THE ALLIANCE FOR THE RIO GRANDE HERITAGE

A Framework for a Restoration Vision for the Rio Grande

Hope for a Living River

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EXECUTIVE SUMMARY

Introduction

The Rio Grande, fifth longest river in North America, is one of the continent's most unique and important ecosystems. It supports an exceptional web of wildlife, including some 250 species of birds, hundreds of native mammals, and many fish and reptiles. The river corridor fulfills a large-scale ecological function as a major highway for birds and other species that migrate within and between the Americas. Humans, too, have long occupied the region, leaving a rich cultural legacy unparalleled in the United States. The Rio Grande flows through two countries, eight states, and over a dozen Native American nations, and today, approximately ten million people live in the basin. But, the health of the Rio Grande ecosystem is failing. For a little over a century, humans have significantly altered the river's flow, sediment load, channel, floodplain, and riparian corridor for farming, flood control, and more recently, drinking water. The cumulative weight of these changes has dramatically altered the functioning of key biological, hydrological, and geomorphological processes within the river corridor. As a result, numerous plant and animal species have become extinct or extirpated from the region, and more are now threatened and endangered. To foster discussion about a sustainable future for the natural and cultural heritage of the Upper Rio Grande Basin, the Alliance for Rio Grande Heritage (Alliance) commissioned this report to frame the opportunities, issues, and constraints for restoration of the Rio Grande, from the headwaters, to Candelaria, Texas.

Need

The need to develop a restoration vision for the Rio Grande is fourfold. First, the Rio Grande has historically been managed for efficient conveyance of water and for flood control. Until recent times, little attention was paid to the ecosystem of the river. Second, as a result of modifying the Rio Grande to serve human needs in the basin, the system is highly altered and many important functions and values are greatly impaired or have been lost. Third, to add urgency to the need for restoration, a growing population along the Rio Grande is placing further demands on its limited water resources. Finally, because of the size and complexity of the ecosystem, there is a compelling need to embrace a system-wide view of the restoration of hundreds of miles of the Rio Grande.

Purpose

The overall purpose of this effort is to develop an outline of what can't be done, what can be done, and what we ought to imagine doing relative to restoration of the Rio Grande. Because of the numerous demands on its water and watersheds, it is not feasible to return the system to its exact condition prior to human influences. Therefore, "restoration" in this document refers to a return to physical and biological conditions that approximate those of the Holocene, but remain within the constraints imposed by sustainable human use of the basin's land and water resources. Much additional work will be required to evaluate, quantify, plan, design, fund and implement the restoration concepts that are presented in the report.

Report

This report is a conceptual document that outlines the key biologic, hydrologic, and geomorphologic processes of the Rio Grande from its headwaters to Candelaria, Texas. It presents issues associated with restoration, and identifies opportunities for restoration activities throughout the project area. To facilitate the presentation of geomorphic and ecological information, the study area has been divided into three bioregions. The Upper Bioregion extends from the headwaters in Colorado to Embudo, New Mexico. The Middle Bioregion encompasses the Rio Grande from Embudo to Caballo Dam, New Mexico. The Lower Bioregion extends from Caballo Dam to Candelaria, Texas.

Restoration opportunities identified in this document are developed under two scenarios. The first suggests tasks that can be accomplished within existing constraints. The more ambitious 'visionary' scenario assumes that in the future, those who use and manage the river will place a higher priority on environmental function and sustainability. Opportunities discussed under the visionary scenario require significant action such as project re-authorization, land acquisition, water rights acquisition, large-scale construction efforts, changes in water rights or their administration, and major funding.

What does a restoration vision of the Rio Grande encompass? This key question was posed to participants at a March 2002 Rio Grande Restoration Vision Workshop. Several overriding themes emerged and have been incorporated into the following Vision Statement:

We envision a Rio Grande that sustainably supports both the ecology and biota of the river, and the needs of human inhabitants of the region. To sustain the Rio Grande ecosystem and its native aquatic and riparian biodiversity, we need to promote flows that more closely resemble the historic hydrograph; re-establish the geomorphic processes and other characteristics that maintain the river's channel, floodplain and riparian corridor; control invasive species; and encourage land use and water resource management that promote and maintain such a system.

The Alliance recognizes that implementation of this Vision will require cooperation from many different stakeholders, and that by definition, a sustainable future must equitably balance all interests. It is hoped that this Vision Statement will foster discussion about a sustainable future for the natural and cultural heritage of the Upper Rio Grande basin, and the Alliance welcomes the opportunity to work with all interested parties to address any concerns and issues.

Issues and Challenges

Human occupation along the Rio Grande has altered the landscape and river system, resulting in a significant decline in plant and animal communities and populations. More than twenty species of vertebrate animals have been extirpated from the Middle Rio Grande basin alone (Scurlock, 1998), and over thirty species along the river have been recorded as warranting some degree of attention. Today, the Endangered Species Act plays a critical role in the management of the Rio Grande, as the US Fish and Wildlife Service, the Bureau of Reclamation, the Army Corps of Engineers, and the State of New Mexico focus their efforts to meet the needs of the endangered Rio Grande silvery minnow (*Hybognathus amarus*), and the Southwestern willow flycatcher (*Empidonax traillii extimus*).

Besides endangered species and the loss of habitat due to water resource development, another important ecological management issue is invasive nonnative species. Saltcedar (*Tamarix ramosissima*) has become the dominant riparian vegetation in much of the Middle and Lower Bioregions, and Russian olive (*Eleagnus angustifolia*) is prevalent through much of the riparian corridor in the Upper and Middle Bioregions. Closely related to the issue of invasive nonnative species is the lack of regeneration of native species. The most notable example of this is the scarcity of young cottonwoods (*Populus deltoides and angustifolia*) in the riparian forest known as the bosque. This is due to the absence of significant overbank flooding events, the timing of flooding events that do occur, stabilization of the river channel that has greatly reduced the erosion and accretion processes that promote cottonwood regeneration, and in some cases, the build-up of salts in soils.

For over a century, the Rio Grande has been managed for water delivery and flood control. In the Lower Bioregion, the alignment of the channel has also been managed to preserve the international boundary between Mexico and the United States. To facilitate these purposes, a large number of dams, diversions, levees, and channelization projects have been constructed on the Rio Grande, and through a combination of hydrologic and physical manipulation, the geomorphology of the river has been greatly altered.

Opportunities

Opportunities for restoration have been divided into two categories. The first identifies restoration work that can be implemented without major changes to institutions, laws, regulations, or societal attitudes. To a large degree, particularly for the Middle Bioregion, the 'existing constraints' category is a synopsis of where restoration efforts are currently heading. The second level of opportunities is more visionary. Many of the ideas were developed at the "Rio Grande Restoration Workshop" (March 2002). The 'vision' is intended to set a high standard, recognizing that values change over time, and occasions for collaboration between different groups of water users will arise.

Opportunities for restoration are further classified as either legal/administrative or physical in nature. Legal and administrative activities are non-structural and involve efforts that permit or facilitate physical changes in the river, or that preserve important existing qualities. In contrast, physical restoration activities involve direct manipulation of the characteristics of the system.

Legal and Administrative Opportunities for Restoration Under Existing Conditions

Commonly recognized legal and administrative policy and rules, otherwise referred to as non-structural restoration measures, are important components of restoration, with applicability throughout the project area. Implementation of these legal and administrative tools can be effective in preserving existing high quality areas in the riparian corridor, and preventing further impediments to future restoration activities. Relevant legal and administrative tools include: floodplain zoning ordinances, transfer of development rights from the riparian corridor to less environmentally sensitive areas, and the purchase of floodplain or floodplain conservation easements from willing sellers to preserve important areas. Better grazing management can also improve riparian conditions throughout the project area.

Incentive-based water conservation, and the purchase of water rights or land with appurtenant rights for environmental purposes are additional non-structural measures that are important tools for restoration. Water can be left in the system for the health of the river, or for downstream users, or to offset or augment increased water depletions arising from physical restoration measures. However, under existing constraints, water obtained for the environment through the retirement of agricultural rights or through conservation can be diverted downstream and is thus not likely to provide benefits for any substantial length of river. Elimination of this constraint is an important element in the visionary scenario.

Legal and Administrative Opportunities for Restoration Under a Visionary Scenario

“Visionary” legal and administrative tools apply to the entire project area, and focus on two goals: recognition of environmental water as a beneficial or authorized use under state and federal law, and the acquisition or creation of “wet” water for restoration purposes. Policies to protect environmental flows as they pass downstream across state boundaries may need to be enacted. Congress can reauthorize federal water projects so that water management and operations serve both traditional missions and environmental needs. Of course, funding to implement restoration activities will have to be obtained.

The acquisition and “creation” of water for environmental purposes can be accomplished by two means. Existing demand can be reduced. Incentives can be provided, or funds can be earmarked to offset revenue losses or additional costs associated with switching to low water use crops. Similarly, incentives can be provided to retrofit irrigation systems for more efficiency. Municipal and industrial water users should also have a mandate to conserve. Water savings or reduction in water losses can also be accomplished by changing the “plumbing” of the Rio Grande. It may be possible to save on the order of 100,000 acre-feet per year by shifting the location or manner of water storage. Between 150,000 and 200,000 acre-feet of water is lost annually because Elephant Butte Reservoir is located in an area where evaporative losses approach 100 inches per year. Upstream reservoirs are subject to evaporation rates of less than half this value. It may also be possible to store water underground, through aquifer recharge programs.

Physical Opportunities for Restoration Under Existing Conditions

Hydrologic Manipulations: Under existing constraints, hydrologic manipulations on a general scale are not possible because of current water law and project authorization, as well to a lack of funding. There are opportunities for specific changes in flow in each bioregion, but there is limited ability to realize large-scale improvements. Under existing constraints, one promising hydrologic tool is replacement of high water use species such as saltcedar with components of the riparian mosaic that require less water. This tool is described in greater detail under Vegetation Management.

Geomorphic Manipulations: A variety of actions can be taken to restore geomorphic conditions in the channel to more natural levels. In areas of heavily channelization, there are opportunities to use “natural channel reconstruction” techniques to reverse negative impacts. These can include altering the channel cross-section, profile, and alignment, and inducing sinuosity in areas where the channel has been physically straightened. However, the presence of levees, infrastructure, and development reduce the footprint of such projects. Grade restoration facilities (GRFs) can be constructed to raise the bed elevation and locally reverse the impacts of channel incision, or prevent future channel incision. GRFs also function to increase floodplain connectivity.

Steps can be taken to restore dynamic conditions such as bank erosion, bar creation, channel avulsion, and the formation of side channels. Side channels can be physically constructed, or remnant channels can be excavated and reconnected to the main channel. Clearing dense vegetation to provide a corridor for the new channel, or excavating a pilot channel and blocking the main channel can simulate channel avulsion. These techniques are limited in their application and dynamic channel processes must be reintroduced very cautiously as adjacent infrastructure and development could be damaged if the channel were to significantly change location.

Geomorphic restoration activities on the floodplain under existing constraints primarily involve actions to increase the hydrologic connectivity with the main channel. The most widely applicable technique would be lowering the floodplain to allow the channel to flood more frequently. Side channels can be constructed to connect low-lying areas away from the main channel may also be used. As previously mentioned, the GRFs can be used in incised channels to help restore floodplain connectivity. Removing or breaching natural levees in specific locations also increases the frequency of overbank flows.

Vegetation Management: The primary goal of vegetation management throughout the project area under existing constraints is the reduction of invasive species and their replacement by appropriate native species. Control of invasive species will require continued maintenance. The primary restoration tool is mechanical removal, which is often supplemented by herbicides applied to roots and stumps. Manipulation to create conditions more favorable to the native species (for example, improving overbank flooding and timing spring peaks in conjunction with planting native species,) are other tools to reach the goal. Grazing management may also play an important role, preventing livestock from feeding on young native plants before they become established. Wetlands and wet meadows, once a more extensive part of the riparian corridor, can be recreated by manipulation of the topography and reintroduction of the proper hydrologic conditions. In some case, manipulation of the soils may also be required.

The ultimate outcome of vegetation management is a mosaic of native vegetation ranging from low-lying willow stands, to wetlands, wet meadows, cottonwood gallery forests, grasslands, and shrub lands. Maintaining such a mosaic under existing constraints will require some intervention, primarily to control invasive species, and possibly to assist in regeneration. Self-sustainability can be increased by restoring hydrologic and geomorphic processes that help native species thrive.

Physical Opportunities for Restoration Under a Visionary Scenario

Under the visionary scenario, a much larger array of restoration activities is possible throughout the project area. Key elements in a vision of a restored Rio Grande include restoration of flows that more closely resemble the historic hydrograph, reinstatement of geomorphic processes and characteristics that represent a more natural system, control of invasive species, and the adoption of land use and water resource management policies that promote and maintain such a system. The central question--how to establish a hydrograph that mimics the historic one while meeting present-day water needs of the inhabitants along the Rio Grande--is not answered in this effort. The solution will be very complex, and may take years, even many decades. It will require the cooperation of all stakeholders, and large capital expenditures to improve existing infrastructure and water use practices. Nonetheless, restoration efforts along the Rio Grande should strive toward just such an objective.

Establishing a hydrograph that “more closely resembles the historic hydrograph” does not mean recreating the conditions that existed prior to human utilization of the Rio Grande. This is hardly achievable since water is needed to sustain the present and future population. Reduced volume and the control of extreme flood events would necessarily be a part of the restored hydrograph. At the same time, essential geomorphic and biological functions could be revived through annual peak discharges to sustain geomorphic processes similar to historic conditions, maintenance of low flow regimes, timing various components to coincide with the shape of the natural hydrograph, and variability from year to year. The idea of generating a spring flood pulse that flows through the system from one end to the other was developed at the Restoration Vision workshop, and should be incorporated into a revised hydrograph (with flood defined as water flowing into overbank areas within managed floodplains and not with catastrophic effects such as widespread property damage). This pulse would not be as large as the natural one, but of a magnitude necessary to sustain the functions of a scaled-down Rio Grande. The peak portion of a hydrograph is important because it maintains the geomorphology of the system. It contains a range of flows to transport sediment in the system, erode banks, and create new low-lying areas through deposition. Peak flows scour areas to create deep pools, and deposit large woody debris, both of which help to provide diverse aquatic habitat. In some cases, peak flows facilitate the avulsion process whereby the current main channel is abandoned, and a new one is formed in the floodplain. The peak portion of the hydrograph also spreads over the channel banks and out onto the floodplain, dispersing seeds, providing moisture and nutrients, and creating the conditions necessary for establishment of much of the native riparian vegetation. Such flows also provide hydrologic input to wetlands and marshes in the floodplain. Finally, deposition, erosion, lateral migration, and avulsion processes provide the variability in floodplain topography that is necessary for a mosaic of native vegetation and a restored Rio Grande.

Conclusions and Recommendations

Under the visionary scenario, a mini-Rio Grande is established that provides a balance between environmental restoration, and water resources to support human activities. Key hydrologic, geomorphic, and habitat features and functions of the historic Rio Grande can be re-created, so that it is possible to re-introduce and sustain fish species that have been extirpated or endangered. Similarly, terrestrial species that depend on the habitat in the riparian corridor also become more sustainable.

A visionary level of restoration is only possible if stakeholders throughout the project area work together to solve the regions' water problems. It is possible to perform very significant physical restoration at the local and regional level through amendments to the channel and vegetation, but to perform truly visionary restoration requires hydrologic conditions that can only be achieved with the cooperation of stakeholders throughout the project area.

Creation of the hydrograph just described will not be an easy task. It will require an extensive effort in terms of research, stakeholder involvement, legislative action, public education, engineering, construction of new facilities, and changes in land and water use. Research will be needed to determine the characteristics of the hydrograph, the resulting morphology of the Rio Grande, and the ecosystem that it will support. Public education and stakeholder involvement will be needed in order for society to make decisions about the desired level of restoration. Legislation will be necessary to provide authorization, and changes in land and water use will be needed to prevent the flows of the Rio Grande from being consumed at a rate of 90-95% in the project area. New projects will need to be constructed and old projects modified to reduce water consumption, and to minimize impacts on the sediment balance within the system. Ultimately, restoration of the Rio Grande will be on a similar scale as the restoration of the Florida Everglades, or the recovery of salmon in the Pacific Northwest.

Realization of the visionary level of restoration will require substantial funds. The likely source for much of these funds would be the Federal government. Large-scale activities associated with more efficient water management, or the "re-plumbing" of the system, will require extensive studies and analysis, in addition to actual capital expenditure. Securing such funding is most likely to be successful if pursued cooperatively by all parties. Planning, implementation, and long-term operation of the improved system will also require a high level of cooperation and stakeholder interaction.

Water is the element that binds all groups seeking to restore the Rio Grande. Significant changes in hydrology, such as the system-wide spring pulse, will require a basin-wide effort. Most current restoration efforts are local in nature, and there are also several regional projects underway such as the Rio Grande Headwaters Restoration in the San Luis Valley, the ESA Habitat Restoration effort in the Middle Rio Grande, and the San Acacia South project in Socorro County. Both local and regional work must continue, and should be coordinated with system-wide efforts.

System-wide restoration must be endorsed as a goal by local and tribal governments, and other key stakeholders on the river. Federal and state legislation supporting system-wide restoration is a necessary step to provide a mandate and resources to local officials. Legislation should be developed with local participation. Momentum for restoration will best be achieved if solutions can be developed that benefit all stakeholders. This may require large-scale alterations to the system to reduce losses such as reservoir evaporation, promote conservation, and increase the efficiency of water delivery and distribution systems. There is a need to work with the agricultural community, as these are the stakeholders with the most land in the historic river corridor, and the greatest number of water rights. They are also the stakeholders that feel most threatened by the restoration effort.

Successful restoration of the Rio Grande system cannot happen without coordination and communication. To this end, it is recommended that a non-profit institution (Rio Grande Restoration Task Force) be established to direct, coordinate, and implement a system-wide restoration effort. The Task Force's Board of Directors should include local, state, and federal representatives from the U.S. and Mexico, non-governmental organizations, and the Pueblos. The "Vision" presented in this document should be considered as a work in progress, and revisited as experience is gained, as situations change, and as constraints to restoration are eased or eliminated.

1 INTRODUCTION

The Rio Grande basin straddles two countries, eight states, and over a dozen Native American nations. It is home to approximately 10 million people, and human populations are growing fast. In addition, the basin supports a unique web of wildlife, including some 250 species of birds, hundreds of native mammals, and many fish and reptiles. The Rio Grande is one of the most unique and valuable ecosystems on the planet. Unfortunately, it is also one of the most degraded.

This document presents a "Restoration Vision for the Rio Grande," developed by Tetra Tech and the Alliance for the Rio Grande Heritage (Alliance). The project covers the area known as the Upper Basin, approximately half of the 1,900 mile-long Rio Grande, from its headwaters in the San Juan Mountains of Colorado, to Candelaria, Texas, just above the confluence with the Rio Conchos. **Figure 1.1** provides an overview of the project area.

1.1 Need for a Restoration Vision

Over the past century, changes have been made to the river in the process of human development: dams have been constructed, periodic natural floods have been eliminated, the river channel has been straightened, riparian habitat (including much of the signature cottonwood forest known as the *bosque*) has been destroyed, and numerous plant and animal species have become extinct, endangered, or extirpated. Many of the river's hydrologic and geomorphic characteristics have been highly altered, and as a result, the unique and valuable ecosystems of the region have become degraded.

The Rio Grande may never return to its pre-developed state, but portions of it are being restored within existing political, economic and physical constraints. As new technologies are developed, as funding for water management and restoration are increased, as further understanding of the river and its ecosystem is gained, and as the desire to manage the system in a more environmentally sensitive manner increases, many existing constraints to restoration will likely be removed. The concept of restoration is not new, and it is gaining ground in the scientific community as a viable solution to balancing the interests of all who depend on the river.

The need to develop a restoration vision for the Upper Basin of the Rio Grande is fourfold. First, the historic priorities for management of the Rio Grande have been efficient conveyance of water and flood control. Until recent times, little attention was paid to environmental and ecosystem aspects of the river. This has changed in the past decade due to a growing public awareness that the health of the bosque is deteriorating, and to the federal listing of the southwestern willow flycatcher and Rio Grande silvery minnow as endangered species. Restoration should be a cornerstone of any approach that constructively addresses these biological issues.

Second, as a result of modification of the Rio Grande to serve human needs associated with development, many of the system's important functions have been greatly impaired or lost. Some of the most obvious changes are to the hydrology. Today, upstream reaches receive as little as 50% of the pre-development volume, and downstream areas less than 10% of the river's historic flow. Other major hydrologic changes include the reduction or elimination of flood peaks that frequently inundated the adjacent floodplain, and alterations to the timing of the hydrograph. In many places, channel geomorphology has also been altered by levee construction, channelization, bank stabilization, and shifts in the sediment balance due to upstream reservoirs. (As an example, nearly 600,000 acre-feet of sediment lies trapped in Elephant Butte, an amount that would entirely fill Cochiti Reservoir.) Unfortunately, even the currently degraded system is not likely to be maintained without some sort of "restoration" effort. Hydrologic and physical manipulation is expected to continue in portions of the study area, causing continued narrowing of the channel, conversion of the substrate from sand to gravel, and continued channel incision. Restoration of the physical characteristics of the hydrology and geomorphology of the Rio Grande is a necessary building block to any restoration of the system's biological component.

Third, to add urgency to the need for restoration, population growth in the Rio Grande Basin is placing further demands on the region's limited water resources. Planning efforts are underway in major cities along the river, including Santa Fe, Albuquerque, Las Cruces, and El Paso/Juarez, to utilize the waters of the Rio Grande. These efforts potentially represent greater stresses on the system, and on the ability to maintain current conditions. At the same time, they present opportunities to incorporate environmental restoration into the management of the Rio Grande. To make use of these opportunities, a system-wide view is needed, just as there should be a system-wide view of water management issues.

Finally, the project area encompasses nearly 900 miles of the Rio Grande, and a broad, overall view of restoration can help maximize benefits to the whole system, as well as avoid inadvertent negative impacts to upstream or downstream areas. Not only are there technically complex issues associated with such a large and diverse system, but also numerous legal, political, economic and social issues that must be properly considered. This report can assist in developing synergistic local, regional and state restoration projects that support solutions to system-wide issues.

1.2 Purpose of Effort

Various agencies and groups are pursuing restoration on the Rio Grande. Some efforts focus on a particular geographic location, for example, Bosque del Apache National Wildlife Refuge, or the Pueblo of Santa Ana. Others address specific aspects of restoration such as the preservation and recovery of the endangered Southwestern willow flycatcher, or the Rio Grande silvery minnow. The work conducted by the Alliance, however, offers a more sweeping view, and provides a framework for integrating the biological and physical aspects of restoration. In the long run, this will help those involved in restoration to look not only at a specific mission, but to a greater level of functioning for the entire system.

The overall purpose of the Vision effort is to outline restoration opportunities, constraints, and issues in the Upper Rio Grande Basin. It is not feasible to restore the system to conditions found prior to human influence. “Restoration” in this document therefore refers to a return to physical and biological conditions that approximate those existing during the Holocene, yet within the constraints imposed by present and future sustainable human use of the basin’s land and water resources. The restoration opportunities identified in this document are developed under two scenarios. One recommends work that can be carried out under existing constraints, while the other, more ‘visionary’ scenario assumes that in the future, those who use and manage the river will place a higher priority on environmental function and sustainability, and many of the current constraints to restoration will have been eased or eliminated.

What does a vision for restoration of the Rio Grande encompass? This key question was posed at a workshop in March of 2002. (See Section 1.4) Many specific recommendations, projects, and potential opportunities were discussed there, but several themes emerged. These are incorporated in the following Vision Statement, with the recognition that implementation will require the cooperation of many different stakeholders, and that by definition, a sustainable future must equitably balance all interests. The Alliance hopes this Vision Statement will foster discussion about a sustainable future for the natural and cultural heritage of the Upper Rio Grande Basin, and welcomes the opportunity to work with all parties to address their concerns and issues.

We envision a Rio Grande that sustainably supports both the ecology and biota of the river, and the needs of human inhabitants of the region. To sustain the Rio Grande ecosystem and its native aquatic and riparian biodiversity, we need to promote flows that more closely resemble the historic hydrograph; re-establish geomorphic processes and other characteristics that maintain the river’s channel, floodplain and riparian corridor; control invasive species; and encourage land use and water resource management that promotes and maintains such a system.

Progress toward this visionary level of restoration for the Rio Grande will require a coordinated, basin-wide effort to address a number of overriding issues. The most important--and contentious--of these is the limited availability of water. This is a basin-wide issue whether the goal is general restoration; specific restoration to address Endangered Species Act compliance; water supply for agricultural, municipal and industrial use; or water to meet Rio Grande Compact deliveries. A major step toward basin-wide management of water resources is the Upper Rio Grande Water Operations Review. This analysis is being undertaken to coordinate Rio Grande water operations from Colorado to Fort Quitman, Texas, within the authorities of three joint lead agencies: the U.S. Army Corps of Engineers, the U.S. Bureau of Reclamation, and the New Mexico Interstate Stream Commission. Besides water supply and operations, other restoration issues that require a basin approach are the control of invasive species, improvement in the sediment balance, development of a water rights administration system that recognizes flows for environmental purposes, and adherence to land use policies that ensure preservation of the river corridor.

Even though there are pressing issues that offer compelling justification for large-scale cooperation, solutions and partial solutions can also evolve from local, regional and state initiatives. These are extremely vital, and it is not the intent of the Vision project to replace or compete with them, but to assist in weaving them into a system-wide restoration effort.

1.3 Project Approach and Scope

This report covers key biological, hydrological and geomorphological processes used to develop and support the Restoration Vision; it also presents the issues and constraints associated with restoration, and identifies opportunities for restoration throughout the project area. It is a conceptual document that identifies what is, or may be, possible. Additional work will be required to further evaluate, quantify, plan, design, fund and implement the restoration concepts presented here.

Some restoration opportunities can be implemented under existing constraints. Others would require significant action such as project re-authorization, land acquisition, water rights acquisition, large-scale construction efforts, changes in water rights administration, or major funding. The “Vision” scenario is therefore one that may only develop after decades of cooperation between entities that currently hold differing views on restoring and utilizing the resources of the Rio Grande.

Restoration opportunities are presented on a “bioregion” basis. The study area was divided into Upper, Middle and Lower Bioregions, based on both geomorphic and ecological conditions. These are shown in **Figure 1.1.** Each bioregion was further divided into ‘reaches’ based on hydrogeomorphic conditions, and a total of nineteen were defined. Delineation of both the bioregions and reaches is further discussed in Chapter II.

Current and historic conditions were reviewed to determine what restoration might actually mean for each reach. This included important biological aspects of the system as well as physical process-oriented features. Next, significant physical, legal, and administrative constraints that could limit restoration were examined. Finally, achievable opportunities for restoration in each bioregion were identified for both the “Existing Constraints” and “Visionary” restoration scenarios.

The general philosophy is one of creating favorable hydrogeomorphic conditions. These may take the form of providing different flow regimes, returning a level of dynamic behavior to the system, removing main-channel constraints such as dense invasive vegetation, expanding the floodplain corridor, managing vegetation and/or sediment, and altering channel geometry. Current science suggests that hydrogeomorphic conditions provide the foundation for biological functions; however, the report addresses biological aspects to ensure that proposed hydrogeomorphic objectives are consistent with biological needs.

1.4 Restoration Workshop

To obtain input from a diverse and interdisciplinary team of scientific and policy specialists, the World Wildlife Fund and the Alliance co-hosted a Rio Grande Restoration Workshop in March of 2002, in Albuquerque, New Mexico. Workshop invitees included U.S. and Mexican representatives from academia, non-governmental organizations, federal and state agencies, irrigation districts, acequia associations, and Pueblos. About 60 people attended, including experts in terrestrial and aquatic ecology, restoration, hydrology, geomorphology, and policy. A list of attendees is provided in **Appendix F**.

The central goal of the workshop was to develop a restoration vision for the Upper Rio Grande Basin based on input from representatives from the three bioregions. In preparation for developing the vision, initial sessions of the workshop were structured around four key topics: (1) identification of biological targets, such as distinct riparian and aquatic communities, habitats, or species assemblages that define the biological health of the river system; (2) identification of ecological, hydrological, and geomorphic conditions that support the biological targets; (3) identification of constraints to preserving, restoring, or creating these conditions; and (4) identification of restoration goals and opportunities on both a localized and an ecoregional scale. With this foundation, the workshop participants broke into groups to develop the 'existing' and 'visionary' restoration scenarios for each of the three bioregions.

The workshop focused on interactive dialogue between experts to capture the complexities and synergies of the entire river system. Breakout groups by bioregion were used to facilitate this process, while larger, plenary sessions provided an avenue for exploring linkages between the regions. Output from the workshop provided the foundation for this Vision document.

1.5 Uses for the Restoration Vision Document

The Restoration Vision document is intended to serve a number of uses. It provides a framework for developing a system-wide model for restoration work on the Rio Grande. It informs restoration participants of overall issues, needs, and opportunities. It identifies major stressors that have precipitated the need for restoration, and it provides some understanding of what the system has lost in terms of hydrogeomorphic conditions, habitat and biodiversity. Finally, it serves as a stimulus for further studies and planning efforts, and offers a tool to assist in pursuing funding for restoration-related activities.

This is not a scientific treatise on restoration, or an engineering document supporting design and implementation of specific restoration projects. Rather it is a framework to assist in planning more specific activities. It is qualitative rather than quantitative, and is not intended to circumvent or take precedence over restoration activities that are currently ongoing or being planned. Many questions must be answered before we know how best to proceed, especially if we are to accommodate the human activities that so often seem pitted against efforts at restoration.

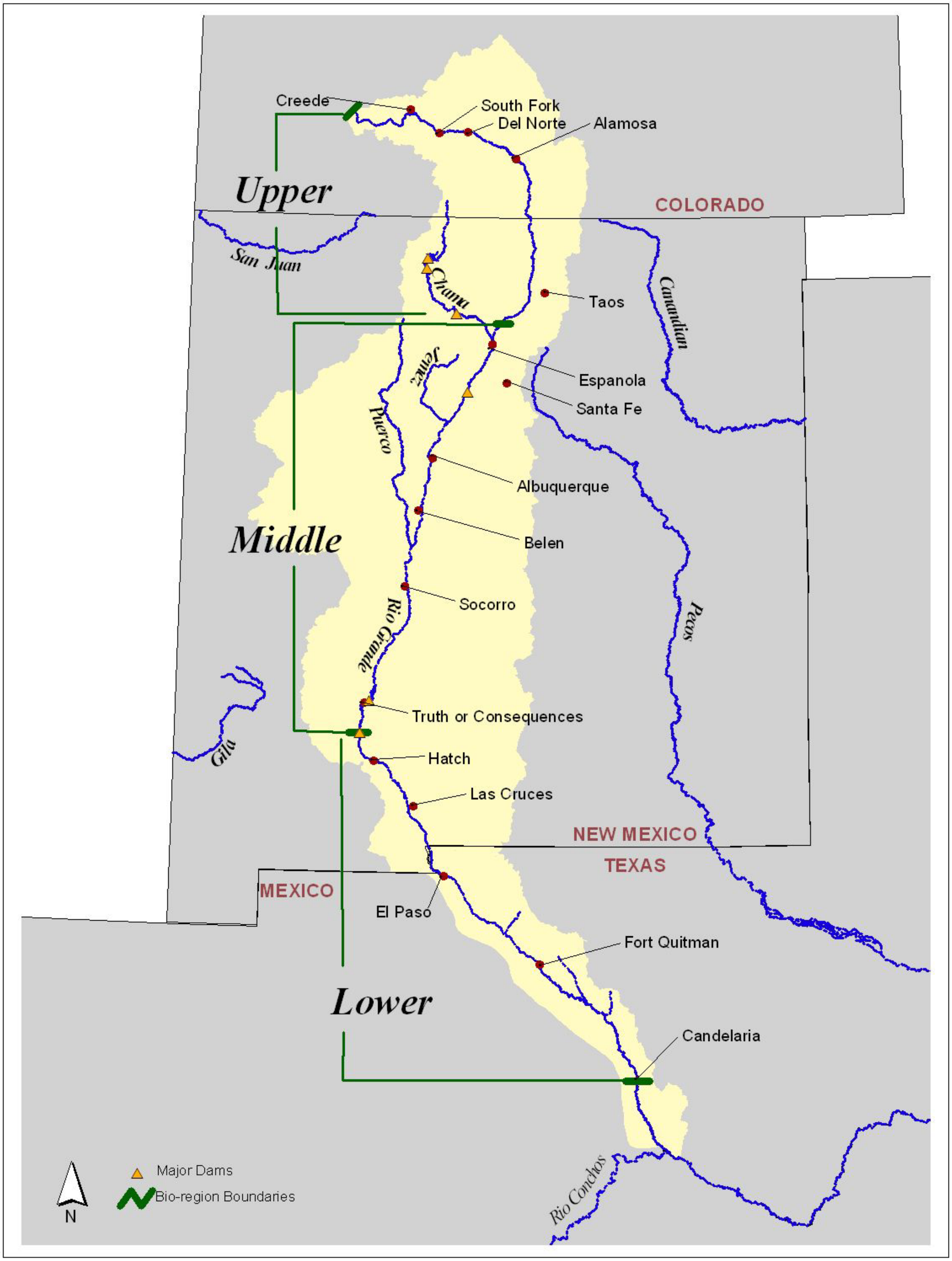

Figure 1.1 – Rio Grande Restoration Vision Project Area Map

2 OVERVIEW OF THE RIO GRANDE

The Rio Grande flows 1,900 miles through a variety of conditions. It starts in the San Juan Mountains of Colorado and traverses mountain valleys, deep canyons, high plains and open deserts until it empties into the Gulf of Mexico near Brownsville, Texas. It drains just over 180,000 square miles of arid and semi-arid lands that average below 15 inches of precipitation annually. A few locations see less than 5 inches a year. The Rio Grande is thus the lifeblood of both the natural ecosystem and of human development, and the river has been greatly altered by human demands on it that date back hundreds of years. Except in remote and confined canyon reaches, its valley is still used for agriculture, and most of the region's major urban centers have also developed there.

2.1 History of Development and Use of the River

Development of water use in the study area has followed similar patterns across the entire system. Initial habitation was by Native Americans. Then followed a period of Spanish settlement and increased water resource development. The most extensive period of development began in the later 1800s and has continued to the present. The following description of development along the Rio Grande is divided into three areas associated with major river valleys. The three areas are the San Luis Valley, the Middle Rio Grande Valley and the Los Palomas/Mesilla/El Paso Valleys, which correspond to portions of the Upper, Middle and Lower Bioregions, respectively.

2.1.1 San Luis Valley

The San Luis Valley is located in southern Colorado and northern New Mexico. One hundred twenty miles long and over 40 miles wide in some locations, its northern limit is Poncha Pass in Colorado, and it extends south to Taos, New Mexico. To the north and west, it is bounded by the Continental Divide, while the Sangre de Cristo Mountains form its jagged eastern boundary. It encompasses an area of over 4,000 square miles, with Alamosa, Colorado near its center, and it lies within the Upper Bioregion of the Rio Grande.

Prior to Spanish exploration in the 1500s, the San Luis Valley was primarily a Native American hunting ground. Spanish settlement began in the 1600s, but unlike downstream valleys of the Rio Grande, extensive development did not begin until the mid-1850s. The oldest town in Colorado, San Luis, was founded in 1850, and contains the state's oldest water right, established in 1852.

Large-scale development of the water resources of the Rio Grande in the San Luis Valley began in around 1880, resulting in the creation of the current delivery system. In the period from 1880 to 1890, six major canals were constructed to irrigate 300,000 acres (Montgomery Watson Harza, 2001). By the early 1900s, the surface water of the San Luis Valley was fully appropriated, and reduced flows to downstream users in the Middle Rio Grande and Mesilla/El Paso Valleys had created concern over allocation of the Rio Grande. In 1886, the United States government suspended all rights-of-way in the valley, preventing further agricultural development. At the same time, negotiations were initiated to apportion the river between Colorado, New Mexico and Texas. In 1928, a preliminary agreement was reached, and the Rio Grande Compact was formally signed ten years later. Today, estimates of the total irrigated cropland in the San Luis Valley are on the order of 500,000 acres, with the primary crops being potatoes, small grains, alfalfa, grass hay, pasture, carrots, lettuce and spinach (Montgomery Watson Harza, 2001).

Both surface water and groundwater play important roles in the valley's water supply. In the period from 1912 to 1915, several private reservoirs were constructed to store early runoff to be used during the irrigation season. Wells have also been used throughout the valley to supplement surface water for irrigation. A moratorium on additional high capacity wells in the confined aquifer was enacted in 1972. In 1981, a similar moratorium prohibited the drilling of new high capacity wells in the unconfined aquifer (Montgomery Watson Harza, 2001). However, the large water and irrigation system in the San Luis Valley is mostly supported by direct diversion of stream flow, and is "primarily run of the river" (Vandiver, 1999). Groundwater does supply 25 to 40 % of the water used for irrigation. Additionally, groundwater from the Closed Basin Project helps Colorado meet its Compact delivery obligations. Since its completion in the mid-1980s, the Closed Basin Project has delivered 30,000 to 40,000 acre-feet per year. The current capacity is 50,000 acre-feet, with an authorized capacity of 100,000 acre-feet annually.

2.1.2 Middle Rio Grande Valley

The geographic extent of the Middle Rio Grande Valley is defined differently, depending on the source. In this document, the Middle Rio Grande is considered to be the area between Cochiti Reservoir and Elephant Butte Dam. This 200-mile segment of the river lies within the Middle Bioregion.

From over 10,000 years ago to about 400 AD, the Middle Rio Grande was inhabited by Native American hunter-gatherer cultures. Limited agricultural development began in 400 AD, and by 1350 AD, both population and agriculture increased in association with the Anasazi culture. This is the period of first significant impact on the native riparian forest, or bosque, with clearing for agriculture, and the diversion of water from the Rio Grande for crops (Crawford, et.al., 1993). The descendents of the Anasazi people, the Pueblos, later established agricultural villages throughout the region. Six Pueblos exist in the Middle Rio Grande today: Isleta, Sandia, Santa Ana, San Felipe, Santo Domingo and Cochiti. These Middle Rio Grande Pueblos are likely to play an important role in future allocation and development of the Rio Grande's water resources, as 8,847 acres of Pueblo land have been recognized as having prior and paramount water rights. Several of the Pueblos have undertaken major river and/or habitat restoration projects, and more are planned.

The first European explorer, Coronado, estimated that 25,000 acres were being farmed. A member of his party wrote, "This River of the Nuestra Senora flows through a broad valley planted with fields of maize and dotted with cottonwood groves." Actual Spanish colonization began in 1590, and more land was cleared and water diverted for farming. By 1800, it is estimated that 100,000 acres of the Middle Rio Grande Valley were irrigated (Crawford, et.al., 1993). Maximum agricultural development, in terms of acreage, occurred around 1880, after an influx of Anglo-American settlers following the end of the Civil War and the arrival of the railroad in 1879. By 1880, a maximum of 125,000 acres was under cultivation.

After 1880, however, agriculture began to decline in the Middle Rio Grande due to increases in shallow groundwater and soil salinity, and a decreased supply of water for irrigation. The river aggraded as overgrazing and deforestation accelerated erosion in the watershed, and increased farming in the San Luis Valley reduced incoming river flows.

The Middle Rio Grande Conservancy District (MRGCD) was formed in 1925 to address the decrease in irrigated lands in the Middle Rio Grande Valley. The conservancy consolidated the headings of some seventy acequias into four major river diversions, constructed drains to convey high groundwater and irrigation return flows back to the river, installed levees to help stabilize the channel, and built El Vado Dam on the Rio Chama to store water for district irrigators. Even with the improvements, the levees were breached and overtopped during the flood of 1941, prompting the U.S. Bureau of Reclamation and Army Corps of Engineers to study solutions to the problem in 1943. A plan was authorized by congress in 1948, and eventually resulted in the construction of four more dams (Abiquiu, Jemez, Galisteo and Cochiti), enlargement of the levees, and stabilization of the "Rio Grande Floodway" with fields of jetty jacks.

In the early 1950s, the Bureau of Reclamation initiated construction of the Low Flow Conveyance Channel (LFCC) from San Acacia Diversion Dam to the Narrows of Elephant Butte Reservoir. The purpose of the LFCC was to assist the state in meeting its Compact delivery requirements, for by the mid-1950s, New Mexico's cumulative deficit had reached 500,000 acre-feet. The Low Flow Channel aided deliver of water to Elephant Butte Reservoir by reducing evaporation and seepage losses, and by concentrating flows of up to 2,000 cfs in the relatively narrow LFCC rather than in the much wider Rio Grande. It is estimated that from the late 1950s to the early 1970s, the LFCC reduced water losses through the 50-mile reach from San Acacia to San Marcial by 35,000 acre-feet (USBR, 2000). The LFCC has not operated since 1985 as a result of sedimentation problems associated with high water levels at Elephant Butte.

Currently, approximately 60,000 acres are under cultivation in the Middle Rio Grande Valley, and urbanization is increasing. The City of Albuquerque plans to begin diverting nearly 100,000 acre-feet a year of surface water imported to the Rio Grande basin by way of the San Juan-Chama Project. Of that amount, 50,000 acre-feet would be used consumptively, and the rest would be returned to the river. The City of Santa Fe is also exploring options for surface diversion of its 5,600 acre-feet of San Juan-Chama water.

2.1.3 Mesilla/El Paso/Los Palomas Valley

The Mesilla, El Paso and Los Palomas Valleys cover about 200 miles of the Rio Grande and the majority of the Lower Bioregion, from Caballo Dam in New Mexico to near Fort Quitman, Texas. The Los Palomas Valley extends from Caballo Dam to the upper limits of Selden Canyon. The Mesilla Valley stretches from the lower limits of Selden Canyon to El Paso, and the El Paso Valley includes the area from El Paso to Fort Quitman.

Native American hunter-gatherers occupied the Mesilla / El Paso Valley from about 10,000 BC to 1 AD. Then the relatively sedentary and agrarian Mesilla culture occupied the valley. In 1100, the Doña Ana phase began, with larger settlements and agricultural fields, although these settlements did not reach the level of the Middle Rio Grande Valley (Stotz, 2000). Around 1400, the settlements appear to have been abandoned, and by the 1500s, early Spanish explorers reported no permanent farming settlements. The first Spanish settlements were established in 1659, along with ditch irrigation from the Rio Grande, and agricultural development continued until the1800s.

In 1906, the United States signed a treaty with Mexico, providing for annual delivery of 60,000 acre-feet of water to the Juarez area. In 1916, Elephant Butte Reservoir, the main component of the Rio Grande Project, was completed, which greatly helped to stabilize the water supply for the region. The signing of the Rio Grande Compact in 1938, and completion of Caballo Reservoir were also significant events in the development of the area. In the 1930s, the International Boundary and Water Commission (IBWC) undertook two projects to facilitate delivery of water to Mexico, and to stabilize the river, which serves as the international border. The Rio Grande Canalization Project extends from several miles below Caballo Dam to El Paso, and the Rio Grande Rectification Project from El Paso to Fort Quitman.

Currently, about 160,000 acres are irrigated in the Mesilla / El Paso and Los Palomas Valleys. About 80% of those lands are in the United States. The City of El Paso currently obtains almost half of its water from the Rio Grande. Plans to secure more Rio Grande water for the cities of El Paso and Las Cruces, referred to as the Sustainable Water Project, have been stalled by failure of the cities to lease water from local irrigators.

2.2 Location and Study Area

The Upper, Middle and Lower bioregions referred to in this document are based on both geomorphic and ecological conditions, and are shown in **Figure 1.1**. Each bioregion is further divided into reaches, or segments of river in which hydrologic, geomorphologic, and biological factors are somewhat consistent. Land use and water resource management activities also play a role in defining reaches. The study area was limited to the main stem of the Rio Grande, and a total of 19 reaches were identified (**Figure 2.1a, 2.1b and 2.1c**). Chapter III provides an overview of the conditions in each bioregion as well as a discussion of the fluvial geomorphology of each of the 19 reaches.

2.3 Management Issues

2.3.1 Ecological Issues

From its mountainous headwaters to its desert canyons, the Rio Grande is the backbone for a rich and diverse assemblage of flora and fauna. Its ecosystems have been significantly altered by natural and human activities for over 400 years. From an ecological standpoint, the most damaging changes have occurred in the last 120 years, resulting in a loss of riparian and aquatic habitat, and reduced functionality. Many native plant and animal species are being replaced by exotic species better adapted to human-induced conditions.

Human occupation along the river corridor has altered the landscape and river system, resulting in a significant decline in plant and animal communities and populations. Over 20 species of vertebrate animals have been extirpated within the Middle Rio Grande basin alone (Scurlock, 1998), and more than 30 species have been recorded as sensitive, warranting some degree of attention (**Table 2.1**). The goal of the Endangered Species Act (ESA) (16 USC §§ 1531-1544 PL 93-205, 1973) is to protect existing sensitive species, making it a primary driver affecting 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 amended water operations to meet the needs of the endangered Rio Grande silvery minnow (*Hybognathus amarus*) and southwestern willow flycatcher (*Empidonax traillii extimus*). This has affected the timing and volume of flows, along with the types of water resource management and maintenance activities that are permitted in the river channel and floodplain.

In June 2001, the US Fish and Wildlife Service 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 Opinion outlines how the Bureau of Reclamation and Army Corps of Engineers will manage water operations along the Rio Grande, subject to Rio Grande Compact requirements. It also provides direction on specific river channel maintenance and restoration activities, and outlines monitoring requirements.

Besides endangered species and the loss of habitat due to water resources development, another important ecological management issue is invasive nonnative species. Most noticeable in this category is saltcedar (*Tamarix ramosissima*), which has become the dominant riparian vegetation in much of the Middle and Lower Bioregions. Additionally, Russian olive (*Eleagnus angustifolia*) is prevalent through the riparian corridor in the Upper and Middle Bioregions.

Closely related to the issue of nonnative species is the lack of regeneration of native species. Most notable is the scarcity of young cottonwoods (*Populus deltoides and angustifolia*) in the bosque. This is largely due to a lack of significant overbank flooding events, the timing of flooding events that do occur, stabilization of the river system that has greatly reduced the erosion and accretion processes that promote cottonwood regeneration, and in some areas, the build-up of salts in soils.

2.3.2 Water Resources

For more than a century, the Rio Grande has been managed for conveyance and delivery of flows, and for flood control. Because of the dynamic nature of the river, flood control efforts have also involved the control of sediment load, channel migration, and avulsion. In the Lower Bioregion, channel alignment has also been managed to preserve the international boundary between Mexico and the United States. To facilitate these missions, a large number of dams, diversions, levees and channelization works have been constructed on the Rio Grande. **Appendix A** provides a list of the most significant of these projects in the study area, and a discussion of the hydrology of the three bioregions identifies some of the hydraulic changes that have resulted from these projects. In addition, considerable legal and administrative infrastructure has been created to manage the Rio Grande. These topics are discussed below.

Flood Control Development in the floodplain has necessitated flood control projects to prevent damage to homes, business, agriculture, and infrastructure. This has been achieved through a combination of dams that store water and sediment, levees that confine floods to the channel area, and stabilization measures such as jetty jacks that prevent channel erosion and migration. At the same time, these projects have reduced flows, and altered the sediment balance and geomorphology of the system. In order to be acceptable to society, restoration efforts must take into account the continued need for flood control. Complete elimination of the flood control system would place hundreds of thousands of people and many acres of farmland and real estate at high risk of flooding on a frequent basis. The majority of those at risk would be in the concentrated urban areas. An effort needs to be made to prevent further encroachment on the floodplain, which increases the need for flood control. Adoption and enforcement of flood plain regulations and voluntary incentive programs to remove structures from the floodplain are non-structural alternatives to flood control that are much less environmentally damaging, and in many cases, less expensive than traditional structural methods.

Water Use By the time the Rio Grande leaves the study area, about 90% of the available water has been consumed by agriculture, riparian vegetation, municipal and industrial use, and evaporation from reservoirs and the river itself. The majority of the water used for agriculture is from surface supply, although about 40% used in the San Luis Valley is from groundwater (Harris, 1999). Most of the major cities along the Rio Grande are dependant on pumped groundwater; 80% of the nearly 250,000 acre-feet of water consumed by Albuquerque, Santa Fe, Las Cruces, El Paso and Ciudad Juarez is from groundwater (Harris, 1999). As aquifers are mined, these and other major cities will look increasingly to surface water to fulfill their needs.

The cities of Albuquerque and Santa Fe plan to utilize surface water imported into the Rio Grande Basin from the San Juan-Chama Project as a major component of their future water supply. But San Juan-Chama water will not meet municipal needs indefinitely. Populations can be expected to continue to grow, and cities will be forced to look for other sources of water.

In recent years, the City of El Paso has attempted to alleviate pressure on its depleting groundwater aquifer by shifting to a higher use of surface water (Paso del Norte Water Task Force, March 2001). Already the city obtains more than 40% of its water from the Rio Grande, and is looking for more. The Sustainable Water Project of 2000 was an effort to build new water treatment plants to make additional surface water available for use in El Paso, Las Cruces, and other communities in southern New Mexico. But no agreement has been reached with irrigators as to the terms under which water would be leased to the municipalities. In El Paso's sister city, Ciudad Juarez, Mexico, all surface waters delivered are currently used for agriculture, but efforts are being made to reallocate that water for urban uses within the next 20 years (Paso del Norte Water Task Force, March 2001).

Since Rio Grande surface water is fully or over-appropriated in almost all portions of the basin, new appropriations will not be available to meet urban needs. Thus it is likely that water for urban growth will be provided by conversion of agricultural water rights. This has happened throughout the west since the early 1900s, when a growing Los Angeles looked to the farms of the Owens Valley to quench its thirst.

Although this scenario appears not to bode well for the Rio Grande in terms of preserving, let alone restoring, its ecological values, it may ultimately provide an opportunity for securing water for environmental purposes. Without serious change, widespread water shortages will occur during periods of drought. Endangered species requirements may ultimately limit the water user's ability to extract the last available flows, and the issue of invasive riparian vegetation will also be at the forefront since dense monocultures may actually consume more water than the mosaic of native vegetation they replaced. Thus the severe conditions that loom ahead may provide an impetus for re-plumbing the system. Reducing water losses from evaporation and inefficient delivery systems, conserving water on farms and in urban areas, and restoring essential components of the ecosystem would actually reduce water demand in some areas, and provide needed flexibility in managing the system.

In the short term, the fully-appropriated status of the river, the difficulty states have in meeting Compact deliveries, and the general physical scarcity of water in the system, creates additional obstacles for restoration beyond the obvious need for hydrologic modifications. In both Colorado and New Mexico, restoration activities are scrutinized for their impact on consumptive water use. Widening the river channel can increase evaporative losses. Creation of wetlands and other alterations to vegetation can also increase depletions. Therefore, it is likely that restoration activities will have to be developed that create no increase in net depletions, or, offset water will have to be obtained.

Water Rights Under current appropriation law, water rights purchased for environmental purposes are not guaranteed to remain in the system, and will almost assuredly be diverted further downstream. To insure that water obtained for the environment remains in the river, such flows will need to be recognized as a beneficial use, and accounted for (along with associated conveyance losses,) throughout the system. Rio Grande Compact recognition of environmental flows will also be necessary, since once water passes a Compact delivery point, it becomes available to a new set of users.

Recognition and quantification of water rights currently claimed by New Mexico's Pueblos and other native peoples is an issue that must also be resolved. Though these cultures were established in the region prior to any development of water management policies, and though state and federal law recognizes their prior standing, there has yet been no overall quantification, and thus no formal recognition of the extent of these rights.

Rio Grande Compact The Rio Grande Compact, signed in 1938, divides the flow of the river between the states of Colorado, New Mexico and Texas. In addition, the Treaty of 1906 requires the United States to deliver 60,000 acre-feet a year to Mexico. The Compact has two delivery points, the Lobatos Gage on the Rio Grande upstream of the Colorado border, and Elephant Butte Reservoir. Typically, Colorado is required to deliver 25-50% percent of the water generated by the Conejos River and the Rio Grande to the Lobatos Gage (Vandiver, 1999), and New Mexico must deliver 50-90% percent of the flow measured at the Otowi Gage to Elephant Butte Reservoir. The percentage of water to be delivered increases as the flow in the river increases. Each of the upper states can accrue credits for over-delivery of water, and debits for under-delivery. In the case of Colorado, the annual debit and accrued debit cannot exceed 100,000 acre-feet. Colorado can accrue up to 150,000 acre-feet per year of credit with no limit on the total credit accrued over multiple years. Similarly, New Mexico can accrue up to 150,000 acre-feet of annual credit with no limitation on accrual over multiple years. New Mexico's accrued debit cannot exceed 200,000 acre-feet, with a limitation of 150,000 acre-feet, plus all gains in storage, for any one year (Rio Grande Compact Commission, 1998).

Since most of the water is generated above Otowi, without the Compact and the treaty with Mexico it is likely there would be less water in the Middle and Lower Bioregions. Those in the San Luis Valley have the capacity to divert and use most of what is generated above the Lobatos Gage, and it should be remembered that usage in Colorado and upstream portions of New Mexico was believed to have contributed to water shortages in the El Paso and Mesilla Valleys prior to 1900. Compliance with the Compact delivery schedules precludes upstream states from utilizing all of the water arising in that state, and provides downstream users with some assurance of a water supply. But the mere existence of the Compact does not ensure flow in any reach of the Rio Grande. Both New Mexico and Colorado have in the past far exceeded the debit limits established by the Compact, and although unlikely, there is no certainty that this will not reoccur in the future. Federal law gives the Rio Grande Compact Commission input to the operation of flood control reservoirs in the mid-Rio Grande Basin. Public Law 86-645 allows the U.S. Army Corps of Engineers to deviate from the operating schedule of Cochiti, Abiquiu, and Jemez Canyon Reservoirs with the consent of the Rio Grande Compact Commission. The flexibility to operate flood control reservoirs in a manner different from that set out in the operating criteria could be used in the future to enhance environmental values, if the Commissioners of the three states were to agree to do so.

There are, however, drawbacks to the Compact in terms of preservation and restoration of the environment. When the Compact was developed, it was generally believed that water not being put to beneficial use was being wasted. Therefore, the agreement does not assign any importance to streamflows other than for delivery of water to specific points, and it primarily addresses volumes of water to be delivered without consideration of timing. It also mandates that unless specified water levels are maintained at Elephant Butte, upstream storage becomes limited. Because of this, water is being stored at a location with very high evaporation losses. Finally, the Compact does not recognize instream or environmental flows, so even if water rights were obtained for environmental purposes, and even if the state of New Mexico condoned this as a beneficial use, once such flows reached a Compact delivery point, they would become available for diversion.

Geomorphology and Sediment Transport Construction and operation of water resource projects along the Rio Grande and throughout the basin have greatly altered the hydrology and sediment balance that governs the morphology of the Rio Grande. These projects include reservoirs on the mainstem and major tributaries, channelization, levee construction, channel stabilization, and diversions. These alterations to the system have resulted in accelerated channel bed degradation in some areas due to confinement of the flow. Other areas have experienced degradation as a result of a reduced sediment supply, channel narrowing as a result of reduced flows, or the invasion of non-native vegetation. In many locations, the planform and profile of the river have been altered directly or indirectly, resulting in changes in velocity, depth, substrate, and other basic fluvial characteristics. To be successful, restoration efforts must recognize changes that have occurred in the processes that govern the system, and either work within current hydrologic and sediment transport regimes, or strive to mimic historic regimes. The latter approach more closely addresses true restoration, but is more difficult to achieve because of the many constraints on the system.

Table 2.1: Sensitive Species Recorded Along the Rio Grande

Common Name	Scientific Name	Bio Region	ESA Listing	CO	NM	TX	MX
<u>Mammals</u>							
American beaver	*Castor canadensis*	M L					E
Ocelot	*Felis pardalis*	L	E			E	E
Jaguarundi	*Felis yaguarondi*	L	E			E	T
Occult myotis	*Myotis lucifugus occultus*	M					
Common muskrat	*Ondatra zibethicus*	M L					T
Silky pocket mouse	*Perognathus flavus*	U					
Eastern mole	*Scalopus aquaticus*	L					E
Hot springs cotton rat	*Sigmodon fulviventer goldmani*	M					
New Mexican jumping mouse	*Zapus hudsonius luteus*	M			T		
<u>Birds</u>							
Cooper's hawk	*Accipiter cooperii*	M L					T
Northern Goshawk	*Accipiter gentilis*	L					T
Sharp-shinned hawk	*Accipiter striatus*	M L					T
Zone-tailed hawk	*Buteo albonotatus*	L				T	
Common black-hawk	*Buteogallus anthracinus*	M			T	T	T
Southwestern willow	*Epidonax traillii extimus*	U M L	E	E	E		
American peregrine falcon	*Falco peregrinus anatum*	M L			T	T	T
Arctic peregrine falcon	*Falco peregrinus tundrius*	M L			T	T	
Whooping crane	*Grus americana*	M	E XN		E	E	E
Greater sandhill crane	*Grus canadensis tabida*	U		SC			
Bald eagle	*Haliaeetus leucocephalus*	U M	T PD	T	T	T	E
Mississippi kite	*Ictinia mississippiensis*	M L					T
Least bittern	*Ixobrychus exilis*	M L					T
White-faced ibis	*Plegadis chihi*	M L				T	
Interior least tern	*Sterna antillarum*	M	E	E	T	E	T
Lucy's warbler	*Vermivora luciae*	M L					T
Bell's vireo	*Vireo bellii*	M	PS		T		
<u>Reptiles</u>							
Reticulated gecko	*Coleonyx reticulatus*	L				T	
Racer	*Coluber constricta*	M L					T
Coachwhip	*Masticophis flagellum*	M L					T
Blotched watersnake	*Nerodia erythrogaster transversa*	L			E		T
Blackneck garter snake	*Thamnophis cryptopsis*	L					T
Western ribbon snake	*Thamnophis proximus*	L			T		T
Big Bend slider	*Trachemys gaigeae*	M					
Texas lyre snake	*Trimorphodon discutatus vilkinsoni*	L				T	
<u>Amphibians</u>							
Boreal toad	*Bufo boreas*	U	C	E			

Table 2.1: Sensitive Species Recorded Along the Rio Grande (continued)

Common Name	Scientific Name	Bio Region	ESA Listing	CO	NM	TX	MX
Fish							
Mexican tetra	*Astyanax mexicanus*	L			T		
Rio Grande sucker	*Catostomus plebeius*	U					
Blue sucker	*Cycleptus elongatus*	M L			E	T	
Prosperine shiner	*Cyprinella prosperpinus*	L				T	T
Rio Grande darter	*Etheostoma grahami*	L				T	
Blotched gambusia	*Gambusia senilis*	L				T	T
Rio Grande chub	*Gila pandora*	U		SC		T	
Rio Grande silvery minnow	*Hybognathus amarus*	M	E		E	E	E
Chihuahua shiner	*Notropis chihuahua*	L				T	
Bluntnose shiner	*Notropis simus simus*	M L				T	E
Rio Grande cutthroat trout	*Oncorhynchus clarki virginalis*	U					
Shovelnose sturgeon	*Scaphirhynchus playtorynchus*	M L				T	E
Gray redhorse	*Scartomyzon congestus*	M L			T		
Insects							
Uncompahgre fritillary	*Boloria improba acrocnema*	U	E				
Plants							
Rock-loving neoparrya	*Aletes lithophilus*	U					
Texas False Saltgrass	*Allolepis texana*	L				S	
Ripley milkvetch	*Astragalus ripleyi*	M			S		
Reflected moonwort	*Botrychium echo*	U					
Swallow spurge	*Chamaesyce goondrina*	L				S	
Slender spiderflower	*Cleome multicaulis*	U					
Smith Whitlow-grass	*Draba smithii*	U					
Black canyon gilia	*Gilia penstemonoides*	U					
Warnock's willow	*Justica warnockii*	L				S	
Wright's woody-aster	*Machaeranthera wrightii*	L				S	
Sand prickly-pear	*Opuntia arenaria*	L					
Weber's catseye	*Oreocarya weberi*	U					
S. Rocky Mountain Cinquefoil	*Potentilla ambigens*	U					
Grama grass cactus	*Toumeya papyracantha*	M			D		

Sources: CNHP 2002; NMNHP 2002; TXNHP 2002; Stotz 2000, *Historic Reconstruction of the Ecology of the Rio Grande/Río Bravo Channel and Floodplain in the Chihuahuan Desert.*
Notes: U = upper, M = middle, L = lower, E = endangered, T = threatened, PT = proposed threatened, PD = proposed for delisting, C = candidate for listing, XN = experimental non-essential population, PS = partial status, S = sensitive, D = dropped list.

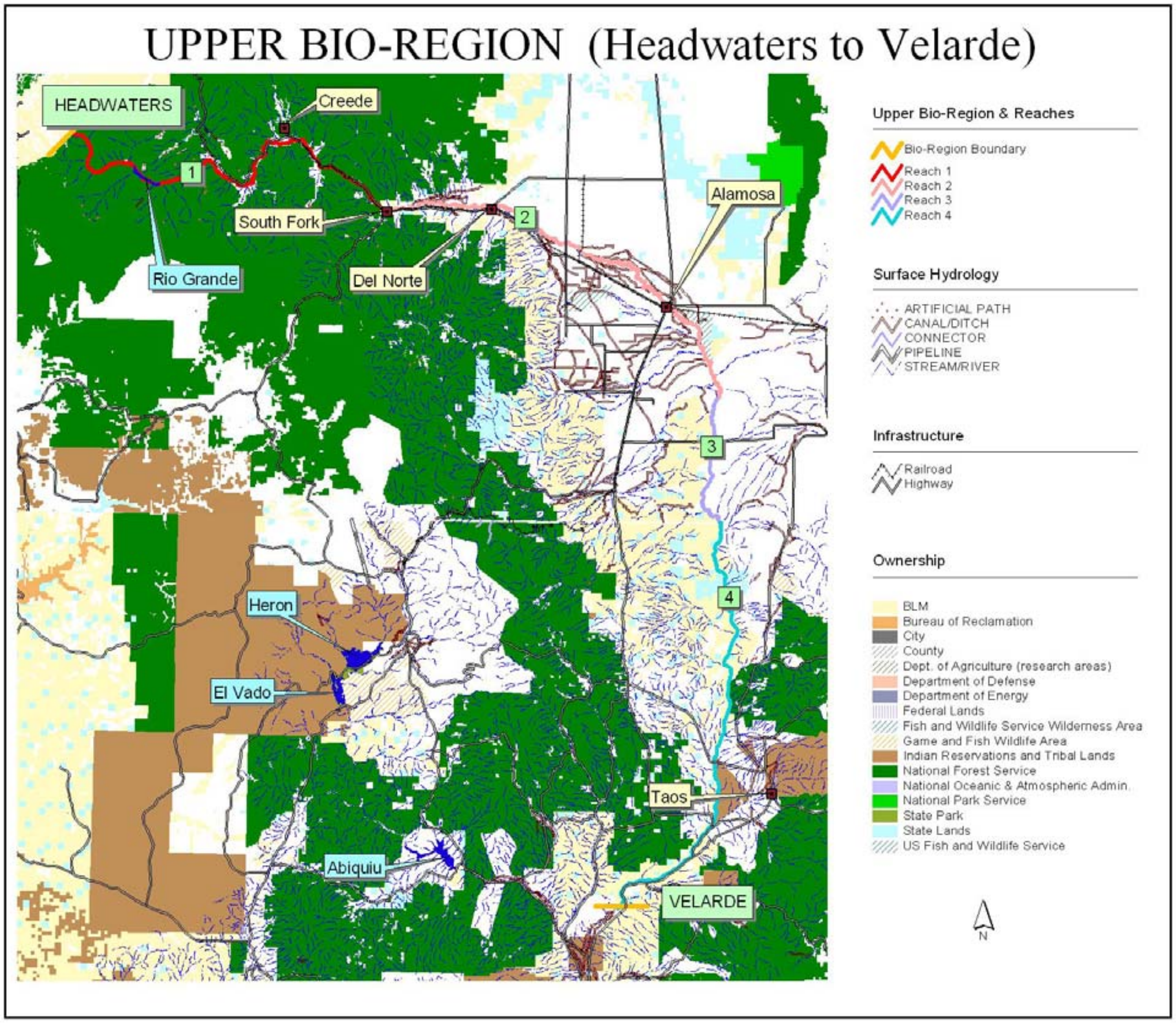

Figure 2.1a – Map of Upper Bioregion and Geomorphic Reach Delineation

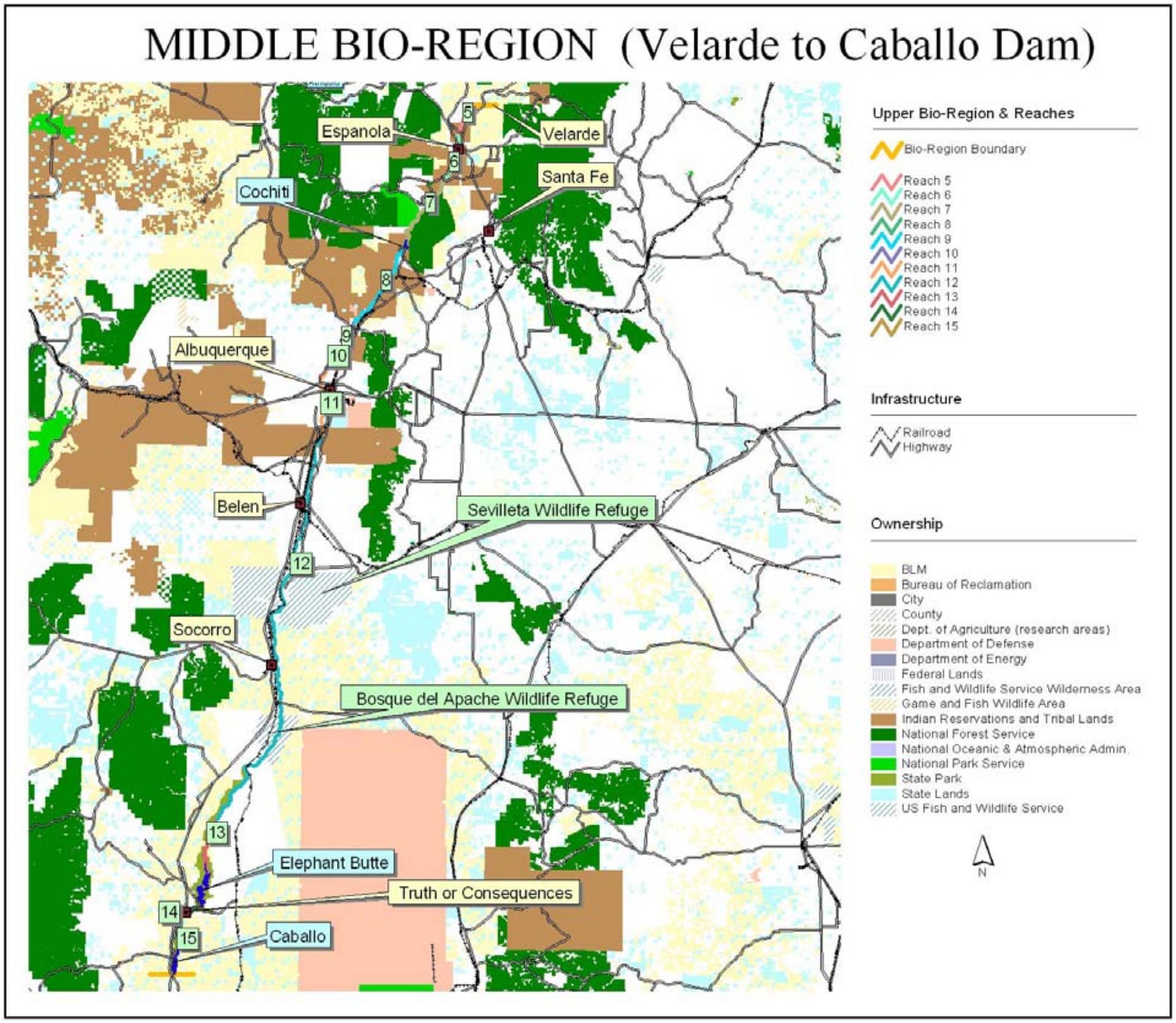

Figure 2.1b – Map of Middle Bioregion and Geomorphic Reach Delineation

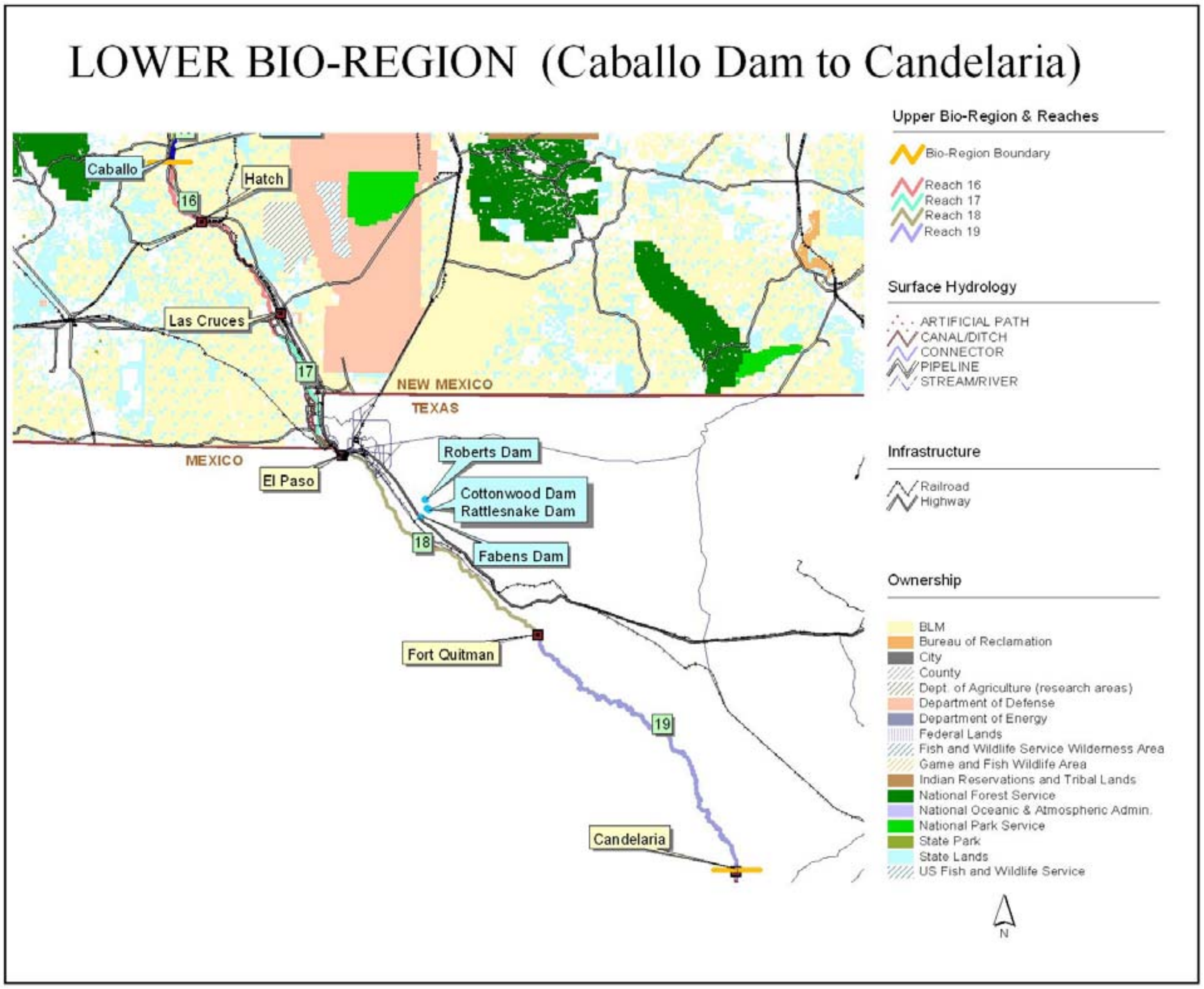

Figure 2.1c – Map of Lower Bioregion and Geomorphic Reach Delineation

3 ENVIRONMENTAL CONDITIONS AND CONSTRAINTS

Restoration of the Rio Grande requires an understanding of both the existing and historic conditions, and consideration of both physical and institutional constraints. This chapter presents an overview of these topics, arranged by bioregion, starting at the headwaters and proceeding downstream.

Descriptions of geomorphic characteristics for each bioregion are provided, along with more specific details of the geomorphic reaches delineated within each bioregion. The discussion centers on aspects of geomorphology that influence the river's function as part of the ecosystem. Besides a general discussion of these characteristics and possible human influences, a specific list of parameters is summarized for each reach in **Appendix B**. These parameters include: reach length, planform, sinuosity, bed material size, presence of lateral and vertical controls, floodplain width, 2-year peak flow, slope (range given in addition to average for reaches with high variability in slope), channel topwidth, and a list of key factors influencing the function of a reach.

The hydrologic description of each bioregion is based on analysis of flow records performed for selected USGS and IBWC stations throughout the study area. Gages selected represent key locations in each bioregion, with long periods of record. (**Figure 3.1**). Three types of analyses were performed: annual peak flow analysis for the 2-year and 100-year floods, determination of average annual flows, and frequency of selected low flow occurrences. The 2-year discharge is representative of annual peaks typically considered to represent the range of flows that play the biggest role in determining channel characteristics. The 100-year flood represents a more extreme range of flows that rarely occur. These are often used in the design of traditional river flood control, channelization, and stabilization projects, and in regulation of development in the river's floodplain. The average annual flow is an indicator of the total flow volume conveyed down the river; thus, multiplying the average annual flow by 724 yields the annual water volume in acre-feet. The three discharges used to characterize low flows were 0, 30 and 100 cfs. These low flows are described in terms of the number of days the flow in the river is equal to, or less than, the designated value. The impact of water resources development on low flows is not always intuitive. The obvious impact would be a reduction in flows and thus an increase in the frequency of low flows. However, in some cases, the end result of water development is to reduce the number of low flow days due to storage and releases for water supply during what would have been naturally low-flow periods. By utilizing the three values, all of which are significantly less than the 2-year peak and usually significantly less than the average annual flow, a quantitative description of changes in low flow characteristics can be made.

In analyzing the various flow characteristics just identified, most of the gage records were broken into several periods to isolate the possible influences of significant water resource development and river management activities (e.g., dam construction or the adoption of the Rio Grande Compact). A listing of water resource projects along the Rio Grande is provided in **Appendix A**.

In interpreting the results of the flow analyses, it must be remembered that although there are gages in all three bioregions dating back to 1900 or earlier, there are no measurements available for periods prior to significant diversions from the Rio Grande. Agricultural development was significant in the San Luis Valley, the Middle Rio Grande Valley, and the Mesilla Valley by the 1890s, and as early as the 1880s, there are reports of water shortages in the Mesilla Valley attributed to diversions in Colorado and the Middle Rio Grande. The fact that the measurement stations on the Rio Grande are among the oldest in the United States is indicative of the important role the river's flow was playing in the region as early as 1890. In reviewing the results of the analysis, it needs to be understood that the earliest records do not represent "natural" or "undeveloped" flow regimes in the Rio Grande. Rather, the early records represent a period when significant direct diversions were already present, even though large dams that could store water for flood control or water supply in dryer periods were not yet constructed.

The Rio Grande supports a complex ecological system made up of riparian areas, wetlands, and aquatic habitat, each with a diverse community of flora and fauna. Some of these communities are similar to those that existed under historic conditions, especially in the Upper Bioregion. Others have been significantly altered by changes in flow regime, water availability, human water use, and invasive species. In the Lower Bioregion, for example, most of the cottonwood galleries have been lost to homogeneous saltcedar thickets. The following discussion is based on a literature review, site visits, Summary Information Sheets prepared for the Rio Grande Restoration Vision Workshop by experts familiar with historic and existing biological conditions in each bioregion, and from input from participants at the Vision Workshop. (The Summary Information Sheets are provided in **Appendix C**.)

Much has been written on the biological condition of the Rio Grande system, and this chapter is not meant to serve as a catalogue of the flora, fauna, and aquatic assemblages of the river. Instead, it summarizes key habitats that indicate the ecological health and functioning of the system, and the biotic and abiotic features required for these habitats to flourish.

Typically, there are impediments or issues associated with restoration opportunities that can make them more challenging, more costly, or in some cases, completely infeasible unless the impediments can be removed. Such constraints on potential restoration activities are identified for each bioregion, and are divided into two categories, physical and legal/administrative. Examples of physical constraints might be the availability of water, the suitability of soils, or the presence of physical features such as dams and levees. Examples of administrative and legal constraints include Rio Grande Compact water deliveries, state water law, floodplain regulations, and operational rules associated with federal project authorization. A constraint may have both physical and legal/administrative issues associated with it. A reservoir alters the flow regime and sediment supply; this is a physical constraint that must be considered in developing downstream restoration projects. However, the ability to change operation of the reservoir will most likely involve water rights, or Compact and project authorization issues that may limit the ability to alter the release patterns and storage levels in the reservoir. Therefore, physical and legal/administrative constraints are intertwined. Constraints are not necessarily “fatal flaws” that prevent a restoration activity from taking place. Some can be overcome by mitigation, re-formulation of a project, acquisition of easements or land from willing sellers, stakeholder involvement, or even changes in project authorization.

3.1 Upper Bioregion: Headwaters to Velarde, NM

This bioregion covers the Rio Grande from its beginning as a high elevation stream in the San Juan Mountains of Colorado, through the open, high elevation San Luis Valley, and into the confined canyon of the Rio Grande Gorge. Four dominant ecological systems are present: upper montane/subalpine riparian forest; montane/subalpine riparian shrubland; lower montane riparian woodland; and foothills riparian woodland/shrubland.

The greatest opportunities for restoration in this bioregion are found in the San Luis Valley, since this is the portion in which river morphology and hydrology have been altered the most. Reach 2 of the geomorphic reach delineation represents the San Luis Valley. The primary restoration issues here are related to diversion of a significant portion of the flow for agriculture, and increasing pressure to develop within the riparian corridor. There is only limited storage of water in upstream reservoirs, so significant changes to runoff characteristics are due mainly to mainstem diversions. For much of the area, the channel still has a functioning floodplain, with overbank flows ranging from an almost yearly basis to 1-out-of-4 years. The channel retains its dynamic behavior, with active migration and even channel avulsion processes occurring. Broad restoration issues are: flows during the later portion of the irrigation season, preservation of the corridor, segmentation of the river by numerous diversions, and possible overloading of sediment in some areas due to water removal and diversion backwater.

Montgomery Watson Harza performed an extensive study of restoration and water diversion issues in this reach for the San Luis Valley Water Conservancy District and the Colorado Water Conservation Board in 2001. The information presented in this section was taken largely from that report.

3.1.1 Geomorphology

Geomorphically, the Upper Bioregion was divided into four reaches. Reach 1 encompasses the headwaters of the Rio Grande along the Continental Divide in the San Juan Mountains of Colorado. In Reach 2, the river enters the San Luis Valley and the Rio Grande depression, where it flows through alluvial, aeolian, and lacustrine deposits. Reach 3 is a transition zone from the broad, open San Luis Valley upstream to the extremely confined Rio Grande Gorge, a deep, narrow canyon that dominates the last reach. Within this bioregion, the Rio Grande originates as a mountain stream, takes on the character of a plains waterway as it meanders through the San Luis Valley, and leaves the bioregion as a confined river, incised into a deep, bedrock canyon.

Reach 1 (RM 1909 to 1839--Headwaters to South Fork Confluence): The mountain peaks at the headwaters of the Rio Grande rise above timberline and range from 12,000 to 14,000 feet in elevation. The river’s actual channel begins in a narrow valley at an elevation of about 11,000 feet, and remains a gravel and cobble bed stream throughout this reach, with many areas of both horizontal and vertical control by bedrock (**Photo 3.1**). In the wider valley sections, the channel has a sinuous, alluvial form. In other areas, the channel is shallow and braided due to either high sediment supply, or unstable banks. In more confined reaches, the channel is much straighter. The downstream end of the reach is at South Fork, at an elevation of about 8,170 feet.

Reach 2 (RM 1839 to 1741--South Fork Confluence to Conejos Confluence): In this 89-mile reach, the Rio Grande's slope decreases dramatically from the mountain reach upstream, averaging 8 ft. / mi. This does not give the total picture of the changes in gradient, however. The channel enters the valley at a gradient of 14 ft. / mi., and gradually decreases until it has a gradient of 1-2 ft. / mi. below Alamosa. This is the lowest gradient encountered on the Rio Grande in the entire study area. Consequently, the stream enters the valley as a cobble and gravel bed steam, and exits as a sand bed channel. (**Photo 3.2** shows a typical section of river in the upper portion of Reach 2.)

The river possesses a split channel in some locations above Monte Vista. Historically, the channel likely had a more braided form, and sediments were deposited on an alluvial fan. This process has been altered by water diversions and associated maintenance to some extent. At Monte Vista, the slope of the channel decreases dramatically and takes on a meandering planform with numerous abandoned oxbows in the floodplain. Once below Monte Vista, the channel has connection with its floodplain, with bankfull discharges ranging from the 1-year to 4-year. The floodplain has not been substantially altered by levees; continuous levees are present for only several miles at Alamosa. (**Photo 3.3**). The sinuous planform continues to the end of the reach, which is marked by the confinement of the San Luis Hills.

Reach 3 (RM 1741 to 1714--Conejos Confluence to CO/NM state line): This reach starts below the Conejos River confluence as the Rio Grande flows into the San Luis Hills, a combination of basalt-capped mesa and volcanic cones 200-300 feet above the valley floor. The channel narrows and becomes more entrenched as it flows southward. Through this reach, the average channel width is about 100 feet, with a gradient of 4 ft. / mi. The channel bed coarsens in the downstream direction from sand and gravel to gravel and cobble, with some basaltic boulders. The floodplain is limited throughout the reach.

Reach 4 (RM 1714 to 1639--CO/NM state line to Velarde): This reach encompasses the Rio Grande Gorge, which ranges from several hundred feet in depth to over 1,000 feet. Throughout the Gorge, the channel has cut into thick basalt flows between the Sangre de Cristo Mountains to the east, and the Tusas Mountains to the west. Other than the headwaters, this is the steepest section of the Rio Grande. Gradients average 25 ft. / mi., with the steepest sections exceeding 50 ft. / mi. Due to the steep gradient, confining canyon walls, and large boulders, numerous rapids exist, with riffles and pools in the flatter reaches created by the accumulation of cobbles and small boulders. The river here is a popular recreational area for whitewater boaters, fishermen, and sightseers. Much of the reach is designated as Wild and Scenic, and portions comprise the Rio Grande Gorge State Park (**Photo 3.4**). Because of the high degree of bedrock control both laterally and vertically, the channel does not degrade or erode its banks. Channel geomorphology in this reach has likely not changed greatly from pre-settlement times.

3.1.2 Hydrology

Five gages were used to characterize the hydrology of this bioregion (**Table 3.1**). Wagon Wheel Gap represents the mountainous area (Reach 1). Del Norte and Lobatos Gages represent the upper and lower ends of the San Luis Valley (Reach 2). Del Norte is indicative of flows upstream of significant diversions in the San Luis Valley; the Alamosa Gage indicates conditions in the area most impacted by diversions; and the Lobatos Gage, below the Conejos River confluence and downstream of all the major diversions, represents the short portion of the river through the San Luis Hills (Reach 3). Flows in the Rio Grande Gorge (Reach 4), are defined by Lobatos at the upper end, and the Embudo Gage at the lower end.

The largest impoundment in this bioregion is Platoro Reservoir on the Conejos River. In addition to the 60,000 acre-feet of water stored in Platoro, another 120,000 acre-feet is distributed among several small headwater reservoirs above Del Norte, all constructed between 1910 and 1925. Rio Grande Reservoir, built in 1912, is the only reservoir on the mainstem of the Rio Grande above Cochiti. Total storage in the Upper Bioregion is less than 200,000 acre-feet, or less than 25% of the average annual runoff. In contrast, total reservoir storage within and above the other bioregions exceeds the average annual stream flow volume. In the Upper Bioregion, diversions are most significant in altering the hydrology; in the Middle and Lower Bioregions, a combination of diversions and reservoirs alter the hydrology.

As a result of direct diversions, significant reductions in flow volumes and peaks occur within the San Luis Valley (Reach 2). The 656,000 acre-feet of inflow to the valley is reduced by 60-75% at the Alamosa and Lobatos Gages. The annual peaks are also lower at Alamosa and Lobatos than at Del Norte. The influence is greater on the lower return periods (2-year) than on the large floods (100-year) because the total flow rate of all diversions is small in comparison to the flow in the river during a large flood. Occurrences of low flow are much more frequent at Alamosa and Lobatos than at Del Norte. Flows of less than 100 cfs occur less than 1% of the time at Del Norte, but occur on the order of 50% of the time at Alamosa, and 25% of the time at Lobatos. Zero flow days occasionally occur at Alamosa. The zero flows recorded at Lobatos happened during the 1950s, when Platoro Reservoir was filling.

Tributary inflow below the Colorado/New Mexico border adds enough water to the Rio Grande that the flow characteristics at Embudo, near the downstream end of the bioregion at Velarde, are very similar to those at Del Norte. **Figure 3.2** presents the recorded mean daily flows at Embudo since 1889. In comparison with similar hydrographs for the Middle and Lower Bioregions, the Upper Bioregion has not seen a large change in flows over the past century. However, flows had already been significantly altered by direct diversions in the San Luis Valley prior to the start of the gage record in 1889.

Table 3.1 - Summary of Hydrologic Information – Rio Grande Upper Bioregion

Reach / Location	Period (from – to)	2-Yr (cfs)	100-Yr (cfs)	Ave. Annual (cfs)	Ave. Annual (afy)	Ave. days/yr 0 cfs	Ave. days/yr < 30 cfs	Ave. days/yr <100cfs
Rio Grande at Wagon Wheel Gap, CO	1951 – 1999	3180	5660	540	394,000	0	0	62
Rio Grande near Del Norte, CO	1890 – 2000	4980	13100	910	656,000	0	0	2
Rio Grande at Alamosa, CO	1912-1995	1150	14900	250	178,000	7	66	155
	1912-1950	1730	19300	320	230,000	9	70	137
	1951-1999	780	6900	160	118,000	5	61	174
Rio Grande near Lobatos, CO	1900 – 1950	4110	19600	360	262,000	0	21	71
	1951 – 1999	1780	12500	210	155,000	3	28	95
Rio Grande at Embudo, NM	1889 – 1999	4150	18800	930	677,000	0	0	0
	1889-1950	5460	19400	1060	769,000	0	0	0
	1951-1999	3090	13800	800	576,000	0	0	0

3.1.3 Ecology

Through the Upper Bioregion, the Rio Grande drops about 4,000 feet, and transits four dominant ecological systems.

Upper montane/subalpine riparian forest and woodland occurs at higher elevations (8,000 to 11,000 feet) and contains a mosaic of one or two communities dominated by one of the following trees: white and subalpine fir (*Abies concolor or A. lasiocarpa*), Englemann and blue spruce (*Picea engelmannii or P. pungens*), or aspen (*Populus tremuloides*).

Montane/subalpine riparian shrubland primarily occurs at higher elevations in shallow, broad valleys, and contains a mosaic of multiple, shrub-dominated communities. Dominant shrubs reflect the large elevational gradient and include alder (*Alnus incana*), dwarf birch (*Betula glandulosa and B. occidentalis*), dogwood (*Cornus sericea*), and various species of willow (*Salix spp*.).

Lower montane riparian woodland generally occurs between 6,000 and 9,000 feet, and is characterized by a mosaic of multiple, tree-dominated communities with a diverse shrub component dependant on elevation, stream gradient, floodplain width, and flooding events. The dominant trees may include box elder (*Acer negundo*), narrow-leafed cottonwood (*Populus angustifolia*), balsam poplar (*P. balsamifera*), common Douglas fir (*Pseudotsuga menziesii*), blue spruce (*Picea pungens*), or Rocky Mountain juniper (*Juniperus scopulorum*). Dominant shrubs include western mountain maple (*Acer glabrum*), alder, birch, dogwood, and willow.

Foothills riparian woodland/shrubland is found on low-to-moderate gradient streams, with narrow-to-broad floodplains at elevations from 5,000 to 7,000 feet. Dominant species of this system include narrow-leafed cottonwood, alder, river hawthorn (*Crataegus rivularis*), willows (*Salix amygdaloides, S. exigua*, and *S. irrorata*), and sumac (*Rhus trilobata*).

Wetlands are also common within and adjacent to the Rio Grande floodplain. Most are classified as freshwater marsh, but in the mountainous areas, montane wet meadow and montane fens may occur. A more detailed discussion of these ecological systems is provided in **Appendix B**.

From the headwaters to Monte Vista, the river is a cold water system, with water temperatures of 40-50 degrees Fahrenheit; a high gradient and velocity; gravel and cobble substrate; a high ratio of pool/riffle sequences; relatively unencumbered fish passage; nutrients of coarse particulate matter; and flows that are in line with the historic hydrograph. Rio Grande cutthroat (*Oncorhynchus clarki virginalis*), an endemic species to the region, occupies only a fraction of its former range, which once stretched from the headwaters to Del Norte. Habitat modifications from historic logging and grazing, competition with non-native trout, and low water flows have had a negative effect on the species. Non-native trout, including rainbows *(Salmo gairdneri*) and browns (*Salmo trutta*) inhabit much of this stretch of river; however, de-watering, canalization, sedimentation, and aggradation limit the extent and quality of trout waters (Montgomery Watson Harza, 2001). Beyond Monte Vista, the gradient and vegetative cover decreases and the river becomes a cool water system, represented by higher temperatures (50-60 degrees Fahrenheit), lower velocities, increased siltation, fewer pool/riffle sequences, and gravel substrate. Native fish inhabiting this reach include the Rio Grande chub (*Gila Pandora*), longnose dace (*Rhinichthys caataractae*), and red shiner (*Notropis lutrensis*). De-watering and predation by non-native species are the largest threats to these species.

In general, the most notable changes in riparian conditions have occurred within and downstream of the San Luis Valley. The majority of this area is foothills riparian woodland/shrubland, with narrow-leaf cottonwood the dominant overstory species, and Bebb willow (*Salix bebbiana*), dogwood, and golden currant *(Ribes aureum*) the dominant shrubs. The density of cottonwood tends to decrease downstream, where willow becomes more dominant. Species include Bebb willow, coyote willow (*S. exigua*), and whiplash willow (*S. lucida ssp. caudata*).

The majority of the cottonwood forest is of a mature age class. Both regeneration and age class diversity appear to be low. A study of regeneration of the cottonwood forest along the river in Rio Grande and Alamosa Counties found that there is an average regeneration range of 11-20% (Montgomery Watson Harza, 2001). This is likely the result of channel modifications, floodplain development, and water management operations (e.g., flood control and irrigation), which disconnect the floodplain from the river and remove seasonal flooding. The best regeneration rates were in the headwaters near South Fork, with little or no regeneration occurring downstream of Alamosa.

A recent analysis of historical aerial photographs of the San Luis Valley from 1941, 1963, and 1998 found that some stretches of the river have undergone substantial changes while other stretches appear relatively similar, suggesting that much of the vegetation modifications occurred prior to 1941 (Montgomery Watson Harza, 2001). Decreases in vegetation density are generally due to agricultural clearing, roads, housing, and other development. In addition to losing direct habitat value, this has resulted in fragmentation, which reduces the overall habitat function. Increased vegetation density was observed in some reaches where meandering of the river channel, or previous scouring of the floodplain, caused better conditions for cottonwood germination and growth.

Key abiotic and biotic process for maintaining and restoring a functioning riparian system include seasonal floods that mimic the natural hydrograph, with peaks generally from mid-May to June; scouring flooding; floodplain-river connection; and a dynamic, meandering channel which is not limited in capacity. The primary threats to these processes include water divisions; levees; channel modifications; stream crossings; invasive species; poor land management practices (uncontrolled runoff from mining sites, logging and livestock grazing within riparian zones, and roads along the river corridor); and encroachment on floodplains from agriculture and development.

3.1.4 Constraints

Primary physical constraints on restoration activities in the Upper Bioregion relate to water resource development and use, and encroachment in the historic river corridor. Details of these physical constraints, along with administrative and legal constraints associated with potential restoration activities in the bioregion, are summarized below.

Physical Constraints

- Human activities and development in the floodplain (levees, communities, agriculture, infrastructure, etc.,) are constraints to the restoration of floodplain connectivity and dynamic, geomorphic channel processes such as bank erosion, lateral migration and avulsion.

- Flood control/protection is also a constraint: levees protect much of Alamosa, and due to encroachment in the floodplain, numerous structures would be impacted by changes in flow and/or by increased floodplain connectivity. The valley is very flat, and flooding can spread for miles in many areas.

- Changes in sediment balance caused by diversions are another constraint to restoration. A disproportionate amount of sediment is left in the channel below diversions, and deposited in the pooled water upstream. In some places, deposition has also limited the channel capacity.

Legal /Administrative Constraints

- Rio Grande Compact deliveries must be met, and there is little, if any, surplus water in most years.

- Under New Mexico water law, the Rio Grande is fully appropriated, and there is no protection for instream flow. Water salvaged or acquired for restoration purposes can be pre-empted by other users, and its benefits may not be realized throughout the system. Also, restoration projects that increase consumptive use (wetland creation, for example,) would have to augment or offset any diverted river or return flows.

- Under current regulations, physical restoration in areas designated by the Federal Emergency Management Agency as floodways cannot cause a rise in the 100-year flood plain elevation. Conversely, regulations allow construction in the floodplain if the structures are elevated above the 100-year flood elevation. This can result in more development in the floodplain that conflicts with potential restoration activities. (Note: in areas where the 100-year flood is contained in suitable levees, constraints on restoration activities in the floodway are less stringent, as long as levee freeboard and stability are maintained.)

- Water management agencies often have conflicting objectives, and there is a lack of coordination in planning between local, state, and federal agencies. Agencies also lack funding to support restoration efforts.

3.2 Middle Bioregion: Velarde, NM to Caballo Dam, NM

This bioregion includes the Española Valley, White Rock Canyon, Cochiti Reservoir, Middle Rio Grande Valley, Elephant Butte Reservoir, and Caballo Reservoir. Within it, the Rio Grande transitions from a riparian woodland/shrubland ecological system along the semiarid mountain valleys and canyons above Cochiti Reservoir, to the Chihuahuan Desert starting near Socorro, NM.

The Middle Bioregion has seen the most activity in regard to restoration. In the area from Cochiti to Elephant Butte, known as the "Middle Rio Grande," there has been intense interest in preservation and restoration since the 1990s. This interest developed because of concerns about the health of the riparian cottonwood forest, or bosque, and has intensified due to the endangered status of the Rio Grande silvery minnow and the Southwestern willow flycatcher. Increasing pressure to develop the area's limited water resources for a growing population has also focused interest on river preservation and restoration. For similar reasons, interest in restoration has spread to the upper portion of the Middle Bioregion, including the Española Valley and White Rock Canyon.

Restoration in this bioregion will have to address a variety of physical changes that have been made to the system. Some of the most significant changes include reduction in flow volume and peaks, reduction in upstream sediment supply from reservoir storage, confinement of the floodplain by levees, and artificial stabilization of the channel by jetty jacks and other means.

3.2.1 Geomorphology

The Middle Bioregion is divided into 11 reaches for purposes of geomorphic characterization. Here, water resource development, urbanization, and agriculture have all significantly impacted the Rio Grande, and the channel is confined between levees through most of the bioregion. Additionally, the magnitude and volume of flows have been reduced by reservoir operations for flood control and water supply storage. Reservoirs have also altered the sediment balance. Stabilization by jetty jacks and other means, as well as thick growth of invasive species, have also altered the river's morphology. A discussion of the geomorphic characteristics of each reach is presented below. Much of the information was taken from the draft report, "Geomorphic Characterization of the River Channel from Velarde to the Headwaters of Elephant Butte by Representative Reaches," USBR, 1998.

Reach 5 (RM 1639 to 1627--Velarde to Rio Chama Confluence): This short reach encompasses the area from the mouth of the Rio Grande Gorge to the confluence with the Rio Chama. In this reach, the Rio Grande flows out into the Española Valley. The channel is relatively straight, owing at least partially to channelization since the 1950s (**Photo 3.5**). The gradient is moderate, at about 12 ft. / mi. Prior to channelization, the stream was braided and occupied much of the floodplain, which approaches 3,000 feet in some areas. Several diversion structures span the channel and provide water to acequias. The bed material is gravel and cobble, with banks comprised of sand and gravel.

Reach 6 (RM 1627 to 1614--Rio Chama to Otowi Bridge): In the lower half of the Española Valley, the Rio Grande changes character as the Rio Chama enters from the west, increasing both the flow and the sediment load. The channel widens to 300-400 feet, and is only slightly sinuous, with non-cohesive banks comprised primarily of sand and gravel. Besides modification of the hydrology from upstream diversions and control by reservoirs on the Rio Chama, the Rio Grande has undergone several changes due to direct human manipulation. As in Reach 5, this section was channelized in the 1950s, and river maintenance was performed periodically for several decades afterward. Additionally, levees have been constructed through the City of Española for flood control. Gravel mining has impacted portions of the reach, resulting in an incised channel with eroding banks, and a lowered groundwater table.

Reach 7 (RM 1614 to 1597--Otowi to Cochiti Reservoir): At Otowi, the Rio Grande leaves the Española Valley and flows into White Rock Canyon. The average gradient through the canyon is 12 ft. / mi., although there are areas with a few rapids where the gradient doubles. The canyon is up to 1,000 feet deep, and through it, the river channel narrows, becoming 100-200 feet in width. The bed is primarily gravel and cobble, with some boulders. As the backwater from Cochiti Reservoir is approached, the channel contains extensive deposits of sand, then silt. During flood operations, Cochiti's pool can extend many miles upstream, and this has resulted in sand deposits in the floodplain and along terraces.

Reach 8 (RM 1597 to 1588--Cochiti Reservoir): This reach of the Rio Grande contains Cochiti Reservoir. The reservoir has a total storage of 597,000 acre-feet, with 492,000 acre-feet of flood control storage, a 100,000 acre-foot sediment pool, and a 50,000 acre-foot recreation pool. The reservoir began operations in 1975, and as of June 1998, had trapped on the order of 20,000 acre-feet of sediment, or roughly 1,000 acre-feet per year. Sediment deposition in the upper portion of the reach has created a sand bed channel, and in some locations, extensive areas of riparian and wetland vegetation that would not otherwise exist in this confined canyon reach.

Reach 9 (RM 1588 to 1561--Cochiti Dam to Bernalillo / Hwy 550): The Rio Grande changes significantly below Cochiti Dam, due to both natural and human-induced conditions. The river enters the broad Middle Rio Grande Valley, which is interrupted only by short constrictions. For hundreds of miles, the river undergoes nearly continuous channelization, constriction by levees, water diversion, or confinement in reservoirs. Peak runoff is controlled at Cochiti. For example, the 2-year peak flood can be reduced from 8,000 cfs above the dam, to 5,600 cfs below it. Historically, a sand bed channel dominated the river from here south, and prior to channelization in the late 1950s and early 1960s, the reach had a braided planform. Currently, the channel has a gravel bed, a sinuosity of 1.1, and a gradient of 6 ft. / mi. The channel has degraded and armored, and the banks have eroded due to the release of clear water from Cochiti Reservoir. In 1918, the channel width averaged 1,000 feet; its current width is about 300 feet. Historically, the floodplain was a mile wide, but levees have confined it to 1,000-2,000 feet.

Reach 10 (RM 1561 to 1526--Bernalillo to Isleta Diversion): This reach of the Rio Grande flows through the Albuquerque metropolitan area. The upstream segment of the reach is transitional, and a conversion from sand bed to gravel bed is occurring. A decade ago, the Rio Grande below Highway 550 was sand bed. Now, gravel is the dominant bed material in the Corrales area, and the channel is becoming entrenched and disconnected from its floodplain. The entire reach is protected by levees, and jetty jacks have been widely used to confine and stabilize the floodway. This has resulted in a channel width of about 600 feet, compared to a historic channel width in the early 1900s of over 1,000 feet. In the past decade, many of the center bars and alternated bars have become permanently vegetated in this reach, further narrowing the effective channel width. Although the channel is currently single thread, historically there were multiple channel braids.

Reach 11 (RM 1526 to 1484--Isleta Diversion to Rio Puerco Confluence): Geomorphic characteristics of this reach are similar to reach 10. Sinuosity is low and the channel is confined by levees on both sides. The once 2-mile-wide floodplain is now 2,000 feet wide, or less. Jetty jacks have been used to stabilize and confine the sand bed channel to a width of approximately 500-600 feet (**Photo 3.6**), compared to more than 1,000 feet in the early 1900s.

Reach 12 (RM 1484 to 1418--Rio Puerco to Elephant Butte Reservoir): This reach retains the highest level of original channel morphology in any portion of the study area downstream of Cochiti Reservoir. However, it has still been significantly changed by manipulation of water and sediment supply, both within the reach and upstream. A levee confines the river on the west side, while topography confines it on the east. Jetty jacks and physical channelization are present in the reach, but there are areas that still exhibit the historic braided channel form (**Photo 3.7**). Sediment inflow from the Rio Puerco and Rio Salado helps maintain the braided planform. These tributaries enter at the upper end of the reach, upstream of the San Acacia Diversion Dam. The channel width in the braided areas often exceeds 1,000 feet, and falls within the 600-900 foot range in many others. In contrast, channelized reaches have widths ranging from 100 feet to 250 feet. The lower portion of this reach maintains a high level of connectivity with the floodplain, particularly downstream of San Antonio. In this area, overbank flows occur at discharges ranging between 2,000 and 4,000 cfs. At the San Marcial Railroad Bridge, aggradation has reduced the channel capacity to less than 4,000 cfs (**Photo 3.8**). The combination of several very low flow years, control of peaks during wetter years, and the lack of larger releases from Cochiti, has influenced the morphology of the channel through reduction in overbank flows and vegetation encroachment on bars.

Reach 13 (RM 1418 to 1383--Elephant Butte Reservoir): When completely full, Elephant Butte Reservoir covers nearly 35 miles of the Rio Grande. At lower stage levels, less than 20 miles of the river is inundated. Due to the large sediment inflow, a significant delta has formed near the upper end of the reservoir. In recent years, the Bureau of Reclamation has excavated a channel though the delta deposits in order to induce channel degradation, and to eliminate some of the sedimentation impacts upstream. As the level of the reservoir recedes, the excavated channel is extended further downstream. More than 500,000 acre-feet of sediment has been deposited in the reservoir. Current storage capacity is 2,065,000 acre-feet, with 50,000 authorized for recreation, and the remainder for conservation storage. The project is also authorized for hydropower generation.

Reach 14 (RM 1383 to 1374--Elephant Butte Dam to Caballo Reservoir): This is a 9-mile reach between two reservoirs. The water is almost totally sediment free when released from Elephant Butte, and as a result, unless a tributary has flowed recently, the bed has scoured to gravel. Releases from Elephant Butte are controlled to about 4,000 cfs or less to prevent flooding in Truth or Consequences. The channel is confined to the east by topography and to the west by development. In some locations, the channel is confined on both the east and west by the topography. Because of these factors, the floodplain is nearly nonexistent in much of this reach.

Reach 15 (RM 1374 to 1356--Caballo Reservoir): Caballo Reservoir occupies this 18-mile reach of the Rio Grande. The project, completed in 1939, is authorized for conservation storage, flood control, and re-regulation of hydropower releases from Elephant Butte. The total storage is 331,000 acre-feet, with 231,000 acre-feet designated for conservation storage, and the remaining 100,000 for flood control.

3.2.2 Hydrology

Six mainstem stations were utilized to characterize the hydrology of the Middle Bioregion: Otowi Bridge, Cochiti, San Acacia, San Marcial, and below the dam at both Elephant Butte and Caballo. The San Acacia and San Marcial Gages have values for the "floodway" and for "total flow." Total flow is the combined flow in the main channel, or floodway, and the Low Flow Conveyance Channel (LFCC). In addition to the main stem stations, the Rio Chama Gage at Chamita, several miles above the Rio Grande confluence, was included to identify the contribution from this major tributary. **Table 3.2** presents the results of the hydrologic analysis. **Figure 3.3** provides a plot of the mean daily flows for the Rio Grande at San Marcial since 1899.

Table 3.2 - Summary of Hydrologic Information – Rio Grande Middle Bioregion

Reach / Location	Period (from – to)	2-Yr (cfs)	100-Yr (cfs)	Ave. Annual (cfs)	Ave. Annual (afy)	Ave. days/yr ~ 0 cfs	Ave. days/yr < 30 cfs	Ave. days/yr < 100 cfs
Rio Chama at Chamita, NM	1912 – 1999	3650	12800	540	393,000	2	26	110
	1912 – 1970	4090	15400	500	362,000	3	37	135
	1971 – 1999	3200	5410	610	444,000	0	4	60
Rio Grande at Otowi Bridge, NM	1895 – 1999	7390	26400	1520	1,100,000	0	0	0
	1895 – 1938	10500	28200	1690	1,226,000	0	0	1
	1939 – 1999	5840	20700	1420	1,029,000	0	0	0
Rio Grande at (or below) Cochiti, NM	1926 – 1999	5580	23800	1360	983,000	0	0.5	6
	1926 – 1938	9310	19500	1480	1,073,000	0	1	6
	1939 – 1973	5480	30500	1230	888,000	0	0	6
	1974 – 1999	4480	12800	1480	1,074,000	0	1	6
Rio Grande at San Acacia, NM TOTAL FLOW	1936 – 1999	8430	36700	1880	848,000	5	43	62
	1939 – 1973	8940	25900	1000	721,000	8	61	81
	1974 – 1999	6420	17900	1360	985,000	0	20	38
Rio Grande FLOODWAY at San Acacia, NM	1958 – 1999	7390	19500	800	577,000	9	149	176
	1958 – 1973	8360	18700	270	194,000	20	255	286
	1974 – 1999	6420	17900	1120	807,000	2	84	109
Rio Grande at San Marcial, NM TOTAL FLOW	1899 – 1999	5100	34700	1200	868,000	16	33	82
	1899 – 1938	11300	49100	1401	1,015,000	33	45	59
	1939 – 1973	4250	26300	960	697,000	6	38	70
	1974 – 1999	4160	11300	1320	956,000	3	9	17
Rio Grande FLOODWAY at San Marcial, NM	1949 – 1999	3960	12600	690	501,000	139	157	171
	1949 – 1973	3550	14800	320	234,000	226	249	263
	1974 – 1999	4160	11300	1050	758,000	56	69	83
Rio Grande at Elephant Butte Dam, NM	1916 – 1999	2340	5900	1000	725,000	2	50	105
	1916 – 1939	2640	4980	1160	837,000	9	78	80
	1939 – 1999	2260	5880	940	684,000	0	103	114
Rio Grande at Caballo	1939 – 1999	2620	6060	930	676,000	0	138	144

Note: TOTAL FLOW denotes sum of the Floodway and Conveyance Channel

The Middle Bioregion is one in which significant change occurs in the hydrology, both from natural and human influences. All of the major mainstem and tributary reservoirs in the study area are contained within this bioregion, and there is significant diversion for both agricultural and municipal water supply. In terms of natural change, the Rio Chama, a major tributary, enters near the region's upstream boundary. In the upper half of the bioregion (above Albuquerque), inflows are dominated by snowmelt from high mountains, while in the lower half, inflows are primarily from rainfall events on ephemeral tributaries. The last significant snowmelt-fed tributary, the Jemez River, enters near Bernalillo.

A variety of events have taken place in the Middle Bioregion that warrant dividing the record into three periods: the signing of the Rio Grande Compact in March 1938, the completion of Cochiti Reservoir in 1975, and the completion of the San Juan-Chama Diversion Project in 1971. Because of the proximity in completion times for the San Juan-Chama Project and Cochiti Dam, a single date of 1974 was chosen to represent these two activities. The completion of Elephant Butte Reservoir in 1916, and Caballo Reservoir in 1939, are also significant events. Unfortunately, there are no gage records prior to 1916 immediately downstream of Elephant Butte or Caballo Dams. The closest downstream record for the period prior to 1916 is the Rio Grande at El Paso, which is influenced by diversions below Caballo Dam.

The Middle Bioregion has a total storage capacity of over 4,000,000 acre-feet, including flood control, water supply, recreation, and sediment pools. This value does not include the approximately 500,000 acre-feet of storage in Elephant Butte Reservoir that has been filled with sediment. Total storage is several times the annual flow into the region. Average annual flows at Otowi have been in the 1,000,000 to 1,200,000 acre-foot range for all three periods previously identified. This is in contrast to the Upper Bioregion, where the ratio is reversed, and annual flow is three to four times greater than the reservoir storage volume.

In terms of peak flows, there has been about a 50-60% reduction in channel-forming flows (2-year) when the period from 1900 to 1939 is compared with the present. For example, at San Marcial, the 2-year peak was 11,300 cfs for the period from 1899 to 1938, and about 4,000 cfs from 1939 to the present. The operation of Cochiti has not altered the 2-year peak (except in very recent years, to accommodate restricted channel capacity,) but it has greatly reduced the 100-year peak (from 26,300 cfs in 1939-1973, to 11,300 in 1974-1999 at the San Marcial Gage). This is expected, since Cochiti was intended to provide control of large events. Below Elephant Butte and Caballo, larger floods have been reduced by an even greater amount, with 100-year flows controlled to a level of about 6,000 cfs.

Storage has generally resulted in fewer days of very low flows in the lower portions of this bioregion. For example, at San Marcial, the number of zero-flow days prior to the Compact and upstream reservoirs was on the order of 30; today, San Marcial averages about 3 days of zero flow, though this is somewhat misleading. During the period when the Low Flow Conveyance Channel was operated and water was being diverted from the floodway, the number of zero-flow days in the main channel exceeded 200 per year.

Besides the reduction in peak flows and the manipulation of flow timing and distribution in this bioregion, a large amount of water is diverted by the Middle Rio Grande Conservancy District at Cochiti, Angostura, Isleta and San Acacia. San Acacia is the point of diversion not only for the Socorro Main Canal, but also for the Low Flow Conveyance Channel. Under current conditions, the 1,000,000 acre-feet of upstream inflow to the region results in about 680,000 acre-feet of outflow. This is a reduction of about one-third, not considering inflows that occur from tributaries below Otowi. A portion of the reduction is due to reservoir evaporation at Cochiti, Elephant Butte and Caballo. The amount of evaporation varies, based on reservoir surface area, but can exceed 100,000 acre-feet in a year.

3.2.3 Ecology

The riparian system of the Middle Bioregion is generally referred to as the Rio Grande cottonwood alliance (Muldavin et.al. 2000), or more commonly, the Rio Grande bosque. The canopy of this riparian galley forest is dominated by mature, native Rio Grande cottonwood trees (*Populus deltoides* ssp. *wislizenii*). Although there is mention of the bosque as early as the 16th century, it probably differed in composition and extent from the present day forest, due to the river's now highly regulated flow regime.

Cottonwoods are established on the lowest alluvial surfaces in the floodplain with the onset and subsidence of early spring floods (Muldavin et.al. 2000). Today, while it is mostly continuous, the bosque usually appears as a narrow strip up to 200 meters in width. Laterally, its distribution within the presently active floodplain is mostly constrained by levees and, south of Socorro, by eastside bluffs. Cottonwood stands range from fairly dense in frequently flooded locations, to relatively open in locations that are hydrologically disconnected. Canopy heights can reach twenty-five meters, but are frequently much lower. Trunk diameters vary among trees of approximately the same age. Small cottonwoods within the forest are probably root and stem sprouts (Crawford 2002).

There are a number of community types in the Rio Grande cottonwood alliance primarily delineated by the dominant understory species. Desirable communities include cottonwood/coyote willow, cottonwood/Goodding's willow, and cottonwood/New Mexico olive (Hink and Ohmart 1984, and Muldavin et.al. 2000). In general, willows contribute to the canopy in low numbers to the north, but become much more common south of Bosque del Apache National Wildlife Refuge, where they can replace cottonwoods as canopy dominants.

These plant communities are adapted to floodplain environments that have significant available moisture from periodic flooding, shallow groundwater, standing surface water, and unstable substratum. Historically, floods caused multiple channels and sandbars, washed away stands of trees, and created wetlands. These processes resulted in a heterogeneous patchwork of vegetation communities and age classes. Flood frequency and intensity has decreased dramatically, however, due to the construction of dams. The water table has decreased in many areas, river channels have been straightened and bermed, banks have been stabilized, and the natural shifting of channels has been virtually halted. The river channel is narrowing and deepening in many locations, and vegetation is stabilizing the riverbank. At the same time, agricultural acreage has encroached on the floodplain.

These combined conditions have had a drastic effect on vegetation communities in the Middle Rio Grande. In the northern portion of the middle reach, there is little or no recruitment of native riparian plants outside of the immediate banks and sandbars of the river channel. To the south, large amounts of sediment enter the river at the confluences of the Rio Puerco and Rio Salado (Lagasse 1980), and flow is insufficient to move this sediment farther downstream. Elephant Butte Dam, at the bottom end of the Middle Rio Grande, has caused the base elevation to rise upstream, enhancing channel widening, deposition, braiding, and aggrading, while sediment deposition creates a substrate for establishment of riparian vegetation, both native and exotic.

In short, the cottonwood bosque as a whole is being replaced by introduced species, including saltcedar (*Tamarix ramosissima*), Russian olive (*Eleagnus angustifolia*), and Siberian elm (*Ulmus pumila*). Saltcedar, which is less shade tolerant than Russian olive, is part of the subcanopy in many sites, and occurs in extensive, continuous open stands south of Bernardo. Russian olive, on the other hand, not only dominates the subcanopy in many places, but often lines the riverbank to the near exclusion of other trees.

In contrast to the existing bosque's present spatial and temporal organization, throughout most of the Holocene the riparian forest was probably a constantly changing mosaic of often discontinuous, uneven-aged cottonwood and willow communities. Not all of them would have been close to the river, but most of the dominant trees, at least, would have originated during periods of overbank flooding. At such times, open areas among the communities would have contained marshes, wet meadows, and oxbows, depending on the topography of the floodplain and the proximity of the river. During dry periods, however, drought resistant grasses and shrubs would have covered much of the landscape not populated by such stands. The Middle Rio Grande cottonwood bosque is still a dynamic ecosystem, but one that differs markedly from its ancestral condition (Crawford 2002).

Other important components of the riparian system include wet meadows, palustrine marshes, spring seeps and perched wetlands, salt marshes, and sandbars. Wet meadows, commonly consisting of sedge, grass, and rush species, were likely the most extensive floodplain habitat in this bioregion prior to installation of agricultural drain systems, and have experienced the greatest decline in surface area of all floodplain habitat types. Palustrine marshes are frequently or permanently inundated wetlands dominated by emergent, herbaceous species like cattails and bulrush, which are adapted to saturated soil substrates. They historically occurred throughout the active floodplain, although today they are primarily found adjacent to the river channel, or as part of oxbows. Spring seeps and perched wetlands, while uncommon in the Middle Rio Grande, provide unusually persistent and long-lived wetlands. They occur where groundwater flow is intercepted above the level of the floodplain by impermeable layers of bedrock or clay, usually near the intersection of the floodplain and valley slopes. Wooded wetlands may include temporally flooded bosque, or any of the other persistent or ephemeral wetland habitats that occur within the riparian zone. They may be found with the cottonwood and willow canopy, or among Russian olive or saltcedar stands. Historical records refer to salt marshes at several locations in the Middle Rio Grande Valley, including Bernardo, La Joya, and Bosque del Apache. A few of these salt marsh areas persist today, although their hydrologic conditions may be greatly modified. Salt-tolerant vegetation such as saltmarsh bulrush, saltgrass, creeping spikerush, and common threesquare rush dominate these wetlands (Coleman 2002).

Sandbars are currently abundant throughout the low gradient portion of the Middle Rio Grande between Bernalillo and Elephant Butte Reservoir. Historical evidence indicates this reach has exhibited dynamic formation and dissolution of sandbars from high flow events. Changes in the flow regime of the river and sediment deposition in reservoirs have altered the dynamic nature of sandbar formation. Currently, sandbars above the confluence of the Rio Puerco and Rio Salado tend to be heavily vegetated with herbaceous species, including many obligate and facultative wetland species such as cattail, bulrush, sedges, rushes, grasses, and annuals. Some sandbars have established stands of cottonwood, coyote willow, saltcedar, 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. Sandbars below the confluence of the Rio Puerco are less vegetated due to periodic (although infrequent) flood events from the Rio Puerco and Rio Salado (Coleman 2002).

The primary abiotic functions for all these riparian systems are flooding and channel avulsion. Scouring floods are required to create bare substrates for seed germination, followed by sustained high moisture conditions for establishment (Muldavin et.al. 2000). Flooding needs to occur in the spring (around mid-May to June,) to facilitate seed dispersion and germination, and requires a functioning floodplain-river connection. In this regard, the greatest stressors to the system are regulation of river flows, channelization, and invasive species.

Through this reach, the river transitions from a cool water system to a warm water system although Cochiti Dam, with its deep reservoir, has pushed the historic cool water/warm water transition further downstream. The gradient tends to be moderate to slight, with a relatively uniform substrate of gravels to sand. Channelization, controlled flows, and sediment depletion (the result of retention in reservoirs,) has restricted the historically dynamic river system and reduced the creation and maintenance of functional aquatic habitat, including backwaters, deepwater pools, and large woody debris. Likewise, de-watering during the irrigation season, and large diversion structures that limit fish movement and increase entrainment further stress the system. Although important in all three bioregions, the fishery in the Middle Bioregion is especially dependent upon in-channel and off-channel habitat. While the river is important as a dispersal corridor, most critical life stages occur in floodplain, oxbow, and backwater habitats.

3.2.4 Constraints

Numerous physical constraints to restoration exist throughout the Middle Bioregion. These constraints relate to water resource development both in terms of reservoir storage and diversion, confinement of the system for flood and erosion control, and encroachment on the river corridor by urbanization and agriculture. The summary of constraints delineates between the Middle Rio Grande (MRG) and the Española Valley / White Rock Canyon sub-areas. Although these two sub-areas share many of the same basic challenges and problems, there are differences that affect the constraints and opportunities for each. Cochiti Reservoir and its alteration of hydrologic and sediment transport regimes creates different restoration challenges for the Middle Rio Grande. Some of the more important differences are discussed below.

Unlike the MRG, the Española-White Rock sub-area does not have an extensive levee system. There are levees within the City of Española, and smaller dikes in some areas upstream. Ironically, the presence of levees and the associated physically-defined floodplain in the MRG has prevented the type of encroachment on the river corridor that is occurring in the Española-White Rock reach, where houses are being constructed immediately adjacent to the channel. This type of encroachment is occurring most extensively above the Rio Chama confluence.

Through the Española-White Rock area, the Rio Grande channel has not been extensively stabilized, although riprap, jetty jacks, and rock groins have been used locally. Since Cochiti Reservoir is below the reach, there has been less manipulation of the hydrology and sediment regime. The Española-White Rock reach was historically a gravel and cobble bed channel, and still is. The MRG, historically a sand bed channel, now has areas of gravel bed due to the storage of sediment in upstream reservoirs. Reduced sediment supply has resulted in channel incision in significant portions of the MRG. Although this has not been the case in the Española-White Rock reach, there are areas of channel incision resulting from instream gravel mining.

Both sub-areas have diversions, but acequias in the Española-White Rock reach divert a much smaller proportion of the flow than the larger conservancy district diversions of the MRG. Zero-flow periods are not an issue in the Española-White Rock area. Both reaches have encroachment of non-native vegetation in the floodplain, though it is not as extensive in the Española-White Rock reach. Water quality and soil characteristics are larger issues in restoration in the MRG, although possible contamination from Los Alamos is an issue in White Rock Canyon, and in sediments deposited in Cochiti Reservoir. Soil characteristics must be considered in selecting which vegetation types will form the "mosaic," as the high salt content in some areas is not compatible with cottonwoods. There is also increasing concern that high concentrations of effluent during low flows may be an issue for recovery of native fish, but this topic needs further research.

Physical Constraints

- In both the MRG and Española-White Rock reaches, human activities in the floodplain (*i.e.*, levees, communities, agricultural acreage, and water or transportation infrastructure,) place some constraints on amending the river/floodplain connection, and on any increase in channel dynamics**.** However, given the fact that the MRG's levees have for decades served as a physical line between developable and undevelopable land, a considerable corridor exists for floodplain reconnection and increased movement of the channel.

- Levees protect almost the entire MRG valley, and a limited amount of the Española-White Rock reach. Extensive development lies outside the levees, and the integrity of the levee system will need to be maintained in most, if not all, locations. Cochiti Reservoir, too, plays an important role in protecting the developed areas of the MRG valley. As in the Upper Bioregion, the valley is very flat, and flooding can spread for miles.

- Water availability is limited in both sub-areas. A sufficient supply of water must be provided for agricultural, industrial, and municipal use, even as reservoir evaporation and increased consumption by non-native species compound the natural losses of an arid/semi-arid region.

- Changes in sediment balance have already been effected by reservoirs in the Middle Bioregion. Increases in peak flows could exacerbate the sediment "starvation" in some reaches below Cochiti. Therefore, the implementation of higher peak discharge to increase floodplain connectivity and facilitate historic geomorphic processes must consider potential adverse impacts on the Rio Grande's sediment balance. Sediment supply may need to be naturally or artificially increased to convert areas of gravel bed back to sand bed in the MRG.

- Flows may be reduced from what they are now due to the demands of increasing population in both the MRG and Española-White Rock sub-areas.

- During periods of low flow, water quality is impacted by the high percentage of wastewater effluent present in the MRG reach.

- Seed sources for Russian olive and saltcedar (which displace and out-compete native riparian plant species,) are virtually uncontrollable throughout the bioregion. This is most severe in the MRG, but it also applies to the Española Valley-White Rocks Canyon reach. In addition, non-native fish tend to out-compete and displace native fish.

- Finally, the deterioration of soils may occur due to the build-up of salts in the MRG.

Legal /Administrative Constraints

- Rio Grande Compact deliveries must be met. There is little, if any, surplus in most years, but the Compact does ensure delivery of water from Colorado to New Mexico, and the flow situation could be worse in both sub-areas without the Compact. The Compact would have to be considered regarding almost any change in reservoir operations.

- Under New Mexico water law, the Rio Grande is fully appropriated, and there is no protection for instream flow. Water salvaged or acquired for restoration purposes can be pre-empted by other users, and its benefits may not be realized throughout the system. Also, restoration projects that increase consumptive use (wetland creation, for example,) would have to augment or offset any diverted river or return flows.

- Federal Law prohibits conservation storage in upstream flood control reservoirs. Re-authorization and an Environmental Impact Statement would likely be needed to change basic reservoir operations.

- Under federal floodplain regulations, physical restoration in areas designated by the Federal Emergency Management Agency as floodways cannot cause a rise in the 100-year floodplain elevation. Neither may such projects increase the likelihood of flooding outside the existing floodplain without land acquisition of flood easements. (Note: In areas where the 100-year flood is contained in suitable levees, constraints on floodplain elevations are less stringent, as long as levee freeboard and stability are maintained.) Floodplain regulations do allow for construction of structures within the floodplain if the structures are elevated above the 100-year flood elevation. This can result in more development in the floodplain that conflicts with potential restoration activities.

- Conflicting management objectives among resource management agencies, lack of funding, and a lack of understanding about how the system functioned historically also place constraints on restoration in both the MRG and Española Valley-White Rocks Canyon reaches.

3.3 Lower Bioregion: Caballo Dam, NM to Candelaria, TX

Throughout the Lower Bioregion, the Rio Grande flows through the Chihuahuan Desert ecosystem. In the upper two-thirds of the reach, the river has been channelized and confined within levees. The primary land use outside the levees is agriculture, except in the urban areas of Las Cruces, El Paso, and Juarez. A series of canyons and narrow river valleys with very little development comprise the remote lower third of the bioregion. Often referred to as the "Forgotten Reach," it has been extensively invaded by saltcedar. Throughout the bioregion, flows decrease in the downstream direction such that the volume is believed to be one-tenth the pre-development levels at Candelaria. Of the three bioregions in this study, the Lower Bioregion has experienced the greatest impacts on its geomorphology, hydrology, and biology.

3.3.1 Geomorphology

The Lower Bioregion has been divided into four reaches. In the upper three, IBWC channelization and river control projects have extensively modified the channel and floodplain, and a series of diversions greatly decreases the flow. The lower segment, Reach 19, has not been directly manipulated by channelization, levee construction, or jetty jacks, but has changed dramatically due to a reduction in flows from upstream, and the establishment of a saltcedar monoculture on most of the floodplain. A discussion of the geomorphic characteristics of each reach is presented below.

Reach 16 (RM 1356 to 1288--Caballo Dam to Mesilla Diversion): This reach of the Rio Grande represents the upper portion of the IBWC "Canalization Project," which consisted of dredging the main channel and constructing levees. Earlier projects had already altered some of the channel prior to the Canalization Project. Channel width typically ranges from 200-300 feet. Levees to the east, and topography or levees to the west (**Photo 3.9**) confine the current floodplain to a width of 600-1200 feet. The exception is Selden Canyon at the downstream end of the reach, where no levees have been constructed, and the floodplain is naturally limited to a width of 600-1,200 feet (**Photo 3.10**). The channel is slightly sinuous, at a value of 1.1, and has a sand bed. Channel alignment is heavily engineered, with constructed curves and tangents, and conveys on the order of 2,000-3,000 cfs before spilling into the limited floodplain. The gradient is similar to upstream values in the Middle Rio Grande Valley at 4 ft. / mi.

Reach 17 (RM 1288 to 1249--Mesilla Diversion Dam to American Dam): The Canalization Project continues downstream for 39 miles to the American Diversion Dam on the Texas / Mexico Border. The reach is similar in character to Reach 16, but somewhat more confined by levees, and further altered by water withdrawal. At the downstream end, the Franklin Mountains to the north, and the Sierra Juarez to the south laterally confine the channel. Through the rest of the reach, the floodplain is confined to an average width of 600 feet. Channel width averages 220 feet. There is less variation in both the levee and channel width than in Reach 16, and the channel is even straighter, at a sinuosity of 1.05. However, the channel slope remains about 4 ft. / mi.

Reach 18 (RM 1249 to 1156--American Dam to near Fort Quitman): Most of this reach is contained within the "Rectification Project," constructed by the IBWC between 1934 and 1938. The project consists of levees approximately 600 feet apart, with a 66-foot wide pilot channel excavated between them (**Photo 3.11**). Over the years, the pilot channel has attained a width of up to 100 feet in some areas, but narrowed to as little as 50 feet in others. The Rectification Project helped to stabilize the river, which serves as the border between Mexico and the United States. Prior to the project, the river was subject to frequent change; old meander scars left by channel avulsion are evident throughout the floodplain. The Rectification Project reduced the channel sinuosity from nearly 2 to its current 1.1. The current gradient of 3.3 ft. / mi. would have been less than 2 ft. / mi. prior to straightening. The current channel receives minimal upstream flows, with a base flow created by agricultural returns and wastewater effluent. Significant peak flows are a result of tributary flooding.

Reach 19 (RM 1156 to 1036--Near Fort Quitman to Candelaria): This reach starts at the downstream end of the Rectification Project, and proceeds to the Capote Creek confluence just above Candelaria, Texas. At 120 miles, this is the longest reach in the project area. It represents a considerable change from upstream reaches, having had little direct physical manipulation of the channel, though some channelization work was performed by the IBWC under the "Boundary Preservation Project" from 1980 to 1986. The work typically included excavation of a 40-foot-wide channel, and clearing saltcedar from the floodplain. The channel is confined by topography. The valley width is 1,000 feet or less, with some areas as wide as 3,000 feet. In contrast, the river also flows through several narrow canyons no more than 200 feet wide. The current channel is very narrow, with a width of 50 feet or less in many areas. Saltcedar has encroached from the channel banks to the valley walls in most locations (**Photo 3.12**). A major problem in the reach is the lack of flow to mobilize and transport sediments deposited by thunderstorm floods on the tributaries. This has resulted in backwater areas and complete loss of the channel, which splits into many small tributaries across the deposits. Channel slope increases to 4.5 ft. / mi., with a sinuosity of 1.5.

3.3.2 Hydrology

There is little inflow to the Rio Grande in this bioregion, and all tributaries are ephemeral. Many areas adjacent to the basin are "closed," or internally draining, and the watershed is narrow. Because of the small contributing watershed area, the ephemeral nature of the tributaries, the large amount of surface water diversion, and natural losses, flows progressively decrease in the downstream direction. There are several tributary flood control structures, typically dry dams on arroyos. Uncontrolled tributaries can still deliver high peaks of short duration as a result of intense thunderstorms. The significant diversions in the reach are Percha, Leasburg, Mesilla, American, International, and Riverside. The primary influences on hydrology within the bioregion are the diversions that reduce flow, and activities in the Upper and Middle Bioregions, as previously discussed.

Four gages were utilized in developing the hydrologic characteristics of this area. These are at Leasburg Dam, El Paso, Fort Quitman, and Rio Grande above Presidio. The upper three illustrate the influence of diversion within the bioregion, while the Presidio Gage is considered to approximate the outflow from the reach. The station below Caballo Dam defines inflow to the reach after 1938. From 1916 to 1938, the Rio Grande below Elephant Butte is the best indicator of inflow to the bioregion. For the earliest record, the most representative inflow gage is San Marcial, which covers the period from 1899 to 1915.

Flow records were divided into three periods when data were available. The first period, from the turn of the century to 1915, represents conditions prior to the operation of Elephant Butte Reservoir. The period of 1916 to 1938 was divided to show conditions after closure of Elephant Butte, but prior to the Rio Grande Compact. The final period, 1939 to 1999, represents conditions after the signing of the Compact. **Figure 3.4** provides a plot of the average daily flows over this period. The influence of Elephant Butte after 1916 is apparent in the reduced peak discharges.

Reviewing the results of the hydrologic analysis in **Table 3.3**, there is significant reduction in flows in the downstream direction throughout this reach. Looking at the most recent period, 1939 to 1999, the average annual flow entering the reach at Caballo Dam (see **Table 3.2**) is 680,000 acre-feet. This volume is reduced to 480,000 acre-feet at Leasburg, 400,000 acre-feet at El Paso, and 140,000 acre-feet at Fort Quitman. The annual flow volume remains relatively constant through the "Forgotten Reach," as an average of 130,000 acre-feet has been measured at the Presidio Gage. In general, the annual flow volumes have decreased at each gage when comparing successively more recent periods of record. The number of low-flow days has generally increased for more recent periods, except at El Paso, where the period with the most low-flows was 1889 to 1915, in all three categories (0 cfs, <30 cfs, and <100 cfs). Interpretation of the peak flow statistics is difficult because of the short time span represented by the two earlier periods. However, it is apparent that these peak flows are generated by tributary inflows rather than flows coming down the mainstem of the Rio Grande, since the 100-year flood from Caballo is on the order of 6,000 cfs, about half the current value for El Paso.

Table 3.3 - Summary of Hydrologic Information – Rio Grande Lower Bioregion

Reach / Location	Period (from – to)	2-Yr (cfs)	100-Yr (cfs)	Ave. Annual (cfs)	Ave. Annual (afy)	Ave. days/yr 0 cfs	Ave. days/yr <30 cfs	Ave. days/yr <100 cfs
Rio Grande at Leasburg Dam, NM	1930 – 1991	---	---	680	490,000	0	105	143
	1930 – 1938	---	---	750	546,000	0	38	90
	1939 – 1991	---	---	660	480,000	0	116	152
Rio Grande at El Paso, TX	1889 – 1999	4260	21900	760	549,000	16	38	73
	1889 – 1915	7320	35400	1280	925,000	67	96	124
	1916 – 1938	4130	13200	840	606,000	0	3	12
	1939 – 1999	3390	11200	560	406,000	0	26	73
Rio Grande at Fort Quitman, TX	1923 – 1999	3150	15900	220	160,000	40	105	170
	1923 – 1938	2100	3730	310	228,000	0	9	54
	1939 – 1999	3810	13900	200	143,000	50	130	201
Rio Grande at Candelaria, TX	1976 – 2001	---	---	280	202,600	50	130	201
Rio Grande above Rio Conchos near Presidio, TX	1900 – 1999	1730	15900	300	218,000	84	135	187
	1900 – 1915	4660	25300	840	611,000	104	117	156
	1916 – 1938	3010	8350	320	235,000	25	59	106
	1939 – 1999	1050	7600	180	132,000	101	169	226

3.3.3 Ecology

The Lower Bioregion has experienced the greatest change in riparian and riverine conditions in the study area. Due to channelization, agriculture, urbanization, changes in flow regime and landscape, and efforts to protect the national border, native vegetation communities have been overtly removed, or replaced by invasive species. Likewise, aquatic habitat has been degraded and functionally impaired.

Riparian habitat communities along the lower reach can be divided into two structural types: tall dense vegetation (cottonwood–willow and saltcedar), and short, sparse vegetation (thorny shrub community, and screwbean mesquite-wolfberry). The cottonwood–willow community is similar to that discussed in the Middle Bioregion. Non-native saltcedar tends to be a monoculture community comprised of dense stands of saltcedar. The plant's ability to propagate and thrive in saline soils has given it an advantage over native species, which did not evolve for the existing conditions.

Screwbean mesquite–wolfberry occurs in the floodplain outside the bands of cottonwood/willow or saltcedar. The overstory is dominated by screwbean mesquite (*Prosopis pubescens*), with an understory of shrubs dominated by wolfberry (*Lycium torreyi*). Honey mesquite (*Prosopis glandulosa*) may occur in this community, along with quailbush (*Atriplex lentiforms*). Openings between shrubs may support species of forbs and grasses such as alkali sacaton (*Sporobolus airoides*) and saltgrass (*Distichlis spicata*). The thorny shrub community consists of mesophylic plants such as honey mesquite and buckthorn (*Rhamnus californica*), and more xerophylic species including creosote bush *(Larrea tridentata*) and lechuguilla (*Agave lechuguilla*). This community is an extension of the upland community that has invaded the drier alluvial soils along the outside edge of the floodplain (Ohmart 2002), and is a direct result of controlled flows, lack of flood events, channelization, and disconnection between the river and its floodplain. As with the Middle Bioregion, wet meadows, palustrine marshes, spring seeps, perched wetlands, salt marshes, and sandbars also occur throughout the Lower Bioregion.

Between Caballo Dam and El Paso, the dominant communities are cottonwood–willow, screwbean mesquite–wolfberry, and saltcedar. Although disconnected from the influence of the river, cottonwood–willow communities occur between Caballo Dam and Selden Canyon, while through the canyon, screwbean mesquite–wolfberry communities are dominant. Within the levees between Las Cruces and El Paso, the riparian habitat is extremely fragmented and of low quality. There is little or no regeneration due to the lack of floods, and to frequent mowing inside the levees. There are isolated pockets of remnant cottonwood–willow habitat, but saltcedar is dominant.

Below El Paso, saltcedar has invaded most of the riparian area (Forgotten Reach), along with the drier thorny shrub community. The topography is variable, with narrow canyons and wide floodplains up to two miles across. In these wide areas, there are large expanses of saltcedar. It has been estimated that only about 60 acres of cottonwood–willow remain below El Paso (Ohmart 2002). Soil salinity is a limiting factor that affects species composition.

The river is nearly de-watered from El Paso to Candelaria. The instream water that does exist is from drainage canals carrying return flows from irrigated fields. Seldom does the river flow overbank, except when tributaries experience flash floods, or when sediment deposition causes plugs in the main channel and therefore overbank flow. The river channel is perched above the floodplain in many areas so that water is trapped and cannot return to the channel. A case in point occurs near Candelaria, where water accumulates as a backwater and evaporates, leaving a highly concentrated saline lake where even saltcedar cannot survive. Occasionally, emergents such as cattail occupy these saline lakes, but usually as scattered individuals, presumably because of the high salinity (Ohmart 2002).

The primary abiotic and biotic process needed for a functioning system include scouring floods, sediment transport, overbank spring floods that flush salts and cause seed dispersion/germination, and native plant seed sources.

3.3.4 Constraints

This portion of the Rio Grande has different conditions and challenges than occur in the upstream bioregions. Here, water availability is even more problematic and restrictive. Flows in this reach are largely a result of Compact requirements to deliver water, and storage in Elephant Butte Reservoir. Water in this bioregion is primarily marked for use by agriculture between Caballo Dam and El Paso. As a result, flows are released at a fairly uniform rate during the irrigation season. This results in a lack of discharge variability, and minimal river flows outside the irrigation season. There is little resemblance to a natural hydrograph, which would typically have had a shorter and higher peak during late spring, and lower flows for the remainder of the summer and fall. Additionally, winter flows would have been higher; today, almost all winter flows are stored in Elephant Butte for release during the irrigation season. Water usage in the reach reduces the inflow by 80-90%, and only a fraction of the natural flow level remains in the lower half of the bioregion.

Another major challenge to restoration in this bioregion is the high level of channel alteration resulting from the IBWC's Canalization and Rectification Projects. The portion of the river from Caballo Dam to Fort Quitman has been more significantly altered by channelization and levee construction than any other reach of the Rio Grande upstream. The river in the lower portion of the bioregion has seen less alteration, though it was modified in some areas by the Boundary Preservation Project. The reach from Fort Quitman to Candaleria has suffered the most extensive impact from saltcedar.

The Lower Bioregion's sediment transport balance has been altered more than in the other bioregions. Sediment-free water is released from Caballo Dam, causing some channel incision, but within a short distance, sediment-laden flows from tributaries enter the system. With no peak flows on the mainstem to wash these tributary sediments downstream, deposits are formed. In the Canalization and Rectification Project reaches, these deposits are often removed by dredging to maintain channel capacity, but in the Boundary Preservation reach, they have not been removed for many years. As a result, the defined channel nearly disappears in some areas.

The following is a summary of primary physical and administrative/legal constraints to restoration in the Lower Bioregion.

Physical Constraints

- Human activities and development in the historic floodplain (levees, communities, agriculture, water and transportation infrastructure, etc.) are constraints to the restoration of floodplain connectivity and dynamic, geomorphic channel processes such as bank erosion, lateral migration, and avulsion.

- Levees line almost the entire portion of the bioregion from the upper end to Fort Quitman, and there is extensive development outside the levees in terms of both infrastructure and communities that need to be protected, except in the Fort Quitman to Candelaria reach. The integrity of the levee system will need to be maintained in most, if not all, locations. The valley is very flat, and flooding can spread for miles if the levees are breached or overtopped.

- Water availability is extremely limited, particularly at the downstream end of the bioregion. Water must be provided for agricultural, industrial, and municipal use. Natural losses due to the arid nature of the region, evaporative losses from reservoirs, and increased water use by non-native species are to be expected. Creating any resemblance to the historic system in the area below El Paso may not be feasible without changing the timing of flows, and without significant additional water. Demand from an increasing population may further reduce flows and exacerbate current conditions.

- Changes to the system's sediment balance are also constraints to restoration. The river is sediment-starved immediately downstream of Caballo Reservoir, but further downstream, arroyos control the inflow of sediment, and in many areas, mainstem flows are unable to remove these tributary deposits.

- Saltcedar is displacing and out-competing native riparian plant species, particularly below El Paso/Juarez, and saltcedar seed sources are virtually uncontrollable throughout the bioregion.

- Salt build-up in soils, and poor water quality both pose challenges to long-term restoration.

Legal /Administrative Constraints

- Water deliveries guaranteed to Mexico by international treaty must be met, leaving little if any surplus in most years.

- The river must be maintained in a fixed location as it forms the international boundary with Mexico. Border crossing and security issues will also affect attempts at restoration.

- As with the Upper and Middle Bioregions, state water law does not facilitate river restoration. The river is fully appropriated, flow schedules are not easily subject to change, restoration activities that increase consumptive use would mean augmenting or offsetting any water utilized from the river or return flows, and there is currently no mechanism to keep water salvaged or acquired for restoration purposes from being diverted by others downstream.

- In addition, federal law prohibits conservation storage in upstream flood control reservoirs, and both re-authorization and an EIS would likely be required in order to change basic reservoir operations.

- Floodplain regulations do not allow physical restoration in areas designated by the Federal Emergency Management Agency as floodways if it will cause a rise in the 100-year floodplain elevation. Neither can the flood potential be increased outside of the existing floodplain without land acquisition of flood easements. (Note: In areas where the 100-year flood is contained in suitable levees, constraints on floodplain elevations are less stringent, as long as levee freeboard and stability are maintained.) Floodplain regulations do allow for construction of structures within the floodplain if the structures are elevated above the 100-year flood elevation. This can result in more development in the floodplain that conflicts with potential restoration activities.

- Conflicting objectives among resource management agencies is another constraint, as is the lack of funding, and the lack of understanding about how the river system functioned historically.

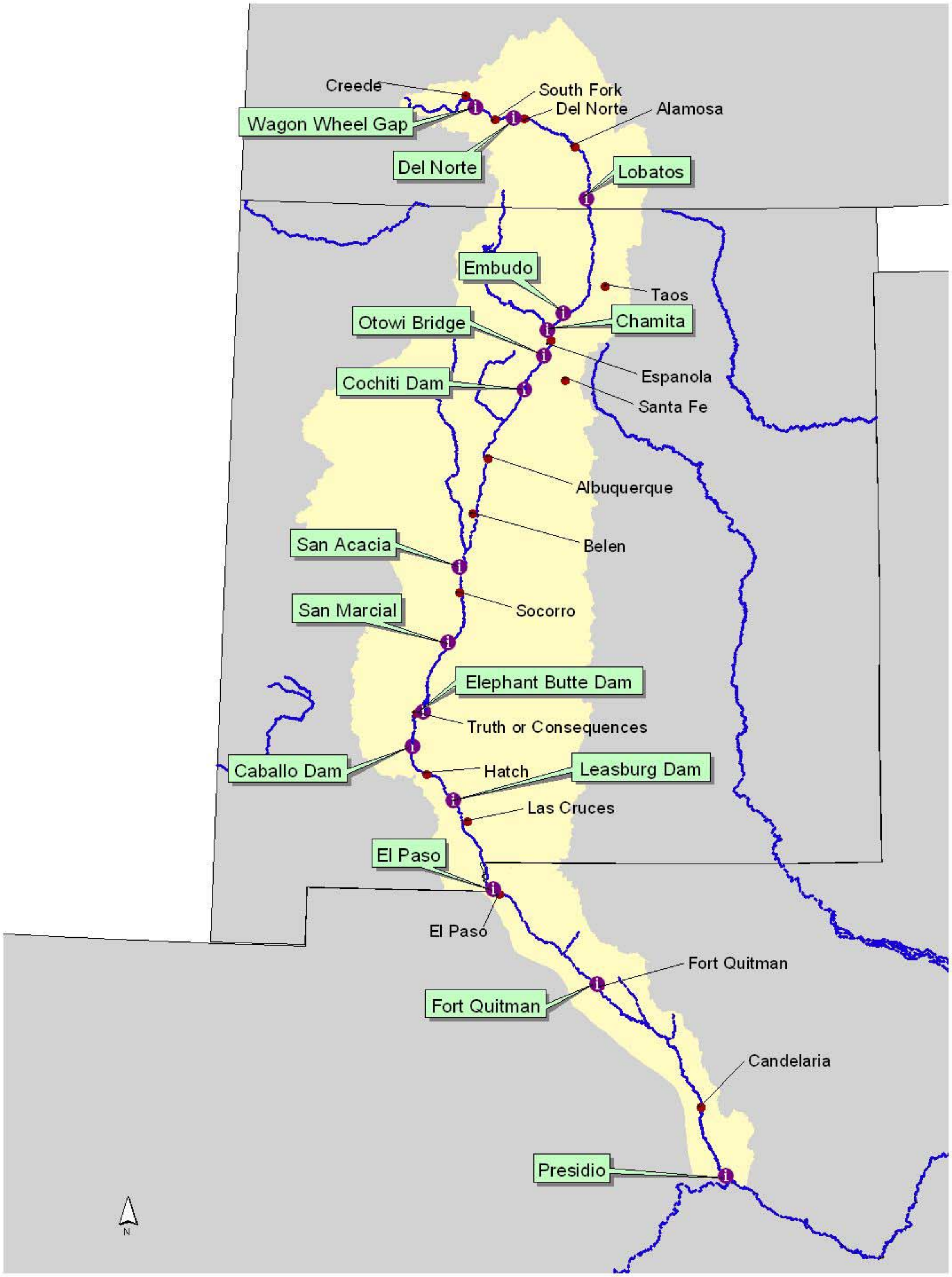

Figure 3.1 – Location of Stream Gages Used in the Hydrologic Analysis

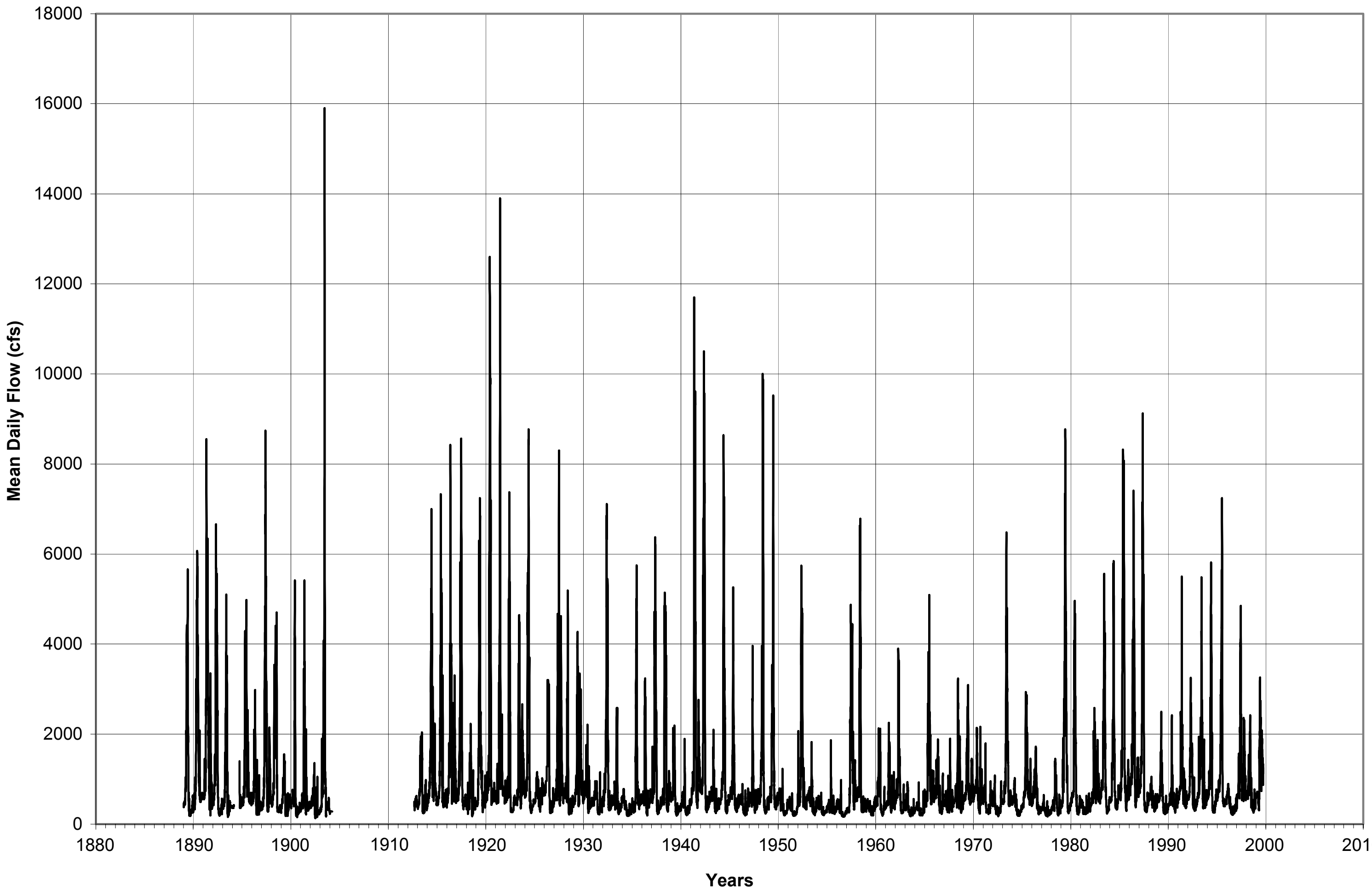

Figure 3.2 – Measured mean daily flows for USGS Gage, Rio Grande at Embudo, NM

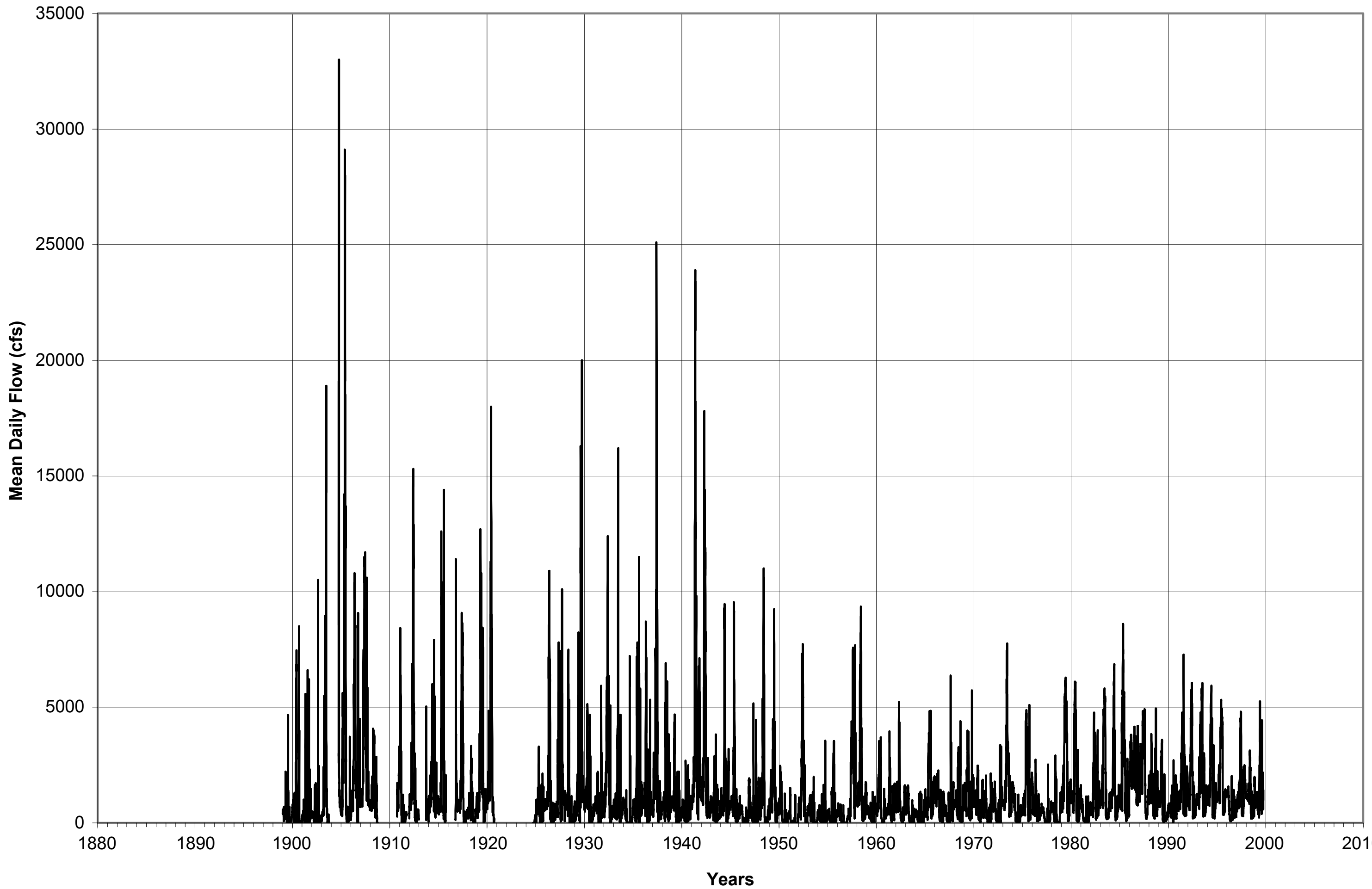

Figure 3.3 – Measured mean daily flows for USGS Gage, Rio Grande at San Marcial, NM

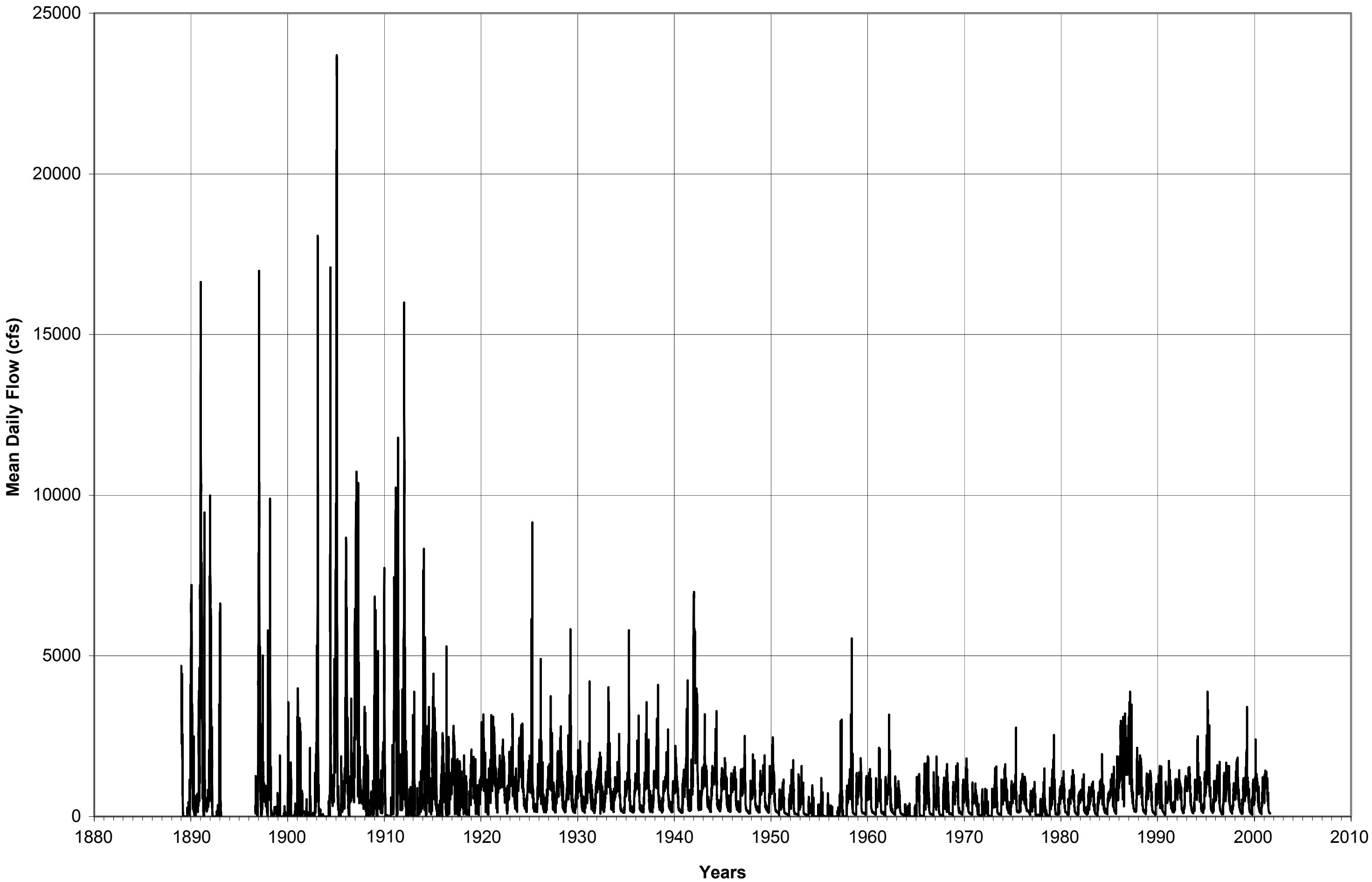

Figure 3.4 – Measured mean daily flows for IBWC Gage, Rio Grande at El Paso, TX

Photo 3.1 - Rio Grande near Creede, Colorado (Reach 1)

Photo 3.2 – Rio Grande in the San Luis Valley (Reach 2)

Photo 3.3 – Leveed section of the Rio Grande at Alamosa, Colorado (Reach 2)

Photo 3.4 – Rio Grande Gorge near Taos, New Mexico (Reach 4)

Photo 3.5 – Rio Grande on the San Juan Pueblo, above the Rio Chama confluence (Reach 5)

Photo 3.6 – Jetty jack removal near Los Lunas, New Mexico (Reach 11)

Photo 3.7 – Braided channel transitioning downstream to a channelized area (Reach 12)

Photo 3.8 – The San Marcial Railroad Bridge (Reach 12)

Photo 3.9 – Upper portion of the Rio Grande Canalization Project (Reach 16)

Photo 3.10 – Rio Grande in Selden Canyon (Reach 16)

Photo 3.11 – Rio Grande Rectification Project (Reach 18)

Photo 3.12 – Saltcedar monoculture in the "Forgotten Reach" (Reach 19)

4 RESTORATION OPPORTUNITIES AND VISION

As indicated in the previous chapter, extensive alterations have occurred to the Rio Grande as a result of human influence. For over one-hundred years, streamflow, the driving force that shapes the river and its surrounding corridor, has been significantly reduced. Pre-1900 changes were primarily related to direct diversion of water for agriculture, but during the 20th Century, more extensive manipulation of the system's hydrology was undertaken to improve the reliability of water delivery throughout the irrigation season, including carry-over of supplies from wet years to drought years. Levees, channel stabilization, and reservoir storage were added to control the floods and sediment that spread beyond the channel banks, damaging surrounding lands and development. The hydrology and morphology of the system have been further altered by the appearance of nonnative species such as saltcedar and Russian olive. Changes have also occurred in water quality due to the introduction of pollutants. The end result is a vastly different Rio Grande than existed several hundred years ago.

Restoring the system to its historical condition is not possible within societal constraints. The Rio Grande Valley is an attractive place for humans to live. Native Americans have occupied it for over a thousand years, it still contains valuable farm and ranch land, and today it supports the largest urban population in New Mexico. There will likely be increasing demands on the river to sustain development, and the valley will continue to need protection from floods. Nevertheless, many negative impacts of human occupation can be reversed, to varying degrees. Some reversals will bear long-term sustainable results; others may require periodic maintenance or manipulation. Some changes will require only local cooperation; others will require cooperation across the entire basin.

For the purposes of this report, opportunities for restoration have been divided into two categories. The first includes scenarios that can be accomplished under "existing constraints," i.e., implemented without major change to institutions, laws, regulations, or societal attitudes. For the most part, this is how river restoration is currently progressing, particularly in the Middle Bioregion. Here, restoration gained momentum with the realization that the area's unique cottonwood bosque is in decline; then, restoration initiatives began receiving considerable legal and financial support due to local Endangered Species Act issues. One of the goals of this project is to encourage a similar level of critical mass in regard to restoration in the Upper and Lower Bioregions. **Appendix D** provides a listing of current and planned restoration activities throughout the study area.

A second level, or "Vision," of restoration opportunities, is also presented. Many of these ideas were developed at the Rio Grande Restoration Workshop (list of attendees provided in Appendix F). The Vision is intended to set a high standard; it may even seem impossible under current realities, but it must be recognized that times change. It should also be noted that truly visionary ideas should address not only restoration issues, but water supply issues as well. Water availability is a problem that will not go away, whether restoration is undertaken or not. Restoration hinges on water conservation, reduction of evaporative losses, reduction in consumptive use by non-native species, higher levels of cooperation among different areas along the river, and sustainability. Though it may seem that current conditions place advocates for restoration and advocates for water use on opposites sides of the "water problem," there is actually more common interest than most perceive. The restoration vision is a scenario that may become possible as cooperation between these different interests improves.

4.1 General System-wide Opportunities

Aspects to restoration that span all three bioregions are presented in this section according to the categories discussed above, and are further divided into legal/administrative and physical opportunities under each scenario. A review of the challenges common to all three bioregions is also provided.

4.1.1 System-wide Challenges

The issue or challenge that most strongly links the three bioregions is availability of water. Due to manipulation of the Rio Grande to reduce flood flows and ensure a water supply for agriculture and the cities, the natural hydrology of the system has been dramatically changed. Peak flows have been reduced, the volume of flow has been reduced, the timing of the hydrograph has been altered, and in some cases, the period of moderate flows has been increased as a result of reservoir releases. These hydrologic alterations increase in severity from north to south for two reasons: (1) the impacts of water removal and reservoir control accumulate in the downstream direction, and (2) the majority of the water in the system is produced upstream, with little inflow in the lower portions to offset the cumulative effects of water resource projects.

A closely related restoration challenge is the alteration of the system's natural geomorphology. Changes in hydrology manifest as changes in channel morphology. Reduced peaks alter the size and planform characteristics of the channel. They also change the hydrologic interaction between the main channel and the floodplain. Reservoirs and diversions result in trapped sediment and altered sediment balance in the system. Other factors have also changed the morphology, including confinement of the channel by levees, and the use of bank stabilization measures to prevent erosion and migration. Development in the floodplain further increases the need to confine the channel and control peak flows.

Throughout all three bioregions, invasion by nonnative species is an issue. To some extent, changes in hydrology and morphology of the system have assisted the establishment of nonnative vegetation. Changes in the timing of peak flows and their magnitude have created conditions that do not favor native riparian vegetation that evolved under the natural flow regime. Many species of native riparian vegetation rely on spring floods for seed dispersal and germination. Additionally, reduction in dynamic channel processes such as bank erosion, bar building, and channel avulsion have reduced the recruitment of native vegetation, which relies on these processes to create conditions favorable to its establishment.

Another common restoration challenge linking the three bioregions falls under the legal/administrative heading, and involves water rights. The Rio Grande has been fully appropriated for decades, and currently only Colorado and to a lesser extent Texas, consider instream flows to be a beneficial use of water. (Note: There is no explicit statutory authorization under Texas State law recognizing instream flows as a beneficial use of water, but administrative regulations do recognize instream flows as beneficial.) Such instream flow rights are junior rights, and mean very little during periods of low flow when they are most critical. Therefore, even when water is secured for environmental purposes, it is difficult to keep it in the system, and the challenge becomes even tougher when the water crosses from one state to the next.

4.1.2 System-wide Restoration Opportunities Under Existing Constraints – Legal and Administrative

Under existing constraints, there are a variety of actions that could be taken toward restoration of the Rio Grande. They fall in two general categories: facilitating coordination of and support for restoration, and implementing non-structural measures to preserve positive qualities of the system.

Coordinating restoration efforts throughout the project area is important. Actions performed in one location can influence the system at other locations, and information sharing among those involved in restoration can be helpful in maximizing benefits and successes. Restoration advocates need to increase public awareness of the importance of a healthy Rio Grande to quality of life in the basin. There is also need for a task force, with representatives from environmental groups, agencies, water users and policy makers, to search for common solutions to restoration and water use problems on the Rio Grande.

Non-structural measures are an important component of restoration, with applicability throughout the project area. They can be used effectively to preserve existing high quality areas in the riparian corridor, and also to prevent further impediments to future restoration activities. One such activity is adoption and enforcement of floodplain ordinances. Floodplain ordinances prevent development in flood prone areas, thus diminishing the potential for damage when floods do occur; they also reduce the economic justification of structural flood control measures such as channelization, levees, and flood control reservoirs. Other means of regulating or preventing development in the floodplain and riparian corridor include zoning, transfer of development rights out of the riparian corridor to less environmentally sensitive areas, and purchasing floodplain and conservation easements to preserve important areas. Utilizing "open space" funds to purchase and preserve land in the riparian corridor is another preservation tool that can be applied throughout the project area. Lands or easements can be purchased from voluntary sellers and converted to native habitats. Better grazing management can also improve riparian conditions throughout the project area.

Currently, there are non-structural opportunities for managing water while supporting restoration. Restoration projects that are likely to increase water depletions will have to mitigate those effects through offset or augmentation. The possibility of purchasing adjacent irrigated acreage from willing sellers, retiring the water rights, and applying them to restoration activities is a non-structural measure that is available throughout the project area. There is also the potential to create incentives for water conservation, thus leaving more water in the system for both the river and downstream users. Under existing constraints, water obtained for environmental uses, whether from retired rights or conservation, becomes available to downstream users and is not likely to provide benefits for any substantial length of river. Elimination of this constraint is an important element in the visionary scenario.

4.1.3 System-wide Restoration Opportunities Under a Visionary Scenario – Legal and Administrative

Legal and administrative avenues should be pursued to make it easier to acquire "wet" water for restoration purposes. There is also the need to obtain further funding to implement restoration activities. It is assumed that all activities under the "existing constraints" scenario will have been initiated throughout the project area.

As mentioned under the existing constraints scenario, a major impediment to securing flows for environmental purposes is that such flows are not always recognized as a beneficial use, or protected as a water right under state law. Even if they are accorded water right status, they are likely to be considered junior rights, subject to diversion by senior users. Therefore, each state needs to recognize environmental flows as a beneficial use, and to ensure that water acquired for environmental proposes remains in the river. There should also be some means of preserving environmental flows once they cross state lines. This could potentially be accomplished through changes to the Compact, or to federal law.

Another important legal and administrative tool for restoration is congressional re-authorization of federal water projects to achieve more balance between traditional missions and environmental needs. Modifications to reservoir operation, for instance, could include creating a pool for environmental purposes, altering minimum pools and other operational criteria to pass sediment through the reservoir, releasing water to create runoff peaks that better mimic the natural hydrograph, and releasing water stored in environmental pools to sustain the system during periods of low flow.

The acquisition of water for environmental purposes can be accomplished by two means. The first is to reduce demand in existing water use sectors. Agricultural users could be reimbursed for revenue losses or costs associated with switching to less water-consumptive crops, or converting to more efficient irrigation systems. Incentives might take the form of direct funding for improvements, or loans for improvements, or making a portion of the saved water available for additional use. A portion of the water savings could be earmarked for environmental purposes, used to help meet Compact deliveries, or "banked" for potential sale or lease. Similar mandates and incentives to conserve could also be implemented for municipal and industrial water users.

A reduction in demand can also be accomplished through alterations to the system's "plumbing." Evaporative losses at Elephant Butte Reservoir offer the greatest opportunity for savings. Typical evaporative losses at Elephant Butte approach 100 inches per year, meaning as much as 200,000 acre-feet of water can be lost. At upstream reservoirs, the evaporation rates are less than half this value. It may also be possible to store water underground, through aquifer recharge programs. On the order of 100,000 acre-feet per year might be saved by shifting the storage location. Such a change would require alterations to the Rio Grande Compact, additional cooperation between the agencies that manage water, and modified infrastructure to allow more flexibility, including enlargement of existing upstream reservoirs, construction of new off-channel reservoirs, and/or the construction of recharge, pumping and conveyance systems to implement aquifer storage.

Flows can also be made available for environmental purposes by acquiring existing water rights from willing sellers, and either converting them to instream flows, or using them to offset increased water depletions. Restoration activities that might require offsetting of depletions include conversion of uplands to wetlands, or increasing the width of the river channel. The most likely source of water for purchase would be irrigated farmland and pasturelands adjacent to the river. Acquisition of such properties could have additional uses beyond the acquisition of water rights; in some cases, levees could be set back further from the river, increasing the width of the floodplain and riparian corridor. In other instances, retired parcels could be converted to native upland habitat.

Realization of this visionary level of restoration will require substantial funds. The likely source for such funds would be the federal government. Large-scale projects associated with more efficient water management and "re-plumbing" will require extensive studies and analysis in additional to actual capital expenditure. Securing funds on such a scale is more likely to be successful if pursued cooperatively by all parties. Additionally, planning, implementation, and long range operation of the improved system will require a high level of cooperation and interaction, from the headwaters to the lower reaches of the Rio Grande.

If the above efforts are successful, the foundation will have been laid for mimicking the natural hydrograph of the Rio Grande. This is the key to achieving a truly high level of restoration.

4.1.4 System-wide Restoration Opportunities Under Existing Constraints – Physical

Physical restoration can be divided into four categories: hydrologic changes, geomorphic manipulations of the main channel, geomorphic manipulations of the floodplain, and vegetation management. The physical restoration opportunities available under existing constraints are discussed below.

Hydrologic manipulations on a general scale are not possible due to the limitations posed by existing water law and project authorization. There are some opportunities for specific changes in flow in each bioregion, but there is limited ability to realize large-scale improvements. The level of geomorphic restoration may also be limited, as many types of channel manipulation are unsustainable without the appropriate hydrologic conditions. Under existing constraints, one hydrologic tool that can be applied is to offset increased depletions for one kind of restoration activity with water saved through other restoration activities. A very promising aspect of restoration work currently underway is the potential to reduce the consumptive water use of floodplain vegetation by re-creating a riparian mosaic. Removing high water use species such as saltcedar, and replacing them with components of the mosaic that require less water is expected to result in a net savings in water consumption. This can offset the increased consumptive use associated with a wider channel, or enhanced floodplain connectivity. Finally, improvement in water availability, particularly during periods of low flow, can be achieved under existing constraints in all bioregions through agricultural, domestic, municipal and industrial water conservation.

Under existing constraints, a variety of actions can be taken to restore geomorphic conditions in the channel to more natural levels. There are opportunities to use "natural channel reconstruction" techniques to reverse the impacts of channelization. These can include altering the channel cross-section, profile and alignment, and restoring sinuosity in areas where the channel has been physically straightened. The presence of levees, infrastructure, and development, however, reduce the footprint for such projects. Grade restoration facilities (GRF) can be constructed to raise the bed elevation and locally reverse the impacts of channel incision, or to prevent future channel incision. GRFs also function to increase floodplain connectivity.

In terms of its geomorphology, the historic Rio Grande was a very dynamic system. Steps can be taken to restore some of those dynamics. Side channels can be physically constructed, or the remnants of side channels can be excavated and reconnected to the main channel. Dense vegetation can be cleared to provide a corridor for the new channel. Excavating a new channel or a pilot channel while blocking the main channel can simulate avulsion. Creating side channels or backwaters in the abandoned main channel allows sediment to be distributed across the river corridor. (Channel avulsions are only appropriate in aggradational reaches that have a surplus of sediment.) In some areas, dense nonnative vegetation, or bank protection devices that prevent the channel from eroding, can be removed. This same process introduces sediment to form bars downstream, building new areas for recruitment of native riparian vegetation such as cottonwoods and willows. Reintroducing dynamic channel processes must be performed very cautiously under existing constraints, as adjacent infrastructure and development could be damaged if the channel were to significantly change its location. These techniques are therefore limited in their application.

Under existing constraints, geomorphic restoration activities on the floodplain primarily involve actions to increase the hydrologic connectivity with the main channel. Connectivity between the main channel and floodplain has been reduced through most of the project area by the reduction in peak flows. Generally, alluvial channels spill flow into their floodplains during discharges in excess of the 1.5 to 2-year return period. In other words, there is at least some overbank flooding two-out-of-three to one-out-of-two years. However, due to reduced peaks, there are many areas along the Rio Grande that experience overbank flooding much less frequently. This situation has been worsened in some places by channel incision, which results in the main channel carrying even higher flows before it spills into the floodplain. The most widely applicable technique in such cases would be lowering the floodplain to a level at which the channel floods more frequently. Construction of side channels to connect low-lying areas some distance from the main channel may also be used. As previously mentioned, the GRFs can be used in incised channels to help restore floodplain connectivity. In some areas, natural levees have built up in dense vegetation near the banks, due to sedimentation. Removal of these natural levees, or breaching them in specific locations, increases the frequency of overbank flows. Under existing constraints, there may be limited applicability of setting levees back to increase the area available for the floodplain. This would also benefit the restoration of dynamic main-channel processes by providing room for channel migration and re-alignment. Opportunities to set back levees is limited under existing constraints because of the costs of land acquisition, and in most cases, the even higher cost of relocating infrastructure adjacent to the levees.

The primary goal of vegetation management throughout the project area, under existing constraints, is the reduction in invasive species and their replacement by appropriate native species. For the existing constraints scenario, the word ‘reduction’ is used rather than elimination, since it will be an extremely difficult task to eliminate invasive species such as saltcedar, Russian olive and elm. This is due to the ubiquitous nature of the current seed sources, which extend well beyond the river corridor and into adjacent basins. Control of invasive species will require continued maintenance. The primary restoration tool is mechanical removal, which is often supplemented by herbicides applied to roots and stumps. Manipulation to create conditions more favorable to the native species, such as improving overbank flooding, and timing spring peaks to conjunct with planting native species, are other tools to reach the goal. Grazing management may also play an important role, preventing livestock from feeding on the young native plants before they become established.

Re-grading overbank areas to provide varying elevations is a technique that can be used to establish native vegetation and provide for diversity. It creates locally variable conditions, particularly in terms of groundwater depth and retention of runoff or overbank flows, that favor different species of vegetation and a diversity of vegetation communities at various stages of succession. Another technique to improve the condition of vegetation is to thin areas of dense understory. This reduces fire danger, and helps to promote establishment of healthy native vegetation.

Wetlands and wet meadows, once an extensive part of the riparian corridor, can be re-created by the manipulation of topography and hydrologic conditions. In some cases, manipulation of soils may also be required. There are opportunities to create the proper hydrologic conditions by excavating to reduce the depth to groundwater, diverting water through side channels to the area, lowering the elevation to increase the duration and frequency of flooding from the main channel, or applying return flows or effluent.

The ultimate outcome of vegetation management would be areas that contain a mosaic of native vegetation, ranging from low-lying willow stands, to wetlands, wet meadows, cottonwood gallery forests, grasslands, and shrub lands. Sustaining such a mosaic under existing constraints will require some intervention, primarily to control invasive species, and possibly, due to the lack of hydrologic and geomorphic processes that help native species thrive, assisting in regeneration. To the extent that such processes can be restored, self-sustainability of the mosaic will be increased.

4.1.5 System-wide Restoration Opportunities Under Visionary Scenario – Physical

Under the visionary scenario, a much larger array of restoration activities is possible throughout the project area. Together, these opportunities could make real the vision of a restored Rio Grande, including its channel, floodplain and riparian corridor. The key elements of this effort are: restoration of flows that more closely resemble the historic hydrograph; re-establishment of geomorphic processes and characteristics that represent a more natural system; control of invasive species; and the management of land and water resources that promote and maintain such a system. In the Visionary scenario, this is achieved while maintaining functions of the system that support the human inhabitants of the region, but in a manner that achieves a sustainable balance with environmental needs. The central question of how to establish a hydrograph that mimics the historic one, while still meeting the water needs of the inhabitants along the Rio Grande, is not answered in this report. The solution will be very complex, and will require intense cooperation between all stakeholders. It may take many years, or even many decades, to develop. It will also require large capital expenditures to improve the existing water management infrastructure and water use practices. However, restoration efforts along the Rio Grande should be striving toward just such an objective.

Establishing a hydrograph that “more closely resembles the historic hydrograph,” does not mean re-creating the exact conditions prior to human utilization of the Rio Grande’s water resources. This does not seem achievable since the Rio Grande's water is needed to sustain the present population. Therefore, the new hydrograph would be one in which volume would be reduced through usage, and extreme flood events would be controlled. The hydrograph would need to have several key elements that are essential to geomorphic and biological functions: annual peak discharges that sustain geomorphic processes, maintenance of low-flow regimes, timing of the various components to coincide with the shape of the natural hydrograph, and variability from year to year. The idea of creating a spring flood pulse that would flow through the system from one end to the other, was developed at the Restoration Workshop, and should be incorporated into a restored hydrograph (with flood defined as water flowing into overbank areas within managed floodplains and not with catastrophic effects such as widespread property damage). In terms of geomorphic processes, such a pulse would help sustain the planform type, bed forms, substrate, erosion and accretion levels, hydraulics, and overbank flooding characteristics that resemble the natural condition. However, these would need to be adjusted to fit a smaller Rio Grande. How much the system can be scaled down and still retain these functions is a question that still needs to be answered, based on analysis of the relationship between flows, geomorphology, sediment transport conditions, and the biological components of the system. Similarly, critical evaluation of water use requirements needs to continue to determine the long-term potential for water savings through changes in management, system efficiency, allocation between various uses, and future demand. With a better understanding of these issues, the scale of the restored Rio Grande can be decided. The topics of hydrologic change, geomorphic manipulation of the main channel, geomorphic manipulation of the floodplain, and vegetation management are addressed below, relative to the Visionary scenario.

The restoration of the hydrology of the upper Rio Grande will center on the creation of a hydrograph that contains a spring flood pulse that starts at the headwaters in Colorado, and travels downstream through the system to Candelaria, Texas. Reservoirs along the system will be operated to maintain the timing of the flood pulse and its intended magnitude. The pulse would not be as large as the "natural" one, but would be of a magnitude necessary to sustain geomorphic and biological functions of the restored, scaled-down Rio Grande. As mentioned before, the peak portion of the hydrograph is important because it maintains the geomorphology of the system, and contains the range of flows that transports a majority of the sediment through the system. These flows are also of sufficient magnitude to erode banks, scour new low-lying areas to create deeper pools, and deposit large woody debris to provide diverse aquatic habitat. In some cases, peak flows can actually create new channels through the avulsion process, whereby the current main channel is abandoned and a new channel is formed in the floodplain. The peak portion of the hydrograph also spreads over the channel banks and out onto the floodplain. Overbank flows disperse seeds, provide moisture and nutrients, and create the conditions necessary for establishment of much of the native riparian vegetation. They also provide hydrologic input to wetlands and marshes in the floodplain. Finally the deposition, erosion, lateral migration, and avulsion processes provide the variability in the floodplain topography needed to create a mosaic of native vegetation that is part of the Vision of a restored Rio Grande.

As previously mentioned, the Vision hydrograph will have flows throughout the year that mimic the timing and relative magnitude of the "natural" hydrograph. Besides a spring pulse, it will also contain periods of low and moderate flows. There is much debate as to the frequency and location of extremely low or non-existent flows along the undeveloped Rio Grande. Eventually, studies and modeling will have been developed to better answer the questions of how often, when, and where such flows occurred, along with their impact on the ecosystem. Under the restored hydrograph, they will happen at similar times and locations as they did historically. Zero flows will not artificially result from diversions that remove the entire initial flood pulse, as they sometimes do currently. Lower flow periods play important roles in the ecosystem; native flora and fauna evolved and adapted to these conditions, and would therefore be expected to compete better against non-native species when low flow timing and magnitude mimic pre-development conditions. The transition periods from low to high flows, and then back to low flows, should also be restored to mimic natural conditions. The restored flows should mimic the steepness and timing of the natural rising and recession limbs of the hydrograph. There will be variability in the hydrograph from year to year. There will still be wet years and dry years, driven by the inherent variability in the hydrologic cycle. By maintaining variability in the hydrograph, diversity in vegetation adjacent to the river and aquatic habitat will both be maintained. Mimicking historic conditions should also favor native species over non-native species.

The potential for reduction in evapotranspiration is a very promising aspect of the control of non-native, invasive species, and the creation of a mosaic of native vegetation along the riparian corridor. Many native species place less demand on the available water supply than invasive species such as saltcedar. Additionally, in a mosaic of native vegetation, there would be areas of higher water use due to wetland species and phreatophytes such as cottonwoods and willows. There would also be areas of lower water use, with vegetation such as upland shrubs and grasslands.

Overall water usage would be reduced under a dynamic system in which flooding, erosion, natural fire and succession did not foster a dense understory. In this manner, many aspects of restoration may “pay their own way” in terms of water usage.

Creation of the hydrograph just described will not be an easy task. It will require an extensive effort in terms of research, stakeholder involvement, legislative action, public education, engineering, construction of new facilities, changes in land and water use, and funding. Research will be needed to determine the characteristics of the new hydrograph, the resulting morphology of the Rio Grande, and the ecosystem that it will support. Public education and stakeholder involvement will be required for society to make decisions as to the level of restoration that will take place. Legislation will be necessary to authorize agencies to carry out the work. Changes in land use and water use will be needed to prevent the flows of the Rio Grande from being consumed at the current rate of 90-95%. A variety of projects will have to be constructed, or modifications made to existing projects, to reduce water consumption, as well as to minimize impacts on sediment balance within the system. Finally, funding must be secured to support these activities. Ultimately, the effort will be on a similar scale as the restoration of the Florida Everglades, or the recovery of salmon in the Pacific Northwest.

4.2 Significant Aspects of Restoration in the Upper Bioregion

The Upper Bioregion has been the least impacted by human activities, though this is not intended to imply that significant changes have not occurred. The hydrology has been altered both in timing and magnitude by reservoirs, and numerous diversions throughout the San Luis Valley have reduced flows and significantly influenced the lower return period peak flows. Diversions also impact local morphology, both directly and as a result of maintenance activities, and alter the system’s sediment transport characteristics. Land use, too, has impacted the river corridor; this region has actually had the most residential development in the floodplain. Only a small portion of the system has been leveed, primarily several miles through Alamosa , Colorado.

4.2.1 Existing Opportunities

In every bioregion, there is the need to protect the river corridor from development. The opportunity to preserve a significant portion of the corridor in a more natural condition is highest in the Upper Bioregion. That opportunity is threatened by increasing pressure to locate homes in the floodplain, particularly in the San Luis Valley. The previously discussed non-structural tools to preserve existing habitat and prevent encroachment on the floodplain are of extreme importance in the Upper Bioregion.

A variety of physical restoration measures are possible under the current conditions. Many of these opportunities were identified in the Montgomery Watson Harza (2001) study, a cooperative effort undertaken to solve environmental problems and those associated with water resources in general, primarily irrigation diversions. This program is a good example of finding synergy among water users and restoration advocates. The study identified diversion maintenance as a primary problem due to high sediment loads in the main channel. Restoration opportunities included improving diversions to pass sediment downstream, consolidating diversions to reduce their impact on channel morphology, and reconnecting floodplain channels and overbank areas to distribute sediments.

Other physical restoration opportunities are associated with improving floodplain and channel conditions. These include placement of habitat structures that also address geomorphic functions (i.e., boulder weirs, J-hooks, and large woody debris); “natural” channel reconstruction; improving water quality in areas degraded by mining activities; and removal of nonnative vegetation, with plantings to restore native vegetation.

In summary, substantial improvements in the functioning of the Rio Grande in the Upper Bioregion can be made under existing constraints. The most significant is preservation of the existing floodplain and riparian corridor. This helps sustain current functions and values of the system, but also facilitates more extensive restoration activity in the future, as do floodplain reconnection projects that address current sediment deposition problems in the channel. Finally, channel morphology and habitat function can be improved through the implementation of physical restoration measures.

4.2.2 Visionary Opportunities

Under the Visionary scenario, various legal, administrative, and capital improvement activities have been conducted to permit a hydrograph that mimics a more natural condition. It is likely that many of the activities that facilitate the creation of such a hydrograph have occurred in this upstream area. These may include conjunctive use of ground and surface water; construction of upstream, off-channel reservoirs to replace or supplement reservoirs in high evaporation areas downstream; the conversion of cropland to native habitat; the purchase and retirement of water rights for environmental purposes; and the adoption of measures that promote more efficient water use. Water savings realized in the San Luis Valley are extremely valuable because under the Visionary scenario, the physical and administrative structure exists to convey these flows throughout the project area. Much of the spring pulse that will flow through the system originates in the San Luis Valley, and consists of water savings and release flows being transferred to downstream reservoirs for use later in the summer.

A wider riparian corridor will have been obtained through much of the valley. It will be broadest in the historic depositional fan area between Del Norte and Monte Vista. Here, the channel will be allowed to spread its excess sediment load, creating new channels, and leaving backwaters and oxbows in the old channels. In this environment, narrow-leafed cottonwoods readily regenerate. Further downstream, sediment overloading in the Alamosa area has been eliminated by reducing sediment yield in the upper watershed, and by deposition in the historic fan area. Through the City of Alamosa, levees will be set back from the channel, creating a corridor of cottonwoods through the city where previously, barren earthen levees dominated the landscape. The Westside diversion has been eliminated, and the river now flows freely where mud flats once dominated the channel during late season, low-flow periods.

The old diversion system has been replaced with fewer structures that are less disruptive to the channel's geomorphic processes. The diversions have been designed to pass a higher portion of the sediment load, and to allow sluicing of sediments through the diversions during peak flows. Conjunctive use allows groundwater to be pumped during periods when river withdrawals would create excessively low flows in the river. Similarly, during higher flow periods (not including the peak pulse), diverted flows are used to recharge the groundwater.

Although improvements to the diversion system and a more natural hydrograph have restored much of the pre-development channel morphology, there is also a program to physically rehabilitate reaches most altered by diversions and channelization. The effort includes restoring the appropriate geometry, profile, and alignment, as well as native vegetation.

The positive results of this scenario will be felt in the Upper Bioregion as well as downstream. Within the bioregion, many of the natural functions of the Rio Grande will be preserved or restored. The channel could exhibit dynamic behavior that includes migration of meander bends, reworking of the floodplain, and deposition of sediments on the alluvial fan areas. Narrow-leafed cottonwood and willow riparian habitats will be functioning and sustainable. Damage from flooding could actually be reduced by removal of structures from the floodplain.

The downstream benefits of restoration and combined water management in the Upper Bioregion would be primarily due to increased delivery of water under a hydrologic regime that mimics natural conditions. This would be both in terms of total volume over the year, and flow levels during critical periods such as seasonal low-flows or droughts. The water management benefits would not only serve the environment, but also downstream water users.

4.3 Significant Aspects of Restoration in the Middle Bioregion

The Rio Grande and its riparian corridor in the Middle Bioregion have been more heavily impacted by human activities than their counterparts in the Upper Bioregion. Changes in the morphology of the Rio Grande below Cochiti Dam were studied and documented over 20 years ago (Lagasse, 1980). Realization of the extent of environmental losses has prompted numerous efforts in the past decade to understand the system, prevent further degradation, and to begin to restore it. There have been significant impacts on the hydrology, geomorphology, corridor size, vegetation, and aquatic and terrestrial habitat within the corridor. The hydrologic impacts in the Middle Bioregion increase in the downstream direction due to the presence of dams on both the mainstem and major tributaries. The dams primarily influence the magnitude of peak flows, and the timing and distribution of flows within the annual hydrograph. The hydrology is also impacted by numerous diversions, which have the greatest influence on the volume of flow and the magnitude and frequency of low flows. The diversions also cause fragmentation of fish habitat.

The Rio Grande in the Middle Bioregion has also been altered by direct changes to the channel and floodplain. This includes channelization of wider braided areas into narrow confined channels, reduction in the floodplain width by levees, and stabilization of the channel, primarily by jetty jacks. In some areas where the floodplain has not been confined by levees, development has encroached into the floodplain.

Changes in hydrology, and direct manipulation of the channel and its floodplain, have altered the morphology of the system. In addition, changes in the sediment transport balance have contributed to disturbances in the morphology. Causes include the trapping of sediments by reservoirs, channelization that concentrates flow, a reduction in sediment supply due to bank stabilization, and even direct extraction of channel materials by instream gravel mining operations in the Española area.

Some of the more severe ecosystem impacts on the Middle Rio Grande have resulted from a combination of hydrologic and geomorphic changes. The impact that has received the most attention is the deterioration and loss of the cottonwood bosque. The decline is due to the elimination of frequent overbank floods, as well as the loss of dynamic channel processes such as bank erosion, bar formation, accretion of new banks, and channel avulsions that support native species. Aquatic habitat has also been impacted by a combination of hydrologic and geomorphic alterations. Changes in hydrology impact flows during critical periods of the year, reducing aquatic habitat. Changes in the channel geometry and substrate, both of which are functions of geomorphology, also affect aquatic habitat.

The connection between basic physical processes associated with the hydrology and geomorphology of the Rio Grande, and degradation of the ecosystem, are strong. This is exemplified by the fact that efforts to restore two endangered species, the Rio Grande silvery minnow and the southwestern willow flycatcher, are centered on activities that will restore healthy hydrologic and geomorphic function to the Rio Grande.

4.3.1 Existing Opportunities

Significant efforts have been ongoing for over a decade to understand and reverse the degradation of the riparian environment of the Middle Rio Grande Bioregion. The Bosque Biological Management Plan (Crawford, et, al., 1993) represented a significant step toward identifying problems and developing solutions to the deterioration of the Middle Rio Grande bosque. A wide range of organizations, agencies, and Pueblos have contributed time and money to a variety of restoration projects implemented since the early 1990s (See Appendix D). Increased emphasis has recently been placed on restoration in the Middle Rio Grande as a result of the listing of the Rio Grande silvery minnow and the southwestern willow flycatcher as endangered species. A collaborative effort is being undertaken to implement restoration activities outlined in a Biological Opinion issued by the U.S. Fish & Wildlife Service in 2001. Thus, interest in restoration in the Middle Bioregion is reaching critical mass, and garnering significant support and momentum. The Existing Constraints restoration scenario presented in this section largely outlines the programs that are currently being pursued, as well as their eventual expansion.

Three general categories of physical restoration activities are underway, and will continue to be pursued under existing conditions. These areas are geomorphic alterations, flow manipulation, and vegetation management. In essence, all three are interrelated since each can impact the others. For example, flow manipulation influences geomorphology by altering sediment transport, and possibly by channel-forming discharges. It also influences vegetation management through overbank flooding, producing conditions for the regeneration of riparian vegetation, and affecting the encroachment of vegetation on bars. The latter can greatly influence channel morphology through channel narrowing once mobile bars become permanent islands, or extensions of existing channel banks.

Under existing constraints, there are significant opportunities throughout the Middle Bioregion to apply the types of physical manipulations of channel and floodplain described under the section on system-wide opportunities. The opportunities exist because the levees were set back from the channel in most locations. The geomorphic changes being pursued primarily address enhancing floodplain connectivity, increasing dynamic channel processes, and reversing channel narrowing and incision trends. Bioregion-specific restoration activities that are being pursued under existing constraints include: construction of grade restoration facilities (GRF) to elevate the channel bed and reestablish floodplain connectivity in areas of channel incision, reestablishment of dynamic channel processes by selective removal of jetty jacks, removal of vegetation from channel bars to prevent channel narrowing, and relocation of the channel in the Tiffany Junction-to-Elephant Butte reach to redistribute sediment deposition and allow relocation of the San Marcial railroad bridge.

Flow alterations will primarily be achieved through the system-wide opportunities previously discussed; however, there are some specific opportunities within the Middle Bioregion that can be pursued to facilitate and support positive changes in the flow regime. Replacement of or changes to the San Marcial railroad bridge to allow passage of higher river flows is being pursued, as is a more permanent method of transferring water from the Low Flow Conveyance Channel to the main channel to help prevent channel-drying in the reach below San Acacia

One very promising aspect of the restoration activities currently underway in the Middle Bioregion combines both hydrologic manipulation and vegetation management. The removal of thick monocultures and understories of non-native species has the potential to reduce consumptive water use in floodplain vegetation by creating a riparian mosaic of lower water use species. This can offset the potential increase in consumptive use that may be associated with creating wider channels, or enhancing floodplain connectivity. Substantial benefits may be recognized from this activity in the Middle Bioregion, which, along with the Forgotten Reach in the Lower Bioregion, has the thickest concentration of vegetation in the study area. Removal of nonnative vegetation and the clearing of dense understory also have the benefit of reducing the impact of fires. Restoration measures to increase floodplain connectivity and enhance or restore dynamic channel processes will also benefit the preservation and restoration of healthy native vegetation.

Under existing constraints, the restoration activities mentioned above will be intermittent along the Rio Grande, and not all activities will be pursued within a particular area. For example, some areas may undergo only understory removal and/or bank lowering, while others see main-channel manipulations but few overbank changes. This is due to limitations of funding, land ownership issues, and concerns over channel stability impacting the integrity of levees. Additionally, many of the activities will require periodic maintenance to fight the reoccurrence of nonnative species, or the return to undesirable geomorphic conditions. Thus, there will be limitations on the practical extent of the area that can be maintained under current levels of funding.

4.3.2 Visionary Opportunities

Several promising restoration activities were not represented in the Existing Opportunities scenario for the Middle Bioregion. Primarily, that scenario dealt with the corridor inside the levees, and only assumed some minor changes to hydrology associated with attempting to recover endangered species and promote bosque regeneration. The Visionary scenario assumes that these constraints will be lifted to a large extent. There will still need to be flood control protection for the Middle Rio Grande, and levees will continue to be part of the landscape, as will Cochiti and the other major reservoirs. However, in certain areas, levees will be set back, and reservoirs operated to better mimic natural hydrologic processes. The flood pulse that flows through the system will be used to restore a more natural morphology, as well as a hydrologic regime favorable to native vegetation. Additionally, the operation of Cochiti, Jemez and Galisteo Dams, as well as their outlet works where necessary, will be modified to pass a substantial portion of the incoming sediment load. Mimicking the timing and duration of the natural hydrograph during periods of moderate and low flows will greatly improve aquatic habitat. Under this scenario, funds are available to perform extensive removal of non-native vegetation.

Considerable water conservation and increased efficiencies will have be instituted for both agricultural and domestic users, resulting in reduced depletion of Middle Rio Grande flows. Additional reduction in agricultural water use will be realized by the purchase of some agricultural lands, and their conversion to natural habitat. Portions of the purchased land will be used to expand the river corridor by several thousand feet in some areas. Water that would have been used on the retired lands will provide additional flows in the river, and will remain in the system. Most of the storage in Elephant Butte Reservoir will be transferred to off-channel reservoirs at higher elevations in the Upper Bioregion, providing on the order of 100,000 acre-feet of additional water for enhanced flows in the Middle and Lower Bioregions. Portions of this flow will be used to solve water shortages in municipal supplies along the Rio Grande Valley as part of a cooperative program between many stakeholders and agencies.

Besides the system-wide measures previously described, several key aspects of water management will undergo change. The need for the Low Flow Conveyance Channel will be eliminated by increased flows, and the effect of the flood pulse and the vast reduction in non-native vegetation will lessen the impact of channel losses on the Rio Grande water balance. Where necessary, drainage from agricultural lands will be returned to the Rio Grande by either gravity or pumping. An improved water distribution system will eliminate the need for some of the diversion works, and fish passages will be provided at the remaining structures. Lastly, the purchase of land adjacent to the floodplain will allow levees to be set back several thousand feet in some areas. In many places, the channel will be allowed to migrate, because the toe of the levee has been stabilized. A majority of the jetty jacks will be removed along the Rio Grande, leaving only a few to protect key infrastructure.

One of the most substantial results of the changes just described is a bluff-to-bluff floodplain in several locations. One example is the reach from Highway 60 to San Acacia; another extends from the northern boundary of Bosque del Apache National Wildlife Refuge to Tiffany Junction. Refuge functions will be maintained by creation of marshes and oxbow lakes hydrologically connected to the main channel, and also by return flows. The refuge area will be expanded where land and water can be acquired.

Grade restoration facilities, reintroduction of sediment load into the Rio Grande, and increased spring flows will result in restoring floodplain connectivity to areas of incised channel from the confluence with Galisteo Creek to the Corrales area, and from San Acacia to Escondida. The conversion of the riverbed to gravel and cobble will be reversed, and silvery minnow and other native fish habitat will be expanded. The channel will retain much of its wide, braided nature, and will migrate across the active floodplain. Channel avulsions--both natural and in some cases induced as part of restoration activities--will be allowed to occur.

Floodplain functions and processes will also be significantly restored. Hydrologic reconnection of the floodplain, and the reintroduction of active channel dynamics will result in development of natural floodplain features such as side channel marshes, wetlands, gallery cottonwood forests, and salt grass meadows. Invasive nonnative vegetation will essentially be eliminated from the system by mechanical and biological control, combined with a return to conditions that are more favorable to native vegetation. Some maintenance will still be required to prevent nonnatives from re-establishing, but the system is largely self-sustaining, due, in part, to successional processes and fire that will convert some areas to upland grasslands and scrublands.

4.4 Significant Aspects of Restoration in the Lower Bioregion

Restoration challenges are greatest in the Lower Bioregion. It has the highest level of hydrologic alteration, the most extensive channel modifications, and also the highest population concentration, in the El Paso, Juarez and Las Cruces area. In contrast, it contains the most extensive undeveloped segment of the entire project area, the remote "Forgotten Reach," from Fort Quitman to Candaleria. This reach is one of the most impacted by upstream water development, and, by saltcedar.

The greatest challenges in the Lower Bioregion are associated with the hydrology and they tend to get more severe in the downstream direction as more water is diverted from the Rio Grande. Changes in hydrology include the elimination of the spring flood hydrograph, a nearly constant hydrograph through the seven-month irrigation season, and extreme low flows outside the irrigation season. Below El Paso, the changes become even more severe; since nearly all the water is diverted, low flows occur year-round.

With upstream reservoirs (Caballo and Elephant Butte) trapping the sediment supply, channel morphology has also been impacted, resulting in some degradation in the upper portions of the Canalization Project. The reduced flow regime lacks the peak discharges and flow volume necessary to remove tributary sediment deposits left by flash floods, causing local aggradation problems. These problems worsen downstream; within the Forgotten Reach, tributary deposits totally block the channel in some areas, resulting in high water losses due to evaporation. Through the Forgotten Reach, the channel has narrowed due to flow reduction and extensive saltcedar invasion. Direct physical changes have also been made to the channel. In the Canalization and Rectification reaches, the channel has been straightened, narrowed, stabilized, and confined to a corridor 400 to 1,000 feet wide by levees. The flow is high in salinity, particularly below El Paso, due to multi-generational return flows.

Another challenge to restoration in this reach is that for the lower two thirds of its length, the river forms the international boundary between Mexico and the United States; any change in channel alignment also alters the border between the two countries. Cooperation and agreement is therefore required before actions may be taken to alter the Rio Grande.

4.4.1 Existing Opportunities

Under existing constraints, opportunities for restoration within the Canalization and Rectification Project reaches are primarily limited to the current corridor established by the levees. Some pilot programs to purchase farmland and/or flood easements can be undertaken to expand the area within levees in advantageous locations. A limited amount of flow manipulation can be performed to provide overbank flooding in some places. The current EIS for the Canalization Project, and the upcoming EIS for the Rectification Project, are tools for realizing some of these restoration measures. In the lower reach, from Fort Quitman to Candaleria, the Border Preservation Act is a mechanism for accomplishing some improvement in conditions. It is not anticipated under current constraints that a pulse of water will be provided on the mainstem through the Forgotten Reach to facilitate geomorphic restoration functions. However, other efforts can lay the groundwork for more extensive restoration in the future.

Some of the system-wide measures discussed at the beginning of the chapter can be applied to aid restoration in the Lower Bioregion. These would primarily be water management and non-structural opportunities. There are specific opportunities for restoration within the Lower Bioregion, but because of the vastly different conditions in the Canalization and Rectification reaches compared with the Forgotten Reach, many of the measures apply to only one of the two general areas.

Hydrologic manipulation is possible in the Lower Bioregion under existing constraints. A spring flood pulse on the order of 4,000 cfs could be released from Caballo Dam to provide overbank flooding in wetter years. The flood may need to be of short enough duration to attenuate prior to reaching the Rectification Reach to avoid flooding. Until a defined channel is developed through the Forgotten Reach, such a flow may not be desirable due to its potential to encourage saltcedars. If an off-channel reservoir is constructed, portions of this water could be used to satisfy obligations to Mexico. Groundwater recharge could also be utilized to minimize evaporative losses from the storage facility, using it only for a short period. Water rights from retired farmlands could offset increased consumptive use associated with the restoration of floodplain vegetation. It could also be possible to supplement flows in the Canalization Project during the non-irrigation season. These flows could be used in part to provide water for El Paso/ Juarez and Las Cruces. This may require off-channel storage, or a groundwater recharge program. Finally, return flows can be utilized to create wetlands; particularly promising opportunities exist for this type of activity in abandoned oxbows adjacent to the Rectification Project.

The highest potential for geomorphic restoration under existing constraints occurs in the Canalization Project reach. A variety of actions can be taken here. Grade Restoration Facilities (GRFs) can be installed to reverse channel incision that has occurred downstream of Caballo and Elephant Butte Dams. This is primarily confined to the area of the Canalization Project above Selden Canyon. Channel manipulations can occur in areas where the river corridor is wide, as in areas where open rangeland and tributary fans bound the project to the west. In addition to installation of GRFs, sinuosity can be increased and riprap bank stabilization can be removed to reinitiate dynamic channel processes. To prevent damage outside the existing corridor, the toes of the adjacent levees should be protected. Potential restoration areas are currently very limited, and the feasibility of this type of action depends on the purchase of lands adjacent to the existing levees. In both the Canalization and Rectification Projects, the setting back of levees in selected areas would also accommodate a larger riparian corridor. Portions of the floodplain, both existing and expanded, can be graded to create overbank depressions that support a more diverse palette of vegetation. These and other areas in the floodplain can be planted with native vegetation. Wetland and emergent vegetation can be promoted by constructing side channels and backwaters. Retired water rights associated with purchased farmland can be used to offset any increase in consumptive use.

Channel restoration efforts can be undertaken in the Forgotten Reach. Arroyo deposits, which result from the inability of main channel flows to transport sediments downstream, can be mechanically removed. In locations with the most severe deposits, it may be advantageous to relocate the channel to eliminate depressed floodplains that currently serve as sinks for the accumulation of salts. Further restoration in the Forgotten Reach can be achieved by the removal of saltcedars and surface soils laden with salts, along with planting of native vegetation at selected locations. Any vegetation restoration efforts within the Forgotten Reach will require considerable long-term maintenance to prevent re-invasion by saltcedar. Even more ambitious would be the establishment of a clear channel through the Forgotten Reach. Though it would require significant periodic maintenance until larger mainstem flows are established, such a restoration effort would salvage water for downstream sections of the Rio Grande.

4.4.2 Visionary Opportunities

Although water use will continue to reduce the availability of flows for this reach to levels far less than those of the predevelopment era, significant strides will be made to mimic a more natural hydrograph at a reduced scale. The hydrograph will have a spring pulse that provides sufficient flow to maintain channel morphologic processes, and to provide hydrologic connection with the floodplain. To make restoration possible, a significant amount of agricultural land adjacent to the river corridor will be purchased, allowing further setback of the levees, and the transfer of water rights to environmental purposes. Additional flow will be made available through water conservation and efficiency in the Upper and Middle Bioregions, as well as within the Lower Bioregion.

In the Canalization and Rectification reaches, the one factor (in addition to hydrologic restoration efforts,) that will make the visionary restoration scenario possible will be the setback of levees. Sinuosity will be restored to the channel, and the erosion and accretion associated with channel migration will help in the establishment of native riparian vegetation. To promote a natural morphology, bank stabilization will be removed except in areas containing key infrastructure. Since the levee will still be required for flood control, and active channel processes will need to be confined to the defined corridor, the toes of levees will be stabilized against erosion. One of the most highly restored areas will be Selden Canyon, purchased as a wildlife refuge and returned to a mosaic of native vegetation across the entire valley floor. The reintroduction of active channel dynamics will result in the development of natural floodplain features such as side-channel marshes, wetlands, gallery cottonwood forests, and salt grass meadows. Successional processes and fire will also convert some areas to upland grasslands and scrublands.

With the introduction of the spring flood pulse, the restoration of a geomorphically based channel through the Forgotten Reach will be achieved, and significant savings in water will be realized by establishing a continuous channel though the reach, and eliminating the saltcedar monoculture. Because of its isolated nature, the restored channel and riparian corridor will become an extremely valuable habitat for a variety of wildlife.

In all three reaches, some maintenance will still be required to prevent non-native vegetation from regaining control of localized areas. Besides the tremendous environmental benefits, another advantage of restoration is reduced flood peaks, and much more attenuation of flash floods from tributaries due to the setback of levees and reconnection of the channel with the floodplain.

4.5 General

Under the Visionary Restoration scenario, a mini-Rio Grande is established that provides for a balance between environmental restoration and preservation, and water resources to support human activities. The mini-Rio Grande exhibits the key hydrologic, geomorphic and habitat features and functions of the historic Rio Grande. Within the mini-Rio Grande, it is possible to re-introduce and sustain fish species that have been extirpated from this reach and endangered in other reaches. Similarly, terrestrial species that depend on the habitat in the riparian corridor also become more sustainable.

This level of restoration will be made possible by people working together to solve the water problems of the Upper Basin. Water is the primary element for both humans and the environment, and though it may be possible to accomplish significant physical river restoration by altering the channel or the vegetation on a local or regional scale, truly visionary restoration will require the recovery of hydrologic conditions that can only be achieved through the mutual efforts of the Rio Grande's many stakeholders, from the headwaters to Candelaria.

5 RECOMMENDATIONS FOR REALIZING THE RESTORATION OF THE RIO GRANDE

The previous chapters provided the background for developing a Restoration Vision for the Rio Grande from the headwaters to Candelaria, Texas. Opportunities for actual restoration were identified and presented in two sets. The first and less ambitious set of opportunities was considered feasible under existing constraints. The second set represents a visionary level of restoration, achievable only after numerous obstacles are overcome. These obstacles include physical conditions as well as social, legal, and administrative constraints. The following recommendations could assist in overcoming the potential roadblocks to restoration of the Rio Grande.

1. **The "Vision" should be considered a living document or work in progress.** It should be revisited as additional stakeholders add new perspectives, experience is gained from other restoration projects, situations change, and constraints to restoration are eased.

2. **Momentum for restoration will best be achieved if solutions can be developed that benefit all stakeholders, including water users**. This may require large-scale alterations to the system to reduce losses such as reservoir evaporation, promote conservation, and increase the efficiency of water delivery and distribution systems. All stakeholders within the Upper Basin could benefit from an expanded reexamination of system-wide water operations and management so that improvements could be made to better meet human and environmental needs within and across bioregions and political jurisdictions.

3. **There is a need to work collaboratively with the agricultural community and Pueblos**. Members of the agricultural community own the most land in the historic river corridor, and the majority of the priority water rights. They are therefore the stakeholders who feel most threatened by restoration efforts.

4. **System-wide restoration must be endorsed as a goal by local and tribal governments, and by other key stakeholders on the river**. Federal and state legislation supporting system-wide restoration is a necessary step to provide a mandate and resources to local officials. Legislation should be developed with local participation. Local and regional restoration efforts must continue, and should be coordinated with system-wide efforts. Any system-wide restoration initiative must be based on a watershed perspective, and must carefully consider impacts to the Lower Rio Grande Basin.

5. **A non-profit institution (Rio Grande Restoration Task Force) should be established to direct, coordinate and implement a system-wide restoration effort**. The restoration of the Rio Grande will require a commitment from and communication between governmental entities at the local, state, federal and tribal levels, in addition to all stakeholders, including domestic water users, water districts, farmers, and environmentalists. The purpose of the Task Force will be to implement the Vision by serving as a clearinghouse for information, facilitating communication and the exchange of technical expertise, and offering a unified voice for policy, legislation, and funding. It will provide guidance to state and federal agencies on all activities affecting the Rio Grande, and will oversee development of a basin-wide restoration master plan. To achieve stakeholder investment and increase credibility, the Task Force's board of directors should consist of local, state and federal representatives from the U.S. and Mexico; non-governmental organizations; and the Pueblos. Federal and state appropriations will be required to fund the Task Force, along with supplemental sources, including grants. A conceptual organizational framework, as developed by the Rio Grande Restoration Vision Workshop, is provided below.

6. **The common restoration issue that should bind all groups seeking to restore the Rio Grande is water.** There are strong local, regional, and state issues associated with water, but realization of significant changes in hydrology, such as the system-wide spring pulse, will require a basin-wide effort. This is also true of water management activities that would need to go hand-in-hand with the hydrologic restoration of the system.

7. **It is essential that further development in the floodplain along the Rio Grande be prevented**. Continued encroachment in the floodplain will narrow restoration options, make restoration more expensive, and provide an impetus for projects that further degrade the system such as additional levees, increased flow regulation, and channelization. Even without considering restoration, development in the floodplain is a poor land use practice.

8. **Additional research and monitoring needs to be undertaken so we have a better understanding of key hydrologic, geomorphic, and biologic components of the Rio Grande ecosystem.** These key components include (1) the consumptive water use and savings from various restoration activities such as channel widening and conversion of nonnative vegetation to native vegetation; (2) sediment balance within the system, particularly the role of significant tributaries, and the long-term dynamic interaction between the more constant flows on the mainstem and ephemeral tributary flows; and (3) the requirements of endangered species as well as other important biological components of the system.

9. **The Task Force should host an annual restoration conference**. There is support among Rio Grande restoration experts for an annual conference, and regardless of whether the Task Force is established, it is recommended that such an annual conference be held. The Alliance could serve as alternative institutional mechanism for coordinating the conference. The purpose of the conference would be to bring technical expertise, the visioning process, and political decision-makers together to maintain awareness about the need and importance of restoration. The conference would provide opportunities to exchange information, update others on specific restoration activities, update the Vision, and keep the restoration momentum going. If interest warranted, published papers and/or conference proceedings could be produced.

10. **A public awareness and education campaign on the value of the Rio Grande ecosystem to humans and wildlife is critical to developing support for restoration**. It is not a coincidence that the area with the most restoration activity, the Middle Rio Grande Valley, is also the area where restoration issues such as preservation of the bosque and endangered species are common knowledge and important to many people.

Board of Directors

- Local representatives
- State representatives
- Federal representatives from US and Mexico
- Alliance for Rio Grande Heritage
- Other NGOs
- Pueblos

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RIO GRANDE RESTORATION TASK FORCE

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OPERATIONAL UNITS		
Education, Partnership, and Outreach	**Data Management** • GIS • Research • Monitoring • Decision support system • Interactive web site for information exchange	**Restoration Coordination**
Restoration Implementation	**Annual Rio Grande Restoration Conference Committee**	**Policy and Legislation**

APPENDIX A
Water Resources Projects

Summary of Water Resources Projects--Rio Grande Headwaters to Candelaria, Texas
(Note: Non-mainstem Rio Grande projects are organized by confluence location, from upstream to downstream, in the order they occur on the tributary)

Project Name	Agency	Location	Date	Size / Extent	Purpose	Physical Features	Ref.
UPPER BIOREGION							
Rio Grande Reservoir	SLV Ir. Co.	RM 1891	1912	51,000 af	Water storage for irrigation	Dam and reservoir, supply for Farmers Union	
Santa Maria Res.	RG Res. & Ditch Co.	Clear Creek Trib.	1912	43,500 af	Water storage for irrigation	Dam and reservoir, supply for Rio Grande Canal and portion of Monte Vista Canal	
Continental Reservoir	RG Res. & Ditch Co.	North Creek	1925	27,000 af	Water storage for irrigation	Dam and reservoir, supply for Rio Grande Canal and portion of Monte Vista Canal	
Aggregate of Diversions from RM 1837.4 to 1818.3	Private	RM 1837.4 to 1818.3		Agg. Decreed Cap. = 302 cfs	Irrigation diversions	Low head diversion and headgate	4
Rio Grande Canal and Schuch Schmidt	RG Res. & Ditch Co.	RM 1819.4		Total Decreed Cap. = 1652.9 cfs	Irrigation diversions (two listed diversions share same diversion point)	Low head diversion and headgate	4
Aggregate of Diversions at RM 1818.0	Private	RM 1818.0		Agg. Decreed Cap. = 88 cfs	Irrigation diversion	Low head diversion and headgate	4
Farmers Union Canal	SLV Irrigation Co.	RM 1818.0		Decreed Cap. = 801 cfs	Irrigation diversion	Low head diversion and headgate	4
Aggregate of Diversions from RM 1808.5 to 1812.7	Private	RM 1808.5 to 1812.7		Agg. Decreed Cap. = 41.3 cfs	Irrigation diversions	Low head diversion and headgate	4
Prairie Ditch	Private	RM 1808.1		Decreed Cap. = 367 cfs	Irrigation diversion	Low head diversion and headgate	4
Monte Vista Canal and Rio Grande Piedra Valley Ditch	Private	RM 1807.3		Decreed Cap. = 341 cfs (MV) and 95 cfs (RGPV)	Irrigation diversions (share same diversion point)	Low head diversion and headgate	4
Empire Canal	Private	RM 1799.3		Decreed Cap. = 506 cfs	Irrigation diversion	Low head diversion and headgate	4
San Luis Valley Canal	Private	RM 1797.6		Decreed Cap. = 501 cfs	Irrigation diversion	Low head diversion and headgate	4
Westside Diversion	Private	RM 1765.6		Decreed Cap. = 35.8 cfs	Irrigation diversion	Low head diversion and headgate	4
Aggregate of Diversions from RM 1757.3 to RM 1806.3	Private	RM 1757.3 to 1806.3		Agg. Decreed Cap. = 447 cfs	Irrigation diversions	Low head diversion and headgate	4
Aggregate of CO Transmountain diversions (6 total)	Varies	Various locations in Colorado		See Purpose	Transmountain diversions into Rio Grande Basin, aggregate totals of 100 to 7300 afy	5 of 6 diversions from San Juan River Basin, 1 from Gunnison River Basin	1
Closed Basin Project	USBR	Closed Basin, CO	1986	See Purpose	To supplement Rio Grande water, help CO make compact deliveries, help US make international treaty deliveries	Well field that pumps water from unconfined aquifer in Closed Basin to Rio Grande. As of 1989, project could pump as much as 50,000 afy into the Rio Grande Basin	1

Project Name	Agency	Location	Date	Size / Extent	Purpose	Physical Features	Ref.
Platoro Reservoir	USBR in con-junction with USACE and State of CO	30 miles east of Antonito, CO on Conejos River	1951 - 1952	See Physical Features	Conservation and flood control	Max. authorized storage = 60,000 af (54,000 af for conservation/snowmelt flood control regulation; 6,000 af exclusively for flood control)	1
MIDDLE BIOREGION							
La Canova	Acequia Assoc.	RM 1640.4			Irrigation diversion	Low head dam and headgate	
El Medio	Acequia Assoc.	RM 1639.9			Irrigation diversion	Low head dam and headgate	
Los Garcias	Acequia Assoc.	RM 1638.9			Irrigation diversion	Low head dam and headgate	
Lyden	Acequia Assoc.	RM 1637.5			Irrigation diversion	Low head dam and headgate	
La Riconada	Acequia Assoc.	RM 1637.3			Irrigation diversion	Low head dam and headgate	
Alcalde	Acequia Assoc.	RM 1635.9			Irrigation diversion	Low head dam and headgate	
El Guique	Acequia Assoc.	RM 1633.7			Irrigation diversion	Low head dam and headgate	
Azotea Tunnel	USBR	Lat 36°51'12" Long 106°40'18"	1973	See Purpose	Transmountain diversion (San Juan – Chama Project, 110,000 acre-ft average annual diversion)	Diverts from Rio Blanco, Little Navajo River, and Navajo River into Azoteo Creek (San Juan Basin into Rio Grande Basin)	1
Heron Reservoir	Operated by: USBR	Willow Creek above confluence with Rio Chama	1971	See Physical Features	Conservation of San Juan – Chama Water	Max. authorized storage = 400,000 af (all conservation); carryover storage by SJC water contractors not allowed	1
El Vado Reservoir	Owned by: MRGCD Operated by: USBR	Near Tierra Amarilla, NM on Rio Chama	1935	See Physical Features	Conservation, power generation (secondary); provides irrigation storage for six Pueblo Indian tribes and other MRGCD lands; subject to operating constraints by Rio Grande Compact except for water for 8,847 Pueblo acres with prior water rights; no storage that would deprive local Rio Chama diverters of their water rights	Max. authorized storage = 180,000 af (all conservation); originally constructed by MRGCD in 1935, rehabilitated by USBR in 1954-55; outlet works modified to accommodate SJC water in 1966; 8 megawatt hydroelectric plant installed by County of Los Alamos in 1988 operates only when releases meet specs for power generation	1
Abiquiu Reservoir	Operated by: USACE	Near Abiquiu, NM on Rio Chama	1963	See Physical Features	Flood control, conservation, power generation (secondary)	Max. authorized storage = 779,000 af (502,000 for flood control, 77,000 for sediment, 200,000 for storage of SJC water); operations dictated by PL 86-645 (Flood Control Act of 1960); power plant consists of 13.2 megawatt hydroelectric plant built by County of Los Alamos in 1989, operated only when releases meet specs for power generation)	1
Los Vigeles	Acequia Assoc.	RM 1627.4		Rock and rubble dam	Irrigation diversion	Low head dam and headgate; often washed out	

Project Name	Agency	Location	Date	Size / Extent	Purpose	Physical Features	Ref.
Santa Cruz Dam and Reservoir	NMISC	Near Chimayo, NM on Santa Cruz River	1929	See Physical Features	Conservation for Santa Cruz Irrigation District (SCID)	Max. storage = 4,490 af minus estimated 1,300 af of sedimentation	3
Nambe Falls Dam	USBR	25 miles north of Santa Fe, NM on Rio Nambe	1976	See Physical Features	Flood control	Max. storage: 2,023 acre-ft	3
Buckman Well Field (Santa Fe)	City of Santa Fe		1972	7,200 afy	Water supply	Wells and pipeline; anticipated capacity was 10,000 afy	
Cochiti Reservoir	Operated by: USACE	Near Cochiti Pueblo, NM on Rio Grande	1975	See Physical Features	Flood control, sediment retention, recreation, diversion	Max. authorized storage = 597,000 af (492,000 for flood control, 105,000 for sediment, 50,000 for recreation pool; San Juan Chama water actual authorization is 1,200 surface acres of SJC water for rec. pool); operations dictated by PL 86-645 (Flood Control Act of 1960); also serves as diversion for Cochiti, Santo Domingo, and San Felipe Pueblos	1 & 2
Galisteo Reservoir	USACE	Near Cerrillos, NM on Galisteo Creek	1970	189,000 af	Flood and Sediment Control	Operations dictated by PL 86-645 (Flood Control Act of 1960); operated as dry dam	1
Angostura Diversion Dam	Original Construction: MRGCD Rehabilitation: USBR	5 miles NW of Bernalillo, NM on Rio Grande	1934	Max. diversion capacity = 650 cfs	Irrigation diversion for MRGCD Albuquerque Division	Low head diversion dam; supplies water directly to Albuquerque Main Canal ; typical diversion of 200 to 300 cfs Rehabilitated by USBR in 1958	2 & 3
Jemez Canyon Reservoir	Operated by: USACE	North of Bernalillo, NM on Jemez River	1953	See Physical Features	Flood control, sediment retention	Max. authorized storage = 117,000 af (73,000 for flood control, 44,000 for sediment); operations dictated by PL 86-645 (Flood Control Act of 1960)	1
Isleta Diversion Dam	Original Construction: MRGCD Rehabilitation: USBR	13 miles south of Albuquerque, NM on Rio Grande	1934	Max. diversion capacity = 1,070 cfs	Irrigation diversion for MRGCD Belen Division	Low head diversion dam.; supplies water directly to Peralta Main Canal and Belen Highline Canal.; typical diversion of 500 to 700 cfs; rehabilitated by USBR in 1955	2 & 3
San Acacia Diversion Dam	Original Construction: MRGCD Rehabilitation: USBR	At San Acacia, NM on Rio Grande	1934	Max. diversion capacity = 283 cfs to Socorro Main Canal, and 1,500 cfs to the Low Flow Conveyance Channel	Irrigation diversion for MRGCD Socorro Division	Low head diversion dam.; supplies water to the Socorro Main Canal and the Low Flow Conveyance Channel ; LFCC has not operated since late 1990's; typical Socorro Main diversion of 130 to 170 cfs	2 & 3
Low Flow Conveyance Channel	USBR	West side of Rio Grande from San Acacia to Elephant Butte	1959	Max. diversion capacity = 1500 cfs	Conveyance channel built between 1951 and 1959 to reduce water delivery losses to Texas/Mexico above Elephant Butte	51-mile-long channel on the west side of levee along Rio Grande; lower 1/3 silted in within first few years; only upper 1/3 operational to this date	1
Elephant Butte Reservoir --"Rio Grande Project"	Operated by: USBR	Near Truth or Consequences, NM on Rio Grande	1916	See Physical Features	Conservation, recreation, power generation	Max. authorized storage = 2,065,000 af (50,000 for recreation stored in conservation pool); 24.3 megawatt hydroelectric power plant; titles held by USBR, but EBID and EPCID No. 1 paying finance costs	1

Project Name	Agency	Location	Date	Size / Extent	Purpose	Physical Features	Ref.
Caballo Reservoir	IBWC (flood control) EBID (irrigation and power)	25 miles downstream of Elephant Butte on Rio Grande	1939	See Physical Features	Conservation, flood control, re-regulation of hydropower releases from Elephant Butte	Max. authorized storage = 331,000 af (231,000 for conservation, 100,000 for flood control)	1
LOWER BIOREGION							
Percha Diversion Dam	USBR (Owner)	2 miles south of Caballo Dam on Rio Grande	1918	Max. diversion capacity = 330 cfs	Irrigation diversion	Low head diversion and headgates	3
Canalization Project	IBWC	From Percha Diversion Dam, NM, to American Diversion Dam, TX	1943	105.4 miles	Flood protection, channel stabilization and water delivery	Channelization, bank protection and levees; undergoing EIS for reevaluation of operations	6
Leasburg Diversion Dam	USBR (Owner and Operator)	15 miles NW of Las Cruces, NM on Rio Grande	1919	Max. diversion capacity = 625 cfs	Irrigation diversion	Leasburg Canal headworks at abutment; 7 slide gates (5’ by 6.75’)	3
Mesilla Diversion Dam	USBR (Owner and Operator)	6 miles south of Las Cruces, NM	1916	Max. diversion capacity = 950 cfs	Irrigation diversion	Low head dam; canal headworks at each abutment	3
American Diversion Dam	IBWC	2 miles NW of El Paso, TX on Rio Grande	1912	Max. diversion capacity = 1,200 cfs	Irrigation diversion	Low head diversion dam to American Canal; Franklin Canal capacity is 325 cfs; remainder returned to river below international diversion	3
International Diversion Dam	Mexico	2 miles below American Diversion	Pre - 1906	Max. diversion capacity = 170 cfs	Irrigation diversion	Low head dam delivers to Acequia Madre; international treaty provides for 60,000 afy	
Rectification Project	IBWC (US and Mexico)	El Paso-Juarez Valley	1939	88 miles	Flood protection throughout El Paso – Juarez Valley; stabilize international boundary line	Straightened Rio Grande, decreasing length from 155 miles to 88 miles, and confined it between levees; authorized construction of Caballo Reservoir for flood control; soon to undergo EIS for evaluation of operations	1 & 6
Riverside Diversion Dam		15 miles SE of El Paso, TX		Max. diversion capacity = 900 cfs	Irrigation diversion	Low head diversion dam; Riverside Canal headworks	
Rio Grande Boundary Preservation Project	IBWC (US and Mexico)	Fort Quitman to Haciendita, TX	1986	194 miles	Restore and preserve character of international boundary	Channelization, floodplain vegetation clearing	6

Sources:
1) USACE, “Reevaluation of the Rio Grande Operating Plan”, July 1989, U.S Army Corps of Engineers, Albuquerque District
2) SSPA, “Middle Rio Grande Water Supply Study”, August 4, 2000, S. S. Papadopulos & Associates, Inc., Boulder, CO.
3) United States Bureau of Reclamation Web Site
4) “Rio Grande Headwaters Restoration Project, Final Report”, SWCA, Agro Engineering, MWH, October, 2001.
5) US Army Corps of Engineers, 1998. "A Map of Selected Surface Hydrological Features and Local Protection Projects," Albuquerque District, Prepared for FEMA
6) Personal communication with Public Information Officer Sally Spener (915) 832-4175 at IBWC

APPENDIX B
Characteristics of Geomorphic Reaches

INTRODUCTION

This document summarizes key aspects of the hydrology and geomorphology for the Vision project area. To organize and facilitate this summary, as well as other aspects of the Vision project, the study area has been subdivided into three Bioregions. These Bioregions are defined as follows:

Upper Bioregion:	Rio Grande headwaters, CO, to Velarde, NM
Middle Bioregion:	Velarde, NM to Caballo Dam, NM
Lower Bioregion:	Caballo Dam, NM to Candelaria, TX

In addition to these three bioregions, to further develop and isolate unique geomorphic characteristics along the Rio Grande, each Bioregion was subdivided into reaches. Table B.1 provides a delineation of the reaches.

Table B.1 – Geomorphic Reach Delineations

Reach	Start (RM)	End (RM)	Start and End Location
1	1909	1839	Colorado headwaters to South Fork, CO
2	1839	1741	South Fork, CO to Conejos River confluence, CO
3	1741	1714	Conejos River confluence, CO to CO/NM state line
4	1714	1639	CO/NM state line to Velarde, NM
5	1639	1627	Velarde, NM to confluence with Rio Chama, NM
6	1627	1614	Rio Chama/ Rio Grande confluence, NM to Otowi Gage, NM
7	1614	1597	Otowi Gage, NM to Cochiti Reservoir, NM
8	1597	1588	Cochiti Reservoir, NM
9	1588	1561	Cochiti Dam, NM to Bernalillo (NM 44 / US 550 bridge)
10	1561	1526	Bernalillo (NM 44 / US 550 bridge) to Isleta Diversion Dam, NM
11	1526	1484	Isleta Diversion, NM to Rio Puerco confluence, NM
12	1484	1418	Rio Puerco confluence, NM to Elephant Butte Reservoir, NM
13	1418	1383	Elephant Butte Reservoir, NM
14	1383	1374	Elephant Butte Dam, NM to Caballo Reservoir, NM
15	1374	1356	Caballo Reservoir, NM
16	1356	1288	Caballo Dam, NM to Mesilla Diversion, NM
17	1288	1249	Mesilla Diversion, NM to El Paso, TX (American Diversion Dam)
18	1249	1156	El Paso, TX (American Diversion Dam) to Fort Quitman, TX
19	1156	1036	Fort Quitman, TX to Candelaria TX

Note: RM represents River Mile from Gulf of Mexico at River Mile 0

UPPER BIOREGION – HEADWATERS TO VELARDE, NM

This bioregion covers the Rio Grande as a high mountain stream originating in the San Juan Mountains of Colorado, through the open high elevation San Luis Valley, and into the confined canyon of the Rio Grande Gorge.

1.1 Geomorphic Characteristics of Upper Bioregion

The Upper Bioregion has been divided into 4 reaches. A discussion of the geomorphic characteristics of each reach is presented below.

Reach 1 (RM 1909 to 1830 / Headwaters to South Fork Confluence)

This reach encompasses the headwaters of the Rio Grande, originating along the Continental Divide in the San Juan Mountains of Colorado. The peaks in this area rise above timberline and range from 12,000 to 14,000 feet in elevation. The actual channel starts in a narrow valley at an elevation of about 11,000 feet. For about 25 miles, the stream flows though a series of narrow mountain valleys and canyons. There is one small reservoir on the main stem, Rio Grande Reservoir constructed in 1912. It is the only reservoir on the mainstem of the Rio Grande above Cochiti. Several miles below Rio Grande Reservoir, the channel enters Antelope Park. Here the valley is nearly a mile wide, and the channel becomes quite sinuous. This planform persists until past the Town of Creede, where the channel flows into a canyon near Wagon Wheel Gap. The canyon gradually widens in the downstream direction until a narrow valley develops. The downstream end of the reach is at South Fork, at an elevation of about 8170 feet.

The Rio Grande is a gravel and cobble bed stream throughout this reach, with many areas of both horizontal and vertical control by bedrock. In the wider valley sections, the channel has a sinuous, alluvial channel form. In some areas, due to either high sediment supply or unstable banks, the channel is shallow and braided; in more confined reaches, the channel is much straighter.

Reach 1 - Summary of Characteristics

Length -	79 miles
Planform -	variable between straight / braided / sinuous
Sinuosity -	ranges from 1.1 to 1.5
Bed material-	gravel / cobble / some boulders
Control -	some bedrock both laterally and vertically
Floodplain -	canyon to greater than 1,000 feet
Q_2 -	3,000 cfs
Slope -	> 100 ft. /mi. to 10 ft. / mi.
Average slope -	35 ft. / mi.
Width -	< 10 ft. to ~ 100 ft.
Key factors -	some reservoir control, high mountain stream

Reach 2 (RM 1839 to 1741 / South Fork Confluence to Conejos Confluence)

(Note: Reach 2 information complied from Montgomery Watson Harza, 2001.)

In this 89-mile reach of the Rio Grande, the river enters the San Luis Valley and the Rio Grande Depression. It flows through alluvium, aeolian and lacustrine deposits. The slope decreases dramatically from the mountain reach upstream, with the average slope though this reach of 8 ft/mi. However, this does not give the total picture of the changes in gradient. The channel enters the valley at a gradient of 14 feet per mile and gradually decreases until it has a gradient of 1 to 2 feet per mile below Alamosa. This is the lowest gradient encountered on the Rio Grande in the study area. Similarly, the stream enters the valley as a cobble and gravel bed steam and exits as a sand bed channel.

From South Fork to Del Norte, the channel is moderately entrenched, and remains moderately so below Del Norte as it flows along the southern margin of an alluvial fan. The river possess a split channel in some locations, but historically, the channel likely had a more braided form in this area. At Monte Vista, the slope of the channel decreases dramatically and takes on a meandering planform with numerous abandoned oxbows in the floodplain. The planform continues to the end of the reach, which is marked by the confinement of the San Luis Hills.

Once below Monte Vista, the channel has connection with its floodplain with bankfull discharges ranging from the 1-year to 4-year. Although water use has reduced flows in the river, the channel has been aggrading. Much of the aggradation is attributable to natural processes as the Rio Grande flows out onto the depositional alluvial fan. This may be due in part to diverting a higher proportion of water than sediment. The aggradational nature of this area has resulted in the stream still accessing its floodplain quite frequently. During floods, the channel may actually avulse and occupy a new location as a result of deposition in the main channel. Analysis of the gage records at Monte Vista indicates aggradation of several feet over the past 65 years. The floodplain has not been substantially altered by levees; continuous levees are present for only several miles at Alamosa.

Reach 2 - Summary of Characteristics

Length -	89 miles
Planform -	variable - sinuous to multi-channel anastomosing
Sinuosity -	ranges from 1.1 to 2.0
Bed -	grading from gravel and cobble to sand in the downstream direction
Control -	limited bedrock vertical control above Monte Vista
Floodplain -	broad, several miles wide in areas
Q_2 -	3,000 cfs (varies through reach)
Slope -	> 14 ft. / mi. to 1 to 2 ft. / mi.
Average slope -	8 ft. / mi.
Width -	100 to 200 feet
Key factors -	removal of water by diversions, aggradational nature of fan, channel avulsion

Reach 3 (RM 1741 to RM 1714 Conejos confluence to CO/NM state line)

This is a transition reach for the Rio Grande, from the broad, open San Luis Valley upstream, to the extremely confined Rio Grande Gorge downstream. The reach starts below the Conejos River confluence as the Rio Grande flows into the San Luis Hills. These hills are a combination of basalt-capped mesa and volcanic hills on the order of 200 to 300 feet above the valley floor. The channel narrows and becomes more entrenched as it flows southward. Through this reach, the average channel width is about 100 feet, with a gradient of 4 ft. / mi. The channel bed coarsens in the downstream direction from sand and gravel to gravel and cobble, with some basaltic boulders. There is only limited floodplain.

Reach 3 - Summary of Characteristics

Length -	27 miles
Planform -	slightly sinuous
Sinuosity -	1.2
Bed -	varies sand and gravel to gravel / cobble / some boulders
Control -	some bedrock both laterally and vertically
Floodplain -	limited
Q_2 -	1,800 cfs
Average slope -	35 ft. / mi.
Width -	~ 100 ft.
Key factors -	water use upstream

Reach 4 (RM 1714 to RM 1639 CO/NM state line to Velarde)

This reach is dominated by the Rio Grande Gorge, which ranges from several hundred feet in depth to over 1,000 feet. At some of its deepest points, such as at the Taos Junction Bridge, the Gorge is only 1,000 feet wide. Throughout the Gorge, the channel has cut into the thick basalt flows lying between the Sangre de Cristo Mountains to the east, and the Tusas Mountains to the west. Other than the headwaters, this is the steepest section of the Rio Grande. The gradient averages 25 ft. / mi., with the steepest sections exceeding 50 ft. / mi.

The bed throughout this reach is dominated by cobbles and boulders, with some areas having only limited amounts of gravel and sand deposited adjacent to eddies and on small floodplain features. Vegetation is limited to thin strips along the banks, exposed bars, and isolated pockets.

Due to the steep gradient, confining canyon walls, and large boulders, numerous rapids exist. These are primarily created by large blocks of basalt that have fallen from the canyon walls, locally constricting the channel. Due to the accumulation of cobbles and small boulders, riffles and pools occur in the flatter reaches. Because of its steep gradient, combined with the flat gradients upstream, the reach has always passed the sediment entering it, and the channel does not degrade or erode its banks because of the high degree of bedrock control, both laterally and vertically. Geomorphology of the channel has likely not changed greatly from pre-settlement times. A popular recreational area for whitewater boaters, fishermen and sightseers, much of the reach is designated as Wild and Scenic, and portions comprise the Rio Grande Gorge State Park.

Reach 4 - Summary of Characteristics

Length -	75 miles
Planform -	straight
Sinuosity -	less than 1.1
Bed -	cobble and boulder
Control -	high degree of bedrock both laterally and vertically
Floodplain -	extremely limited
Q_2 -	4,100 cfs
Slope -	20 ft. / mi. to 50 ft. / mi.
Average slope -	25 ft. / mi.
Width -	50 to 100 feet
Key factors -	bedrock control

MIDDLE BIOREGION – VELARDE, NM TO CABALLO DAM, NM

This bioregion includes the Española Valley-White Rock Canyon, Cochiti Reservoir, the Middle Rio Grande Valley, and Elephant Butte and Caballo Reservoirs. A major tributary, the Rio Chama, enters near the upstream boundary. In the upper half of the reach, above Albuquerque, inflows are dominated by snowmelt from high mountains, while in the lower half, inflows are primarily from rainfall events on ephemeral tributaries. The major mainstem and tributary reservoirs of the study area are all contained within this bioregion.

1.2 Geomorphic Characteristics of Middle Bioregion

The Middle Bioregion has been divided into 11 reaches. A discussion of the geomorphic characteristics of each reach is presented below.

Reach 5 (RM 1639 to 1627 Velarde to Rio Chama Confluence)

(Note: Much of the description provided for Reaches 5 through 15 was taken from USBR 2001.)

This short reach of the Rio Grande encompasses the area from the mouth of the Rio Grande Gorge to the confluence with the Rio Chama. In this reach, the Rio Grande flows out into the Española Valley, and the channel is relatively straight, owing at least partially to channelization since the 1950's. The gradient is moderate at about 12 ft. / mi. Prior to channelization, the stream was braided and occupied much of the floodplain, which approaches 3,000 feet in some areas. The reach has several diversion structures that span the channel and provide water to acequias. The bed material is gravel and cobble. The non-cohesive banks, comprised of sand and gravel, are subject to erosion, with the most noticeable area of erosion occurring below the San Juan Diversion near Acalde.

Reach 5 - Summary of Characteristics

Length -	12 miles
Planform -	straight to slightly sinuous
Sinuosity -	ranges from 1.1
Bed -	gravel and cobble
Control -	laterally confined by levees in some areas, diversions control vertical
Floodplain -	controlled by levees in some areas, but over 1,000 feet in others
Q_2 -	4,400 cfs
Slope -	12 ft. / mi.
Width -	200 ft.
Key factors -	levees, several acequias diversions, past channelization and river maintenance

Reach 6 (RM 1627 to RM 1614 Rio Chama to Otowi Bridge)

The Rio Grande changes character as the Rio Chama enters from the west, increasing both the flow and the sediment load. As a result, the channel bed is finer, being primarily gravel but with significant amounts of both sand and cobbles in some areas. Because of the increased water and sediment load, the channel widens to 300 - 400 feet, and is only slightly sinuous, with non-cohesive banks comprised primarily of sand and gravel. Considerable bank erosion is occurring in several sections.

Besides modification of the hydrology from upstream diversions and control by reservoirs on the Rio Chama, the Rio Grande has undergone several changes due to direct human manipulation. Similar to Reach 5, this section was channelized in the 1950's and river maintenance was performed periodically for several decades afterwards. Additionally, levees have been constructed through the City of Española for flood control. Gravel mining has impacted portions of the reach, resulting in an incised channel with eroding banks, and a lowering of the adjacent groundwater table. Along several sections of the channel, the bank is protected with riprap, rock groins or root wads.

Reach 6 - Summary of Characteristics

Length -	13 miles
Planform -	straight to slightly sinuous
Sinuosity -	1.1
Bed -	gravel with sand and cobble
Control -	some bedrock both laterally and vertically
Floodplain -	canyon to greater than 1,000 feet
Q_2 -	5,800 cfs
Slope -	9 ft. / mi.
Width -	300 to 400 feet
Key factors -	channelization, levees, gravel mining

Reach 7 (RM 1614 to RM 1597 Otowi to Cochiti Reservoir)

At Otowi, the Rio Grande leaves the Española Valley and flows into White Rock Canyon. The average gradient through the canyon is 12 ft. / mi., although there are areas with a few rapids where the gradient doubles. The canyon is up to 1,000 feet deep, and the channel narrows to 100-200 feet in width. The bed is primarily gravel and cobble, with some boulders. As the backwater from Cochiti Reservoir is approached, the channel has extensive deposits of sand, then silt. During flood operations, the Cochiti pool can extend many miles upstream, and this has resulted in sand deposits in the floodplain and along terraces.

Reach 7 - Summary of Characteristics

Length -	17 miles
Planform -	slightly sinuous, meanders entrenched in bedrock
Sinuosity -	ranges from 1.1
Bed -	gravel and cobble with some boulders
Control -	significant bedrock both laterally and vertically
Floodplain -	canyon
Q_2 -	5,800 cfs
Slope -	10 ft. / mi. to 25 ft. / mi.
Average slope -	25 ft. / mi.
Width -	100 to 200 feet
Key factors -	backwater from Cochiti and inundation during flood operations

Reach 8 (RM 1597 to RM 1588 Cochiti Reservoir)

This reach of the Rio Grande contains Cochiti Reservoir. The reservoir has a recreational pool of 49,500 af with an elevation of 5,341 feet. The reservoir began operations in 1975, and as of June 1998, had trapped on the order of 20,000 af of sediment, or roughly 1,000 afy, on the average. Sediment deposition in the upper portion of the reach has created a sand bed channel, and in some places, extensive areas of riparian and wetland vegetation that would not otherwise exist in this confined canyon reach.

Reach 9 (RM 1588 to RM 1561 Cochiti Dam to Bernalillo / Hwy 550)

The Rio Grande changes significantly below Cochiti Dam, due to both natural and human-induced conditions. The broad Middle Rio Grande Valley is interrupted by only a few short constrictions, and the river here has historically been dominated by a sand bed channel, and receives very little flow from snowmelt runoff. The last significant snowmelt-fed tributary, the Rio Jemez , enters within this reach. Below its confluence, the primary inflow to the Rio Grande is from thunderstorms. Cochiti Reservoir controls the peak runoff, so that the 2-year peak flood is reduced from 8,000 cfs above the dam, to 5,600 cfs below the dam, and the 100-year flood is reduced to on the order of 10,000 cfs. For hundreds of miles, the river is now modified by nearly continuous channelization, levees, water diversions and major reservoirs, and the upstream sediment supply that once altered the morphology of the channel downstream is trapped by Cochiti Reservoir.

Currently, the Rio Grande through this reach has a gravel bed channel with a sinuosity of 1.1, and a gradient of 6 ft. / mi. Prior to channelization in the late 1950's and early 1960's, this reach had a braided planform. In addition to changes brought about by channelization, the river has degraded and armored, and the banks have eroded due to the release of clear water from Cochiti Reservoir. In many locations, a smaller channel has been entrenched within the historic channel banks. In 1918, the channel averaged about 1,000 feet wide, compared to its current 300 feet. Because of the lack of sediment supply since Cochiti began operation, many of the jetty jacks placed to stabilize the channel have ceased to be effective in controlling bank erosion. Historically, the floodplain was a mile wide, but levees in many locations have confined the floodplain to 1,000 to 2,000 feet in width.

It is noted that since October of 2000, the sediment pool at Jemez Reservoir has been eliminated. This should add perhaps 1,000 acre feet per year of sediment to the river. This is on the order of the amount of sediment trapped behind Cochiti Dam on an annual basis, and should be considered a significant change.

Reach 9 - Summary Of Characteristics

Length -	26 miles
Planform -	slightly sinuous
Sinuosity -	1.1
Bed -	gravel with some sand
Control -	vertical control by Angostura Diversion and several areas of coarse tributary deposits
Floodplain -	historically over a mile wide in places, but confined by levees to 1,00 to 2,000 feet
Q_2 -	4,500 cfs
Slope -	6 ft. / mi.
Width -	300 ft.
Key factors -	reservoir control of peak flows and sediment reduction, channelization and levees

Reach 10 (RM 1561 to RM 1526 Bernalillo to Isleta Diversion)

This reach of the Rio Grande flows through the Albuquerque Metropolitan area. The upstream end of the reach is transitional in that it undergoes progressive conversion from a sand to a gravel bed. A decade ago, the Rio Grande below Highway 550 (formerly NM Highway 44) was sand bed. Now, gravel is becoming the dominant bed material in the Corrales area. Consequently, the channel is becoming more entrenched and disconnected from its floodplain.

The entire reach is confined by levee, and jetty jacks have been widely used to confine and stabilize the main channel or floodway. This has resulted in a channel width of about 600 feet, compared to a historic channel width in the early 1900's of over 1,000 feet. During the past decade, many of the center bars and alternated bars have become permanently vegetated in this reach. These features further narrow the effective channel width.

The gradient is typical of the Middle Rio Grande from Bernalillo to Elephant Butte, at 4 to 5 ft. / mi. The sinuosity is low, at a value of 1.1. Although the channel is currently single thread, historically there were multiple channel braids. The median diameter of the bed material is 2 mm, placing it in the upper end of the sand bed range. As previously mentioned, however, the conversion to a gravel bed channel has started to progress downstream from the upper end of the reach.

Reach 10 - Summary of Characteristics

Length -	35 miles
Planform -	variable between straight / braided / sinuous
Sinuosity -	1.1
Bed -	1.5 mm sand
Control -	lateral by jetty jacks, vertical by Isleta Diversion Dam
Floodplain -	historically over a mile wide, but limited by levees to 1,000 to 2,000 feet
Q_2 -	4,500 cfs
Slope -	4.5 ft. / mi.
Width -	400 to 600 feet
Key factors -	levees, jetty jacks and upstream hydrologic changes including sediment reduction

Reach 11 (RM 1526 to RM 1484 Isleta Diversion to Rio Puerco Confluence)

Geomorphic characteristics of this reach are similar to Reach 10, except for the segment of Reach 10 that has converted to a gravel bed. The channel has a low sinuosity, at a value of 1.1, and is confined by levees on both sides. The once 2-mile-wide floodplain averages 2,000 feet or less. Jetty jacks have been used to stabilize and confine the channel to a width of approximately 500 to 600 feet. This compares with a width in excess of 1,000 feet in the early 1900's. The bed material size is sand, though it is finer than in Reach 10, at 0.6 mm.

Reach 11 - Summary of Characteristics

Length -	42 miles
Planform -	slightly sinuous
Sinuosity -	1.1
Bed -	0.6 mm sand
Control -	laterally confined by jetty jacks
Floodplain -	historically over a mile, but confined by levees to less than 2,000 feet
Q_2 -	4,500 cfs
Slope -	4 ft. / mi.
Width -	500 to 600 feet
Key factors -	levees, jetty jacks, upstream hydrologic manipulation

Reach 12 (RM 1484 to RM 1418 Rio Puerco to Elephant Butte Reservoir)

This reach appears to retain the highest level of original channel morphology in any portion of the study area downstream of Cochiti Reservoir. Nevertheless, it has been significantly changed by manipulation within the reach, as well as by upstream changes in water and sediment supply. A levee confines the river on the west, while topography restricts it on the east. Jetty jacks and physical channelization have been utilized in this reach to stabilize the channel, but there are areas that still exhibit the historic braided channel form.

Large sediment inflows from both the Rio Puerco and Rio Salado help to maintain the braided planform that still persists in much of this reach. These tributaries enter at the upper end of the reach, upstream of the San Acacia Diversion Dam. Areas of braided channel exceed 1,000 feet in some places, and fall within the 600 to 900 foot range in others. In contrast to the wide braided areas, some of the narrowest channel sections in the Middle Rio Grande also occur within this reach. Several segments, which were channelized more than 50 years ago, have widths ranging from 100 feet to 250 feet.

Even with the sediment supply from the Rio Puerco and Rio Salado, the upper portion of this reach is degradational. The segment from San Acacia to Escondida has degraded nearly 10 feet in the past 40 years. It has been postulated that this segment of Reach 12 will be transformed into a gravel bed channel in the next several years as the degradational trend continues and the gravel armor layer develops. In contrast, in the area from the southern boundary of Bosque del Apache NWR to San Marcial, sediment deposition has caused aggradation to the point that a "sediment plug" has formed several times.

Throughout this reach, the planform alternates between wide braided sections and narrow channelized sections. The lower portions of this reach maintain a high level of connectivity with the floodplain, particularly downstream of San Antonio. In this area, overbank flooding occurs at discharges ranging between 2,000 to 4,000 cfs. In general, the further downstream in this reach, the lower the discharge associated with initiation of overbank flows. This is at least partially due to the influence of backwater and sedimentation from Elephant Butte at higher reservoir pool elevations. At the San Marcial Railroad Bridge, aggradation has reduced river capacity to less than 4,000 cfs, necessitating smaller-than-normal releases from Cochiti Reservoir. In turn, the lack of larger releases has influenced the morphology of the channel by reducing overbank flows and promoting the encroachment of vegetation on bars.

Reach 12 - Summary of Characteristics

Length -	66 miles
Planform -	alternates between wide, braided segments, and narrow, straight segments
Sinuosity -	1.1
Bed -	.3 mm sand
Control -	San Acacia Diversion Dam and some tributary deposits control vertical locally; jetty jacks control laterally
Floodplain -	historically up to 2 miles, currently 1,500 to 3,000 feet
Q_2 -	4,200 cfs
Slope -	4 ft. / mi.
Width -	100 to 1,000 feet
Key factors -	sediment supply from Rio Puerco and Rio Salado, jetty jacks, west side levee, channelization, Elephant Butte backwater, upstream flow alteration

Reach 13 (RM 1418 to RM 1383 Elephant Butte Reservoir)

Elephant Butte Reservoir encompasses nearly 35 miles of the Rio Grande when completely filled. At lower stage levels, less than 20 miles of the river is inundated. Due to the large sediment inflow, a significant delta has formed near the upper end of the reservoir. In recent years, the Bureau of Reclamation has excavated a channel though the delta deposits to induce channel degradation, and to eliminate some of the sedimentation impacts to the Rio Grande further upstream. As the level of the reservoir has receded over the past six years, the channel has been extended further downstream.

Reach 14 (RM 1383 to RM 1374 Elephant Butte Dam to Caballo Reservoir)

This is a 9-mile reach between two reservoirs. The water is nearly sediment free when released from Elephant Butte Reservoir. As a result, unless a tributary has flowed recently, the bed is gravel. Releases from Elephant Butte are controlled to about 2,000 cfs or less to prevent flooding in Truth or Consequences. The channel is confined to the east by the topography, and to the west by development. In some locations, the channel is confined on both the east and west by the topography. Because of these factors, the floodplain is nearly nonexistent in much of this reach.

Reach 14 - Summary of Characteristics

Length -	9 miles
Planform -	slightly sinuous
Sinuosity -	1.2
Bed -	gravel
Control -	some bedrock both laterally
Floodplain -	limited
Q_2 -	2,300 cfs
Slope -	4 ft. / mi.
Width -	200 to 300 feet
Key factors -	clear water release from Elephant Butte, changes in hydrology, development adjacent to channel

Reach 15 (RM 1374 to RM 1356 Caballo Reservoir)

Caballo Reservoir occupies this 18-mile reach of the Rio Grande.

LOWER BIOREGION – CABALLO DAM, NM TO CANDELARIA, TX

Within this bioregion there is little inflow to the Rio Grande. The tributaries are all ephemeral. The watershed is narrow on both sides, as many areas adjacent to the basin are drained internally. Throughout this reach, therefore, flows decrease in the downstream direction.

1.3 Geomorphic Characteristics of Lower Bioregion

The Lower Bioregion has been divided into 4 reaches. A discussion of the geomorphic characteristics of each is presented below.

Reach 16 (RM 1356 to RM 1288 Caballo Dam to Mesilla Diversion)

This reach of the Rio Grande represents the upper portion of the "Canalization Project" undertaken by the International Boundary and Water Commission between 1938 and 1943 to provide flood control and water delivery. The project consisted of dredging the main channel and levee construction, and resulted in major changes to the Rio Grande channel and floodplain.

Riprap and a thin strip of dense vegetation have stabilized channel banks in this reach. The flood plain is mowed between the channel banks and levees. Channel width typically ranges from 200 to 300 feet, with some areas near the upper end as narrow as 150 feet, and some segments in the lower end approaching 400 feet in width. The width generally increases in the downstream direction and is likely the result of increased water and sediment inflow as arroyos, primarily from the west, enter the channel. Levees to the east, and topography or levees to the west confine the current floodplain to a width of 600 to 1200 feet. The exception is Seldon Canyon at the downstream end of the reach, where no levees have been constructed. In this segment, the floodplain is naturally limited to a width of 600 to 1,200 feet.

The channel is slightly sinuous at a value of 1.1. Its alignment is heavily engineered with constructed curves and tangents, and it conveys on the order of 2,000 to 3,000 cfs before spilling into the limited floodplain. The channel gradient is similar to upstream values in the Middle Rio Grande Valley at 4 ft. / mi. The sand bed channel has shown some areas of degradation or incision near the upper end.

Reach 16 - Summary of Characteristics

Length -	68 miles
Planform -	straight to slightly sinuous
Sinuosity -	1.1
Bed -	sand
Control -	vertical control by Percha Dam, Leasburg Dam and an exposed inverted siphon
Floodplain -	about 800 feet, but ranging from 400 feet to 1,200 feet; historically 1 to 2 miles
Q_2 -	2,600 cfs
Slope -	4 ft. / mi.
Width -	200 to 300 feet
Key factors -	channelization, levees, bank stabilization, flow and sediment alterations

Reach 17 (RM 1288 to 1249 Mesilla Diversion Dam to American Dam)

The Canalization Project continues downstream in this reach for 39 miles, to the American Diversion Dam on the Texas / Mexico Border. The reach is similar in character to Reach 16, though it is somewhat more confined by levees, and is further altered by water withdrawal. Unlike the upper portion of the Canalization Project, few large arroyos empty into the river within this reach.

At the downstream end, the channel is laterally confined by the Franklin Mountains to the north, and the Sierra Juarez to the south. Through the rest of the reach, the floodplain is confined to an average width of 600 feet, while the channel averages about 220 feet. There is less variation in both levee and channel compared to Reach 16. The channel is straighter, at a sinuosity of 1.05, but its slope remains about 4 ft. / mi.

Reach 17 - Summary of Characteristics

Length -	39 miles
Planform -	straight to slightly sinuous
Sinuosity -	1.05
Bed -	sand
Control -	vertical control by American Diversion Dam
Floodplain -	average of 600 feet, with range of 400 to 1,000 feet
Q_2 -	3,400 cfs
Slope -	4 ft. / mi.
Average slope -	35 ft. / mi.
Width -	220 feet
Key factors -	channelization, levees, bank stabilization, flow and sediment alteration

Reach 18 (RM 1249 to RM 11156 American Dam to near Fort Quitman)

Most of this reach is contained within the "Rectification Project" constructed by the IBWC between 1934 and 1938, with supplemental construction during 1943 through 1950. The project consists of levees approximately 600 feet apart, with a 66-foot-wide pilot channel between them. Over the years, the pilot channel has attained a width of up to 100 feet in many places, although some areas are as narrow as 50 feet. The Rectification Project's purpose was to stabilize the location of the border between Mexico and the United States, as it is formed by the Rio Grande and was therefore subject to changes due to a shifting, meandering channel. The primary mechanism of change was sedimentation in the main channel, causing the river to take a path through a lower lying area during a flood. This process is known as channel avulsion, and old meander scars left by channel avulsions are evident throughout the floodplain.

In constructing the Rectification Project, 155 miles of channel were reduced to 86 miles. This indicates that the historic sinuosity of the channel was approaching 2.0 rather than the current 1.1. The current gradient of 3.3 ft. / mi. would have been less than 2 ft. / mi. The floodplain is mowed on the United States side, while the level of maintenance on the Mexican side is variable.

The current channel receives only minimal upstream flows, with the base flow being created by agricultural and wastewater returns. Significant flows are a result of tributary flooding.

Reach 18 - Summary of Characteristics

Length -	93 miles
Planform -	straight to slightly sinuous
Sinuosity -	1.1
Bed -	sand
Control -	vertical control by Riverside Diversion, and International Diversion
Floodplain -	600 feet; historically 2,000 to 10,000 feet
Q_2 -	3,600 cfs
Slope -	3.3 ft. / mi.
Width -	50 to 100 feet
Key factors -	channelization, levee construction, bank stabilization, flow and sediment alteration

Reach 19 (RM 1156 to RM 1036 Near Fort Quitman to Candelaria)

This reach begins at the downstream end of the Rectification Project, and stretches to the Capote Creek confluence, just upstream of Candelaria. At 120 miles, it is the longest reach in the project area, and is often refereed to as "the Forgotten Reach" due to its remoteness. It represents a considerable change from upstream reaches: there has been little direct physical manipulation of the channel, although some channel work was performed by the IBWC under the "Boundary Preservation Project" from 1980 to 1986. The work typically included excavation of a 40-foot-wide channel and clearing of the floodplain.

Within Reach 19, the channel is confined by topography. Typically, the valley width is 1,000 feet or less, though in some places it is as wide as 3,000 feet. In contrast, the river also flows through several narrow canyons, perhaps 200 feet wide. The current channel is very narrow, less than 50 feet wide in many areas. Saltcedar has encroached from the channel banks to the valley walls in most locations. A major problem in the reach is the lack of flow to mobilize and transport sediments deposited by thunderstorm floods on the tributaries. This has resulted in backwater areas and complete loss of the channel as it splits into many small distributaries across the deposits. The channel slope increases to 4.5 feet per mile, with a sinuosity of 1.5.

Reach 19 - Summary of Characteristics

Length -	120 miles
Planform -	sinuous
Sinuosity -	1.5
Bed -	sand
Control -	lateral control by bedrock and some vertical in canyons
Floodplain -	100 feet typical but ranges from 0 to 3,000
Q_2 -	2,500 cfs (varies from 3,800 at Fort Quitman to 1,000 at Presidio)
Slope -	4.5 ft. / mi.
Width -	50 to 100 feet
Key factors -	lack of mainstem flows from upstream, inability to transport tributary deposits, vegetation encroachment

APPENDIX C
Biological Conditions Summary and Information Sheets

UPPER BIOREGION – HEADWATERS TO VELARDE
Riparian Habitat

Authors: Renée Rondeau and Terri Schulz

1. Upper Montane/Subalpine Riparian Forest and Woodland Ecological System—Linear

Upper montane/subalpine riparian forest and woodland ecological system is a linear system confined to specific environments occurring on floodplains or terraces of upper the Rio Grande and its tributaries. This ecological system occurs primarily between 8,000 and 11,000 feet. It is the primary riparian matrix of the upper Rio Grande watershed. The montane/subalpine riparian shrubland ecological system forms small patches within this linear-matrix system. Occurrences often contain a mosaic of one or two communities dominated by one of the following trees: *Abies concolor, A. lasiocarpa, Picea engelmannii, P. pungens,* or *Populus tremuloides.* Generally the vegetation surrounding these riparian systems is dominated by the same tree that is dominant in the riparian area, e.g., if the riparian forest is *Picea engelmannii,* the dominant upland vegetation is a *Picea engelmannii* forest.

. The primary ecological process necessary to maintain this ecological system is hydrology, more specifically surface flow, although ground water is also important, as are annual and episodic flooding. Alteration of the flooding regime due to water impoundment and diversions may produce changes to plant and community composition (Kittel et al. 1999). In addition, upstream activities that effect water quality, e.g., mining, may be important to the vertebrate and invertebrate species that use this system.

Aquatic species and water quality may be as important an indicator of system health as is the vegetation. For example one study on ptarmigan showed that what appears to be a healthy willow community is in reality a sink for ptarmigan due to the excessive heavy metals that are found in the willows below mining areas.

- Indicator Species
  - Narrowleaf cottonwood regeneration
  - Warbling vireo
  - Ground-nesting birds

- Primary Ecological Processes
  - Hydrology (specifically surface flow, although ground water is important)
  - Annual and episodic flooding

- Indicators of High Quality Condition
  - <u>A-rated condition:</u> The natural hydrologic regime is intact, including an unaltered floodplain. There is little or no evidence of alteration due to drainage, flood control, irrigation canals, livestock grazing, soil compaction, digging, burning, mining or vehicle use. No or very few exotic species are present, with no potential for expansion. Species composition is primarily of native species, with a diverse physiognomic structure. Stream banks are not overly steep, and the channel is not widened or stripped of vegetation by excessive livestock grazing.
  - <u>Justification for A-rated criteria</u>: Subalpine riparian forest and woodlands are dependent on specific hydrologic regimes, soils, and the ability to move both up and down the stream, and side to side within the floodplain. A-ranked occurrences have natural flooding processes, species composition, and an intact physical environment

- Stressors
  - Agricultural withdrawals and diversions
  - Urban and rural development within the floodplain
  - Lack of spring floods and regeneration
  - Channelization
  - Bank hardening
  - Invasive non-native species, including mesopredators
  - Improper, or season-long grazing
  - Current and historic mining

- Restoration Goals
  - Reestablish floodplain-river connections to create or enhance overbank flooding to mimic historic levels
  - Restore (as nearly as possible) the historic hydrologic regime, including timing, duration, and magnitude of historic peak flows and late season drawdown periods
  - Employ passive restoration where feasible, and pole planting of narrowleaf cottonwood and willow in disturbed areas
  - Manage livestock grazing
  - Minimize or reduce vehicular stream crossings where feasible
  - Eliminate or minimize the threat from nonnative species

Literature Cited:

Kittel, G., E. VanWie, M. Damm, R. Rondeau, S. Kettler, and J. Sanderson. 1999. A classification of the riparian vegetation of the Rio Grande and Closed Basin watersheds, Colorado. Colorado State University, Fort Collins, CO: Colorado Natural Heritage Program.

2. Montane/Subalpine Riparian Shrubland Ecological System—Linear

Montane/subalpine riparian shrubland ecological system is a linear and small patch system confined to specific environments occurring on floodplains or terraces of the upper Rio Grande and its tributaries. It primarily occurs in shallow broad valleys. This ecological system is can be found within a broad elevation range, from approximately 8,000 to 11,000 feet. It often occurs as a mosaic of multiple communities that are shrub-dominated. The dominant shrubs reflect the large elevational gradient and include *Alnus incana, Betula glandulosa, B. occidentalis, Cornus sericea, Salix bebbiana, S. boothii, S. brachycarpa, S. drummondiana, S. eriocephala, S. geyeiriana, S. moniticola, S. planifolia,* and *S. wolfii.* Generally, the upland vegetation surrounding these riparian systems are of either conifer or aspen forests, while adjacent riparian systems range from herbaceous-dominated communities to tree-dominated communities.

Beavers are primary users and maintainers of this ecological system, and the foremost abiotic ecological process necessary to maintain it is hydrology, more specifically, surface flow. Annual and episodic flooding is important, too, as any alteration of the flooding regime may produce changes to plant composition or community composition (Kittel et al. 1999). Aquatic species and water quality may be as important as vegetation as indicators of system health.

- Indicator Species
  - Native shrub regeneration
  - Lincoln’s sparrow
  - Wilson’s warbler
  - White-crowned sparrow

- Primary Ecological Processes
  - Hydrology (specifically surface flow, although ground water is important)
  - Annual and episodic flooding

- Indicators of High Quality Condition

  A-rated condition: The natural hydrologic regime is intact, including an unaltered floodplain. There is no or little evidence of alteration due to drainage, flood control, irrigation canals, livestock grazing, digging, burning, mining, or vehicle use. No or very few exotic species are present, and there is no potential for their expansion. Species composition is primarily of native species, with a diverse physiognomic structure. Stream banks are not overly steep, and the channel has not been widened or stripped of vegetation by excessive grazing.

  Justification for A-rated criteria: Subalpine/montane riparian shrublands are dependent on specific hydrologic regimes, soils, and the ability to move both up and down the stream, and side to side within the floodplain. A-ranked occurrences have natural flooding processes, species composition, and an intact physical environment.

- Stressors

  Agricultural withdrawals and diversions
  Urban and rural development within the floodplain
  Lack of spring floods and regeneration
  Channelization
  Bank hardening
  Invasive non-native species, including mesopredators
  Inappropriate livestock grazing
  Current and historic mining impacts

- Restoration Goals

  Reestablish floodplain-river connections to create or enhance overbank flooding
  Restore (as nearly as possible) the historic hydrologic regime, including timing, duration, and magnitude of peak flows and late season drawdown periods
  Employ passive restoration where feasible, and pole planting of willows in disturbed areas
  Manage livestock grazing
  Eliminate or minimize the threat from nonnative species

Literature Cited:

Kittel, G., E.VanWie, M. Damm, R. Rondeau, S. Kettler, and J. Sanderson. 1999. A classification of the riparian vegetation of the Rio Grande and Closed Basin watersheds, Colorado. Colorado State University, Fort Collins, CO: Colorado Natural Heritage Program.

3. Lower Montane Riparian Woodland Ecological System

Lower montane riparian woodland ecological system is a linear system confined to specific environments occurring on floodplains or terraces of the upper Rio Grande and its tributaries. It is scattered throughout the upper watershed within a broad elevation range, from approximately 6,000 to 9,000 feet. This system often occurs as a mosaic of multiple communities that are tree-dominated with a diverse shrub component. The plant associations connected to this system reflect a variety of elevations, stream gradients, floodplain widths, and flooding events. The dominant trees may include *Acer negundo, Populus angustifolia, P. balsamifera, Pseudotsuga menziesii, Picea pungens,* or *Juniperus scopulorum*. Dominant shrubs include *Acer glabrum, Alnus incana, Betula occidentalis, Cornus sericea, Crataegus rivularis, Prunus virginiana, Salix monticola, S. drummondiana, S. exigua, S. lucida, Shepherdia argentea,* or *Symphoricarpos* spp. Generally, the upland vegetation surrounding this riparian system ranges from grasslands to forests.

The primary abiotic ecological process necessary to maintain this ecological system is hydrology, and more specifically, surface flow. Annual and episodic flooding is extremely important for maintaining a diversity of age classes of *Populus angustifolia,* as well as a mosaic of plant associations within any given floodplain. Alteration of the flooding regime due to water impoundment, diversions, etc., may produce changes to plant and community composition. In addition, upstream activities that effect water quality, e.g., mining may be important to the vertebrate and invertebrate species that use this system.

- Indicator Species
  - Beaver
  - Wintering bald eagle roosting sites
  - MacGillivray's warbler
  - Cottonwood trees (multiple age-classes)

- Primary Ecological Processes
  - Hydrology (specifically surface flow, although ground water is important)
  - Annual and episodic flooding
  - Channel migration and redistribution of sediment, providing suitable sites for narrowleaf cottonwood establishment
  - Peak flows and flooding events coinciding with cottonwood reproduction (mid-June to early July)

- Indicators of High Quality Condition
  - A-rated condition: The natural hydrologic regime is intact, including an unaltered floodplain. There is no or little evidence of alteration due to drainage, flood control, irrigation canals, livestock grazing, digging, burning, mining, or vehicle use. No or very few exotic species are present, with no potential for their expansion. Species composition is primarily of native species with a diverse physiognomic structure. Stream banks are not overly steep, and the channel is not overly widened or stripped of vegetation by excessive grazing.
  - Justification for A-rated criteria: Riparian woodlands are often composed of a mosaic of different plant associations, including small patches of shrublands and herbaceous vegetation. Occurrences of this size have a wide range of plant associations that indicate great variation in hydrology, soil texture, and geomorphology, e.g., point bars. Occurrences of this size would likely contain sufficient internal variability to capture characteristic biophysical gradients and retain natural geomorphic and hydrologic disturbance. They are buffered from edge effects and small hydrology alterations.

- Stressors
  - Agricultural withdrawals and diversions
  - Urban and rural development within the floodplain
  - Lack of spring floods and regeneration
  - Channelization
  - Bank hardening
  - Invasive non-native species, including mesopredators
  - Inappropriate livestock grazing

- Restoration Goals
  - Reestablish floodplain-river connections to create or enhance overbank flooding to historic levels
  - Support spring flooding for seed dispersion and germination
  - Employ passive restoration where feasible, and pole planting of narrowleaf cottonwood and willow in disturbed areas
  - Manage livestock grazing
  - Eliminate or minimize the threat from nonnative species

4. Foothills Riparian Woodland and Shrubland Ecological System

Foothills riparian woodland and shrubland ecological system is a linear system confined to specific environments occurring on floodplains and terraces of the upper Rio Grande and its tributaries. This system is primarily found at the lowest elevations, between 5,000 and 7,000 feet. The system is dependent on a natural hydrologic regime, especially annual to episodic flooding. Riparian areas of the upper Rio Grande valley are extremely diverse and often, several linear ecological systems lie within close proximity to each other, e.g., wet meadows, montane riparian woodlands and foothills riparian woodland and shrubland ecological systems may be closely associated. Primary driving factors are elevation, stream gradient, and floodplain width. Foothills riparian woodland and shrubland system is usually found on low to moderate gradient streams, with narrow to broad floodplains. Dominant species of this system include *Alnus incana, Crataegus rivularis, Forestiera pubescens, Populus deltoides, P. fremontii, Prunus virginina, Rhus trilobata, Salix amygdaloides, S. exigua,* and *S. irrorata.* The surrounding upland systems range from grasslands, to shrublands and woodlands.

Primary threats to this system include the cessation of flooding, water diversions, the clearing of riparian vegetation, excessive livestock grazing, and channelization.

- Indicator Species
  - Southwestern willow flycatcher
  - Beaver
  - Wintering bald eagle roosting sites
  - Brewer's blackbird
  - Cottonwood trees (multiple age-classes)

- Primary Ecological Processes
  - Hydrology (specifically surface flow, although ground water is important)
  - Annual and episodic flooding
  - Fluvial processes (channel narrowing and redistribution of sediment) to provide suitable sites for narrowleaf cottonwood establishment

- Indicators of High Quality Condition
  - <u>A-rated condition:</u> The natural hydrologic regime is intact, including an unaltered floodplain. There is no or little evidence of alteration due to drainage, flood control, irrigation canals, livestock grazing, digging, burning, vehicle use, etc. Non-native species provide less than 3% canopy cover, with a small chance for expansion. Species composition is primarily of native species with a diverse physiognomic structure. Stream banks are not overly steep or stripped of vegetation by excessive grazing or other human-caused actions.
  - <u>Justification for A-rated criteria</u>: Riparian woodlands and shrublands are dependent on specific hydrologic regimes, soils, and the ability to move both up and down the stream, and side to side within the floodplain. A-ranked occurrences have natural flooding processes, species composition, and an intact physical environment.

- Stressors
  - Agricultural withdrawals and diversions
  - Urban and rural development within the floodplain
  - Lack of spring floods and regeneration
  - Channelization
  - Bank hardening
  - Invasive non-native species, including mesopredators
  - Inappropriate livestock grazing

- Restoration Goals
  - Reestablish floodplain-river connections to create/enhance overbank flooding
  - Support spring flooding for seed dispersion and germination
  - Employ passive restoration where feasible, and pole planting of narrowleaf cottonwood and willow in disturbed areas
  - Manage livestock grazing
  - Eliminate or minimize the threat from nonnative species

MIDDLE BIOREGION – VELARDE, NM TO CABALLO DAM, NM
Riparian Habitat

Author: Cliff Crawford

Rio Grande Cottonwood Bosque

The canopy of this aging riparian galley forest is dominated mainly by mature native Rio Grande cottonwood trees (*Populus deltoides* ssp.*wislizenii*). These and the willows that comprise the majority of the bosque's native woody vegetation, are products of the Middle Rio Grande's now highly regulated flow regime. Although mostly continuous, the bosque usually appears as a narrow strip up to ~200 m in width. Laterally, its distribution within the presently active floodplain is mostly constrained by levees and, south of Socorro, by eastside bluffs. Cottonwood stands within the bosque range from fairly dense in frequently flooded locations to relatively open in locations that are hydrologically disconnected. Canopy heights can reach ~25 m but are frequently much lower. Trunk diameters vary among trees of approximately the same age. Small cottonwoods within the forest are probably root and stem sprouts; cottonwood seedlings require open, wet areas in late spring for germination. *Salix gooddingii* willows contribute to the canopy in low numbers to the north but become much more common south of Bosque del Apache National Wildlife Refuge, where they can replace cottonwoods as canopy dominants.

The cottonwood bosque as a whole is being replaced by introduced saltcedar (*Tamarix ramosissima*), Russian olive (*Eleagnus angustifolia*), Siberian elm (*Ulmus pumila*), and other woody species. Saltcedar, which is less shade tolerant than Russian olive, is part of the subcanopy in many sites, and occurs in extensive continuous open stands south of Bernardo. Russian olive, on the other hand, not only dominates the subcanopy in many places, but often lines the riverbank to the near exclusion of other trees. Occurring lower than the mature subcanopy of these largely introduced species are riparian forest shrubs that vary greatly in density and distribution. They include coyote willow (*Salix exigua*), New Mexico olive (*Forestiera pubescens* var. *pubescens*), seep willow (*Baccharis salicifolia*), screwbean mesquite (*Prosopis pubescens*), and false indigo (*Amorpha fruticosa*). Virginia creeper (*Parthenocissus inserta*) vines sometimes grow in dense patches and can climb high into trees and shrubs along the river.

The herbaceous layer beneath the woody vegetation is often sparse, especially in areas of dense canopy cover. However, grasses, sedges, and rushes are at times common in hydrologically well connected locations, while other grasses, notably saltgrass (*Distichlis spicata*) and dropseeds (*Sporobolus* spp.) are widespread in drier parts of the bosque. A variety of composites, legumes, mustards and members of other plant families is also present in the herbaceous layer; these are often annuals and regionally distributed. The native perennial, yerba mansa (*Anemopsis californica*), sometimes occurs in striking swards, especially in moist habitats. Expanses of the introduced white sweet clover (*Melilotus albus*), a biennial, can be even more evident in places that seldom flood, while common sunflower (*Heliantus annus*), an annual, occurs in dense patches in flooded or unflooded locations, as long as such places are open. Extensive patches of horseweed (*Conyza canadensis*), a perennial composite, are often found nearby.

In contrast to the existing bosque's present spatial and temporal organization, throughout most of the Holocene the riparian forest was probably a constantly changing mosaic of often discontinuous, uneven-aged cottonwood and willow communities. Not all of them would have been close to the river, but most of the dominant trees, at least, would have originated during periods of overbank flooding. At such times, open areas among the communities would have contained wetlands such as marshes, wet meadows, and oxbows depending on the topography of the floodplain and the proximity of the river. During dry periods, however, drought resistant grasses and shrubs would have covered much of the landscape not populated by such stands. The Middle Rio Grande cottonwood bosque is still a dynamic ecosystem, but one that differs markedly from its ancestral condition.

- Indicator Species
  - Plants mentioned above
  - Southwestern willow flycatcher
  - Summer tanager
  - Bald eagle
  - Beaver
  - Muskrat
  - Tawny-bellied cotton rat
  - Meadow jumping mouse
  - Carabid beetles (a number of species)
  - *Crematogaster cerasi* ant
  - *Gryllus alogus* cricket
  - *Armadillidium vulgare* and *Porcellio laevis* (introduced isopods)

- Biotic/Abiotic Processes and Targets
  - A flow regime that generates late spring overbank flooding intervals and events sufficient to promote periodic cottonwood/willow seedling germination in cleared, open parts of the active floodplain; periodic wetting of the soil column to ensure sustainable rates of key biotic processes such as litter decomposition, mineralization, nutrient uptake, and nutrient cycling
  - Groundwater tables no deeper than 3 meters are essential for cottonwood and willow survival; monitoring using shallow groundwater wells (piezometers) to track groundwater depths at restoration and reference sites
  - Soil salinity, which varies with soil type and groundwater table depth, should be moderate (20-50 mS/m?) for native tree establishment and maintenance

- Stressors
  - Reduced water availability due to riverbed degradation and low flows; the combination restricts overbank flooding and surface seepage, and also lowers groundwater tables
  - Lack of cleared, open areas for native tree seedling establishment
  - Competition from introduced tree species
  - Fire, which stimulates rapid regrowth of saltcedar and Russian olive; its effects on cottonwood and willow regrowth have not undergone enough long-term study to make definitive conclusions in the Middle Rio Grande valley
  - Fragmentation due to road construction and heavy use of the active floodplain by humans
  - Air pollution is currently being tested for ozone effects on cottonwood defoliation by leaf beetles

- Restoration Goals
  - Create mosaics of uneven-aged stands of native woody vegetation in parts of the active floodplain where periodic (but not necessarily annual) overbank flooding or groundwater seepage in late spring can be expected to occur.
  - Do this by using a) various combinations of removing and/or containing introduced tree species, b) removing senescent or poorly growing native tree species, and c) clearing and lowering selected near-bank sites to allow for flooding or groundwater seepage. These activities will help reduce the current heavy fuel loads in much of the bosque and create open spaces that, if well managed, will reduce evapotranspiration at restoration sites.
  - Simultaneously continue with ongoing fuel reduction efforts that include removal of dead and downed wood. However, old dead cottonwoods are used by many animals and should be retained to a point that balances wildlife benefits and wildfire costs.
  - Improve hydrologic connectivity between restoration sites and the river by creating shallow side channels in the lowered near-bank sites, and/or by excavating old side channel beds that no longer flood; doing so will also develop temporary slow moving water habitat benefiting young silvery minnows, other fish and aquatic invertebrates, and emergent plants.
  - Devise strategies for alternative soil wetting by pumping from shallow groundwater wells, irrigation return flows, or riverside drains. Gravity flow might be possible in the latter two cases.

Apply carefully developed monitoring protocols to both restoration and reference (control) sites. These protocols will undoubtedly vary according to specific restoration objectives, but should include procedures already demonstrated to effectively track the biological effects of flooding and seepage on the bosque.

Continue to improve communication and planning among managing agencies that control the river and the bosque.

LOWER BIOREGION – CABALLO DAM, NM TO CANDELARIA, TX
Riparian Habitat

Author: Robert Ohmart

Caballo Dam, NM to El Paso, TX

1. Cottonwood-Willow

This community is comprised of Gooding willow (*Salix goodingii*) and cottonwoods that may have a dense understory of seepwillow (*Baccharis salicifolia*), with a mix of grasses and forbs occurring along the riverbanks.

- Indicator Species
  - Beaver
  - Southwestern willow flycatcher

- Biotic/Abiotic Processes and Targets
  - Aggrade river channel to within 3 to 5 feet of the present primary floodplain
  - Raise the water table to within 3 to 5 feet of the soil surface
  - Simulate spring or early summer floods to recharge the overbanks, disperse seeds, and rejuvenate the alluvial soils
  - Encourage establishment of emergent, forb, and grass species

- Stressors
  - Caballo Dam, which disallows floods and reduces instream flows
  - Agricultural return irrigation flows containing salts, herbicides, and pesticides
  - Fire in the absence of annual floods

- Restoration Goals
  - Reverse floodplain salinity with overbank flooding
  - Reverse stream entrenchment

2. Screwbean Mesquite-Wolfberry

This plant community occurs in the floodplain outside the bands of cottonwood/willow or saltcedar. Trees of screwbean mesquite (*Prosopis pubescens*) are scattered through an understory of shrubs that includes wolfberry (*Lycium torreyi*). An occasional honey mesquite (*Prosopis glandulosa*) may occur in this community. Openings between shrubs may support species of forbs and grasses such as alkali sacaton (*Sporobolus airoides*) and saltgrass (*Distichlis spicata*).

- Indicator Species
  - Mockingbirds
  - *Prrhuloxias*
  - Verdin

- Biotic/Abiotic Processes and Targets
  - Recover overbank flooding

- Stressors
  - Caballo Dam (cessation of annual and overbank flooding)

- Restoration Goals
  Reverse floodplain salinity with overbank flooding
  Reverse stream entrenchment

3. Saltcedar

If the above restoration goals are achieved, this community will disappear or become insignificant relative to the native communities. Through time, overbank watering and recharge will flush the salts from the floodplain soils to a point that saltcedar will find the soils less attractive for its growth and spread. This, in turn, will allow native communities to reclaim their original placement along the reach.

4. Thorny Shrub

This community is an extension of the upland community that has invaded the drier alluvial soils along the outside edge of the floodplain. With overbank flooding and bank recharge, the soil moisture levels will allow the reinvasion of more mesophilic riparian species.

- Indicator Species
  Black-throated sparrow

El Paso, TX to Candelaria, TX

The floodplain along the approximately 200 miles of the Rio Grande in Hudspeth and Presidio Counties, Texas, is topographically variable. The river flows through 30 miles of canyons interspersed with 170 miles of valleys. The width of the floodplain varies from less than 650 feet in some of the canyons, to nearly two miles in the widest valley. Both valleys and canyons contain a varied assemblage of desert and riparian communities.

The river is essentially de-watered from El Paso, Texas to Haciendita, Texas. The instream water is from drainage canals carrying water away from irrigated fields. In general, these waters contain high concentrations of salts, pesticides, and herbicides. Seldom is there sufficient water to create overbank flows, except in unusual cases of regulated releases of water from Caballo Dam. In the one instance that this occurred, plugs formed in the river and it flowed over the floodplain in numerous reaches. Further, the river channel is perched above the floodplain in many areas, so the water is trapped and cannot return to the channel. A case in point occurs near Candelaria, Texas where the water accumulates as a backwater and evaporates, leaving a highly concentrated saline lake where even saltcedar cannot survive. Occasionally, emergents such as cattail occupy these saline lakes but usually as scattered individuals, presumably because of the high salinity.

Four plant communities occur in this lower reach, the most abundant being the saltcedar community. Two other communities, cottonwood-willow and screwbean mesquite-wolfberry, were very rare and were present in areas where salinity was much lower than most of the floodplain soils. The fourth community occurring on floodplain soils was termed thorny scrub.

1. Cottonwood-Willow

There are only about 60 acres of this community type remaining in the lower reach. Most trees are mature or over-mature, and when present, occur as scattered trees. Both Fremont cottonwood and Gooding willow occurs as a mix, with only a few scattered individuals being present. Generally, there is an usually dense understory of seepwillow, various grasses, forbs, and dock. The greatest density of birds throughout the year occurred in mature communities of this habitat type. During the breeding season (May through July), 786 birds per 100 acres were recorded for this community.

- Indicator Species
  None

- Biotic/Abiotic Processes and Targets
    - Improve water quality and quantity to elevate groundwater table
    - Provide spring floods for overbank watering, leaching salts, and establishing new seedbeds
    - Habitat supports greatest density of breeding birds

- Stressors
    - Agricultural return flows
    - Absence of flood events, preventing sand-bar formation for seed germination
    - No overbank flooding for bank storage and leaching of salts
    - Extreme soil salinities
    - Fire

- Restoration Goals
    - Improve water quality and quantity
    - Water releases to simulate spring floods
    - Return perched channel to floodplain height
    - Remove plugs where they occur

2. Screwbean Mesquite-Wolfberry

This community was also rare in the lower reach and occurred on the floodplain outside the band of saltcedar adjacent to the river. Mature screwbean mesquites occurred as scattered trees, with wolfberry and honey mesquite forming a shrubby understory. Openings between shrubs were often covered with grasses and forbs. Screwbean mesquite is more salt tolerant than the other species in the community, and reached a greater vertical height.

- Indicator Species
    - Black-tailed gnatcatcher
    - Crissal thrasher
    - Loggerhead shrike
    - Verdin

- Biotic/Abiotic Processes and Targets
    - None

- Stressors
    - Soil salinity levels
    - Reduced water availability and lack of overbank flooding

- Restoration Goals
    - Increase water quantity and quality with releases that simulate overbank floods

3. Thorny shrub

This community is a product of reduced instream flows and cessation of overbank flooding; soil moisture levels at the lateral edges of the floodplain alluvium have been reduced to the point that upland vegetation has invaded these areas. Soil textures are different in the thorny shrub communities in the alluvial soils of the floodplain as compared the regasoils in the upland. Members of this community also occurred in the canyon reaches where soil moisture levels are higher and support more mesophylic plants such as honey mesquite and buckthorn. More xerophylic species such as creosote bush, Lechugilla, and leatherstem were only found on the upland areas. In the upland areas, mesquites were either very stunted, or absent in the plant community mix.

- Indicator Species
    - Desert or desert-like birds, mammals, and reptiles

- Biotic/Abiotic Processes and Targets
  None

- Stressors
  None

- Restoration Goals
  None

4. Saltcedar

This community is virtually a monoculture and dominates the floodplain over the lower reach. Interestingly enough, its wildlife value and structural height increases from west (Colorado River Valley) to east (Rio Grande Valley). The tallest communities of this species provide the highest values for wildlife. The reasons for this are probably numerous, but two important ones appear to be community vertical structure and lower ambient summer temperatures. Communities of this species on the Colorado River seldom exceed 25 feet in height, where on the Rio Grande, the trees are often taller than 30 feet. On the Colorado River, ambient summer temperatures average about 115 F, and may approach 125 F for a week or more. In the Rio Grande Valley, summer temperatures are generally lower than 110 F, and seldom exceed that value for any period of time. Very few birds nest in the canopy of saltcedar in the Colorado River Valley, where a number of species use the canopy for nesting in the Rio Grande Valley. Bird species using the saltcedar community in the Rio Grande were virtually identical to those nesting in the cottonwood-willow community. The major difference between breeding avian communities in saltcedar and cottonwood-willow communities in the Rio Grande Valley was in breeding densities: saltcedar supported 489 birds/100 acres, while cottonwood-willow supported 786 birds. Relative to small mammals, there essentially is no difference between saltcedar and the cottonwood-willow communities. Further, this community fits the foliage profile most attractive to nesting habitat for the White-winged dove. A sampling of dove nesting densities in the better habitats showed a mean of 28 nests per acre per nesting season, with the best nesting habitat supporting 35 nests per acre per nesting season.

- Indicator Species
  White-winged dove

- Biotic/Abiotic Processes and Targets
  None

- Stressors
  Lack of overbank flooding and recharge of floodplain
  Increased soil salinity
  Fire

- Restoration Goals
  Maintain healthy communities

Conclusion: Habitats along the lower reach can be divided into two structural types: tall dense vegetation (saltcedar and cottonwood-willow), and shorted, sparse vegetation (thorny shrub and screwbean mesquite-wolfberry). Ruby-crowned kinglets, white-winged doves, yellow-breasted chats, summer tanagers, and house finches dominated the former, and while the same species were found in the latter communities, they occurred in much lower numbers.

Species dominating the latter communities were Pyrrhuloxia, Gambel quail, mockingbird, verdin, Lucy warbler, and black-tailed gnatcatcher.

Habitat breadth, or how evenly a species is distributed among different communities, allows one to determine how specialized or generalized a particular species is in using different communities. For example, a species that is equally abundant in all four communities would be considered a generalist, whereas one occurring in limited numbers in one habitat or more while showing high densities in one or two other habitats would be considered a specialist. Specialists can be classified as being strongly tied to a particular community, or moderately so.

In the breeding season, about two-thirds (18) of the 28 bird species were ranked as specialists. All showed preferences for particular communities, and 8 showed strong preferences. Cottonwood-willow and screwbean mesquite-wolfberry were preferred by twice as many species as any other community. Many of these were species that nest and forage in trees. In contrast, only one species, the white-winged dove, was more abundant in saltcedar than in any other community. In winter, 86% of the species present were deemed specialists, showing a strong affinity for the cottonwood-willow habitat.

These types of data should not be surprising since native fauna evolved with native flora. Accounts by early naturalists such as Emory (1859), described extensive stands of cottonwoods, willows, and large tracts of screwbean mesquite with an understory of seepwillow along the lower reach of the Rio Grande. In our never-ending effort to squeeze every last drop of water from rivers in the west, we have shifted the ecological advantage away from native trees, which cannot tolerate high salinity, to an exotic tree that can. Native flora did not evolve with fire, while saltcedar is fire-adapted. With the cessation of overbank flooding, litter is no longer carried away by floodwaters. The result is fuel accumulations that carry destructive fires, further destroying native vegetation.

As native communities disappeared, many bird species probably did as well, while others declined in numbers. Though many appear to dislike saltcedar, it is, after all, far better wildlife habitat than bare soil.

UPPER BIOREGION – HEADWATERS TO VELARDE
Wetland Habitat

Authors: Renée Rondeau and Terri Schulz

1. Montane Wet Meadow—Small Patch

Montane wet meadow ecological system is a small patch system that is widely distributed both in elevation and latitude, and confined to specific environments defined primarily by hydrology. Water levels in this system are often at or near the ground surface for much or all of the growing season, but also may fluctuate considerably through the year. Surface inundation may occur, but it typically does not last for long. Physical disturbance during inundation (e.g., during flood events) may be significant for the structure and composition of these systems. Wet meadows occur on mineral soils that have typical hydric soil characteristics, including relatively high organic content and redoximorphic features. This system usually occurs as a mosaic of several plant associations. The surrounding landscape often contains other wetland systems, e.g., riparian shrublands, or a variety of upland systems from grasslands to forest. Although this system usually occurs in small patches, the San Luis Valley has some large examples of montane wet meadows. These often occur in the oxbows of the Rio Grande, and are extremely important to aquatic species such as the northern leopard frog.

- Indicator Species
  - Northern leopard frog
  - Common snipe
  - Dragonflies (*Aeschna* spp.)

- Primary Ecological Processes
  - Hydrology (groundwater at least as important as surface water)

- Indicators of High Quality Condition
  - A-rated condition: The natural hydrologic regime is intact, with no or little evidence of wetland alteration due to increased or decreased drainage, clearing, livestock grazing, or anthropogenic nutrient inputs. No or very few exotic species are present, and there is no potential for their expansion. Native species that increase with disturbance or changes in hydrology/nutrients (e.g., nitrogen and phosphorus) are absent or low in abundance.
  - Justification for A-rated criteria: Montane wet meadows in the Southern Rocky Mountains depend on seasonally-to-permanently saturated soils, and occasional flooding disturbance; alteration of the hydrologic regime invariably compromises natural communities. Other anthropogenic influences such as grazing and nutrient inputs can significantly alter community composition by shifting competitive interactions. Non-native species (e.g., *Poa pratensis*), when in sufficient number, can displace native species. A-ranked occurrences have intact hydrologic processes that support native species composition, nutrient status, and other natural conditions.

- Stressors
  - Agricultural withdrawals and diversions
  - Urban and rural development around the wetlands
  - Channelization and draining
  - Invasive non-native species
  - Inappropriate livestock grazing

- Restoration Goals
  - Manage livestock grazing
  - Reduce or eliminate water diversions and draining
  - Eliminate or minimize the threat from nonnative species
  - Mine cleanup, if appropriate

2. Montane Fen—Small Patch

Montane fen ecological system is a small patch system confined to specific environments defined by ground water discharge, soil chemistry, and peat accumulations of at least 40 cm. This system includes extreme rich fens and iron fens, both rare within the Southern Rocky Mountains ecoregion and the Rio Grande watershed. Fens form at low points in the landscape, or near slopes where ground water intercepts the soil surface. Ground water inflows maintain a fairly constant water level year-round, with water at or near the surface most of the time. Constant high water levels lead to the accumulation of organic material. In addition to peat accumulation and perennially saturated soils, extreme rich and iron fens have distinct soil and water chemistry, with high levels of one or more minerals such as calcium, magnesium, or iron. They usually occur as a mosaic of several plant associations dominated by *Carex aquatilis, Betula glandulosa, Kobresia myosuroides, K. simpliciuscula* or *Scirpus pumilus*. Moss (*Sphagnum* spp.) is indicative of iron fens. The surrounding landscape may be ringed with other wetland systems, e.g., riparian shrublands, or a variety of upland systems from grasslands to forest. Within the upper Rio Grande Valley watershed, this system is limited to iron fens in Rio Grande and Conejos Counties in Colorado.

The montane fen ecological system is rare in the Southern Rocky Mountains ecoregion. Since this system is reliant on groundwater, any disturbances that impact water quality or quantity are a threat, including groundwater pumping, mining, and improper placement of septic systems.

- Indicator Species
  Unknown

- Primary Ecological Processes
  Hydrology (specifically groundwater flow)

- Indicators of High Quality Condition
  <u>A-rated condition:</u> The natural hydrologic regime is intact, with no or little evidence of wetland alteration due to increased or decreased drainage, clearing, livestock grazing, mining (especially peat mining), etc. Native species that increase with hydrologic and surface disturbance, e.g., *Deschampsia cespitosa* and *Carex aquatilis*, are present in typical proportions in diverse communities rather than in expansive, low-diversity stands. Non-native species are generally not a problem in fens of the Southern Rockies, and A-ranked occurrences should exemplify this pattern by having no or very few exotic species present. Roads or other antrhopogenically-induced fragmentation is limited to less than 1% of the occurrence.
  <u>Justification for A-rated criteria</u>: Montane fens in the Southern Rocky Mountains depend on a perennial water regime, seasonally-to-permanently saturated soils, and occasional flooding disturbance. A-ranked occurrences have these processes intact, with no history of alteration to the hydrology or surface structure.

- Stressors
  Agricultural withdrawals and diversions
  Urban and rural development around the wetlands
  Channelization and draining
  Invasive non-native species
  Inappropriate livestock grazing

- Restoration Goals
  Manage livestock grazing
  Reduce or eliminate water diversions and draining
  Mine cleanup if appropriate
  Eliminate or minimize threat from nonnative species

3. Freshwater Marsh—Small Patch

Freshwater marsh ecological system is a small patch system confined to specific environments defined primarily by hydrology. Marshes are frequently or continually inundated, with water depths up to 2 m.

Water levels may be stable, or may fluctuate 1 m or more over the course of the growing season. Natural marshes may occur in depressions in the landscape (ponds, kettle ponds); as fringes around lakes; or along slow-flowing streams and rivers. Such riparian marshes are also referred to as sloughs. Marshes have distinctive soils that are typically mineral, but can also accumulate organic material. The soils have characteristics that result from long periods of anaerobic conditions (e.g., gleyed soils, high organic content, and redoximorphic features). Marshes are characterized by herbaceous vegetation adapted to saturated soil conditions. Vegetation is typically emergent (rising out of the water), like *Typha* spp. and *Scirpus* spp., or submergent/floating, as in *Potamogeton* spp. and *Lemna* spp. Freshwater marshes are usually composed of mosaics of several plant associations, and may be dominated by *Eleocharis* spp., *Glyceria borealis, Myriophyllum sibiricum, Nuphar lutea, Polygonum amphibium, Potamogeton* spp., *Ranunculus aquatilis, Scirpus* spp., *Sparganium* spp. or *Typha*. Within the upper Rio Grande watershed, this system is mostly associated with oxbows of the Rio Grande.

Primary threats to this system include changes in water quality and quantity, diversions, mining, logging, and invasive species.

- Indicator Species
  - Marsh wren, if large
  - Common yellowthroat
  - Northern leopard frog

- Primary Ecological Processes
  - Hydrology (surface flow and groundwater)

- Indicators of High Quality Condition
  - <u>A-rated condition:</u> The natural hydrologic regime is intact, with no or little evidence of marsh or wetland complex alteration due to increased or decreased drainage, clearing, livestock grazing, anthropogenic nutrient input, mining, or other human impacts. No or very few exotic species are present, and there is no potential for their expansion. Native species that increase with disturbance to changes in hydrology or nutrients are absent or low in abundance.
  - <u>Justification for A-rated criteria</u>: Freshwater marshes in the Southern Rocky Mountain ecoregion depend on a perennial water regime, permanently saturated soils, and occasional flooding disturbance. A-ranked occurrences have these processes intact, with no history of alteration to the hydrology or surface structure.

- Stressors
  - Agricultural withdrawals and diversions
  - Urban and rural development around the wetlands
  - Lack of spring floods and regeneration
  - Channelization and draining
  - Invasive non-native species, including stocked nonnative fish and bullfrogs
  - Inappropriate livestock grazing

- Restoration Goals
  - Manage livestock grazing
  - Reduce or eliminate water diversions and draining
  - Mine cleanup if appropriate
  - Eliminate or minimize threat from nonnative species

MIDDLE BIOREGION - VELARDE TO CABALLO, NM
Wetland and Sandbar Habitats

Author: Ross Coleman

1. Wet Meadows

Wet meadows were likely the most extensive floodplain habitat in this reach of the Rio Grande prior to the installation of the agricultural drain system and have experienced the greatest decline in surface area of all floodplain habitat types. While a portion of these wetlands resulted from flood irrigation practices with subsequent water-logging of soils and locally elevated ground water levels from increased sedimentation (aggradation) of the river channel, wet meadows were clearly a major component of the historic floodplain community. Composed primarily of sedge, grass, and rush species, wet meadows often occurred where saturated soils were present near the soil surface, in areas of periodic or frequent inundation, along the riverbanks, and within the riparian area. While generally adapted to open areas with high solar exposure, wet meadows species can also be found growing under moderate to dense canopies of riparian vegetation. Most of the former wet meadows have been converted to agricultural fields. Common herbaceous species include: Yerba manza (*Anemopsis californicus*), Emory's sedge (*Carex emoryi*), clustered field sedge (*Carex praegracilis*), yellow nut-grass (*Cyperus esculentus*), inland saltgrass (*Disticlis spicata*), creeping spikerush (*Eleocharis palustris*), scouring rush (*Equisetum hyemale*), Baltic rush (*Juncus balticus*), Torrey's rush (*Juncus torreyi*), common threesquare rush (*Scirpus pungens*), and sprangletop and dropseed grasses (Sporobolus and Leptochloa species).

- Indicator species
  White-faced ibis
  Long-billed curlew
  Snowy egret
  Northern leopard frog
  Woodhouse toad
  Meadow jumping mouse

- Biotic/Abiotic Processes and Targets
  High groundwater and/or periodic-to-frequent inundation of the floodplain are the most common conditions that create and sustain wet meadows. Both conditions would have been common throughout much of this reach prior to the installation of the river levee and agricultural drain systems. A low gradient aggrading river system, avulsion events, sediment deposition, and a broad floodplain with extensive lateral channel meandering contribute to wet meadow formation. The establishment of new wet meadow vegetation on disturbed floodplain sites occurs via several pathways, including: extant seed banks (normally viable for many decades), seed dispersal from overbank flows, wind and the alimentary tracts of various bird and mammal species, and rhizomatous spreading from nearby wet meadow areas. These same means of vegetation establishment are also applicable to all wetland types listed below. Wet meadows are characterized by high primary productivity, and the filtration of fine sediments and organic debris during flow events. Like most riverine wetland habitats, wet meadows may experience both episodic inundation and desiccation.

- Stressors
  De-coupling of the floodplain from the river
  Lowered groundwater levels
  Reduced flows onto floodplain areas
  Reduced river channel meandering
  Conversion to agricultural fields
  Jetty jack system (which encourages bank stability and domination by woody species)
  Invasive exotic species such as saltcedar and Johnson grass

Continuous grazing by livestock
Urbanization

- Restoration Goals
  - Protect and enhance the remaining rare examples of wet meadow wetlands.
  - Create additional wet meadow habitat by restoring periodic seasonal overbank flows during the growing season; lowering banks to permit flooding; encouraging lateral river channel meandering where possible; removing jetty jacks where meander can be encouraged; re-wetting floodplain areas with agricultural supply, return waters or pumped groundwater; and reusing treated wastewater or stormwater run-off for wet meadow creation.
  - Reduce large-scale groundwater withdrawals, and encourage groundwater recharge.
  - Abandon and fill agricultural drains where they are not needed.
  - Provide incentives to return agricultural fields to wet meadow habitat.
  - Monitor all wetland restoration efforts for the successful establishment of appropriate hydrologic conditions, vegetation and use by target species. Long term management strategies should be employed to ensure longevity of the wetlands.

2. Palustrine Marshes

Palustrine marshes are frequently or permanently inundated wetlands that are dominated by emergent herbaceous species adapted to saturated soil substrates. They historically occurred throughout the active floodplain and often had several associated habitat types, including riparian, wet meadow and upland. Remnant examples are located on the west side of the Rio Grande, downstream of Isleta Pueblo, and at the Oxbow marsh north of Interstate 40 in Albuquerque. Vegetation often found in palustrine marshes in this reach includes cattails (*Typha latifolia* and *T. angustifolia*), hardstem and softstem bulrushes (*Scirpus acutus, S. validus*), threesquare bulrushes (*S. pungens, S.americanus*), saltmarsh bulrush (*S. maritimus*), creeping spikerush (*Eleocharis palustris*), sago pondweed (*Potomogeton pectinatus*), giant smartweed (*Polygonum pennsylvanicum*), Arrowhead (Sagittaria species), duckweed (*Lemna minor*), mosquito fern (*Azolla mexicana*), water milfoil (*Myriophyllum spicatum*), hornwort (*Ceratophylum demursum*) and a wide variety of algae species. Palustrine marshes are often bordered by riparian species such as coyote willow (*Salix exigua*,) Goodding's willow (*Salix gooddingii*), seepwillow (*Bacharis salicifolia*), and Rio Grande cottonwood (*Populus deltoids spp. wislizeni*).

- Indicator species
  - Waterfowl
  - Red-wing and yellow-headed blackbird
  - American bittern
  - Virginia and sora rail
  - Great blue heron
  - Belted kingfisher
  - Northern harrier
  - Bluegill
  - Fathead minnow
  - Western painted turtle
  - Northern leopard frog
  - Bullfrog
  - Tiger salamander
  - New Mexico garter snake
  - Muskrat
  - Dragonfly

- Biotic/Abiotic Processes and Targets
  - Palustrine marshes are most often created by lateral and downstream meandering of the river channel and subsequent meander cutoff, or by the scouring of deep channel sections where the river encounters channel obstructions such as bedrock outcrops or valley walls at the edge of the floodplain. Marshes historically occurred along relatively straight river reaches between old

riverbank swales, or within abandoned river channel segments, or along the convex side of meander bends where the scouring was usually deepest. The abandoned channel segments often fill with groundwater if the depth of the scoured zone is sufficient to intercept the groundwater, or with surface water from high flow events. Oxbow lakes or ponds may form, later becoming dominated by emergent vegetation as they fill with sediment from overbank flows and organic debris. These marshes often mature to become wet meadows as they continue to fill with sediment and organic deposits. They have one of the highest productivity rates of all habitat types and frequently exhibit high biodiversity and high species density. Palustrine marshes serve as refugia for many species during periods of drought or low river flow; spawning and rearing areas for fish, herpetofauna, and aquatic invertebrates; and they also perform water filtration and purification, flood flow attenuation, groundwater recharge, organic litter decomposition, and nutrient cycling functions.

- Stressors

  Low flows within the river system
  Reduction or absence of powerful scouring flows
  Reduction or absence of an active laterally migrating river channel
  Channel degradation and subsequent lowered groundwater levels
  Intentional drainage or fill

- Restoration Goals

  Protection and enhancement of remaining marshes should be a priority.
  Creation of new palustrine marshes using natural geomorphic processes may be possible where high flows can permit channel meandering within the existing floodplain (such as the reach below the San Acacia diversion). Marshes can also be created by cutting back channels or side channels that permit river water to enter a still water zone at moderate to high flows. Large scale marshes have been created using berm and water level control structures on historic floodplain areas, and supplying water from the irrigation and drain system, or pumped groundwater (Bernardo and La Joya State Wildlife Refuges, Bosque del Apache National Wildlife Refuge). This is still the most economical method for creating large new wetland areas. Excavation into areas with shallow groundwater is another viable method of marsh creation. Marshes can be created using treated wastewater (the only water supply that is increasing annually due to increased groundwater pumping) or stormwater runoff. Sand and gravel mining operations from floodplain sites can be restored to marsh habitat. Operation of the many miles of irrigation drains to protect and enhance both herbaceous and woody vegetation can create valuable marsh habitat. Use irrigation tail-water, drains, or low flow diversion flows to create or sustain marshes. Encourage marsh development at river-reservoir deltas by *not* cutting delivery channels that drain wetland areas. Observe long term sedimentation of reservoirs that will create substantial marsh areas.

3. Spring Seeps and Perched Wetlands

Spring seeps and perched wetlands, while uncommon within the Middle Rio Grande, provide unusually persistent and long-lived wetlands. They occur where groundwater flow is intercepted above the level of the floodplain by impermeable layers of bedrock or clay, usually near the intersection of the floodplain and valley slopes. There are existing examples in the Española Valley and at the base of the basaltic cliffs near San Marcial. Irrigation diversions and retention structures have created similar wetlands via seepage from ditches. While these wetlands are frequently wet meadows, they may also be palustrine, wooded, or saltmarsh habitat types.

- Indicator species

  See other wetland types (except sandbars)

- Biotic/Abiotic Processes and Targets

  Interception of groundwater by impermeable substrates
- Stressors

  Lowering of groundwater

Diversion of spring source
Continuous grazing by livestock

- Restoration Goals
  Protect groundwater and spring sources; fence wetlands from livestock

4. Wooded Wetlands

Wooded wetlands may include temporally flooded bosque or any of the other persistent or ephemeral wetland habitats that occur within the riparian zone. They may be found within the cottonwood and willow canopy, or among Russian olive or saltcedar stands.

- Indicator species
  Willow flycatcher
  Beaver
  Western chorus frog
  Woodhouse toad

- Biotic/Abiotic Processes and Targets
  The same processes that create other wetland habitat types are operational for wooded wetlands. Historically, the spring runoff and summer rains that brought overbank flooding to much of the valley floor sustained riparian trees and shrubs and a wide variety of herbaceous wetland species. Depending on the depth and duration of flooding, the wetlands can range from wet meadow and salt marshes to palustrine marshes and oxbow lakes.

- Stressors
  Low flow volume
  Reduced overbank flooding
  Lowered groundwater levels
  Interrupted fluvial processes that create topographic relief where surface water can pool

- Restoration Goals
  Encourage periodic overbank flows during the growing season, especially during the spring runoff period.
  Excavate side channels to connect riparian areas that contain low-lying zones with the river channel.
  Encourage the use of riparian areas that are dominated by exotic woody species, or have clearings within healthy stands of native cottonwood and willow, as borrow areas for levee repairs, road surfacing, etc. Borrow areas should have a hydrological connection to the river via shallow groundwater or side channels.

5. Salt Marshes

Salt marshes were evident in historical records at several locations in the Middle Rio Grande Valley including Bernardo, La Joya, and Bosque del Apache. A few of these salt marsh areas persist today, although their hydrologic conditions may be greatly modified. Salt tolerant vegetation such as saltmarsh bulrush, saltgrass, creeping spikerush and common threesquare rush dominate these wetlands.

- Indicator species
  Avocet
  Black-necked stilt
  Black-crowned night heron
  Spotted sandpiper

- Biotic/Abiotic Processes and Targets
  Salt marshes occur within the floodplain where evaporation of water at the soil surface due to high groundwater leaves salt deposits behind, or where frequent inundation of low-lying areas,

followed by subsequent evaporation of pooled water, gradually increases the local concentration of salts. Low vegetative species diversity is typical as only the most salt tolerant plants can utilize the saline sites. Cottonwood, willow and many other woody species are generally absent. Expanses of bare soil, or salt-encrusted soil along the littoral zone, are common.

- Stressors
  - Reduced overbank flows in areas with alkaline soils
  - Lowered groundwater levels
  - Intentional leaching of surface salts through flood irrigation and drainage practices

- Restoration Goals
  - Restore a hydrologic regime that periodically floods low-lying areas adjacent to the river channel where alkaline soils are present. Use agricultural return flows, diverted irrigation water, treated wastewater or stormwater flows in low-lying or bermed areas to create or enhance salt marshes. Create shallow excavations in areas with high groundwater to expose saturated soils and ponded areas to evaporation. Pump brackish or saline groundwater to shallow depressions.

6. Sandbars

Sandbars are currently abundant throughout the low gradient portion of the Middle Rio Grande between Bernalillo and Elephant Butte Reservoir. Historical evidence indicates this reach has exhibited dynamic formation and dissolution of sandbars from high flow events. Changes in the flow regime of the river and sediment deposition in reservoirs have altered the dynamic nature of sandbar formation. Currently, sandbars above the confluence of the Rio Puerco and Rio Salado tend to be heavily vegetated with herbaceous species, including many obligate and facultative wetland species such as cattail, bulrush, sedges, rushes, grasses, and annuals. Some sandbars have established stands of cottonwood, coyote willow, saltcedar, and Russian olive. While these vegetated islands provide excellent habitat for many species, others species require the open and dynamic nature of true sandbars. Sandbars are often bisected by shallow channels that provide lower velocity, lower sediment, and warmer aquatic habitats than the adjacent river channel. Algae formation is common on bottom substrates of these shallow backwaters. Sandbars below the confluence of the Rio Puerco are less vegetated due to periodic (although infrequent) flood events from the Rio Puerco and Rio Salado.

- Indicator species
  - Shorebirds
  - Common merganser
  - Canada goose
  - Mallard duck
  - Sandhill crane
  - Silvery minnow
  - Spiny soft-shell turtle

- Biotic/Abiotic Processes and Targets
  - Sandbars form with the deposition of sediments in low gradient, aggrading, and braided river channels. Substantive vegetation establishment is an indication that natural geomorphic processes have been interrupted.
- Stressors
  - Discharge of clear, sediment "hungry" water from reservoirs
  - Low river flows
  - Sediment loss (especially sandy sediments) to reservoirs and irrigation systems
  - Stabilization of existing sandbars and their subsequent transformation to permanent islands due to the establishment of vegetation

- Restoration Goals
  - Create a flow regime with sufficient flow that the processes required for the dynamic creation and dissolution of sandbars is restored; such a flow regime will reduce the armoring of sandbars through periodic scouring of vegetation.
  - Encourage lateral channel meandering and a broader river channel in selected locations.
  - Transport sandy sediments that are now sequestered in reservoirs (Jemez, Cochiti, Abiquii, and Gallisteo) to the river channel.
  - Deposit sediments from bank-lowering operations into the river channel, create bedload sediment skimmers at irrigation diversions, and return sandy irrigation ditch dredge materials to the river channel.

LOWER BIOREGION - CABALLO, NM TO CANDELARIA TX
Wetland and Sandbar Habitats

Author: Ross Coleman

Historically, the geomorphic, hydrologic and biotic processes that create and sustain wetland habitats would have been similar in the Velarde-to-Caballo and Caballo-to-Candelaria reaches. For this reason, I will emphasize the current differences in these reaches of the Rio Grande, and the unique challenges for wetland restoration in the Lower Reach. While the Middle Rio Grande has undergone dramatic change due to dams, irrigation diversions, drains, conversion of floodplain areas to agricultural fields, construction of river levees, introduction of exotic species, urbanization, and other human impacts, it still retains some measure of healthy riparian and wetland functions in the remnant bosque, and scattered palustrine marshes and wet meadows. The hydrologic status in the Lower Reach is so dramatically different today than in the period prior to irrigated agriculture, that few remnant wetland areas remain.

In addition to water diversions and control of flood flows, a tremendous quantity of water historically available to this reach of the river is lost to evaporation while being detained in Elephant Butte and Caballo Reservoirs. Sediment transport has been interrupted by the reservoirs upstream, and the paucity of flow in the river channel is insufficient in portions of the reach to move stormwater sediment downstream, creating aggrading conditions that ironically threaten some of the few remaining riparian areas with drowning and salination. Regular mowing of riverbanks and levee areas also reduces the wildlife value of wetland vegetation that might occur there.

Historical descriptions of this reach indicate the presence of oxbow lakes, palustrine marshes, salt marshes and wet meadows. The largest floodplain habitat type was wet meadow and floodplain grass communities, with a much smaller portion of the floodplain in marsh or oxbow lake habitat.

Substantive restoration of wetlands in the Lower Reach will require creative solutions from diverse groups of stakeholders who will need to reassess the allocation and delivery methods of water resources.

1. Wet Meadows

Wet meadows were evident in the historic records for the Lower Reach of the Rio Grande. The geomorphic and hydrologic processes responsible for wet meadow formation are essentially the same as in the Middle Reach: periodic overbank flooding, high sediment loads, and groundwater near the soil surface. The river channel exhibited high sinuosity in portions of the lower reach, such as in the Mesilla Valley, which would have contributed to wetland formation of all types via lateral migration and meander cut-offs. Vegetation communities and means of propagation are also similar in the two reaches, with the notable addition of the introduced cane (*arundo donax*), a greater presence of saltcedar, and diminished numbers of Russian olive.

- Indicator species
  - White-faced ibis
  - Killdeer
  - Snowy egret
  - Northern leopard frog
  - Gopher snake

- Biotic/Abiotic Processes and Targets

  High groundwater and/or periodic-to-frequent inundation of the floodplain are the most common conditions that create and sustain wet meadows. Both conditions would have been common throughout much of this reach prior to the installation of the river levee and agricultural drain systems. A low-gradient aggrading river system, avulsion events, sediment deposition, and a broad floodplain with extensive lateral channel meandering contribute to wet meadow formation. The establishment of new wet meadow vegetation on disturbed floodplain sites occurs via several pathways including: extant seed banks (normally viable for many decades), seed dispersal from overbank flows, wind and the alimentary tracts of various bird and mammal species, and rhizomatous spreading from nearby wet meadow areas. These same means of vegetation establishment are also applicable to all wetland types listed below. Wet meadows are characterized by high primary productivity, and the filtration of fine sediments and organic debris during flow events. Like most riverine wetland habitats, wet meadows may experience both episodic inundation and desiccation.

- Stressors
  - Severe de-watering of the river channel during the growing season by irrigation diversion
  - Canalization and sinuosity reduction
  - Near elimination of channel meandering through the Mesilla Valley
  - Aggradation and subsurface flow below Ft. Quitman
  - De-coupling of the floodplain from the river due to levees and diverted flow
  - Lowered groundwater levels
  - Conversion to agricultural fields
  - Invasive exotic species such as saltcedar and giant cane
  - Rapid urban and industrial growth

- Restoration Goals
  - Protect and enhance the few remaining wet meadow wetlands
  - Create additional wet meadow habitat by: restoring periodic seasonal overbank flows with a designed flood during the growing season; lowering banks to permit flooding and connection with the river flow via side channels; encouraging lateral river channel meandering where possible; re-wetting floodplain areas with agricultural supply, return flows, or pumped groundwater; reusing treated wastewater or stormwater runoff for wet meadow creation.
  - Reduce large-scale groundwater withdrawals and encourage groundwater recharge
  - Provide incentives to return agricultural fields to wet meadow habitat

2. Palustrine Marshes

Historic records give evidence of palustrine marshes in the Mesilla Valley and, sporadically, downstream of El Paso. A very few marshes remain on the former floodplain adjacent to the river. These are usually separated from the river by levees. Dominant vegetation is similar to Middle Reach marshes.

- Indicator species
  - Waterfowl
  - Red-wing and yellow-headed blackbird
  - Great blue heron
  - Belted kingfisher
  - Mosquito fish
  - Yellow mud turtle
  - Bullfrog
  - Muskrat
  - Dragonfly

- Biotic/Abiotic Processes and Targets
  - Palustrine marshes are most often created by lateral and downstream meandering of the river channel and subsequent meander cutoff, or by the scouring of deep channel sections where the river encounters channel obstructions such as bedrock outcrops or valley walls at the edge of the floodplain. Marshes historically occurred along relatively straight river reaches (between old river bank swales or within abandoned river channel segments) or along the convex side of meander bends where the scouring was usually deepest. The abandoned channel segments often fill with groundwater if the depth of the scoured zone is sufficient to intercept the groundwater, or with surface water from high flow events. Oxbow lakes or ponds may form and later become dominated by emergent vegetation as they fill with sediment from overbank flows and organic debris. These marshes often mature to become wet meadows. They have one

of the highest productivity rates of all habitat types and frequently exhibit high biodiversity and species density. Palustrine marshes serve as refugia for many species during periods of drought or low river flow, and as spawning and rearing areas for fish, herpetofauna, and aquatic invertebrates. They also provide water filtration and purification, flood flow attenuation, groundwater recharge, organic litter decomposition, and nutrient cycling.

- Stressors
  - Low flows within the river system
  - Reduction or absence of powerful scouring flows and an active laterally migrating river channel
  - Channel degradation in the Mesilla Valley
  - Dramatic channel aggradation below Ft. Quitman, with very little flow
  - Lowered groundwater levels
  - Intentional drainage or fill

- Restoration Goals
  - Protect and enhance remaining marshes.
  - Create new palustrine marshes using the methods described for the Middle Reach, although the potential for frequent overbank flows or scouring flows and channel meander are much less in the Lower Reach. Special attention should be paid to existing low-lying areas that can be re-wetted or re-connected to the river channel. The use of agricultural drains and tail waters may be one of best means for marsh (or wet meadow) creation. Concentration of salts in irrigation water due to alkaline soils will likely mean that salt marsh conditions will occur in many areas. Flow-through wetland hydrology will be important to reduce salt build-up and subsequent reduction in vegetation diversity. The reuse of treated wastewater or stormwater run-off can also provide adequate hydrology for wetland creation. Water quality improvement may be an added benefit from such wetland systems.

3. Spring Seeps and Perched Wetlands

Spring seeps and perched wetlands such as the remnant Keystone Marsh near Sunland Park, are exceedingly rare now in the Lower Reach. The Keystone Marsh was an extensive wetland area prior to fill and drain operations that have taken place in this century. The oldest known archeological evidence of a Native American community west of the Mississippi River is located at this site. Estimated to be over 5,000 years old, this wetland is spring-fed and saline.

- Indicator species
  - See other wetland types (except sandbars)

- Biotic/Abiotic Processes and Targets
  - Interception of groundwater by impermeable substrates

- Stressors
  - Lowering of groundwater
  - Diversion of spring sources
  - Drainage
  - Fill for development

- Restoration Goals
  - Protect groundwater and spring sources; fence livestock out of wetlands

4. Wooded Wetlands

Wooded wetlands will be limited throughout this reach due to diminished riparian areas. Some of the same methods used for restoring the native riparian forest, combined with wetland creation methods outlined for the Middle Reach, can eventually establish this type of habitat. Removal of monotypic stands of saltcedar should be undertaken anywhere wetland creation is proposed.

- Indicator species
  - Southwestern willow flycatcher
  - Muskrat
  - Texas toad

- Biotic/Abiotic Processes and Targets
  - The same processes that create other wetland habitat types are operational for wooded wetlands. Historically, the spring runoff and summer rains that brought overbank flooding to much of the valley floor sustained riparian trees and shrubs as well as a wide variety of herbaceous wetland species. Depending on the depth and duration of flooding, the wetlands can range from wet meadow and salt marshes, to palustrine marshes and oxbow lakes.

- Stressors
  - Lack of riparian forests or domination by saltcedar
  - Low flow volume
  - Reduced overbank flooding
  - Lowered groundwater
  - Interrupted fluvial processes that create topographic relief where surface water can pool

- Restoration Goals
  - Encourage periodic overbank flows during the growing season, especially during the spring runoff period.
  - Excavate side channels to connect riparian areas that contain low-lying zones with the river channel.
  - Encourage the use of riparian areas that are dominated by exotic woody species or have clearings within healthy stands of native cottonwood and willow as borrow areas for levee repairs, road surfacing, etc. Borrow areas should have a hydrological connection to the river via shallow groundwater or side channels.

5. Salt Marshes

Salt marshes occurred sporadically throughout this reach prior to irrigated agriculture. A few salt marsh habitats remain, such as the one near Sunland Park racetrack. While salt marshes can provide excellent habitat for some species, biodiversity is usually lower than in freshwater marshes. Salt tolerant vegetation such as saltmarsh bulrush, saltgrass, creeping spikerush and common threesquare rush dominate these wetlands.

- Indicator species
  - Avocet
  - Black-necked stilt
  - Spotted sandpiper
  - Waterfowl

- Biotic/Abiotic Processes and Targets
  - Salt marshes occur within the floodplain where evaporation of water at the soil surface due to high groundwater leaves salt deposits behind, or where frequent inundation of low-lying areas followed by subsequent evaporation of pooled water gradually increases the local concentration of salts. Only the most salt tolerant plants can utilize the saline sites. Cottonwood, willow and many other woody species are generally absent. Expanses of bare soil or salt encrusted soil along the littoral zone are common. Increased salt concentrations from flood irrigation practices make salt marshes a more likely result of wetland creation efforts; if a salt marsh is not the desired result, provide flow-through hydrology where possible to reduce salt

- Stressors
  - Reduced overbank flows in areas with alkaline soils

Lowered groundwater levels
Intentional leaching of surface salts through flood irrigation and drainage practices

- Restoration Goals
  - Restore a hydrologic regime that periodically floods low-lying areas adjacent to the river channel where alkaline soils are present.
  - Use agricultural return flows, diverted irrigation water, treated wastewater or stormwater flows in low-lying or bermed areas to create or enhance salt marshes.
  - Create shallow excavations in areas with high groundwater to expose saturated soils and ponded areas to evaporation. Pump brackish or saline groundwater to shallow depressions. Salt marshes will be more easily attained for this reach compared to the middle reach due to higher salt concentrations in the water supply.

6. Sandbars

Sandbars are largely absent from the river in the Mesilla Valley due to the disruption of sediment transport at Elephant Butte and Caballo Reservoirs. This low gradient reach would have exhibited sandbar formation historically when flows and sediment were unimpeded. Further downstream, below El Paso, sandbars begin to play a more important role in the river's ecology. Below Ft. Quitman, the reduced flows and channel aggradation have created a situation where there is too much sediment to be transported by the meager flows that move through this broad, saltcedar-choked floodplain.

- Indicator species
  - Shorebirds
  - Common merganser
  - Spiny soft-shell turtle

- Biotic/Abiotic Processes and Targets
  - Sandbars form with the deposition of sediments in low gradient, aggrading, and braided river channels. Substantive vegetation establishment is an indication that natural geomorphic processes have been interrupted.

- Stressors
  - Discharge of clear, sediment "hungry" water from reservoirs
  - Low river flows
  - Sediment loss (especially sandy sediments) to reservoirs and irrigation systems
  - Stabilization of existing sandbars with vegetation and subsequent transformation to permanent islands

- Restoration Goals
  - Create a regime with sufficient flow that the processes required for the dynamic creation and dissolution of sandbars is restored; such a flow regime will reduce the armoring of sandbars with permanent stands of vegetation by periodically scouring away the vegetation.
  - Encourage lateral channel meandering and a broader river channel in selected locations
  - Transport sandy sediments that are now sequestered in reservoirs (Jemez, Cochiti, Abiquii, and Gallisteo) to the river channel.
  - Deposit sediments from bank lowering operations into the river channel
  - Create bedload sediment skimmers at irrigation diversions, and return sandy irrigation ditch dredge materials to the river channel

UPPER BIOREGION
Aquatic Habitats

Author: Steven P. Platania

Coldwater Trout Stream

Coldwater trout streams are characterized by perennial flows with relatively cold temperatures and high oxygen levels. The channel is generally narrow, with a high gradient. Large particles, i.e., cobble and gravel, characterize the upper reach substrate. This community is largely dependent on the health of the surrounding riparian area.

- Indicator Species
  - Rio Grande cutthroat trout
  - Rio Grande chub
  - Rio Grande sucker
  - Longnose dace
  - American dipper
  - Mayfly (*Ephemeroptera*), stonefly (*Plecoptera*) and caddisfly (*Trihoptera*) nymphs

- Biotic/Abiotic Processes and Targets
  - Spring high flows
  - Provides habitat for trout and other aquatic organisms with appropriate substrate, shoreline irregularities, and cold water
  - Largely dependent on surrounding and upstream riparian areas for health of system

- Stressors
  - Agriculture
  - Urban development
  - Lack of spring floods
  - Non-native fish species
  - Grazing
  - Channelization
  - Pollution
  - Sedimentation

- Restoration Goals
  - Removal of non-native fish species
  - Reduce cattle grazing
  - Establish development buffers
  - Create runs and riffles
  - Create additional in-stream cover with boulders, etc.
  - Institute special fishing regulations and additional stocking
  - Prevent erosion through bank stabilization, etc.
  - Pole plant willows in disturbed areas
  - Increase water flows
  - Reverse channelization and aggradation
  - Place instream barriers to prevent re-invasion by non-native species

MIDDLE BIOREGION
Aquatic Habitats

Author: Steven P. Platania

Plains aquatic ecosystem
Characteristics of plains aquatic ecosystems include a wide, meandering river channel or braided channel, moderate gradient, a shifting sand substrate, and aquatic habitat heterogeneity (primary and secondary runs, riffles, pools, low-velocity habitats). It is a markedly dynamic system.

- Indicator Species:
  - Rio Grande silvery minnow
  - Red shiner
  - River carpsucker
  - Extirpated Cyprinids
  - Rio Grande bluntnose shiner
  - Rio Grande shiner
  - Speckled chub
  - Phantom shiner

- Biotic/Abiotic Processes and Targets
  - Low velocity
  - Deep, protected pools
  - Diversity of channel structure (e.g., wide, pools, backwater, access to side channels)
  - Spring (generally May) flows for spawning of remaining endemic species (silvery minnow), and summer flows for extirpated fish taxa
  - Eggs and larvae drift for several hundred km
  - Sandy substrate and sediment transport
  - Shallow waters (<40cm, perhaps, though there is nothing sacred about being this shallow. Currently in the Rio Grande, there is a strong autocorrelation between velocity and depth, with faster water being deeper.)

- Stressors
  - Channelization (narrow width with no backwater, pools, or side channels)
  - Dewatering and desiccation of stream channel, or extreme low flows (<30cfs)
  - High flows in confined channels
  - Sediment depletion
  - Sediment aggradations
  - Agriculture
  - Entrainment
  - Habitat range fragmentation due to instream diversion structures
  - Ammoleriation of spring peak flows

- Restoration Goals
  - Encourage dynamic fluvial processes through changes in dam operations (e.g., releases to provide flow regimes more like those found in natural conditions)
  - Create and enhance low-velocity habitats
  - Control invasive non-native phreatophytes (e.g., salt cedar)
  - Re-connect channel to floodplain
  - River connectivity
  - Stabilize and enhance streamflow through conjunctive use, and changes in diversion and dam operations

Manage/acquire water to maintain continuous flows throughout the Middle Rio Grande (e.g., 200 cfs between San Acacia and San Marcial)

Increase sediment loading in sediment-deficient reaches (e.g., Cochiti to Angostura) to enhance or create sandy substrate

LOWER BIOREGION
Aquatic Habitats

Author: Steven P. Platania

Oxbow lakes

- Indicator Species
  Diamondback water snake
  Former indicator species included river carpsucker, blue sucker, and other extirpated cyprinids

- Biotic/Abiotic Processes and Targets
  Low velocity
  Source of freshwater outside river channel
  Wetland, riparian, and aquatic habitat for fish, amphibians and reptiles, birds, and invertebrates

- Stressors
  Non-point source pollution
  Hydrology disconnected from river
  Urbanization
  Agriculture
  Low (and non-existent) river flows
  Lack of spring floods
  Non-native fish species
  Channelization
  Pollution

- Restoration Goals
  Restore river flow (This is the number one goal; the rest are unnecessary if this can not be achieved.)
  Removal of salt cedar
  Prevent pollution
  Restore connectivity to river

APPENDIX D

Current and Planned Restoration Projects
Rio Grande Headwaters to Candelaria, TX

Table D-1 Listing of Rio Grande Restoration Projects - Headwaters to Candaleria, Texas

Reach & Number	Status	Name	Sponsors	Location	Cost (k)	Extent	Purpose	Physical Features	Source
U-1	Report finished Oct 2001	Rio Grande Headwaters Restoration Project	San Luis Valley Water Conservancy District	South Fork, Colorado to the Alamosa-Conejos County line.	20000	91 miles	Analyze and develop a restoration master plan for the Rio Grande. Maintenance of channel capacity and overbank capacity. Protection of channel and floodplain from damage by flooding. Maintenance of riparian habitat. Delivery of Rio Grande Compact commitments. Access to river for water diversion.	Grade control/ sediment capture structures, reconnect meanders using spill structures, eliminate, consolidate, and relocate diversions. Reconnect channel and floodplain using rock spill structures, construct setback levees.	Momtgomery Watson Harza
U-2	Ongoing	Restoration Projects in Rio Grande County, CO.	The Natural Resources Conservation Service (NRCS)	Rio Grande County, CO.	NA	NA	General river restoration.	The projects typically consist of barbs (bendway weirs),bioengineered structures, water return flow structures and grazing management changes designed to control erosion of channel banks and improve riparian areas.	http://www.co.nrcs.usda .gov/
U-3	Funding June 2001	Rio Grande Restoration Near Monte Vista	Rio Grande Soil Conservation District(s) /State of Colorado(f)	Monte Vista, CO	125	NA	The goals of the projects are to improve natural streambank stability, increase river capacity, improve riparian habitat and improve the function of the floodplain.	Benefits will include reduced sediment loadings, improved fish habitat, reduced flood damage andpublic education of existing best management practices (NRCS, 1999).	Contact Steve Russell, district conservationist, (719) 852-5114
U-4	Planning complete	Alamosa River Restoration Project[1]	Obtained funding from CWCB and the Section 319 Grant program	Approx. 10 miles upstream from Rio Grande confluence	300	5 miles of river in 18 mile reach	Restore channel characteristics to straightened channel.	Reconnect floodplain and channel, create meanders.	Jeff SternConejos County Soil Conservation District 719-274-5868
U-5	Planning stage	Rio Grande Wetland and River Restoration - Alamosa	Corps, City of Alamosa (s)	Alamosa, CO	5,000 cap	0.5 miles river, 25 acres wetland	To restore ecosystem function to degraded habitat.	Plantings, lowering wetlands beds, flow control structures, recreational facilities, shape and vegetate bars.	Mark Harberg - USACE
U-6	Ongoing / planning	Alamosa Wildlife Refuge - Habitat Restoration	NA	Alamosa wildlife refuge	NA	NA	Habitat restoration.	NA	Scott Miller AWR (719) 852 0128
M-1	Ongoing / planning	BOR River Restoration / River Maintenance Program, Velarde Reach[2]	BOR	Velarde, NM to Rio Chama Confluence	NA	NA	Preserving and creating native riparian habitat, expanding the active floodplain, and creating wetlands.	Rock weirs, deformable bankline, rock vanes, toe revetment planting, vegetation planting and natural re-generation, non-native vegetation clearing and floodplain expansion, terrace lowering, river bar / island enhancement, oxbow re-establishment, jetty / snag removal, woody debris snags and boulder placement, native material bank stabilization, freeboard dikes, revetments and windrows, curve shaping, arroyo plug grading and removal, and transect brushing.	Programmatic Biological Assessment, June 2001
M-2	Future	Biological Opinion, Velarde Reach[3]	FWS	Velarde, NM to Rio Chama Confluence	NA	Approx. 60 acres	Habitat / ecosystem restoration for silvery minnow and willow flycatcher recovery.	Increase backwaters and oxbows, widen the river channel, lower riverbanks to increase overbank flooding and regenerate stands of willows and cottonwoods.	Programmatic Biological Opinion, June 2001
M-3	Begun 1997	Archuleta Ranch Project[4]	Rio Grande Restoration	Rio Chama	NA	160 acre river terrace	Vegetation planting.	Seedlings and pole plantings of native vegetation.	Rio Grande Restoration

Reach & Number	Status	Name	Sponsors	Location	Cost (k)	Extent	Purpose	Physical Features	Source
M-4	Ongoing / planning	BOR River Restoration / River Maintenance Program, Espanola Reach[2]	BOR	Rio Chama Confluence to Otowi	NA	NA	Removing exotic vegetation and encouraging native revegetation, enhancing aquatic habitat in reaches impacted by gravel mining, restoring oxbows, and creating wetlands.	Rock weirs, deformable bankline, vegetation planting and natural re-generation, non-native vegetation clearing and floodplain expansion, channel realignment / pilot channel, terrace lowering, river bar / island enhancement, oxbow re-establishment, jetty / snag removal, channel widening / bank destabilization, channel avulsions, woody debris snags and boulder placement, rock vanes, toe revetment planting, native material bank stabilization, freeboard dikes, revetments and windrows, curve shaping, arroyo plug grading and removal, and transect brushing.	Programmatic Biological Assessment, June 2001
M-5	Future	Biological Opinion, Espanola Reach[3]	FWS	Rio Chama Confluence to Otowi	NA	Approx 60 acres	Habitat / ecosystem restoration for silvery minnow and willow flycatcher recovery.	Increase backwaters and oxbows, widen the river channel, lower riverbanks to increase overbank flooding and regenerate stands of willows and cottonwoods.	Programmatic Biological Opinion, June 2001
M-6	Ongoing	Riparian and Wetland Restoration at San Juan Pueblo	San Juan Pueblo and EPA	San Juan Pueblo	150	3 areas, 75 acres total	Habitat restoration.	Vegetation removal, wetland excavation, planting of cottonwoods, native shrubs and grasses.	David Morgan Eco Solutions (505) 920 4706
M-7	Completed	Riparian and Wetland Restoration at San Juan Pueblo	San Juan Pueblo and NM highway Dept.	San Juan Pueblo	NA	25 acres	Habitat restoration.	During construction of a new bridge a wetlands area was restored. Vegetation removal, wetland excavation, plantings.	Charles Lujan - San Juan Pueblo Environmental Director
M-8	Ongoing / planning	BOR River Restoration / River Maintenance Program, Cochiti Reach[2]	BOR	Cochiti Dam to Hwy 44 Bridge Bernalillo	NA	NA	Raising the river bed and lowering terraces to reconnect it with the abandoned floodplain, removing exotic vegetation and encouraging native revegetation, encouraging localized sedimentation, and creating side channels, oxbows, and wetlands.	Deformable bankline, vegetation planting and natural re-generation, non-native vegetation clearing and floodplain expansion, channel realignment / pilot channel, terrace lowering, river bar / island enhancement, oxbow re-establishment, jetty / snag removal, channel widening / bank destabilization, channel avulsions, woody debris snags and boulder placement, rock vanes, toe revetment planting, native material bank stabilization, revetments and windrows, curve shaping, arroyo plug grading and removal, transect brushing, high flow side channels, increase sand load to reach, floodplain hydrologic connectivity, grade restoration facilities, rock weirs, levee maintenance, clearing of understory vegetation, removal of lateral confinements, and restoration of native riparian mosaic.	Programmatic Biological Assessment, June 2001
M-9	Future	Biological Opinion, Cochiti Reach[3]	FWS	Cochiti Dam to Hwy 44 Bridge Bernalillo	NA	Approx. 60 acres	Habitat / ecosystem restoration for silvery minnow and willow flycatcher recovery.	Increase backwaters and oxbows, widen the river channel, lower riverbanks to increase overbank flooding and regenerate stands of willows and cottonwoods.	Programmatic Biological Opinion, June 2001
M-10	Jan-02	Cochiti Pueblo Bosque Restoration	Cochiti Pueblo	Cochiti Pueblo	NA	10 river miles	Bosque habitat restoration.	Exotic vegetation removal, native seeding and pole planting.	Jacob Pecos Cochiti Pueblo Environmental Department (505)465-0617
M-11	1995-96	Cochiti Wetfields Project	Corps	Cochiti Pueblo	NA	NA	Habitat restoration.	Underground drains below dam, vegetation plantings.	Mark Harberg - USACE
M-12	Feasibility study	Abiquiu and Jemez Reservoirs Supplemental Water Storage and Release	Corps	Jemez Reservoir	NA	NA	Sediment passage through dam.	Modify operation of dam to pass increased sediment load.	Mark Harberg - USACE
M-13	Ongoing	Santa Ana Pueblo	Santa Ana Pueblo, BOR, Corps, FWS, BIA/ section 1135	Santa Ana Pueblo	NA	6 river miles, 200 acres of Bosque	River channel modification, eradication of non-native vegetation.	Mechanical removal of Salt Cedar and Russian Olive, native vegetation plantings, bioengineered banks, installation of GRF, relocate river channel, lower floodplain.	Todd Caplan Santa Ana Environmental Dept. (505) 867 1623

Reach & Number	Status	Name	Sponsors	Location	Cost (k)	Extent	Purpose	Physical Features	Source
M-14	Ongoing / planning	BOR River Restoration / River Maintenance Program, Middle Reach[2]	BOR	Hwy 44 Bridge Bernalillo to Isleta Diversion Dam	NA	NA	Restoring areas disturbed by fire, enhancing aquatic habitat and riparian vegetation potential on alternate river bars, destabilizing river banks to encourage channel widening, removing of exotic vegetation and encouraging native revegetation, and creating low terraces and wetlands.	Same as M-8 and include mowing and/or rootplowing, groins/bendways, and training dikes	Programmatic Biological Assessment, June 2001
M-15	Future	Biological Opinion, Middle Reach[3]	FWS	Hwy 44 Bridge Bernalillo to Isleta Diversion Dam	NA	Approx. 60 acres	Habitat / ecosystem restoration for silvery minnow and willow flycatcher recovery.	Increase backwaters and oxbows, widen the river channel, lower riverbanks to increase overbank flooding and regenerate stands of willows and cottonwoods.	Programmatic Biological Opinion, June 2001
M-16	Ongoing	Sandia Pueblo	Sandia Pueblo, BOR, FWS, NRCS	Sandia Pueblo	NA	NA	Bosque restoration.	Water quality studies, removal of jetty jacks, non-native veg removal, native plantings.	Beth Janello Sandia Pueblo Environmental Department (505) 867 4533
M-17	Ongoing	McCauley family wetland restoration	FWS	Corrales	NA	NA	Wetland restoration.	NA	NA
M-18	Ongoing	Corrales Levee Project	Corps	Corrales	NA	NA	Bosque restoration.	Vegetation plantings.	Mark Harberg - USACE
M-19	Ongoing	Minimax, Inc.	NA	Corrales	NA	NA	Cottonwood regeneration.	Micro-flooding pump system to enable natural cottonwood regeneration, remove excess fuel and exotic species.	Minimax, Inc.
M-20	Completed 1999	Alameda/Rio Grande wetland	Alb OS,FWS, BOR, Intel, Phillips	Albuquerque	150	34 acres	Recreate wetland habitat.	Excavation, lining installed, native plantings	Alb. Open Sapce
M-21	Ongoing	Montano wetland	Alb. OS	Albuquerque		0.25 acres	Recreate wetland habitat.	Excavation, lining installed, native plantings	Alb. Open Sapce
M-22	Ongoing	San Antonio Oxbow	Alb. OS, Ducks Unlimited	Albuquerque	200	54 acres	Recreate wetland habitat.	Maintain flows to marsh by silt plug, beaver dam, and vegetation removal. Non-native plant removal and native plantings.	Alb. Open Sapce
M-23	Completed 2001	Candelaria Farm	BOR, FWS, Friends of Rio Grannde Nature Center, GE	Albuquerque	130	5 acres	Recreate wetland habitat.	Excavation, lining installed, native plantings.	Travis Bauer BOR
M-24	Ongoing	Albuquerque Biopark	Rio Grande Restoration, Corps / section 1135	AlbuquerqueTingley Beach	NA	5 acres	Bosque restoration, wetlands recreation, and fuel reduction.	Non-native vegetation removal, native seed and pole planting.	Mark Harberg - USACE
M-25	Completed 1998	Albuquerque Overbank Project	Alb. OS, BOR, UNM, MRGCD, NM natural Heritage Program, Corps, FWS	Albuquerque	NA	8 acres	Bosque restoration.	Bank lowering, vegetation removal, native plantings.	Travis Bauer BOR
M-26	Proposed	Lewis Family Wetland Restoration in South Valley	FWS, Fish and Wildlife Partners	Albuquerque	NA	NA	Wetland restoration.	NA	NA
M-27	Ongoing / planning	BOR River Restoration / River Maintenance Program, Belen Reach[2]	BOR	Isleta Diversion Dam to Rio Puerco Confluence	NA	NA	Same as M-14.	Same as M-14.	Programmatic Biological Assessment, June 2001
M-28	Start Dec 2001	Los Lunas Habitat Restoration Project, Biological Opinion, Belen Reach[3]	BOR, Corps	Los Lunas	NA	6000' river bank, 40 acres floodplain	Habitat / ecosystem restoration for silvery minnow and willow flycatcher recovery	Jetty Jack removal, non-native vegetation removal, bank lowering.	Travis Bauer BOR
M-29	Future	Los Lunas River Park Project	NA	Los Lunas	NA	NA	Habitat restoration.	NA	Sue Probert FWS
M-30	Future	Fire Rehabilitation/ Habitat Enhancement	MRGCD, ISC, Corps	Los Lunas	NA	NA	Habitat restoration.	NA	Mark Harberg - USACE

Reach & Number	Status	Name	Sponsors	Location	Cost (k)	Extent	Purpose	Physical Features	Source
M-31	Proposed	Los Chavez Ditch, Native Revegetation Project	FWS, FWP	Los Lunas	NA	NA	Habitat restoration.	NA	NA
M-32	Ongoing / planning	BOR River Restoration / River Maintenance Program, Rio Puerco Reach[2]	BOR	Rio Puerco Confluence to San Acacia Diversion Dam	NA	NA	Restoring areas disturbed by fire, enhancing aquatic habitat and riparian vegetation potential on alternate river bars, destabilizing river banks to encourage channel widening, removing of exotic vegetation and encouraging native revegetation, random woody debris pile placement to promote bar formation and micro aquatic habitats, and creating low terraces, high flow side channels, and wetlands.	Same as M-14.	Programmatic Biological Assessment, June 2001
M-33	Future	Biological Opinion, Rio Puerco Reach[3]	FWS	Rio Puerco Confluence to San Acacia Diversion Dam	NA	Approx. 60 acres	Habitat / ecosystem restoration for silvery minnow and willow flycatcher recovery.	Increase backwaters and oxbows, widen the river channel, lower riverbanks to increase overbank flooding and regenerate stands of willows and cottonwoods.	Programmatic Biological Opinion, June 2001
M-34	Planning stage	La Joya River Enhancement Projects #1 and #2	BOR	La Joya Wildlife Refuge	NA	NA	Floodplain and channel habitat restoration.	Vegetation removal and bank lowering.	Travis Bauer BOR
M-35	Future	Tinnin Family Salt Cedar Removal	FWS, FWP	Bernardo	NA	100 acres	Habitat restoration.	NA	NA
M-36	Future	Habitat Restoration	NA	Polvadera	NA	1 acre	Create wetland and upland riparian habitat in former Rio Grande floodplain.	NA	NA
M-37	Feasibility study	San Acacia Fish Passage Study	BOR	San Acacia Dam	NA	NA	Silvery minnow passage.	NA	Travis Bauer BOR
M-38	Ongoing / planning	BOR River Restoration / River Maintenance Program, Socorro Reach[2]	BOR	San Acacia Diversion Dam to River Mile 78 (middle of BDANWR)	NA	NA	Same as M-32.	Same as M-14.	Programmatic Biological Assessment, June 2001
M-39	Future	Biological Opinion, Socorro Reach[3]	FWS	San Acacia Diversion Dam to River Mile 78 (middle of BDANWR)	NA	Approx. 60 acres	Habitat / ecosystem restoration for silvery minnow and willow flycatcher recovery.	Increase backwaters and oxbows, widen the river channel, lower riverbanks to increase overbank flooding and regenerate stands of willows and cottonwoods.	Programmatic Biological Opinion, June 2001
M-40	ongoing	Bosque del Apache NWR South End Habitat Restoration (Present & Future)	FWS (s) / NAWCA & non-federal partners (f)	Bosque del Apache NWR	750	800 Acres of refuge lands outside the levee system	This project will convert 800 acres dominated by monotypic stands of saltcedar 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. The increase in plant diversity for nesting and feeding requirements will help to lessen the negative impacts on wildlife because of degraded habitats along the Rio Grande.	Use of an established water right of the refuge makes it possible to mimic natural conditions to the extent possible in the historic floodplain of the Rio Grande. A water delivery system, including a concrete lined main ditch and several small ditches and drains will be constructed to supply water when needed to assure quality habitat conditions. Grasslands will be established in areas where water delivery is difficult or site conditions favor this habitat. Wetlands will be created at lower elevations in areas of denser soils, and riparian areas will be created in areas where periodic flooding and soil conditions are favorable to these plants.	John P. Taylor BDANWR 505-835-1828
M-41	Planning stage only	Restoration Plan for the Active Floodplain on Bosque del Apache NWR	FWS (s) / Bosque Initiative, Bosque del Apache NWR (f)	Bosque del Apache NWR	8	10 river miles; approx. 4,000 acres	The refuge will be pursuing funding and opportunities for habitat enhancement, river function improvement on the active floodplain portion of its lands. The first step in the refuge's efforts to improve conditions on the active floodplain of the Rio Grande is this planning effort.	Undetermined	Gina Dello Russo BDANWR 505-835-1828 & Paul Tashjian FWS 505-248-7958

Reach & Number	Status	Name	Sponsors	Location	Cost (k)	Extent	Purpose	Physical Features	Source
M-42	constructed over the last 20 years	Bosque del Apache NWR Habitat Restoration (Past)	FWS (s) / FWS and non-federal grantmaking organizations (f)	Bosque del Apache NWR	NA	Approx. 2200 acres of wetland, grassland and forest lands restored and maintained	The purpose of the refuge is to improve and maintain quality habitat requirements for wildlife species, especially wintering waterfowl. To accomplish this, the refuge has developed extensive wetland management and riparian restoration programs. To date, the refuge manages approximately 1,200 acres of seasonal or semi-permanent wetlands and has restored native plant species to approximately 1,000 acres of floodplain forest areas. This increase in habitat diversity has been shown in an ongoing biomonitoring program be used more extensively by resident and migratory wildlife species.	Water management is key to the success of this program on the portion of the refuge that is no longer connected to river processes. The water delivery infrastructure and active management of these areas has been and will be of utmost importance to the continued health and productivity of these areas. Water is applied via irrigation ditches to these areas at the most beneficial times in the season to promote grass, forb and woody vegetation establishment and growth. Wetlands are managed to provide a variety of habitat requirements.	John P. Taylor BDANWR 505-835-1828
M-43	planning stage only	Floodplain Management Program	Floodplain Management Group, Save Our Bosque Task Force (s)	Location San Acacia to San Marcial, NM on the Rio Grande	NA	Approx. 20,000 Acres of flood prone including private and public lands	This program offers private landowners the option of selling or donating permanent conservation easements on flood prone portions of their lands and working in a partnership with restoration groups to convert non-native habitat areas to native dominated habitat areas. This program is voluntary and designed to address flooding and fire hazards to private lands.	The opportunity to restore river function and dynamics exists in the area covered by this program. Planning for prioritizing projects, looking for opportunities to partner with landowners will be evaluated in the Conceptual Restoration Plan for this reach that will be developed in 2002. The ability to pass higher flows safely through this reach is of utmost importance to local and regional water and land management entities. Limiting development in the flood prone areas helps to accomplish this without jeopardizing private landowner rights or land values.	Gina Dello Russo BDANWR505-835-1828 & Dick Kreiner USACE 505-342-3383
M-44	partially funded, to be Contracted in 2002; completed early in 2003	San Acacia to San Marcial Reach of the Rio Grande - Conceptual Restoration Plan	Save Our Bosque Task Force (s) / different non-federal and federal funding sources (f)	Rio Grande, Socorro County	220	Approx. 45 river miles	To supply water and resource management agencies and the general public with a conceptual tool to discuss, prioritize, and seek funding for long term on-the-ground river restoration. The plan will address specific issues pertinent to this reach of river, incorporate citizen and private landowner concerns, and designate opportunities to efficiently manage the riparian habitats in the area.	A contract will be awarded to develop this plan over a 12 month period. A distinguishing feature of the plan is the involvement by stakeholders in the process. An oversight committee will meet regularly to review and comment on sections of the plan to assure that the end product is one that will be useful to all concerned.	Gina Dello Russo BDANWR 505-835-1828
M-45	Ongoing / planning	BOR River Restoration / River Maintenance Program, San Marcial Reach[2]	BOR	River Mile 78 (middle of BDANWR) to Headwaters of Elephant Butte Reservoir	NA	NA	Removing of exotic vegetation and encouraging native revegetation, increasing the main channel width, creating channel avulsions, and high flow channels for overbank flows to inundate cleared areas, creating side channel and back water refugia areas, and creating wetlands.	Same as M-14 and include culvert and low water crossing, random / bank boulder and snag placements, permeable jetties, and dredging / sediment settling basins.	Programmatic Biological Assessment, June 2001
M-46	Future	Biological Opinion, San Marcial Reach[3]	FWS	River Mile 78 (middle of BDANWR) to Headwaters of Elephant Butte Reservoir	NA	Approx. 60 acres	Habitat / ecosystem restoration for silvery minnow and willow flycatcher recovery.	Increase backwaters and oxbows, widen the river channel, lower riverbanks to increase overbank flooding and regenerate stands of willows and cottonwoods.	Programmatic Biological Opinion, June 2001
M-47	Future	San Marcial RR Bridge Relocation	Corps	San Marcial RR Bridge	NA	NA	Increase capacity of the Rio Grande.	Relocation of railroad Bridge	Mark Harberg - USACE
M-48	Completed 1996	Habitat enhancement from Tiffany Junction to Elephant Butte Reservoir	BOR	Rio Grande,Tiffany Junction to Elephant Butte	NA	NA	Wetlands habitat restoration.	Texas (Dip) and culvert crossing, groundwater ponds, and salt cedar clearing / native species regeneration.	Travis Bauer BOR

Reach & Number	Status	Name	Sponsors	Location	Cost (k)	Extent	Purpose	Physical Features	Source
M-49	Ongoing / planning	BOR River Restoration / River Maintenance Program, Hot Springs Reach[2]	BOR	Elephant Butte Dam to Headwaters of Caballo Reservoir	NA	NA	Removing of exotic vegetation and encouraging native revegetation, increasing the main channel width, creating channel avulsions, and high flow channels for overbank flows to inundate cleared areas, creating side channel and back water refugia areas, and creating wetlands.	vegetation planting and natural re-generation, non-native vegetation clearing and floodplain expansion, jetty / snag removal, woody debris snags and boulder placement, rock vanes, toe revetment planting, revetments, curve shaping, transect brushing, rock weirs, groins / bendways, training dikes, GRF, low flow stage control dikes, arroyo plug grading and removal, and dredging / sediment settling basins.	Programmatic Biological Assessment, June 2001
M-50	Ongoing	Brush removal and Fire Break Project	Sevilleta NWR	Sevilleta NWR	NA	NA	Reduce Fire Risk.	Brush and undesrtory removal	MRGBI
M-51	Ongoing	Pilot Restoration Project - Conklin: on the Rio Grande	Socorro Save Our Bosque Task Force	Conklin Land - private; east of Escondida drain	NA	NA	Habitat restoration.	NA	MRGBI
M-52	Ongoing	Pilot Restoration Project - Mitchell: on the Rio Grande	Socorro Save Our Bosque Task Force	Mitchell Land - private; near Bosquecito, NM	NA	NA	Habitat restoration.	NA	MRGBI
M-53	Ongoing	Fire Breaks on Floodplain of Rio Grande, Socorro County	Socorro Soil and Water Conservation District	East side of Rio Grande between Escondido and US HWY 380 Bridge; river miles 93, 95-97, 99, 101, 105	NA	NA	Reduce Fire Risk.	Cleared fire breaks	MRGBI
M-54	Ongoing	Protect Native Forests from Wildfire	Bosque del Apache NMR	Bosque del Apache NWR; 4 zones	NA	NA	Reduce Fire Risk.	Brush and understory removal	MRGBI
L-1	Future	Las Crucas overbank project	Corps	Las Crusas	NA	NA	Habitat restoration.	Undetermined	Mark Harberg - USACE
L-2	Future	IBWC - Percha Dam to American Dam	IBWC	Percha Dam to American Dam (Caballo End to El Paso)	NA	NA	Channel and floodplain habitat restoration.	Undetermined	Kevin Bixby Southwest Environmental Center (505)522 5552
L-3	Initial recon. level planning	Forgotten River Reach	None	Fort Quitman to Candelaria	NA	75 river miles	General restoration to address issues of channel formation, non native vegetation, flushing of tributary deposits.	Undetermined	Rio Grande Restoration

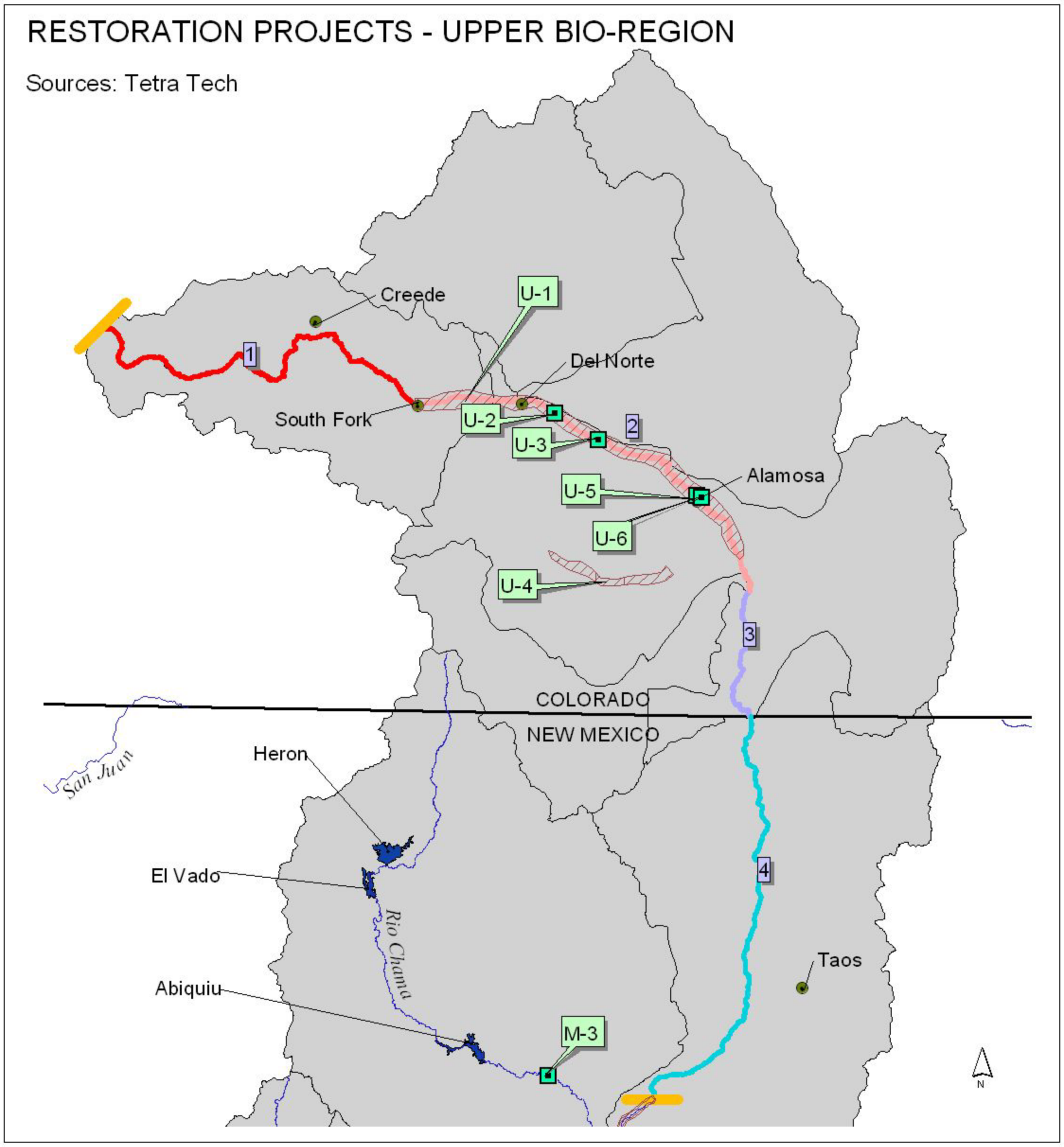

Figure D-1 Map of Existing and Planned Restoration Projects – Upper Bioregion

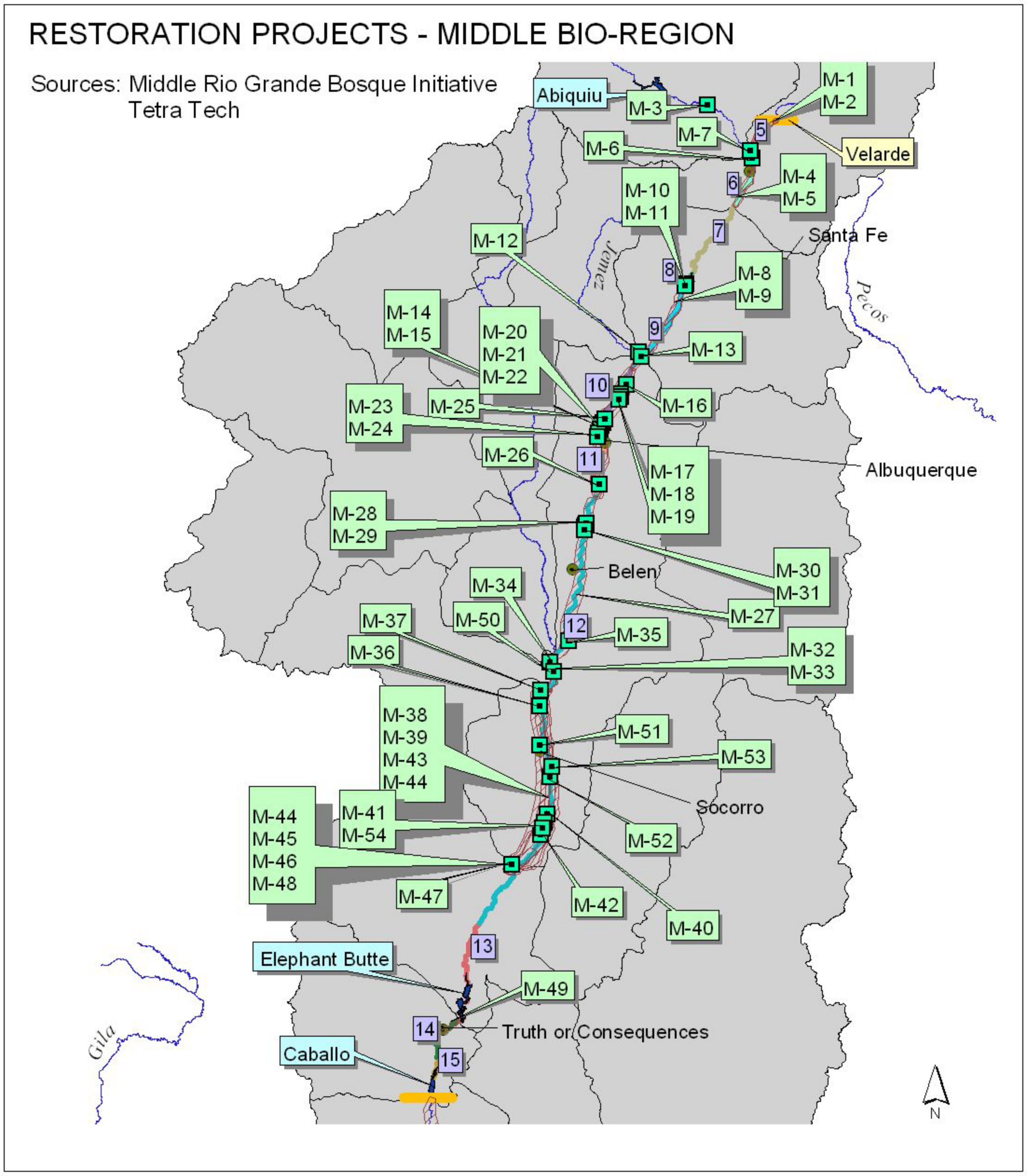

Figure D-2 Map of Existing and Planned Restoration Projects – Middle Bioregion

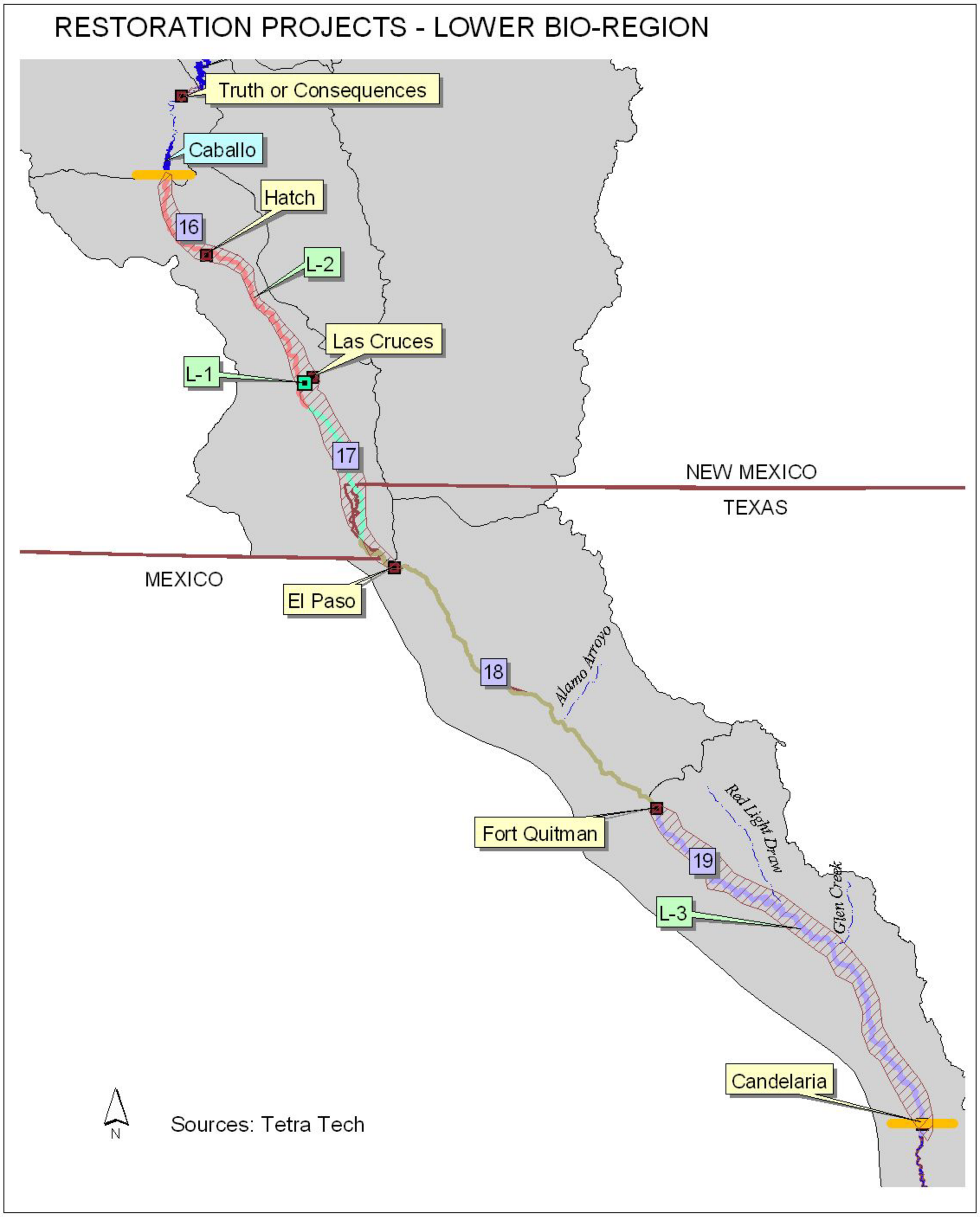

Figure D-3 Map of Existing and Planned Restoration Projects – Lower Bioregion

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APPENDIX F
Rio Grande Restoration Vision Workshop Participants
Albuquerque, New Mexico
March 6-8, 2002

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