surface water infiltrates into the groundwater system and then moves from the perched river to the floodplain areas to the east and west of the river. Groundwater flowing to the west is intercepted by the Low Flow Conveyance Channel. The perched river (aggraded channel) creates steep positive groundwater gradients to the LFCC drain. The gradients are clearly seen in Figures H.2–H.4 taken from groundwater/surface water interaction research and monitoring conducted by the New Mexico Interstate Commission and New Mexico Tech's Earth and Environmental Science Department (2001 and 2002). The Low Flow Conveyance Channel has the lowest invert and subsequently acts to collect and drain groundwater from the perched river as well as from agricultural lands to the west.

The river is the major control on the groundwater system (Logan, 1991). This control is evident when comparing depth to groundwater with river discharge. Figures H.5–H.7 show this correlation in Bosque Del Apache NWR at a University of New Mexico monitoring well. The well is located 1000 ft from the river and the depth to groundwater is plotted with the San Marcial Gage daily average flow (Coonrod and Schmidt, 2002). Groundwater levels rising up to 6 ft in response to flooding 600 ft from the monitoring sites on the Bosque del Apache National Wildlife Refuge were observed (Crawford, et. al., 1993). This demonstrates the high connectivity between surface water flows and shallow alluvial fill groundwater levels.

Figure 15 indicates that groundwater levels in the vicinity of the river at the northern boundary of the Bosque del Apache have risen considerably from the 1950's (note also the large gradients at present from the river to the west in this location). Three factors are attributable to this local surcharge; during LFCC operation in the 1960s, there was less water in the river with LFCC diversion; the Bosque del Apache NWR irrigates and ponds water to support the riparian ecosystem on the refuge and secondly, the LFCC operations ceased in 1985 and subsequently the river water infiltrates to groundwater at higher rates. This is evident when looking at historical baseflows (seepage gains) in the LFCC. Pre-1985 when the LFCC was not conveying large discharges, the average baseflow in the LFCC was 130 cfs. Following the cessation of LFCC operation in 1985, the baseflow average has been 310 cfs. More than twice the volume of water is now seeping out of the river into the LFCC compared to what had historically had been lost from the river during the LFCC's operation. It is also interesting to note that the LFCC's terminus no longer extends to Elephant Butte Reservoir. Upstream of the reservoir delta, the LFCC has filled with sediment and lost its conveyance capacity. The water in the LFCC ultimately flows out of the channel, ponds and passes unconfined through a densely vegetated part of the delta before finally making it to the reservoir. It is plausible that the river channel could convey the LFCC drainage water to Elephant Butte more efficiently than the Low Flow Conveyance Channel system. It should be noted that the LFCC flooded terminus area is considered to be significant habitat for the endangered Southwestern Willow Flycatcher.

Figure 15 also illustrates the magnitude of the gradient from the river to the LFCC at the northern boundary of the BDAWR. If the channel were moved 1500 ft to 2000 ft to the east away from the LFCC as part of the restoration plan in some reaches, the groundwater gradient would be reduced by more than an order of magnitude. The potential decrease in the seepage loss from the river to the LFCC would help maintain river low flows during dry periods.

Potential for Reducing River Seepage Losses

Based on the available groundwater information in the San Acacia to San Marcial Reach, the following conclusions can be drawn:

- The Socorro Basin acts like a bathtub with the shallow alluvial fill confining groundwater stored in it.

- Groundwater levels in the Middle Rio Grande Valley and in the Socorro Basin have decreased over the past 100-200 years because of the implementation of the Middle Rio Grande Conservancy District drainage system.

- The Rio Grande and the LFCC are hydrologically connected by steep groundwater gradients.

- River aggradation and the cessation of LFCC operation have increased the seepage losses to the LFCC which has negatively effected the river low flow.

- There is a disconnection of the LFCC with the Elephant Butte Reservoir resulting in a loss of LFCC drainage water in the ponded delta areas.

There is no simple method to reduce seepage losses from the river to the LFCC. Three possible methods for decreasing seepage losses and increasing instream Rio Grande low flows in the San Acacia to San Marcial Reach are:

- Relocating the river to the east wherever possible to lengthen the groundwater path (decreasing the gradient) between the river and the LFCC.

- Installing groundwater barriers such as a clay key trench or a metal sheet pile cutoff wall into the spoil-bank levee to reduce the seepage rates from the river to the LFCC.

- Implementing restoration measures that promote fine sediment deposition in overbank areas between the river and LFCC to naturally seal floodplain surface to infiltration. This occurs naturally and enhancing overbank flooding will promote this sealing process.

Relocating the river may be construed as a restoration activity, but constructing groundwater barriers is probably infeasible. While these measures appear to be extreme, unless the LFCC is moved or reconstructed, there is no other way to reduce the groundwater gradient to the LFCC in order to reduce the seepage losses. If river relocation is considered as an alternative in some reaches, riparian areas between the river and the LFCC levee may function better as terraces with deeper groundwater. In this case, promoting terrace native vegetation would be advantageous.

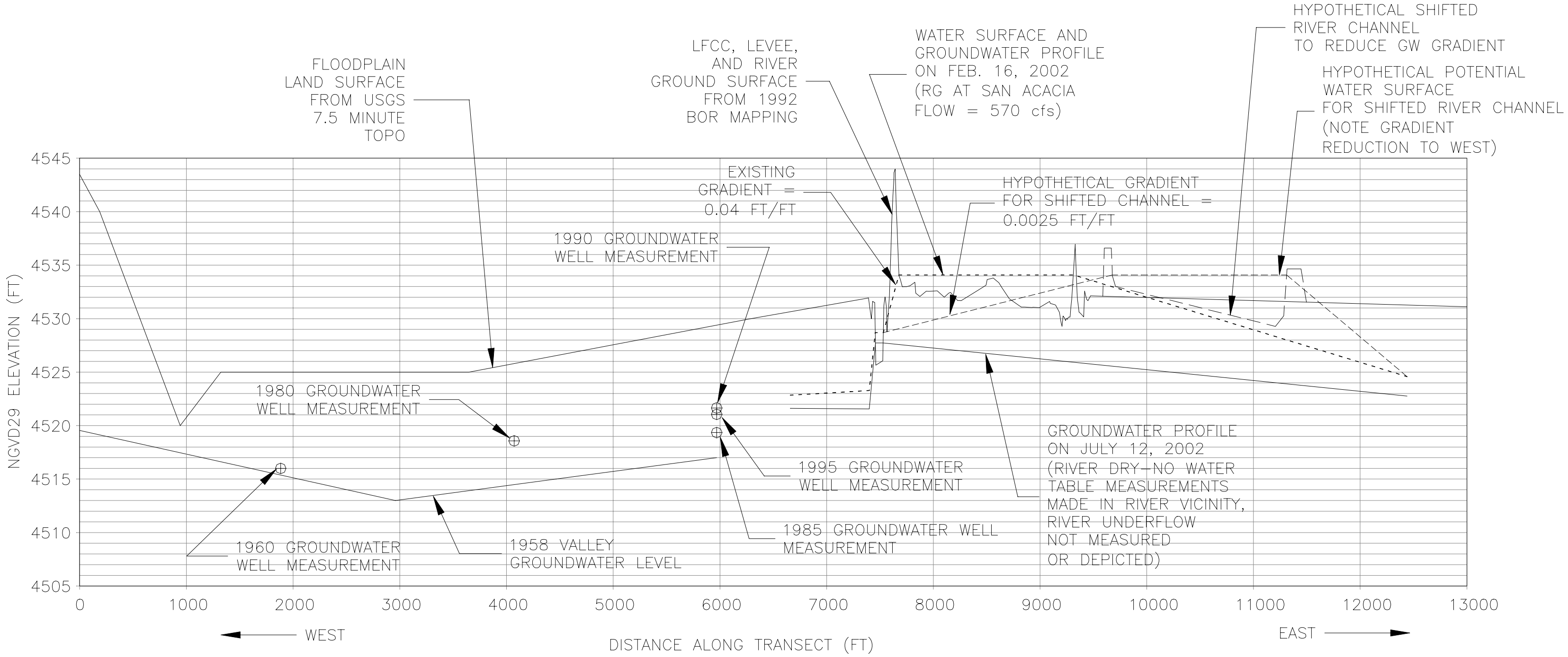
The FLO-2D model computes infiltration volumes from both the river and the overbank flooded areas. It will be possible to test the various project scenarios to determine the change in the volume of water infiltrated to the groundwater system. If an additional 3,000 acre-ft of water can be stored in the groundwater system along San Acacia to San Marcial reach that will return to the river during low flow conditions, a minimum of 25 cfs can be sustained in the river channel for two months. Groundwater storage levels will have to be raised by more than 3,000 acre-ft in order to make 3,000 acre-ft available from bank storage and the groundwater table during low flow conditions.

Current Groundwater Research and Monitoring

There are several investigations involving groundwater in the San Acacia to San Marcial reach. Research at New Mexico Institute of Mining and Technology (New Mexico Tech) under the auspices of R.S. Bowman is attempting to quantify interconnections between the river and shallow groundwater in this reach extending all the way to Elephant Butte Reservoir. A network of 30 monitoring wells has been established in transects across the Rio Grande and the parallel LFCC. Almost all the wells are located on the west side of the LFCC. The data collection will include monthly monitoring of well water elevations, water surface in the Rio Grande, and water surfaces in the LFCC and the major drainage canals. This project began in October 2001 and will continue through 2003. The project indicates that there may be a deep groundwater contribution to the river/shallow groundwater system at the upper (near San Acacia) and lower (near San Marcial) ends of the reach.

The New Mexico Interstate Stream Commission is developing a groundwater and surface water exchange model for the Middle Rio Grande basin. The data being collected by New Mexico Tech will be used to calibrate the model. It is anticipated that the model will assist in determining groundwater storage variation with surface flows.

FIGURE 15. GROUNDWATER LEVELS AND SURFACE WATER INTERACTION NEAR THE RIO GRANDE AT THE NORTHERN BOUNDARY OF THE BOSQUE DEL APACHE WILDLIFE REFUGE



–VALLEY GROUNDWATER MEASUREMENTS AND VALLEY GROUND SURFACE COURTESY OF THE U.S. GEOLOGICAL SURVEY

–GROUNDWATER PROFILES AND WATER SURFACE MEASUREMENTS COURTESY OF NEW MEXICO INSTITUTE OF MINING AND TECHNOLOGY "BOWMAN/RIO GRANDE PROJECT" AND THE NEW MEXICO INTERSTATE STREAM COMMISSION

–RIVER AND LOW FLOW DETAILED GROUND SURFACE COURTESY OF THE U.S. BUREAU OF RECLAMATION

Criteria for Evaluating Restoration Components

Restoration Goals and Objectives

Restoration goals and objectives evolve from the restoration vision statement and from the focus to create riparian restoration opportunities by establishing favorable hydrogeomorphic conditions in the San Acacia – San Marcial reach. One vision statement proposed by the Save Our Bosque Task Force:

"A riparian ecosystem that functions as natural as possible within the confines of 21st Century infrastructure and political limitations while respecting the traditional customs and cultures of the citizens of Socorro County."

The restoration opportunities may take the form of providing a greater range of flow regimes, creating a more dynamic channel, removing constraints on channel processes, expanding the active floodplain, increasing channel-floodplain hydrologic connectivity, physical reformation of the channel geometry and enhancement of the native riparian ecosystem. This restoration vision can be defined by two primary goals:

- Restore natural river function.
- Enhance riparian biological diversity.

To achieve these goals, a number of restoration objectives have been outlined. The proposed restoration objectives are:

Goal 1: Restore natural river function.

Objectives:

1) Enhance channel dynamics.
2) Promote overbank flooding.
3) Increase groundwater storage.
4) Expand marshes, wet meadows and flooded bottomlands.
5) Create water salvage.

Goal 2: Enhance riparian biological diversity.

Objectives:

1) Protect high quality habitats.
2) Expand native riparian habitats.
3) Improve aquatic habitats.
4) Promote cottonwood/willow regeneration.
5) Support endangered species.

Restoration Tools, Methods and Techniques

To accomplish these objectives, a number of techniques and methods have been researched including both resource management and mechanical restoration methods. The selection of various restoration techniques and methods for the San Acacia to San Marcial reach will recognize which tools are compatible with existing geomorphic trends, which tools can be applied to overcome constraints and obstacles to restoration and what will be cost effective. Prioritizing river and riparian restoration needs and proposing the application of those tools will be the basis of Phase III in selecting the restoration plan project components. A list of the basic restoration techniques along with a brief description is presented below.

Channel Activities

1. Mow and disc sand bar vegetation
2. Plow and rake islands
3. Remove bank vegetation (deformable banklines)
4. Destabilize and lower banks (terrace lowering)
5. Widen channels (bank destabilization)
6. Create high flow side channels
7. Cut pilot channels (initiate channel avulsions)
8. Realign channel
9. Locate and placement of large woody debris
10. Reconnect oxbow and old channels
11. Implement river training facilities such as dikes/spurs/rock weirs
12. Raise channel bed (grade restoration facilities)
13. Shape curves and banks
14. Remove sediment plugs
15. Increase sediment loading

Floodplain Activities

1. Remove exotic vegetation (selective and clear cut)
2. Prepare seedbed areas, plant and seed native vegetation
3. Create wetlands and marshes
4. Develop variable floodplain topography
5. Lower flood terraces
6. Enhance groundwater storage and interaction
7. Mechanically remove woody debris for fuel reduction
8. Remove jetty jacks
9. Manage livestock grazing
10. Create larger floodplain corridor - stabilize levees
11. Eliminate structural limitations on flooding
12. Manage future development

Water Management Activities

1. Enhance spring flushing flows
2. Sustain fall maintenance flows
3. Return LFCC low flows to the channel
4. Increase frequency/duration of flooding
5. Time high flow with seed dispersal
6. Increase groundwater storage (focus on east side)
7. Establish management tools to work within climatic variation of water availability

Channel Activities

1. Mow and disc sand bar vegetation – Vegetation growing on river sand bars can be cut with mowers up to a height of about 4 ft. This would constitute a vegetation age group of 2 years or less. Reworking the sand bars would be accomplished with an appropriate tractor such as a Challenger operating a mower and disc. The disc should be large enough to rework the vegetation root system requiring disc blades of 18 to 24 inches in diameter. Annual occurrence of appropriate spring flushing flows and fall maintenance flows will minimize the required reworking of the sand bars.

Photo 2. Whooping Crane Trust Tractor Used on the Platte River, Nebraska

Photo 3. Mower for the Trust Tractor

Photo 4. Platte River, Nebraska Recently Mowed and Disked

The high percent of fine sediment depositions in the Rio Grande may present a challenge in reworking the sand bars. Mowing and disking should be accomplished with tandem vehicles for support when one vehicle is mired.

2. Plow and rake islands – When vegetation becomes established on a sand bar after several years of growth, sediment deposition will ensue during high flows and the sand bar will vertically accrete into a permanent island feature. If the woody vegetation trunk diameter is still small, the plants can be removed by plowing or root plowing. A root plow is a large blade that is pulled by a tractor through the ground beneath the surface to destroy underground rootstocks. Root plowing is ordinarily used to eliminate non-native woody species such as salt cedar and Russian olive trees. Vegetation debris can then be raked, piled and burned within the cleared area or it removed to an offsite location.

3. Remove bank vegetation (deformable banklines) – Creating a more active, wider channel is one of the restoration objectives. Bank erosion and channel migration are features of a dynamic river system. Removal of bank vegetation and root plowing a fifty foot strip along a bank will stimulate bank erosion and channel widening. Once the bank vegetation has been removed, the banks can be reworked with a bulldozer to activate bank erosion.

4. Destabilize and lower banks (terrace lowering) – This restoration activity is an extension of the deformable bankline technique and would expand the active floodplain while providing lower terraces along the river's banks for the establishment of habitat. It would entail excavation of large areas of the floodplain terrace. The lowered terraces would be inundated more frequently providing refuge for aquatic organisms, restoration of native riparian vegetation and re-establishment of a river channel/floodplain hydrologic connectivity. Proposed restoration activity, including terraces and jetty jack removal, would required analysis to ensure that flood control facilities were not compromised.

5. Widen channels (bank destabilization) – Taking the previous two methods one step further, the objective would be to have an immediate wider channel. In this case, a new prescribe channel width would be mechanically imposed by vegetation clearing, root plowing, jetty jack removal and bank lowering. In areas where the river is constricted channel widening would be the primary restoration activity.

6. Create high flow side channels – One method to enhance the hydrologic connectivity of the river and floodplain is the creation of overbank side channels that would flood at high flows. The purpose of the side channels would be to get the water out of the channel and into backwater or wetland areas at bankfull discharge. The channels would be limited in length and would only flow as the river stage approached bankfull discharge. The positive slope away from the channel would serve to deliver the flow to the target areas. The backwater habitat would provide slower velocity areas for aquatic and terrestrial species and increase the potential for native species regeneration. The construction procedure would involve pilot channel excavation through the bank, inner channel shaping and floodplain vegetation removal. Drainage of backwater or wetlands areas would be designed. Maintaining the side channel connectivity during recessional limb sediment deposition would have to be analyzed.

7. Cut pilot channels (initiate channel avulsions) – Pilot channels are small channels excavated to relocate the river. The river reforms the pilot channel geometry quickly when flow is introduced. The purpose of the pilot channel is to create a self-forming channel in a prescribed location. This would minimize the disturbance to the floodplain required to relocate the river channel. It would also minimize the removal of spoils associated with excavating the entire channel. Channel avulsion is an important process for keeping the channel and floodplain fully integrated. Historically the Rio Grande migrated across the floodplain through channel avulsions. Pilot channels would be used to mimic this process. Pilot channels could also be used to re-occupy abandoned channels or oxbows and move the river further to the east away from the Low Flow Conveyance Channel.

8. Realign channels – Channel realignment is used to accomplish various objectives. The channel may be relocated to re-occupy old channels or oxbow bends or to preserve existing riverside facilities that may be threatened by erosion. Realignment along a new route might promote new habitat development with flooded backwaters or wetlands or it might be used to mimic channel avulsion or migration. Moving the river away from the LFCC to the east may help salvage water. Realignment may also serve to increase sinuosity and increase width to depth ratio. A pilot channel combined with partial blockage of the existing channel could be used to implement channel realignment. Channel realignment may incorporate deformable banks to establish the new channel pattern. Aquatic and riparian habitat enhancement would accompany any channel realignment.

9. Locate and place large woody debris – Large woody debris (cottonwood trunks) can be placed at locations within the river channel or along riverbanks to provide aquatic habitat or work in conjunction with other channel restoration techniques. Large woody debris can be used to enhance planform stability and promote river bar/island formation with sediment deposition. Woody debris snags could be placed individually or in groupings. On the outside of bends, woody debris may enhance bank erosion. Over the long term, large woody debris could be made a more important part of the river environment with the introduction of more beavers.

10. Reconnect oxbow and old channels – Oxbows, old meander bends and old channel remnants can be reconnected to the river using high flow side channels, pilot channels or through river realignment. These historic floodplain features are important backwater, wetlands or marsh areas for wildlife habitat and native vegetation regeneration. If reconnected as part of the existing channel system, these areas can be designed to provide silvery minnow slackwater habitat. These features will lengthen the channel, increase sinuosity and create a more dynamic river with increased habitat diversity. There are several old oxbows on the river floodplain between Highway 380 Bridge and San Marcial that can be considered in the conceptual restoration plan.

11. Implement river training facilities such as dikes/spurs/rock weirs – While these training features are not natural for this reach, they could serve to support other important channel restoration activities such as pilot channels or channel realignment. A rock spur or dike could be used to constrict the river channel or divert water from the existing channel. River training structures may also be used for influencing flow alignment, bank stabilization and controlling overbank flow. River training facilities should only be considered when river restoration activities alone are inadequate for the protection of critical riverside facilities or the protection of in-stream structures.

12. Raise the channel bed (grade restoration facilities) – Gradient restoration facilities (GRFs) are low head grade control structures with fish passage aprons. These structures are utilized to halt channel degradation, reduce upstream velocities and increase water surface elevations. The only use for a GRF in the San Acacia – San Marcial reach would be to raise the water surface in the Escondida subreach where the river channel is incised. A GRF will store a minor amount of sediment upstream of the structure until an equilibrium slope is attained, but the primary function would be to increase groundwater levels in the surrounding floodplain to support native riparian vegetation and salt grass meadows. The GRF might also stabilize the location of other channel restoration components such as high flow side channels. The channel incision in most of the Escondida subreach is too severe for GRF to be used to promote overbank flooding. GRF fish passage would be designed with the most current silvery minnow criteria available perhaps to mimic natural riffles in the upstream Rio Grande.

13. Shape curves and banks – Deformable bank lines will be an important component of the conceptual restoration plan. It is anticipated that some reworking of the river banks will occur in all three subreaches. Channel bank curve alignments will be determined by right-of-way considerations and hydraulic parameters. Initiating bank erosion will be an effective method to create a more dynamic channel so that detailed bank shaping would not be necessary in many locations.

14. Remove sediment plugs – Sediment plugs have been historically reported in the San Marcial area and became more frequent as the backwater effects of Elephant Butte Reservoir became pronounced. Sediment plugs can also form in the river channel at the mouths of tributary arroyos. In most instances, sediment plugs will increase the channel dynamics by reducing channel capacity and forcing more water overbank onto the floodplain. In extreme cases, sediment plugs could result in channel avulsion. These are desirable river functions. In the case where a large arroyo plug might deflect flows into riverside facilities, it might be necessary to consider arroyo sediment plug removal or grading, but most sediment plugs should remain in place. Arroyo plugs are usually excavated or graded by dozers or scrapers. Spoil material may be destabilized or relocated within the river channel to be naturally redistributed by the river thus providing a sediment source to enrich the sediment load.

15. Increase sediment loading – The San Acacia to San Marcial reach has a sediment deficit that over the past 30 years has resulted in channel incision in the Escondida subreach. The opportunities for naturally increasing the sediment loading to this reach are limited especially in view of the various soil conservation programs in the Rio Salado and Rio Puerco watersheds. It may be possible to increase the sediment load slightly at San Acacia by improving the sediment exclusion facilities diverting water into the Socorro Main Canal and the Low Flow Conveyance Canal. Reconnecting arroyos to the river where vegetation has obliterated the arroyo channel across the floodplain could enhance the arroyo sediment supply. The other possible option is that sand could be mechanically introduced into the river. Excessive sand generated from restoration activities that involve major excavation of the floodplain or river bank should be added to the river channel. Any upstream restoration practice or water resource management activity that could increase sediment loading should be considered including sediment passage through upstream reservoirs.

Floodplain Activities

1. Remove exotic vegetation (selective and clear cut) – Mechanical clearing of exotic vegetation (primarily salt cedar and Russian olive) adjacent to the river channel is designed to promote native species regeneration and increase habitat diversity. Replacing exotic vegetation with native cottonwoods and willows has the benefit of decreasing evapotranspiration. Removing dense exotic floodplain vegetation will enhance overbank flooding and improve the opportunities for river bank erosion. Salt cedar removal practices have been successfully implemented at the Bosque del Apache National Wildlife Refuge. Selective removal of exotic vegetation could be used to create fire breaks and create buffer zones along agricultural areas.

2. Plant and seed native vegetation – Restoration of native riparian vegetation is designed to create a mosaic of vegetation communities including salt grass, shrub, and bosque communities. Revegetation can occur through planting or re-establishing seedling regeneration through hydrologic connectivity. Potential planting methods include planting individual pole and willow whips, willow bundles/mats or other planting techniques. Vegetative plantings may also be an important component in re-establishing lower floodplain terraces.

3. Create wetlands and marshes – Wetlands and marshes were an integral part of the historical Rio Grande floodplain. The Phase I report documents the extent of wetlands, flood bottomlands and cienegas throughout the Middle Rio Grande Valley. Wetlands and marshes can be created inside the levee system. During most years a series of old oxbows and channels along the east side of the river south of the Highway 380 Bridge contain water. By increasing the connectivity with the river through high flow side channels and inducing more frequent flooding, wetlands and marshes can be perennial and become important components of increased floodplain habitat diversity. Selective clearing of woody debris may enhance the wetland habitat. Drainage should be considered for some wetland areas. Potential wetland and marsh areas are topographically conducive to flooding under existing conditions.

4. Develop variable floodplain topography – When removing exotic vegetation, lowering the floodplain terrace or otherwise reconstructing the floodplain, topographic variability is suggested to create habitat diversity during flooding. This will help generate a mosaic of native riparian vegetation. It may also help with drainage.

5. Create flooded bottomlands – Flooded bottomlands represent a different form of riparian floodplain habitat. At high flow, a flow path extends through the flooded bottomlands and becomes a part of the river channel system. Flooded bottomlands can provide a nutrient rich spawning area, nursery or adult habitat for a variety of aquatic species. Flooded bottomlands were an extensive part of the historical Rio Grande Valley river system. New flooded bottomlands can be created with high flow overbank side channels or pilot channels that will supply water to old channels or oxbows.

6. Enhance groundwater storage and interaction – The Low Flow Conveyance Channel and the system of drains has lowered the groundwater levels in the reach from San Acacia to San Marcial. The lower groundwater table adversely affects low flows in the river channel and the perennial nature of wetlands and marshes on the floodplain. Overbank flooding will increase the surface water – groundwater exchange and promote nutrient availability for bosque vegetation. There is potential for increasing the channel low flows by raising the water table. In addition to flooding, it may be possible to dam drains and ditches to generate higher ground water levels. Water from the Low Flow Conveyance Channel is being returned to the river, but in many locations the river is so close to the LFCC that the water quickly seeps back into the LFCC. Relocating the river eastward may greatly enhance groundwater levels east of the present river channel.

7. Mechanically remove woody debris – This activity would involve the removal of deadfall and/or non-native species vegetation beneath a native species vegetation canopy. Woody debris removal would reduce fire hazard while improving the bosque habitat and its appearance. It is important to balance low fuel loads to prevent high intensity fires with having a desirable quantity of dead snags for cavity nesting.

8. Remove jetty jacks – Removal of jetty jacks from floodplain areas should be considered where they are no longer necessary, where they create obstructions on the floodplain, or where the jacks pose a hazard in the river channel. For the most part, the jetty jack lines are no longer affecting the habitat or the river channel morphology. But the jacks pose a serious obstruction to restoration activities and will have to be removed in concert with floodplain vegetation removal. The jetty fields obstruct access to the river channel in a number of locations.

9. Manage livestock grazing – Livestock grazing has removed some of the undergrowth in mature cottonwood stands through the San Acacia – San Marcial reach resulting in low biotic diversity. Livestock have eaten back cottonwood and willow seedlings along the river. This has inhibited native vegetation regeneration. Some areas have also been subject to excess use resulting in overbank side channels along rangelines. If managed properly, livestock grazing can increase the diversity of bosque habitats by developing a series of successional vegetative stages.

10. Create a larger floodplain corridor by stabilizing levees – Enhancing river migration could result in the river impinging on the levee system. Levee stability may enable large portions of the floodplain to be conducive to river migration. Destabilizing banks in certain reaches may require attention to this detail. However, the focus should be realigning the river to the east away from both the LFCC and the levee.

11. Eliminate structural limitations on flooding – There are only a few structures that directly affect the potential for overbank flooding. These include the San Marcial Railroad Bridge and several buildings on the floodplain. At the present time, the San Marcial Bridge is the biggest limitation to increasing flood discharges in the San Acacia to San Marcial reach. This obstacle may be eliminated by plans that will relocate or raise the bridge. The few structures that limit flooding on the east side of the river can either be purchased, moved, raised or bermed. Options to remove these obstacles to enhance flood potential will be addressed in Phase III.

12. Manage future development – To avoid limitations on future water management and potential flooding, it is recommended that future development be limited to areas outside the 100-year floodplain. One way to accomplish this is to delineate the 100-year floodplain, participate in FEMA Flood Insurance Program and create zoning that incorporates the FEMA 100-year floodplain.

Water Management Activities

1. Enhance spring flushing flows – Managing water resources to restore or mimic the natural historical hydrograph is critical to the entire conceptual restoration plan. Providing spring high flows in the river to mimic the historic hydrograph in terms of timing, frequency, duration and to the extent possible discharge, will improve the abundance and diversity of aquatic and riparian species. This was the first recommendation of the Bosque Biological Management Plan (Crawford, et al., 1993).

2. Sustain fall maintenance flows – Moderate flows of 500 to 1,500 cfs in the late fall, after irrigation season, have several beneficial effects. Through lateral erosion, fall maintenance flows can rework significant portions of sand bars within the active channel that are covered with a veneer of exotic vegetation seedlings. These flows also serve to flush some of fine sediments that have deposited in the channel during the summer and fall monsoon season storms. Spot locations of concentrated deposits of silt and clay up to a half foot can limit the potential for high flows to rework the channel bed. If the fine sediment can be flushed and dispersed downstream before drying and consolidating, the river channel dynamics can be enhanced at high flows in the spring.

3. Return LFCC low flows to the channel – There are presently four locations in the San Acacia to San Marcial reach where the drainage water in the Low Flow Conveyance Channel is returned by pumping it to the river. Unfortunately, the river is located close to the LFCC for a large portion of the reach. There is a high groundwater gradient from the river to the LFCC because of the perched nature of the river bed and the excavated LFCC canal. Some of the benefit of returning the drainage water to the river is lost because the water quickly returns as seepage to the LFCC. Additional opportunities to maximize the efficiency of reusing the LFCC drainage water should be investigated.

4. Increase frequency/duration of flooding – While it may not be possible to mimic the natural spring hydrograph on an annual basis because of water resource commitments and upstream water storage, increasing the frequency and duration of flooding should be a focus for bosque regeneration and sustaining the active channel. Adaptive management strategy will play a major role in assessing the flood frequency. For active channel maintenance, it is recommended that no more than two consecutive years pass without a bankfull discharge for a three to five days duration. Channel forming flows on the order of the bankfull discharge (~ 5,660 cfs) are necessary almost every other year. If three years pass without a high flow of sufficient duration, the vegetation growth on active channel sand bars will not be removed by successive high flow events regardless of their magnitude or duration. The flushing flow duration should be prescribed by an adaptive management monitoring effort. When possible, tributary flooding should be augmented by reservoir releases to increase the duration of the flood event.

5. Time overbank flows with seed dispersal – To support bosque regeneration of cottonwood and willow cohorts, overbank flooding should be timed to maximize the germination of cottonwood seedlings on the floodplain. This will optimize the opportunity for cottonwoods to compete with tamarisk seedlings that disperse seed for a much longer period during the growing season.

6. Increase groundwater storage (focus on east side) – Maintaining low flows in the Rio Grande channel from San Acacia to San Marcial will support aquatic and silvery minnow habitat during dry periods. One mechanism to enhance low flows is to increase groundwater levels which will reduce the loss of river surface water to groundwater. The Low Flow Conveyance Channel acts as a drain for the river seepage water. In many reaches, the river is close to the LFCC levee and the groundwater gradient to the LFCC is very steep due to the perched nature of the river and excavated bed of the LFCC. There are several approaches to reducing this gradient and all of them are likely to be expensive. Wherever possible, the river should be relocated to the east to increase the flow path to the LFCC, thereby reducing the groundwater gradient. The old channel bed would then serve as wetland or backwater habitat and would gradually seal with fine sediments. It would also increase the groundwater level between the river and the LFCC. Other solutions would be to provide a seepage cutoff wall at the LFCC levee using sheetpile or a key trench of fine sediment. This task could be accomplished with the Corps levee reconstruction project. Reducing the loss of river low flow seepage to the LFCC may eliminate the need for upstream reservoir management during low flow periods to maintain a minimal flow in this reach of river.

Mapping the Project Components

A cursory attempt at mapping the project areas and components is presented in Appendix F to illustrate how these components would be represented on mapping with flood delineation and land ownership. These maps are just examples of how to present this information and do represent any of the selected components at this time. All possible projects areas were assigned some representative example project component. These possible project components will be analyzed and ranked and based on input from the Task Force, project components will be selected for further feasibility investigations. The final flood delineation and project mapping will be displayed on similar maps and on GIS images. The Appendix F maps are for discussion and feedback on how to present the maps. The project components on these maps essentially represent a ‘wish list’ of the full compliment of potential restoration activities.

Prioritizing River and Riparian Restoration Needs

Water is the key variable that drives the process of a self-sustaining river system. Restoration activities should support those river functions that have ceased to have a spatial and temporal continuum with the historic channel. Mechanical restoration should be focused on returning the physical system to a status where the processes can be self-sustaining again with appropriate frequency, timing and duration of prescribed flows. While successive dry periods will limit the river's ability to be self-sustaining, ideally river restoration should be viewed as a one time event that will get the channel and riparian environment back to a point where water resource management can take over. Realistically, adaptive management strategies based on long term monitoring will identify the successes and failures of river restoration techniques. It is anticipated that annual maintenance will be required to sustain river function and biological diversity for the immediate future.

River Function and Biological Diversity

To prioritize river function and biological diversity restoration activities in Phase III, it will be necessary to rank the restoration activities in terms of their contribution to the overall conceptual restoration plan. There are several components that will play an important role in the restoration plan. These include:

- Coordinating Rio Grande water management activities to support and enhance river function and riparian biological diversity by mimicking natural hydrograph shape, timing and frequency of occurrence.
- Restoring the active channel geometry by removing in-channel vegetation and reworking the sand bars so that the river can begin a new self-sustaining period.
- Increasing the hydrologic connectivity between the river channel and floodplain by promoting overbank flooding through both mechanical and water resource management activities
- Enhancing biological diversity in the riparian and floodplain habitats
- Improving the dynamics of the surface water/groundwater exchange. Increasing groundwater levels in some locations of the active floodplain area on the east side of the river may benefit channel low flows.

Other restoration objectives include:

- Increasing groundwater storage and levels.
- Expanding marshes and wet meadows.
- Generating water salvage.
- Promoting cottonwood/willow regeneration.
- Supporting endangered species and habitat.

The potential project components are organized by objective in Matrix I. Matrix I will be updated and revised in Phase III, but it is presented here for discussion purposes.

Rio Grande Restoration Activities - San Acacia to San Marcia

Restoration Goals

Restoration Technique	Enhance River Function					Increase Habitat Diversity			
	Objectives					Objectives			
Channel Activities	Enhance Channel Dynamics	Promote Overbank Flooding	Increase Groundwater Storage	Expand Marshes/Wet Meadows	Create Water Salvage	Expand Native Riparian Habitat	Improve Aquatic Habitat	Promote Cottonwood/Willow Regeneration	Support Endangered Species
Disc and mow sand bar vegetation	✓				✓	✓	✓	✓	✓
Plow and rake islands	✓				✓	✓	✓	✓	✓
Remove bank vegetation (deformable banklines)	✓	✓			✓	✓	✓	✓	✓
Destabilize and lower banks (terrace lowering)	✓	✓	✓	✓	✓	✓	✓	✓	✓
Widen channels (bank destabilization)	✓	✓				✓	✓		✓
Create high flow side channels	✓	✓	✓	✓		✓	✓	✓	✓
Cut pilot channels (initiate channel avulsions)	✓		✓	✓		✓	✓	✓	✓
Realign channelst	✓	✓	✓			✓	✓	✓	✓
Locate and place of large woody debris	✓						✓		
Reconnect oxbow and old channels		✓	✓	✓		✓	✓	✓	✓
Implement training dikes/spurs/rock weirs									
Raise channel bed (grade restoration facilities)		✓	✓	✓					
Shape curves and banks	✓						✓		
Remove sediment plugs									
Increase sediment loading	✓	✓	✓	✓		✓	✓	✓	✓
Floodplain Activities									
Remove exotic vegetation			✓	✓	✓	✓		✓	✓
Plant and seed native vegetation					✓	✓		✓	✓
Create wetlands and marshes		✓	✓	✓		✓		✓	✓
Develop variable floodplain topography		✓				✓		✓	✓
Create flooded bottomlands		✓	✓	✓		✓	✓	✓	✓
Enhance groundwater storage and interaction			✓	✓					
Mechanically remove woody debris									
Remove jetty jacks		✓							✓
Manage livestock grazing		✓		✓	✓	✓		✓	✓
Create larger floodplain corridor - stabilize levees	✓	✓	✓	✓		✓		✓	✓
Eliminate structural limitations on flooding	✓	✓	✓	✓		✓		✓	✓
Manage future development		✓		✓		✓		✓	✓
Recreational access									
Water Management									
Enhance spring flushing flows	✓	✓	✓	✓	✓	✓	✓	✓	✓
Sustain fall maintenance flows	✓				✓	✓	✓	✓	✓
Return LFCC low flows to the channel					✓		✓		✓
Increase frequency/duration of flooding	✓	✓	✓	✓		✓	✓	✓	✓
Time flood with seed dispersal	✓				✓	✓	✓	✓	✓
Increase groundwater storage on east side		✓	✓	✓					✓

Matrix II is a tool to evaluate and rank the potential contribution of each project component. There are nine project areas that will be composed of the various project components listed in Matrix II. Each project area will be assigned its own matrix similar to Matrix II. These project components will be both quantitatively and qualitatively assessed for the contribution to the overall project restoration plan. Matrix II will also be expanded and revised in Phase III, but it is presented here for discussion and feedback. A few of the brackets have been assigned values to provide an idea of how the project component matrix selection process may proceed.

Blending Geomorphic Trends and Restoration Activities

The Phase I report presented a detailed discussion of channel geomorphic trends that would govern the selection of restoration components. Vegetation encroachment, channel narrowing, bed material coarsening, channel incision and aggradation were all documented in the Phase I discussion of river geomorphology. Understanding and predicting the channel geometry responses to restoration activities is the key to planning and designing a self-sustaining river system. The channel morphology trends for the three subreaches from San Acacia to San Marcial include:

- A slight channel widening with a relatively stable thalweg profile (or slight incision) in the upstream Escondida subreach. The Escondida subreach may be stabilizing.
- Channel narrowing in the San Antonio middle subreach.
- Sediment deposition and channel aggradation in the lower Refuge subreach.

In the Escondida reach, restoration activities should focus on in-channel dynamics and habitat, channel widening and bank destabilization and raising groundwater levels. In the middle San Antonio subreach, the restoration activities should include reworking sand bars, channel widening, enhancing river floodplain hydrologic connectivity, expanding wetlands and marshes, enhancing riparian habitat diversity and relocating the river to the east. The lower Refuge subreach is aggrading and there will be opportunities for channel realignment, channel widening and channel reworking. Once the channel has been reworked, this reach should be capable of self-sustaining its channel morphology given appropriate bankfull discharge frequency. Over the long term, channel overbank flooding will improve naturally with sediment deposition and loss of channel conveyance capacity. Removal of extensive stands of exotic vegetation will open the way for improved channel floodplain hydrologic connectivity. Eventually channel avulsions and migration may ensue. This lower subreach has the greatest potential for maintaining a dynamic channel and overbank flooding.

Project Component Evaluation Matrix

		River Function															Habitat Diversity								Component Function					
Project Area 1	Component Weight (Percent)	Increase Channel Width			Impact on Flood Levels			Increase Groundwater Storage			Expand Marshes/Wet Meadows			Water Salvage			Riparian Impacts		Aquatic Habitat Impacts		Cottonwood/Willow Regeneration		Support Endangered Species		Capital Cost		Operation and Maintenance		Expected Life	
		acres	score	weighted score	stage or acres	score	weighted score	acre-ft	score	weighted score	acres	score	weighted score	acre-ft	score	weighted score	score	weighted score	score	weighted score	score	weighted score	score	weighted score	score	weighted score	score	weighted score	score	weighted score
Disc and Mow	0.15	400	0.5	0.08		1.0																								
Grade Restoration Facilities	0.05	0	0.0	0.00		0.5			1.0			0.0			0.0			1.0						1.0		1.0				-1.0
			0.5			-1.0												0.0						0.0		1.0				0.0
			-0.5			-1.0												0.0						0.0		-0.5				0.0
			-0.5			-0.1												0.0						0.0		-0.5				0.0
			0.0															0.2						0.2		0.2				-0.2
			1.0																											
			-1.0																											
			0.5																											
			0.0																											
			-0.5																											
			0.0																											
			0.0																											
Total Weighted Score				0.08																										

no impact = 0
moderate negative impact = - 0.5
significant negative impact = -1.0
moderate postive impact = 0.5
significant positive impact = 1.0

Overcoming the Constraints to Restoration

Restoration opportunities in the San Acacia to San Marcial reach are constrained by several issues:

- Limitations of flood frequency and magnitude including physical limitations, water resource limitations and infrastructure limitations.
- Soil salinity.
- Land ownership that may restrict proposed restoration activities in some areas.
- Permits related to restoration activities.
- Restoration costs.

Physical limitations to various restoration components include limitations to flood magnitude and frequency. The primary physical limitation to flood magnitude is the San Marcial railroad bridge conveyance capacity of less than 6,000 cfs and building structures on the floodplain upstream of the Highway 380 Bridge that could be inundated at flows greater than 7,000 cfs. These limitations can be surmounted by replacing or moving the bridge and by removing the buildings, raising the buildings or berming the structures.

Water resource limitations are a more severe constraint on flood flows. Recent peak discharge releases from Cochiti Dam and other upstream reservoirs have been limited by successive dry years. When reservoir storage is low, spring high flow events will be less than bankfull discharge. The frequency of channel forming flows should occur essentially every other year in the San Acacia to San Marcial reach to avoid vegetation encroachment in the active channel. There have not been any significant high flows for the past several years and much of the active channel now has vegetation on the sand bars that cannot be removed by flooding. The infrastructure limitation on peak flows is the outlet facilities at Cochiti Dam. The maximum peak design discharge is about 10,000 cfs. This limitation on releases from Cochiti Dam creates a dependence on the Rio Salado and Rio Puerco to generate large floods that would significantly rework the channel.

Restoration component design and site location may be limited by soil salinity. High soil salinity may restrict the opportunity for creating native mosaics in areas of cleared salt cedar. High soil salinities can reduce seedling growth in cottonwood, while salt cedar can tolerate higher salinities (Sprenger et al. 2000). Research on seasonal flooding has shown that native vegetation can out-compete exotics in moderate saline soils if other factors, such as rate of groundwater drawdown and soil texture are favorable. Restoration components will be mapped with areas of high soil salinity in Phase III to determine potential area limitations on restoration design. In healthy lotic riparian ecosystems annual spring floods remove excess salts (Briggs 1996). It may be possible to reduce soil salinity by creating floodplain side channels and inducing significant overbank flooding to flush out salts. This potential limitation to restoration design will be addressed on a site by site basis when the restoration components are selected.

Land ownership and current land uses may limit restoration activities within the project reach. There are federal, state, and privately owned lands in San Acacia to San Marcial reach. Each of the "owners" and associated land uses require individual as well as, holistic consideration. Public Law will govern many of the proposed restoration alternatives in the project reach.

The Flood Control Act of 1948. PL 80-858 provided authorization for the construction of the Low Flow Conveyance Channel (LFCC) from San Acacia to the headwaters of Elephant Butte Reservoir. This legislation authorized the Bureau of Reclamation to maintain the river channel from Velarde to Caballo Reservoir for a conveyance capacity of 5,000 cfs. Two Executive Order's; 11990 (Protection of Wetlands) and 11988 (Floodplain Management) also have language that will affect potential restoration activities.

Executive Order 11990 requires the avoidance, to the greatest extent possible, of both long and short term impacts associated with the destruction, modification, or other disturbance of wetland habitats. Section 5(b) of the Executive Order calls for the maintenance of natural systems, including the conservation and long-term productivity of existing flora and fauna, species and habitat, diversity and stability, hydrologic utility, fish, wildlife, timber, and food and fiber resources. Executive Order 11988 provides Federal guidance for activities within floodplains. This order requires Federal agencies to take action to reduce the risk of flood loss, to minimize the impact of floods on human safety, health, and welfare, and to restore and preserve the natural and beneficial values served by floodplains.

The goals of restoration activities in this reach will abide by and be consistent with the intent of the Public Laws and Executive Orders. All the proposed restoration will be located within the active floodplain on both sides of the main channel limited by the LFCC levee on the west and high ground on the east. This floodplain is typically reserved for floodway purposes, wildlife habitat, and various types of recreation.

Where restoration is proposed on private land, close coordination with affected and adjacent landowners is necessary. One approach to addressing restoration on private land would be to obtain a conservation or flooding easement. These easements would allow the holder of the easement to periodically inundate the land. Easements to occasionally flood land are less expensive than permanent easements, and in most cases, offer the landowner the benefit of using the land for other purposes, such as for agriculture use.

Any large-scale excavation, river relocation or possible designed migration of the river channel will require special consideration and coordination with the affected landowner. It may be necessary to design mitigation features with the proposed project components. Mitigation measures may include protection of structures or other property through relocation, raising or berming. These mitigation measures would also require the cooperation of the landowner.

As identified in the Materials and Methods section of the draft Feasibility Study: San Acacia Diversion Dam to Bosque del Apache NWR North Boundary Socorro County, New Mexico (July 2002), the Middle Rio Grande Conservancy District (MRGCD), New Mexico Institute for Mining and Technology (NM Tech), and the U.S. Fish and Wildlife Service (Bosque del Apache Refuge) have land holdings within the project reach. Close coordination with these stakeholders will be necessary to insure proposed activities are consistent with existing and future planned land uses.

Restoration activities or other work affecting waters of the United States are regulated under Section 404 of the Clean Water Act (CWA). Section 404 insures that the biological and chemical quality of the nation's waters is protected from unregulated discharges of dredged or fill material. The U.S. Army Corps of Engineers Regulatory Branch is responsible for the administration of the program and issues permits to regulate the discharge of dredged or fill material. Other federal laws that need to be considered for the restoration plan include the National Environmental Policy Act (NEPA) of 1969, the Fish and Wildlife Coordination Act, the Endangered Species Act, the National Historic Preservation Act, the Federal Power Act, the Wild and Scenic Rivers Act, and the National Fishing Enhancement Act.

"Waters of the United States" are administratively defined as (a) the traditional "navigable waters of the United States" including adjacent wetlands; (b) all other waters such as lakes, rivers, streams (including intermittent streams), wet meadows, wetlands, natural ponds, etc. (c) all impoundments of these waters; (d) tributaries of the above listed waters; and (e) wetlands adjacent to the above waters. "Wetlands" are areas inundated or saturated by surface or ground water at a frequency and duration sufficient to support a prevalence of vegetation typically adapted for life in saturated soil conditions. Given that the San Acacia to San Marcial reach of the Rio Grande and its adjacent floodplain clearly meet the guidelines listed above, any proposed restoration will require the issuance of a 404 permit.

The section 404 individual permit application form and instructions are available from the Albuquerque District Corps office. For informational purposes, the application typically requires (1) drawings (8 ½ " x 11") showing sufficient detail to understand the project; (2) locations, purpose, types and quantities of fill, and intended use; (3) expected construction start and finish dates; (4) names and addresses of adjacent landowners; and (5) locations and dimensions of adjacent structures. The addition of photographs is helpful and may be submitted with the application. The Regulatory Office of the Corps of Engineers should be contacted for additional submittal information.

In addition to individual 404 permits, the Corps issues nationwide permits for common activities in waterways. It is unlikely, however, that proposed restoration activities for the San Acacia to San Marcial reach would fall under a nationwide permit. However, conditions associated with these permits are periodically revised and the Corps should be contacted for a summary of current nationwide permit conditions.

It is probable that a federal action will occur in association with restoration activities in this reach. It will be necessary, therefore, to follow the Council on Environmental Quality's regulations implementing NEPA that require the appropriate federal agency to develop alternatives to a proposed action, to analyze and compare the impacts of each alternative and the proposed action, and to keep the public informed and involved throughout the project planning and implementation. Due to the likelihood of multiple "federal actions" being involved with restoration, a lead federal agency and cooperating agencies should be established. This will help facilitate agency coordination and adoption of the NEPA document as the planning process evolves.

Restoration costs are going to be significant for channel realignment, clearing large acreages of salt cedar and lowering the floodplain terrace. Funding limitations necessitate the prioritizing and ranking of the potential restoration components. Ranking the restoration components will be accomplished in Phase III.

Coordinating with Other Programs

The success of the Conceptual Restoration Plan is contingent upon integrating, learning and growing with other restoration and research projects. This includes activities occurring in both the public and private sectors including on-going research at education institutions. There are a number of potential restoration programs planned for other Rio Grande reaches and at least two recent river channel restoration projects that have been implemented; one just north of Bernalillo within Santa Ana Pueblo and one in Los Lunas. The response of these projects to high flows will be closely observed. Both the Corps of Engineers and the Bureau of Reclamation have on-going or planned project for the San Acacia to San Marcial reach. These include:

- **BOR River Restoration/River Maintenance Program, Socorro Reach.** The objectives of this program are to restore areas disturbed by fire, enhance aquatic habitat and riparian vegetation potential on alternate river bars, destabilize river banks to encourage channel widening, remove exotic vegetation and encourage native vegetation, placing random woody debris piles to promote bar formation and micro aquatic habitat, and create low terraces, high flow side channels, and wetlands.

- **River Restoration/River Maintenance Program, San Marcial Reach.** BOR has a program to remove exotic vegetation and encourage native revegetation, increase the main channel width, create channel avulsions, develop high flow side channels for overbank flooding, inundate cleared areas, and create backwater refugia areas, and wetlands. This program is from river mile 78 to the headwaters of Elephant Butte Reservoir.

- **BOR Gradient Restoration Facilities.** Downstream of the Amole arroyo in the reach between San Acacia Diversion Dam and the Escondida Bridge, the BOR has plans for two gradient restoration facilities (GRF).

- **BOR Levee Maintenance Program.** Upstream of the Amole Arroyo there are two river locations that are identified as "priority sites" under the levee maintenance program. Measures to insure adequate protection for the levee at these sites have been initiated.

- **Corps of Engineers Levee Restoration Project.** The Corps of Engineers is planning a levee restoration project in the San Acacia to San Marcial reach that may be coordinated with other activities such as salt cedar clearing and San Marcial bridge replacement.

There are proposed and planned projects in the San Acacia to San Marcial reach that will be addressed further during the selection of the restoration components for the Conceptual Restoration Plan. These include on-going projects on the Bosque del Apache NWR by the FWS to clear exotic vegetation on the floodplain**.** The FWS under the National American Wetlands Conservation Act and non-federal partners are converting 800 acres dominated by monotypic stands of salt cedar to a mosaic of native habitats including a mixture of grassland, wetland, and forests for the purpose of providing migratory and resident wildlife species with quality habitat.

As more river and riparian restoration projects enter the planning stage with 2003 and 2004 Middle Rio Grande Endangered Species Act Collaborative Program support, the restoration data base and learning process will accelerate. For these projects, the Save Our Bosque Conceptual Restoration Plan could serve as a template to guide these restoration designs. It is anticipated that other restoration activities on other upstream reaches will also contribute concepts and implementation practices with the phased restoration plan in this reach.

One of the on-going research and planning tools the Conceptual Restoration Plan is being coordinated with is the Upper Rio Grande Water Operations Review (URGWOPS) and EIS. Management of the Rio Grande involves a number of agencies, each with its own mission, rules and guidelines. Three of the agencies are developing an integrated plan for water operations at existing facilities in the upper Rio Grande basin. The Corps, Reclamation, and the New Mexico Interstate Stream Commission have agreed to examine what can be accomplished under their existing authorities to improve how water is managed in the upper and middle Rio Grande basins.

This water operations review will provide the basis for an environmental impact statement (EIS) on selected water operations activities in the Rio Grande basin above Fort Quitman, Texas, that are within the joint lead agencies' existing authorities. Water management in the upper Rio Grande basin involves an international treaty with Mexico, an interstate compact among Colorado, New Mexico and Texas, more than a dozen federal water project authorizations, water laws of the three states, and state and tribal water quality standards. The current schedule indicates the EIS will be completed in 2004.

Two of the more significant roles of the Corps of Engineers in the Rio Grande basin are to reduce flood damage losses and minimize the negative impacts associated with sediment. The Bureau of Reclamation manages water delivery to private, municipal, and industrial users which includes a significant river maintenance program. The Interstate Stream Commission monitors compact deliveries and San Juan-Chama project water storage and releases. The URGWOPS Review process will examine how the agencies can use their existing water operations authorities to:

- Help meet water needs of all users.
- Meet downstream delivery requirements mandated by the Rio Grande Compact and the international treaty with Mexico.
- Provide flood protection and sediment control.
- Assure safe dam operations.
- Support compliance with local, state, tribal, and federal water quality regulations.
- Create flexibility for operation of federal reservoirs and facilities.
- Assist managing agencies to operate these facilities more efficiently.
- Improve water operations through better interagency and public communication.
- Support compliance with the National Environmental Policy Act (NEPA), the Endangered Species Act and all other applicable laws and regulations.
- Address endangered species issues.

As required by NEPA, interdisciplinary teams of resource specialists have been identified and are in the process of analyzing alternative water operation plans to support the development of the EIS. Technical teams have been organized and are supporting the interdisciplinary teams. These teams have identified resources to be studied, determined the indicators and the methods to be used for analyzing impacts on the resources, and are in the process of recommending alternative water operations to be considered. Tools such as Upper Rio Grande Water Operations Model will be used to assist in the analysis. The Middle Rio Grande FLO-2D model will work in conjunction with the Water Operations Model to route flows through the system, providing a spatial and temporal representation of the flow alternatives under consideration.

The goal of fuel reduction programs in the Socorro Valley is to effectively manage bosque fires. A number of government entities and resource stakeholders are working thinning bosque understory to protect riparian areas from wildfire and at the same time maintain quality habitat for wildlife species. The lack of bosque flooding has resulted in the increase in accumulations of leaf litter and woody debris which increases fire severity (Ellis, 2000). There is an urgent need to reduce fuel loads through either frequent flooding or mechanical removal. Reduction of fuel loading has to be balance to avoid compromising vegetation structure diversity for bird habitat (Taylor, 2000). Other measures to prevent severe fires include exotic vegetation control, riparian restoration and fire breaks. All of these fire mitigation methods will be considered in the selection of components for the restoration plan. The restoration plan has to be coordinated with a number of agencies involved with fire management to ensure that areas with high potential for severe fires have opportunities for fire mitigation.

Data Gaps and Information Requirements

The San Acacia to San Marcial reach has a sufficient number of cross sections to analyze and design restoration components. USGS gaging stations with extensive historical data bases are currently operating at each end of the reach. In addition to the flow records at the USGS gages, there are data bases on bed material data, sediment load data and detailed floodplain topography in the form of digital terrain models. These data sets will be used to simulate river flooding associated with channel and riparian restoration design. Data requirements for this reach include the following:

- Water surface elevations at all the cross sections under bankfull conditions. Although this hydrographic data was collected in 1998, there have been significant changes in many of the cross sections related to vegetation encroachment and channel narrowing. A new set of high flow discharge water surface elevations would improve the calibration of the current MRG FLO-2D model, thus providing a better tool for evaluating both existing conditions and determining restoration component impacts.

- Overbank flooding aerial photos and videos to calibrate predicted flood inundation areas. This is a critical missing data base.

- Detailed local topography and additional channel cross sections will be needed at sites of individual restoration components.

- Post-construction cross section data for the Bureau of Reclamation’s pilot channel project are necessary to update the FLO-2D model prior to designing restoration components. This set of cross sections should be surveyed several times during the year for the next several years to monitor the pilot channel evolution and potential upstream and downstream river bed slope adjustments.

- Biology data needs are discussed in the Condition of the Aquatic and Riparian Habitat Section.

- Instantaneous flood peak discharge measurements at both the San Acacia and San Marcial gage. The recording of instantaneous peaks was terminated for both gages because of the poor reliability of the data. It is recommended that appropriate measures be considered to improve the discharge data integrity and resume peak discharge records. Such measures may include gage relocation, construction of permanent gaging cross section such as a concrete sill or developing a stable constriction. The improved discharge and sediment load data base would serve both the short term needs of the restoration projects in this reach as well as the long term monitoring of flow volumes.

Potential Restoration Project Areas

Subreach Areas of High Flood Potential

Flood inundation of the San Acacia to San Marcial reach of the Middle Rio Grande was predicted for various return period flows for existing conditions using the FLO-2D model. The model was applied using a mobile bed and the derived sediment rating curve for bed material load discussed in the sediment load section. The FLO-2D model included the infiltration component and recent cross section surveys from 2002. Four return period floods were simulated including the 1.25-year event (3,700 cfs), 2-year flood (5,660 cfs), the 5-year return period flood (8,480 cfs) and the 10-year event (10,400 cfs). Flows less than or equal to 10,000 cfs were selected because of the limitation on peak discharge release from Cochiti Dam. In Phase IV, the restoration project design will be tested with the 100-year return period flood. Additional calibration runs using the September 2002 flood event were attempted with the FLO-2D model, but this effort was limited because the USGS real time data was inconsistent at the San Acacia and San Marcial gages.

After several months of testing the FLO-2D mobile bed component, it was decided to use this component to simulate the existing condition flooding. Of the six sediment transport equations available in the model, Yang's sediment transport equation (Yang, 1996) was selected to compute the sediment transport capacity. It computed a range of sediment transport discharge comparable to the Zeller and Fullerton equation (a regression analysis of combined Meyer Peter Mueller bed load and Einstein equations). These two equations provided mid-range values of sediment transports when compared to the other equations available in the FLO-2D model including Toffaletti (lower), Laursen (lower), Ackers and White (higher) and Englund and Hansen (higher) equations. The mobile bed analysis included a non-uniform sediment distribution on the bed (either scour or deposition). The model generally predicted cross section scour in the upper Escondida subreach and deposition in the lower Refuge subreach. The non-uniform sediment distribution on the cross section was based on a shear stress approach proposed by Zhou and Lin (1998). The sediment routing component and cross section changes force more water overbank in reaches of sediment deposition and increase the conveyance capacity in channel elements experiencing scour.

Based on the flow duration analysis for the period from 1974 to 2001, there were approximately 6 days when the flow equaled or exceeded the 2-year flood event. This flood duration should maximize the area of inundation for the reach and was applied to all the various return period flood events. A one day of ramp-up to the return period peak discharge was applied in the model. The results for each return period flood were then imported into the Mapper processor program to generate maximum area of inundation maps. The flood inundation maps are presented in Appendix E.

The area of inundation maps are based on a maximum flow depth or water surface elevation regardless of the time of occurrence. In other words, the maximum area of inundation does not occur simultaneously but represents the spatial maximum area of inundation (not the temporal variation). The maximum water surface elevation for each grid element is imported into the Mapper program and the DTM ground surface points are subtracted from the appropriate grid element water surface. This generates a detailed maximum flow depth map based on the large DTM data base of ground points. A color contour map of the maximum flow depth is then generated in Mapper and exported as an ESRI shape file for importation to ArcView GIS. The flood contour mapping becomes a layer that can be overlaid with other GIS data base resources such as vegetation classifications and private land.

The FLO-2D area of inundation maps are thus represented by the following list of assumptions and criteria:

- The entire Middle Rio Grande FLO-2D model consists of 29,997 500-ft square grid elements and 1637 channel elements. Only the portion from San Acacia to San Marcial was used in this investigation.
- The entire MRG FLO-2D model was calibrated to 1997, 1998 and 2001 hydrographs measured at gaging stations throughout the Cochiti Dam to Elephant Butte Reservoir. Channel roughness was calibrated by reviewing the timing of the hydrograph peaks and hydrograph volume was calibrated with infiltration hydraulic conductivity.
- The model cross section data base was updated using the 2002 cross section surveys in the San Acacia to San Marcial reach.
- The flood return period discharges were analyzed using the 1974-2002 San Acacia gage record.
- A six day duration of flooding was applied that reflects the 1974 to 2002 period flood duration for flows greater than 5,660 cfs (2-year flood).
- The mobile bed component was applied in the model using Yang’s sand bed equation.
- A uniform bed material size of 0.22 mm was used for the sediment routing component.
- A non-uniform sediment distribution on the channel cross section (scour or deposition) was estimated used a method derived by recent research in China.
- The water surface over a grid element is represented by a single elevation. This assumes that there is little variation in the floodplain water surface over the 500 ft element.
- The maximum flow depth for mapping purposes is computed in Mapper by subtracting the DTM ground surface points contained within the coordinates of the grid element from the maximum FLO-2D water surface predicted for that grid element.
- A color contour map of the maximum flow depths is interpolated by a contour plotting routine within the Mapper processor program. This contour map is then generated as a shape file by the ESRI Map Objects processor in the Mapper program.

Overbank flooding results loss of surface flow volume from the Rio Grande to channel infiltration and evaporation and floodplain infiltration and evaporation. The loss of surface water to infiltration is not considered a depletion from the system as discussed in the section on the Rio Grande Compact. Based on the four return period floods simulated for 144 hours, the FLO-2D model estimated the losses as shown in Table 22.

TABLE 22. FLO-2D PREDICTED SURFACE FLOW LOSSES FOR 4 FLOODS FLOWS (SIMULATION TIME = 144 HOURS)

Return Period (yr)	Flow (cfs)	Total Inflow Volume (af)	Loss Location	Infiltration Volume (af)	Evaporation Volume (af)
1.25	3,700	41,750	Floodplain	2,830	110
			Channel	8,270	330
2	5,660	62,160	Floodplain	7,970	350
			Channel	21,110	330
5	8,480	93,020	Floodplain	11,740	520
			Channel	46,720	340
10	10,400	113,760	Floodplain	11,910	520
			Channel	67,520	340

Flooding of the San Acacia to San Marcial reach initiates on the Bosque del Apache National Wildlife Refuge. The Escondida subreach experiences only a minor amount of overbank flow for the 10,400 cfs event (10-year flood). Almost all of the flood inundation is south of the Highway 380 Bridge. To assess the flood inundation for the four selected return period floods, it is necessary to have sufficient duration (at least 5 days) to inundate all the potential flood acreage. The predicted areas of flood inundation are displayed in the GIS layers along with habitat values and private land ownership.

Flooding Associated with Habitat and Land Ownership

Flooded Habitats

Based on the habitat classifications in the Habitat Value Assessment section, the active floodplain in the San Acacia to San Marcial reach is comprised of 21% high quality habitat (4,440 acres), 61% low quality habitat (12,570 acres) and 18% medium quality habitat (3,660 acres). Please refer to the Habitat Assessment Section for a description of the three types of habitat. Most of the high quality habitat is located south of the Bosque del Apache NWR. North of the Highway 380 Bridge there are only two small areas of high quality habitat (See Figures A.1 and A.2). These two areas are not flooded by the 10-year flood event. The opportunity to flood high quality habitat land is limited by the existing habitat classifications and most of the land that will be inundated will be low quality habitat. The actual inundated acreages of the three levels of habitat quality will be reported in the final draft report.

For the 1.25 year return period discharge of 3,700 cfs, only a limited area of low and medium quality habitat is flooded north of the Highway 380 Bridge. South of the Highway 380 Bridge, most of the area inundated is low quality habitat of dense salt cedar stands. Only a small area of the floodplain in the vicinity of San Marcial is flooded that is considered high quality habitat.

At the suggested restoration discharge of 5,660 cfs, most of the habitat that is flooded is considered to be low or medium quality habitat in the San Antonio and Refuge subreaches. Since the high quality habitat areas are limited, the only significant high quality habitat area being flooded is near Black Mesa south of the Bosque del Apache NWR. For a two year return period flood of 5,660 cfs (the recommended restoration flow), habitat enhancement through vegetation removal will be necessary to flood more high quality habitat.

There is extensive flooding for the 5-year flood of 8,480 cfs. The two high quality habitat areas are flooded north of the Highway 380 Bridge. In the Black Mesa area some of the high quality habitat is flooded; however, most of the inundated areas are low or medium quality habitat. The low quality habitat is the most extensively flooded, primarily because there is more of it. South of the Escondida Bridge, most of the active floodplain is inundated at 8,480 cfs until Tiffany Junction where a short reach of the floodplain remains dry until the river reaches Black Mesa.

At 10,400 cfs (10-year flood event), the flooding begins at essentially the same location as the 8,480 cfs in the downstream direction. Most of the active floodplain south of the Escondida Bridge is inundated. The flood peak is attenuated by the South Boundary of Bosque del Apache and the Tiffany Junction area is still not flooded. Upstream of Tiffany Junction over 90% of the floodplain is inundated by this flow. Again, most of the flooded area is low quality habitat consisting primarily of dense stands of salt cedar.

Flooding and Land Ownership

Land ownership can be categorized as federal, state and private. The primary federal land is the Bosque del Apache National Wildlife Refuge. There is only a limited amount of state land within the active floodplain and none of it is flooded for flows less than the 10-year flood. Note that MRGCD lands are classified as private lands in this case, but the MRGCD lands are delineated in the detailed GIS mapping. The inundated acreage by land classification will be identified in the final draft report. General observations regarding the inundated floodplain as a function of land ownership are discussed in this section.

Most of the land inundated by the 1.25 year flood (3,700 cfs) is on the Bosque del Apache NWR. A small fraction of private land north (near the North Boundary) and south (near Black Mesa) of the Refuge is inundated. Floods at this level do not adversely impact private land.

At 5,660 cfs (2-year return period flood), about half the flooding occurs on the Bosque del Apache NWR and half on private land. Again, a small area near Black Mesa is flooded, but most of the inundated private land occurs north of the Refuge. The flooding for this recommended restoration flow would not impact any existing structures on private land.

The five-year return period flood of 8,480 cfs inundates more private land than federal land. Most of the flooded private land occurs north of the Refuge. There are a few structures that may be adversely impacted by this return period event on the east side of the river, north of the Highway 380 Bridge. Most of the active floodplain between Escondida Bridge and the south boundary of Bosque del Apache NWR is inundated at this flow.

The land inundated by the 10-year flood (10,400 cfs) is not significantly greater in areal extent than the five year flood. Essentially the same general reaches are inundated, but they are flooded to a greater depth and greater percentage within the reach. Most of the active floodplain is inundated (> 90%) downstream of Escondida Bridge in the San Acacia to San Marcial reach. More private land than federal land is flooded by the 10-year return period flood event.

Potential Water Salvage Associated With Restoration

Potential Changes in Water Depletion

One of the objectives of the conceptual restoration plan is to generate water salvage (or decrease depletions) associated with ET losses by replacing dense stands of exotic vegetation with native cottonwood/willow bosque, salt grass, shrubs or wet meadows. In the section 'Potential Effects of Restoration Activities on Evapotranspiration,' the variation in ET losses associated with various vegetation types based on the University of New Mexico research was discussed. An example water budget analysis has been prepared to show the potential difference between water depletion between the existing condition compared to a restoration project condition. In this example, all the potential restoration project areas have been considered. The purpose of this analysis is not to compute absolute numbers for water salvage, but rather to demonstrate the methodology and potential impact that restoration could have on water depletion. In this analysis, two project components were analyzed: Bank lowering where salt cedar and Russian Olive dense stands are restored to open channel sand bar areas that are flooded in April and May; and exotic vegetation removal on the floodplain where dense stands of salt cedar and Russian olive are replaced to a cottonwood/willow/salt grass mosaic. For the first restoration component, the open channel sand bar areas are considered to be open water for the two months. Table 23 shows the potential restoration area by subreach. These acreages are for discussion purposes only and do not represent the conceptual restoration plan at this stage.

Table 23. Increase in Restoration Acreage by Subreach

	Restoration Project Condition		
Subreach	Increase in Open Water	Bank Lowering	Vegetation Removal
Escondida	625	625	949
San Antonio	1530	1530	3519
Refuge	397	397	374

Table 24 shows evapotranspiration rates for different vegetation types in feet of depletion per year. In the restoration areas where exotic vegetation removal will occur it is assumed that a native habitat mix of cottonwood, willows and salt grass meadow will become established. The ET rates are derived from the Environmental Assessment for the Rio Grande Habitat Restoration Project in Los Lunas, New Mexico (BOR and Corps, 2002). In Table 24, the composite cottonwood/willow/salt grass evapotranspiration rate column is determined by summing one third of each vegetation type evapotranspiration rate. The ET Work Group (ETWG) ET rate value is used for cottonwood. The salt cedar/Russian olive evapotranspiration rate is based on an assumption of dense vegetation stands. A value of 3.27 ft/yr that constitutes two-thirds of the original ETWG value was selected to represent the restoration area.

Table 24. Evapotranspiration Rates for Different Vegetation Types

CW[1] ETWG[2] (ft/yr)	CW BOR[3] (ft/yr)	Willow (ft/yr)	Grassland (ft/yr)	Composite[4] (ft/yr)	Salt cedar/ Russian olive ETWG (ft/yr)	Salt cedar/ Russian olive BOR (ft/yr)
3.00	4.80	4.20	1.99	3.06	4.90	4.20

[1] Cottonwood
[2] ETWG is a value determined by the Evapotranspiration Work Group
[3] BOR is the Bureau of Reclamation
[4] Cottonwood\willow\salt grass

Table 25 presents the evapotranspiration rates for open sand bars. For April and May the rate of evaporation for open water has been inserted based on the assumption that the sand bars will be flooded during these months. Open water evaporation rates are presented for two pan coefficients 0.7 and 0.85 (recommended by Interstate Stream Commission) (BOR and Corps, 2002). The higher value from the ISC will be used in the final analysis.

Table 25. Open Sand Bar Evaportranspiration

Month	ET Pan Coefficients 0.7 ft/yr	 0.85 ft/yr
Jan	0.06	0.06
Feb	0.08	0.08
March	0.14	0.14
April*	0.46	0.56
May*	0.54	0.66
June	0.25	0.25
July	0.22	0.22
Aug	0.2	0.2
Sept	0.15	0.15
Oct	0.12	0.12
Nov	0.07	0.07
Dec	0.05	0.05
Annual Rate	2.34	2.56

*rates for open water

Potential Water Salvage

Restoration activities can reduce water depletion by removal and replacement of exotic vegetation with native vegetation. For the bank and terrace lowering component, the evapotranspiration rate is changed from a scattered salt cedar/Russian olive vegetation stand to a sand bar which is flooded during April and May. The net reduction in ET for this project component is from 3.27 ft/yr to 2.56 ft/yr, or a water salvage of 0.71 ft/yr. For the floodplain exotic vegetation removal the evapotranspiration rate is reduced from 3.27 ft/yr for a scattered salt cedar/Russian olive stand to 3.06 ft/yr to a cottonwood/willow/salt grass mosaic habitat; a net reduction of 0.21 ft/yr. Table 26 displays the total salvage in acre-ft/yr.

Table 26. Potential Restoration Project Water Salvage

Subreach	Bank/Terrace Lowering (acre-ft/yr)	Floodplain Exotic Vegetation Removal (acre-ft/yr)
Escondida	444	199
San Antonio	1086	739
Refuge	282	79
Total	1812	1017

These two project components would result is a net water salvage of roughly 2,800 acre-ft/yr. This is comparable to the 3,000 acre-ft water salvage per year estimated in the ET section. Over the 25 year life of the project, this would result in a net water salvage of 70,700 acre-ft. This water budget example was prepared to demonstrate the analysis of potential reduction in water depletion associated with restoration components. The initial water salvage for the first few years of the project could be substantially higher because the estimate is based upon fully grown native vegetation.

Phase II Summary

The San Acacia to San Marcial reach of the Middle Rio Grande was divided into three subreaches according to the predicted geomorphic response to river restoration activities. These subreaches were based on the probability of the river channel degrading or aggrading in response to channel widening techniques. The subreaches were divided at the North Socorro Diversion and the North Bosque del Apache Refuge boundary. For the project design, the three subreaches were further delineated into nine project areas.

To assess the potential for overbank flooding in the San Acacia South reach, it was necessary to conduct a flood frequency analysis for the San Acacia USGS gage. Previous flood frequency analysis did not include a sufficiently long post-Cochiti Dam record (1974-2002) to assess the impacts of all the upstream water resource flow regulation in the Rio Grande basin. Following consultation with the various federal agencies including the USGS, Bureau of Reclamation and the Corps of Engineers, it was determined that the post-1974 record was sufficient to develop a flood frequency analysis for restoration purposes (events less than the 25-year return period floods). The post-1974 record, however, did not include any major tributary floods and as a result, the entire 1936 to 2002 record (adjusted for flow regulation) was used to estimate the less frequent flood events that are greater than the 25-year return period flood. The flood frequency curve, therefore, consists of two components, flood frequency for river restoration and the frequency for flood hazard applications. The two year return period flood based on the San Acacia post-1974 record was 5,660 cfs.

The mean annual flow duration for 5,660 cfs (post-Cochiti, 2-yr flood) for the post-Cochiti period from 1974 to 2002 is roughly 6 days. For restoration purposes in the San Acacia to San Marcial reach, a spring flushing hydrograph of 5,660 cfs with a duration of approximately 6 days is recommended as a spring restoration maintenance flow. This flow should occur with a frequency of approximately every other year or about 4 times in every 10 years with no more than 2 consecutive years without this spring hydrograph. This spring flushing flow hydrograph has a volume of approximately 68,000 acre-ft.

The fall discharge in the San Acacia to San Marcial reach increases in late October or early November with the decrease in irrigation diversion. To assess an optimum discharge for the fall maintenance flow, the FLO-2D model was applied to the San Acacia South reach using a range of flows from 50 to 1,500 cfs. The analysis indicated that the rate of increase in wetted channel surface area begins to decrease for flows above 500 cfs. It is recommended that 500 cfs be considered as a target fall channel maintenance flow. Flows of 500 cfs or greater have occurred roughly 39 percent of the time (approximately 23 days) during the months of October and November for the post-1974 period. Therefore, the target duration for the fall maintenance flow therefore should be 500 cfs or greater for approximately three weeks on an annual basis. This constitutes a minimum volume of 21,000 acre-ft.

The long term upstream sediment loading to the San Acacia gage has been declining. It is estimated that the current sediment load is only about 30% of the historic sediment load. A sediment supply analysis was conducted to determine the potential bed material sediment load at San Acacia for restoration project design. All the USGS sediment measurement records at San Acacia and San Marcial as well as all known sediment load analyses were compiled. A bed material rating curve was developed and various annual suspended and total sediment loads were computed and compared.

The sediment load being delivered by the Rio Grande to San Acacia is highly variable based on the erratic sediment loading from the Rio Salado and Rio Puerco tributaries. Under the discharge and sediment load conditions of the last 25 years, the entire reach appears to be slightly aggrading (more sediment entering the reach than is leaving it), but most of the sediment deposition is occurring in the Refuge subreach. This is reflected in both the measured load and the regressed sediment load equations. Approximately 2.0 million tons per year of sand-sized sediment is being supplied to this reach. The total annual sediment load is on the order of 3.5 to 4.5 million tons per year. A bed material load regression equation was developed that will be used in the FLO-2D model as the sand-sized sediment supply at San Acacia.

An analysis of the channel conveyance capacity or bankfull discharge was performed. This analysis clearly demonstrated the difference between the potential for flooding in the incised Escondida subreach compared to the two downstream subreaches. Flooding initiates in the two downstream subreaches at one-third the discharge of Escondida subreach. More acreage is flooded by the same discharge in the Refuge subreach than the San Antonio subreach. On the basis of flooding alone, the Refuge subreach appears to have the best restoration opportunities. Between 5,000 cfs and 10,000 cfs, approximately 1,000 more acres are flooded in the Refuge reach than the San Antonio reach for the same discharge. The discharge at which some significant flooding initiates is approximately 10,000 cfs for the Escondida subreach, 3,000 cfs for the San Antonio subreach and 2,700 cfs for the Refuge subreach.

Restoration activities that increase the flooded area of inundation in the San Acacia to San Marcial reach will increase water lost to evapotranspiration, however, restoration projects that also replace exotic plant species in a riparian area with a mosaic of natural vegetation should result in a water salvage. A number of proposed restoration components are focused on increasing the overbank flooding to improve the river/floodplain hydrologic connectivity. Increased water surface area will result in increased evaporation from both the river channel and the floodplain. Increased evaporation losses can be evaluated directly from the FLO-2D model that separately tracks the volume of water evaporated from the channel and floodplain free water surface area. Estimates of evapotranspiration losses due to restoration activities are more difficult to assess and are subject to significant natural variability and uncertainties. ET was determined by measurement at towers equipped with meteorological instruments at four UNM sites along the Middle Rio Grande including the Bosque del Apache National Wildlife Refuge. The daily variation in ET ranged from 5 mm to 11 mm per day at the Albuquerque tower site. In addition to the ET towers, each site contains a series of groundwater wells. The University of New Mexico is investigating the relationship between water table fluctuations and ET rates. Large fluctuations in groundwater may inhibit riparian poplars while salt cedar can thrive in a dynamic water table environment.

The UNM research indicates that mature stands of cottonwoods with a closed canopy had smaller ET rates for the growing season compared to dense stands of salt cedar and Russian Olives. This is the basis for recommending the eradication of dense salt cedar stands on large tracts of land throughout the San Acacia to San Marcial reach as part of the conceptual restoration plan. Based on a rough estimate of the riparian zone ET, the savings associated with converting dense stands of salt cedar to cottonwood could result in water salvage in San Acacia to San Marcial reach over the long term of 3,000 acre-ft per year. This is comparable to having 25 cfs in the river for two months during a dry year. These estimates will be refined in the Phase III analysis as the acreage of dense salt cedar proposed for eradication in the conceptual restoration plan is selected. Water salvage resulting from salt cedar eradication will be an important component of the conceptual restoration plan.

The habitat assessment characterized the existing habitat values and broadly identified potential restoration and reference areas. Based on a review of previous classifications, mappings and a field survey, most of the habitat on the San Acacia to San Marcial floodplain was classified as medium or low quality. These areas generally contain exotic vegetation as the dominant component of the vegetation community. Areas classified as medium were typically a mix of native and nonnative species, whereas the low value areas tend to contain a high density salt cedar. There were a few small areas of high quality habitat that generally consisted of native woodland habitat. The high habitat value areas attract a more diverse fauna than monotypic salt cedar stands. Native woodlands were characterized by an overstory of cottonwood and black willow with understories of coyote willow, New Mexico olive, screwbean mesquite and seepwillow.

The extensive cottonwood-willow riparian forest is largely an ecological legacy of past flooding. These stands may be rapidly senescing and new stands of cottonwood are not being established. In general, existing stands of native woodlands are becoming decadent and are being replaced by nonnative species. This trend toward nonnative vegetation has affected the survival of wildlife species that have evolved in cottonwood bosque. Some obligate riparian species are limited to cottonwood bosques which are declining in areal extent.

Floodplain restoration would involve a combination of restoring seasonal flooding and the removal of exotic vegetation. The removal of nonnative plants would be focused on areas of dense salt cedar that have the greatest potential for restoration. In addition to removing salt cedar to encourage cottonwood growth, some selective vegetation clearing would reduce the potential for fire. Those floodplain areas identified as high quality habitat should be protected and complimented with an appropriate hydrologic connection to the river.

A brief history of the Rio Grande Compact was presented that included a discussion of the New Mexico compliance with delivery schedule, pre-Compact groundwater conditions and water utilization in the San Acacia to San Marcial reach. The overview of water use included water rights and surface water diversions by the Middle Rio Grande Conservancy District and the Bosque del Apache National Wildlife Refuge. The drainage system and the Low Flow Conveyance Channel were described.

Planning of restoration activities will include an evaluation of the potential impact in the consumptive use of water. Changes in depletions related to restoration activities in the San Acacia to San Marcial reach could impact the delivery of water to Elephant Butte Reservoir and New Mexico's credit or debit status. Since no water rights are served by direct diversion from the Rio Grande below the San Acacia Dam, consumptive use impacts of restoration activities should have no impact on water rights above Elephant Butte Dam. It is presumed at this time, that there will be a water salvage not a water depletion associated with restoration activities. The evaluation of changes in depletion or salvage should be based on the net change in consumptive use based on a "pre-restoration" condition. The areas that have the highest potential for restoration are areas already experiencing significant evapotranspiration losses.

The quantification of the net depletion/salvage associated with restoration activities should take into consideration the historic changes in depletion in the San Acacia to San Marcial reach. The gross annual depletion in the San Acacia to San Marcial reach has varied between about 71,000 acre-feet and 119,000 acre-feet from both natural causes and man's activities. If the restoration activities result in depletions within this range, the depletions would be within the historical levels experienced in this reach since the 1938 Rio Grande Compact was signed.

Restoration activities may increase groundwater levels, resulting in higher losses due to evapotranspiration. Groundwater not lost to evaporation or evapotranspiration are increases in groundwater storage. This increase in groundwater storage could potentially affect New Mexico's compact water delivery to Texas. The analysis of the final restoration project design will address this issue. The use of groundwater aquifers for the storage of surface water would not invoke or be subject to the storage restrictions on reservoirs constructed after 1929 as provided for in Articles VI and VII of the Compact. The recharge of aquifers through percolation of surface water or the construction of injection wells does not infer that these aquifers become storage reservoirs as contemplated by the Compact.

Depending upon the nature of the proposed restoration activity, a water right permit may not be required. If the restoration activity does not involve the diversion of water through man-made works, the jurisdiction of the State Engineer is not invoked. This means that a proposed restoration activity would not be subject to the requirements of the rules and regulations of the State Engineer involving application, public notice and administrative hearing procedures.

Two primary restoration goals were established: Restoring natural river function; and enhancing biological diversity. To achieve these goals, a number of restoration objectives were outlined including: Enhancing channel dynamics, promoting overbank flooding, increase groundwater storage, expanding marshes, wet meadows and flooded bottomlands, creating water salvage, expanding native riparian habitat, improving aquatic habitat, promoting cottonwood/willow regeneration and supporting endangered species. A number of restoration techniques and methods were researched and discussed to accomplish these objectives. The selection of various combinations of restoration techniques and methods will recognize which tools are compatible with existing geomorphic trends, which tools can be applied to overcome constraints and obstacles to restoration and which tools will be cost effective. The restoration techniques were listed and described. To prioritize river function and biological diversity restoration activities in Phase III, it will be necessary to rank the restoration activities in terms of their contribution to overall conceptual restoration plan. The selection of restoration components will also depend on those activities that can overcome or work within existing physical, water resource or infrastructure constraints. Land ownership or restoration costs may limit some proposed restoration activities in some areas.

Flood inundation of the San Acacia to San Marcial reach of the Middle Rio Grande was predicted for various return period flows for existing conditions using the FLO-2D model. The model was applied using a mobile bed, the derived bed material rating curve, the infiltration component and the 2002 cross section surveys. Four return period floods were simulated including the 1.25-year event (3,700 cfs), 2-year flood (5,660 cfs), the 5-year return period flood (8,480 cfs) and the 10-year event (10,400 cfs). Flooding in the San Acacia to San Marcial reach initiates on the Bosque del Apache National Wildlife Refuge. The Escondida subreach only experiences a minor amount of overbank flow for the 10,400 cfs event (10-year flood). Almost all of the flooding for the various return period events is south of the Highway 380 Bridge. The flood inundation maps were prepared as GIS overlays so that the flood areas could be viewed with respect to habitat value and land ownership. The relationship between habitat value, land ownership and flood areas will play a major role in prioritizing restoration project components in Phase III.

With the completion of Phase II, the major issues and constraints to restoration activities have been identified. The alternative project restoration components that will function in the San Acacia to San Marcial reach have been outlined. Prioritizing river and riparian restoration needs and proposing the application of those tools will be the basis of Phase III in selecting the restoration plan project components. The foundation has been laid to analyze the project components. The restoration project will be an assemblage of components in nine project areas within the three delineated subreaches.

Phase III Work Plan – Concepts and Strategies for River Restoration Activities

The conceptual restoration plan will be based on ranking the project components in Phase III. Phases I and II involving the data collection and analysis and examination of specific river issues have created the basis for performing Phase III. Phase III will include the following tasks in the component selection process:

- Completion of an evaluation matrix of project components (Matrix II).
- Linking together restoration components based on functionality, geomorphic compatibility, benefits and costs and potential maintenance requirements.
- Prioritizing subreaches, project areas and restoration techniques.
- Evolving an overall restoration strategy for a phased implementation of the project components and areas.
- Researching site specific restoration details and data needs.
- Presenting the selection process and ranking of the proposed restoration project areas.

For each subreach, the project components will be ranked and prioritized. These measures as displayed in Matrix II will be evaluated by quantifying the potential contribution of each component so that they can be numerically ranked. The evaluation criteria will include the likelihood of success, consistency with restoration activities in other subreaches, cost, construction feasibility, environmental contribution, long term sustainability, adaptive management response and potential conflicts. Constraints and areal limitations on the restoration components will be highlighted. Project component selection would also consider the opportunity to restore river and riparian conditions to near 'historic' conditions. The lowest priority ranking would be assigned to project components that had such severe constraints that the effective restoration or habitat enhancement would not be possible. The selection process will be approved by the SOB oversight committee.

The preparation of the conceptual restoration plan and draft report would occur in Phase IV of the project following the ranking of the project components. This would include finalizing the project component maps and figures that will illustrate proposed construction associated with the components. Required data and information to bring the conceptual design to a feasibility design level will be outlined.

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