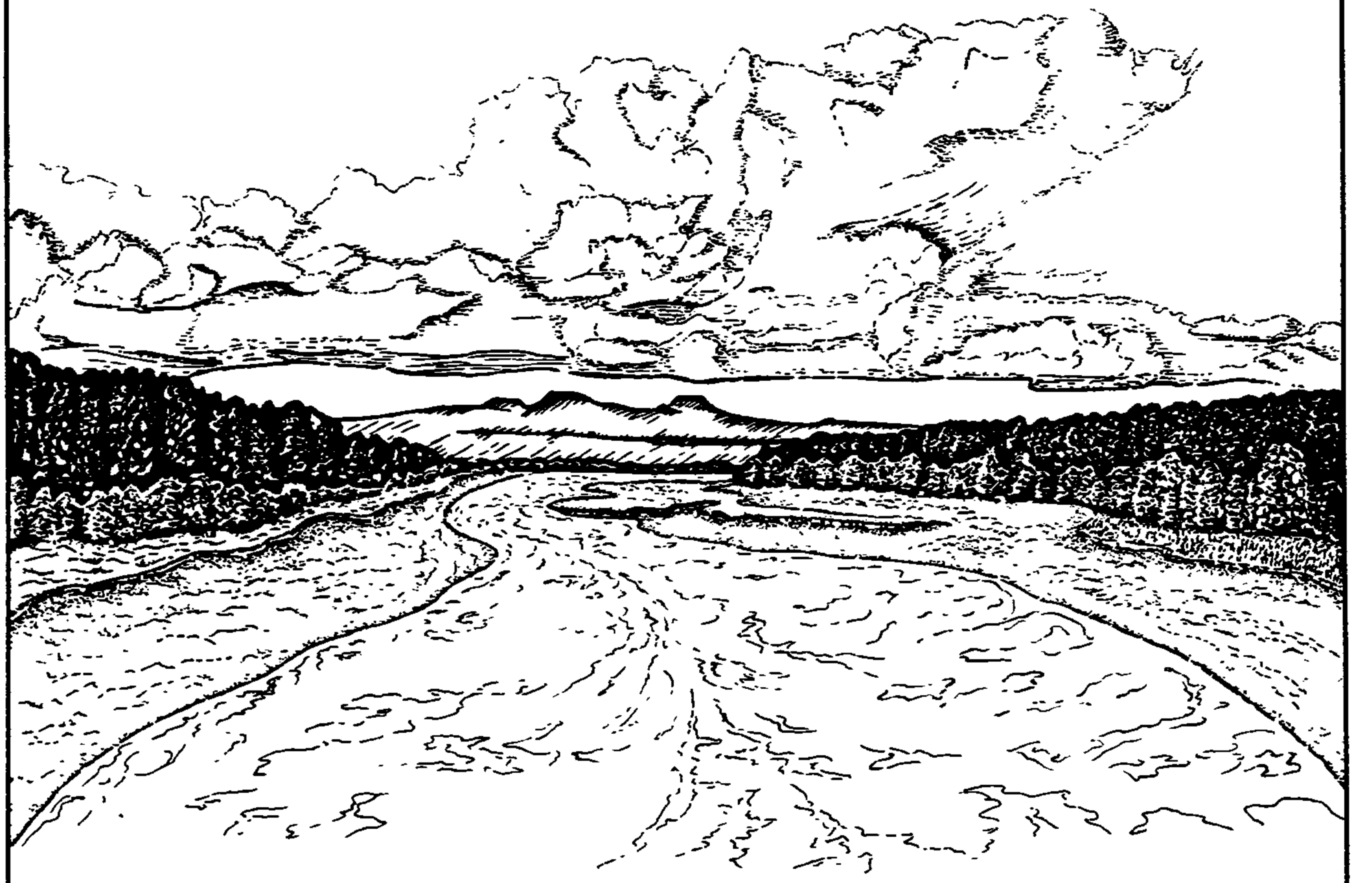
Middle Rio Grande Ecosystem: Bosque Biological Management Plan



Biological Interagency Team

Illustration by B. Dennis

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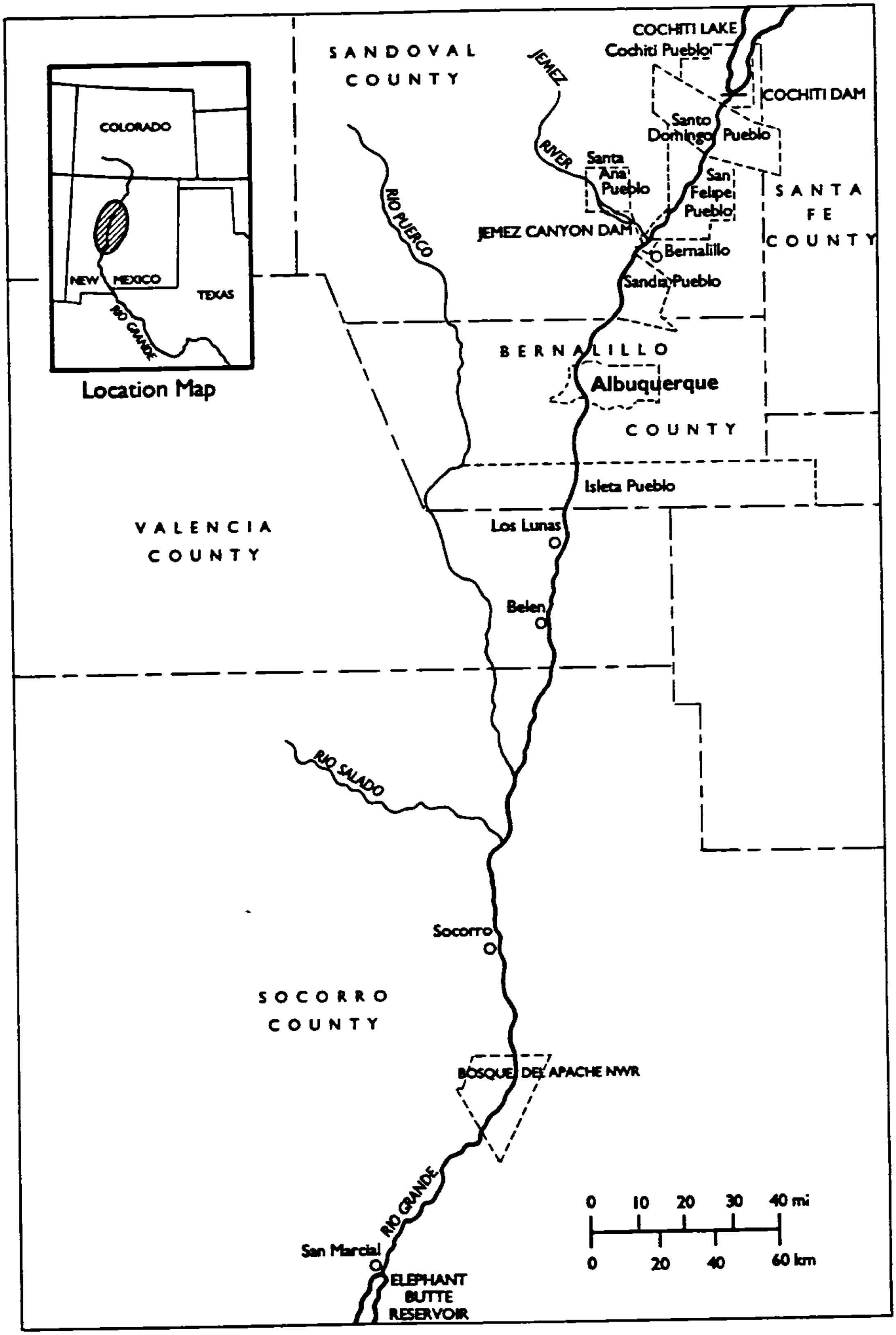

Frontispiece: Middle Rio Grande, New Mexico, between Cochiti Lake and Elephant Butte Reservoir

MIDDLE RIO GRANDE ECOSYSTEM:

BOSQUE BIOLOGICAL MANAGEMENT PLAN

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PREFACE

This Middle Rio Grande Ecosystem: Bosque Biological Management Plan was developed to bring change to the way the biological resources of the riparian ecosystem, from Cochiti Dam to San Marcial, New Mexico, are managed. More specifically, it was our charge to do this "as a first step toward restoring the Bosque's health," as directed by the Rio Grande Bosque Conservation Committee that created our team in 1992. Appendix I gives the background for our work.

The plan is directed to agency managers, scientists, land and water users, conservationists, and just about anyone in the Middle Rio Grande Valley concerned with the way the ecosystem seems to work and might best be managed. It covers a lot of ground: history, existing conditions, the future, and a series of specific recommendations for management—plus some thoughts on the kind of collaborative structure that could do the job and keep this plan alive through the years.

As written, the document is much too long to read at one sitting. We recommend, instead, that you first spend a little time with the Executive Summary. Appendix I provides the broadest context for the plan and should also be consulted before moving into the body of the document. Then look at the Table of Contents to get an idea of the plan's specific coverage. If you are a manager, you might wish to go straight to the Recommendations and to focus on only one or a few of them. Or, if you have the time and inclination, you may actually want to start at the beginning and slowly read all the way through.

We sincerely hope that the plan will set the stage for a new era in Rio Grande management. We recognize that its implementation will not be easy and that it is sure to undergo changes before much time has passed. But change is what the plan is all about.

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ACKNOWLEDGEMENTS

We did not write this plan in a vacuum. In fact, we could not have done it at all without the enormous support we got from so many people that we had to list their names in Appendix II. We are deeply grateful to each of them. We also owe much to our employing organizations, the U.S. Bureau of Reclamation, U.S. Army Corps of Engineers, U.S. Fish and Wildlife Service, and University of New Mexico; they gave us time and free rein to incorporate statements with which they might not always officially agree.

Two individuals must be singled out for their special roles in the creation of the plan. Senator Pete Domenici, in a most bipartisan and supportive way, made the plan, and the entire "Bosque Initiative" that fostered it, possible. Bill deBuys, whose organizational skills and deep enthusiasm for the initiative and the plan never flagged, gave us direction without pressure.

This project was made possible by Congressional funding through the U.S. Fish and Wildlife Service, Region 2, and the U.S. Army Corps of Engineers, Albuquerque District. John Peterson of the Fish and Wildlife Service handled cooperative agreements and financial matters, assisted by the Ecological Services staff at Region 2 and the New Mexico Field Office. While at Refuge Operations in Region 2, Nita Fuller acted as liaison between the Service, the team, and the Rio Grande Bosque Citizen's Conservation Committee.

The U.S. Fish and Wildlife Service, National Ecology Research Center, at Fort Collins, Colorado, provided background material, developed Geographic Information System data bases for our use, and provided thoughtful assistance throughout the writing of the plan. We thank Lee Ischinger, James Roelle, Barbara White, Robert Waltermire, Diane Schneider, Jan Hart, Dale Crawford, and many others at NERC for their help. Through the cooperation of the Department of Biology and the Museum of Southwestern Biology at the University of New Mexico, and the National Ecology Research Center, Albuquerque Field Station, the team had office space and access to telephones and facsimile and photocopying machines.

The U.S. Bureau of Reclamation, Denver Office, provided maps of the Middle Rio Grande for our use. Don Alberts, Albuquerque Office, provided editorial assistance with the final manuscript. We thank Karl Wood, New Mexico State University, for assisting with information about livestock grazing.

Illustrations, figures, and maps were provided by Beth Dennis and Aimée Reese, Department of Biology, University of New Mexico, and by William J. Underwood.

John M Mahoney and Stewart B. Rood, University of Lethbridge, Lethbridge, Alberta, Canada, and James R Creitz, Jr, of the American Fisheries Society Publication Department, Bethesda, Maryland, kindly gave their permission for us to use Figs. IV.17 and IV.23, respectively, taken from their publications.

Rayann Robino is acknowledged on the title page for her technical and editorial skills; she should also be recognized for her reliable, quick, and patient administrative assistance to the rest of the team, so that we could continue with the business of writing. Although Rayann changed jobs while the plan was being written, her new employers at Refuge Operations, Fish and Wildlife Service, Region 2, allowed her to continue working on the plan through its completion. Without her superb assistance, the plan would never have been completed within the allotted time.

The Authors

EXECUTIVE SUMMARY

INTRODUCTION

New Mexico's Rio Grande and its riparian forest, the "bosque," were for centuries central to the region's culture and development. Now, despite their importance in the past, the river and the bosque are being impacted by the effects of management and development accommodating needs of the region's growing human population. As a result, some of the last great cottonwood stands, trees that are the integral components of native biological communities, are now confined to the banks of a highly controlled and physically altered river. River dynamics on which the native communities depend have been changed so much that these communities are no longer able to sustain themselves. Compounding the problem are introduced species such as salt cedar and Russian olive that are steadily replacing the aging native trees. Other factors, including a managed water table level in the floodplain, a reduced amount of wetlands, and a fragmented bosque, have also disrupted the original dynamics of the river and the riparian zone. Clearly the ecosystem is stressed.

The Bosque Biological Management Plan was created to mitigate that stress in the Middle Rio Grande Valley from Cochiti Dam to San Marcial and to send a message to resource managers and decisionmakers that a new approach is needed. The plan's purpose is to determine conditions and to recommend action that will sustain and enhance the **biological quality** and **ecosystem integrity** of the Middle Rio Grande bosque, together with the river and floodplain that it integrates. Here, the term "biological quality" refers to the diversity and abundance of native species in particular, coupled with the environments and ecological processes that support them. "Ecosystem integrity" refers to the capacity of the ecosystem to return to an organizing, self-correcting state following major disturbance.

The preparation of this plan was proposed by the Rio Grande Bosque Conservation Committee, a citizen's group formed by Senator Pete Domenici (New Mexico) to examine the bosque's problems, to solicit public involvement, and to recommend the means for its protection and the continuation of its benefits to human society. An interagency team of biologists from the U.S. Fish and Wildlife Service, the U.S. Army Corps of Engineers, the U.S. Bureau of Reclamation, and the University of New Mexico was appointed to develop the plan in consultation with scientists, historians, and other experts on the Middle Rio Grande Valley. The first draft was reviewed by these technical experts. A second draft was sent to a broader audience concerned with managing the ecosystem.

The plan's goals are as follows. (1) Synthesize past and present available information about the ecosystem. (2) Identify key species, communities, and ecological processes essential to sustaining the ecosystem's biological quality and integrity. (3) Recommend methods for establishing and maintaining these species, communities, and processes. (4) Recommend procedures for monitoring, conducting research, and managing the ecosystem. (5) Identify procedures for incorporating new information and recommendations into the management plan.

The plan is organized into seven sections. The first is an introduction, summarized here. The second gives the setting of the Middle Rio Grande Valley and its bosque ecosystem. The third considers the past physical and biological conditions that led to the present state of the ecosystem. The fourth section summarizes existing conditions in some detail; data in it and previous sections are used in the fifth section to develop a scenario of future conditions with no active change in biological management. Against that background, the essence of the plan is presented in the sixth section. This consists of recommendations, based on information presented throughout the plan, that, if implemented, should lead to achievement of the plan's purpose and goals. The final section points to the future; it recommends a structure for coordinating the implementation of the recommendations and for keeping the plan current.

GENERAL SETTING

The San Juan, Sangre de Cristo, Jemez, Sandia, Manzano, and Magdalena mountain ranges all contribute to the Middle Rio Grande Valley's drainage system. The ecology of the valley is conditioned by the Great Basin Grassland, Semidesert Grassland, and Chihuahuan Desertscrub biotic communities through which the river runs. The valley's temperate, semiarid climate is characterized by highly variable seasonal precipitation. In summer, moist air from the Gulf of México releases nearly half of the region's annual precipitation during thunderstorms. In winter and spring, moisture transported from the Pacific by westerly winds can be amplified by the El Niño phenomenon which ties regional precipitation to global climate.

The Middle Rio Grande Valley overlies the deep, sediment-filled Rio Grande Rift. For the past 5 million years, the Rio Grande has flowed south through this valley from its origin in the San Juan Mountains. The river is bounded on the east and west by raised landforms and mountains of varying geological origins. The underlying rift still produces seismic effects.

Nearly 40% of New Mexico's population live in the valley, which traverses four counties and six pueblos. Three-fourths of this population is essentially urban, and urbanization is steadily encroaching on agricultural lands along the river. Management of river water and ground water under these circumstances is clearly essential; it is also complex. Federal and state laws and an international treaty control the allocation of Rio Grande water to Colorado, New Mexico, Texas, and the Republic of México. Within the valley, the river is managed mainly by the Middle Rio Grande Conservancy District, the U.S. Bureau of Reclamation, and the U.S. Army Corps of Engineers. Water rights are held by individuals, municipalities, pueblos, and wildlife refuges. Flood control, ground-water drainage, and irrigation are under the jurisdiction of the District and other agencies.

HISTORICAL CONDITIONS

Hydrologic and geomorphologic changes along the Middle Rio Grande have accelerated over historical time. The Rio Grande before the 14th century was somewhat sinuous and braided, and its bed had a tendency to aggrade. As it migrated freely across its floodplain, it created ephemeral mosaics of riparian vegetation (forests and shrublands) and wetlands (ponds, marshes, wet meadows). The use of irrigated agriculture, first on a small scale by Native Americans and later by Spaniards and Anglos, progressively diminished river flows during growing seasons. Increased sediment loading from the watershed, most likely the result of climatic variations and human land-use practices, then caused the channel to become broader and shallower, increasing its tendency to flood. In the late 1800's, ground-water levels in the floodplain rose dramatically due to the rising riverbed, irrigation, and poor return of irrigation water. Salts, leached upward by the rising ground water, created salinity problems for farmers.

Levees were built in the 1920's and 1930's to cope with the floods; levees also constrained the Rio Grande's floodway and reduced its tendency to meander—a tendency critical to establishing native bosque vegetation. In the early 20th century, dams were constructed in tributaries and later at Cochiti for water storage and/or flood control. In addition, drainage systems were established to lower water tables in the floodplain. Combined with a series of water diversion channels and increased ground-water pumping (in Albuquerque), these practices had the potential to disrupt the ancient connection between river water and ground water in the adjacent floodplain. Unfortunately, it was that connection, stimulated by periodic flooding, which for millions of years had been responsible for maintaining native bosque vegetation by supplying water and nutrients to the riparian zone.

Biological changes have also accelerated with growing human use of the Middle Rio Grande Valley. Cottonwood-willow forests along the river were increasingly reduced by land clearing, tree harvesting, water diversion, and agriculture. Livestock grazed back new riparian vegetation. In recent centuries, grazing contributed to watershed erosion, which in turn contributed to riverine sediment loading. Then ground-water drainage, coupled with the absence of periodic flooding, caused most of the valley's wetlands to dry up. Many species of plants and animals that rely on wetland resources either disappeared locally or were confined to restricted habitats such as drainbanks.

Species introductions and extirpations have been pronounced in this century. Sites formerly occupied by cottonwood-willow stands were taken over by salt cedar in the south and Russian olive in the north. These Old World trees, together with other introduced vegetation (white clover, summer cypress), continue to spread in the riparian zone. The new trees, unlike cottonwood, do not rely on spring flooding for their reproduction.

Changes in the communities of terrestrial animals paralleled the reorganization of the valley's plant communities. Large mammals such as the gray wolf and grizzly bear were removed from the region. Feral animals (cats, dogs) and other introduced species (house mice, starlings, pill bugs) made distinct ecological impacts on the bosque and the floodplain.

In the river, fish populations underwent considerable and well-documented changes. Many of the larger species (longnose gar, shovelnose sturgeon) were gone by the end of the 19th century. At the present, roughly half of the original fish fauna has disappeared from the Middle Rio Grande, and about half of the existing fauna is composed of introduced species such as the mosquitofish and white sucker.

EXISTING CONDITIONS

The hydrology of the Middle Rio Grande is currently managed in order to control its surface flows. About 90% of all river water use in the middle valley is by agriculture, which is the principal reason for the construction of water storage and diversion dams. Such structures, together with drainage practices, have altered the original patterns of water and sediment/nutrient distribution within the river, riparian zone, and floodplain.

For the purpose of this plan, we have subdivided the Middle Rio Grande into the following units: (1) Cochiti Dam to Angostura Diversion Dam (low sediment load, incised river channel with gravel, low flooding probability), (2) Angostura to Isleta Diversion Dam (higher sediment load, slightly degrading sandy riverbed, moderately incised banks, low flooding probability), (3) Isleta to Bernardo (still higher sediment load, aggrading sandy riverbed, low sandy banks, higher flooding probability), and (4) Bernardo to San Marcial (high sediment load, aggrading sandy riverbed with braided reaches, low banks, high flooding probability).

The interaction of river and ground water provides a critical link between the riverine and riparian components of the Middle Rio Grande ecosystem. Deep-rooted native trees in the bosque rely on ground water for natural functioning and presumably depend on river water to supply nutrients and oxygen to that ground water for their optimal growth. Historically, the Rio Grande recharged shallow (valley) and deep (basin aquifer) ground-water systems. Although this process still occurs, the periodic, well-distributed recharge that resulted from flood events has been all but eliminated except for in the southern reaches. Currently, irrigation canals and drains also contribute to recharge of and withdrawal from the valley's ground water. Ground-water contamination occurs from municipal, domestic, industrial, and agricultural activities.

A number of key ecological processes occurs in the river. One is the transport of organic detritus originating mainly from riparian vegetation. Detritus is fragmented by stream invertebrates, which enter the riverine food web as they are eaten by predators. Remaining aquatic detritus is decomposed by microorganisms; these add to the pool of water-borne nutrients of value to terrestrial vegetation. Sediment is also transported by the river and is the major contributor of materials to nutrient-rich soils when the riparian zone is flooded. Because total nitrogen, phosphorous, and organic carbon increase from north to south in the Middle Rio Grande, flooding has the potential to provide relatively great amounts of nutrient to the southern bosque.

Aquatic producers are comparatively scarce in the relatively fast-flowing waters of the river and ditches. They are more abundant—mainly as emergent and other vascular plants and free-floating algae—in the quieter waters of ponds, marshes, and drains. Wet meadows are dominated by sedges and grasses.

Aquatic consumers include mostly fish and benthic (bottom-dwelling) invertebrates. Species and individuals of native fish are declining; introduced species are increasing. Attempts to preserve the diversity of native species and to simultaneously introduce sportfish may be in conflict. Flow regimes affect aquatic habitats and fish biology. The timing and duration of high flows may affect reproductive success in certain native species. Pollutants from agricultural and municipal discharges may impact fish species.

In the terrestrial environment, much of the riparian zone along the Middle Rio Grande is dominated by cottonwood trees, which form a sparse to dense canopy cover along the river. In the understory, native plant species remain, but introduced species such as salt cedar and Russian olive have become increasingly important—frequently dominating the understory and occasionally the canopy. To the south (below Bernardo), salt cedar is prevalent in the understory, and it also forms large monotypic stands along the river and adjacent floodplain. Other introduced species (e.g., Siberian elm, tree-of-heaven, china-berry tree, mulberry, and black locust) are found in the bosque, mostly along levee roads and other disturbed areas. These exotics have the potential to become the dominant bosque tree species.

Six structural types of plant communities have been described in the riparian zone. These include mostly mature overstory trees with and without a shrubby understory; intermediate-aged trees with and without understory; dense low vegetation; and sparse, low vegetation types. These types are expected to provide a valuable basis for planning community diversity.

Soils in cottonwood forests not flooded for half a century appear to be nitrogen-limited, although this may not be a problem for introduced Russian olive and native leguminous species which fix atmospheric nitrogen. The capacity of flood water to make nitrogen and other nutrients available in the bosque is under study.

Although riparian forests dominated by native trees have a much greater habitat diversity than monocultures of salt cedar, the abundance and species richness of rodents seems about equal in both environments. Overall, white-footed mice are the most abundant bosque rodents. Pocket gophers move considerable amounts of soil in some cottonwood forests. Beavers, once extirpated but later reintroduced in the valley, are now abundant to the point of causing excessive damage to cottonwoods in some areas.

Domestic livestock use the bosque and the floodplain. While their grazing can be environmentally damaging, it can also be used as a management tool to maintain habitat and biodiversity.

Birds, whose nearly 300 species constitute the largest number of vertebrate species in the bosque, are more abundant in cottonwood forests but are still well-represented in salt cedar. Many bird species consume Russian olive fruits. Many also use dead cottonwood snags or limbs as important sites for food and shelter. The further decline of the cottonwoods will continue to change the nature of bosque habitats and should have a significant impact on bird diversity, in part because cottonwoods appear to harbor a greater diversity of arthropods—a major protein resource—than introduced trees in the bosque. Habitat alteration—especially wetland removal—in the valley, together with the introduction of new species, has already had a pronounced, adverse impact on populations of amphibians and reptiles.

Invertebrate animals, particularly arthropods such as insects and spiders, are by far the most diverse organisms in the bosque. Invertebrates provide critical links between producers and other consumers, including fungal and bacterial decomposers. Consisting of herbivores, carnivores, and detritivores, arthropods occupy a great range of habitats and control rates of many important processes, such as seed germination and decomposition. Ants may be the most significant terrestrial process regulators in the bosque.

In the soil, mites, earthworms, nematodes, and other small invertebrates prepare leaf litter fragments (many of which first pass through the guts of native termites and introduced isopods) for mineralization by fungi and bacteria. Mineralized compounds, under the right conditions, can then be absorbed by roots. Root-associated mycorrhizal fungi facilitate the process. How the absence of frequent flooding has affected both the complex flow of nutrients and the organization of bosque communities and habitats, are questions of fundamental importance to the management of the entire ecosystem.

FUTURE CONDITIONS WITH NO ACTIVE CHANGE IN BIOLOGICAL MANAGEMENT

Given the previous descriptions of the past and present Middle Rio Grande ecosystem, what will happen to the ecosystem with no change in biological management? We attempt to answer the question in order to develop a basis for the management plan's biological resource recommendations, and in order to assist managers to decide whether individual recommendations are appropriate for their specific needs. Based on our estimates, we assume that (1) projected population estimates of a 41% increase in the valley for the period 1990 to 2020 are accurate; (2) current water management practices will have varying effects on the ecosystem's hydrology, river morphology, and water quality as increased population pressure is put on water resources; and (3) current land-use and management practices will intensify their impacts on the bosque.

We predict that much would happen in the aquatic environment if no management changes take place. Between Angostura and the Rio Puerco the river would gradually become narrower and deeper. These trends would negatively affect warmwater fishes and reduce the availability of native aquatic habitat. Meanwhile, reduced overbank flooding and a lowered water table in the reach would restricted opportunities for wetland formation. Continued fragmentation of riverine habitats would occur because of water management practices; however, the exact nature of the effect of fragmentation on riverine faunal diversity in the Middle Rio Grande is unclear.

The quality of river and ground water would be increasingly affected by urban discharges, less so by agricultural runoff. Urban effluents would locally impact fish abundance. More widespread extirpations of native fish species could continue for many reasons and would result in a greatly altered riverine community.

Changes in the terrestrial environment would be influenced by changes in the riverine environment. Along the Rio Grande's northern reach, lack of overbank flooding would cause cottonwoods to die off and be replaced by introduced trees. Native trees would have a better chance for establishment in the more frequently flooded southern reach, assuming control of salt cedar expansion.

The decline of deep-rooted native vegetation that depends on a certain level of ground water would have repercussions on animals using the vegetation for food and habitat. Cottonwood decline would decrease the diversity and abundance of canopy-dwelling arthropods (but probably not of ground-dwelling arthropods), which would mean less protein for birds. However, replacement of cottonwoods by Russian olive in the northern reach would increase the supply of that tree's fruit, which is heavily utilized by birds and mammals.

Reduction of foliage height diversity and density, which would accompany a decline in cottonwood bosque, would reduce the diversity of forest specialist birds. A temporary increase in standing dead cottonwood snags, caused by age and increased burning, would provide habitat for other birds, until the snags were removed. Replacement of cottonwood by salt cedar in the southern reach would lower the diversity and abundance of birds but not of small mammals.

Fragmentation of the riparian zone by residential development, roads, bridges, and power lines would combine with native plant species' mortality and wetland reduction to lower the density, biomass, and productivity of riparian plant and animal communities. Further reduction of wetlands would cause the continued decline of certain species of plants and animals.

Certain ecological processes would continue to undergo change if there were no modification of biological management of the bosque. Takeover in the northern reach by Russian olive would increase soil nitrogen, but since solid stands of that species seldom have much undergrowth, the increase would benefit few other plants. Lack of flooding there would continue leaf-litter buildup; in drought cycles that would contribute to fire frequency. Lack of flooding would progressively reduce the dynamic interaction of river water and ground water that is needed for release of soil-bound nutrients used by riparian vegetation.

BIOLOGICAL MANAGEMENT RECOMMENDATIONS

The team foresees the boundaries of the Middle Rio Grande bosque not only as being protected from development but also as expanded in the future. We envision a perennial Rio Grande whose flows mimic the natural hydrograph to the maximum extent possible, and a river channel that is permitted maximum freedom within the floodway. The attainment of these fundamental conditions will facilitate the achievement of all other recommendations to enhance the biological quality and ecosystem integrity of the bosque.

Hydrology

Water is the key variable that drives the processes of the riparian ecosystem. Whenever water cannot do its work, people will have to attempt to replace vital, missing functions and processes in the ecosystem. The following three recommendations deal with the management of surface and ground water in the Middle Rio Grande:

- Coordinate Rio Grande water management activities to support and improve the bosque's riverine and terrestrial habitats, with special emphasis placed on mimicking typical natural hydrographs.

- Implement measures to allow fluvial processes to occur within the river channel and the adjacent bosque to the extent possible.

- Reintroduce the dynamics of surface-water/ground-water exchange, manage ground-water withdrawal, and restrict contamination.

Aquatic Resources

Recommendations about aquatic resources overlap and are related to those for hydrology but focus on communities and species that are primarily dependent on the presence of surface and ground water either throughout or at critical times during their life history. The recommendations are as follows:

- Protect, extend, and enhance the structure of the aquatic habitat to the benefit of native communities.

- Protect and enhance surface-water quality.

- Integrate management of nonnative and native fish species in all aquatic environments in the riparian ecosystem, including wetlands, canals, and drains.

Terrestrial Resources

Recommendations about terrestrial resources in the riparian ecosystem focus on the protection, enhancement, and restoration of communities and habitats in the riparian zone and the floodplain. Human activities have severely impacted these portions of the riparian ecosystem, and it is in the terrestrial areas that the most visible needs for management exist. The following recommendations attempt to replace some of the known processes that have been eliminated from or diminished in the ecosystem:

- Protect the geographic extent of the Rio Grande bosque and avoid fragmentation of the riparian ecosystem and component habitats.

- Protect, extend, and enhance riparian vegetation in noncontiguous areas in the floodplain.

- Manage the buffer zone of the contiguous bosque to protect ecosystem processes, enhance wildlife values, and maintain rural and semirural conditions.

- Manage livestock grazing activities in a manner compatible with biological quality and ecosystem integrity.

- Manage activities that remove dead wood in a manner compatible with biological quality and ecosystem integrity.

- Manage recreational activities in the bosque in a manner compatible with biological quality and ecosystem integrity.

- Prevent unmanaged fires in all reaches of the bosque.

- Use native plant species and local genetic stock in vegetation establishment and management efforts throughout the bosque.

- Protect, enhance, and extend (create) wetlands throughout the Middle Rio Grande riparian zone.

- Sustain and enhance existing cottonwood communities, and create new native cottonwood communities wherever possible throughout the Middle Rio Grande riparian zone.

- Contain the expansion of existing large stands of nonnative vegetation in the Middle Rio Grande riparian zone. At the same time, study the ecology of these stands and develop creative ways of maximizing their biological values.

Monitoring and Research

Monitoring to determine the effects of management actions is vital to the implementation of all recommendations included in this document. Systematic, coordinated monitoring of key ecological variables is needed for the development of a comprehensive, ecosystem-based management plan. Research related to management questions should be pursued, but research addressing purely scientific goals should also be encouraged. Both research approaches will generate information that can be applied to management issues. We have made two recommendations relating to these topics:

- Develop a coordinated program to monitor biological quality (with emphasis on diversity and abundance of native species) and ecosystem integrity (with emphasis on restoring the functional connection between the river and riparian zone) of the Middle Rio Grande ecosystem.

- Develop a coordinated research program to study the ecological processes and biotic communities that characterize the Middle Rio Grande riparian ecosystem.

Implementing and Revising the Bosque Biological Management Plan

Monitoring and research provide the information for updating and revising the biological management plan. This information needs to be compiled in a central location. Coordination and communication among river managers needs to be improved if the Rio Grande is to be managed as an ecosystem. The following recommendation addresses the need for enhanced cooperation and a flexible and enduring plan for the Middle Rio Grande riparian ecosystem:

- Regularly review and update of the Middle Rio Grande Ecosystem: Bosque Biological Management Plan.

The Middle Rio Grande—Part of a Larger Riparian System

The Middle Rio Grande is only a portion of the total river system and includes a small fraction of the entire watershed. This part of the river is dependent on what enters the system upstream, and how we manage our section affects the river downstream. While we have attempted to take an ecosystem approach to management of the Middle Rio Grande, we recognize that to be truly comprehensive, the whole river and its watershed should be included. The following recommendation deals with how this management plan could be adapted to fit into a larger management scheme for the entire Rio Grande.

- Integrate resource management activities along the Rio Grande and within the contributing watersheds to protect and enhance biological quality and ecosystem integrity.

FUTURE DIRECTIONS FOR THE BOSQUE BIOLOGICAL MANAGEMENT PLAN

The recommendations in this Bosque Biological Management Plan define a major shift in long-term management of the Middle Rio Grande bosque ecosystem. The plan emphasizes an **integrated** management approach, with special emphasis being placed on "communication" and "coordination."

Implementing the plan's recommendations will require (1) a central coordinating structure and (2) an active, representative council of managers and concerned citizens. We have tentatively called this structure the "Middle Rio Grande Coordinating Council" and its executive leader the "Middle Rio Grande Bosque Coordinator."

Because federal Middle Rio Grande bosque initiative funds are available through the U.S. Fish and Wildlife Service, that agency's Region 2 Director could appoint and fund the Middle Rio Grande Bosque Coordinator (who need not, but could be a Fish and Wildlife Service employee) and his or her supporting staff. The Region 2 Director could also identify and convene an initial meeting of riverine and riparian managers and concerned citizens as council members ("Riparian Coordinators").

The Middle Rio Grande Bosque Coordinator would develop and operate a clearinghouse for receiving, storing, and transmitting management-related information, as well as directing such other activities as annual council meetings, newsletter publication, and annual report preparation.

Riparian Coordinator council members would, at subsequent semiannual meetings, address questions of communication and coordination and ongoing activities and projects, making specific recommendations concerning monitoring and research in the Middle Rio Grande bosque ecosystem. They would also be responsible for periodically reviewing and updating the Bosque Biological Management Plan and for enhancing the flow of information among managing entities.

Obviously, strong leadership and active council and organizational participation will be needed to successfully implement the Bosque Biological Management Plan—but the future of the Middle Rio Grande is at stake.

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I. INTRODUCTION

A. PURPOSE, GOALS, AND NEEDS

1. Purpose

New Mexico's Rio Grande and its riparian forest, the "bosque," were for centuries central to the region's culture and development. Now, despite their importance in the past, the river and the bosque are being impacted by the effects of management and development accommodating the needs of the region's growing human population. As a result, the last great stands of cottonwood bosque that are the integral components of native biological communities are largely confined to the banks of a highly controlled and physically altered river. The river dynamics on which the native communities depend have been changed so much that these communities are unable to sustain themselves. Compounding the problem are introduced species such as salt cedar and Russian olive that are steadily replacing the aging native trees. Other factors, including lack of flooding, reduced wetlands, and a fragmented bosque, have also disrupted the original dynamics of the river and the riparian zone. Clearly the ecosystem is stressed.

The purpose of the Middle Rio Grande Ecosystem Bosque Biological Management Plan is to determine conditions and to recommend management that will sustain and enhance the **biological quality** and **ecosystem integrity** of the Middle Rio Grande bosque, together with the river and floodplain which it links and with which it interacts. The plan applies to New Mexico's Middle Rio Grande Valley, which runs south from Cochiti Dam to San Marcial. The valley's inhabitants have always used the bosque and depended on the Rio Grande, but never more so than they do today.

In this document the term "biological quality" refers to the diversity and abundance of species—especially native species—coupled with the environments and ecological processes that sustain them. "Ecosystem integrity" is a concept increasingly associated with the restoration of severely disturbed environments (references in Woodley et al. 1993). An **ecosystem** can be most simply defined as a biological community and the physical and chemical environment with which it interacts (National Research Council 1992). "Integrity," as used here, refers to the capacity of an ecosystem to return to an organizing, self-correcting condition following a major disturbance (Regier 1993).

This biological management plan provides a foundation of biological information about the Rio Grande Valley ecosystem which individuals, organized groups, governmental agencies, and pueblos can use to formulate and implement management decisions in keeping with the plan's purpose. The plan is designed to be the basis for integrated decisions that will ultimately result in a comprehensive approach to the management of the bosque, together with the river and floodplain that it structurally and functionally links.

2. Goals

This document presents a comprehensive yet flexible plan for management of the ecosystem. The plan has five broad goals:

(1) synthesize past and present information about the ecosystem;
(2) identify key species, communities, and ecological processes essential to sustaining the ecosystem's biological quality and integrity;
(3) recommend methods for establishing and maintaining these species, communities, and processes;
(4) recommend procedures for monitoring, conducting research, and managing the ecosystem; and,
(5) identify procedures for incorporating new information and recommendations into the management plan.

3. Needs

The bosque ecosystem of the Middle Rio Grande Valley has evolved over thousands of years in response to natural events and to human activities. The collective actions of humans have greatly influenced the ecology of the valley we see today. Although altered (not nearly as much, however, as below Elephant Butte Reservoir to the south), the valley supports a rich diversity of biological communities. These communities have undergone and are continuing to undergo major changes due to modifications of the valley's normal hydrologic regime, introduction of nonnative plants and animals, drainage, and floodplain development.

Communities dominated by native trees such as cottonwood and willow need to be protected and restored if any resemblance of the **riparian**, or streambank, community to its original condition is to continue. Protection and restoration are also needed for wetlands such as ponds, marshes, and wet meadows. Communities dominated by introduced trees such as salt cedar and Russian olive need to be managed to prevent their continued spread and to allow native species and wetlands to exist within their borders. Underlying these requirements is a fundamental need to understand how the ecosystem worked in the past and how it works now. In particular, there is a need to learn how the interaction of river water and ground water regulates the health of the **riparian zone** (which some [e.g., Gregory et al. 1991] feel has the same outer limits as the floodplain, namely that area historically inundated by periodic floods).

Finally, there is a need to recognize that future management will require a departure from past practices. It will have to be more integrated than it is now if the purpose of this plan is to be realized. That means a new management structure will have to be created, based on a coordinated system of planning, monitoring, and implementing. Inherent in that structure will be the need for continuous rethinking of management practices based on new facts and interpretations.

B. BACKGROUND

In September 1991, Senator Pete Domenici (New Mexico) announced the formation of a nine-member citizen's group, the Rio Grande Bosque Conservation Committee. The purpose of the committee was "to examine the problems affecting the Bosque, to solicit broad public involvement, and to make recommendations for the long term protection of the Bosque and continuation of the many benefits it provides." In March 1992, the committee proposed that an interagency biological management plan for the bosque be prepared. An interagency team was subsequently formed, and funds for preparation of the management plan were appropriated by the federal government. The team convened in January 1993. The central purposes of the team were to send a message to resource managers and decisionmakers that a new management approach is needed and to make specific recommendations that will enable that new approach to be undertaken.

The University of New Mexico (UNM) and three federal agencies (U.S. Fish and Wildlife Service [FWS], U.S. Army Corps of Engineers [COE], and U.S. Bureau of Reclamation [BOR]) are formally represented on the team. In addition, New Mexico State University (NMSU) is represented by an adjunct member. In maintaining its focus on the bosque and the ecosystem to which it belongs, the team sought out biologists, ecologists, physical scientists, historians, and other experts with appropriate knowledge.

C. DEVELOPMENT OF THE PLAN

1. Approach and Methods

The committee and the team are well aware of the complexity of social and institutional interests affecting the bosque ecosystem and of the implications of that complexity for its management. Nevertheless, the team's clear mandate was to focus on the biology of the bosque and its environment while keeping in mind that these have long been affected by human values and activities. The team's management plan therefore leads to recommendations driven primarily by the need to sustain and restore the bosque ecosystem's integrity and biological quality, and at the same time to address the reality of human activity along the Middle Rio Grande.

To accomplish the goals of the plan, the team relied on available data and information. Realizing that a wealth of information on the bosque ecosystem was unpublished, the team consulted with numerous experts. The team sent letters requesting knowledge and material to those persons, convened in-depth meetings with some, discussed issues with others, and generally expanded the "team" concept to include them all. After writing a preliminary draft of the plan, the team solicited a technical review from most of the experts it originally contacted. Then, following a revision that incorporated many of the comments and ideas of the technical reviewers, the team submitted a revised document to a wider audience for formal review. The collective critique of this audience was incorporated into its final revision.

In addition, the team amassed printed and electronic material that either directly or indirectly pertained to the Rio Grande and the bosque. Most of the documents were in the form of special reports prepared for or by governmental agencies. All agencies contacted were generous in providing the team copies of these reports. Of particular utility were Geographic Information Systems (GIS) data bases and historic photographs.

2. The Plan's Organization

As now constituted, this document initially provides the reader with a picture of the general setting of the Middle Rio Grande Valley and the bosque ecosystem (Figs. 1 and 2). Then it dwells broadly on past conditions (geological, geomorphologic, human, hydrologic, and biological) that led to what we see today. Next, it considers in some detail the conditions that now exist. Topics in this section are arrayed under the headings of hydrology and geomorphology, aquatic ecology, and terrestrial ecology; these are explored to the point of giving the reader a fairly comprehensive and up-to-date background regarding the structure and function of the ecosystem as a whole. The section that follows begins to address management of the bosque and its environs by focusing on what its future would be like with no active change in management. This prediction sets the stage for the essence of the team's report: the biological management recommendations. Finally, after the recommendations and methods of implementing them are described and discussed, the document ends with a section on future directions for the plan.

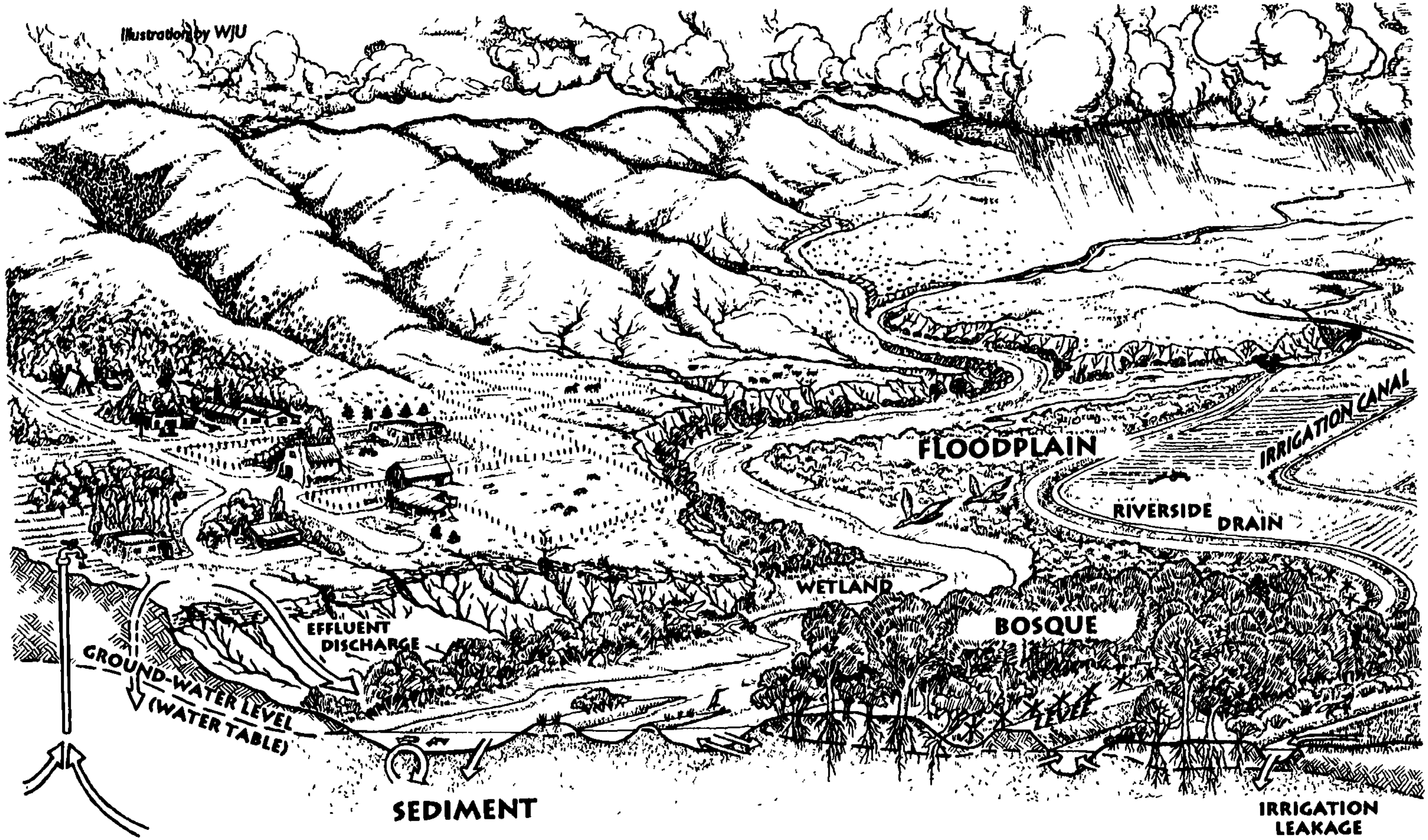

Fig. 1. Idealized picture of the Middle Rio Grande Valley as an ecosystem.

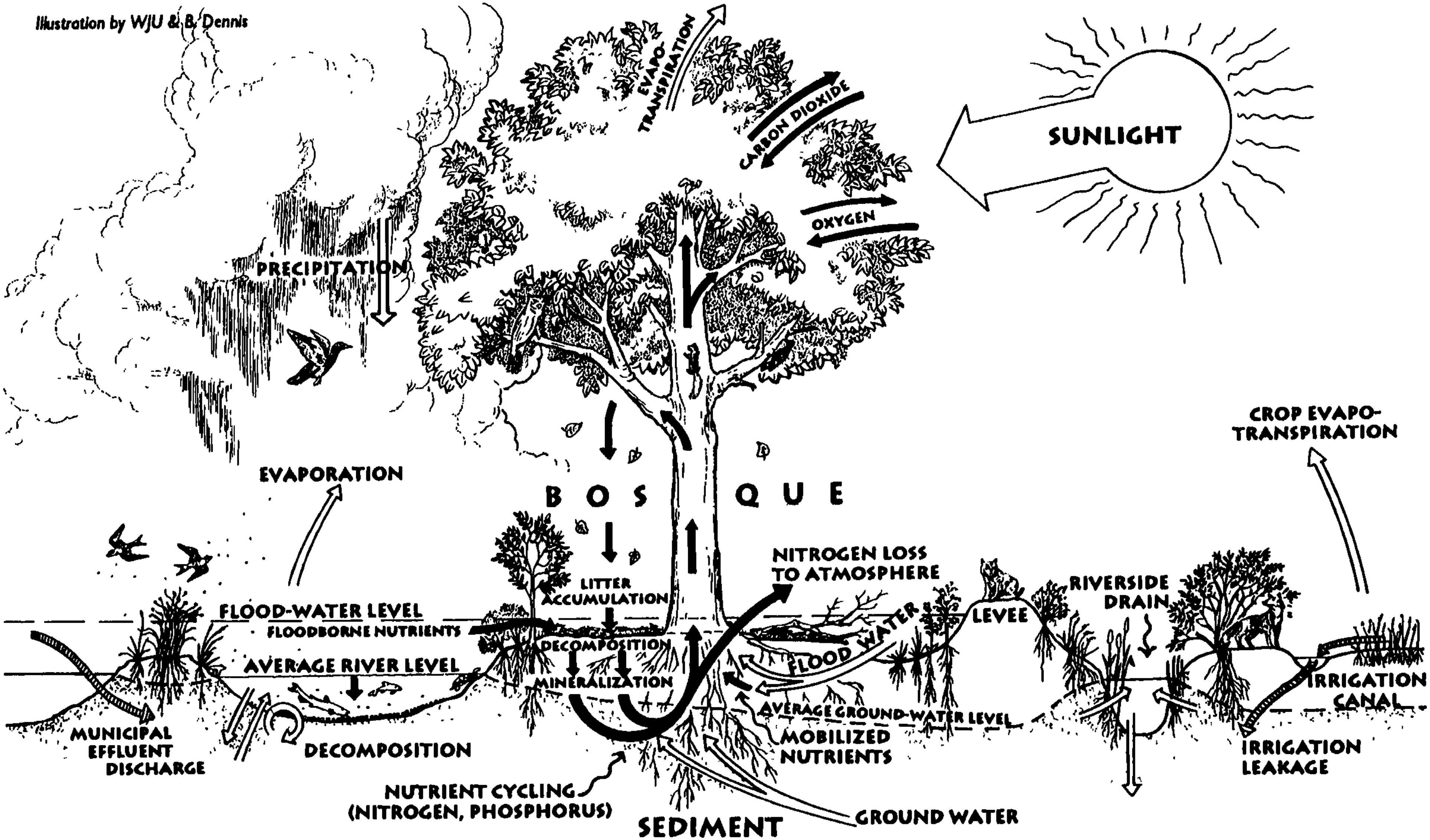

Fig. 2. Diagram of energy, water, and nutrient flows in the Middle Rio Grande Valley ecosystem.

II. SETTING

A. GEOGRAPHIC SETTING

From its headwaters along the Continental Divide in the San Juan Mountains in southern Colorado, the Rio Grande stretches a little over 3,220 km (2,000 mi) to its outfall in the Gulf of México near Brownsville, Texas. En route, about 750 km (465 mi) of the river course from north to south through the midsection of New Mexico. It then continues on to form the international boundary between Texas and the Republic of México. The headwaters are at elevations ranging from 2,440 m (8,000 ft) to 3,660 m (12,000 ft). In the middle valley, the Rio Grande channel descends from 1,594 m (5,225 ft) at Cochiti Dam to 1,357 m (4,450 ft) at San Marcial.

The drainage basin for the entire Rio Grande is about 470,000 km^2 (181,420 mi^2); the total drainage area for the Middle Rio Grande Valley is 64,150 km^2 (24,760 mi^2) and includes extensive mountainous areas in addition to the San Juan Mountains. The most significant of these are the Sangre de Cristo, Jemez, Sandia, Manzano, and Magdalena mountains which range from 3,080 to 3,990 m (10,100-13,100 ft). The presence of these mountains and the associated weather patterns influences the Rio Grande's hydrologic cycle.

The direct tributary drainage area for the Middle Rio Grande Valley is about 33,160 km^2 (12,800 mi^2). From north to south, the Middle Rio Grande's major tributaries, and their corresponding drainage areas, are:

Galisteo Creek	1,660 km^2	(640 mi^2)
Jemez River	2,695 km^2	(1,040 mi^2)
Rio Puerco	15,175 km^2	(5,860 mi^2)
Rio Salado	3,575 km^2	(1,380 mi^2)

Upstream of the valley, the Rio Chama is the principal tributary to the Rio Grande in New Mexico. The juncture of the two rivers is about 55 river km (35 mi) above Cochiti Dam.

The Middle Rio Grande constitutes 8% of the river's total length and 34% of its length in New Mexico. The middle valley's direct tributary drainage accounts for 7% of the total Rio Grande drainage and about half of New Mexico's direct tributary drainage.

B. DESCRIPTION OF MIDDLE RIO GRANDE VALLEY

The Middle Rio Grande Valley extends from Cochiti Dam downstream 260 river km (160 mi) to San Marcial, New Mexico (see frontispiece). The valley traverses three major biotic communities, as defined by Brown and Lowe (1980). From north to south, these are: Great Basin Grassland, Semidesert Grassland, and Chihuahuan Desertscrub. The latter community is considered to be a warm-temperate type, and the others, cold-temperate (Hink and Ohmart 1984).

For the purposes of this plan, the river has been divided into four reaches (Table 1), which reflect somewhat discrete differences in biological, hydrologic, geological, and human-use

Table 1. Middle Rio Grande Reaches.*

Reach Name	Location	River Length
Cochiti	Cochiti Dam to Angostura Diversion Dam	34 km (21 mi)
Albuquerque	Angostura to Isleta Diversion Dam	61 km (38 mi)
Belen	Isleta to Bernardo	63 km (39 mi)
Socorro	Bernardo to San Marcial	100 km (62 mi)

* Note that the Belen and Socorro reaches as defined in this report differ slightly from the definitions generally used by federal and state agencies, which separate the Belen and Socorro reaches at San Acacia instead of at Bernardo

patterns. They are Cochiti Dam to Angostura Diversion Dam, Angostura to Isleta Diversion Dam, Isleta to Bernardo, and Bernardo to San Marcial.

The Middle Rio Grande is slightly sinuous with straight, meandering, and braided reaches. The river is generally characterized by a shifting sandbed in the lower reaches and by a gravel riverbed in the Cochiti Reach. Although a perennial river, there are reaches of the Rio Grande that experience no surface flow during some summer months in dry climatic periods. The Middle Rio Grande is regulated for water supply (primarily irrigation) and flood control. There are irrigation water diversion structures on the Rio Grande and flood control levees that parallel portions of the river.

The river's floodplain varies in width from less than 1.5 km to about 10 km (1-6 mi). It is generally bounded by lower terraces, then by 90- to 150-m (300-500 ft) mesas. The mesas slope gently upward to the foot of mountain ranges (predominately to the east) or to plateau highlands (predominantly to the west). The floodplain is punctuated by short canyons, or narrows, at San Felipe, Isleta, San Acacia, and San Marcial.

The existing contiguous bosque that abuts the Rio Grande is generally limited by the system of levees or natural bluffs where such features are present. In the southern half of the valley where the bosque is at its widest, the bosque is up to 4-5 km (2.5-3 mi) wide.

C. CLIMATE

The hydrology and morphology of the Rio Grande are ultimately dependent on the climate and geology of the area. An overview of these topics will create a foundation of understanding for later discussions.

The valley's climate is characterized as having moderate temperatures and being semiarid above Bernalillo to arid south of Bernalillo (Tuan et al. 1973). Temperatures increase and precipitation decreases from north to south. Annual average maximum temperatures, which

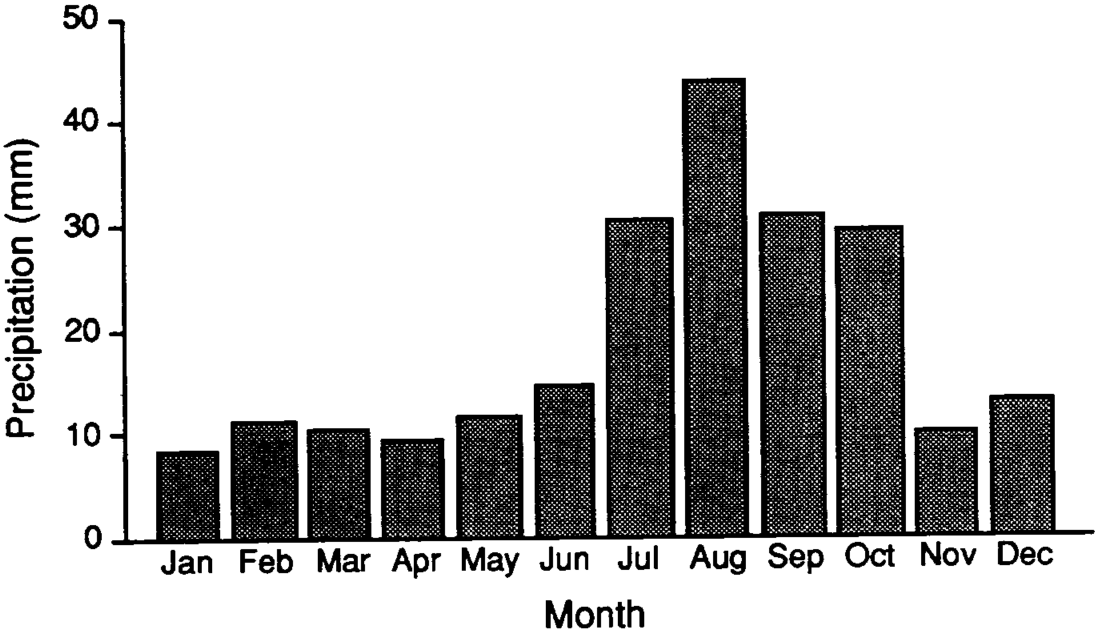

Fig. 3. Monthly average precipitation distribution in the Middle Rio Grande Valley.

usually occur in July, range from 21°C (69°F) at Cochiti Dam to 24°C (76°F) at Bosque del Apache National Wildlife Refuge (NWR). Annual average minimum temperatures (January) are about 4°C (40°F) throughout the valley. The growing season also increases southward through the valley. In Bernalillo and Albuquerque, the typical frost-free period begins in early May and extends through mid-October, lasting on average 160 days. In Socorro, the average period is 197 days, beginning in mid-May and lasting through late October.

Average annual precipitation decreases from 30.7 cm (12.1 inches) at Cochiti Pueblo to 20.1 cm (7.9 inches) at Bosque del Apache NWR. Forty-three to fifty-three percent of the annual precipitation is supplied by summer storms (Fig. 3; U.S. Bureau of Reclamation 1977). The summer precipitation results from moist unstable air arriving from the Gulf of México (Bennett 1986). Thunderstorms, most prevalent from mid-July through early September, are often brief and intense but generally localized. However, some of the largest flood-generating storms occur during spring and autumn (Bullard and Wells 1992) Winter and spring precipitation generally results from occasional Pacific storms that lose most of their moisture as they move inland (Bennett 1986). During spring, heavy snowfalls in the mountains may occur simultaneously with rains elsewhere in the basin. Later in the spring and in early autumn, storms are of high intensity and cover large portions of the basin.

D. GEOLOGY

The major land forms of the Middle Rio Grande Valley are the result of the area's dominant geologic feature, the Rio Grande Rift, which extends more than 800 km (500 mi) from central Colorado through New Mexico. The rift, active for at least 18 million years (Wilkins 1986), is characterized by extension, seismicity, local tectonic uplift, and volcanism (Lozinski et al. 1991). From about Santa Fe southward, the rift is in the Basin and Range Physiographic Province which separates the Colorado Plateau Province to the west from the Great Plains Province to the east.

A simplified east-west cross section across the Albuquerque Basin reveals a deep trough—estimated to be up to be 4,000 m (13,000 ft) deep in some locations (Lozinski et al. 1991)—which is the result of the tectonic extension and downfaulting. From about 30 million to 1 million years ago, the trough filled with sediments (sand, clay, silt, gravel, and cobble) collectively referred to as the Santa Fe Group. About a million years ago, Post-Santa Fe sediments were deposited during a series of incision and backfilling episodes. The most recent backfilling episode has deposited as much as 60 m (200 ft) of the youngest valley fill (Hawley and Haase 1992). The type of deposited material, and its location, is not uniform throughout the trough. Typically, the sediments deposited on the valley floor by fluvial (river) processes intertongue with the pediment-slope (upland) deposits (Thorn et al. 1993). The cross section also shows blocks of uplifts on either side of and parallel to the valley, slightly angled away from the valley's vertical plane. Some of these, mainly to the east such as the Sandia Mountains, rise thousands of feet above the surrounding terrain. Then, principally to the west, comparatively recent volcanic material is deposited atop the uplifts. The escarpments that parallel the valley are the product of additional movement along the major fault zones.

The valley is actually a series of basins. These grabens (depressions) formed a series of linked, but slightly offset, depositional basins, each of which contained its own ephemeral lake. Over time, the surface water eroded canyons between the intervening bedrock sills that defined the basins, integrating the area into the Rio Grande river system (Bullard and Wells 1992). The through-flowing ancestral Rio Grande drainage developed into a single river about 5 million years ago (Lozinski et al. 1991). The basins in the Middle Rio Grande (which roughly coincide with the four river reaches referred to in this report) are:

Santo Domingo Basin	White Rock Canyon to San Felipe
Albuquerque Basin	San Felipe to Isleta
Belen Basin	Isleta to San Acacia
Socorro Basin	San Acacia to San Marcial

The rift continues to be geologically active with manifestations of seismic activity. The strongest earthquake on record occurred north of the valley near Santa Fe in 1918 (Lagasse 1980). Over the past century there has been considerable, but localized, seismic activity in the Albuquerque to Socorro area. These events are thought to be the result of crustal deformation caused by a shallow magma body (Lagasse 1980). Various measurements indicate a 9-14 cm (3.5-5.5 inches) uplift of the valley in the Socorro area since the early 1900's (Lagasse 1980, Bullard and Wells 1992).

E. INSTITUTIONAL SETTING

The valley traverses four counties (Sandoval, Bernalillo, Valencia, and Socorro) and six Indian pueblos (Cochiti, Santo Domingo, San Felipe, Santa Ana, Sandia, and Isleta). In addition to the pueblos, the principal land and facility managers include the Middle Rio Grande

Conservancy District (MRGCD), BOR, COE, New Mexico Department of Game of Fish (NMDGF), FWS, New Mexico State Parks and Recreation Division/City of Albuquerque, and private landowners (Fig. 4).

1. Population

Thirty-eight percent (578,000 persons) of the State of New Mexico's population reside in the Middle Rio Grande Valley (U.S. Department of Commerce 1991). Of this population, 77% live in urban areas (communities and contiguous areas with populations greater than 5,000 persons). The principal cities and towns, and their respective 1990 populations, are:

Bernalillo	5,960
Rio Rancho	32,505
Albuquerque	384,734
Los Lunas	6,013
Belen	6,547
Socorro	8,159

2. Land Use

Irrigated agriculture, almost all of which is within the MRGCD boundaries, is the dominant active land use in the Rio Grande floodplain. In 1992, of 36,305 irrigable ha (89,711 acres), 23,281 ha (57,529 acres) were actively irrigated; another 4,944 ha (12,241 acres) were temporarily fallow or idle. There were 735 full-time farms within the MRGCD and 2,751 part-time farms (U.S. Bureau of Reclamation 1993a).

The MRGCD extends from Cochiti Dam to the north boundary of the Bosque del Apache NWR. The major functions of the MRGCD are to "divert, transport and deliver irrigation water efficiently to the water users, provide flood protection from the Rio Grande via properly maintained levees and provide subsurface drainage benefits to the valley by operating and maintaining the drains..." (Shah 1991). MRGCD boundaries encompass 112,407 ha (277,760 acres), of which 11,534 ha (28,500 acres) are pueblo lands.

Urbanization is steadily converting agricultural lands to other uses in the valley. This trend is most pronounced in the greater Albuquerque area, in the Bernalillo area, and in the Los Lunas/Belen area. Between 1975 and 1986, urban lands increased from 17.4% to 26.4% of the total MRGCD lands, with an increasing share coming from the conversion of agricultural lands (Dumars and Nunn 1993).

Various state and federal wildlife facilities have been developed in the Rio Grande floodplain. Included in Table 2 are the lands in the Middle Rio Grande Valley that assist in conserving wildlife and that provide educational and recreational opportunities.

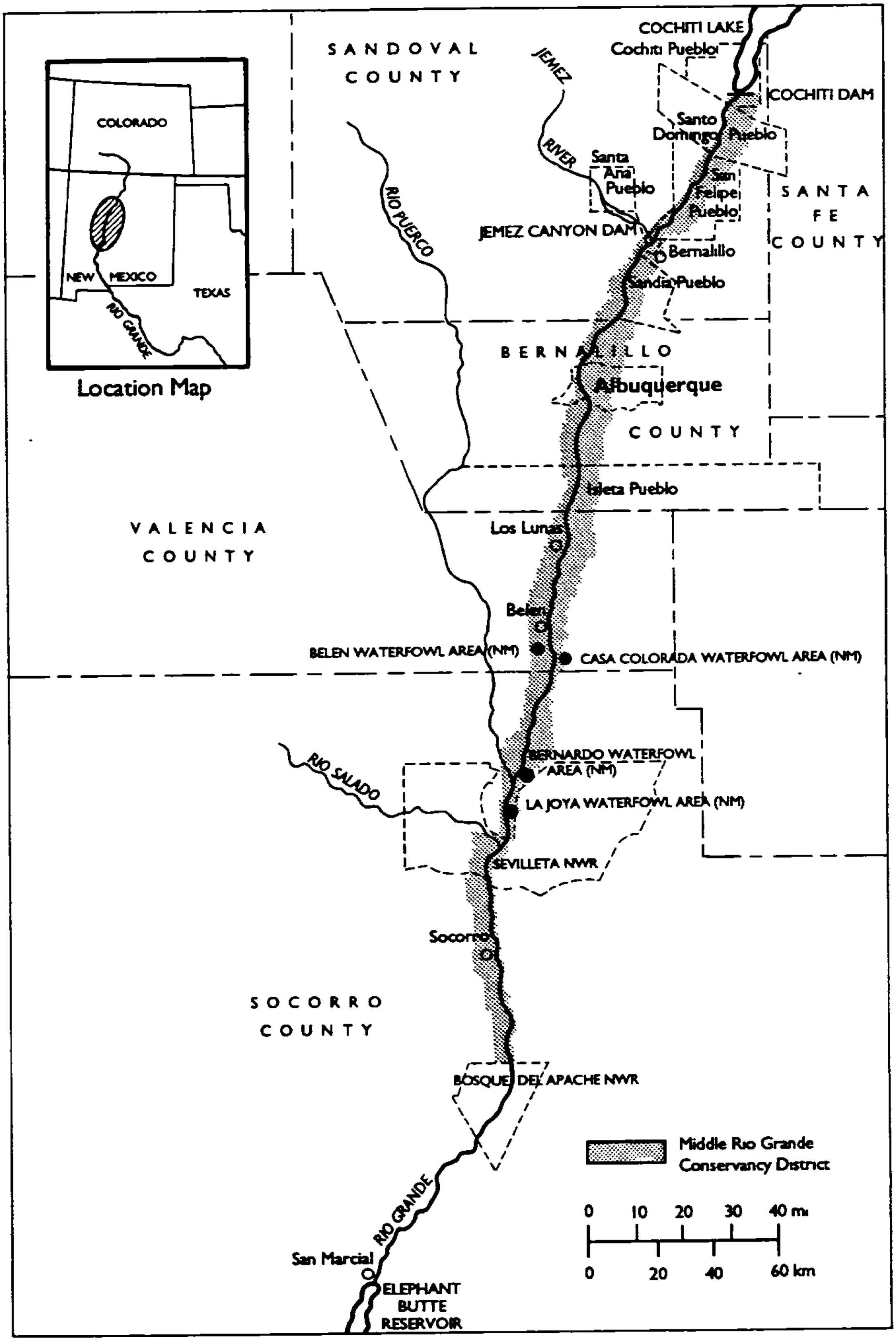

Fig. 4. Institutional boundaries in the Middle Rio Grande Valley.

Table 2. City, state, and federal lands in the Middle Rio Grande Valley that are dedicated to managing and conserving wildlife resources and that provide recreational and educational opportunities.

Facility	Location	When Acquired	Size	Function
City of Albuquerque				
Candelaria Farms	Located immediately N of Rio Grande Nature Center	1977	40 ha 100 acres	Provide winter feed for waterfowl
State of New Mexico				
Belen Waterfowl Area	3 km (2 mi) S of Belen on west side of Rio Grande	1958-82	100 ha 247 acres	Provide winter feed for waterfowl
Bernardo Waterfowl Area	42 km (26 mi) S of Belen on west side of Rio Grande	1971-81	679 ha 1,676 acres including 7 ponds	Waterfowl and upland game habitat and production of feed
Casa Colorada Waterfowl Area	11 km (7 mi) S of Belen on east side of Rio Grande	1981	171 ha 423 acres	Provide winter feed for waterfowl
La Joya Waterfowl Area	32 km (20 mi) N of Socorro on west side Rio Grande	1930-52	143 ha 353 acres including 6 large impoundments	Waterfowl and upland game habitat and production of feed
Rio Grande Nature Center State Park	2901 Candelaria Road, NW, Albuquerque	1982	109 ha 270 acres including 6 wetlands	Wildlife conservation and educational and recreational opportunities
Federal				
Sevilleta National Wildlife Refuge	Between Bernardo and Socorro on both sides of Rio Grande	1973	89,150 ha 220,200 acres	Managed in its "natural" state (no public use)
Bosque del Apache National Wildlife Refuge	29 km (18 mi) S of Socorro on both sides of Rio Grande	1939	23,154 ha 57,191 acres	Refuge and breeding ground for migratory birds and other wildlife

3. Water Management

There are many institutional and individual interests involved in the management of Rio Grande water, not only within the middle valley but also upstream and downstream.

Water in New Mexico is managed under state law as administered by the New Mexico State Engineer, and also under federal and international law. Because the Rio Grande is an interstate and international resource, mechanisms for allocating its waters were determined to be necessary. A treaty between the United States and the Republic of México was signed in 1906 which guarantees a minimum annual delivery of water to México. In 1939, 10 years after ratification of an interim agreement, the federal government, Colorado, New Mexico, and Texas ratified the Rio Grande Compact, which allocates water between the three states.

In addition to the New Mexico State Engineer's Office, other principal water management entities active in the area include, but are not limited to: MRGCD (irrigation water delivery), BOR (water delivery), COE (flood control), Rio Grande Compact Commission, and the International Boundary Water Commission. Obviously, those individuals and entities holding the rights to use water (pueblos, City of Albuquerque and other municipalities, wildlife refuges, etc.) are also critical participants in the Middle Rio Grande Valley water management community. And the larger citizenry, represented by various interest groups, is becoming increasingly involved in water management decisions.

III. HISTORICAL CONDITIONS

A. CLIMATE

There is no evidence which indicates any major climatic changes, at least in the northern portion of the valley, in the last 5,000 years (Cully 1977). Consistent with this statement, however, are indications of climatic variability. From about 4,000 to 8,000 years ago, the climate was warmer than present and, in some locales, drier. From the mid-14th to mid-19th centuries, temperatures were, on the average, a few degrees cooler than those experienced today (D. Scurlock, pers. comm.). Conditions in most of the western United States were drier from 3,500 to 2,500 years ago, followed by peaks of drought conditions (Cully 1977).

Meteorological records and tree-ring analyses indicate that, at least in the northern portion of the valley and in the corresponding contributing drainages, the years roughly between 1905 and 1920 were the wettest 15 years in the last two and half centuries (deBuys 1985). Other significant departures from the norm in this century include the extremely high precipitation year of 1941 and the 1951-56 drought. National Oceanographic and Atmospheric Administration data for Socorro, 1931-86, show that total precipitation in 1941 was 44.8 cm (17.7 inches) or 195% of average, and that the average annual precipitation for 1951-56 was 16.2 cm (6.4 inches) or about 70% of average. The low year of record was 1956 at 7.7 cm (3.0 inches). In addition, precipitation records for Santa Fe (1850's to present) do not indicate a long-term trend in total annual precipitation. They do suggest that from the 1850's through the 1920's rainfalls greater than 1.25 cm (0.5 inches) became progressively more frequent, with the trend peaking in the 1920's. Since then, despite the large interannual variations, this trend has reversed (Graf 1991).

This information demonstrates the extreme variability of precipitation in the valley, which influences not only the hydrology of the Rio Grande but also the general environmental conditions of importance to the biological condition of the valley's ecosystem.

On the whole, however, the climate of the area was arid to semiarid, as it is today, and over the past 5,000 years it has been subjected to drought/wet-year cycles comparable to those documented in historic times (Fig. 5). El Niño and La Niña events over the past 50 years are also shown in Fig. 5. The El Niño/La Niña phenomenon is caused by periods of variation in water temperatures and barometric pressures in the eastern Pacific Ocean (Molles et al. 1992) There are strong correlations between El Niño years and high spring flows in New Mexico's Pecos and Gila rivers (Molles and Dahm 1990) as well as for flooding episodes in Arizona (Webb and Betancourt 1990). This relationship apparently is also true for the Middle Rio Grande Valley.

B. GEOLOGY

Incision of the middle valley has been cyclic, with at least three major cycles of downcutting-backfilling-stabilization. These processes led to the formation of gravel, sand, and silt terraces 10-55 m (30-175 ft) above the current floodplain (Wilkins 1986). It is estimated that the maximum entrenchment of the Rio Grande occurred about 11,000 to 22,000 years ago (Wilkins 1986), at a depth 18-40 m (60-130 ft) below the current valley floor (Hawley 1969).

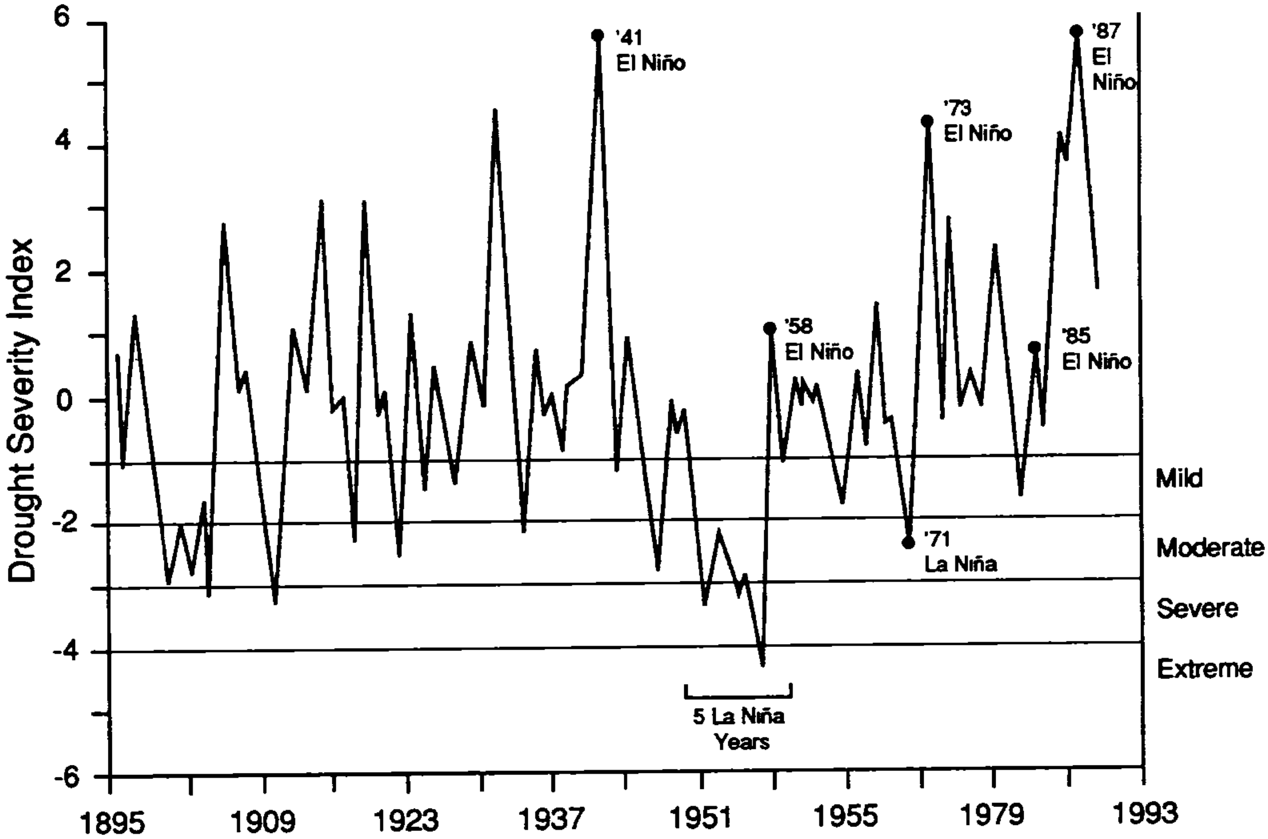

Fig. 5. Drought severity index 1895 through 1988 and El Niña and La Niña events over the past 50 years for the Middle Rio Grande Valley (after U.S. Army Corps of Engineers 1991).

Since that time, the valley has slowly been aggrading (Leopold et al. 1964, Hawley et al. 1976). This aggradation is due to tributaries contributing more sediment than the Rio Grande system can remove from the middle valley (Thorn et al. 1993). There is no evidence, however, that the general morphology of the Middle Rio Grande Valley has significantly changed over the past 5,000 years (J. Hawley, pers. comm.).

C. HYDROLOGICAL RESOURCES

1. Surface-water Hydrology

The river has been a focus of human settlement and development since prehistoric times. This section addresses the hydrologic resource trends from about 5,000 years ago up to the present. A thorough description of the current conditions and the contemporary water management physical infrastructure is presented in the following section. Generally the Middle Rio Grande was a braided, slightly sinuous aggrading river with a shifting sand substrate. In the past, as now, the slope of the riverbed decreased from north to south and the tributaries'

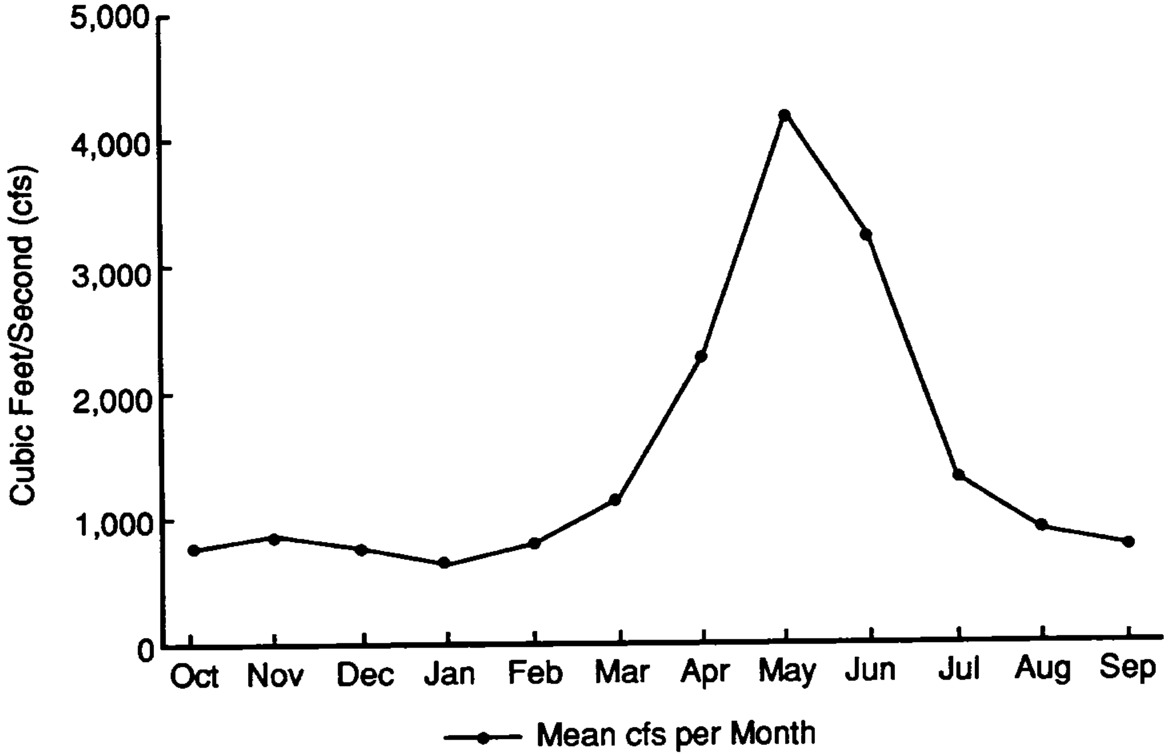

Fig. 6. Mean monthly discharge in cubic feet per second (cfs) of the Rio Grande at the Otowi gauge above Cochiti Lake (U.S. Geological Survey data, 1895-1991).

contributions of water and sediment were important in defining the river's local and overall morphology.

Because there were no diversions and because of the relative hydrologic stability of the system, we believe that the Rio Grande generally supported perennial flows. Exceptions could have occurred during periods of prolonged drought and would have been more prevalent farther downstream. With no water regulation, the river's hydrograph would have reflected the seasonal events of snowmelt runoff and summer/fall precipitation (Fig. 6; note that these river discharge records do not reflect "natural" flows because upstream storage and diversions were already in place during the period of record, but they do indicate the general shape of the hydrograph).

The total flow in the Middle Rio Grande also fluctuated from year to year in response to annual climatic variability. Figure 7 graphs the total annual Rio Grande flows at the Otowi gauge above Cochiti over the past 100 years. Although these data also include the effects of human water management practices, they too are indicative of this annual variability.

As human settlement and irrigated agriculture expanded in the middle valley and upstream in the Upper Rio Grande Basin, more irrigation water was diverted from the river reducing total river discharges. The further downstream one proceeded in the system, the less water there was. Prior to the construction of storage and flood control facilities, diversions from the Rio Grande

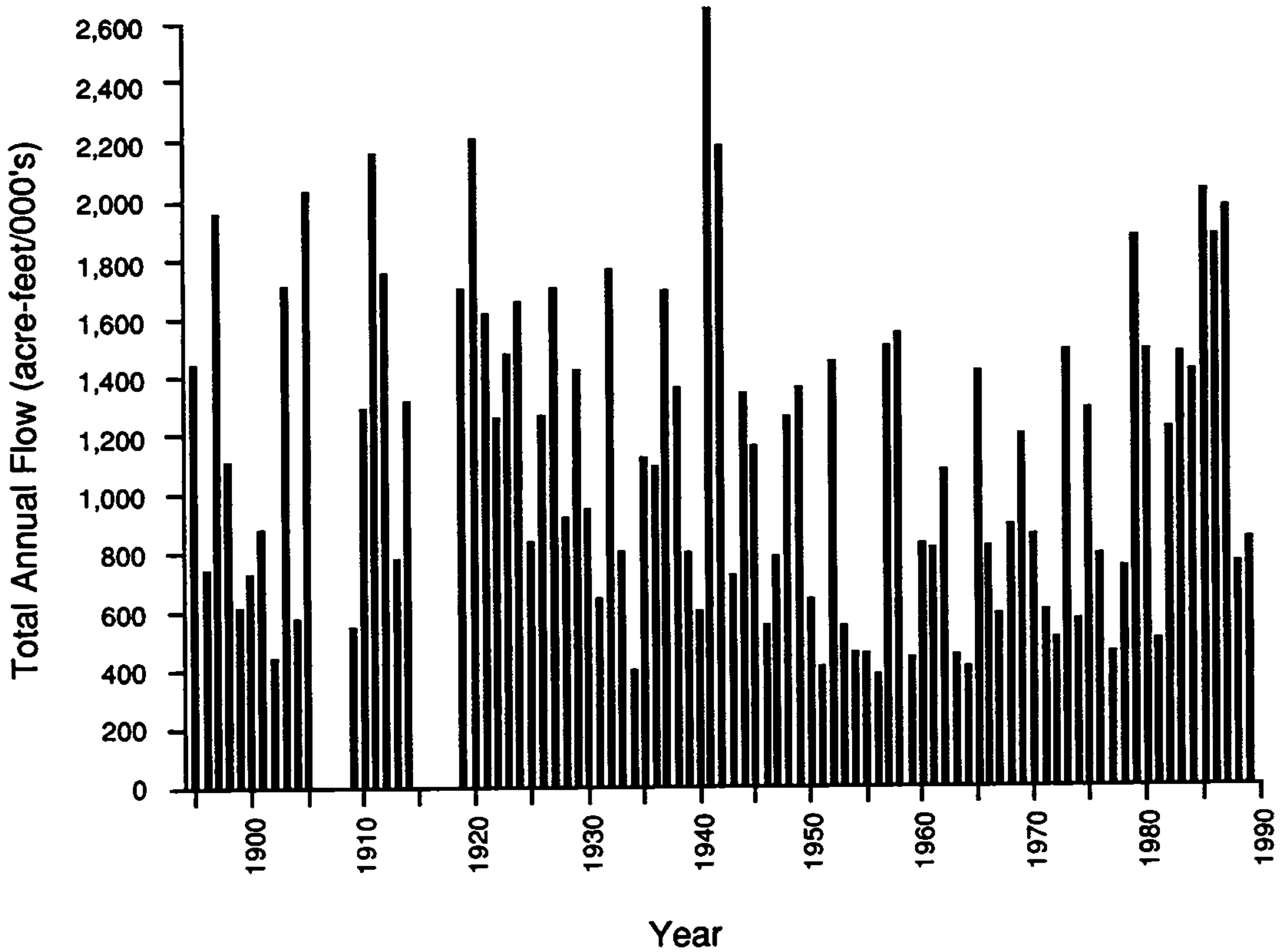

Fig. 7. Total annual flow, Rio Grande at the Otowi gauge (from Allen et al. 1993).

and some of its tributaries were limited to the growing season. Other seasonal flows, peak runoff, and precipitation flows were not affected. By 1913, storage reservoirs near the headwaters of the Rio Grande had been built, and in 1935 the MRGCD completed El Vado Reservoir on the Rio Chama (Shupe and Folk-Williams 1988). These facilities began to take the peaks off of some of the high river discharges and to increase the duration of lower flows. The expansion of these reservoirs and the addition of the flood and sediment control dams and reservoirs further accentuated this trend.

Other water management facilities have influenced the hydrology of the Middle Rio Grande. The 120-km (75-mi) long Low Flow Conveyance Channel, its downstream half operational in 1954 and its full length completed in 1959, reduced flows in the river channel in the Socorro Reach. The San Juan-Chama Project, completed in 1971, imports up to 110,000 acre-feet of San Juan River water from the Colorado River Basin to the Rio Chama/Rio Grande basins, 69,100 acre-feet of which is delivered to or through the middle valley. The effect of this importation has been to increase mean daily flows. In addition, the City of Albuquerque's annual treated wastewater discharge into the Rio Grande is currently about 60,000 acre-feet (R. Hogrefe, pers. comm.).

2. River Morphology

In all discussions regarding river morphology, it is important to recognize the differences within spatial and temporal scales. To describe a river system as being in a state of dynamic equilibrium (or energy balance) does not mean that it is static. To the contrary, this equilibrium results from a collection of processes that are by definition predicated on change. For example, even during periods when the entire river system is considered to be in a state of dynamic equilibrium, changes constantly occur in subareas as small as the outside bank of a meander, or as large as many river kilometers (or miles) upstream and downstream from a tributary inflow. Likewise, this state of dynamic equilibrium can accommodate climatic deviations from the norm that persist for periods ranging from several decades to 1-day flood events. Also, a river cannot distinguish between natural and human-caused perturbations. The geomorphic processes triggered in response to a change in the magnitude or duration of a variable, regardless of the cause, will be the same (Leopold et al. 1964). The river constantly adjusts, always trying to establish a new equilibrium between its discharge and sediment load (Bullard and Wells 1992).

Prior to measurable human influence on the system, up to the 14th century (Biella and Chapman 1977), the river was a perennially flowing, aggrading river with a shifting sand substrate. As stated, its pattern was, as a rule, braided and slightly sinuous.[1] The river would freely migrate across the floodplain, the extent being limited only by the valley terraces and bedrock outcroppings. The Rio Grande's bed would aggrade over time; then, in response to a hydrologic event or series of events, it would leave its elevated channel and establish a new course at a lower elevation in the valley. This process is called river avulsion (Leopold et al. 1964). Although an aggrading system, the Rio Grande was in a state of dynamic equilibrium, providing periods of stability that allowed riparian vegetation to become established on riverbanks and islands alternating with periods of instability (e.g., extreme flooding) that provided, by erosion and deposition, new locations for riparian vegetation.

The Rio Puerco was not as stable as the Rio Grande over the last 5,000 years. The Rio Puerco's valley floor aggraded more than 3,000 years ago. Since that time, at least three major channels have been cut and filled. The entrenchment of the lower Rio Puerco in forming its present configuration occurred episodically since at least the 1760's (Love and Young 1983). This resulted in fluctuating levels of sediment being exported to the Rio Grande, with the river's morphology adjusting to the variations.

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[1]A braided pattern for the ancestral Rio Grande is not inconsistent with the evidence that large river fishes, such as the shovelnose sturgeon and longnose gar, once inhabited at least portions of the Rio Grande (Koster 1957, Sublette et al 1990). A perennially flowing, braided river could well have maintained at least minimally adequate riverine habitat for these fishes even during low flow periods During prolonged periods of drought (if the lower reaches did temporarily dry up), the fishes could have migrated upstream in the system to areas where there were perennial flows

The earliest phase of significant water development activities (from about A.D. 1400 through the early part of this century) progressively decreased river flows as irrigated agriculture increased. More influential on the morphology of the river, however, was the increased sediment deposition into the system resulting from land-use activities in the watershed. When coupled with natural climatic variability, the net effect was to accelerate the raising (aggradation) of the riverbed and, accordingly, the frequency of overbank flooding and the river avulsion. The channel configuration, while still braided and sinuous, began to broaden and became shallower. Because of the increasing rapidity of channel movement, riverbanks and islands were as a rule less stable. This likely contributed to an increased frequency of floods. Between 1822 and 1941, a total of 46 moderate to severe floods was recorded along the reach (D. Scurlock, pers. comm.). During nonflood periods, diminished river flows caused the active channel to retreat to fewer, narrower channels within the wide and shallow sandy riverbed.

During the next phase of human interaction with the river, from the mid-1920's through 1950, a system of levees were constructed to constrain the river to a single floodway through portions of the middle valley. Concurrently, water diversions in the middle valley and upstream in the Rio Grande Basin increased. This had the net effect of further accelerating channel aggradation, especially in those areas where levees concentrated the deposition of sediment in the floodway.

In the contemporary phase of human water management beginning in the early 1950's, the sediment and flood control structures constructed in the upper portion of the Middle Rio Grande Valley accelerated the reversal of channel aggradation in the Cochiti and Albuquerque reaches. The lowering riverbed is resulting in a more incised and sinuous single-channel river (see Fig. 8 for a visual example in the Belen Reach). This process becomes less pronounced with downstream distance from Cochiti and Jemez Canyon dams. The reduction of the peak flows, both spring runoff and summer/fall precipitation events, however, has had an opposite effect where unregulated tributaries and arroyos such as Calabicillas Arroyo discharge into the Rio Grande. Adequate flows are not available to transport the sediment. Sediment deltas are more persistent; they reduce river gradient upstream (tending to increase aggradation) and increase the gradient downstream (tending to reduce aggradation).

The channel modification program, described above, immediately affected the river's channel morphology. To increase the water delivery efficiency and flood flow capacity within the floodway the BOR initiated the program in 1953. Although the techniques have evolved over the years, the program continues. Within the stabilized floodway, reaches of the Middle Rio Grande have been straightened, the irregularity of the channel width has been reduced, and the riverbanks have been stabilized.

3. Ground Water

Historically, as now, a strong hydraulic connection existed between the surface- and ground-water systems. Ground-water inflows to the valley from the margins of the basins sloped toward the center of the valley and supplemented the Rio Grande flows (U.S. Bureau of Reclamation 1977). In reaches where the riverbed had aggraded above the elevation of the surrounding terrain, the river discharged to the ground-water system, locally elevating the water table. And

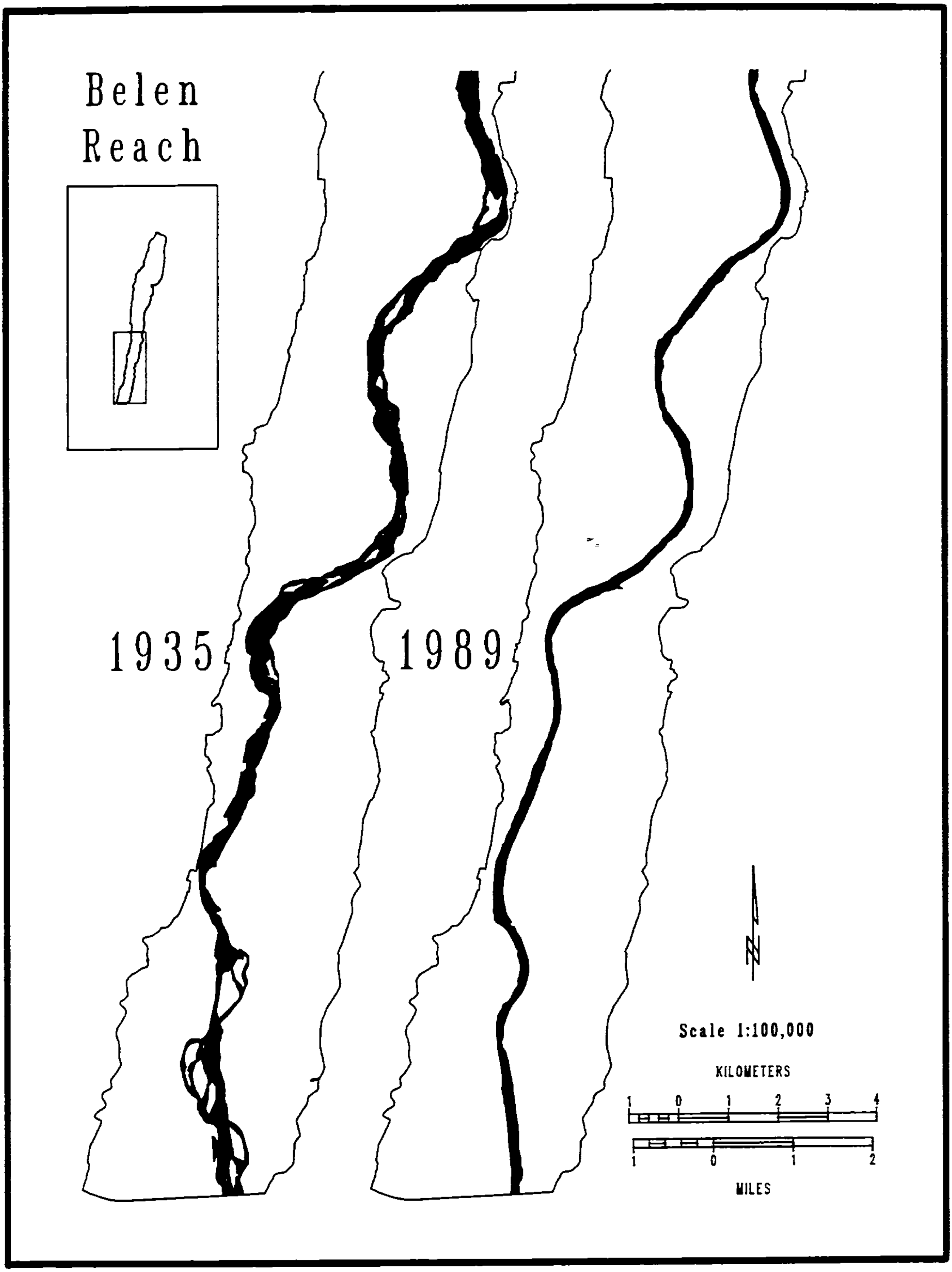


Fig. 8. Changes from braided to single channel, 1935-89, portions of Belen Reach, Middle Rio Grande.

in those areas where there were topographic depressions, possibly resulting from previous hydrologic events, the water table was at or above the ground surface as manifested by springs, marshes, wet meadows, etc.

In the 1880's and 1890's, however, the shallow ground-water level throughout portions of the valley rose dramatically. This was caused by a combination of factors. The riverbed was continuing to rise in response to increased sediment deposition in the river, thereby draining to the lower terrain; water was being distributed throughout the valley for irrigated agriculture, enhancing ground-water recharge; and irrigation return flows could not drain into the elevated river channel. A manifestation of this waterlogging of valley lands was a precipitous drop in irrigated agriculture from 1880 to 1925 (Lagasse 1980).

Between 1925 and 1936, the MRGCD completed a system of drains that parallel the river. The result was to lower the water table by 1.5 m (5 ft) or more in 70% of the valley (Shah 1991). During low flow periods, the Low Flow Conveyance Channel in the Socorro Reach also acts as a deep drain to withdraw ground water from the shallow valley fill (Ong et al. 1991).

Ground-water extraction has increased markedly during this century. In addition to individual domestic wells and smaller municipal systems in the valley that increased proportionally with the population, the City of Albuquerque, and to a lesser extent Kirtland Air Force Base, developed an extensive system of wells to serve its growing population with municipal and industrial water. In the late 1920's, the City of Albuquerque completed its Main Well Field in the Rio Grande floodplain, yielding about 3,000 acre-feet per year (Thorn et al. 1993). After 1958, however, the city began developing well fields outside of the floodplain; and in recent years, most of the ground-water withdrawal has been east of the floodplain (Thorn et al. 1993). From 1960 to 1990, the City of Albuquerque's ground-water pumping increased from 42,000 acre-feet to about 118,000 acre-feet annually, and is projected to steadily increase at about 1.5% per year for the next 40 years (Summers 1992). Between 1960 and 1992, ground-water levels between the Sandia Mountains and the Rio Grande declined by 42 m (140 ft) in the east Albuquerque area (Thorn et al. 1993). The drop in the ground-water level gradually diminishes in a radial configuration as one proceeds towards the Rio Grande and to the north and south as well (Lance et al 1990, Logan 1990, Thorn et al. 1993). This has had the effect of reversing the ground-water gradient away from the river in some locales.

Taking into account all ground-water uses in the ground-basin from Cochiti Lake to San Acacia, the net decrease in storage due to ground-water withdrawal from 1960 to 1992 is estimated to be 994,000 acre-feet (Thorn et al. 1993).

D. HUMAN SETTLEMENT, USE, AND DEVELOPMENT

The Rio Grande Valley has served as a major travel corridor and habitation center from the time of earliest human occupation of New Mexico. As with subsequent inhabitants, these early people were attracted to the area by the diverse resources of the river valley, the nearby Sandia and Manzano mountains, and the surrounding grasslands. The earliest human beings in the Middle Rio Grande Valley arrived about 11,000 to 15,000 years ago, toward the end of the last ice age. These early people hunted some animals that are extinct today, such as the mammoth, tapir, and sloth. By about 5000 B.C. these animals had disappeared and, until the introduction of agriculture about A.D. 400, subsistence was based on increased utilization of wild plants and hunting of modern fauna. Nomadic hunters and gatherers moved in small bands up and down the valley and across the grasslands and foothills in search of animals and food plants (Scurlock 1988). Valley resources sought by these early native Americans consisted of small mammals, rabbits, deer, beaver, raccoons, porcupines, small birds, waterfowl, cranes, herons, turtles, frogs, toads, snakes, and lizards. The river was habitat for shovelnose sturgeon (*Scaphirhynchus platorynchus*), longnose gar (*Lepisosteus osseus*), American eel (*Anguilla rostrata*), flathead catfish (*Pylodictus olivaris*), smallmouth buffalo (*Ictiobus bubalus*), blue catfish (*Ictalurus furcatus*), and river carpsucker (*Carpoides carpio*). Many plants were collected, some for food and others for medicinal purposes, shelter, tools, weapons, and baskets. Because these small bands moved over such a large area, use of a given location was relatively minimal, and fauna and flora presumably recovered rapidly (Scurlock 1988). The possible burning of the cottonwood forest to drive game out into the open and to clear land for crops would have removed some stands of cottonwood.

With the advent of agriculture, this nomadic type of existence in the valley came to a close. People became more sedentary, and their villages steadily increased in size and complexity. Requiring a permanent water supply for their crops, settlements became concentrated near the Rio Grande and its tributaries. These prehistoric farmers were the Anasazi whom the later Spanish named Pueblo Indians. The magnitude of the first human influence on the river and its bosque was probably minimal, but it increased proportionally as populations increased. Beginning about A.D. 1350, an era of great population increase and development began in the Middle Rio Grande Valley (Biella and Chapman 1977).

The first significant impact on the bosque by humans probably began at this time of significant population increase and associated development by the Anasazi. This impact principally resulted from its clearing for cultivated agriculture and the diversion of water from the Rio Grande and its tributaries for irrigation of crops. Accompanying this clearing was the construction of diversion works and a network of irrigation ditches to convey water from the river to crops. The diversion works most likely consisted of brush and boulder structures which would have washed away during flood events (Graf 1991). Alluvial fans at the mouths of tributary arroyos were probably also cultivated using runoff water. Irrigation likely began with the harvesting of precipitation runoff and hauling water for waffle gardens. As technology advanced, increasing amounts of water were diverted from the Rio Grande.

When the first Europeans, led by Don Francisco Vasquez de Coronado, entered the middle valley in 1540, an estimated 10,122 ha (25,000 acres) of land were being farmed (Burkholder 1928). The earliest written description of the valley near Albuquerque was by one of Coronado's chroniclers: "This river of Nuestra Senora flows through a broad valley planted with fields of maize and dotted with cottonwood groves. There are twelve pueblos, whose houses are built of mud and are two stories high" (Bolton 1964).

Following the Spanish colonization that began in 1598, human influence on the Middle Rio Grande Valley increased markedly as more land was cleared of riparian vegetation and more water was diverted from the Rio Grande for farming by the growing European settlements along the river. Under Spanish influence, more canals and acequias (irrigation ditches) were developed to bring water to the fields. By 1700, the area of irrigated land had increased to about 29,800 ha (73,600 acres) and by 1800, to about 40,650 ha (100,400 acres; Stafford et al. 1938).

By about 1850, valley communities were generally established in their present locations. The post-American Civil War influx of Anglo-Americans into Colorado's and New Mexico's Rio Grande Basin, along with the arrival of the railroad in 1879-80 which opened distant markets for agricultural goods, further accelerated diversions, sediment loading, and conversion of floodplain land to agriculture. These changes had a correspondingly significant change in the character of the river, riparian vegetation, and animal communities. Cycles of increased rainfall further exacerbated sediment inflow to the Rio Grande in the 1880's, the same period of intense land use in tributary watersheds (Lagasse 1980).

By about 1880 a maximum development of about 50,607 ha (125,000 acres) in the middle valley was under cultivation (Burkholder 1928); when the Upper Rio Grande Basin is taken into account, the maximum was reached in the late 1890's (Bullard and Wells 1992). During this period the economy of most settlements along the river was based on irrigated farming in the floodplain and livestock grazing on the adjacent grassland. After this peak, there was a pronounced regression in the amount of land being farmed. Follett (1898) reported 12,830 irrigated ha (31,700 acres) in the Middle Rio Grande Valley in 1896. By 1925 only about 16,190 ha (40,000 acres) were being irrigated (Burkholder 1928) and in 1926-27 about 18,220 ha (45,000 acres). This reduction was caused by a progressive increase in shallow ground-water levels, increased salinity of the soil, and a decreasing supply of water for irrigation. A diversion of labor from agriculture to railroad construction also contributed to the reduction in land being farmed and irrigated (Follett 1898). The high water table resulted from extensive irrigation (both leakage from the extensive system of unlined ditches and from applied water), recurring floods, and an aggrading riverbed (Burkholder 1928). This aggradation resulted in an increase in the frequency of flooding and saturation of the surface of the floodplain, but also raising the water table. Aggradation and high sediment loads were the result of increased erosion of the watershed due to overgrazing, deforestation, and a decrease in the volume of water to convey sediment downstream. Also, numerous high runoff years in the early part of the century likely accelerated the erosion of soil from a deteriorated watershed. A decreasing supply of water for irrigation was a result of more intensive farming upstream, especially in the San Luis Valley, and an accompanying increase in diversion of water for irrigation. Lee (1907) described the Rio Grande above El Paso, Texas, as essentially a storm-water stream, subject to great and sudden floods.

Figure 9 gives an historical perspective of the area of land irrigated in the middle valley and indicates the rate of change experienced in the floodplain due to human influence.

The period of increasing settlement and development up to about 1846 saw an increase in human utilization of the plant and animal resources of the Rio Grande Valley. More of the floodplain vegetation was cleared for farming, and cottonwood trees were rapidly removed to provide building timber, fence posts, and fuelwood. Historical accounts on the condition of floodplain vegetation and animals by trappers, explorers, naturalists, and military expeditions (J.O. Pattie 1824, Josiah Gregg 1839, Lt. W.H. Emory 1846, F.A. Wislizenus 1846, Lt. J.S. Abert 1846, William Bell 1867) noted the general poverty or absence of trees throughout the range of

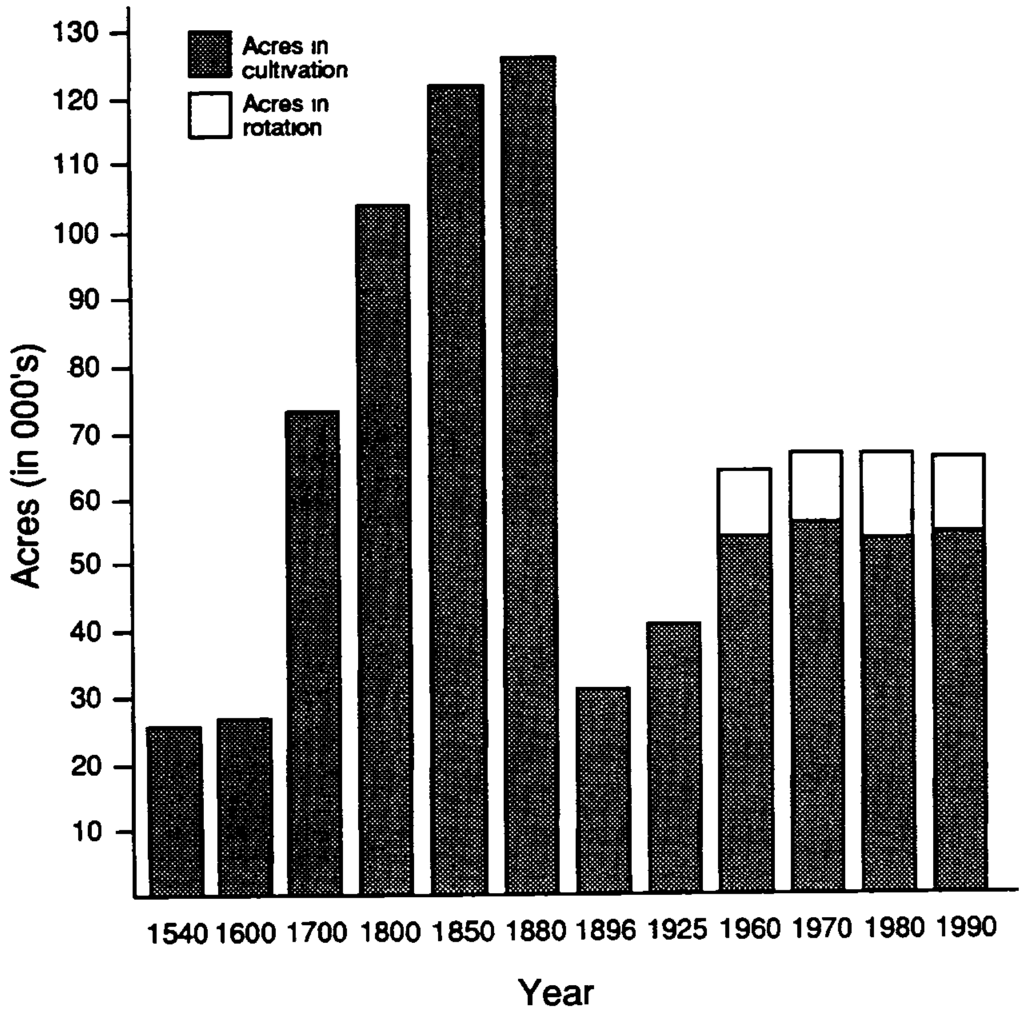


Fig. 9. Historical account of acres of land under cultivation in the Middle Rio Grande Valley (acres/2.47 = hectares).

human settlements in the middle valley, with the frequency and size of cottonwood stands generally increasing from Isleta Pueblo to San Marcial. In Abert's 1846 description of floodplain vegetation he noted an absence of trees near human settlements: there was no wood to be had within 14.5-16.0 km (9-10 mi) of Albuquerque. Abert also wrote "From Joya we observed quite a change in the appearance of the country. The river banks are now heavily timbered with cotton wood" (Abert 1962). The sparsity and absence of cottonwood trees were attributed not only to human activity such as cutting cottonwood for firewood and construction, but also to the meandering and flooding of the river which frequently changed its course, resulting in cyclic destruction and regeneration of cottonwood stands. Intensive livestock grazing statewide during this time period also undoubtedly reduced plant cover, especially grasses, forbs, and shrubs. By 1880 there were over 2,000,000 sheep, over 150,000 cattle, and about 50,000 horses, mules, and burros utilizing the rangelands of the Rio Grande valley and adjacent mesas and mountains from La Bajada (head of the middle valley) to El Paso (D. Scurlock, pers. comm.). Much of the heavy utilization of the cottonwood forest had subsided by the beginning of the 20th century, largely due to new energy sources and alternate timber sources.

Water management facilities were increasingly constructed on the Rio Grande in support of irrigated agriculture and associated floodplain development. Numerous upstream and downstream facilities had been constructed along the Rio Grande prior to 1900. By 1913, several water supply dams and reservoirs had been built in the Rio Grande headwaters in southern Colorado (Shupe and Folk-Williams 1988). Elephant Butte Dam at the lower end of the Middle Rio Grande Valley was completed in 1916.

Because of concerns over the decrease in irrigated land in the Middle Rio Grande Valley resulting from water shortages, poor drainage, inadequate irrigation facilities, and periodic flooding, the MRGCD was formed in 1925. The goal of the Conservancy District was to provide the middle valley with a complete and efficient irrigation system and drainage and flood control facilities. Main features of the resulting plan of improvement were a dam and storage reservoir at El Vado on the Rio Chama, six diversion dams or headings located in the middle valley, 555 km (345 mi) of drainage canals, 290 km (181 mi) of river levees, 400 km (250 mi) of main irrigation ditches, and rehabilitation of almost 640 km (400 mi) of old irrigation ditches (acequias). The protective levees, constructed of earth excavated from the riverside drains and pushed up from adjacent land, were about 2.5 m (8 ft) above the riverbed and created a floodway about 460 m (1,500 ft) wide. Construction of these facilities was initiated in 1930 and completed by 1936.

The work of the MRGCD did much to improve distribution of irrigation water and reduce the waterlogging of lands within the valley. Their efforts are the reason why agriculture is productive today in the middle valley. However, while successful with drainage and irrigation, the flood control system did not fare as well. A major flood in 1941 breached and overtopped parts of the levee system and inundated parts of Albuquerque and other river communities. It was clearly evident that the floodway would not afford the protection it was designed to provide.

Because of the lack of adequate flood protection and other factors (water shortages for irrigation, streambed aggradation, siltation of ditches, rising water tables, financial difficulties, and increasing urbanization), the COE and the BOR jointly began studies in 1943 into the potential for rehabilitating and further developing the land and water resources and protecting levees and property in the middle valley. The results of these studies were reported as the Rio Grande Comprehensive Plan (Comprehensive Plan). This plan proposed a system of flood control reservoirs on the Rio Grande and its tributaries near the head of the middle valley and the existing floodway. The plan was subsequently authorized by the Flood Control Act of 1948. Under the Comprehensive Plan the COE was responsible for constructing flood control reservoirs; for rehabilitating, modifying, and extending the levee system constructed by the MRGCD; and providing the necessary bank and levee protection works. The BOR was responsible for clearing a floodway and installing jetty fields to confine the river to a well-defined, stable channel and rehabilitating existing drainage and irrigation facilities.

Implementation of the Comprehensive Plan by the COE and subsequent authorization resulted in the construction of four upstream dams that function in flood control, sediment retention, fish and wildlife enhancement, and recreation. Another component of the plan was the "Rio Grande Floodway Project" constructed jointly by the COE and the BOR. The project consisted of clearing a floodway to a width comparable with hydraulic and sediment transport characteristics of the Rio Grande; channel straightening; installation of intermittent jetty fields to stabilize the channel and, in combination with riparian vegetation, protection of levees from floodflows; and levee enlargement and construction.

E. BIOLOGICAL RESOURCES

1. Plant Communities

Prehistoric

Much of the modern southwestern vegetation may have developed by the Pliocene, about 5 million years ago, with a proliferation and amplification of plant communities (Axelrod 1948). Ancestors of modern species in rift valleys were likely present in the mid-Miocene, about 14 million years ago (Axelrod and Bailey 1976, Meyers 1983). Fossil evidence indicates that the Rio Grande cottonwood forest that existed about 2 million years ago during the early Pleistocene was well developed and structurally similar to that known by humans 10,000-20,000 years ago (Knight et al. [undated]). Because of the colder, wetter climate that existed at that time, species now found in higher and wetter altitudes such as birch (*Betula* sp.) and western chokecherry (*Prunus virginiana*) also formed part of the plant community in the Middle Rio Grande Valley. Cattails (*Typha* sp.) grew around the edges of ponds and oxbows, much as they presently do.

There is no documented description of the valley prior to its use for farming by early Pueblo Indians. However, based on anecdotal descriptions of the valley by early Spanish explorers, knowledge of hydrologic and biological processes, the biological and archaeological record, and characteristics of present plant communities, a hypothetical description can be made.

The prehistoric, and historic, range of the Rio Grande cottonwood (*Populus fremontii* var. *wislizenii*) was probably similar to its current range. It grew on streambanks and in valleys at altitudes ranging from 760 to 2,130 m (2,500 to 7,000 ft) in what is now southern Utah and Colorado, in the Rio Grande Valley and its tributaries in New Mexico, and south into the Trans-Pecos area of Texas. In Mexico it was present in the States of Chihuahua and Sonora (Vines 1976).

Historic

As stated, the floodplain that existed prior to substantial human alteration, and probably for some 5,000 years prior to the arrival of Europeans, was characterized by a braided, slightly sinuous river that broadly meandered laterally within the 2-6 km (1-4 mi) wide floodplain. The river was bordered by a continually changing mosaic of cottonwood and willow (*Salix* sp.) stands of varying ages, sizes, and configurations, interspersed with more open areas of grass meadows, ponds, small lakes, and marshes. The Rio Grande was likely a larger, deeper river that was perennial throughout its course in New Mexico. It probably carried less sediment than the heavy load that was present in the last three decades of the 19th century and early 20th century, which was undoubtedly reflected in a more stable channel. Its bed was likely sandy with some pebble gravel, but above the confluence of the Jemez River gravel and cobbles were more common. Numerous islands were present, some ephemeral and some that survived for longer periods. The level of ground water should have been high because of perennial flow, restricted drainage, and frequent flooding.

The discontinuous groves of cottonwood trees that were present when Europeans arrived were probably associated with a few species of shrubs that grew in their shade or along edges of the groves. Coyote willow (*Salix exigua*) formed thickets in clearings and along the river's edge, and tree willows (*Salix gooddingii* and *S. amygdaloides*) grew in shadier locations. New Mexico olive (*Forestiera neomexicana*), baccharis (*Baccharis wrightii*), false indigo bush (*Amorpha fruticosa*), wolfberry (*Lycium andersonii*), and mesquite (*Prosopis* sp.) formed a shrub understory in isolated locations. Very little herbaceous vegetation was likely present because of shading and the scouring effects of flooding.

Wetlands in the form of small lakes, marshes, and meadows were probably a significant component of the floodplain biological community. Early Spanish accounts frequently mentioned large sloughs and marshes (D. Scurlock, pers. comm.). Plant communities were likely similar to those described by Van Cleave (1935). The shallow water margins of small lakes formed in oxbows or abandoned river channels grew cattails, sedges (*Carex* sp., *Eleocharis* sp.), rush (*Juncus* sp.), scouring rush (*Equisetum hiemale*), buttercup (*Ranunculus cymbalaria*), pepperwort (*Marsilea mucronata*), and mosquito fern (*Azolla mexicana*). The wet banks of these lakes were fringed with coyote willow and cottonwood. In the deeper water of these lakes there was a floating plant community of algae (*Spirogyra*, *Vaucheria*, *Oedogonium*) and duckweed (*Lemna minor*) while in shallow water there were submerged species of *Chara*, water-milfoil (*Myriophyllum spicatum*), and hornwort (*Ceratophyllum demersum*).

Wetlands with shallow water formed marshes, and the floating plant composition and distribution was likely similar to that of deeper bodies of water. Areas where the water table was at or near the surface and were high in salts had wet meadows consisting of sedges, rushes, reed (*Phragmites communis*), saltgrass (*Distichlis stricta*), and yerba-mansa (*Anemopsis californica*).

Flooding, either due to the melting of mountain snowpacks in the spring or from runoff from intense summer thunderstorms, and the presence of high ground water are prime determinants of the presence, diversity, age structure, distribution, and perpetuation of floodplain communities. Flood flows, whether light, moderate, or severe, create conditions that influence biological processes. Primary features of flooding include floodplain wetting, aggradation and degradation, scouring, and channel realignment. The presence and depth of ground water determine the composition of plant communities and distribution within the floodplain.

The erosional-depositional processes of the river promote forest and age diversity on the floodplain and its meandering process creates the distribution of the different communities and age classes. In places where the river has historically meandered frequently, stands undergo a cyclic process of frequent removal and regeneration, resulting in a relatively low mean stand age (Johnson et al. 1976 cited in Hink and Ohmart 1984). Stands nearer the river are frequently eroded away and do not attain sufficient age to reach advanced successional stages. Those trees near the outer edge of the floodplain, where the erosional effects of the river are less frequent, or stands nearer the river that have escaped removal (perhaps by aggradation within the stand) survive to attain maturity. Fire undoubtedly also played a minor role in the age structure, composition, and distribution of riparian plant communities.

These dynamic effects of flooding created and perpetuated a changing mosaic of cottonwood and willow forest, lakes, marshes, and meadows. This pattern of large-scale channel migration, annual flooding, and regeneration probably characterized the riparian ecosystem until around the 1920's (Hink and Ohmart 1984).

A Changing System

The beginnings of irrigated agriculture 1,500 to 2,000 years ago added a new dimension of change to river dynamics and the floodplain plant community. Floodplain vegetation was beginning to be cleared and replaced with crops, and water was diverted from the river to sustain these crops. Early Europeans intensified this pattern beginning in 1598, removing more vegetation for crops, fuelwood and building material, constructing irrigation systems, and pasturing with increasing numbers of livestock. Probably by the turn of the 18th century, there was less water than normal present in the channel due to upstream and local irrigation diversion, and more sediment than normal was being contributed to the channel due to a deterioration of the watershed caused by overgrazing and deforestation for timber and fuelwood (D. Scurlock, pers. comm.). This increase in sediment and reduction in river discharge caused the river channel to widen (up to 1.6 km [1 mi]), decrease in depth, and become more braided.

Although there are brief anecdotal accounts of the plants and animals of the middle valley by early Spanish Colonial and later Anglo explorers, the earliest detailed information of floodplain vegetation communities in the vicinity of Albuquerque was given by Watson (1912). He described two major floristic associations: (1) cottonwood forest, with a few willows and scattered clumps of baccharis and senna (*Cassia bauhinioides*), and on the ground rush (*Juncus balticus*), clover (*Trifolium longipes*), spiny aster (*Aster spinosus*), and little grass; and (2) a wet, meadow-like association dominated by rush and yerba-mansa. Other characteristic plants of this association were baccharis, false indigo bush, sunflower (*Helianthus annus*), marigold (*Dyssodia papposa*), evening-primrose (*Oenothera jamesii*), and dock (*Rumex* sp.). Watson (1912) described the cottonwood forest as uniform, composed of small trees and poor in species diversity. He attributed the trees' small size to their being harvested for fuel and fence posts. He stated that since much of the valley was under ditch (irrigated) farming it did not show characteristic vegetation, but that dense thickets composed of senna, willows, sunflowers, goldenrod (*Solidago altissima*), and others grew along the irrigation ditches. Exposed mudbanks colonized by cottonwood, willow, and cattails were considered to be an early seral stage in cottonwood forest succession. Watson observed that the usual fate of such young growth was to be washed away upon the return of high water, but should this not happen for a year or two, the young cottonwoods might become large enough to hold the soil, and develop into a forest. In another publication, Watson (1912) noted that salt cedar (*Tamarix chinensis*) was commonly planted in Albuquerque as a hedge plant, but he did not mention Russian olive.

Fergusson (1931) described cyclic destruction and regeneration of cottonwood stands through river meandering, and noted that "Most of the cottonwood forest never lives long enough to be more than a dense covert, twenty or thirty feet high, but whenever the trees escape the river for a period of years they grow into beautiful groves...."

Beginning in the early 1900's a number of events transpired that would contribute significantly to the changing mosaic of plant communities in the river valley. One was the introduction of exotic plant species, particularly salt cedar. Salt cedar, introduced into the U.S. as an ornamental and shelterbelt tree from the eastern Mediterranean region in the early 1800's, was present in Albuquerque as an ornamental in 1908 (Watson 1912) and at Mesilla Park in 1910 (Thompson 1958). Up until about 1926, there was no significant growth of salt cedar in the Rio Grande Valley in New Mexico (Robinson 1965), and salt cedar did not become important in the plant life of the Rio Grande until about 1936 when it rapidly proliferated and became widely naturalized. During 1926 and 1927 numerous plantings of salt cedar seedlings were made at many places in the Rio Puerco and Rio Salado drainages, and perhaps in other places for erosion and silt control. The plants spread rapidly after the flood of 1929, and by 1936 salt cedar covered about 2,226 ha (5,500 acres) in the Bernardo to San Marcial reach (Robinson 1965). By 1947, the area covered by salt cedar in this reach increased to 10,648 ha (26,300 acres; Robinson 1965). Although present above Bernardo, it did not, as now, have high densities.

Russian olive (*Eleagnus angustifolia*), another Near Eastern and Central Asian tree brought to the Southwest for shade, shelterbelt, and erosion control purposes, was introduced into the valley between 1900 and 1915, probably in Albuquerque (Hink and Ohmart 1984). Like salt cedar, it rapidly proliferated and also became widely naturalized in the middle valley between 1920 and 1935; it reached its present distribution by the early 1930's (Freehling 1982). Campbell and Dick-Peddie (1964) found that Russian olive had become a dominant component of riparian vegetation in the Middle Rio Grande Valley by 1960. Other imported trees that are rapidly becoming major components of riparian plant communities, particularly in the more urbanized areas, include Siberian elm (*Ulmus pumila*; this tree is commonly, but incorrectly, called Chinese elm), tree of heaven (*Ailanthus altissima*), and white mulberry (*Morus alba*).

Facilities constructed from 1930 to 1936 to alleviate the deterioration of the irrigated farming industry and protect floodplain development from frequent flooding contributed to the continuing modification of the floodplain plant communities. Lowering of the water table by drainage canals had the most significant effect of all water management actions on the plant communities. Van Cleave (1935) described the vegetation communities present in the middle valley at that time, and the changes that took place as a result of drainage. Most of Van Cleave's observations of plant communities were made from MRGCD districts in the vicinity of Albuquerque. She described five types of floodplain communities present prior to construction of drains. (1) Small lakes maintained by seepage water from the river. These supported algae and aquatic plants (*Chara* sp., duckweed, water-milfoil, hornwort) and were edged by a marsh-like community of cattail, sedges, rush, watercress (*Rorippa nasturtium aquaticum*), buttercup, algae, scouring rush, and mosquito fern, and a fringe of woody vegetation, including willows, cottonwood, salt cedar, and Russian olive. (2) Swampland (= marsh) where the water table was slightly above the surface due to the higher elevation of the river and water contributed from higher irrigated fields. These marshes were composed of the same marsh plants that occurred in the shallow waters of lakes and were also fringed by woody vegetation. (3) A wet meadow-like community where the water table was at or just below the surface, which supported sedges, rush, saltgrass, and yerba-mansa, similar to that described by Watson (1912). This was the most extensive plant community in the valley. (4) A grass-woodland bosque on elevated sites in the meadowland, composed of willows, cottonwood, salt cedar, and Russian olive, with an understory of saltgrass, yerba-mansa, fleabane (*Erigeron philadelphicus*), and horseweed (*Conyza canadensis*). (5) Cottonwood-willow forest bordering the river, several hundred yards wide, with very little understory vegetation due to shading and periodic flooding. When present, this understory consisted of patches of herbaceous plants and saltgrass in the lower alkaline areas. Salt cedar and Russian olive are not mentioned as being part of the forest vegetation.

After drainage, the lake and marsh communities "disappeared almost immediately" (i.e., within the first year), and these sites were quickly invaded by cottonwood, willow, salt cedar, and Russian olive. The wet meadows gradually became drier, and many were made into agricultural fields, while the willows in the grass-woodland bosque and the river edge cottonwood-willow forest died out. Cottonwoods in the vicinity of Socorro were observed to be dying out, presumably because of a rapid drop in ground water and accompanying insufficient water to meet the higher transpiration needs of cottonwoods in this hotter, southern part of the valley (Van Cleave 1935). Vegetation communities similar to those of the former marshes and lakes developed along margins of the drains, although they were limited in extent due to steep side slopes and flowing water. Borrow areas resulting from earth removal also developed this type of vegetation if they were below the water table.

The improvement and extension of flood control levees begun in the 1920's to form a defined floodway also further defined the area where riparian vegetation could regenerate and develop to a narrow band. Some reaches both north and south of Albuquerque are not leveed and, consequently, riparian communities may be wider. Stands of trees on the landward side of the levee were isolated from the normal recycling process of the river. A significant reduction of these isolated stands has occurred due to their removal for agriculture and urban development. This removal is more significant in the more urbanized areas of the valley, and less pronounced in the upper and lower reaches where some large stands and individual trees remain.

The combination of drainage measures and large-scale spring and summer flooding in 1929, 1935, 1941, and 1942 may have accelerated the spread of salt cedar and Russian olive by wetting soil extensively and making former wetlands available for colonization, particularly in the summer. Both salt cedar and Russian olive have certain phenological and reproductive characteristics that give them advantages over native vegetation in colonization of certain types of disturbed sites or during certain times of the year. Russian olive not only readily colonizes disturbed areas, but can also tolerate and invade existing stands of woodland.

Although the levees had greatly reduced the area over which the river meandered, the river still migrated within the floodway and continued to expose new sites for colonization by cottonwood and other riparian species (Hink and Ohmart 1984). The use of Kellner jetty jacks beginning in 1953 as part of the "Rio Grande Floodway Project," to provide additional flood protection by establishing a defined, stable channel and protecting existing levees, played a major role in forming the current riparian forest between the levees. These newly created jack fields stabilized large areas of moist alluvium which then were rapidly colonized by cottonwood, willow, salt cedar, and Russian olive. Together with older riparian plant communities, these vegetated areas have evolved into the narrow band of riparian vegetation that now characterizes the Rio Grande.

Coincident with features to safely contain flood water within the river channel was the beginning of a system of four flood- and sediment-control dams on the Rio Grande and its tributaries above the Middle Rio Grande Valley. With the gradual completion of these facilities, Cochiti Dam being the final component and completed in 1975, the peaks of spring flood flows have been progressively reduced and the duration of the early summer high water period has been extended.

This management of river flows for flood protection of the extensively developed floodplain has removed the disturbance element of scouring that historically provided the cyclic regeneration and diversity of riverine plant communities. The river still floods the area between the levees (where they exist) periodically, but the rate of water release is kept below what would threaten the integrity of the protective levees and is not of sufficient magnitude to remove established woody vegetation from the riparian zone and leave the barren sediment required for seedling establishment. Seedling development still occurs in the sandy channel after high flows, but seedlings are soon scoured away by subsequent flows. Under current operation and maintenance programs, the river channel is kept free of most vegetation and debris by river flows and clearing, and woody vegetation is periodically cleared from designated portions of the channel to maintain a 183-m (600-ft) wide floodway.

Table 3 presents an historical comparison of the surface area covered by the major floodplain plant communities from Cochiti Dam to San Marcial from 1918 to the present. This comparison demonstrates that the area occupied by floodplain forest has remained fairly constant since 1918. While the acreage of trees and shrubs has been maintained, the same cannot be said for wetlands. Represented by marsh, open water, saltgrass meadow, and alkali flats, and covering some 21,053 ha (52,000 acres) in 1918, wetlands have been significantly reduced to largely relic and man-made wetlands (e.g., state and federal refuges). Wetlands were reduced throughout the Middle Rio Grande; Fig. 10 provides visual evidence of the changes between 1935 and 1989 in portions of the Belen reach.

Although the area of floodplain trees and shrubs has been maintained, its distribution and composition have changed appreciably since 1918. Expanding agriculture and urbanization have replaced an appreciable amount of native floodplain communities of cottonwood and willow, as well as saltgrass meadow, and have drained wetlands. Some of this displacement has been replaced by colonization and development on sandbars enclosed by flood control levees. These events have acted to define significant reaches of the riparian plant community as a narrow zone that borders the river.

Salt cedar has become established on sandbars, alkali flats, drained saltgrass meadows and marshes, abandoned cropland, and areas of disturbance. This establishment is particularly pronounced south of Bernardo. Salt cedar has also become an important component of native plant communities throughout the entire study reach, as has Russian olive.

Table 3. Historical comparison of areal extent of floodplain forest, shrub, meadow, and marsh from Cochiti Dam to San Marcial.

Year	Category	Hectares	Acres	Source
1918	Timber (Cottonwood) and Brush	14,760 (14,410)	36,459 (37,594)	U.S. Reclamation Service Maps (1922), (Burkholder 1928)
	Marsh	2,540	6,274	U.S. Reclamation Service Maps (1922)
1926	Bosque	15,312	37,821	Burkholder (1928)
	Saltgrass Meadow	19,677	48,603	
	Swamp and Lake (Marsh and Open Water)	1,346	3,324	
	Alkali	111	275	
1936	Tree, Bosque	15,540	38,384	Stafford et al. (1938)
1966	Phreatophytes	14,939	36,900	U.S. Bureau of Reclamation (1977)
1982, 1989	Forest, Shrub (including Salt Cedar)	18,462	45,601*	Hink and Ohmart (1984), U.S. Bureau of Reclamation (1993b)
	Marsh and Open Water	1,486	3,671	

* If low shrub and herbaceous vegetation is subtracted this figure is 15,902 ha (39,278 acres). This vegetation structure classification may not have been included in previous vegetation surveys.

Table 4 further demonstrates the change in the composition in floodplain plant communities by river reach. Particularly noteworthy is the decrease in acreage of cottonwood and a compensatory increase in salt cedar, which thereby maintains the extent of riparian vegetation in the middle valley. Table 5 indicates general changes in vegetation between 1935 and 1989. There was a major loss of open water, marsh, and wet meadow.

Floodplain vegetation and the hydrologic processes that sustain it have changed significantly in the recent past. These changes have resulted from the increasing agricultural and urban development of the Middle Rio Grande Valley, with the most significant changes being the spread of exotic species, primarily salt cedar and Russian olive; the construction of drains; clearing of floodplain vegetation; and regulation and modification of the river for flood and sediment control. The evidence for these changes is documented dramatically in maps taken from aerial photographs of the Middle Rio Grande Valley in 1935 and in 1989. These maps (1-4) indicate the changes visually and include data on changes in area of wetlands, forest, scrub shrub, agricultural lands, and urban zones.

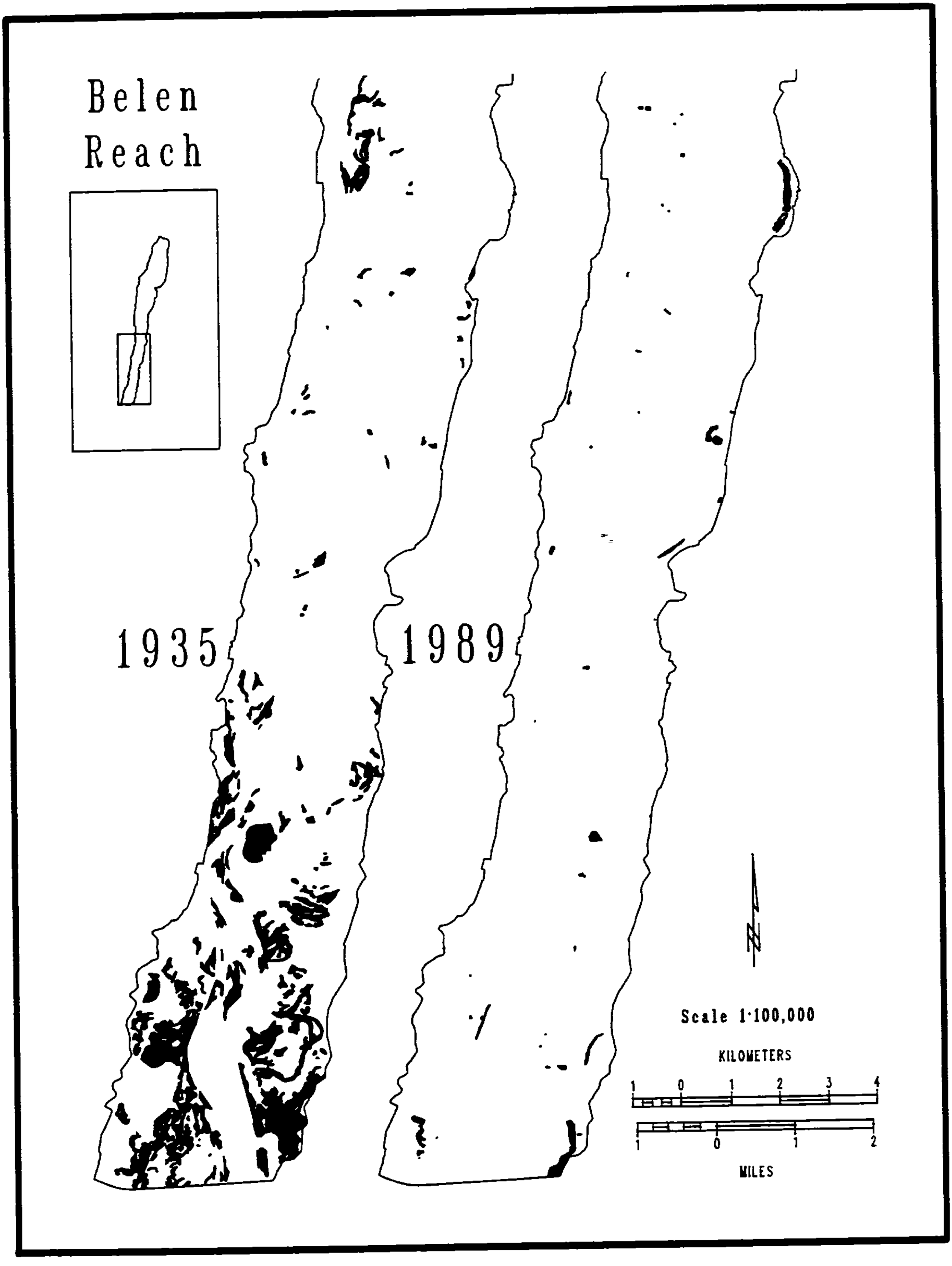


Fig. 10. Changes in wetland area, 1935-89, portions of Belen Reach, Middle Rio Grande.

Table 4. Historical comparison of areal extent in hectares (acres) of cottonwood, Russian olive, salt cedar, saltgrass meadow, and marsh for selected reaches and periods. Data for 1918 are from U.S. Reclamation Service Maps (1922); and data for 1982, 1989 are from Hink and Ohmart (1984) and U.S. Bureau of Reclamation (1993b). Recent acreages exclude 2,560 ha (6,323 acres) of low shrub and herbaceous vegetation (mostly salt cedar and predominantly in the Bernardo to San Acacia Reach) because this vegetation classification may not have been identified in the 1918 survey.

	Cottonwood Dominated Timber and Brush	Russian Olive	Salt Cedar	Saltgrass Meadow	Marsh/ Standing Water
1918					
Cochiti to Bernardo	7,053 (17,422)	—	—	↓	1,392 (3,439)*
Bernardo to San Acacia	353 (872)	—	—	19,677 (48,603)	59 (146)
San Acacia to San Marcial	7,354 (18,165)	—	—	↑	1,089 (2,689)
Total	14,760 (36,459)*	—	—	19,677 (48,603)	2,540 (6,274)*
	15,312 (37,821)†				1,346 (3,324)†
1982, 1989					
Cochiti to Bernardo	6,543 (16,162)	335 (828)	660 (1,629)	—	267 (659)‡
Bernardo to San Acacia	137 (338)	119 (294)	605 (1,494)	—	262 (647)
San Acacia to San Marcial	1,548 (3,823)	—	5,955 (14,710)	—	1,028 (2,538)
Total	8,228 (20,323)	454 (1,122)	7,220 (17,833)	—	1,557 (3,844)

* Planimetering by Biological Interagency Team.
† Burkholder (1928).
‡ Includes 91 ha (224 acres) of wet meadow.

Table 5. Comparison between vegetation types in hectares (acres), 1935 and 1989, National Wetlands Inventory (1989) Riparian Classification.

	1935	1989	Change
Wet Meadow, Marsh Pond, or Lake	3,884 (9,593)	1,638 (4,046)	–2,246 (–5,547)
Scrub Shrub	13,370 (33,024)	9,304 (22,980)	–4,066 (–10,044)
Forest	8,432 (20,828)	7,812 (19,296)	–620 (–1,531)
River Channel	8,916 (22,023)	4,347 (10,736)	–4,569 (–11,287)

2. Animal Communities

General

As with plant communities, there is no documented description of aquatic and terrestrial animals prior to the arrival of Europeans. However, a combination of the archaeological and historical record and a knowledge of animal species that currently exist provides insight into the past. The great diversity of landform, elevation, vegetation, and climate in New Mexico that has produced one of the world's most diversified fauna was likely reflected in a corresponding historical wealth of animal species in the Middle Rio Grande Valley. Surrounding the river valley are biotic communities of Chihuahuan Desertscrub, Semidesert Grassland, and Great Basin Grassland and Conifer Woodland. Appreciably complementing this diversity of life were migratory species that still utilize the Rio Grande Valley as a major flyway and seasonal habitat. Although densities of species are not known, the presence of a perennial river and extensive wetlands certainly provided increased habitat for aquatic and semiaquatic species.

Aquatic

The aquatic resources of the State of New Mexico, including the Rio Grande, have been influenced by people for many centuries. Before the 13th century, early human impacts on aquatic habitats were generally localized and probably had no lasting effect. Subsequent to this period, modifications of aquatic habitats by Pueblo Indians were both extensive and undoubtedly somewhat detrimental to native fishes. These changes, stemming directly from irrigation and indirectly from wood gathering, led to the destruction of vegetation within watersheds, along with accelerated erosion and water quality (Sublette et al. 1990). Western migration of Euro-American settlers accelerated after the Civil War, resulting in a greatly increased population, especially in the Rio Grande Valley in southern Colorado and New Mexico. With the immigrants came an intensification of both farming and ranching (Sublette et al. 1990). Accompanying these agricultural activities was the harvesting of large numbers of trees for structural uses as well as for mining. As these activities intensified, erosion and depletion of river flows correspondingly increased. The resulting increase in streambed sedimentation, depletion of flows, and degradation of water quality had a significant adverse effect on aquatic habitat and associated aquatic organisms.

The historic, native fish fauna of the Rio Grande in New Mexico is thought to have consisted of 17 to 27 species. Big river fishes such as the longnose gar, shovelnose sturgeon, gray redhorse (*Moxostoma congestum*), blue sucker (*Cycleptus elongatus*), and freshwater drum (*Aplodinotus grunniens*) were present in the historic Rio Grande. American eel elvers (immature eels) migrated from their hatching grounds in the Atlantic Ocean near Bermuda to the mouth of the Rio Grande. While the males did move far inland, female elvers traveled up the entire length of the river where they matured and remained for most of their lives. Included in Table 6 are those fish species thought to be present in the Middle Rio Grande Valley at the time Coronado arrived and their current status (Sublette et al. 1990). Early Spanish explorers (de Oñate, 1599; Villagra, 1610; de Benavides, 1630) described the abundance of fish in the Rio Grande as well as turtles (Hodge and Lummis 1916, Espinosa 1936).

Table 6. Native fishes of the Middle Rio Grande Valley and current status (based on Sublette et al. 1990). Ex = Extirpated, P = Present, and E = probably Extinct.

Species	Status
Shovelnose sturgeon (*Scaphirhynchus platorynchus*)	Ex
Longnose gar (*Lepisosteus osseus*)	Ex
American eel (*Anguilla rostrata*)*	Ex
Gizzard shad (*Dorosoma cepedianum*)	P
Red shiner (*Cyprinella lutrensis*)	P
Roundnose minnow (*Dionda episcopa*)	Ex
Speckled chub (*Macrhybopsis aestivalis*)	Ex
Rio Grande chub (*Gila pandora*)	P
Rio Grande silvery minnow (*Hybognathus amarus*)	P
Rio Grande shiner (*Notropis jemezanus*)	Ex
Phantom shiner (*Notropis orca*)	Ex, E
Rio Grande bluntnose shiner (*Notropis simus simus*)	Ex, E
Fathead minnow (*Pimephales promelas*)	P
Flathead chub (*Platygobio gracilis*)	P
Longnose dace (*Rhinichthys cataractae*)	P
Rio Grande sucker (*Catostomus plebeius*)	P
River carpsucker (*Carpiodes carpio*)	P
Blue sucker (*Cycleptus elongatus*)	Ex
Smallmouth buffalo (*Ictiobus bubalus*)	P
Gray redhorse (*Moxostoma congestum*)	Ex
Blue catfish (*Ictalurus furcatus*)†	Ex
Flathead catfish (*Pylodictis olivaris*)†	P
Bluegill (*Lepomis macrochirus*)	P
Freshwater drum (*Aplodinotus grunniens*)	Ex

* Currently present due to recent introductions.
† These species persist in Elephant Butte and Caballo reservoirs

The first scientific account of New Mexico fish fauna began with material collected by railroad surveys that were initiated in the early 1850's (Sublette et al. 1990). The earliest recorded fish samples were collected by Cope and Yarrow in 1874 in the vicinity of San Ildefonso (Platania 1991a). Included in their report (Cope and Yarrow 1875) was the collection of the shovelnose sturgeon near Albuquerque in 1874 and the mention of American eel near Santa Fe. A few sporadic collections followed, but detailed collections and biological data gathering on New Mexico's fishes first began with Dr. William J. Koster of the University of New Mexico in 1939. An overview of his work was reflected in the *Guide to the Fishes of New Mexico* in 1957. Intensive fish surveys were reinitiated in the 1980's.

Historically, the Rio Grande below the general area of the confluence of the Jemez River consisted of primarily warmwater aquatic habitat characterized by a shifting sand substrate. Above the Jemez River the river was likely cooler with a channel bed composed of mostly gravel and cobble. Warmwater habitat may have extended upstream as the river became increasingly shallower due to accelerated sedimentation and depletion of flows caused by increasing human use of the watershed. The operation of Cochiti Dam, beginning in 1975, is resulting in the removal of accumulated sediment and lower water temperatures in this upper reach. Lower water temperatures extend to approximately Bernalillo.

The major aquatic invertebrate orders historically occurring in New Mexico are Diptera (flies and midges), Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies). Chironomid midge larvae are common in freshwater ecosystems and are a significant food source to fish (Jacobi et al. 1993). Members of Tricoptera and Diptera are commonly found in submerged gravel bars, whereas Ephemeroptera can withstand silty conditions and exist in shifting, sand habitat. Macroinvertebrates have a wide range of habitat preference and have been used as indicators of habitat quality. They are also important components of stream ecosystems as intermediate consumers of plant material and nutrient recyclers (U.S. Environmental Protection Agency 1989). Sampling for macroinvertebrates did not begin in the Middle Rio Grande until very recently and is discussed later in this document.

Terrestrial

Most terrestrial animal species that currently use the middle valley were present before and for a considerable period after the arrival of Coronado in 1540. In addition, there were large mammals such as the jaguar (*Felis onca*), gray wolf (*Canis lupus*), and grizzly bear (*Ursus arctos*) that were likely occasional users of valley resources. Pronghorns (*Antilocapra americana*) commonly browsed and still browse on the bordering terraces.

New Mexico has the distinction of having the earliest recorded notes on birds of any state. Castaneda, chronicler of Coronado's expedition, commented on the abundance of geese, cranes, turkeys, and other native fowl in the valley (quoted in Bailey 1928). Several Spanish colonists, explorers, and priests that followed Coronado also commented on New Mexico's wildlife and fish and their abundance. Beginning with Stephan H. Long of the Engineer Corps in 1820 and continuing to 1889, various individuals, many with military expeditions, made recordings of animals in the state and in the Middle Rio Grande Valley. Most of these observations were incidental to other purposes. Several of these early naturalists commented on the large numbers of sandhill cranes, herons, ducks, geese, kestrels, quail, mourning doves, crows, blackbirds, and beaver in the middle valley. James O. Pattie (1966), a trapper in 1824, commented on the great number of bear, deer, and turkey in the valley. Lieutenant J.S. Abert in 1846 observed and collected many species of birds among which were swans (probably *Cygnus columbianus*), loons (probably *Gavia immer*), and bald eagles (*Haliaeetus leucocephalus*; Abert 1962).

Beginning about 1889, biologists from the U.S. Bureau of Biological Survey, among the most important were Vernon and Florence Merriam Bailey, studied birds and mammals in the state. This work was intensive from 1889 to 1924. Mrs. Bailey's work was published in 1928 as *Birds of New Mexico* and Mr. Bailey's work on mammals in 1932 as *Mammals of New Mexico*.

More recent investigations of birds of the Rio Grande Valley are not extensive, and Monson (1946), in his observations of birds in the vicinity of Bosque del Apache NWR, was one of the first observers to note the importance of riparian habitat for birds.

Terrestrial invertebrates in the Middle Rio Grande riparian ecosystem include many more species and much larger populations than do terrestrial vertebrates. However, the biology and ecology of these small, easily overlooked animals were ignored until recently. As will be discussed below, relict populations of what were probably widespread wetland-associated species now appear restricted to the banks of seeps, drains, and the few remaining ponds and marshes. Also to be discussed are introduced isopods (pillbugs and woodlice) which, because of their large populations in the bosque, are important consumers of leaf litter there.

Extirpations and Introductions

Terrestrial and aquatic animals were affected to varying degrees by the rapid increase in settlement of the Southwest and the Rio Grande Basin from 1821 to the present. The increasing removal of native floodplain cottonwood/willow forest and woodland, hunting and trapping, depleting of river flows for irrigation, increasing sedimentation of the river channel by timber removal and livestock grazing, pollution, flood control features, and draining of wetlands certainly reduced or deteriorated habitat for many species and populations. Also, the introduction of nonnative species has had a significant impact on native species and communities through competition, predation, and hybridization.

The jaguar, gray wolf, and grizzly bear have disappeared not only from the middle valley but also from a significant area of their former ranges. Mink (*Mustela vison*), which had been captured in La Joya and Elephant Butte (Hink and Ohmart 1984), were last reported in the valley just before 1920. Beaver (*Castor canadensis*), which were largely eliminated near the end of the 19th century possibly due to trapping and habitat depletion, recovered due to restocking efforts from 1947 to 1958. Also, the Rio Grande turkey (*Meleagris gallopavo*) was eliminated. Intense hunting may have contributed to the elimination of the whooping crane (*Grus americana*) and severe reduction in numbers of sandhill cranes (*Grus canadensis*).

Exotic additions to the rich native bird fauna of the valley have been the European starling (*Sturnus vulgaris*), house sparrow (*Passer domesticus*), and domestic pigeon (*Columba livia*). Starlings and house sparrows have become abundant and the former have likely adversely affected native birds, particularly cavity nesters. Pheasants (*Phasianus colchicus*) have also been introduced in the valley as game birds (M. Sifuentes, pers. obs.). Mammalian species that have been introduced are the house mouse (*Mus musculus*) and the Norway rat (*Rattus norvegicus*). The burro (*Equus asinus*) was once present in the Rio Grande Valley, and it is still present in the canyons running from the Jemez Mountains into White Rock Canyon and in the Rio Puerco drainage (D. Scurlock, pers. comm.). Cattle are frequent users of the riparian forest and woodland, particularly in the upper and lower reaches. Many species of invertebrates could easily have been introduced to the region by Spanish and Anglo settlers. Several species of terrestrial isopods were introduced from the Old World and are now dominant detrivores in much of the valley.

By the end of the 19th century many of the larger big river fishes such as the longnose gar, shovelnose sturgeon, gray redhorse, blue sucker, and freshwater drum had disappeared from the Middle Rio Grande. The American eel was probably eliminated from the middle valley by the construction of Elephant Butte Dam in 1916 which blocked its migration (recent escapees from rearing ponds in Colorado, however, have resulted in the capture of this species in the Rio Grande). More recently, an increasing number of fishes has been eliminated from or their populations appreciably reduced in certain river segments. Thirty-six to sixty-three percent of the native fish species have been extirpated from the Middle Rio Grande (B. Montoya, in litt.). The speckled chub (*Macrhybopsis aestivalis*), Rio Grande shiner (*Notropis jemezanus*), phantom shiner (*Notropis orca*), and Rio Grande bluntnose shiner (*Notropis simus simus*) have disappeared from the Rio Grande; and both the phantom and Rio Grande bluntnose shiners are considered extinct (Chernoff et al. 1982; Bestgen and Platania 1990, 1991; Platania 1991a). Also, the Rio Grande silvery minnow (*Hybognathus amarus*) has declined so severely that it is threatened with extinction (Bestgen and Platania 1991). A combination of factors (both past and current) are likely responsible for the decline or extinction of native fishes including the depletion of river flows, reduction in water quality, sedimentation, water resource development and management actions, and introduction of nonnative fish through stocking or use of baitfish (Sublette et al. 1990).

From 13 to 19 nonnative species have been introduced into the Middle Rio Grande and now comprise 38-76% of the total number of fish species (Platania 1991a; B. Montoya, in litt.). A few of the more common nonnative fishes include the rainbow trout (*Oncorhynchus mykiss*), common carp (*Cyprinus carpio*), white sucker (*Catostomus commersoni*), black bullhead (*Ameiurus melas*), yellow bullhead (*Ameiurus natalis*), channel catfish (*Ictalurus punctatus*), and largemouth bass (*Micropterus salmoides*).

The appreciable reduction in wetlands in the 1930's and the long-term depletion of river flows undoubtedly led to a corresponding reduction in resident aquatic and semiaquatic species (e.g., the jumping mouse and leopard frog) and habitat for migratory species.

IV. EXISTING CONDITIONS

A. THE MIDDLE RIO GRANDE ECOSYSTEM

1. Riparian Ecosystems

A riparian ecosystem is made up of three major components: a river or stream, the riparian zone (the streambank and adjacent area), and the surrounding floodplain. The major driving force, or external variable, of the system is water; its characteristic availability and pulses determine the nature of associated aquatic and terrestrial plant and animal communities of the river, riparian zone, and floodplain, through direct and indirect effects. Riparian ecosystems are linear features on the landscape and act as corridors for transport of water and eroded material. They are an interface between terrestrial and aquatic ecosystems that facilitates an exchange of material and energy. In some cases, the floodplain portion of the system acts as a storage area for ground water, sediment, and nutrients. This is particularly true for broad floodplains of coarse alluvium, such as the Middle Rio Grande Valley.

Riparian vegetation, which is supported by the enhanced moisture of the river or stream, acts as a buffer for protecting parts of the system from changes in the watershed. Pollutants, nutrients, and sediments from disturbance upstream become trapped and assimilated along streambanks and in floodplains (Brinson et al. 1981).

Riparian zones support diverse and abundant populations of wildlife, particularly in comparison to surrounding upland areas. The predominance of woody vegetation provides roosting, foraging, and shade. Dead limbs on live trees and standing dead trees (snags) provide nests, dens, and feeding and perching sites. Fallen logs provide cover, feeding, and nest sites. Roots of woody vegetation along streams stabilize banks and serve as cover for fish and other aquatic animals. Leaf litter is food for aquatic and terrestrial invertebrates. Shade from live, leafy trees and shrubs moderates water temperature and benefits aquatic invertebrates, which in turn influence fish species and communities.

Periodic flooding allows for spawning of some fish species and transport of organic debris to the main channel and downstream. Even if flooding is absent, the increase in soil moisture in riparian areas influences plant communities. Vegetation, seeds, and insects are relatively more abundant in riparian zones than in uplands, and this increases the abundance and diversity of some birds and mammals.

Within riparian ecosystems, the variety and diversity of habitat features are important to fish and wildlife species. Herbaceous, shrubby and forest vegetation, aquatic areas, and nonvegetated substrates are complex and productive wildlife habitats. The linear nature of riparian ecosystems provides protected corridors for migration and movements between habitats (Brinson et al. 1981).

2. Riverine and Riparian Systems

Like other natural systems, riverine and riparian systems can be described as being dynamic (constantly changing) and open-ended (with inputs and outputs), having external factors or variables as driving forces, and having internal factors or variables that vary with a given set of conditions (Kitching 1983). Focusing on system dynamics allows us to better understand the processes that determine the conditions of riverine and riparian systems. Hydrologic, geomorphic, and biotic variables can be defined for rivers or sections of rivers; within each sector, equilibrium, or partial balance, can exist among these factors. Any major change will cause disruption of the equilibrium state. Some changes, such as annual flooding, are a natural part of the riverine system. Human-made or human-caused changes, resulting from abstraction of water for irrigation, floodplain and watershed development, flood-control measures, flow regulation, etc., change the natural equilibrium state. A long time period may elapse before equilibrium is reestablished, particularly after major human-made (or caused) alterations to the system (Williams and Wolman 1984, Heede 1986, Petts 1991).

Recent work on riverine and riparian systems has emphasized an integrated approach in research and management. Riverine and riparian processes are linked and interdependent. Flow regime and sediment sources determine the structure of the river, which in turn determines the characteristics of the associated plant and animal communities. Conversely, these communities may influence certain riverine processes (Fig. 1). Because of the interdependence between riverine and riparian processes, we are including both in our concept of a riparian ecosystem (Brinson et al. 1981, Heede 1986, Petts 1991, National Research Council 1992).

B. HYDROLOGICAL RESOURCES

1. Surface Water

Water Management Physical Infrastructure

As stated above, the hydrology of the Middle Rio Grande is greatly influenced by water management activities and facilities. This section will describe the major features of the contemporary system causing human disruptions of existing equilibrium states in the river.

Flood and Sediment Control Facilities.—These facilities and improvements consist of flood and sediment retention dams, runoff conveyance channels, levees, and the maintenance of water conveyance capacity within the Rio Grande's cleared floodway.

Since the mid-1950's, the COE has constructed four **flood and sediment control dams and reservoirs** that affect the hydrology of the Rio Grande in the Middle Rio Grande Valley: Abiquiu Dam, Jemez Canyon Dam, Galisteo Dam, and Cochiti Dam (Table 7). These facilities have had a major impact on the timing and amount of water flowing through the riparian ecosystem. All the dams except for Galisteo have controlled release operations. At Galisteo, water stored during a high runoff event flows through the outlet at a steady but unregulated rate.

The flood flow capacity of the Rio Grande is determined by the location, size, and strength of the levee system and natural features, such as terraces, mesas, and rock outcrops, which collectively define the boundaries of the floodway. The channel capacity, on the other hand, is the river channel's bank-to-bank flow capacity within the floodway. In the Middle Rio Grande, water managers extend the concept of channel capacity to include overbank flows to the point

Table 7. Principal flood control and water storage facilities affecting the Middle Rio Grande Valley.

Facility	Principal Function	Location	Date of Completion, Ownership/Administration
Heron Reservoir	Water supply storage	Willow Creek (Rio Chama)	1971, BOR
El Vado Reservoir	Irrigation, water supply storage; hydroelectric power	Rio Chama	1935, MRGCD
Abiquiu Reservoir	Flood and sediment; water supply	Rio Chama	1963, COE
Cochiti Reservoir	Flood and sediment; fish and wildlife; recreation	Rio Grande	1975, COE
Jemez Canyon Reservoir	Flood and sediment	Jemez River	1954, COE
Galisteo Reservoir	Flood and sediment	Galisteo Creek	1970, COE
Elephant Butte Reservoir	Irrigation; water supply; recreation; hydroelectric power	Rio Grande	1916, BOR

of where they do not cause damage to the levees (by partially or unevenly wetting them) or to other structures in the floodway (D. Baird, pers. comm.).

By 1962, the COE and BOR cooperatively raised and strengthened about 190 km (125 mi) of existing levees originally constructed by the MRGCD from Cochiti to near La Joya (U.S. Army Corps of Engineers 1989). The 30-km (20-mi) reach through Albuquerque have the highest flood flow capacity: 20,000 cubic feet per second (cfs) for sustained (spring) flows and 42,000 cfs for short duration (summer) flows. At the other extreme, however, on the west side of the river in the Corrales area and below Albuquerque to Isleta on both sides of the river, the flood flow capacity is 7,500 cfs (U.S. Army Corps of Engineers 1989). The designed sustained flood flow capacity in the Socorro Reach is 20,000 cfs (U.S. Bureau of Reclamation 1977) although recent spring releases suggest that the capacity may be considerably lower. In the Cochiti Reach the recent spring discharges of up to 7,500 cfs were well contained within the river channel.

To maintain the river channel capacity for the purposes of safely passing high flows, reducing water losses while conveying water to downstream users, and moving sediments through the valley, the BOR began a **channel modification** program in 1953. As a result of this ongoing program, the channel capacity of the Middle Rio Grande currently is about 7,000 cfs. The specific areas on the river that limit flows, or "choke points," are not static. They have variously included, for example, the river outfall to Elephant Butte Reservoir, the railroad bridge immediately below San Marcial, a residence in the Bernardo Reach, MRGCD drain outfalls to the Rio Grande, and levees in the Belen Reach.

There are four categories of channel maintenance activities that are included in the BOR program: bank stabilization, river training, sediment removal, and vegetation control.

- *Bank stabilization* is accomplished through a variety of techniques. The installation of jetty jack systems has been the most commonly employed method in the Middle Rio Grande (Fig. 11). Jetty jacks are designed to reduce water velocities thereby encouraging sediment to drop out. When enough sediment has been deposited in an area, riparian vegetation becomes established, which ultimately stabilizes the banks. Jetty jacks are still being installed in the Bernardo and Socorro reaches in locations to protect the levees. In-place bank stabilization is being increasingly applied, especially in the Cochiti Reach, whereby the riverbank is shaped and then faced with erosion resistant material, such as riprap. The change in strategy was partially in response to the decreased sediment loads in this reach, thereby rendering jetty jack systems largely ineffective.

- *River training* activities are intended to influence flow alignment and manage overbank flows. Groins and training dikes are in-channel embankments constructed to protect riverbanks from the erosional forces of the river flow. Pilot channels are excavated in the floodway to establish new river courses. Since the mid-1980's, in-place bank stabilization has been used in favor of pilot channels in the Cochiti Reach (D. Baird, pers. comm.). Pilot cuts, excavation of a narrow channel in the existing river channel, are now employed to allow hydraulic processes reestablish channel capacity in selected locations.

- *Sediment removal* from the river channel in select locations by mechanical means is done to maintain the flow capacity of the river. Sediment deltas deposited by arroyos are removed when determined necessary to maintain channel capacity. Islands and sand or gravel bars are shaped or removed as well. Dredging is employed sparingly, most recently to remove sediments from the lower end of the Low Flow Conveyance Channel.

- The purpose of *vegetation control* is to increase the floodway capacity for passage of extreme flows. This is now largely limited to the periodic mowing of vegetation on river bars in the Albuquerque and Belen reaches.

Table 8 is a description of the Rio Grande conveyance system and channel stabilization works with the dates of completion. Figure 12 shows locations of channel improvements and dates of completion.

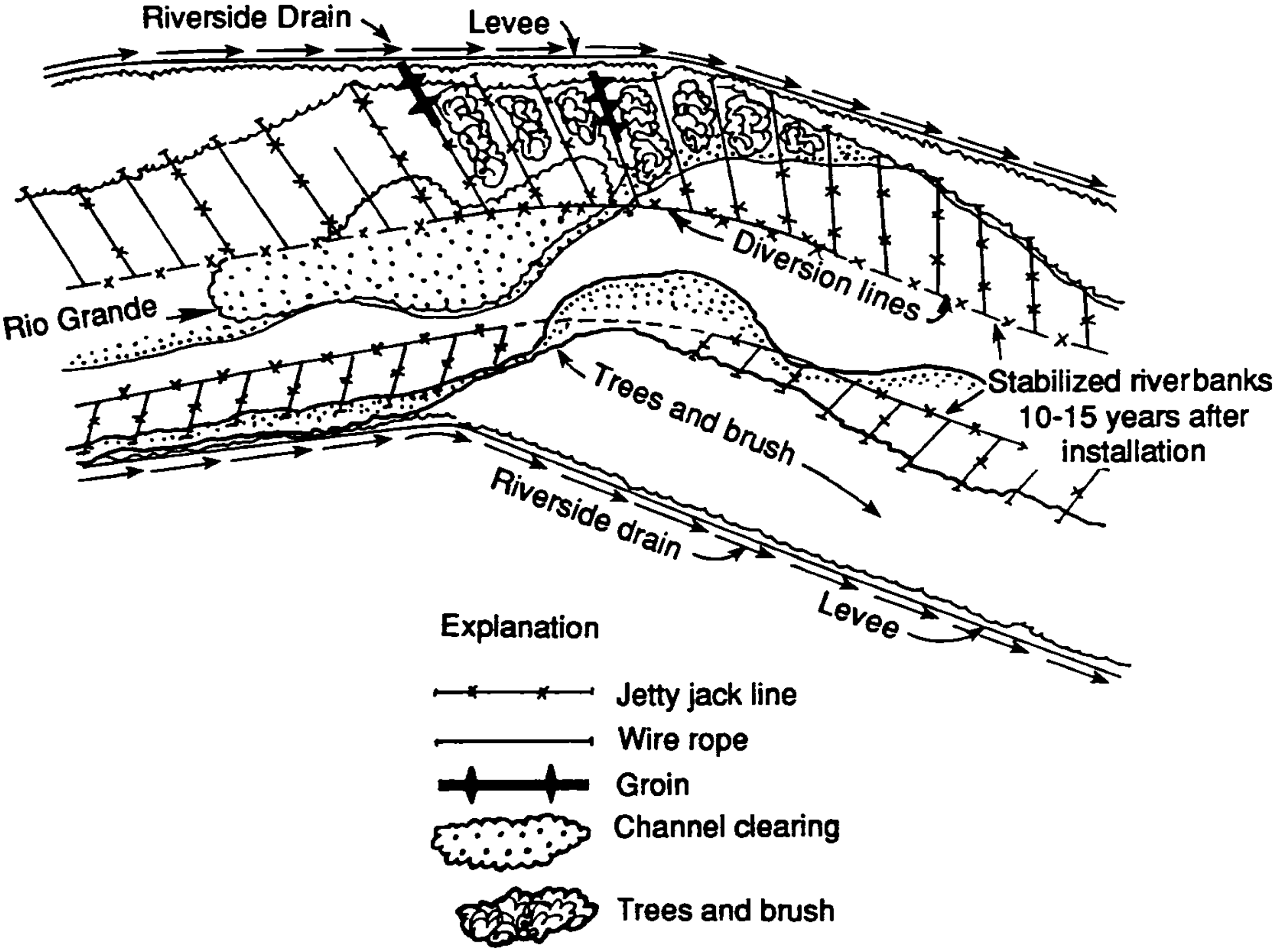


Fig. 11. Channel stabilization works on the Middle Rio Grande (after Bullard and Wells 1992).

There are several **flood-water drainage facilities** that direct water from adjacent uplands to the Rio Grande. These developments are located primarily in urban areas. Among these are the Albuquerque Diversion Channels, which were completed in 1972 by the COE to convey flood water originating near or on the steep slopes of the Sandia Mountains east of Albuquerque through the highly developed residential and business districts and to discharge that water into the Rio Grande. Consisting of two large diversion or collection channels and appurtenant works, one discharges north of Albuquerque near Alameda and the other south of Albuquerque approximately where Tijeras Arroyo previously discharged into the Rio Grande.

The Albuquerque Metropolitan Arroyo Flood Control Authority (AMAFCA) has also constructed several detention dams and conveyance channels on the terraces and alluvial fans on

Table 8. Description of Middle Rio Grande conveyance system and channel improvement works (U.S. Bureau of Reclamation 1977; D. Baird, pers. comm.).

Cochiti to Angostura	
Floodway width	70-1,400 m (230-4,720 ft)
Channel width (average)	91 m (300 ft)
Cleared floodway	no active clearing
Channel stabilization type(s)	jetty jacks, in situ riprap, pilot channel
Channel stabilization period	jetty jacks 1953-74, riprap 1985-present
Angostura to Isleta	
Floodway width	75-920 m (250-3,020 ft)
Channel width (average)	183 m (600 ft)
Cleared floodway width	183 m (600 ft)
Channel stabilization type(s)	jetty jacks, pilot channels, arroyo plug removal
Channel stabilization period	1953-75
Isleta to San Acacia	
Floodway width	150-930 m (500-3,060 ft)
Channel width	60-305 m (200-1,000 ft)
Cleared floodway	185 m (600 ft)
Channel stabilization type(s)	jetty jacks, pilot channels, arroyo plug removal
Channel stabilization period	1953-74
San Acacia to San Marcial	
Floodway width	245-1,495 m (800-4,900 ft)
Channel width	30-305 m (100-1,000 ft)
Cleared floodway	no active clearing
Channel stabilization type(s)	jetty jacks, pilot channels, arroyo plug removal
Channel stabilization period	jetty jacks 1953-present

which the City of Albuquerque has developed. These facilities either directly or indirectly discharge into the Middle Rio Grande. The Harvey Jones Channel, constructed by the Soil Conservation Service (SCS) in 1988, provides flood protection to the upper part of the village of Corrales from runoff originating on the uplands west of the floodplain. Additional drainages that discharge into the Rio Grande are located in Socorro and south of Socorro.

Water Supply and Drainage Facilities.—The MRGCD is composed of four Divisions: Cochiti, Albuquerque, Belen, and Socorro. Rio Grande water is supplied to Cochiti Division via an outlet works on Cochiti Dam. Angostura, Isleta, and San Acacia diversion dams (Fig. 13) deliver water to the other divisions' water systems as shown schematically in Fig. 14. The drains intercept shallow ground-water flow—mainly from irrigation applications, but from river and

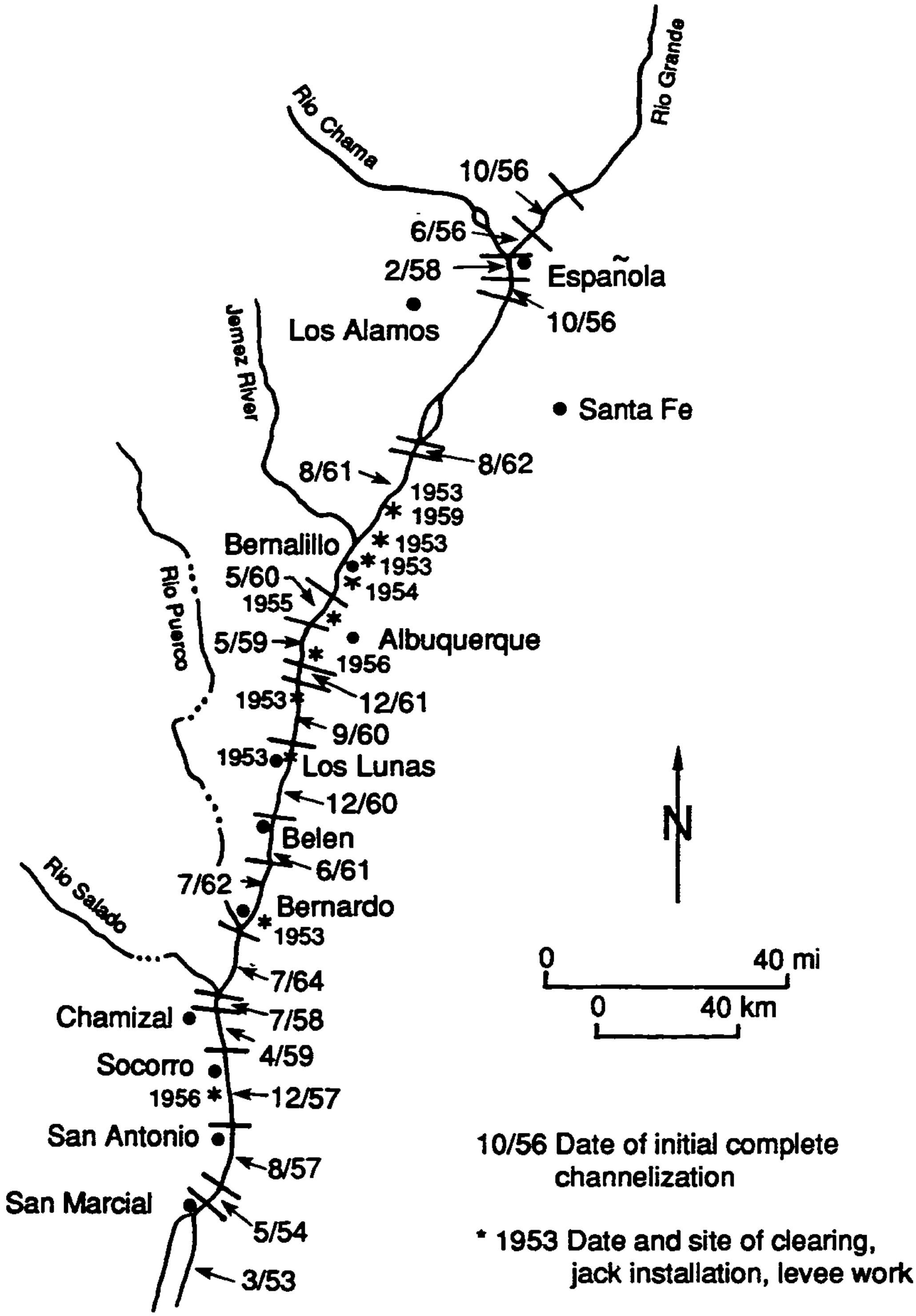


Fig. 12. Completion dates for initial channel engineering works along the northern Rio Grande in the post-1948 era (after Graf 1991).

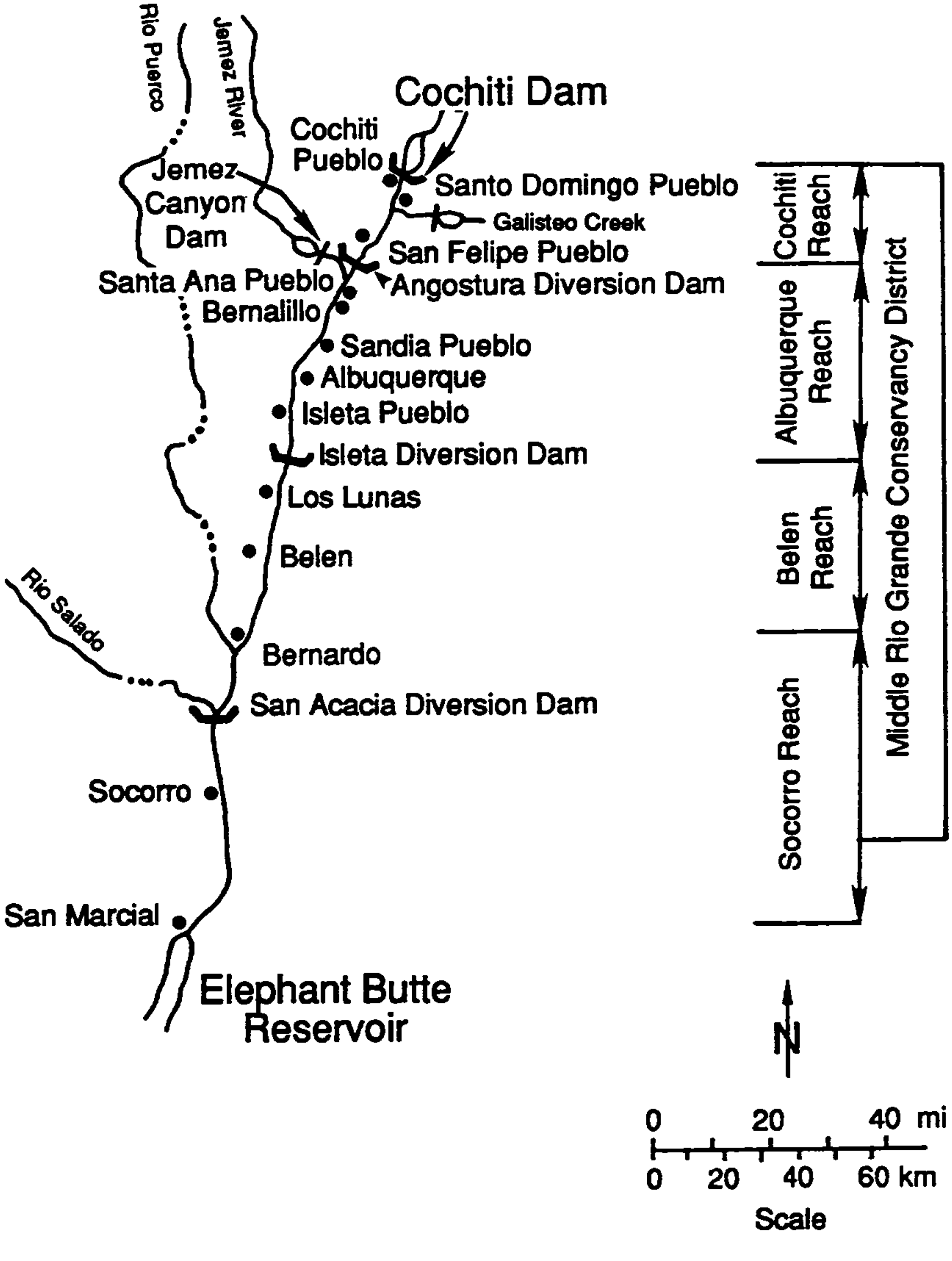


Fig. 13. Map showing Middle Rio Grande Conservancy District limits, division, and reaches for the Middle Rio Grande (U.S. Bureau of Reclamation 1977, Bullard and Wells 1992).

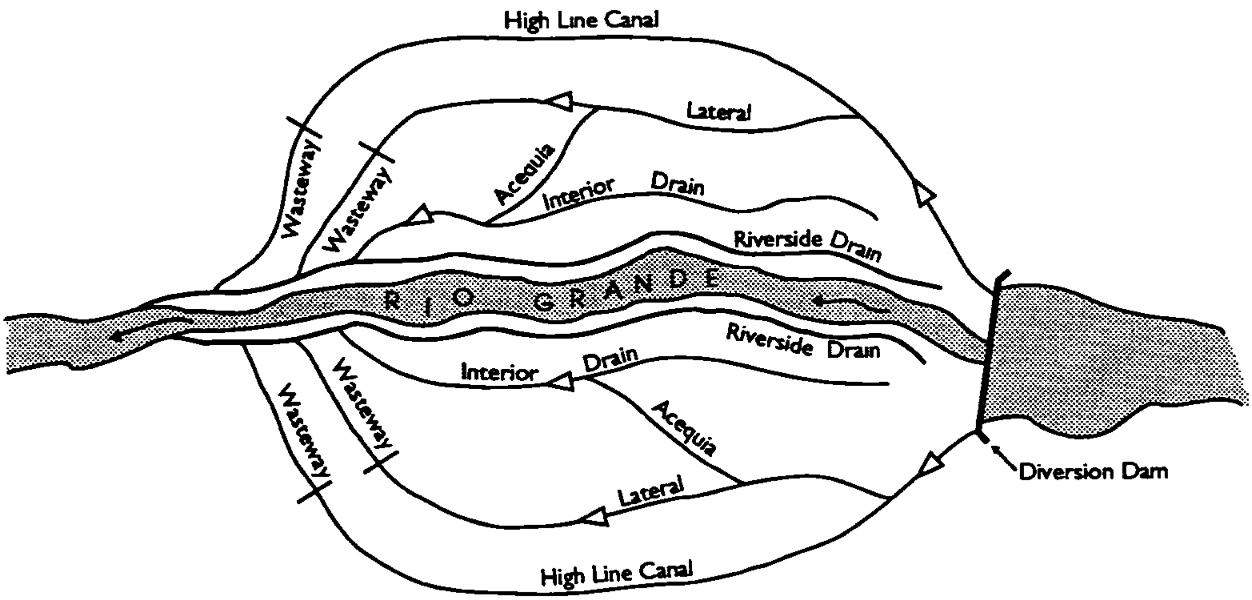


Fig. 14. Schematic map of an irrigation network on the Middle Rio Grande (U.S. Bureau of Reclamation 1977, Bullard and Wells 1992).

canal seepage as well—and return the flows to the river or the canal system. The water supply and drainage system are extensive: there are 1,341 km (834 mi) of irrigation canals, laterals, and acequias, and 650 km (404 mi) of interior and riverside drains in the MRGCD (Shah 1991).

There are no water supply reservoirs in the middle valley itself although there are several which influence the valley's hydrology (Table 7). Heron Reservoir (San Juan-Chama Project) is located on Willow Creek, a tributary to the upper Rio Chama, and El Vado Reservoir (Middle Rio Grande Project) is located on the Rio Chama. Being upstream of the valley, their operation does influence water delivery through the valley. Although primarily a flood control facility, Abiquiu Reservoir also stores water for downstream uses. Elephant Butte Reservoir is located on the Rio Grande just downstream from the valley.

The Low Flow Conveyance Channel has a capacity of approximately 2,000 cfs. When in operation (with a minor exception, it has not been operated since March 1985), it diverts water from the San Acacia Diversion Dam and delivers it to Elephant Butte Reservoir. Its purpose is to efficiently transport water through a high water loss area. A New Mexico Water Resources Research Institute period-of-record analysis indicates that on an average, the channel saves about 34,000 acre-feet a year when in full operation (U.S. Army Corps of Engineers 1989). The channel also functions as a drain when not delivering diverted water. During periods when Elephant Butte Reservoir is full or near full, as occurred in the mid- to late-1980's and again in 1993, sediments are deposited in the lower end of the Low Flow Conveyance Channel. These sediments must be removed before water can again be diverted into the channel. With the exception of 15 months in 1983-85, and a couple of months in 1989, water from the Rio Grande has not been diverted into the channel.

Elephant Butte Reservoir was completed in 1916 by the BOR to provide water storage for the irrigation of farmlands along the Rio Grande between Truth or Consequences, New Mexico, and Fort Quitman, Texas, and to provide storage for supplying the Republic of México with water in accordance with the Treaty of 1906. The reservoir's original capacity was 2,634,800 acre-feet at spillway crest; its present capacity is about 2,065,000 acre-feet. Because of its effects on sediment transport and channel capacity, this water supply and recreational facility influences the Middle Rio Grande's hydrograph and morphology.

Institutional Infrastructure

The waters of the Rio Grande are managed by an interwoven fabric of federal, state, interstate, and international water laws, agreements, and regulations. The fabric defines how water is released through the system, influencing not only the quantity of water, but often the timing of the releases as well. The following are the principal management components.

- The **Treaty of 1906** between the United States and México provides for the annual delivery of 60,000 acre-feet of water to México.

- The **Rio Grande Compact** allocates Rio Grande water between the states of Colorado, New Mexico, and Texas via a complex set of delivery schedules that relate runoff volumes to delivery obligations at set river index points. For example, during normal water years, New Mexico must ensure that about 60% of the Rio Grande flow passing the Otowi gauge reaches Elephant Butte Reservoir (the delivery point for Texas' allocation of the Rio Grande). In extremely wet years, the requirement increases up to over 80% (Shupe and Folk-Williams 1988). The Compact also provides rules for accruing and repaying water credits and debits, water storage restrictions, and operation of reservoirs. The Compact does not "affect the obligations of the United States owed to Mexico or to Indian tribes, nor does it impair the rights of tribes" (Shupe and Folk-Williams 1988).

- **Federal law and regulations** are the primary determinants in the operations of Cochiti and Jemez Canyon reservoirs. The COE operates the dams in concert to release runoff waters at channel capacity (currently estimated to be about 8,000 cfs) as quickly as possible without causing unreasonable damage to channel protective works. No flood storage can be released from Cochiti Dam after July 1 when the Rio Grande's natural flow at the Otowi gauge is less than 1,500 cfs. The COE operates Cochiti and Abiquiu reservoirs so that all flood water held through the summer months under this restriction is retained in Abiquiu Reservoir. This carryover water must be released by March 31 of the following year (R. Kreiner, pers. comm.).

  The BOR manages the San Juan-Chama water in accordance with federal law and in response to water delivery calls from water contractors. The MRGCD and City of Albuquerque are the largest water purchasers, respectively contracting for 20,900 acre-feet and 48,800 acre-feet annually.

- **State water law** controls the use of water within the state via the administration of water rights—both surface and ground water. In the Middle Rio Grande Valley, the relationship between surface- and ground-water rights is of particular significance in that the City of Albuquerque's ground-water pumping must be offset with releases of San Juan-Chama water into the Rio Grande in order to keep the river "whole." These releases are scheduled to begin in 1994 (Summers 1992).

Hydrology

In the broadest terms, the cumulative effect of water management (flood control and irrigation development) activities in the Upper (in Colorado) and Middle Rio Grande basins has been to: (1) reduce the total Rio Grande flow in the Middle Rio Grande Valley, (2) control the spring runoff flows, and (3) reduce the magnitude of discharges resulting from thunderstorm runoff events (with the exception of localized flooding that occurs as the result of uncontrolled Rio Puerco and Rio Salado discharges and other small tributaries). Water management activities, however, have not eliminated pre-water management cycles in the Rio Grande's mean annual flow but rather have dampened past extremes (Bullard and Wells 1992).

Although the drainage area increases as one proceeds downstream, annual water yield decreases (Graf 1991). From 1895 through 1985, the average annual inflow into the middle valley, as measured at the Otowi gauge, is about 1,050,000 acre-feet (1,440 cfs); at San Marcial the average annual flow is 820,000 acre-feet (1,120 cfs; Fig. 15), a decrease of about 23% (Graf 1991). The difference between inflow and outflow can be accounted for by surface-water evaporation, consumptive use by crops, evapotranspiration by riparian vegetation, and ground-water recharge (Ong et al. 1991).

Agriculture accounts for almost 90% of all Middle Rio Grande managed consumptive water use in the middle valley. About 45% of the water diverted for agriculture eventually returns to the river, and only 20% of the total diversion is consumptively used by crops (Bullard and Wells 1992). The remainder is lost to surface-water evaporation, riparian vegetation evapotranspiration, and ground-water recharge. Average agricultural diversions in the middle valley for the period 1975-89, including San Juan-Chama Project water, are as follows (U.S. Bureau of Reclamation 1993c):

MRGCD Division	Average Diversions (1975-89) (acre-feet)
Cochiti	85,200
Albuquerque	133,870
Belen	202,310
Socorro (including conveyance channel)	113,900

Cochiti Dam has essentially eliminated downstream spring runoff flood damage to channel protective works and human developments; but as shown in Fig. 16, the overall average discharge has been greater since closure of the dam (Bullard and Wells 1992). This is likely the result of

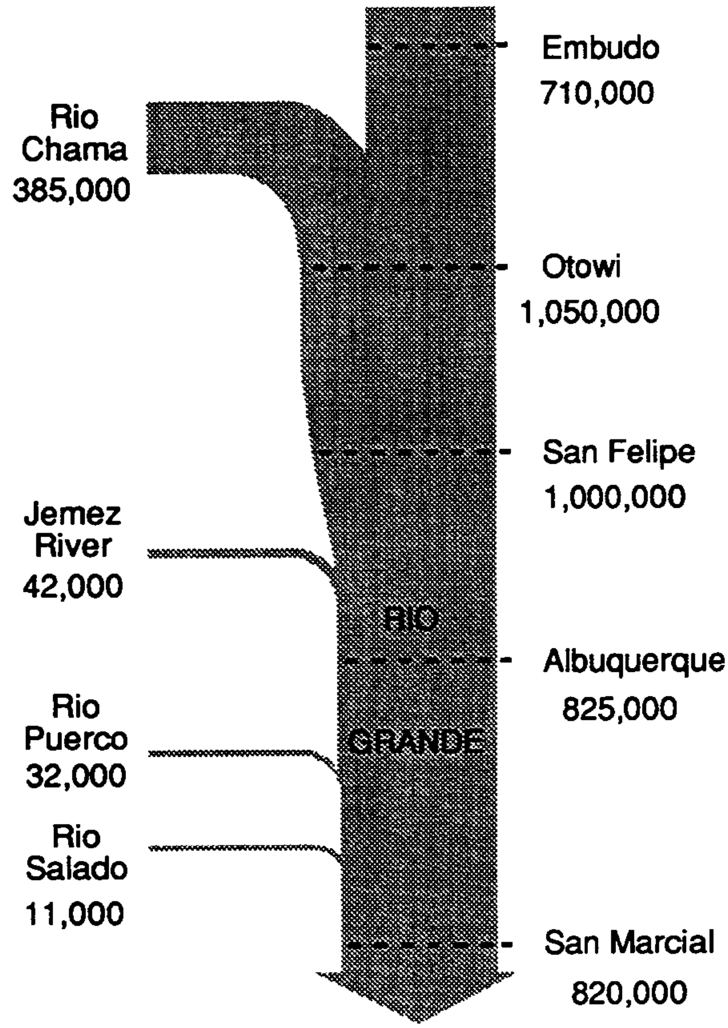


Fig. 15. Flow diagram for annual water yield budget of the Rio Grande from Embudo to San Marcial in acre-feet (after Graf 1991).

higher than long-term average runoff experienced since the late-1970's[1] and the importation of San Juan-Chama Project water into the Rio Grande system since 1971. The subsequent release of temporarily stored runoff water from Cochiti Dam (and Jemez Canyon Dam) provides for a more constant downstream flow (Lagasse 1980).

The San Juan-Chama Project also contributes water to the Middle Rio Grande. Its releases into the system, however, are uneven because the water is managed to satisfy the users who hold contract rights to the water. Ignoring seasonal variations, the City of Albuquerque consistently

[1]Since 1979, 8 of 10 years have produced runoff 200-300% above the 20- to 25-year average (Bullard and Wells 1992).

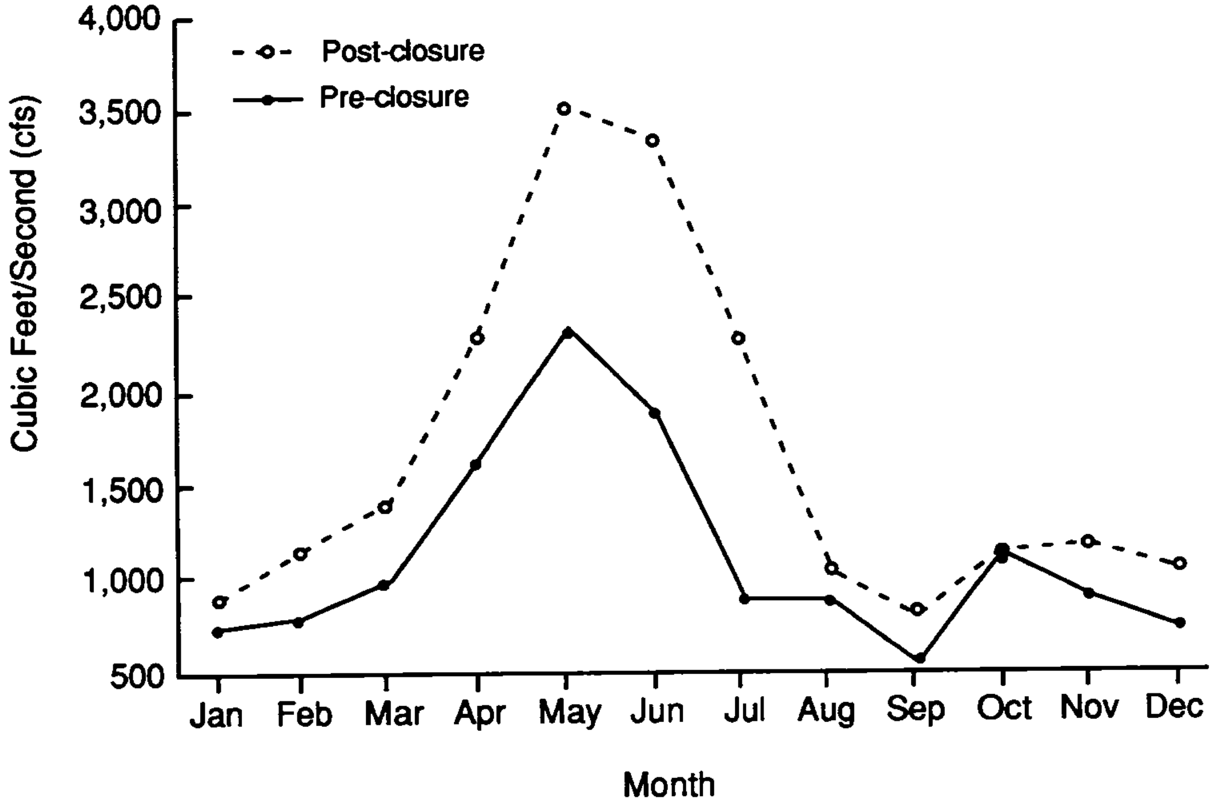


Fig. 16. Fifteen-year average of Rio Grande monthly mean discharge for pre- and post-Cochiti Dam closure periods at San Felipe gauge (after U.S. Bureau of Reclamation 1993b).

discharges about 85 cfs of treated ground water to the river. This water too, however, is subject to diversion for agricultural applications once in the river.

The Rio Puerco and Rio Salado are the two significant tributaries that do not have any flood control or water supply structures. Both rivers support only ephemeral flows, with the majority being brief but intense discharges resulting from summer thunderstorms. Of the annual water yield budget, the Rio Puerco and Rio Salado respectively contribute 4% and 1.3% of that reaching San Marcial (Graf 1991). From 1934 to 1982, the peak Rio Puerco flows averaged 9,082 cfs, as compared to 5,664 cfs on the Rio Grande at Bernardo (approximately 5 km [3 mi] upstream from the confluence) for the same period of time (Heath 1983). Most peak discharges from the Rio Puerco occurred during August, followed by lower frequencies in September and October (Heath 1983).

Sediment Load and Transport

River systems attempt to establish an equilibrium between discharge and sediment load. Change in available sediment will cause a river to compensate to regain equilibrium (Bullard and Wells 1992). A decrease in sediment causes the river to erode its channel and banks, i.e., degradation. An increase in sediment will result in deposition of the sediment load, i.e., aggradation.

The Middle Rio Grande has one of the highest sediment concentrations of any major river in the world (U.S. Bureau of Reclamation 1993b). Sediment loads in the Middle Rio Grande have decreased as the result of flood and sediment control dams, bank protection activities, and possibly regional factors.[2] The most dramatic decrease is attributed to Cochiti Dam, which indicates that sediments from the upper Rio Grande Basin are effectively trapped in the reservoir (Bullard and Wells 1992). Prior to dam construction, the maximum daily sediment load just below the dam was 4,580 tons; in 1987, the maximum was 442 tons (Bullard and Wells 1992). As of 1991, the total volume of sediment in Cochiti Lake's sediment reserve pool was about 18,486 acre-feet (U.S. Army Corps of Engineers 1992a). This is an average of about 1,150 acre-feet per year since Cochiti Dam began operations in 1975. Arroyo flows during the July to September precipitation events, however, still contribute slugs of sediment to the Rio Grande.

The Rio Puerco is a principal sediment contributor to the system (Table 9). It contributes about one-half of the sediment load in the Rio Grande downstream of its confluence, to Elephant Butte Reservoir, or about 2,600,000 tons per year (U.S. Bureau of Reclamation 1993b). Up to 82% of the sediment transported by the Rio Puerco occurs during once-a-year events (Leopold et al. 1964). Rio Puerco sediment concentrations have exceeded 680,000 mg/L (Bullard and Wells 1992) but have steadily decreased since the mid-1950's (Table 9). The reasons for these decreases are not fully understood but are probably attributable to variations in climate/weather patterns, improved land management in the drainage, and cyclical geomorphic trends.

River Morphology

Garde and Raju (1977) discussed the concept of dominant discharge as it applies to alluvial streams such as the Rio Grande. Dominant discharge determines average channel dimensions and is often near bankfull discharge or some percentage of maximum discharge. A river's morphology will change if alterations in discharge and sediment load are of sufficient magnitude (Schumm 1977). A river discharge influences the size of channels whereas the type of material transported influences the character of channels (Schumm 1977). Clearly this is the case with the Middle Rio Grande, especially upstream of the confluence with the Rio Puerco, as water management has reduced the dominant discharge and sediment load.

Periodic high discharge events are required to maintain the channel capacity and geomorphology of the entire Middle Rio Grande. Without these flows, the river would evolve

[2]There is evidence of a decrease in annual sediment concentrations throughout New Mexico, at least since the mid-1950's (Gellis 1991)

Table 9. Rio Grande and Rio Puerco average sediment concentrations (after U.S. Bureau of Reclamation 1992).

	Average Sediment Concentration (mg/l)	
Rio Grande	1966-77	1978-82
Albuquerque	4,000	900
San Acacia	28,000	10,000
San Marcial	13,000	5,300
Rio Puerco (near confluence with the Rio Grande)		
1956-61	152,000	
1962-76	115,000	
1977-84	92,000	

and "close down" in response to a lower discharge regime (C. Gorbach, pers. comm.). A dampening of peak discharge and subsequent decrease in bed load movement will result in channel narrowing (Schumm 1977). Analysis of aerial photographs of the Middle Rio Grande from 1935 and 1989 identifies an approximate 50% reduction in river channel area. This narrowing of the Middle Rio Grande channel is the one morphological response that is consistent throughout all four study reaches.

As mentioned in the previous section, the Rio Grande Rift is still geologically active. There continues to be earthquake activity and there is an active uplift in the Socorro area. Active tectonics can influence fluvial systems, and studies indicate that changes in the behavior and pattern of the Middle Rio Grande can be expected to occur independent of human-associated or climatic changes (Bullard and Wells 1992). Measurable changes in the Rio Grande due to the Socorro uplift include changes in flow characteristics and sediment transport ability (Bullard and Wells 1992) by altering the river gradient.

The location of the contemporary floodway in the valley is not "unnatural" as compared to the premanagement era. The Middle Rio Grande floodway snakes through the valley abutting natural impediments in some areas, such as the bluffs to the west in Albuquerque, and wanders through the middle of the valley in the upper and central portion of the Cochiti Reach. It has a repeated sinuosity in a large portion of the Belen Reach, and follows almost a gooseneck course through San Acacia. What constrains river processes is that the floodway has been largely immobilized. This fact, combined with managed hydrology and channel maintenance activities, has resulted in largely predictable river morphology responses within the floodway.

A brief description of the Middle Rio Grande's channel morphology follows.

Cochiti to Angostura (Cochiti Reach).—Prior to construction of Cochiti Dam, this reach was characterized by braided channels separated by bars and islands composed of coarse gravels and cobbles (Lagasse 1980, Graf 1991). Reduction of sediment loading from the mainstem and, to a much lesser extent, channel stabilization activities have caused the riverbed to gradually incise (or degrade); and since the 1940's, the river has become more narrow and less braided (Graf 1991). Cochiti Dam accelerated this change in river configuration; however, the transition was well established before the dam's construction (Graf 1991). The channel degradation process has proceeded through this entire reach and the riverbanks, generally 1.2 to 1.5 m (4-5 ft) high, are higher than in any of the other reaches. The riverbed is now well armored with gravel material, and the degradation process is stabilized (D. Baird, pers. comm.). A predictable response of an alluvial river to a dam is that channel degradation is generally greatest at the dam and decreases somewhat progressively downstream. Likewise, the rate of degradation normally decreases with time and the length of degradation increases with time as new equilibria are approached (Williams and Wolman 1984). This is the case with the Rio Grande below Cochiti Dam.

The riverbank material in the Cochiti Reach remains unstable, however, and the river is becoming more sinuous in seeking a new equilibrium between river discharges and sediment transport capacity. This is resulting in bank erosion. In response to this, the BOR has recently begun a bank stabilization program, where the vulnerable riverbanks are being stabilized in place (i.e., armoring the outside banks of channel bends with riprap material).

Regulated discharges from Cochiti Dam are insufficient to transport the sediment still imported to the Rio Grande from small unregulated tributaries. This results in local channel aggradation and unstable channel configurations (Bullard and Wells 1992). Small, but persistent deltas form at the point of confluence with Galisteo Creek and lesser arroyos. The deltas affect not only the immediate locales, but also upstream and downstream river configurations by altering the slope of the channel bed (Lagasse 1980). The Angostura Diversion Dam (and the other diversion dams) similarly acts as a hydrologic control. The effect on the river is to reduce water velocities and river slope upstream from the control resulting in a wider river channel with more fine materials in the riverbed. Downstream, the slope and water velocities increase, and the river channel has more of a tendency to establish a well-defined course.

The incision of the river channel in the Cochiti Reach makes it very unlikely that the controlled Rio Grande discharges will overtop the riverbanks under present reservoir management practices. This assumption is supported by the fact that the recent spring flow releases from Cochiti Dam (1992: 5,600 cfs; 1993: 7,500 cfs) were contained within the channel throughout this reach (U.S. Bureau of Reclamation 1993d).

Angostura to Bernardo (Albuquerque and Belen Reaches).—The Rio Grande in these reaches is predominantly a sandbed river with low, sandy banks. The river channel tends to be straighter and more uniformly wide in these reaches than in the other reaches. There are numerous sandbars. At less than bank-to-bank flows, the river is establishing a sinuous configuration within the cleared floodway. The channel degradation process is proceeding through the Albuquerque Reach and gravels are beginning to appear in the riverbed material (U.S. Bureau of Reclamation 1993b). The presence of gravel bars in the lower portion of the Albuquerque Reach, in fact, became more prevalent from 1992 to 1993 following the 1993 spring flows (R. Leutheuser, pers. obs.). Major sediment-contributing tributaries in this portion of the river include Rio Grande Arroyo de las Barrancas, Calabacillas Arroyo, and Abo Wash. Riparian vegetation is firmly established along the banks of the cleared floodway, contributing to the stability of the riverbanks.

The 1992 and 1993 spring flow releases produced overbank flows downstream of Isleta Diversion Dam through the Belen Reach, with most of the bosque flooding occurring from the diversion dam to south of Belen. Generally, the extent of flooding increased somewhat proportionally to the spring river discharges, which peaked at about 5,400 cfs in 1992 and at 7,000 cfs in 1993 (U.S. Bureau of Reclamation 1993d).

Bernardo to San Marcial (Socorro Reach).—The riverbed is sand in the Socorro Reach, and the banks are low and sandy. The character of the Rio Grande changes significantly below its confluence with the Rio Puerco and Rio Salado due to sediment inflow and hydrologic discharges from the tributaries. Equally significant to the shape of the river below San Acacia are the Low Flow Conveyance Channel and associated spoil levees on the west side of the river (Milhous et al. 1993), the absence of any channel rectification projects on the east side of the Rio Grande, and the upstream (backwater) effects of Elephant Butte Reservoir (Bullard and Wells 1992).

An increase in sediment loading, with a decrease in receiving river water flows, leads to channel aggradation (Leopold et al. 1964). The river channel below the Rio Puerco tends more toward being braided—although less so than in historic times (Bullard and Wells 1992). It has alternating wide and narrow widths but as a rule tends to be wide (U.S. Bureau of Reclamation 1992). Elephant Butte Reservoir influences sediment transport as well, especially when the reservoir pool is very high, which creates backwater conditions at the upper end of the reservoir. Near San Marcial, the Rio Grande forms a delta at the head of the reservoir. Between 1979 and 1988, the riverbed just below San Marcial aggraded 3.5 m (12 ft; C. Gorbach, pers. comm.). In 1985 and 1986 alone an estimated >25,000 acre-feet of sediment was deposited in the upper 19 km (12 mi) of the reservoir (U.S. Army Corps of Engineers 1989). This reduced the slope of the river, which in turn decreased flow velocity and increased sediment deposition, i.e. channel aggradation (Bullard and Wells 1992). The river channel is now braided and flows spread over a large area.

It is interesting to note that the 1992 spring flow release program did not produce uniform overbank flows in this reach. All flows remained in the channel between Bernardo and San Acacia. From San Acacia to San Antonio, all flows (about 3,900 cfs to 5,600 cfs) produced flooding over about 10% of the floodplain. South of San Antonio, through the Bosque del Apache NWR to San Marcial, however, all discharges flooded about 90% of the floodplain (U.S. Bureau of Reclamation 1992). The results of the 1993 spring release program, maximum discharge of about 7,000 cfs, were similar.

Quality

Aubertin and Patric (1972) used the term water quality to represent "the state or condition of water which determines its usefulness." Water quality in the Middle Rio Grande Valley has been affected by human activity over the last century. Mainstream dams and diversions have trapped sediment and affected the physical characteristics of water released downstream. Increased use of chemicals for agricultural purposes represents a potential nonpoint source of pollution. Development has resulted in an influx of pollutants entering the river as surface runoff. Also, discharge of municipal effluents has impacted the natural chemical balance.

Chemical characteristics of rivers are a function of geological, biological, and meteorological conditions within the watershed (Curry 1972). The common classes of compounds naturally found in water are dissolved inorganic ions and compounds, particulate inorganic compounds, dissolved organic compounds, particulate organic material, and dissolved gases (Winger 1981). Concentrations of these compounds may vary dramatically both temporally (daily, seasonally, annually) and spatially relative to location and depth. Aquatic organisms also have a wide range of tolerance to these conditions.

The snowmelt sources of Rio Grande water, which dominate the spring flows, is characteristically low in total dissolved solids (TDS). Runoff from the summer thunderstorms is comparatively high in TDS and sediments due to the nature of the local soils and geology. Water quality of some river reaches is heavily influenced, therefore, by the dominant contributing tributaries and the time of the year (U.S. Bureau of Reclamation 1993b).

As seen in Fig. 17, total suspended solids (TSS) increase dramatically between Bernardo and San Acacia. The mean and maximum TSS in the Rio Grande at Bernardo (immediately upstream from its confluence with the Rio Puerco) are 2,078 mg/l (9,914 tons/day) and 31,100 mg/l (245,000 tons/day), respectively. At San Acacia, downstream from both the Rio Puerco and Rio Salado inflows, the mean and maximum values are 19,700 mg/l (56,647 tons/day) and 200,000 mg/l (537,000 tons/day; U.S. Bureau of Reclamation 1993b).

Total dissolved solids and turbidity increase as one proceeds downstream because of surface runoff, irrigation, and municipal discharges into the river. As seen in Table 10, mean TDS increases from 223 mg/l at San Felipe to 490 mg/l at San Marcial. Maximum turbidity increases from 2,800 NTUs at San Felipe to 80,000 NTUs at San Marcial (U.S. Bureau of Reclamation 1993b). The inflow of the Rio Puerco and Rio Salado is a principal reason for these trends. This is explained not only by the quality of the water these tributaries contribute to the Rio Grande, but also by the fact that sediment loading leads to channel aggradation, which in turn leads to a broader, shallower channel upstream. The resultant increased water surface area induces more water losses due to evaporation and seepage, thereby increasing TDS concentrations.

Water temperature generally increases, and total dissolved oxygen decreases, going downstream through the valley (Table 10). This is consistent with releases from Cochiti Dam being comparatively cool then warming downstream due to changing river morphology and increasing ambient air temperatures. Other variables being equal, dissolved oxygen concentrations decrease with increasing water temperatures. The pH, a measure of alkalinity or acidity, remains fairly constant throughout the Middle Rio Grande.

Ong et al. (1991) conducted a reconnaissance investigation of water quality, bottom sediment, and biota associated with irrigation drainage in the Middle Rio Grande Valley and at Bosque del Apache NWR. Physical properties such as temperature, dissolved oxygen, pH, and TDS did not

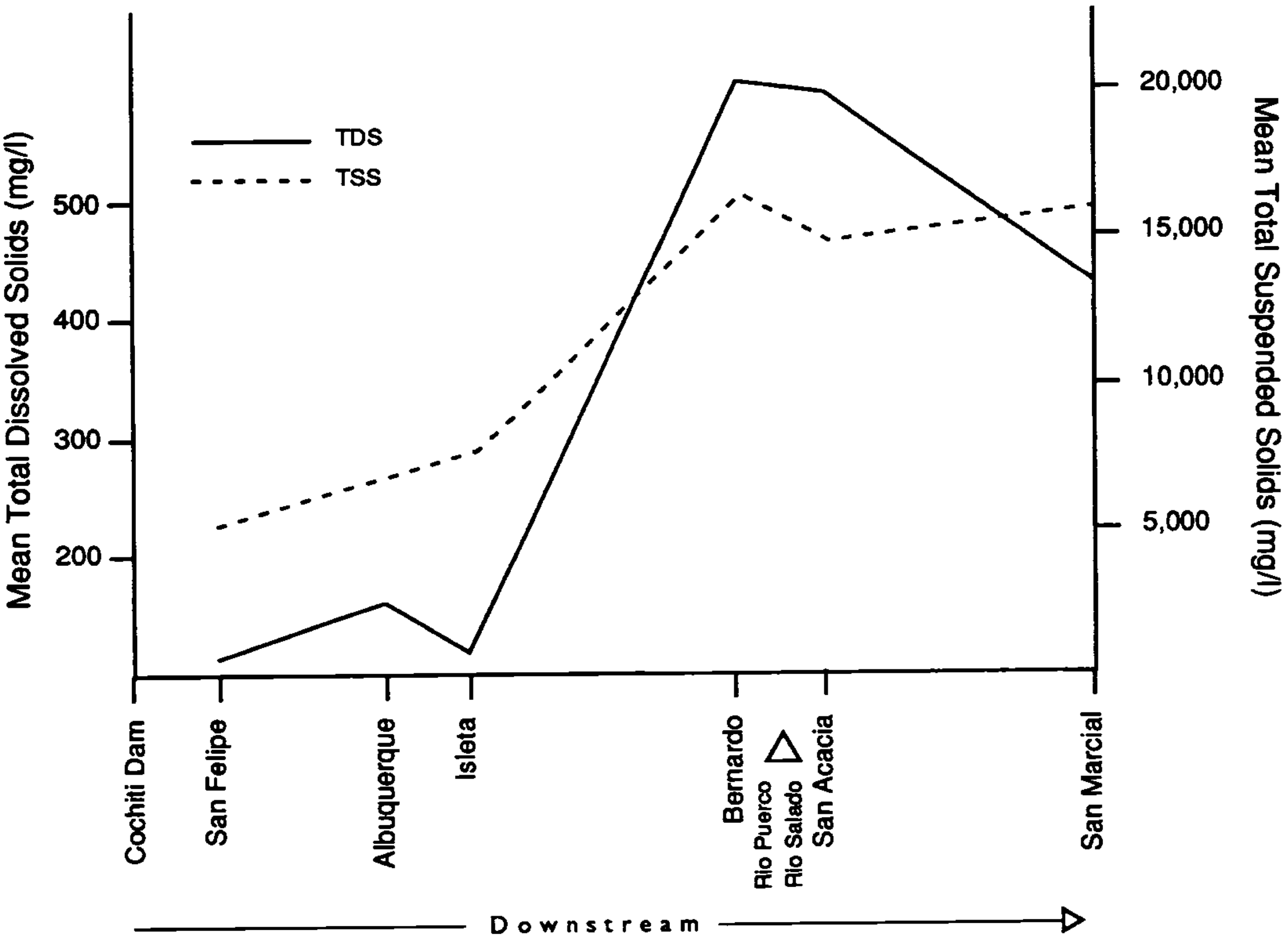


Fig. 17. Middle Rio Grande mean total dissolved solids (TDS) and mean total suspended solids (TSS), 1960-90 (see Table 10).

exceed New Mexico State standards for the protection of wildlife and fish. Potentially toxic trace elements were less in almost all samples than the maximum contaminant limit for safe drinking water as set by the U.S. Environmental Protection Agency (EPA). Pesticide concentrations were generally less than laboratory reporting limits with the exception of 2,4-D and diazinon.

The New Mexico Environment Department conducted an intensive water quality survey of the Rio Grande from Angostura to the I-25 bridge in 1988 (Pierce 1989). The primary objectives of this study were to (1) assess water quality of the Rio Grande and (2) determine the effects of effluent from wastewater treatment facilities in Bernalillo and Albuquerque. Water quality was characterized as highly turbid and slightly alkaline. Chemical constituents and nutrients were found in moderate concentrations except for iron and manganese, which occurred in moderately to extremely high concentrations at sites downstream of Angostura Diversion Dam after a rain event. Elevated levels of fecal coliform bacteria occurred only after runoff events or in association with chlorination problems at treatment facilities. A similar study in 1984 (Potter

Table 10. Middle Rio Grande water quality.

Constituent	Location	Maximum	Minimum	Mean
Total Suspended Solids[1] (mg/l)	San Felipe[1.1]	14,300	5	467
	Albuquerque[1.2]	76,600	9	2,493
	Isleta[1.1]	10,100	22	720
	Bernardo[1.3]	31,100	21	2,078
	San Acacia[1.4]	200,000	225	19,700
	San Marcial[1.3]	124,00	41	13,243
Total Suspended Solids[1] (tons/day)	San Felipe[1.1]	69,600	6.5	4,139
	Albuquerque[1.2]	58,000	0.8	13,481
	Isleta[1.1]	69,700	1.9	6,081
	Bernardo[1.3]	245,000	0.9	9,914
	San Acacia[1.4]	537,000	0.5	56,647
	San Marcial[1.3]	639,000	6.0	41,958
Total Dissolved Solids[1] (mg/l)	San Felipe[1.1]	314	115	223
	Albuquerque[1.2]	690	192	268
	Isleta[1.1]	426	123	285
	Bernardo[1.3]	1,690	231	510
	San Acacia[1.4]	790	256	472
	San Marcial[1.3]	1,600	159	490
Water Temperature[2] (°C)	San Felipe	25.5	0.5	12.9
	Albuquerque	28.0	0.0	14.3
	Isleta	29.5	1.0	15.9
	Bernardo	31.0	0.0	15.8
	San Acacia	32.0	2.0	16.3
	San Marcial	36.0	0.0	15.8
Dissolved Oxygen[2] (mg/L)	San Felipe	13.4	7.2	9.7
	Albuquerque	11.5	7.0	9.2
	Isleta	10.8	5.0	7.7
	Bernardo	11.4	6.5	9.0
	San Acacia	13.0	6.0	8.8
	San Marcial	12.1	5.6	8.4
pH[2]	San Felipe	8.8	7.3	8.1
	Albuquerque	8.7	6.8	8.1
	Isleta	8.3	6.6	7.9
	Bernardo	9.1	7.5	8.1
	San Acacia	8.7	7.6	8.2
	San Marcial	8.7	7.5	8.2

[1] Source U.S Environmental Protection Agency data *in* U S Bureau of Reclamation (1993b) 1 1 = 1970-90, 1.2 =1969-90, 1 3 = 1959-90, and 1 4 = 1960-90

[2] Source U S Geological Survey Gauging Station Report, October 1980-September 1990

1984) found that water quality data differed between sites upstream and downstream of wastewater treatment facilities. Mean conductivity, total ammonia, and chlorine residual concentrations were higher at downstream sites.

Urban runoff also affects water quality. In the middle valley, the City of Albuquerque, although not the only contributor of urban runoff to the Rio Grande, is the principal discharger. Storm-water runoff in Albuquerque is collected and discharged into the Rio Grande by a system of concrete-lined conveyance channels, storm sewers, and, in some instances, via MRGCD drains. The water quality of urban runoff in the arid Southwest, where the summer thunderstorm events generally result in short-lived but violent runoff, presents particular problems in terms of "shock loading" the receiving waters.

The EPA is phasing in a storm-water discharge permitting system, under the authority of the Clean Water Act, applicable to cities with a population of 100,000 or greater, certain industries, and construction activities. The results of the EPA-sponsored National Urban Runoff Program (NURP) survey (1978-83) characterized the problem on a national scale (U.S. Environmental Protection Agency 1983). The survey concluded that heavy metals, especially copper, lead, and zinc, are by far the most prevalent "priority pollutant constituents" found in urban runoff. Coliform bacteria are also present at high levels, and nutrients are generally present but are of lesser concern when compared with other possible discharges. Other studies demonstrate that urban runoff is an important source of oil and grease, which tend to accumulate in bottom sediments (Federal Register 1990).

The City of Albuquerque and AMAFCA have recently initiated a water quality monitoring program to identify and quantify constituents in the water discharged to the Rio Grande. The findings of this monitoring are not yet available; however, storm-water runoff was monitored in 1977 and 1978 as part of the NURP survey. The results, as summarized by Tague and Drypolcher (1979), found that the annual loading of fecal coliform bacteria in the storm-water runoff was about 50 times greater than the wastewater treatment facility effluent. Tague and Drypolcher (1979) concluded, therefore, that the runoff likely was responsible for the elevated levels of bacteria in the Rio Grande during the thunderstorm season. Furthermore, the survey determined that the annual mass loadings of all forms of phosphorus and nitrogen in runoff was low in comparison to discharges from the wastewater treatment discharge. Total suspended solids, zinc, lead, and chromium in runoff comprised about 50% to almost 100% of the combined annual loading from runoff and wastewater treatment facility discharge. Lastly, the survey confirmed that shock loading can be high. After a single thunderstorm event, the nitrogen and phosphorus loads in the runoff were almost twice those in the effluent from the treatment facility.

2. Ground Water

Ground water flows from north to south through the Middle Rio Grande Valley along the axis of the connected ground-water basins. Within each of the basins, the ground-water level slopes toward the axis of river from the adjacent mountains and plateaus (U.S. Bureau of Reclamation 1977). The geology of the lower end of each basin constricts ground-water movement from one basin to the next, thereby controlling its southward migration.

Movement and Use

The Rio Grande is hydrologically connected to the shallow valley-fill ground-water system throughout the valley. The river recharges the shallow system which functions as a connection between the surface-water system and the deeper Santa Fe Group aquifer (Ong et al. 1991; Hawley and Haase 1992). The river likely contributes more to the entire ground-water system than any other single source (Bullard and Wells 1992), and is the primary control on the nearly steady state water levels in the floodplain (Logan 1990).

The valley fill, as stated, is not homogeneous. There are discontinuous lenses of clay deposited in the coarser alluvial materials. In much of the Albuquerque Basin's floodplain, there are layers of clay up to about 4.5 m (15 ft) thick (Thorn et al. 1993). The clay is less permeable; where present, it limits the downward movement of water to the deeper Santa Fe Group and associated ground water. In these instances, areas of a perched ground-water zone can be created. Such a zone has been identified in the southern Albuquerque metropolitan area near the City of Albuquerque's San Jon Well Field (Thorn et al. 1993).

Results from a controlled experimental flood at Bosque del Apache NWR in the spring of 1993 documented the strong hydrologic linkage between flood water and ground water. In response to controlled flooding about 200 m (600 ft) from the monitoring sites, ground water began rising within 20 hours and ultimately rose as much as 1.8 m (6 ft). Ground-water dissolved oxygen content increased from nearly 0 to as high as 4 mg/l, indicating that surface-water/ground-water exchange had occurred. Also observed were large increases in dissolved organic carbon, probably responding to materials leached from the forest floor, as well as to alterations in forms and concentrations of plant-available nitrogen. These data suggest that floods in the Middle Rio Grande probably are major linking events between ground water, the riparian zone, and the river channel (H.M. Valett, pers. comm.; C.S. Crawford, pers. obs.).

It is variously estimated that one-third to two-thirds of the water conveyed in the canal system and applied to the agricultural fields returns to the ground-water system (Bjorklund and Maxwell 1961, U.S. Army Corps of Engineers 1979). Shallow ground-water levels fluctuate on a seasonal basis; irrigation and ground-water withdrawals lower ground-water levels during the summer months (Bullard and Wells 1992). The agricultural water distribution and drain network (Fig. 18A) has an important influence on ground-water levels and flows within the floodplain of the middle valley. The complex of canals and laterals is responsible for the spatially well-distributed seasonal recharge of the floodplain's shallow ground-water system more distant from the Rio Grande.

Inflows from adjacent areas, although locally important, influence the ground water to a lesser degree (Fig. 18B). Urban development and continued construction of the storm-water conveyance system, especially in the greater Albuquerque metropolitan area, efficiently deliver an increasing proportion of runoff directly to the Middle Rio Grande. As a result, less water is recharging the ground water from these areas than occurred in the past.

Alluvial ground water supplies all nonagricultural water uses and some supplementary irrigation in the valley. Domestic, public supply, irrigation, commercial, and industrial wells are

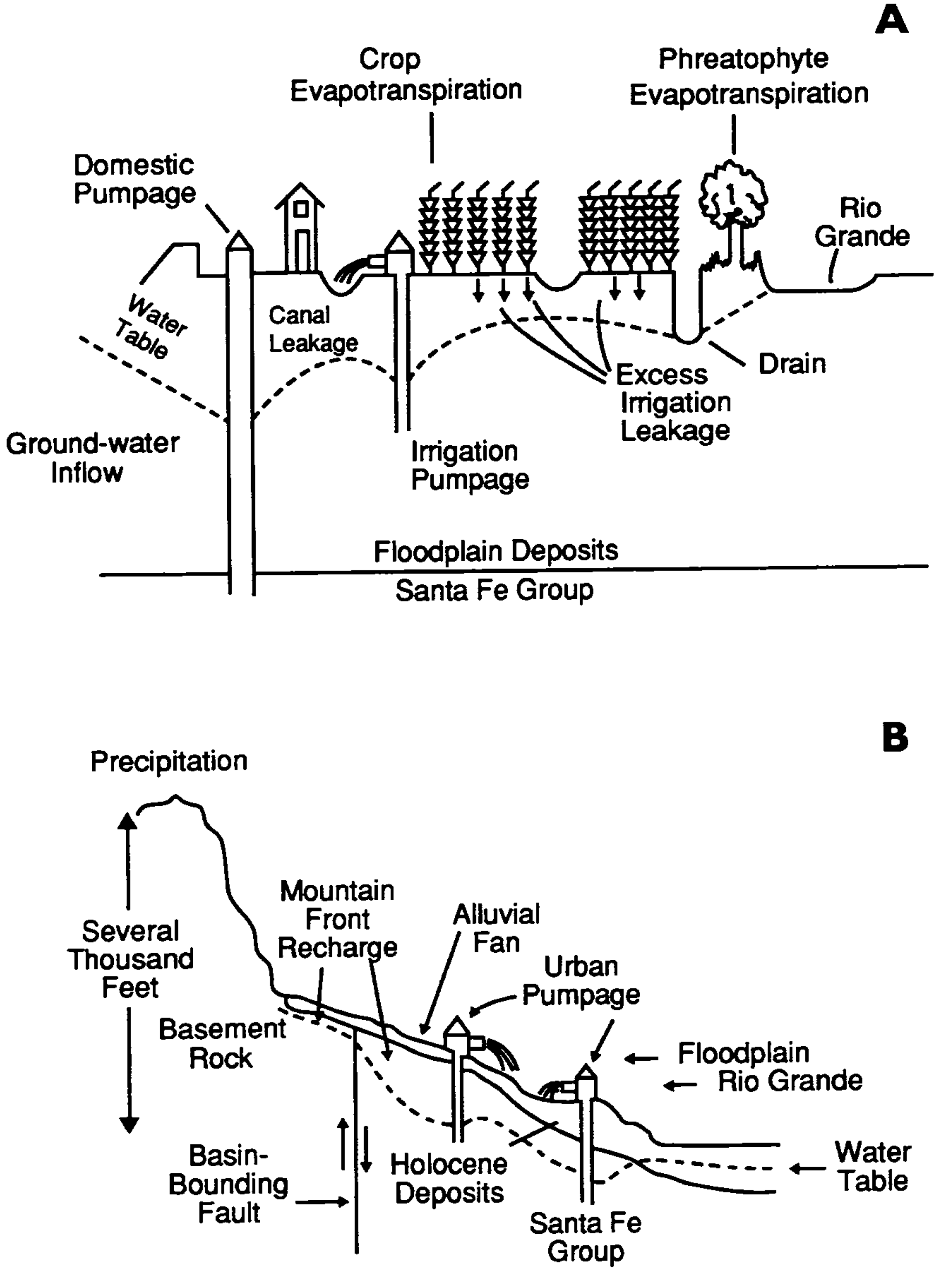


Fig. 18. Ground-water movement (A) and basin-aquifer and floodplain flow system (B) in the Middle Rio Grande Valley (after Wilkins 1986).

generally located in or near the floodplain where depths to ground water are shallow and where settlement first occurred (Lance et al. 1990). Figure 19 shows the locations of different ground-water uses in the Middle Rio Grande Valley.

Depth to ground water in the floodplain varies from basin to basin, but it is usually near river level along the river's axis (U.S. Bureau of Reclamation 1977). In the Albuquerque and Belen reaches, ground water is about 3 m (10 ft) below the ground surface in the floodplain, and in the upper end of the Socorro Reach it varies from 0-2.4 m (0-8 ft) below the bosque's ground surface (U.S. Bureau of Reclamation 1977). In Bosque del Apache NWR, its depth is 1.2-3.4 m (4-11 ft; C.S. Crawford, pers. obs.).

Albuquerque supplies the greater metropolitan population with ground water pumped from deep wells. A cluster of wells midway between the Rio Grande and the Sandia Mountains has created a depression in the ground-water level which in turn has reversed the direction of ground-water flow. Ground water now flows away from the floodplain instead of towards it from the bordering higher elevations (Lance et al. 1990, Logan 1990). Wells in the floodplain's alluvial material also can locally lower ground-water levels. However, because of the rapid flow of water through loose material, the ground-water levels recover rapidly, with inflows from the canals, drains, and river (Anderholm 1987 cited in Bullard and Wells 1992).

Quality

The ground-water system underlying the valley contains large quantities of fresh and slightly saline water in storage. Freshwater is generally found in the Santa Fe Group alluvium. The fresh-water zone is frequently underlain by a zone of slightly saline water (1,000 to 3,000 mg/l dissolved solids). Likewise, the shallower saline water is often underlain by more saline water (U.S. Bureau of Reclamation 1977).

In determining ground-water vulnerability to human-related contamination, Lance et al. (1990) rated the Rio Grande inner valley to be the most vulnerable because of shallow depths to ground water, flat topographic slopes, and coarse surficial materials. Relying mainly on New Mexico Environment Department and Southwest Research Information Center records, they plotted the recorded cases of ground-water contamination in the middle valley. The greatest concentration of sites is in the Albuquerque metropolitan area. A lesser concentration of sites extends south of Albuquerque from Bosque Farms south to Socorro with fewer sites yet extending north from Albuquerque to the Bernalillo area. Only one site, at San Marcial, is located south of Socorro.

Point sources of ground-water contamination (discreet geographical locations to which contaminants can be traced) consist mainly of gasoline products, chlorinated solvents, and heavy metals. Nonpoint sources of contamination are related to contaminants spread over a wide geographic area. Figure 20 shows the locations of known ground-water pollution in and adjacent to the floodplain from Cochiti Dam to San Acacia and in the Albuquerque area. The prevalent nonpoint sources are high density septic tanks and leach fields and agricultural activities. The high septic tank/leach field concentrations in Albuquerque's North and South Valleys, and to a lesser extent communities to the south, have resulted in elevated levels of iron, manganese, and

Fig. 19. Distribution of ground-water uses in the Middle Rio Grande Valley (after Lance et al. 1991).

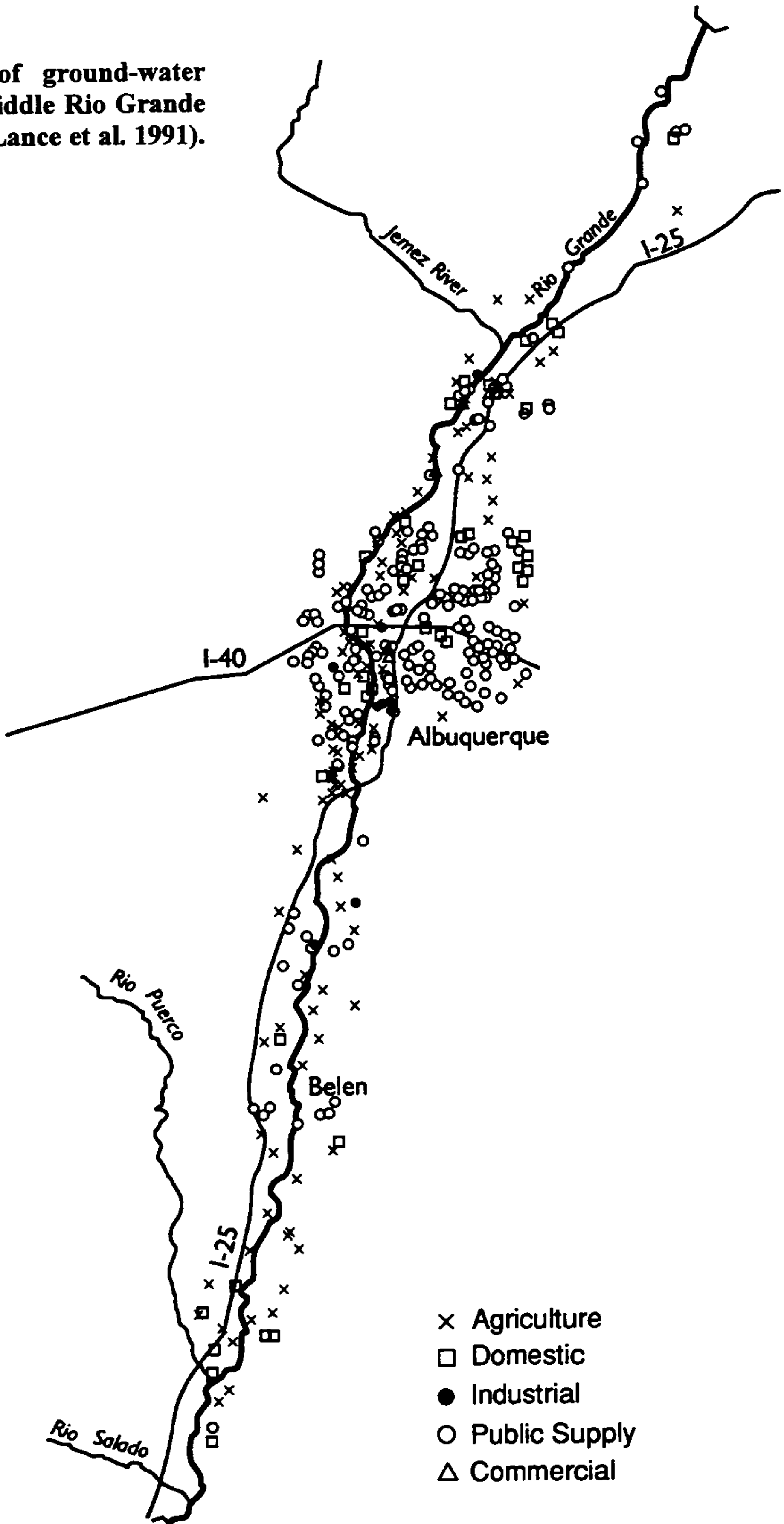
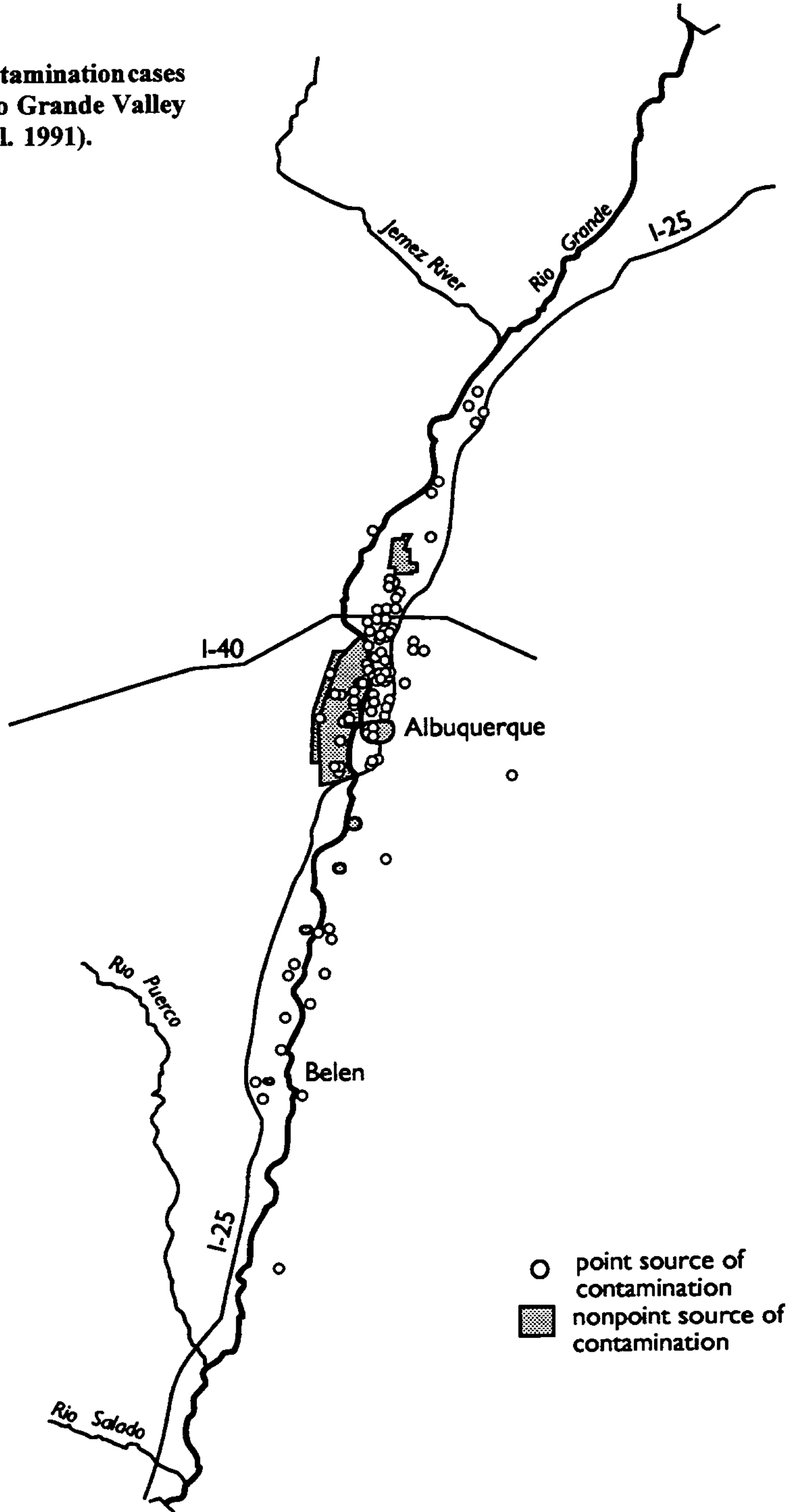


Fig. 20. **Gound-water contamination cases in the Middle Rio Grande Valley (after Lance et al. 1991).**



the presence of hydrogen sulfide (in oxygen poor environments); or in nitrate contamination (in oxygen-rich environments; Lance et al. 1990). Application of irrigation water not only transports fertilizers and pesticides applied to agricultural lands but also increases concentrations of dissolved solids (salinity) in the ground water (Lance et al. 1990) which can affect river water quality (Bullard and Wells 1992).

Natural processes also adversely affect ground-water quality. Riparian vegetation, through the natural evapotranspiraton process, concentrates total dissolved solids in ground water (Wilson et al. 1977 cited in Bullard and Wells 1992). In the Socorro region, high concentrations of chloride have been attributed to circulation patterns within the ground-water system, which bring deep, chloride-enriched ground water into contact with near-surface ground water (Anderholm 1987 cited in Bullard and Wells 1992).

C. AQUATIC ECOLOGY

1. Processes

A wide range of both natural and human-caused factors has influenced the current status of the Middle Rio Grande aquatic resource. The natural hydrology, including low flow conditions and water quality (e.g., warmwater), has selected for specific native aquatic communities. Other factors such as regulated water storage and delivery, changes in channel morphology, and introduction of nonnative fish have greatly impacted the existing aquatic ecosystem.

Transport of Organic Matter

The nutrient cycle within the Middle Rio Grande is not well understood. In general, primary energy sources for rivers are organic material from riparian vegetation (allochthonous) and organic material generated within the river (autochthonous; Benfield 1981). Rivers with a high sediment load, such as the Rio Grande, generally have a paucity of aquatic vegetation and thus minimal autochthonous input (Blum 1956). Allochthonous input from upstream is a critical source of organic carbon for these systems (Benfield 1981). Allochthonous input in the Middle Rio Grande supports bacteria and algae that assimilate carbon and thus are vital to the food chain (B. Montoya, in litt.). Cole et al. (1987) stated that organic matter input from the riparian zone below Cochiti Dam may be relatively unimportant when compared with allochthonous input from reservoirs.

Primary production in aquatic ecosystems is extremely complex and variable. Organic matter (detritus) processing is a key component in maintaining the trophic dynamics of aquatic ecosystems. Figure 21 presents a general model of detritus processing in streams (Benfield 1981). Allochthonous and autochthonous inputs enter the river as either coarse, fine, or dissolved particulate organic matter. The periphyton (plant material attached to underwater surfaces, e.g., algae) component of the autochthonous input is often converted to fine organic matter by scraper macroinvertebrates. Course organic matter is initially attacked by microbial organisms and converted to fine organic matter either by natural degradation or shredder macroinvertebrates. Consumer invertebrates, such as detritivores and collectors, use the fine organic matter as an energy source and are subsequently consumed by both vertebrate and invertebrate predators.

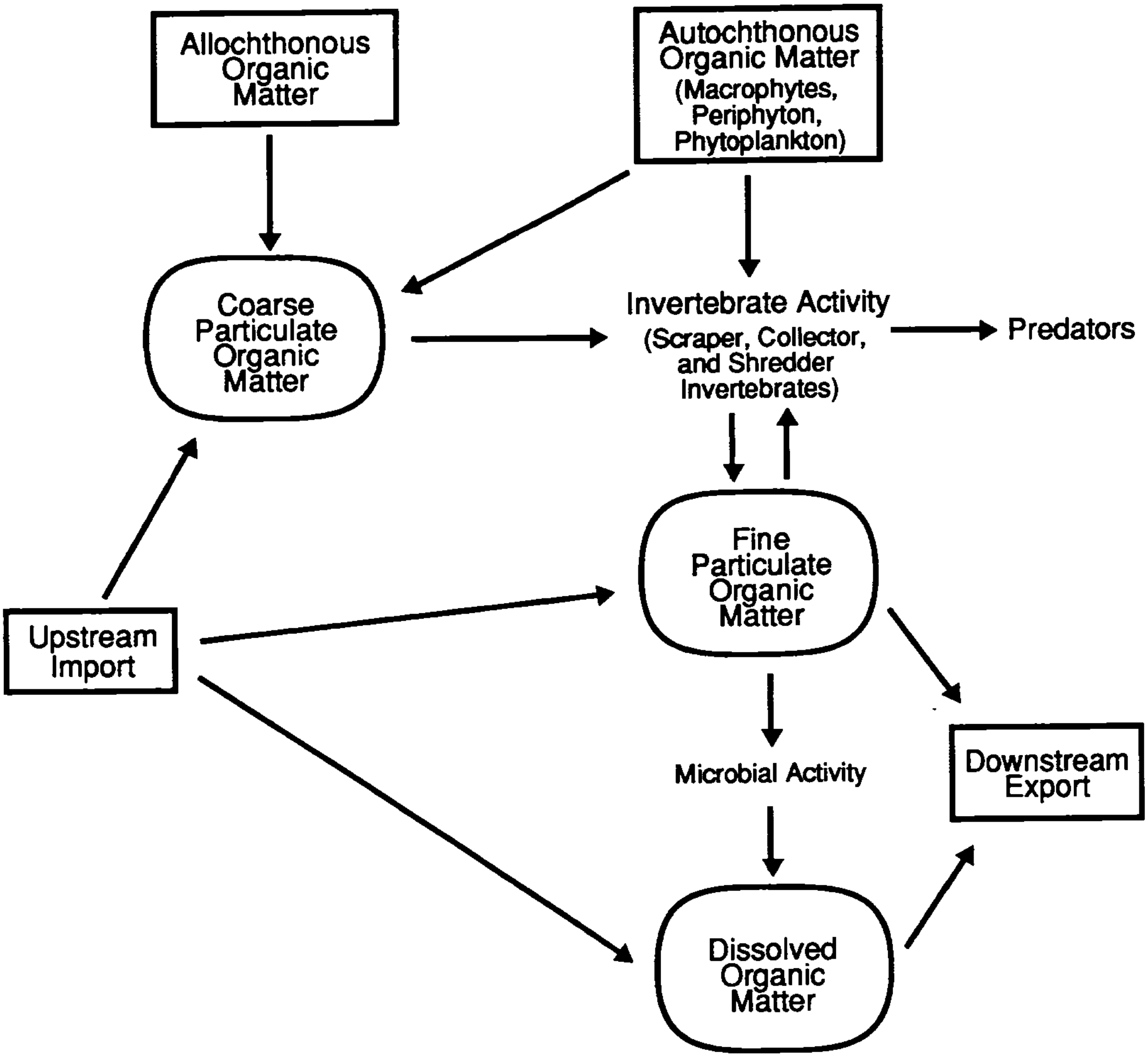


Fig. 21. Conceptual model of primary production and detritus processing in stream ecosystems (after Benfield 1981).

Primary production in the Middle Rio Grande tends to peak in early spring and late summer before and after spring runoff (Cole et al. 1987). Benthic (bottom-dwelling) algae are important producers in the Cochiti Dam tailwater, especially during low flow (Cole et al. 1987). The Middle Rio Grande supports a limited aquatic macrophyte community due to a shifting sand substrate. Most macrophytes occur in the Cochiti Reach (S. Platania, pers. comm.). Zooplankton are abundant in Cochiti Lake and therefore are exported, albeit minimally, during reservoir releases (Cole et al. 1987). Cole et al. (1987) also noted that many fish below Cochiti Dam are either zoobenthivores or piscivores due to the overall paucity of zooplankton. Riparian allochthonous input from within the study reach also provides organic matter to the river.

The impacts of Cochiti Dam and other diversion structures on the transport of organic matter throughout the Middle Rio Grande have not been studied. As mentioned previously, organic carbon concentrations are low below Cochiti Dam but increase downstream, possibly due to tributary inputs. Longitudinal variation in fish and invertebrate communities throughout the Middle Rio Grande suggests that changes in hydrology, channel morphology, and water quality are primary influences on the aquatic ecosystem. There are no apparent trends to suggest that organic matter input is a limiting factor.

Hydrology

The flow regime of a river is a primary factor characterizing aquatic habitats and associated fish and invertebrate community relationships (Stalnaker 1981, National Research Council 1992). Flow regime impacts habitat by influencing habitat characteristics such as depth, velocity, substrate, surface area, shoreline profile, wetted perimeter, and channel shape (Stalnaker 1981). Aquatic organisms are sensitive to the timing, volume, and duration of different flow events. Hydrologic impacts on Middle Rio Grande aquatic resources are extremely dynamic and change both by seasonal and by river reach.

Cold, clear water releases (hypolimnetic) from Cochiti Dam have created a downstream aquatic system that is representative of upstream cool-water reaches. The lack of sediment in the Cochiti Reach and subsequent channel degradation yields a predominately gravel substrate that is habitat for a suite of cool-water fishes and invertebrates. Conversely, this zone of degradation limits the upstream distribution of many warmwater fish. Thus, existing aquatic communities in the lower Cochiti Reach may differ from those occurring historically.

The Albuquerque Reach contains a transition zone between cool and warmwater aquatic ecosystems. Hypolimnetic releases from Cochiti Dam influence the upper portions of this reach. The majority of the Albuquerque Reach, however, contains sandy substrate with associated habitats supporting characteristic warmwater communities. The sinuosity of the river at less than bank-to-bank flows supports a variety of macrohabitat types (e.g., pools, backwaters, side channels, shoreline).

The Belen and Socorro reaches exclusively support a warmwater ecosystem. Increased sediment loading supports habitat with shifting sand substrate. Extended low flow periods also create conditions that select against cool-water species. Extremes in habitat characteristics, such as depth, velocity, and cross sectional area, and water quality parameters, such as temperature and dissolved oxygen, require existing communities to have wide environmental tolerances. Throughout the Middle Rio Grande, the variable nature of natural flow regimes including spring high flows, summer rain discharge peaks, and seasonal low flow periods help maintain the fluvial channel dynamics necessary to create and sustain critical endemic aquatic habitat and community diversity.

Chemistry

Water Quality.—Water quality was listed by the National Research Council (1992) as one of the five major classes of human-influenced environmental factors that affect aquatic ecosystems. Generalized effects of both natural and man-induced water quality alterations on aquatic communities have been well studied. Effects may be either chronic or acute. For example, 18% of all fish kills nationally from 1961 to 1975 were pesticide related (Hitch 1981). Pesticides may also have sublethal effects on aquatic organisms such as decreased reproduction and growth. Lewis et al. (1981) studied the impacts of secondary sewage discharge on fish communities. They found that residual chlorine had a negative impact on fish variety and numbers. Winger (1981) showed that nitrogen is relatively nontoxic to fish when nitrate nitrogen is less than 90 ppm and nitrite nitrogen is less than 5 ppm.

Changes in physical properties of water quality, such as temperature, dissolved oxygen, pH, TDS, and turbidity, also influence aquatic community stability. Elevated temperature may cause stress or mortality in fish and may be lethal to incubating eggs. Fish have species-specific preferred temperature ranges along with upper lethal temperatures. Reduction in dissolved oxygen has a major effect on physiological, biochemical, and behavioral processes in fish (Winger 1981). For example, swimming is generally impaired at dissolved oxygen levels below 5 ppm (Dahlberg et al. 1968). A pH of 5 to 9 generally is suitable for aquatic life (Winger 1981). Some minerals necessary for survival may be unavailable at higher pH levels (Winger 1981). Contaminant toxicity is also influenced by pH (Winger 1981).

Total dissolved solids (TDS) impact aquatic organisms by influencing nutrient supply and internal osmotic diffusion mechanisms (Reid and Wood 1976). Elevated turbidity may cause mechanical injury to aquatic life through abrasion and clogging (Cairns 1968). The lethal concentration of suspended sediment is approximately 100,000 ppm, but elevated natural levels can influence behavior and stress and increase the organism's susceptibility to infection or disease (Winger 1981).

Current baseline water quality levels in the Middle Rio Grande are generally within the tolerance range of the existing aquatic communities (Table 10). Though water quality limits the distribution of some species (e.g., longnose dace), communities have adapted to current conditions that occur within specific reaches. Minimum and maximum pH levels fall within an acceptable range, i.e., 5-9. Minimum dissolved oxygen values normally do not fall below 5 mg/L.

However, extreme conditions in the Middle Rio Grande caused by events such as low flow and large discharge fluctuations may impact aquatic communities. Maximum water temperature levels in the Belen and Socorro reaches are near the upper lethal limit for several native and nonnative species. The upper lethal temperatures for red shiner, white sucker, and fathead minnow are approximately 38, 32, and 29°C, respectively, depending on the temperature at which the fish are acclimated. Temperatures above 25°C will generally limit spawning activities and impact feeding and growth. Low dissolved oxygen becomes a concern in habitat with limited water exchange and elevated temperatures. Significant increases in maximum levels of TDS and TSS (Table 10) along with elevated temperatures suggest that aquatic organisms may be subjected to periods of increased stress and possibly mortality in the Belen and Socorro reaches.

Specific impacts of water quality fluctuations on Middle Rio Grande aquatic communities have not been well studied. Beyers (1993) conducted acute laboratory toxicity studies to determine the impacts of Rodeo herbicide and X-77 surfactant on fish, i.e., plains minnow and fathead minnow, and benthic invertebrate organisms, i.e., the amphipod crustacean, *Hyalella azteca*, and larvae of the chironomid midge, *Chironomus tentans*. Rodeo is a chemical widely used in the Middle Rio Grande Valley to control noxious vegetation especially within the irrigation system. The plains minnow was selected as a surrogate species for the Rio Grande silvery minnow. The active ingredient of Rodeo is glyphosate. Glyphosate breaks down rapidly in the environment and does not persist for an extended period in the water column (Comes et al. 1976). Beyers (1993) characterized glyphosate as relatively harmless to both fish and benthic organisms, whereas X-77 tested as moderately to slightly toxic. Based on this study, expected environmental concentrations, and area of application, the current irrigation system vegetation control program appears to have minimal impact on the main channel aquatic ecosystem.

Wastewater effluent discharge has been shown to impact water quality in the Middle Rio Grande (Potter 1984, Pierce 1989). Studies have also identified a decreased fish diversity and abundance for significant distances downstream of municipal effluent discharge (S. Platania, pers. comm.). The City of Albuquerque and other municipalities currently conduct biotoxicity studies on effluent to determine impacts, if any, on aquatic life.

Platania (1993) collected a large number of Rio Grande silvery minnows with curvature of the spine, lordosis. This phenomenon was prevalent throughout the range of the Rio Grande silvery minnow. This condition has been previously associated with several causative agents including contaminants and water quality problems.

Water quality problems may be exacerbated during periods of low flow. Less water is available to dilute pollutants, and fish are often confined to isolated pools. Pollutants may be concentrated in these isolated pools to the detriment of the existing aquatic community. Also, increased temperature and decreased dissolved oxygen within low flow habitat elevate stress levels in aquatic organisms and reduce survival.

Sediment and Decomposition.—Forbes et al. (1981) reported that accumulation of pollutants in bottom sediment may inhibit decomposition and microbial colonization. Ong et al. (1991) analyzed bottom sediment from the Middle Rio Grande in the Bosque del Apache NWR (Socorro Reach) for pesticides and geochemical elements. Concentrations of geochemicals (e.g., selenium) were generally below baseline levels for western United States soils. Ten percent of sediment samples from the river, canals, ponds, marshes, and fields were positive for pesticides (DDE, DDD, DDT, chlordane, aldrin, and PCB). Inhibition of decomposition and microbial action can greatly impact energy production in a system by reducing the quantity and quality of food for organisms up the food chain.

Not all water quality constituents negatively impact decomposition. Elevated concentrations of nitrogen in aquatic systems stimulate primary production (Winger 1981). Phosphorus has a similar impact but is usually the nutrient most limiting to primary production (Schindler 1971). Impacts of pollutants on primary production of the Middle Rio Grande have not been studied.

2. Producers

Wetlands

Marshes and wet meadows (and perhaps ditches and drains) fall into the general category of wetlands. Wetlands, like other aspects of the riparian zone, exist as an interface between aquatic and dry land environments. Wetlands can be defined as transitional between terrestrial and aquatic systems, where the water table is at or near the surface, or where the land is covered by shallow water at least part of the year (Cowardin et al. 1979).

Wetlands have recently come to be widely appreciated for their inherent biotic characteristics. They support a multiplicity of life forms and species; they are capable of extensive hydrologic modification, including flood storage and ground-water recharge; and they enhance water quality by removal of chemicals, nutrients, and sediments (National Research Council 1992).

Because wetland functions and values were not understood or acknowledged in the past, many wetland areas have been lost to drainage for various purposes, including agriculture and urban development. Researchers estimate that approximately 50% of the wetlands of the United States have been lost since European settlement in North America (Dahl 1990, Hammer 1992).

Because of the semiarid nature of much of the uplands in the southwestern region of the United States, wetlands are extremely important to wildlife because of the water, food, and shelter they provide. Wetland losses in New Mexico have been estimated to be about 33% of those existing before extensive European settlement (Dahl 1990). Along the Rio Grande, Van Cleave (1935) reported that marshes and wet meadows were the wetland habitats most reduced by agriculture and related draining and levee building that occurred from the late 1800's through the time of her study.

While natural wetlands in the Rio Grande Valley have been reduced, some artificial or man-made wetlands have resulted from human activity, as pointed out earlier in this document. Ditches, drains, and to a certain extent, irrigated fields have replaced a portion of the natural wetland functions and values.

Middle Rio Grande Aquatic Plant Communities

Emergent vegetation characteristic of marshes and other areas of permanent, slow moving water in the Rio Grande bosque includes cattail, bulrush (*Scirpus* spp.), sedges (*Carex* spp.), spikerush (*Eleocharis* spp.), flatsedge (*Cyperus* spp.), scouring rush (*Equisetum* spp.), common reed (*Phragmites communis*), coyote willow, and other species (Howe 1983, Hink and Ohmart 1984). Emergent species grow at the margins of permanent water, rooted in wet soils but with leaves and flowering structures primarily above the water's surface. Many of these species, such as cattail, reproduce vegetatively as well as sexually from rhizomes (underground stems) or other nonflowering parts.

In the still or slow-moving water of ponds, marshes, or drains, aquatic plant species may become established. These range from free-floating algal species like *Chara*, *Nitella*, and

Spyrogyra, through floating vascular plants like duckweed (*Lemna minor*), to water-milfoil (*Myriophyllum spicatum*) and pond-weed (*Potomageton pectinatus*), which are rooted on the bottom (Correll and Correll 1972, Howe 1983, Molles [1988], Sivinski et al. 1990).

Wet meadows may be seasonally flooded by runoff or by elevated water tables, and their vegetation is often a mixture of wetland and upland species. Sedges and flatsedges are common, along with saltgrass, rice cutgrass (*Leersia oryzoides*), witch's broom (*Panicum capillare*), alkali muhly (*Muhlenbergia asperifolia*), alkali sacaton (*Sporobolus airoides*), and other species (Hink and Ohmart 1984, Sivinski et al. 1990).

Fast-moving waters of the Rio Grande do not contain abundant aquatic macrophyte vegetation. Water also moves quickly through irrigation ditches, inhibiting establishment of aquatic vegetation. Ditches are periodically dredged, preventing long-term colonization by bottom-rooted species. However, ditchbanks do provide substrate for emergent plants and other mesic-adapted species.

Management of irrigation and drainage ditchbanks by the MRGCD has a strong influence on species composition. Herbicides, burning, mowing, and mechanical clearing probably have detrimental effects by removing cover and food sources for seed eaters. However, burning and mowing probably allow survival of most of the emergents and wetland species listed above. Herbicides, however, drastically alter the composition of the ditchbank community, allowing exotic, annual, weedy species to become dominant there.

Aquatic, emergent, and wetland plant species provide abundant food and cover for wildlife. Algae and zooplankton provide food for invertebrates. Floating plants (e.g., duckweed) and rooted aquatics also provide food and cover for invertebrates and fish. The minute invertebrate life in turn provides food for fish and birds. Ducks, marsh birds, and shorebirds scoop up and eat plants and the associated invertebrates living among them. Waterfowl eat the tuberous roots of pondweed and flatsedge. Waterfowl, marsh birds, and shorebirds eat the seeds of pondweed and water-milfoil. Cattail roots and sometimes their seeds are eaten by geese and teal. Both cattails and bulrushes are extremely important in providing cover for waterfowl, marsh birds, and shorebirds during nesting and migration. Pondweed is eaten by nonavian species, including muskrats, beaver, and deer (Correll and Correll 1972).

As described by Howe (1983), Molles and Pietruszka [1983], and Molles [1988], standing and slow-moving marsh and wetland habitats provide an abundance of insects for birds other than waterfowl, marsh birds, and shorebirds. Black-chinned hummingbirds, barn swallows, flycatchers including the southwestern willow flycatcher, Mississippi kites, and numerous other insect-eating birds forage at aquatic and wetland sites along the river during migration and breeding seasons and also in winter.

3. Consumers

Benthic Organisms

Benthic (bottom-dwelling) macroinvertebrates are important components of aquatic ecosystems as intermediate consumers of plant and detrital material and as a food base for higher trophic level organisms. Macroinvertebrates also have wide habitat preferences and are good indicators of environmental quality. Since macroinvertebrates have a short generation span and are not as mobile as fish, they are indicators of not only current but also past environmental conditions (Jacobi 1980).

Benthic macroinvertebrate distribution and abundance generally vary both longitudinally relative to changes in stream order and locally relative to habitat type. Larvae of caddisflies (Trichoptera) and some true flies (Diptera) are commonly found in submerged gravel bars, whereas larvae of mayflies (Ephemoptera) can withstand high turbidity and exist in shifting sand conditions. Chironomids, nonbiting midge larvae of the order Diptera, are often the dominant taxa in lower elevation sandy bottom streams (Jacobi et al. 1993). Common chironomid subfamilies in sandy bottomed streams east of the Continental Divide are Tanypodinae and Orthocladiinae (Jacobi et al. 1993). Macroinvertebrates generally require instream structure (e.g., substrate and debris) for egg deposition, attachment surfaces for larvae and casings, cover from predation and adverse flows, and feeding areas.

Little is known of the historic benthic macroinvertebrate distribution and abundance in the Middle Rio Grande. Zimmerman (1971) studied the distribution of predaceous diving beetles (Coleoptera: Dytiscidae) in the Rio Grande. Systematic sampling of macroinvertebrate communities in the Middle Rio Grande began in the late 1970's.

As a part of the EPA-State Basic Water Monitoring Program, Jacobi (1980, 1983) sampled sites in the Middle Rio Grande for macroinvertebrates. Sampling locations were established at San Felipe, Isleta, San Acacia, and San Marcial. The following summarizes 1979 monitoring data. Twenty-three taxa were present at the San Felipe site. The dominant taxa were the caddisfly *Hydropsyche*, 60% of total sample and 94% of total biomass, the mayfly *Baetis*, and the true fly *Polypedilum*. Only nine taxa were sampled at the Isleta site. The dominant species were the mayfly *Heptagenia*, 53% of total sample and 79% of total biomass, the mayfly *Tricorythodes*, 26% of total sample, and the true fly *Calospectra*. The San Acacia site had the lowest macroinvertebrate diversity with only five taxa. The mayfly *Baetis* comprised 50% of the total organisms sampled. Finally, 16 taxa were collected from the San Marcial site. The caddisfly *Hydropsyche* and the black fly *Simulium* were the dominant taxa. Highly variable discharges and elevated turbidity may discourage macroinvertebrate colonization in the Belen and Socorro reaches (Jacobi 1980). Jacobi also conducted similar biological monitoring in September 1980 and 1981 (Table 11). Species abundance was similar to 1979 monitoring data with the exceptions that the black fly *Simulium* was second most abundant at San Felipe and the true fly *Ablabesmyia* was the dominant species at Isleta.

Aquatic macroinvertebrates have also been sampled at various locations within the Middle Rio Grande Project irrigation system. Four locations along the Alameda and Riverside drains

Table 11. Aquatic macroinvertebrates collected in the Rio Grande at San Marcial, Isleta Pueblo, and San Felipe Pueblo, New Mexico, September 1980 and 1981 (Jacobi 1983).

Taxon	Number Collected		
	San Felipe	Isleta	San Marcial
Ephemeroptera (mayflies)	865	498	68
Odonata (damsel, dragonflies)	17	20	11
Trichoptera (caddisflies)	5,195	12	801
Coleoptera (beetles)	0	2	16
Diptera (true flies)	2,422	1,415	189
Plecoptera (stoneflies)	0	0	2
Hemiptera (true bugs)	17	0	0
Tubellaria (flatworms)	1	0	0
Oligochaeta (bristle worms)	0	11	0
Nematomorpha (horsehair worms)	71	0	0
Decapoda (crayfish)	0	5	0

were sampled in 1988 for macroinvertebrate abundance and diversity (City of Albuquerque Hydrology Division 1991). The dominant taxa were chironomid midges, 42% of total sample; oligochaete worms, 27%; and trichorythrid mayflies, 12%.

The NMDGF is currently developing a database relating species distribution information from the insect orders Diptera (Chironomidae), Ephemeroptera, Plecoptera, and Trichoptera to environmental parameters and fish populations to selected water bodies in New Mexico (Jacobi et al. 1993). The study is the first comprehensive, statewide effort to characterize macroinvertebrate communities. It includes six Middle Rio Grande sample locations. A major goal is the delineation of aquatic ecoregions as the basis for defining the ecological potential of specific reaches as they relate to fishery management goals and objectives (Jacobi et al. 1993).

The distribution of freshwater molluscs in the Rio Grande was studied by the New Mexico Bureau of Mines and Mineral Resources (1987) to determine the value of molluscs in characterizing historic river drainages. Molluscan diversity in the Middle Rio Grande is relatively low and confined to specific springs. These springs are not directly influenced by the Rio Grande but they do occur within the watershed and are impacted by hydrologic changes in the system. Three species are endemic to the Upper and Middle Rio Grande and are state endangered: Socorro spring snail (*Fonticella neomexicana*), Chupadera spring snail (*Fonticella chupadera*), and Alamosa spring snail (*Tyronia alamosae*). The Socorro isopod (*Thermosphaeroma thermophilus*) is a state and federally listed endangered species. It is endemic to central New Mexico (Pennak 1978) and occurs only in Sedillo Spring about 3 km west of Socorro. The introduced Asian fingernail clam (*Corbicula* sp.) is the principal mussel within the Middle Rio Grande Valley.

The exotic zebra mussel (*Dreissena* spp.) was first introduced to the United States through ballast water discharged in the St. Lawrence Seaway near Detroit in 1988 (Hebert et al. 1989). The mussel has spread rapidly and is currently colonizing several major river systems (e.g., the Mississippi and Arkansas rivers). Zebra mussels have also recently been found in Texas and Oklahoma. Zebra mussels are not currently known to exist in any New Mexico waters, yet a basic understanding of their biology and life requisites is important to address potential management concerns.

Zebra mussels are usually transported within a watershed through larval and juvenile drift and may be translocated across land barriers via boats, bait buckets, aquatic plants, etc. Not all water bodies are susceptible to zebra mussel infestation (McNabb 1993). Minimum water quality parameters required for zebra mussel colonization have been established (pH > 7.0, turbidity < 50 NTU) and temperature conditionally between 13 and 25°C. Cochiti Reservoir and the downstream cool-water reach appear to be susceptible to zebra mussel colonization based on these parameters. When established, zebra mussels attach to and eliminate native clams. Zebra mussels can also deplete local food sources and impact growth and survival of early fish life stages (McNabb 1993). Early detection and response are critical to avoiding or controlling zebra mussel infestations (McNabb 1993).

The transition zone between ground water and surface water is referred to as the hyporheic zone and is important in the life cycle of many macroinvertebrates and in nutrient cycling. Many organisms, such as water stoneflies and ostracod crustaceans that are rarely found in streambeds are often dominant components of this zone (U.S. Bureau of Reclamation 1993e). The hyporheic zone may also be an important indicator of aquatic ecosystem recovery since it accumulates high concentrations of contaminants (U.S. Bureau of Reclamation 1993e). No studies of the biological component of the hyporheic zone of the Middle Rio Grande have been conducted. However, it is speculated that this hyporheic zone should support a rich diversity and abundance of aquatic organisms (C. Dahm, pers. comm.)

Nonbenthic Organisms

The Middle Rio Grande currently supports a relatively diverse ichthyofauna composed of native and nonnative fish species. Nonnative species have been introduced to the this area through both accidental releases and sportfish management by the NMDGF. The Middle Rio Grande and the associated irrigation system do not support a large sportfishery, but are still managed to enhance angling opportunities. The overall impact of various aquatic management strategies in the Middle Rio Grande is not well understood. However, the introduction of nonnative species has coincided with decreases in the distribution and abundance of native species in many rivers (Minckley and Douglas 1991), including the Rio Grande (Bestgen and Platania 1991).

The current status of native fish in the Middle Rio Grande shows a decline in both diversity and abundance of species. Of the four species endemic to the Upper and Middle Rio Grande, the Rio Grande shiner (*Notropis jemezanus*), phantom shiner (*Notropis orca*), and Rio Grande bluntnose shiner have been extirpated from the Rio Grande with the latter two species presumed extinct (Table 6; Platania 1991a). Speckled chub (*Macrhybopsis aestivalis*) is also a member of the suite of extirpated Rio Grande fishes. Although the number of native fish species has declined, many are still abundant within their range, e.g., red shiner (*Cyprinella lutrensis*), longnose dace (*Rhynichthys chataractae*), and flathead chub (*Platygobio gracilis*; Platania 1991a). The extant native fish community generally must tolerate at least one of the following conditions which occur in the Middle Rio Grande: (1) cool-water mainstream or tributary habitat, (2) standing water, warmwater, or degraded habitat, and (3) reservoir refugia (Bestgen and Platania 1990).

The Middle Rio Grande contains several special status aquatic species. The Rio Grande silvery minnow is listed as a state endangered, Group 2, species and was proposed as an endangered species with critical habitat, under the Endangered Species Act, on March 1, 1993. The Rio Grande silvery minnow has declined precipitously in abundance in recent years and currently occupies only 5% of its historic range. It occurs only between Cochiti Dam and the headwaters of Elephant Butte reservoir. In 1984, it was one of the four most abundant fish sampled within the Middle Rio Grande. In 1992, it represented only 4% of the total catch (Lang and Platania 1993). Table 12 summarizes the distribution and abundance of the Rio Grande silvery minnow by reach in 1992. The Rio Grande silvery minnow is unevenly distributed within the Middle Rio Grande, indicating fragmented habitat conditions.

Table 12. Distribution and abundance of the Rio Grande silvery minnow by reach for summer (103 sites) and winter (109 sites) 1992 (Lang and Platania 1993). Percentage values refer to percent of total silvery minnow catch.

River Reach	Summer 1992 # of Individuals (%)	Winter 1992 # of Individuals (%)
Cochiti	0 (0)	0 (0)
Albuquerque	600 (21)	45 (9.5)
Belen	85 (3)	10 (2)
Socorro	2,141 (76)	417 (88.5)
TOTAL	2,826	472

In 1992, Platania (1993) completed a study designed to characterize the fish community between Velarde and Elephant Butte Reservoir. The study also identified habitat availability and use. Nine sites were established at which both habitat and fish inventory data were collected. The following is a list of these sites as they relate to both the aforementioned cool and warmwater reach designations and the river reaches identified in Table 1.

Inventory/Macrohabitat Site	Reach Type	Reach Name
1. San Juan Pueblo	Cool water	Representative of Cochiti
2. Angostura	Cool water	Albuquerque
3. Alameda Bridge	Transition	Albuquerque
4. Central Bridge	Warmwater	Albuquerque
5. Pipeline Crossing	Warmwater	Belen
6. Arroyo los Alamos	Warmwater	Belen
7. San Acacia	Warmwater	Socorro
8. Socorro	Warmwater	Socorro
9. Bosque del Apache NWR	Warmwater	Socorro

Figure 22 shows the percent of community per site composed of red shiner, flathead chub, fathead minnow (*Pimephales promelas*), longnose dace, river carpsucker (*Carpiodes carpio*), white sucker (*Catostomus commersoni*), channel catfish (*Ictalurus punctatus*), and western mosquitofish (*Gambusia affinis*; Platania 1993). The cool water reach contained primarily longnose dace, white sucker, and flathead chub. The Cochiti Reach also is the northern boundary for the Rio Grande silvery minnow. Red shiner, river carpsucker, and western mosquitofish increased in abundance within the Albuquerque Reach. Although red shiner was the dominant species, the transitional nature of this reach still supported cool water species such as longnose dace. Red shiner and mosquitofish were the most common species in the Belen Reach. The Socorro and Belen reaches have a similar fish community composition. The Rio Grande silvery minnow is most abundant in the Socorro Reach.

Platania (1993) found that fish communities contained an abundance of native individuals (85.1% of the total catch), but species diversity was greater for nonnative (almost twice as many nonnative species). Species abundance was also very unevenly distributed. Red shiner, the most abundant native fish, was the dominant species, comprising 53% of the total catch. Mosquitofish and white sucker were the two most abundant nonnative species, comprising 73% of the total nonnative catch (Platania 1993). This community unevenness could indicate an unstable fish community (Platania 1993).

B. Montoya (in litt.) compiled existing data and showed that 36% to 63% of native species have been extirpated within various river reaches. Nonnative fish impact closely related native fish and fish competing for the same resource. Hybridization of the introduced white sucker with the native Rio Grande sucker (*Pantosteus plebius*) may be contributing to the decline of the latter species (Platania 1993; B. Montoya, in litt.). Platania (1993) found that, at sites of sympatry, white sucker was five times more abundant than Rio Grande sucker. Also, introduced predators, such as white crappie (*Pomoxis annularis*), are often found in habitat preferred by native species and may have a detrimental impact (Baird et al. 1993).

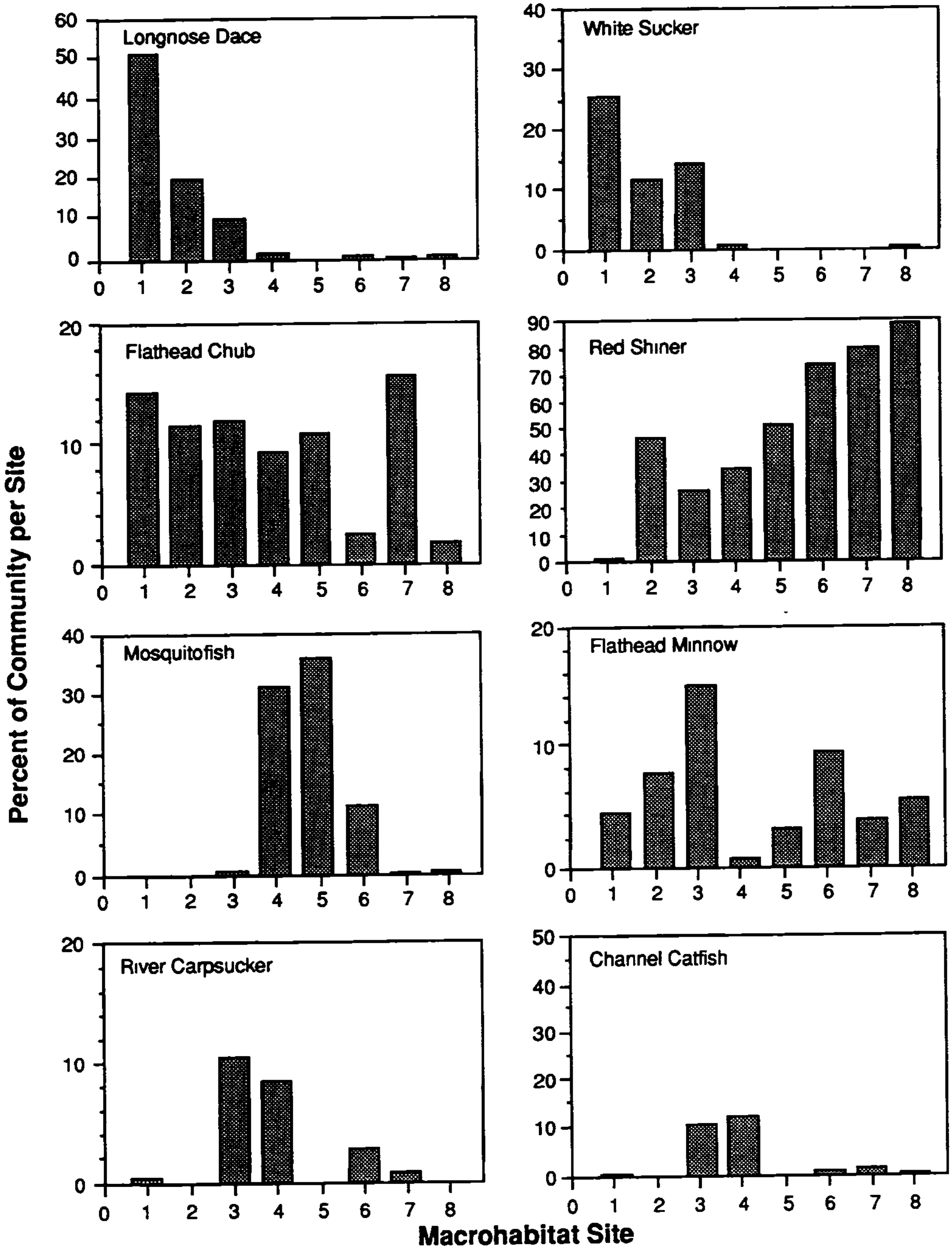


Fig. 22. Relative abundance of fish expressed as percent per macrohabitat site of a community (Platania 1993). See text for description of macrohabitat sites.

Edwards and Contreras-Balderas (1991) noted that stream flow regulation in the Rio Grande in Texas has ultimately resulted in fewer fish in less diverse assemblages. Other fish studies have shown that introduction of nonnatives may actually increase overall diversity but reduce the number and abundance of native species (Burke 1992). Platania (1993) hypothesized that the current unevenness in Middle Rio Grande fish populations may indicate an unstable community. It is apparent that the current Middle Rio Grande fish community has been significantly impacted by human activities.

Fish have also been collected from the Low Flow Conveyance Channel and the Middle Rio Grande Project irrigation system. Collections from the late 1970's and early 1990's identify the dominant species within these systems as white sucker, red shiner, fathead minnow, and western mosquitofish. A cursory 1992 survey of the irrigation system near the end of the irrigation season (October) found that red shiner comprised almost 50% of the total sample. Western mosquitofish were collected in the highest percentage (76%) of sites sampled (Table 13; Lang and Platania 1993). No Rio Grande silvery minnow were collected during this survey. Though these water delivery systems provide habitat for certain species, they generally do not maintain viable, self-sustaining populations.

Sportfish Management.—The management of New Mexico's fishery resource is part of the mission of the NMDGF. The NMDGF's primary fishery goals are to (1) protect and/or improve aquatic habitat and (2) preserve the natural diversity and distribution patterns of native fish (New Mexico Department of Game and Fish 1987). The Department's Fisheries Management Units 6 and 7 contain the sections of the Middle Rio Grande in which active fishery management occurs. The NMDGF (1987) published an operation plan that defines both fish and habitat management plans for the years 1987-95.

The operation plan designates the following irrigation system drains to be capable of supporting trout during colder months: Albuquerque, Atrisco, Belen Riverside, Bernalillo, Corrales Riverside, Peralta, and Tome Riverside. Within Unit 6, the operation plan calls for stocking brown trout (*Salmo trutta*) in the Corrales Riverside Drain and rainbow trout (*Oncorhynchus mykiss*) in reaches of the aforementioned drains and the Rio Grande. Largemouth bass (*Micropterus salmoides*) and channel catfish were initially stocked in the Albuquerque, Belen, and Peralta riverside drains; and channel catfish were released in the Bernalillo, Bernardo, and La Joya drains. The NMDGF has subsequently discontinued the introduction of largemouth bass and channel catfish into these habitats. The aquatic habitat of the Corrales Drain is to be enhanced to produce acceptable catch rates of larger than average brown trout.

Management in Unit 7 includes stocking rainbow trout, largemouth bass, and walleye (*Stizostedion vitreum*) in Cochiti Reservoir. White bass (*Morone chrysops*) have become established in Cochiti Reservoir and are no longer stocked. The NMDGF has also discontinued the stocking of channel catfish in Cochiti Reservoir. These stockings, though at the upper end of the middle valley, are important because fish introduced into Cochiti Reservoir can escape downstream during reservoir releases. These fish are an important component of the nonnative fish community of the Middle Rio Grande.

Table 13. Abundance of fish collected from the Middle Rio Grande Project irrigation system in 1992 (29 sites sampled; Lang and Platania 1993).

Species Common Name	Total	% of Total	Frequency of Occurrence (# of Sites)	% Occurrence
HERRINGS				
Gizzard shad	1	<0.1	1	3.4
CARPS AND MINNOWS				
Red shiner	1,418	46.6	14	48.3
Common carp	51	1.7	12	41.4
Rio Grande chub	20	0.7	2	6.9
Fathead minnow	236	7.8	18	62.1
Flathead chub	36	1.2	10	34.5
Longnose dace	65	2.1	13	44.8
SUCKERS				
River carpsucker	8	0.3	7	24.1
White sucker	165	5.4	16	55.2
CATFISHES				
Black bullhead	3	0.1	2	6.9
Yellow bullhead	9	0.3	4	13.8
Channel catfish	44	1.4	8	27.6
SALMON AND TROUT				
Rainbow trout	4	0.1	2	6.9
LIVEBEARERS				
Western mosquitofish	971	32.0	22	75.9
SUNFISHES				
Green sunfish	1	<0.1	1	3.4
Bluegill	5	0.2	1	3.4
Largemouth bass	4	0.1	4	13.8
PERCHES				
Yellow perch	1	<0.1	1	3.4

In New Mexico State fiscal year 1990-91, approximately 30,000 rainbow trout over 6 inches in length were stocked in the Albuquerque, Belen, Bernalillo, Corrales, and Peralta drains. Almost 76,000 rainbow trout and 1.5 million walleye were stocked in Cochiti Reservoir. The Cochiti Dam tailwater has been managed as a brown and rainbow trout fishery. Approximately 31,000 brown trout and 8,000 rainbow trout were introduced into this reach in 1990-91. Also in the same fiscal year, 30,000 channel catfish were stocked in riverside drains. Except for salmonids and channel catfish (at Tingley Beach), the stocking of nonnative fish in the Middle Rio Grande and its drains has been terminated to benefit the native fish community, especially the Rio Grande silvery minnow.

Cole et al. (1987) developed a sportfish management model designed to (1) improve predictions of water operations and impacts on fish productivity, predator-prey relationships, etc.; (2) develop alternative operational scenarios to increase fish reproduction and yield; and (3) assess the value of water for improved fisheries. The model has hydrologic, biological, and economic components. The hydrologic component models water level/discharge, nutrient concentration, light penetration, and temperature. The biological component monitors fish biomass as determined by light transmission, nutrient loading, primary production, temperature, water level/discharge fluctuation, and other factors. The economic portion of the model addresses angler harvest and visitation rates by location.

Ultimately, the model can simulate fish population dynamics for a variety of sportfish. An interactive computer version of the model, RIOFISH, allows users to determine the biologic and economic impacts of management activities on fish populations. RIOFISH is a predictive management tool, and as with all tools, must be operated with a full understanding of its strengths and limitations (Cole et al. 1987).

4. Habitat

Habitat Diversity in River and Wetlands

Riverine Habitat.—The Middle Rio Grande is characterized as a warmwater river. Winger (1981) noted that warmwater streams generally encompass a broad spectrum of physical and chemical conditions and have warm summer water temperature, low velocity, high turbidity, more pools than riffles, small particle substrate, and a paucity of shade and cover. Moyle and Nichols (1973) also observed that warmwater streams generally have more human perturbation and contain more introduced species. Riverine habitats associated with riparian vegetation can develop diverse shading, ponding, and channel characteristics when adequate vegetation, woody debris, and landform are present, thus contributing to biodiversity (U.S. Bureau of Land Management 1993).

Aquatic habitat and associated fish communities vary longitudinally in the Middle Rio Grande (Platania 1991a). Platania (1991a) divided the Middle Rio Grande into an upstream cool-water reach (Cochiti Reach), a downstream warmwater reach (from Bernalillo to the headwaters of Elephant Butte), and a transition zone (from Angostura Diversion Dam to Bernalillo). The upper reach is characterized by cool, clear, high velocity water confined to a single channel with a gravel substrate (Platania 1993). The dominant species in this reach are flathead chub and longnose dace, both representatives of cool-water habitat (Platania 1991a). Fluctuations in discharge from Cochiti Dam significantly influence availability of side channel and backwater habitat within this reach (Platania 1993). The transition zone consists of a wider channel with an increase in sediment load and temperature and a decrease in velocity (Platania 1991a, 1993). The substrate is primarily sand and silt. The warmwater reach is characterized by warmwater, shifting sand substrate, low velocity, and a variety of aquatic habitats (Platania 1993). Red shiner, Rio Grande silvery minnow, and common carp are indicator warmwater species (Platania 1991a).

One objective of Platania's (1993) fish/habitat association study in the Middle Rio Grande was to quantify macrohabitat availability. Habitat sampling occurred during the low flow period in summer of 1991 and in the winter of 1992 at the previously listed sites. Macrohabitat availability is directly correlated to flow regime. Thus macrohabitat data must always be related to discharge. The following is a list of specific habitat types that were identified in the Middle Rio Grande.

Habitat Type	**Definition**
Main Channel	channel containing greatest depth and majority of flow
Side Channel	channel containing secondary flow volume
Run	higher velocity, laminar flow
Riffle	shallow, turbulent flow
Flat	low velocity, depth less than 0.06 m
Pool	deep, low velocity
Eddy	water current flowing contrary to the main current
Backwater	low velocity, single opening to channel
Isolated Pool	completely isolated from channel
Shoreline	habitat adjacent to shore
Island	vegetated islands or sandbars

Existing macrohabitat conditions at the San Juan Pueblo site were representative of cool-water conditions in the Cochiti Reach and were dominated by main channel run and shoreline habitat, 88%. Eight percent of available habitat was secondary channel runs or riffles. Low velocity (pools and backwaters) and island habitats were rare. The substrate is predominately gravel or cobble, 86%, with some sand and silt.

The Alameda Bridge site, transition zone, Albuquerque Reach, was composed primarily of main and secondary channel runs, 57.5%. Islands and main channel flats comprised approximately 25% of the habitat. Low velocity habitat increased from that available in the cool-water reach. The substrate was predominately sand, 69%, representing a significant change from the upstream cool-water site.

Habitat variation increased at the Central Bridge site, warmwater, Albuquerque Reach. Thirteen habitats were identified and main and secondary channel runs comprised 56% of available habitat. Islands comprised 20% of the habitat due to a increased braiding of the river. Main and secondary channel flats constituted 14% of the habitat. Sand and silt was the dominant substrate, 68%.

Typical habitat, in order of abundance, for the Arroyo los Alamos site, warmwater, Belen Reach, was main channel, 43%, island, 19%, and side channel run and main channel flat, 11% each. The river was generally wider in this reach with predominantly sand and silt substrate, 77%.

The Socorro site, warmwater, Socorro Reach, is seasonally ephemeral with runs, flats, and shoreline constituting 93% of the available habitat. Backwaters and island habitat were rare, 2% and 5%, respectively. Substrate type is 100% sand and silt.

The habitat associations of several native species were also examined by Platania (1993). Red shiner were most abundant in low velocity habitats, such as backwaters, debris piles, pools, and eddies. Adult flathead chub were more frequently found in high velocity run or riffle habitat, whereas juvenile and young-of-year individuals tended to occupy low velocity habitats (i.e., backwaters and pools). Longnose dace were associated with high velocity run or riffle habitat. Lower velocity habitats, such as main channel pools and debris piles, occupied by juvenile longnose dace were normally adjacent to high velocity water. Fathead minnow were abundant in low velocity, backwater habitat and were also associated with pool, eddy, and isolated pool habitats.

A unique aquatic habitat component of the Middle Rio Grande is the area below diversion dams. The channel below San Acacia Diversion Dam is composed of primarily runs, 47% (32% main channel, 15% secondary channel) and island habitat, 32% (Platania 1993). Only the reach near Bosque del Apache NWR had a higher prevalence of island habitat. This habitat is important for fish as refugia during low flow periods (Platania 1991a). Seepage from the diversion structures maintains wetted habitat below dams even when the downstream channel is intermittent. Fish move upstream to this habitat during low flow periods and redisperse when flows increase (Platania 1991a). Approximately 15% of the total catch of Rio Grande silvery minnow in 1992 was collected below San Acacia Diversion Dam (Lang and Platania 1993).

Additional sources of within-channel habitat are large woody debris and snags, which create pools and slack water and provide critical cover habitat for many species of fish (B. Montoya, in litt.). Debris also functions as cover and attachment sites for aquatic macroinvertebrates. Island and bank vegetation provides shading and cover habitat. Bank and riparian vegetation also provides critical feeding and mating habitat for terrestrial stages of many aquatic macroinvertebrates.

Wetland Habitat.—Several wetland areas occur in the Middle Rio Grande Valley. The location and general features of these systems will be described below. Wetlands contain vital aquatic habitat. The Isleta Marsh and a constructed wetland near Los Lunas support complex invertebrate communities along with some fish populations (Alexander and Martinez 1982). The structural features of these wetlands include aquatic vegetation, floating and submerged debris, sand and mud substrate, and algal mats.

Alexander and Martinez (1982) and Molles and Pietruszka [1983] studied aquatic communities of Isleta Marsh and the Los Lunas wetland in the early 1980's. Different layers of algae support unique invertebrate communities. Chironomid larvae were abundant in a top layer of algae floating at or near the surface. Water beetles were often found in benthic algae. Microinvertebrates (crustaceans) also preferred bottom layers of algae. Algal populations fluctuated dramatically with changes in temperature and light conditions. Warm, sunny days would result in an algal bloom, but cool, cloudy days could cause up to 90% mortality (Alexander and Martinez 1982). *Spirogyra* and *Protococcus* were the most abundant algae at both Isleta Marsh and Los Lunas ponds. Isleta Marsh does not have a benthic layer of algae, possibly due to disturbance from bottom-dwelling fish (e.g., carp and catfish) and a prevalence of silt.

Substrate type is a critical component of wetland habitat (Alexander and Martinez 1982). Sand and organic matter substrate support a higher diversity of invertebrates than silty areas. Alexander and Martinez (1982) found oligocheate worms in mud near shorelines. Hydrophilid beetle larvae were common in sandy substrate. Anaerobic conditions selected for specific communities such as oligochaetes and nematodes.

Aquatic wetland vegetation supports both fish and invertebrate communities. Wetland benefits to main channel fish are directly related to the hydrology of the system. Fish often spawn during peak flows and use shallow (e.g., wetland) areas that are available during these high flows for cover, nursery, and feeding areas. Fish use recently flooded wetland areas as spawning habitat (Allen et al. 1993). Allen et al. (1993) also noted that cover provided by littoral vegetation is critical escape habitat for larval and juvenile fish. Invertebrates use wetland vegetation as an attachment site and nutrient source.

Floating and submerged debris are important attachment sites for invertebrates and provide cover for fish. Wetland depth is also an important consideration because deep, cool-water areas function as refugia from high summer temperatures (Alexander and Martinez 1982). Periodic inundation of wetlands increases their productivity and utilization by aquatic organisms. Conversely, the gradual subsidence of flows allows for fish emigration to main channel habitat.

An additional source of habitat (albeit less preferred) for a variety of fish and aquatic invertebrates is the network of irrigation ditches bordering the mainstem of the Middle Rio Grande. Irrigation supply canals are characterized by steep banks, uniform bottom depth, silt substrate, high turbidity, and intermittent flow. Drains have a more constant, clear water source that supports aquatic macrophytes, algae, and an associated organic substrate. Drains have generally degraded, through lack of intensive management, and provide some aquatic habitat such as aquatic vegetation and woody debris. Outfall areas, where water returns to the Middle Rio Grande, often provide a source of constant water during periods when the main channel is dry and thus may provide temporary refugia for some fish species. Federal Register (1993a) noted that the Rio Grande silvery minnow possibly survives extended periods of channel desiccation in areas of irrigation return flow and below diversion dams. However, irrigation ditches do not support self-sustaining populations of many fish species (S. Platania, pers. comm.).

Effects of Disturbance on Habitats and Species Therein

Miller (1961) reported that most changes in the Middle Rio Grande fish community occurred within the past century due to human disturbances of the aquatic environment. Disturbance is also a natural process and may be both positive and negative. For example, the process of lateral stream migration may result in bank erosion and loss of riparian vegetation. However, the same process is also critical in creating new and dynamic instream aquatic habitat such as side channels and backwaters.

Hydrology is the primary factor influencing Middle Rio Grande aquatic habitat. As mentioned previously, flow dynamics are directly related to existing channel geomorphology and aquatic habitat. Historically, the Middle Rio Grande has maintained periods of high, flooding flows and low, desiccating flows. Effects of these conditions are generally understood. Low flow periods often result in channel drying and fragmentation of aquatic habitat. The resulting isolated pools may be the last refuge for populations of fish and invertebrates. Native aquatic species have adapted to survive these conditions until high flows reestablish habitat continuity and availability. Human influence often exacerbates the impacts of natural disturbances. The introduction of a water regulation infrastructure in the Middle Rio Grande has increased the potential for longer and more frequent periods of low flow and habitat fragmentation.

The extent of channel desiccation due, in part, to water regulation has been identified as a causative factor in the decline and extirpation of several Middle Rio Grande fish species (Bestgen and Platania 1990, 1991; Edwards and Contreras-Balderas 1991; Federal Register 1993a). The impact of nonnative predators on native fish communities is probably greatest during low flow. Native species are often unable to compete and become prey to introduced predators.

Timing and duration of low flow periods also impact habitat utility. Individuals seek refuge in preferred habitat, if possible, during periods of stress. The characterization of preferred habitat is species specific. If the onset of low flow conditions occurs rapidly, individuals may be stranded in unsuitable habitat. If periods of low flow are extended, habitat and organisms therein will be lost.

The rate of change between flow extremes, high and low flow, is important. Fish adapt to flow conditions and may be physiologically incapable of responding to dramatic, seasonal changes in discharge. For example, during winter low flow months, some fish seek cover in low velocity habitat and become physiologically less active. An early spring high flow event may reduce the availability of low velocity habitat and expose fish to different temperatures and higher velocity water than they can tolerate.

High flows significantly change the type of habitat available to aquatic organisms (Matthews and Hill 1980, Allen et al. 1993). Platania (1993) found that main channel run habitat in the lower reaches of the Middle Rio Grande was more prevalent at higher flows. Timing of these conditions also impact habitat use. It is believed that high flows may trigger spawning for several fish species in the Middle Rio Grande (e.g., Rio Grande silvery minnow). Concurrently, these high flows must also provide adequate spawning and nursery habitat. Flooding often connects riverine and wetland habitat. As mentioned previously, wetlands provide important habitat for aquatic organisms. Conversely, subsidence of flood conditions may strand individuals in nonsupportive habitat. Since flooding generally occurs less frequently than low flow events, individuals may be stranded in undesirable habitat for an extended period or may be permanently isolated from main channel populations.

Accidental and bait-bucket introductions are difficult to regulate but have devastating effects on fish populations. For example, the Rio Grande silvery minnow once occurred in the Pecos River drainage. Bait-bucket introduction of the plains minnow (*Hybognathus placitus*) to this system resulted in increased competition between the two species and contributed to the extirpation of the Rio Grande silvery minnow from the drainage. Habitat preference of introduced species also influences the extent of impact on native fish.

Impacts of disease and parasites on fish and invertebrate communities in the Middle Rio Grande have not been studied. It should be expected that fish under increased stress will be more susceptible to disease and parasites. The presence of the protozoan *Ichthophthirius multifilis* is often related to stress (Federal Register 1993a). Disease and parasite transmission rates may increase in confined habitats. All of these factors can cause a decrease in fish and invertebrate community diversity and abundance.

The presence of main channel dams and diversions limits the upstream migration of fish and thus impacts distribution. In 1992, approximately 75% of the Rio Grande silvery minnow population occurred below San Acacia Diversion Dam (Lang and Platania 1993). Fish are also drawn into irrigation canals during the irrigation season and are thus isolated from main channel populations. The ephemeral nature of these systems and the paucity of aquatic habitat may increase mortality rates for these fish. Research has shown that eggs and larval fish from the Rio Grande silvery minnow genus, *Hybognathus*, drift downstream for a period of time during their development (Platania 1993). This drift may help repopulate downstream reaches. Conversely, if downstream habitat is undesirable for a certain species and upstream migration is limited, mortality of displaced individuals can be high.

Other human disturbances impacting aquatic habitat are within-channel construction activities and pollution. Channel construction activities such as bank stabilization result in a localized loss and fragmentation of existing shoreline habitat. Bank stabilization is accomplished by placing a revetment on the riverbank to resist and prevent further erosion. This stabilization of lateral channel migration reduces the extent of dynamic natural habitat creation. Construction and mitigation efforts attempt to recreate habitat such as backwaters and main channel slack water areas.

Ongoing fish sampling suggests that current river maintenance activities do not significantly impact the overall longitudinal distribution of fish species. This may reflect the fact that only a small portion of the Middle Rio Grande has been stabilized to date. Local impacts to fish and macroinvertebrate populations do occur. Riprap used in bank stabilization introduces a new habitat to the ecosystem. Selected species opportunistically use riprap habitat when it is available (Baird et al. 1993). White sucker, longnose dace, and common carp are dominant species in riprapped banks within the Cochiti Reach. Relative abundance of western mosquitofish decreased significantly in stabilized banks. The dominant species in backwaters created as mitigation were western mosquitofish, white sucker, and white crappie (Baird et al. 1993).

Both point and nonpoint source pollution affect aquatic habitat and species therein. As mentioned previously, contaminants can influence instream primary production and thus affect species composition of certain habitats. Also, habitat fragmentation and confinement affect temperature and dissolved oxygen. Temperature may increase and dissolved oxygen may decrease over time as habitat becomes isolated. Local impacts of pollutants can be severe in isolated habitats supporting refugial populations of fish and invertebrates. Aquatic organisms can bioaccumulate contaminants. Largemouth bass in Elephant Butte Reservoir have been found to bioaccumulate mercury at levels that require fish consumption guidelines.

Poor water quality in the Albuquerque Reach may have contributed to low numbers of Rio Grande silvery minnow and to an overall reduction in fish abundance (Bestgen and Platania 1991). Water samples taken <1.2 km (0.75 mi) downstream from the Albuquerque Water Treatment Plant and at the Isleta Pueblo Bridge on April 25, 1993, revealed ammonia concentrations between 0.26 and 0.40 ppm, respectively, whereas at sites near the Bridge Street and Rio Bravo bridges (above the plant), ammonia concentrations were below 0.02 ppm (M. McCormick, pers. comm.; P. Plagge, pers. comm.). When these values are compared with the July and September 1992 seining results of Platania (1993) just above the plant's effluent discharge into the Rio Grande (10 species of fish) and 4.7 km (2.9 mi) below the plant (no fish at all), and if one accepts the toxic level of ammonia to most fish to be about 0.5 ppm, then an association of high ammonia levels and absence of fish below the discharge becomes a concern (C. Dahm, pers. comm.).

D. TERRESTRIAL ECOLOGY

1. Processes

Decomposition and Nutrient Cycling

The bosque floor contains fallen wood as well as a layer of leaf litter that is added during each fall season. As these materials decompose and finally release mainly mineralized nitrogen and phosphorous compounds (most importantly as ammonium and phosphate), they contribute to the supply of soil nutrients taken up by the roots of trees, shrubs, and herbaceous plants. The extent to which decomposition and mineralization produce nutrients, relative to nutrient inputs from the atmosphere, from surface and ground water, and from fire, has not been seriously studied in the Middle Rio Grande riparian zone. Information on this subject, however, is fundamental to sound management of the riparian ecosystem. A brief overview of decomposition and nutrient cycling, as these processes apply to the Middle Rio Grande ecosystem, is given in the following paragraphs.

Surface litter in temperate forests such as the Rio Grande bosque has an average residence time of about 4 years (Schlesinger 1991). Its decomposition is accomplished largely by enzymes produced by bacteria and fungi. Consumption of these organisms by scavenging soil invertebrates, such as nematodes, earthworms, isopods, and mites, increases rates of mineralization. Most mineralized nitrogen in the soil comes from the bodies of dead microbes (Schlesinger 1991).

Atmospheric nitrogen gas can also be incorporated into the soil. Nutrients contained in precipitation and on airborne particles can enter the soil directly which can be important in arid regions (West 1978). Fixation of nitrogen gas is accomplished by free-living bacteria and blue-green algae (cyanobacteria), which form "cryptogamic crusts" on the soil, and also by bacteria associated with plant roots. Measurable fixation occurs in these crusts in the bosque (C. White, pers. comm.) which appear as dark, often lumpy surfaces on mineral soils. Active crusts in the Middle Rio Grande riparian zone are common, especially during cool moist seasons and in open areas without much leaf litter.

Root-associated fixation of atmospheric nitrogen takes place in nodules occurring on the roots of Russian olive and *Shepherdia* (silver buffaloberry is in this genus; Sprent and Sprent 1985), and a great variety of leguminous plants (examples of these in the bosque are native false indigo bush, New Mexico olive, and introduced white sweetclover; Allen and Allen 1981). Cottonwood is not known to have root nodules (G.V. Johnson, pers. comm.). The potential importance of this form of nitrogen input can be inferred from results of a study showing that significantly more total organic nitrogen plus ammonium, as well as phosphorous, occurred in the dead leaves of Russian olive, and in the soil beneath that tree, than occurred in dead leaves of and soil beneath cottonwood in the Rio Grande Nature Center (M.C. Parker, pers. comm.).

Burning rapidly mineralizes organic matter. Combustion of forest litter makes compounds of phosphorous, in particular, available in the form of ash. However, combustion is not a conservative process, and nutrients are lost in forest burning. Schlesinger (1991) noted that up to 40% of the nitrogen in forest vegetation and litter can be volatilized in fires and that nutrients not taken up soon after can be lost through leaching and runoff.

Sediment Deposition and Soil Formation

Riparian soils originate mainly from river-borne (fluvial) sediments deposited on bars and floodplains (Lewin 1992). These often occur as fine colloidal clays produced initially by mechanical weathering and erosion. Another fraction occurs as dissolved ions, such as calcium, magnesium, and potassium, which are derived from rainfall, chemical weathering, and leaching of plant litter (Schlesinger 1991). Non-river-borne (colluvial) sediments, such as those resulting from slope erosion and wind-borne material, can also add appreciably to floodplain soils (Schlesinger 1991). Cores taken from the soil surface to the level of ground water in the Rio Grande floodplain reveal great variation in the texture of deposited materials, even when the cores are within meters of one another (C. White, pers. comm.). This reflects the differential effects of past flooding events and may contribute to the variation in ground-water flows, judging from inconsistent changes in ground-water levels in closely spaced wells at the Rio Grande Nature Center in Albuquerque (C.S. Crawford, pers. obs.).

Soil development on the surface of floodplain sediments involves organic matter being transported by overbank flows and/or deposited as leaf litter which then decomposes. Eventually, depending on how long a site remains undisturbed by flooding or other forces, and on rates of litter accumulation and decomposition, recognizable layers (horizons) of increasing mineralization become evident in the organic portion. Rates and amounts of soil horizon development in the bosque must vary greatly in space and time, owing to the deposition of fluvial sediments on the surface of existing soils and to the disruption of organic horizons by flood water. Currently, in areas of the bosque not flooded for half a century, soil horizons beneath dense cottonwood stands are moderately well developed and possess rich biotas of soil organisms (M.C. Molles, pers. comm.; C.S. Crawford, pers. obs.).

Carbon:nitrogen ratios from soil cores at Bosque del Apache NWR, ranged from 30:1 to 45:1 (S. Portman, pers. comm.), indicating that cottonwood and salt cedar forests on sites not flooded for about 50 years are definitely nitrogen-limited (C. White, pers. comm.). Ratios <20:1 indicate mineralizing conditions (Swift et al. 1979). Were these forests nitrogen-limited when they were flooded with some regularity? And would renewed flooding restore favorable carbon:nitrogen ratios? The answers to these questions have important management implications.

Riverine Transport and Forest Retention of Nutrients

Unpublished data collected by the U.S. Geological Survey (S. Anderholm, pers. comm.) between 1980 and 1990 showed distinct patterns of nutrient concentrations and ratios in the Middle Rio Grande. Mean values of total nitrogen, organic carbon, and phosphorous increase from north to south along the reach, with carbon rising dramatically between Bernardo and San Acacia, and phosphorous doing the same between Albuquerque and Isleta (Figs. 23 and 24). Sediment contributed by the Rio Puerco in particular and to some extent by the Rio Salado probably accounts for the carbon increase. The change in phosphorous could be due mainly to urban runoff from Bernalillo County.

Nutrient ratios taken from values given in Figs. 23 and 24 also show distinct patterns in water along the reach. Thus the nitrogen:phosphorous ratio is relatively high above Albuquerque but consistently low from Isleta south, while the carbon:nitrogen ratio is relatively low above Bernardo but high at and below San Acacia (Fig. 25).

Riparian forests can remove most of the dissolved nitrates that pass to them from croplands in the floodplain (Chauvet and Décamps 1989). Large amounts of phosphorous can also be retained by riparian forests (Gregory et al. 1991). These findings have important implications for the Middle Rio Grande riparian zone because of the potential for increasing runoff of nitrogen and phosphorous from urban and agricultural areas. This issue will be discussed more fully under Biological Management Recommendations.

2. Producers

Description of Existing Terrestrial Plant Communities

System Processes Affecting Plant Communities along the Rio Grande.—Along the Rio Grande, past conditions included a shifting alluvial channel, meandering/downcutting in some areas, and braiding/aggrading in others. The channel shifted throughout the floodplain, and there was abundant sediment in the river. Unregulated high spring flows caused flooding, major shifts in the river channel, new meanders, formation of oxbows, and bank erosion (Bullard and Wells 1992). These disruptions of the equilibrium state created conditions for establishment of riparian species, with vegetation responding to fluctuations in the fluvial system (Fig. 26; Brady et al. 1985, Szaro 1989, Mahoney and Rood 1991).

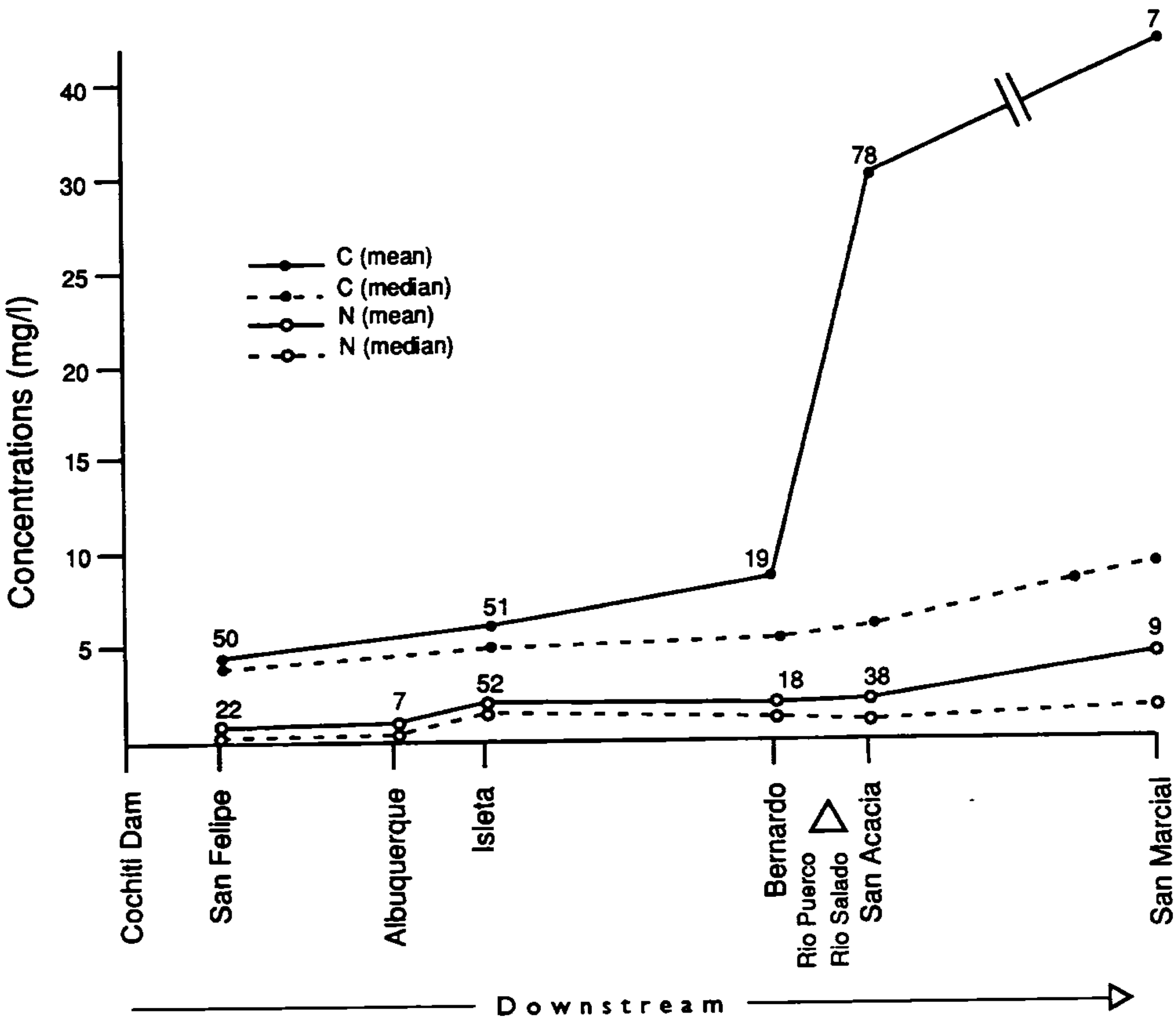


Fig. 23. Mean and median of total nitrogen and carbon collected at designated stations from October 1980 to September 1990 along the Middle Rio Grande reach (U.S. Geological Survey data). Values above symbols are sample sizes.

Native riparian plant species evolved reproductive strategies that enabled them to survive in the fluvial system. Phenological development and seed dispersal for cottonwoods, willows, and other species coincide with high flows in the river. High flows scour existing vegetation and deposit sediments. These bare substrates are required for successful germination and establishment of riparian species. Also required are suitable moisture conditions (Horton et al. 1960). If too wet, seedlings will weaken or perish; if too dry, they will die before their roots reach the water table. To find suitable substrate and moisture conditions, seed dispersal must coincide with the gradual lowering of the peak flows. This does not necessarily occur every year; conditions may only be optimum once in several years. Added to this uncertainty is the need for flows of a particular magnitude throughout the growing season the first year and also in succeeding years. The young plants need moisture, but if floods arrive before they are well

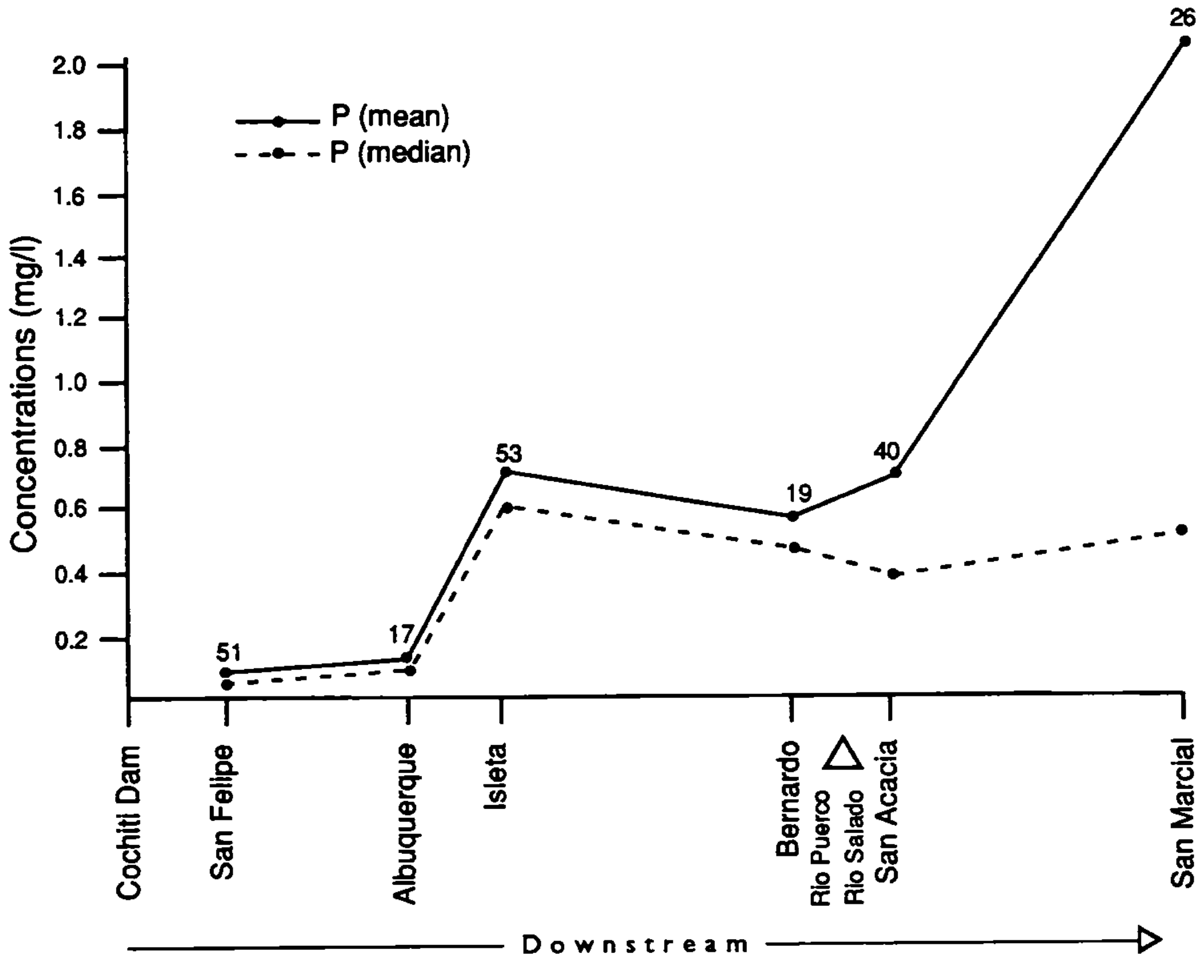


Fig. 24. Mean and median of total phosphorous collected at designated stations from October 1980 to September 1990 along the Middle Rio Grande reach (U.S. Geological Survey data). Values above symbols are sample sizes.

established, the plants will be scoured from their places (Asplund and Gooch 1988, Szaro 1989, Mahoney and Rood 1991, Stromberg et al. 1991). The characteristic river flow and congruence of circumstances (recruitment box) that result in the establishment of cottonwood are illustrated in Fig. 27A and B. Although taken from Mahoney and Rood (1991) for Alberta, Canada, the concepts are applicable to the Middle Rio Grande.

Reproductive strategies of introduced plants vary from species to species. Salt cedar, for example, requires the same bare, moist, substrate conditions as native species for successful germination and development. However, there is a critical difference between salt cedar and native species in that salt cedar can flower and produce seed throughout the growing season (Horton et al. 1960). Hence, germination and establishment of salt cedar occur anytime proper substrate and adequate moisture are available and are not restricted to spring and early summer (Fig. 27). If bare substrate is colonized by salt cedar in mid- to late-summer, native species will

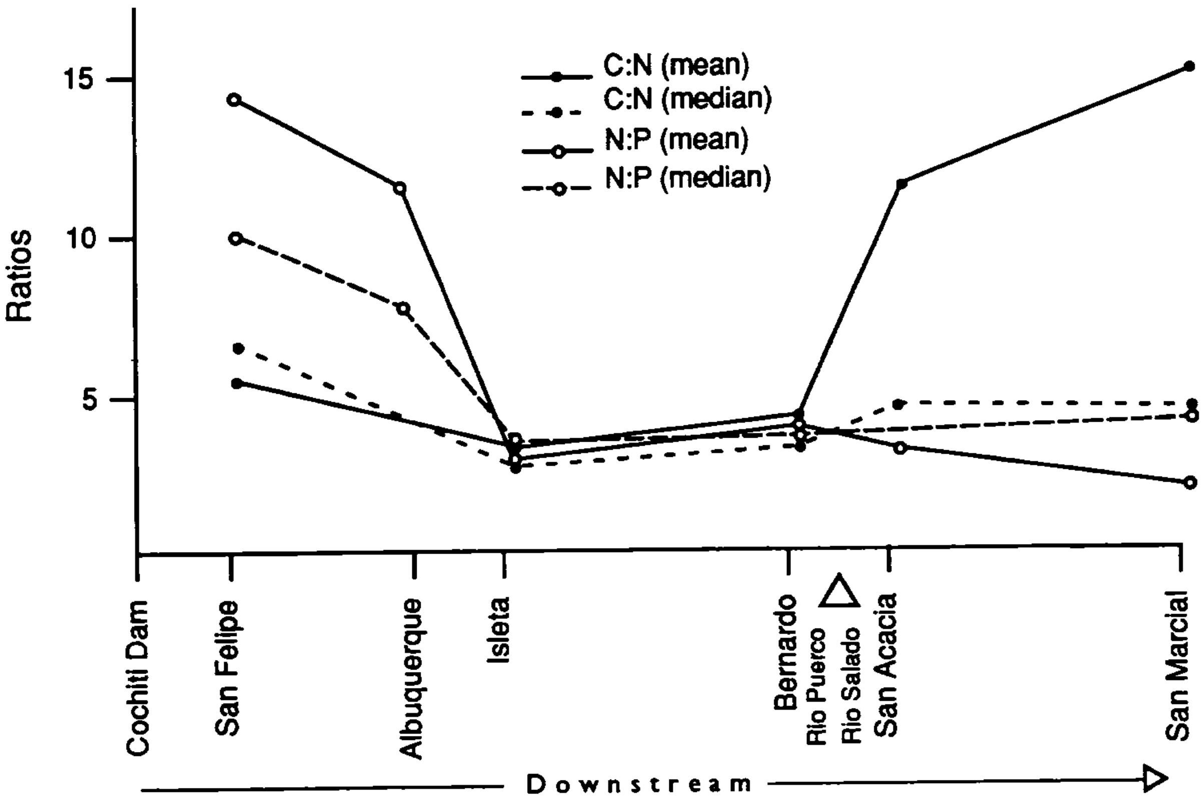


Fig. 25. Ratios of nitrogen, phosphorous, and carbon derived from total values collected at designated stations from October 1980 to September 1990 along the Middle Rio Grande reach (U.S. Geological Survey data).

not be able to become established there in the following year. Salt cedar has become widespread in the Southwest and is the dominant plant, almost to the complete exclusion of other species in some areas, in the southern reach of the Middle Rio Grande.

Nonnative species, such as Russian olive, Siberian elm, mulberry, and others, can germinate and grow in shady areas, under existing tree canopies. Russian olive, in particular, has become an extensive part of the understory in the riparian zones of some western rivers including the Rio Grande (Freehling 1982, Hink and Ohmart 1984, Sivinski et al. 1990).

Fire probably did not play a major role in the evolution of Rio Grande riparian communities. Occasional fires probably broke out from lightning strikes; and, after human occupation of the valley, purposeful and accidental fires became common in some areas. Prior to the introduction of nonnative plant species, burned areas were probably recolonized by either upland or riparian species depending on available moisture and seed source. Today, fires usually result in the death of cottonwoods and revegetation by salt cedar, Russian olive, and Siberian elm. Once established, these species are generally more resistant than cottonwoods to fire (G. Fitch, pers.

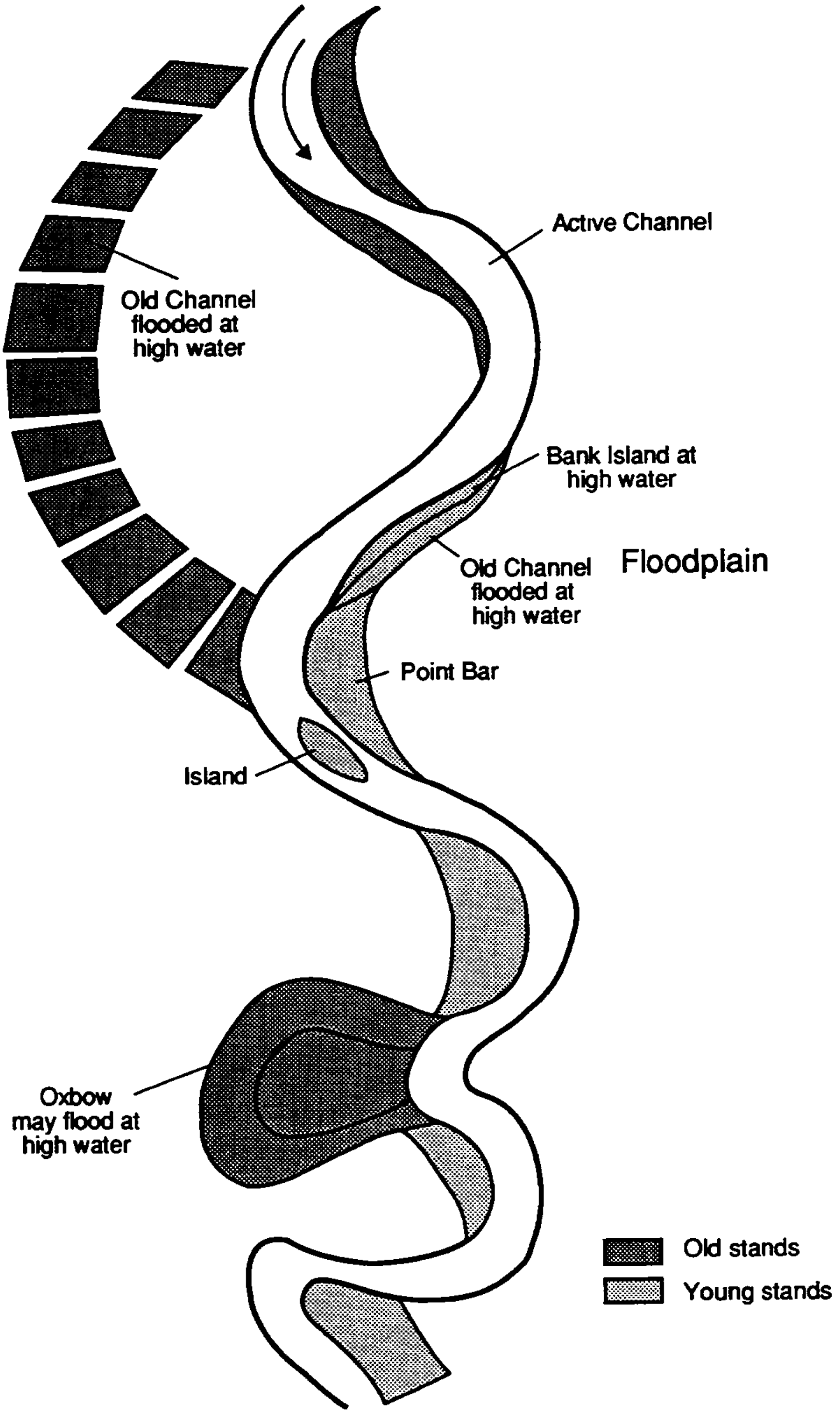


Fig. 26. Zones of cottonwood and other riparian species establishment along an unmodified river.

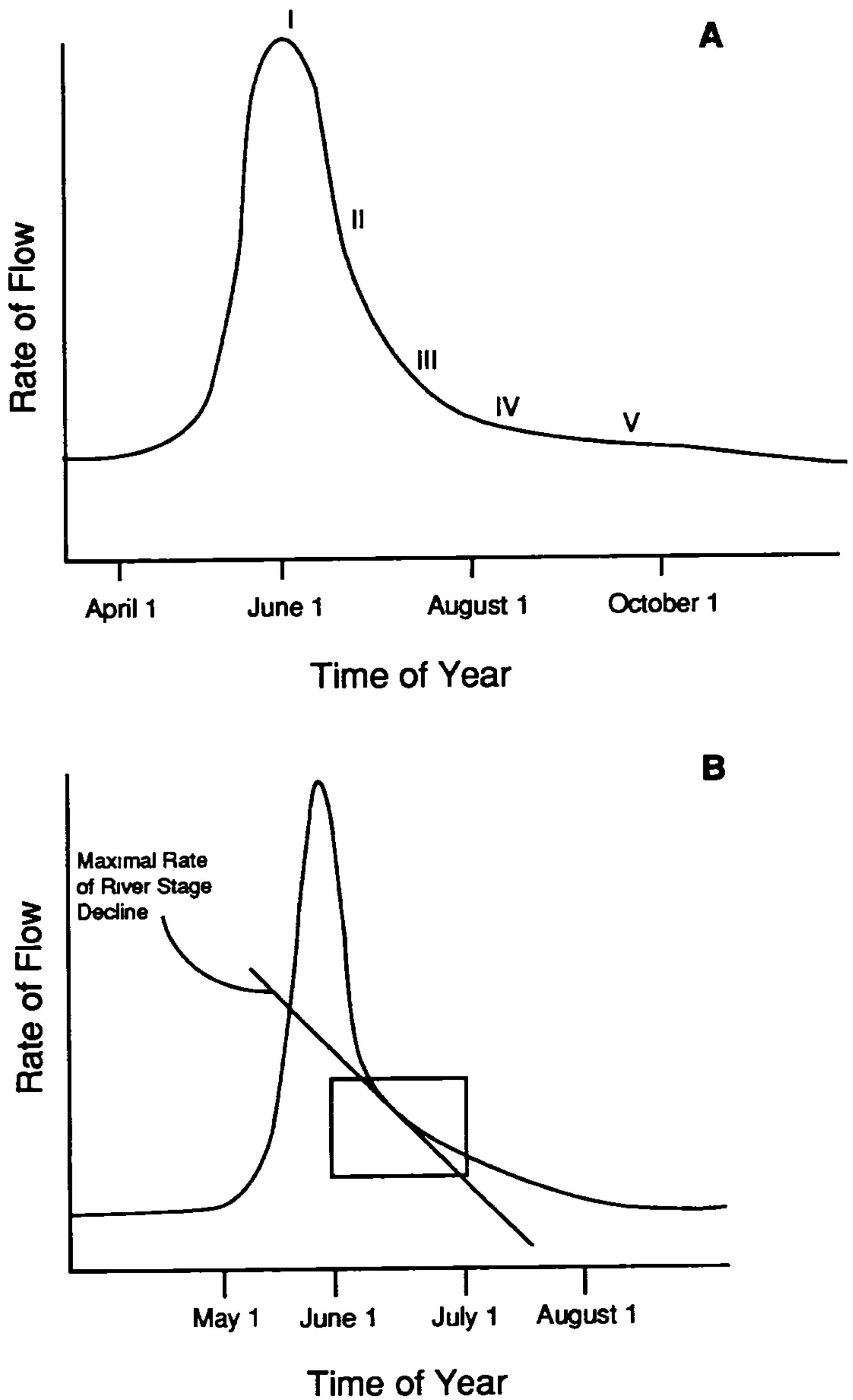


Fig. 27. (A) Representative flow regime on a river characterized by annual spring peak floods: I, peak flows prepare germination sites; II, receding flows expose germination sites; III, declining water table; IV, adequate summer flows; and V, adequate autumn flow. (B) Peak flood and drawdown stages which provide opportunity for germination and recruitment of cottonwoods. Box represents limits set by river flow and time of seed release; rate of water table decline limits survival of seedlings after germination (after Mahoney and Rood 1991).

comm.; M. Stuever, pers. comm.). Burned areas are easily identifiable and have been mapped in the Albuquerque area (Fig. 28).

3. Current Hydrologic Regime and Its Effects on the Riparian Vegetation

Present conditions in the Rio Grande include levees, dams, and channelization. Cochiti Dam has had a major impact on the river and riparian zone below it by reducing peak flows and sediments in the system. The timing and duration of releases of peak flows may not be suitable for germination and establishment of native species (Fenner et al. 1985, Szaro 1989). Levees have restricted the lateral movement of the river, and channelization has occurred along some reaches. The consequence of all these actions for native riparian vegetation, once areas have become vegetated, is a drastic reduction in numbers of sites and opportunities for further recruitment (Fig. 29; Howe and Knopf 1991, Milhous et al. 1993).

As stated, probably as a result of the construction of Cochiti Dam, the northern reaches (Cochiti and Albuquerque) of the Middle Rio Grande are now degrading. Because sediments are trapped at the dam, released waters have high potential for erosion and the channel is deepening. Vegetation is stabilizing the riverbanks, enhancing the narrowing and deepening of the channel. Comparison of 1935 to 1989 aerial photos indicates that the riverine, or river channel portion of the Middle Rio Grande, has been reduced by 49% (8,920 ha [22,032 acres] in 1935 to 4,347 ha [10,736 acres] in 1980; see Fig. 30). For native riparian plant species, there is little or no recruitment, except for banks and bars adjacent to the main channel of the river that are exposed after high flows. These areas may be scoured by the next high flows and are often subject to mowing to maintain the floodway. This lack of recruitment is a consequence of the presence of existing riparian vegetation and the absence of high magnitude flows to remove established vegetation and create barren areas for colonization.

In the southern reaches (Belen and Socorro) of the Middle Rio Grande, large amounts of sediment are introduced into the system at the confluences of the Rio Puerco and Rio Salado (Lagasse 1980). Some areas are without levees, and waters spread out there and deposit sediments. In these reaches, decreases in peak flows prevent sediments in the channel from being moved downstream. At the southern end of the Middle Rio Grande, Elephant Butte Dam has caused the base elevation to rise upstream enhancing deposition, channel widening, river braiding, and aggrading in some areas. Sediment deposition creates substrate for recruitment of native cottonwoods and willows and introduced salt cedar.

Middle Rio Grande Terrestrial Riparian Plant Communities

Two recent maps of the riparian vegetation throughout most of the length of the middle valley area were available to us. These included the National Wetlands Inventory maps (1989) which delineate broad vegetation classes in the riparian and wetland areas; and the mapped classifications of the riparian zone that accompanied the Middle Rio Grande Biological Survey (Hink and Ohmart 1984). The National Wetlands Inventory maps were used as the basis for assessing changes in the vegetation through time. Digitized information from 1935 aerial photography was available for comparison to the same type of information digitized in 1989 for the National Wetlands Inventory (see Maps 1-4). The study by Hink and Ohmart (1984)

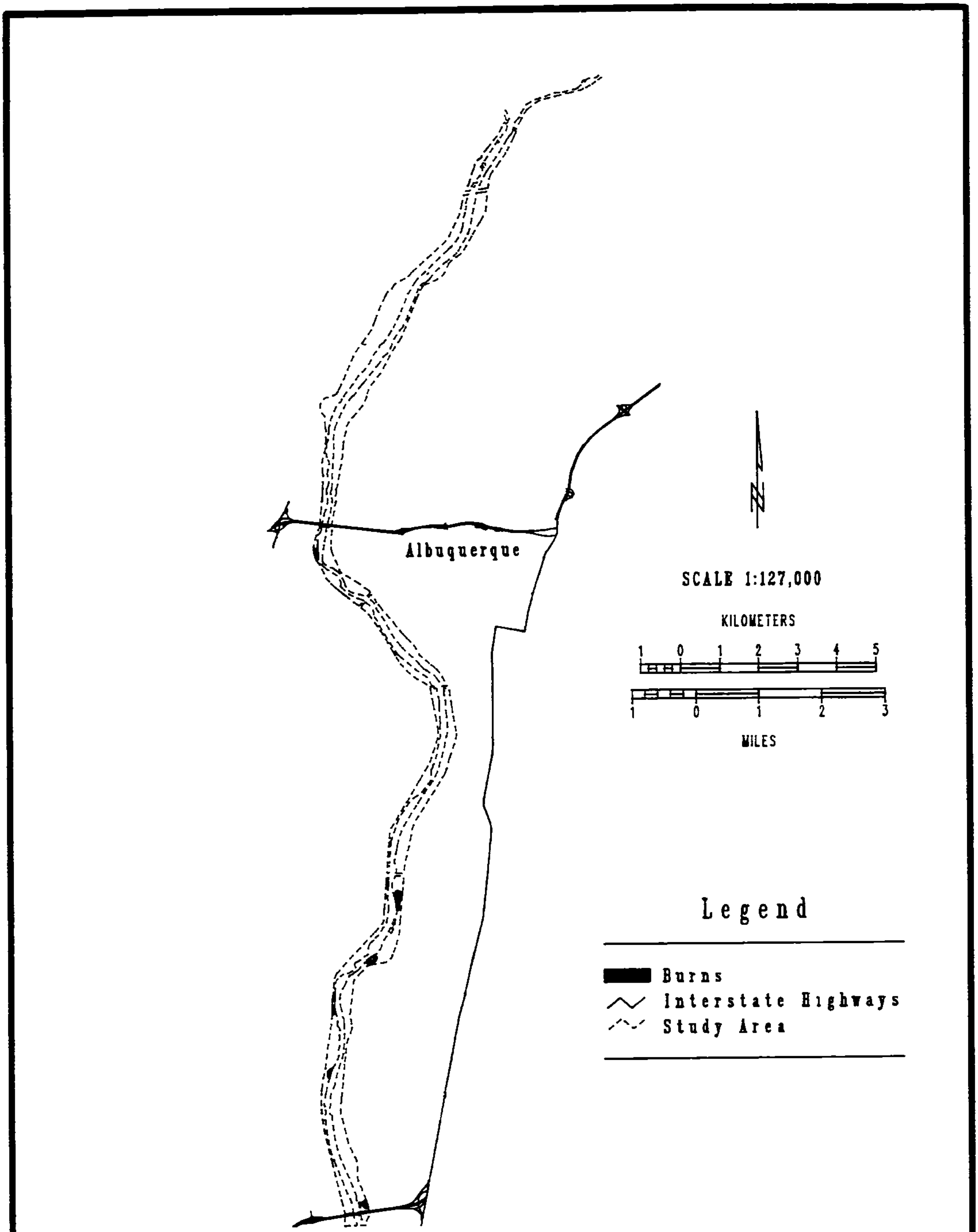


Fig. 28. Burned areas in the Rio Grande bosque, Albuquerque area (taken from Sivinski et al. 1990).

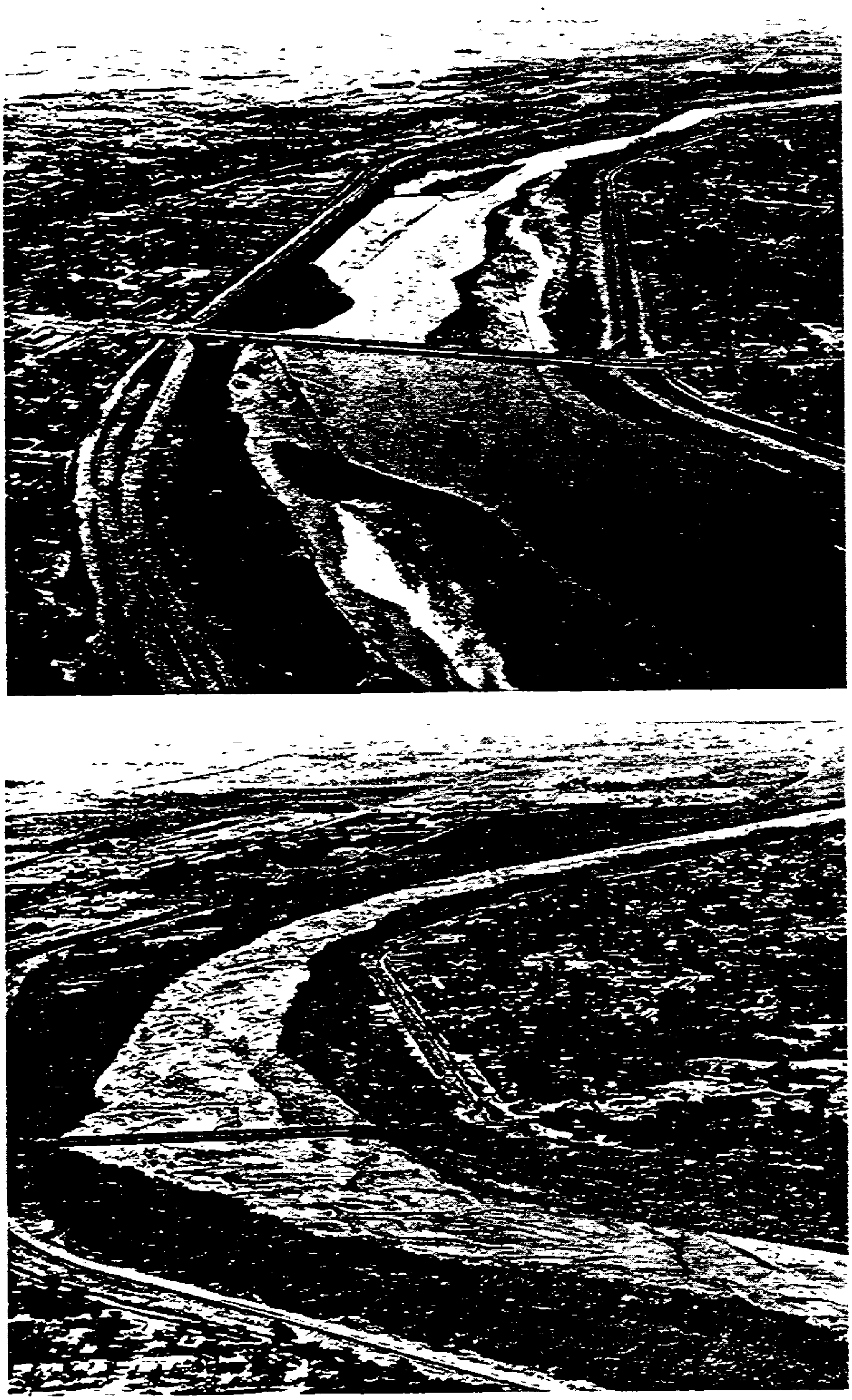


Fig. 29. Jetty installation in April 1960 (above) and regrowth of vegetation in May 1972 (below) at U.S. Highway 85 Bridge, Middle Rio Grande Project, U.S. Bureau of Reclamation, Albuquerque.

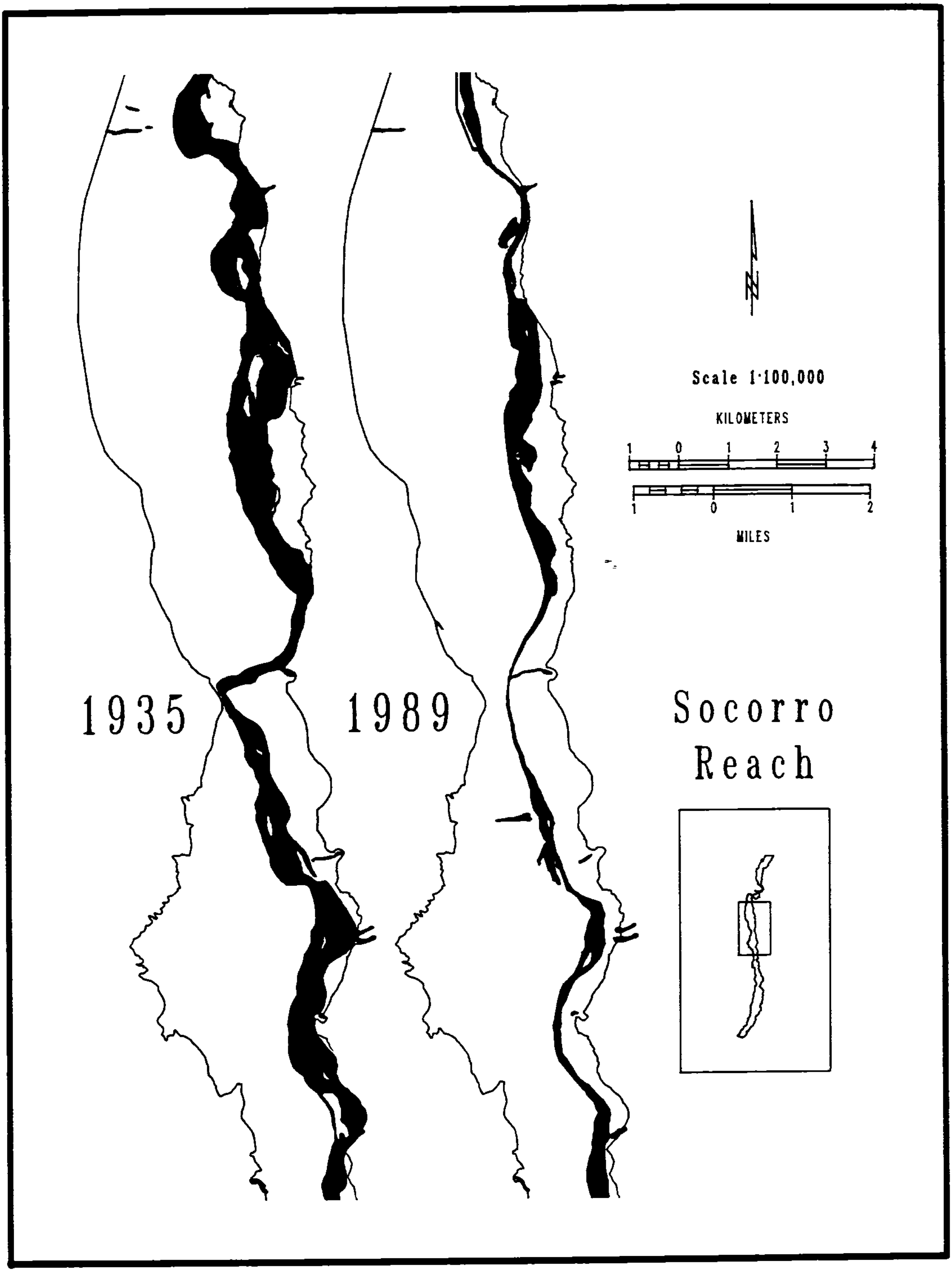


Fig. 30. Changes in width of river channel, 1935-89, portions of Socorro Reach, Middle Rio Grande.

provided greater detail on species composition and structure of cover types and formed the basis of our discussion of the terrestrial flora and fauna and for recommendations for management options.

Much of the riparian zone along the Middle Rio Grande is dominated by cottonwood trees, which form a sparse to dense canopy cover along the river. In the understory, native species include the shrubs coyote willow, seepwillow, false indigo bush, New Mexico olive, and others. Introduced species have become increasingly important in numbers, frequently becoming the dominant species in the understory and occasionally in the canopy. In the northern reach, the major introduced species is Russian olive. In the south (below Bernardo), salt cedar is prevalent in the understory, and it also forms large monotypic stands along the river and adjacent floodplain. Other introduced species (e.g., Siberian elm, tree-of-heaven, china-berry tree, mulberry, and black locust) are found in the bosque, mostly along levee roads and other disturbed areas predominantly in urbanized areas. However, these species are encroaching on the plant communities now dominated by native species and have the potential for becoming the primary species there through time.

Hink and Ohmart (1984) described three cottonwood-dominated community types based on the overstory species and on the type and abundance of the understory species. The cottonwood/coyote willow community (Table 14) consisted of a cottonwood overstory, with an understory dominated by coyote willow, interspersed with salt cedar, Russian olive, and seepwillow. The cottonwood/Russian olive community consisted of cottonwood with an understory composed primarily of Russian olive trees. In some areas, the Russian olive trees were tall enough to reach into the canopy. The cottonwood/juniper community was found in the northern reach and was made up of cottonwood with one-seed juniper as the principal understory species. Within all these communities, New Mexico olive, false indigo bush, and other species were also found.

Other plant communities also occurred in the study area (Hink and Ohmart 1984). Russian olive occurred along the river channel in narrow, 15-60 m (50-200 ft) wide bands. Cattail marshes, dominated by cattails with some bulrush and sedge, are found in areas that are inundated or have a high water table. Wet meadows with saltgrass and sedges were also designated as marsh communities. (These types, along with ditches and drains, are treated in greater detail below.) In the southern reach, salt cedar was the primary component of the plant community almost to the complete exclusion of other species.

Hink and Ohmart (1984) also delineated sandbars in and adjacent to the river, and the river channel. Most of the sandbars were bare, but some had developed vegetation consisting of grasses, forbs, cottonwood and willow seedlings, and other species. Many of these bars were scoured during each year's high flows. If not removed by scouring, vegetation in these locations is periodically mowed by the BOR to keep the floodway clear.

Six structural types of plant communities were recognized by Hink and Ohmart (1984), based on the overall height of the vegetation and the amount of vegetation in the understory or lower layers. Type I (see Fig. 31) had vegetation in all layers, with trees 15-18 m (50-60 ft) high. Type I areas were mostly mixed to mature age class stands dominated by cottonwood/coyote

Table 14. Community type designations and plant species names used in Hink and Ohmart (1984).

Designation	Common Name	Scientific Name
C	Fremont's cottonwood	*Populus fremontii*
RO	Russian olive	*Eleagnus angustifolia*
SC	Salt cedar; tamarisk	*Tamarix* spp.
CW	Coyote willow	*Salix exigua*
TW	Peachleaf or Goodding's willow	*Salix amygdaloides* *S gooddingii*
SE	Siberian elm	*Ulmus pumila*
SW	Seepwillow	*Baccharis salicina*
I	(False) indigo bush	*Amorpha fruticosa*
J	One-seed juniper	*Juniperus monosperma*
Wb	Wolfberry	*Lycium andersonii*
Sn	Snakeweed	*Gutierrezia sarothrae*
Rb	Rabbitbrush	*Chrysothamnus nauseosus*
Sa	Sagebrush	*Artemisia filifolia, A dracunculoides*
NMO	New Mexico olive	*Forestieria neomexicana*
Op	Prickly-pear or cholla cactus	*Opuntia* spp.
Cat	Cattail	*Typha latifolia*
Gr	Grasses	
Ann	Annual plants	
Dr	Drain	
LV	Levee	
E	Edge	
MH	Marsh	
OP	Small opening	
SB	Sandbar	
RV	River channel	

willow, cottonwood/Russian olive, and cottonwood/juniper. Type II areas consisted of mature trees from 15 to 18 m (50 to 60 ft) tall with a sparse understory. Intermediate age stands of cottonwood trees with a dense understory were classified as Type III, while similarly aged trees with open understory were called Type IV. Type V was characterized by dense vegetation up to about 4.6 m (15 ft) often with dense grasses and annuals. Type VI had low, often sparse vegetation, typical of sandbars with cottonwood, willow, and other seedlings. This type also included sparsely vegetated drains.

While the structure and diversity of native plant communities appear to be significant to the diversity of species in animal communities, introduced plant species that have become naturalized

Fig. 31. Vegetation structural types I-VI, Middle Rio Grande riparian zone (after Hink and Ohmart 1984).

I II III

Illustration by WJU

IV V VI

in the region also provide shelter and sometimes food. The fruits of the Russian olive, a species which is prominent in the community types in the northern reach of our study area, appear to be a significant part of the diet for some resident, migrant, and breeding bird species. Salt cedar, found throughout the study area but particularly abundant in the southern portion, provides cover for birds and mammals and habitat for many insect species (Hink and Ohmart 1984).

4. Consumers

Animal Communities–Amphibians

Most amphibians depend on the aquatic habitats of the bosque for at least a portion of their life cycle. Breeding and development of eggs and larvae occur in aquatic habitats such as intermittent pools formed by flooding and summer rains, permanent ponds, drains, and irrigation canals. Adult stages of several species are found in riparian and upland habitats. Different species have different aquatic and riparian habitat requirements resulting in diverse amphibian populations. Amphibians are not so much associated with any riparian vegetation type as they are with proximity to water, openings, sandbars, and for frogs, wet meadows and marshes. Table 15 compares habitat associations of amphibians known to occur in the bosque (Applegarth 1982, Hink and Ohmart 1984).

Amphibians associated with the diminished habitats of the bosque such as wet meadows and marshes are chorus frogs, leopard frogs, and bullfrogs. Of these, the leopard frogs appear to be continuing to decline.

Historically, northern leopard frogs (*Rana pipiens*) were apparently common in the Rio Grande Valley. The oxbow ponds and marshes created by the freely meandering Rio Grande were ideal habitat (Applegarth 1983). Wetland drainage, control of the Rio Grande, and possibly the introduction of bullfrogs have greatly reduced the habitat available to this species. Before bullfrogs were introduced (mid-1930's), northern leopard frogs had invaded and were abundant in drains, irrigation canals, and even stock ponds (Applegarth 1983).

Today, leopard frogs are restricted to a few scattered wetlands along the Rio Grande (Table 16). They forage in wet meadows and breed in quiet waters that are relatively free of predaceous fish and bullfrogs. Optimal habitat is a combination of wet meadow interspersed with shallow, clear, semipermanent ponds that are present in the month of April (Applegarth 1983). Ideal breeding ponds are shallow and support dense growth of aquatic and emergent vegetation. Because of reduction of optimum habitat and apparent population declines, we consider the leopard frog a species of management concern in the Middle Rio Grande riparian ecosystem.

Reptiles

Hink and Ohmart (1984) documented 3 turtle species, 17 lizard species, and 18 snake species in the Middle Rio Grande Valley. Many of these are upland species, are uncommon in the bosque, and do not occur regularly in riparian habitats. Of those that are common in the bosque, the plateau lizard (*Sceloporus undulatus*) and the New Mexico whiptail (*Cnemidophorus neomexicanus*) are the most widespread and frequently observed lizards.

Table 15. A comparison of amphibian habitat associations in the Middle Rio Grande bosque.

Species	Aquatic Requirements	Riparian Association
Tiger salamander *Ambystoma tigrinum*	Small ponds and cattle tanks	Downed logs and rodent burrows; wet channels and other moist areas of bosque
Couch's spadefoot *Scaphiopus couchii*	Pools formed by summer rains and floods	Clay substrate in desert, grassland, salt cedar, and irrigated agriculture
Plains spadefoot *Spea bombifrons*	Pools formed by summer rains and floods	Open sandy areas in floodplain and adjacent grasslands
New Mexico spadefoot *Spea multiplicata*	Pools formed by summer rains and floods	Alluvial fans and floodplains within hilly terrain
Red-spotted toad *Bufo punctatus*	Intermittent streams and pools left by flooding	Prefers rocky terrain in upland habitats, occasional on floodplains
Woodhouse's toad *Bufo woodhousei*	Pools, ditches, marshes, and backwaters	Common and widespread in sandy areas, particularly on riverine sandbars
Great Plains toad *Bufo cognatus*	Pools formed by rains and floods	Sandy areas, particularly on riverine sandbars
Western chorus frog *Pseudacris triseriata*	Marshes, flooded swales, and small pools between Albuquerque and Bernardo	Wet meadows
Northern leopard frog *Rana pipiens*	Permanent shallow pools, springs, ditches, and streams without predators	Forages in marshes and wet meadows
Bullfrog *Rana catesbeiana*	Deeper ponds, canals, and ditches	Marshes, riparian-aquatic edge not far from water

Table 16. Locations known to support recent northern leopard frog populations and source.

Location	Source
Wet meadows near Bernardo Bridge	Applegarth 1982
Shallow pond, west levee, 5 km N of Bosque Bridge	Applegarth 1982
Pasture, 2 km SW of Pena Blanca	Applegarth 1982
Marshy area, 2 km SE of Bernardo	Applegarth 1982
COE experimental borrow-pit pond	Applegarth 1982
Madrone ponds	Hink and Ohmart 1984
Unmaintained drain, 2.7 km downstream of San Felipe	M. Sifuentes, pers. obs.
Isleta Marsh, S of Isleta Pueblo	J. Stuart, pers. comm.
Cochiti Pueblo wetfields	J. Stuart, pers. comm.
Santa Fe River below Cochiti Dam	J. Stuart, pers. comm.

The turtle species found by Hink and Ohmart (1984) were the ornate box turtle (*Terrapene ornata*), painted turtle (*Chrysemys picta*), and spiny softshell turtle (*Trionyx spiniferus*). The box turtle, which is more associated with terrestrial habitat, has probably expanded its range into the more northern reaches near Albuquerque from previous distribution limits at Belen. The spiny softshell, a highly aquatic species, occurs in the river in areas with a sandy bottom and strong currents as well as in deep river backwaters and turbid ditches.

Historically, painted turtles were common in the Rio Grande Valley. The oxbow ponds and marshes throughout the Rio Grande floodplain were ideal habitat for them (Applegarth 1983). Today, they are found in drains and canals, isolated wetlands, permanent ponds, and occasionally in backwaters along the river channel (Hink and Ohmart 1984). Painted turtles prefer aquatic habitats with quiet water with a soft bottom and an abundance of aquatic plants. Measures to protect and restore leopard frog habitat would certainly benefit painted turtles.

The Big Bend slider (*Trachemys gaigeae*) has been found at Elephant Butte Reservoir and Bosque del Apache NWR (Stolz [not dated]) which represents the northernmost known occurrence for the species. Other turtles reported from the Middle Rio Grande include the common snapping turtle (*Chelydra serpentina*) and red-eared slider (*Trachemys scripta*). These are uncommon in aquatic habitats in the Middle Rio Grande; the red-eared slider may have been recently introduced (J.N. Stuart, pers. comm.).

The highest number of lizard species are found in open areas rather than densely vegetated areas. The highest capture rates were in low, shrubby salt cedar at the mouth of the Jemez River, which had less vegetation cover than any habitat except sandbars. A variety of other community-structure types with relative high capture rates included sandy, open areas with sparse or scattered understory, sandbars, and levee banks (Hink and Ohmart 1984).

Unlike most other reptiles in the bosque, Great Plains skinks (*Eumeces obsoletus*) and gartersnakes (*Thamnophis* sp.) favor moist riparian habitats (Hink and Ohmart 1984). They are often found in vegetation types with well-developed herbaceous and shrub understory vegetation.

Mammals

Small Mammals.—Although inconspicuous, small mammals (rodents and insectivores) are both numerous and well-studied. Habitat use and interactions in rodent populations have been intensively studied in community ecology. The species composition and density of small mammals have been used to study the riparian community because the trophic and species composition are closely related to plant community structure as discussed by French (1978).

In forest habitats, small mammals may have more significant roles as herbivores and granivores in the earlier stages of plant succession, than they do in later stages, when trees and other plants are young and most susceptible to damage and when seed and seedling mortality are more likely to impact community succession (Potter 1978). Potter (1978) concluded that, unlike in grassland and deserts, small mammals in mature forest habitats play only a minimal role in nutrient recycling. Most of the nutrients from a plant community pass directly to the decomposer community with relatively little being diverted by small mammals. However, small mammals play an important role in energy flow to higher trophic levels since they are an important food for bird and mammal predators.

Burrowing rodents' preferred habitat is often based on soil texture and moisture (Ohmart and Anderson 1986). Heteromyids may prefer sandy, open habitats; cricetids prefer dense vegetation and moister soils; and zapodids prefer dense grass or low willows in moist soils. Stamp and Ohmart (1979) found that total small mammal biomass was greater in southwestern riparian habitats than in adjacent uplands.

Hink and Ohmart (1984) conducted an in-depth inventory of small mammals along the Middle Rio Grande. The study was used to compare species diversity and density of small mammals in different community and structure types and to predict impacts from human activity. Ellis et al. (1993) studied rodent populations in cottonwood forests and monotypic salt cedar stands to determine the effects of flooding on these communities. The following summarizes findings from these studies.

The density of small mammals is higher in wetter habitats where herbaceous vegetation and understory shrubs are lush. In addition, leaf litter, dead and downed wood, and brush piles also contribute to the abundance of small mammals. Ellis et al. (1993) found more species of rodents in salt cedar than in nearby cottonwood.

Distribution, diversity, and abundance of small mammal species relate to the mosaic of community and structural types in the bosque. Table 17 summarizes the relationships of small mammals found in riparian habitat along the Middle Rio Grande (from Hink and Ohmart 1984).

Hink and Ohmart (1984) found that the three most common and widespread rodents in the bosque were the white-footed mouse (*Peromyscus leucopus*), western harvest mouse

Table 17. Vegetation relationships of small mammals found in riparian habitat along the Middle Rio Grande (from Hink and Ohmart 1984).

Species		
White-footed mouse **Desert shrew**		Most numerous in dense, moist cottonwood forest, especially with willow understory
Western harvest mouse **Hispid cotton rat** **Plains harvest mouse**		More numerous in habitats with dense grass, sedges, and annuals
House mouse	Most numerous in wet areas along marsh and drain edges	Most numerous in grassy habitats without forest canopy
Meadow jumping mouse **Tawny-bellied cotton rat**	Occur primarily in wet meadows with saltgrass and sedges (Isleta Marsh)	
Deer mouse **Piñon mouse**		Occur primarily in open cottonwood forests with juniper and upland shrubs
Plains pocket mouse **Silky pocket mouse** **Ord kangaroo rat** **Merriam kangaroo rat** **Northern grasshopper mouse**		Occur primarily in arid salt cedar habitat adjacent to upland habitat

(*Reithrodontomys megalotis*), and the house mouse (*Mus musculus*); the white-footed mouse was the most numerous. These three species accounted for 92% of captured small mammals in cottonwood-shrub habitats. Although these species are found in many adjacent upland habitats, they are more abundant and numerous in Middle Rio Grande riparian habitats. Ellis et al. (1993) found that the white-footed mouse was active in trees and shrubs, as well as on the ground. It was the most numerous species in both cottonwood and salt cedar.

Desert shrews (*Notiosorex crawfordi*) occur in heavily vegetated cottonwood forests, marshes, and salt cedar stands. They are abundant in moist cottonwood forests with willow understory (Hink and Ohmart 1984).

Plains harvest mice (*Reithrodontomys montanus*) are uncommon. Findley et al. (1975) reported that this species occurs in grassy areas of the floodplain.

Areas of salt cedar with sandy soils in the southern part of the bosque had a relatively high number of rodent species. This was a function of the addition of several species usually found in adjacent desert and grassland including plains pocket mouse (*Perognathus flavescens*), silky pocket mouse (*Perognathus flavus*), Ord kangaroo rat (*Dipodomys ordii*), Merriam kangaroo rat (*Dipodomys merriami*), and northern grasshopper mouse (*Onychomys leucogaster*; Hink and Ohmart 1984).

There was a relatively high number of species in the wet meadow habitat such as Isleta Marsh. This habitat, historically common, is now rare. Importantly, two of the seven species, the meadow jumping mouse (*Zapus hudsonius leutes*) and the tawny-bellied cotton rat (*Sigmodon fulviventer*), are rare and declining. Both Hink and Ohmart (1984) and Morrison (1988) recommended protecting and enhancing wet meadow and marsh habitat for the benefit of the rarer small mammals. The hispid cotton rat (*Sigmodon hispidus*) may be replacing the tawny-bellied cotton rat due to its tolerance for slightly drier sites.

Botta pocket gophers (*Thomomys bottae*) are widespread throughout the riparian zone in areas of deep, sandy soil where trees are not too dense. They are especially common where coyote willow is the dominant plant species (Hink and Ohmart 1984). The tunneling of pocket gophers mixes large quantities of soil, provides habitat for many invertebrates, and transfers ingested fungal spores important to plant nutrition and decomposition (Allen 1987, Reichman et al. 1993).

Eleven species of bats are known from the valley. Of these, the Yuma myotis (*Myotis yumanensis*) and the little brown myotis (*Myotis lucifugus*) use riparian and aquatic habitats exclusively. They forage over open water, drains, ponds, and the river. They breed in the valley using old buildings, undersides of bridges, and snags for shelter and nest sites.

Hink and Ohmart (1984) documented that the number of species varied significantly with community type structure. Tables 18 and 19 summarize their findings and correlate small mammal species diversity (number of species) and relative density with community and structure type.

Large Mammals.—Of the larger mammals, beaver (*Castor canadensis*), muskrat (*Ondatra zibethicus*), and raccoon (*Procyon lotor*) are strictly associated with riparian habitat and permanent water. These three species are fairly common. Mink (*Mustela vison*), another riparian obligate, was found historically along the Middle Rio Grande, but has been extirpated since about 1920 (Bailey 1932).

Beavers probably were common historically along the Middle Rio Grande in scattered areas with lush cottonwood-willow associations, marshes, and permanent water. Trapping almost eliminated them from much of their range until the NMDGF initiated a restocking effort between 1947 and 1958. Today, beavers are found in the river, irrigation ditches, drains, and marshes where water is significantly deep (Hink and Ohmart 1984). They prefer cottonwood-willow associations, but use Russian olive and even salt cedar. Middle Rio Grande populations are "bank beavers." Dens are dug on the riverbanks and sides of drains.

Table 18. Number of small mammal species and relative density within community structure types as determined by Hink and Ohmart (1984). Relative density is based on mean capture rate (mean N/270 trap nights). H = high (N ≈ 14-23), M = moderate (N ≈ 6-10), L = low (N ≈ 1-5), and VL = very low (N ≤ 1).

Plant Community Structure Type	Number of Species	Relative Density	Plant Community Structure Type	Number of Species	Relative Density
SC VI	9	M	C/CW I	4	L
SC VI A	8	L	SB VI 4	4	L
DR VI	7	M	C/CW IV	4	VL
C/RO E I	7	M	C/CW E V	3	H
MH VI (Isleta)	7	M	DR V	3	H
SC V	7	L	OP VI (C/CW)	3	M
MH V	6	H	OP V (C/CW)	3	M
WET E V	6	H	C/RO IV	3	L
C/CW E III	5	H	C/RO II	3	L
RO V	5	H	C/RO I	2	L
C/CW V	5	M	C/J I	2	L
C/CW E I	5	M	C/J IV	2	VL
C/CW VI	5	L			

Key to Hink and Ohmart (1984) community-structure types used in Tables 18, 20, and 21:

C/CW I = Mature cottonwood forest with coyote willow dominated understory
C/CW II = Mature open cottonwood forest with scattered coyote willow understory
C/CW III = Intermediate aged cottonwoods with a thick understory of coyote willow
C/CW IV = Open stands of intermediate aged cottonwoods with widely spaced coyote willow
C/CW V = Dense, shrubby vegetation dominated by coyote willow with tall, scattered cottonwoods
C/CW VI = Early stage cottonwood/coyote willow under 1.5 m (5 ft)
C/CW E I = Edge of mature cottonwood forest with coyote willow dominated understory
C/J I = Mature cottonwood forest with dense understory dominated by juniper
C/J IV = Moderate aged cottonwood stands dominated by juniper
C/RO I = Mature cottonwood stands/Russian olive dominated shrub understory
C/RO II = Mature cottonwood stands/sparse understory dominated by Russian olive
C/RO III = Moderate aged cottonwood/Russian olive with dense shrub understory
C/RO IV = Moderate aged cottonwood/Russian olive with sparse understory
DR V = Dense, shrubby vegetation along margins of riverside drains
DR VI = Sparse herbaceous or low, shrubby vegetation along margins of drain
E = Edge
MH V = Cattail Marsh

Table, 18, continued.

MH VI	=	Saltgrass/wet meadow
MS V(MH)	=	Marsh, with low vegetation
OP VI (C/CW)	=	Open areas near cottonwood/coyote willow stands
OP V (C/CW)	=	Open areas near cottonwood/coyote willow stands
RO V	=	Young to intermediate aged Russian olive
RO VI	=	Low, sparse Russian olive under 1.5 m (5 ft)
RV	=	River channel
SB VI	=	River sandbars, either barren or with sparse, low vegetation
SB VI 4	=	Sandbars
SC V	=	Moderately young, dense salt cedar
SC VI	=	Very young, low, sparse salt cedar
SC VI A	=	Very young, low, sparse salt cedar with false indigo bush
SCE VI	=	Edge of young, low, sparse salt cedar
WET E V	=	Edge of wet open area with low vegetation

Table 19. Summary of relation of small mammal abundance and species diversity to vegetation composition and structure (Hink and Ohmart 1984).

Highest densities of rodents were found in the following situations:

- areas of dense herbaceous and shrubby vegetation, with little canopy
- the younger successional stages
- edges of riparian forests with understory near water
- areas adjacent to drains, ponds, and wetlands
- dense "impenetrable" growth of shrubs, especially coyote willow
- moist areas with heavy growth of grasses and annuals
- wetter years—higher water table—more herbaceous growth—more seeds
- areas near flooding where small mammals were concentrated on higher ground

Highest numbers of rodent species were associated with the following situations:

- in salt cedar stands adjacent to upland habitats with addition of six heteromyids
- in wet meadows, marshes, and along drains
- on edge of mature and intermediate aged cottonwood forests
- in young successional stage cottonwood/willow and Russian olive stands

Lowest densities of rodent populations were found in the following situations:

- dry areas with relatively sparse shrub and herbaceous vegetation
- cottonwood forests with major part of foliage in upper canopy

Lowest numbers of rodent species were found in the following situations:

- mature cottonwood-Russian olive and cottonwood-juniper with sparse understory

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Optimum forage for beaver is cottonwood, willow, and herbaceous vegetation. Russian olive and elm are considered to have moderate forage value. Beavers prefer younger stands that have about 50% canopy closure. Dense stands of larger trees and shrubs are of low value due to an inability of beavers to fell and obtain trees in dense situations (Allen 1983).

The effects of beaver activity are widespread and controversial. Beavers can create and maintain wetlands; however, beaver dams impact the operation of irrigation ditches and drains. Beavers can severely impact stands of regenerating willows and cottonwood-willow revegetation projects (Ohmart et al. 1988, Swenson 1992). Depredation is occurring to all age classes of cottonwoods from saplings to mature trees within the Rio Grande Valley State Park (Campbell 1990). Reduction of cottonwood habitat is thought to affect the equilibrium between beaver and forage vegetation thereby exacerbating the effects of other impacts on cottonwood and willow (Rood and Mahoney 1991). Management of beavers is usually the responsibility of the NMDGF. Swenson (1992) recommended that beaver control be required to maintain optimum habitat quality in the Oxbow Wetlands Area.

Muskrats occur throughout the Middle Rio Grande wherever permanent water is present. They are most common along ditches, quiet backwaters, and other waters bordered by abundant emergent vegetation.

Raccoons are a highly successful abundant omnivore throughout Middle Rio Grande riparian habitats most frequently found along the water's edge. Russian olive fruit appears to be an important food; snags and fallen logs, important habitat components, are used for shelter (Campbell 1990).

Several species of carnivores occur throughout the bosque, including coyote (*Canis latrans*), gray fox (*Urocyon cinereoargenteus*), bobcat (*Lynx rufus*), striped skunk (*Mephitis mephitis*), and long-tailed weasel (*Mustela frenata*). Hink and Ohmart (1984) presented anecdotal evidence that while most of these species have population levels and distributions similar to those of the 1930's, bobcats are apparently increasing for unknown reasons. Although these species are also associated with a wide range of upland habitats, they probably are more numerous in riparian areas due to the abundance of prey species, especially rodents. Coyotes and foxes often eat small mammals and birds, as well as Russian olive and mesquite fruits. Feral and domestic dogs and cats are common in local areas in the bosque. Dog packs are known to kill wildlife, especially beaver, as well as domestic livestock (Campbell 1990).

Several other species of larger mammals without any strong habitat association are regularly found in the bosque as documented by Hink and Ohmart (1984) and Morrison (1988). These include desert cottontail (*Sylvilagus auduboni*), rock squirrel (*Spermophilus variegatus*), porcupine (*Erethizon dorsatum*), and occasionally black-tailed jackrabbit (*Lepus californicus*). Some uncommon upland species of limited distribution in the bosque include Gunnison prairie dog (*Cynomys gunnisoni*), spotted ground squirrel (*Spermophilus spilosoma*), badger (*Taxidea taxus*), and black bear (*Ursus americanus*). There have been recent sightings of mountain lion (*Felis concolor*) and elk (*Cervus canadensis*) at Bosque del Apache NWR.

Resident mule deer (*Odocoileus hemionus*) are often found in riparian corridors adjacent to desert or grassland habitats. Mule deer densities probably declined in the bosque following European settlement due to more efficient hunting methods in this relatively restricted environment. Today, there are resident populations in the isolated, large, protected areas of La Joya and Bernardo State wildlife areas, Bosque del Apache NWR, and areas between Bosque del Apache and the head of Elephant Butte Reservoir. The deer favor meadow openings and prefer browse vegetation such as screwbean mesquite. They are especially attracted to the large acreages of corn planted at the wildlife areas. Fawning occurs in dense stands of understory vegetation adjacent to meadows, marshes, and other openings.

Livestock including cattle, sheep, goats, horses, donkeys, and mules forage on trees, shrubs, grasses, and forbs in the Middle Rio Grande floodplain (M.K. Wood, pers. comm.). Areas providing forage include native riparian habitats, improved pastures, and croplands. They are used for work, pleasure, food, by-products such as leather, and sale by people in all the cultures found along the Rio Grande. Livestock have beneficial and/or detrimental effects on the plant, soil, water, and wildlife resources depending on the management techniques (Kauffman and Krueger 1984, Campsey 1991).

Birds

General.—Riparian vegetation occurs on less than 1% of the western North American landscape, yet it provides habitats for more species of birds than all other vegetation types combined (Knopf et al. 1988). It is important not only to breeding birds but to winter residents and migrants as well and acts to concentrate birds. In the Southwest, riparian studies have shown that high values of four vegetation variables—foliage density; patchiness; foliage height diversity; and numbers of cottonwood trees, willow trees, or both—were best predictors of high habitat use by birds.

As discussed, Hink and Ohmart (1984) classified the plant communities that collectively make up the riparian and riverine habitats and recorded animal species occurrence and densities for each community type. The 257 km (160 mi) long study area from Española to San Acacia was divided into an intensively sampled reach extending from Bernalillo to Bosque Bridge and a less frequently sampled general study area that made up the remainder. Much of the following discussion of birds and their habitat associations is taken from this study. Other studies include those from Rio Grande Valley State Park (Hoffman 1990), Elephant Butte and Caballo reservoirs (Raitt et al. 1981), and Bosque del Apache NWR (Ellis et al. 1993, Farley et al. 1993, Stuart et 1993).

Hink and Ohmart (1984) stated that in their 2-year biological survey of riparian habitats of the Rio Grande, birds were the largest and most diverse group among the terrestrial vertebrate fauna occurring in the riparian zone and adjacent agricultural area. The total number of species recorded was 277, which is over 60% of the total number of species known to occur in New Mexico. In addition, 85 to 95 of the normally occurring bird species probably bred in the valley. Most of these species were primarily associated with riparian forest or shrub habitat.

In addition to being rich in numbers of species, the riparian habitat of the valley supports high densities of birds. Estimated densities of 300 to 600 birds per 100 acres were about average for cottonwood habitats in the Bernalillo to Bosque Bridge (located about 13 km [8 mi] south of Belen) reach of the valley, but densities of over 1,000 birds per 100 acres were estimated for certain habitats in certain seasons.

Population Densities.—Both the plant species that comprise a particular community and the structure of the community are prime determinants in the densities and numbers of bird species that use these habitats. Presented in Table 20 is a comparison of total avian density and species numbers in the major habitat types in the Hink and Ohmart (1984) intensive study area. Table 21 provides avian densities and species numbers in the general study area.

Of the seven high avian density habitat types (Table 20), all were densely vegetated, especially in the lower vegetation layers, and six of the seven were edges. This presence of a substantial understory of shrub vegetation characterizes the I, III, and V structure types. The habitat types with low bird densities, except for cottonwood/coyote willow I, had relatively little vegetation cover. Avian densities in the general study area (Table 21) were in the same range as those observed in the intensive study area and the habitat types in the high end of the range were also densely vegetated. Avian density was significantly correlated with dense foliage volume during spring, summer, and fall, but not in winter.

Density of birds was associated with the species composition of the plant community types. Cottonwood with a Russian olive understory and marsh habitats had the highest densities of birds throughout most of the year in the general area of the Hink and Ohmart (1984) study. Ellis et al. (1993), in a survey of avian use of mixed cottonwood woodland and dense homogeneous salt cedar on Bosque del Apache NWR, found, however, that there were higher numbers of individuals in salt cedar than in cottonwood in winter, and slightly more in fall.

Raitt et al. (1981), in a study of bird populations in relation to six riparian habitat types in Elephant Butte and Caballo reservoirs, found that cottonwoods and open floodplain parkland supported the highest breeding bird densities, closely followed by young salt cedar. In all other seasons young salt cedar was consistently the most densely inhabited followed by mature salt cedar.

Stuart et al. (1993) found the highest densities of birds in 5-year old revegetated cottonwood sites at Bosque del Apache NWR in fall and winter, reflecting an influx of both granivores and insectivores.

Number of Species.—Species numbers in the intensive study area surveyed by Hink and Ohmart (1984) ranged from seven or eight per habitat type per season to as many as 55 (Table 20). The highest number of species was observed in drain VI in spring, and drain VI and cottonwood/coyote willow edge I in fall. However, the number of species present among the various cottonwood-dominated habitat types was quite similar, usually averaging between 30 and 50, and these species overlapped substantially among habitat types. Within a particular season, cottonwood habitat types differed more in density of birds than in numbers of species. In general, those habitat types having the greatest total densities of birds also had the highest number

Table 20. Comparison of total avian density and numbers of species in major intensive study area community-structure types from Hink and Ohmart (1984). Data for 1981 and 1982 were averaged to yield one density and one species number value for each season. All densities are expressed as the number of birds per 100 acres (40.5 ha). Number of species is expressed in densities ≥0.5 per 100 acres. See Table 18 for the key to community-structure types.

	Spring		Summer		Fall		Winter	
C-S Type	Density	Number of Species	Density	Number of Species	Density	Number of Species	Density	Number of Species
High Density >500								
C/RO E I	1,086	47	971	47	1,115	49	2,159*	25
MH V	1,327†	20†	972†	11†	1,092	17	793*	12
C/CW E V	726	40	623	29	821	32	1,209*	22
C/CW E III	871	33	535	30	670	38	1,166*	17
RO V	673†	49†	528	42	676	46	1,133*	29
C/CW E I	550	49	511	43	829	55	933	25
DR V	417	41	558	38	811	48	617	28
Medium Density 200-450								
DR VI	366	51	258	43	427	50	924	41
C/CW VI	202	34	265	36	603	41	505	22
C/RO II	382	36	439	32	227	29	148	16
C/CW V	236	36	345	31	308	42	283*	20
C/RO I	323	33	341	27	187	27	373*	17
C/CW E IV	332	19	346	15	340†	24†	109 *†	5†
Low Density <200								
RO VI	130	8	199*	21*	159	14	453*	8
C/CW I	152	36	186	28	243	37	114	16
C/CW IV	106	24	205	26	112	24	161	15
SV VI	52	15	98	18	112	18	273*	15
RV	100	14	47	7	51	7	167*	9

* Marked difference between 1981 and 1982

† Includes data from only 1 year

Table 21. Comparison of total avian density and numbers of species in major general study area community-structure types from Hink and Ohmart (1984). Data for 1981 and 1982 were averaged. Densities are expressed as the number of birds per 100 acres (40.5 ha). Number of species is expressed in densities ≥0.5 per 100 acres. See Table 18 for key to community-structure types.

	Spring		Summer		Fall		Winter		
C-S Type	Density	Number of Species	Density	Number of Species	Density	Number of Species	Density	Number of Species	Number of Transects
				High Density >500					
C/RO E II	1,250	13	656*	12*	1,077	15	677	8	1
MS V (MH)†	838	13	808‡	11	558‡	8	767‡	6	1
C/CW E I	624	20	532	16	699	21	288‡	6	2
RO V	117	11	477‡	13	1,068	13	1,820‡	12	1
				Medium Density 200-450					
C/RO I	258	19	329*	35*	226‡	15	301	12	2
DR V	178	26	176	23	346	23	1,601	24	2
SC E VI†	141	8	374‡	8	478‡	10	995‡	8	1
C/J I†	207	15	214	15	250‡	14	375	14	2
C/J IV†	255	16	219	15	166	14	284	11	2
C/CW V†	238	14	297	12	188‡	9	35	2	1
				Low Density <200					
C/RO IV†	129	12	172‡	13	149‡	11	235	9	2
SC VI	68	21	85	19	223‡	18	36	8	8
SC V†	33	10	142	11	108	9	155‡	7	2
SC VI A†	112	9	120	8	85	7	92	2	2
C/CW I	64	7	159	8	100‡	8	15	2	1
C/CW II	111	9	105	7	37	7	9	1	1

* Includes data from only 1 year.
† C-S type censused only in general study area.
‡ Marked difference between 1981 and 1982

of species. The notable exception to this pattern of high densities being associated with high numbers of species was marsh V where a relatively small number of species typically occurred in very high densities; e.g., red-winged blackbirds (*Agelaius phoeniceus*) occurred in densities up to 10 times as great as the next most common species in marsh V. In contrast to bird population densities, the number of bird species was not significantly correlated with foliage volume during any season. However, Farley et al. (1993) found that the number of bird species increased during fall migration in those habitats with denser vegetation as migrant insectivores moved down the valley.

At Bosque del Apache NWR, Ellis et al. (1993) observed that the total number of species was higher in cottonwood than in salt cedar during all seasons. The highest numbers of species for both habitats were detected in fall, followed by spring, summer, and winter. Relative differences in numbers of species were similar to those observed by Raitt et al. (1981). Ellis et al. (1993) also found cottonwood to have a higher diversity of foraging groups than salt cedar.

Hink and Ohmart (1984) found that salt cedar habitats had very low species numbers. Hoffman (1990) also observed that salt cedar, and especially Siberian elm, had limited habitat value for birds inhabiting the riparian zone in the Rio Grande Valley State Park.

Raitt et al. (1981) observed that during the breeding season the habitats dominated by native trees were consistently higher in number of species than in salt cedar habitats. Also, the diversity of foraging groups was higher in cottonwoods. In all the other three seasons the open floodplain parkland had the highest number of species, closely followed by cottonwood. Again, the diversity of foraging groups was highest in cottonwood and open parkland and lowest in salt cedar communities. Farley et al. (1993) noted that the diversity of foraging groups increases with the age of the cottonwood stand.

Hoffman (1990) found that wetlands and canopied, old-growth cottonwood forest are the most valuable habitat for birds. Hoffman also observed that the width of riparian vegetation appears to be an important habitat feature affecting abundance and diversity and that widths exceeding 122 m (400 ft) appear to be especially valuable habitat for birds and other animals.

Species Composition and Habitat Association.—Cottonwood-dominated community types were found by all investigators to support greater numbers of bird species than nonnative dominated or monotypic stands of introduced species. During the breeding season in some areas, the density of birds was also higher in general in the cottonwood-dominated plant communities than in the monotypic stands of salt cedar.

Habitat types that were associated with the riverside drains and river channel attracted a unique set of species. American robins and red-winged blackbirds were among the most common species along the drains in spring and summer. Mallards (*Anas platyrhynchos*), belted kingfishers (*Ceryle alcyon*), and black phoebes (*Sayornis nigricans*) were also recorded along drains regularly. Species encountered on drains and sandbar/river channel sample sites in spring and summer included spotted sandpipers (*Actitis macularia*), killdeer (*Charadrius vociferus*), and black-crowned night-herons (*Nycticorax nycticoras*), snowy egrets (*Egretta thula*), great blue herons (*Ardea herodias*), and green-backed herons (*Butorides striatus*).

Drain and sandbar/river channel habitats in fall and winter again were characterized by a distinctive complement of species. These included great blue herons and a variety of ducks, the most common of which were mallards, cinnamon teal (*Anas cyanoptera*), American wigeons (*A. americana*), gadwall (*A. strepera*), and northern shovelers (*A clypeata*). The numbers of mallards and great blue herons in these habitats were greater in winter than in summer. American pipits (*Anthus rubescens*) and mountain bluebirds (*Sialia currucoides*) were observed using sandbars, and common snipe (*Gallinago gallinago*) and marsh wrens (*Cistothorus palustris*) occurred along the drains.

Nearly all the bird species that occurred in the intensive study area were also found in one or both parts of the general study area. Patterns of habitat use by both resident and migrant species in the intensive study area also applied to corresponding habitat types in the general study area, and avian use of cottonwood/juniper was comparable to use of cottonwood/Russian olive stands of similar structure. Salt cedar types, however, were distinct in terms of avian habitat.

The salt cedar habitat types were used by a distinct assemblage of summer resident species. Besides the ubiquitous mourning doves and blue grosbeaks, the most common species in salt cedar in summer were northern mockingbirds (*Mimus polyglottos*), lark sparrows (*Chondestes grammacus*), western meadowlarks (*Sturnella neglecta*), and black-throated sparrows (*Amphispiza bilineata*). The latter four common salt cedar community species rarely if ever occurred in other riparian habitats.

In winter, salt cedar habitat types supported much the same avian community as the other forest and woodland habitat types in the study area. White-crowned sparrows, dark-eyed juncos, American robins, and northern flickers were the most common species. The principal difference between salt cedar and non-salt cedar habitats in winter was the greater abundance of western meadowlarks in salt cedar.

Raitt et al. (1981) observed a group of four species—common yellowthroats, yellow-breasted chats, brown-headed cowbirds, and rufous-sided towhees—showing a significant preference for dense salt cedar habitats in the breeding season with blue grosbeaks preferring young salt cedar. Another group of four species—mourning doves, ash-throated flycatchers, Lucy's warblers, and summer tanagers—showed a marked preference for native vegetation.

Habitat Specialists, Generalists, and Value.—The value of a given riparian habitat varies from species to species and seasonally for the same species (Anderson and Ohmart 1976). Hink and Ohmart (1984) analyzed 62 selected species to determine preference of individual species for a particular habitat or habitat types, the degree to which particular species are strongly tied to one or two habitats or have their population density more evenly distributed across a range of habitats, and the value of particular habitat types to the community as a whole.

Thirteen permanent and summer resident species had very limited distribution among community types in the summer, including nine that were strongly associated with water or wet communities: pied-billed grebes (*Podilymbus podiceps*), Virginia rails (*Rallus limicola*), soras (*Porzana carolina*), American coots (*Fulica americana*), and yellow-headed blackbirds (*Xanthocephalus xanthocephalus*) were largely restricted to marsh; snowy egrets, killdeer, and spotted sandpipers occurred primarily in sandbar/river channel; and black phoebes were found only in drains. The other four species of limited distribution were forest birds: great horned owls (*Bubo virginianus*), hairy woodpeckers, and mountain chickadees (*Parus gambeli*) occurred primarily in cottonwood/Russian olive, whereas Lewis' woodpeckers (*Melanerpes lewis*) were found only in cottonwood/coyote willow.

Five species—black-headed grosbeaks, blue grosbeaks, black-chinned hummingbirds, gray catbirds, and yellow warblers—were habitat generalists. These were all primarily forest birds, but they occurred almost as often in drain and Russian olive as in the two cottonwood communities. Only black-chinned hummingbirds and mourning doves occurred in all six communities.

Four of the six communities, cottonwood/Russian olive, cottonwood/coyote willow, Russian olive, and drain, were used by large numbers of species during the summer, whereas the other two, marsh and sandbar/river channel, were used by relatively few species. In addition to being used by large numbers of bird species, cottonwood/Russian olive and cottonwood/coyote willow were also preferred habitat (as defined as use by a significant percentage of the species population density) for a large proportion of those species. A significant number of breeding species showed preference for one or both of these communities, illustrating the importance of the riparian cottonwood forest to the breeding bird community in the Middle Rio Grande. Cottonwood/Russian olive was preferred by the greatest number of species and almost half of those showing preference showed strong preference. About half of the species using cottonwood/coyote willow showed preference for that community.

Most of the cavity-nesting species (American kestrels, hairy woodpeckers, northern flickers, black-capped and mountain chickadees, white-breasted nuthatches) preferred cottonwood/Russian olive over cottonwood/coyote willow, as did the flycatchers (western wood-pewees, western kingbirds [*Tyrannus verticalis*] and ash-throated flycatchers) and gray catbirds, summer tanagers (*Piranga rubra*), rufous-sided towhees, lesser goldfinches, and mourning doves. The strong association of cavity nesters with cottonwood/Russian olive may be related to the concentration of larger, more mature trees in the community, providing potential nest cavities rather than to the understory component. Gray catbirds and rufous-sided towhees were often found in areas characterized by dense growth of Russian olive, and both occurred in Russian olive communities in relatively high proportions as well as in cottonwood/Russian olive. Summer tanagers occurred in association with mature cottonwood stands. Mourning doves often nested in high densities in Russian olive thickets under a forest canopy in the Middle Rio Grande. Freehling (1982) also observed the correlation of dense Russian olive understory with high densities of nesting mourning doves.

Drain and Russian olive communities, although they were used by about as many species as the two cottonwood communities, were preferred habitat for very few. Green-backed herons and black-crowned night-herons showed preference for drains, and belted kingfishers and black phoebes both showed strong preference for drains. However, most species occurring in drains were more common in other communities. While the Russian olive community is distinct in terms of vegetation structure and species composition, it does not attract a distinct complement of bird species. The bird species occurring in Russian olive were the same as those occurring in cottonwood forest. When Russian olive occurs in association with cottonwood (i.e., cottonwood/Russian olive communities), however, it apparently contributes to the attractiveness of that community to many species of birds. Freehling (1982) observed that Russian olive fruits are extremely important as a winter food supply for most riparian birds.

Marsh and sandbar/river channels were used by far fewer bird species than the other four communities, but of the species that did use the marsh and sandbar/river channel communities, a high proportion (over one-third), showed strong preferences for them. Pied-billed grebes, Virginia rails, soras, and yellow-headed blackbirds occurred only in marsh. Common yellowthroats, American coots, and red-winged blackbirds were more common in marsh than in any other community, the former showing preference and the latter two showing strong preference. Black-crowned night-herons, snowy egrets, mallards, killdeer, and spotted sandpipers showed strong preference for sandbar/river channel, and belted kingfishers, although most common along drains, also show a preference for sandbar/river channel. The degree to which most of those species were tied to these communities indicates that they contribute a unique component to the overall species richness of the Middle Rio Grande avian summer resident community. Marshes enrich the local fauna by attracting many species of birds that are otherwise uncommon in the arid Southwest.

There was little change in habitat use at the community type level from summer to winter among permanent residents, and species population distribution among habitat types for selected species was similar during summer and winter. The few shifts in habitat use that did occur did not involve changes in preferred habitat, except possibly for the hairy woodpecker.

Patterns of community use by wintering bird species were similar to those observed in summer with one notable exception. Whereas cottonwood/Russian olive was preferred over cottonwood/coyote willow by a large proportion of the summer bird community, cottonwood/Russian olive and cottonwood/coyote willow were used more equally during winter. The two cottonwood forest communities were used by about the same number of species during winter, and in both communities about half the species showed preference. Cottonwood/Russian olive was distinguished by having a greater number of species exhibiting strong preference for that community, but this was still a lower proportion of the total than in summer. Cottonwood/Russian olive was apparently a preferred breeding season habitat for many of the summer resident species, but the wintering species did not exhibit as great a preference for cottonwood/Russian olive. Use of cottonwood/coyote willow, on the other hand, was nearly the same during both summer and winter.

Russian olive and especially drains, were more heavily used during winter than summer. Two of the winter residents showed strong preference for Russian olive: cedar waxwings and white-throated sparrows (*Zonotrichia albicollis*). The drains supported great blue herons and common snipe in winter showing preference and strong preference, respectively, for this community type. In addition, large numbers of song sparrows and white-crowned sparrows used the margins of drains in winter. American goldfinches were also found most commonly along drains and showed a preference for drain habitat.

Marsh and sandbar/river communities, as in summer, were used by fewer species than the previous four communities, but the proportion of species strongly tied to these communities remained high. Marshes, in particular, were strongly preferred by a high proportion of species in winter. Of the 16 species using marsh in winter, seven showed strong preference; in addition to the four permanent resident marsh species, marsh wrens, song sparrows, and swamp sparrows

(*Melospiza georgiana*) also occurred in highest concentrations in marsh. The sandbar/river community was strongly preferred by water pipits and by a large variety of waterfowl.

Seasonal changes in habitat use by the Middle Rio Grande avian community were subtle, more a matter of degree than of marked shifts in species-habitat associations. The overall pattern was similar throughout the year, with a high proportion of the avian community being associated with or showing preference for one or both of the cottonwood forest communities, and a smaller, more habitat-specific group associated with marsh or riverine habitats. The two most regularly disturbed communities, drains and Russian olive stands, were used by large number of species but were preferred habitat for very few. The main difference in habitat use between summer and winter avian communities was the greater preference among the summer (breeding) species for cottonwood/Russian olive.

Hoffman (1990) found that wetlands and canopied, old-growth cottonwood forest are the most valuable habitat for birds. Hoffman also observed that the width of riparian vegetation zones appears to be an important habitat feature affecting abundance and diversity and that widths exceeding 122 m (400 ft) appear to be especially valuable habitat for birds and other animals.

Raptors and Large Birds.—Sixty-two species of raptors and large birds were detected by Hink and Ohmart (1984) along levee census routes. This number is greater when additional species present at bordering Bernardo and La Joya waterfowl areas (Baltosser 1991) and especially Bosque del Apache NWR are added. Raptors and large birds exhibited significant differences in seasonal species composition. Fifteen of these species were raptors, most of which occurred in low numbers. The greatest numbers of raptor species were present during fall and winter because many species migrate through or winter in the valley. The smallest numbers were present in summer. Red-tailed hawks (*Buteo jamaicensis*) and American kestrels were the commonly observed species.

Six species, northern harriers (*Circus cyaneus*), sharp-shinned hawks (*Accipiter striatus*), red-tailed hawks, ferruginous hawks (*Buteo regalis*), rough-legged hawks (*B. lagopus*), and bald eagles (*Haliaeetus leucocephalus*), occurred primarily in fall and winter, whereas five species, turkey vultures (*Cathartes aura*), ospreys (*Pandion haliaetus*), Mississippi kites (*Ictinia mississippiensis*), American kestrels, and prairie falcons (*Falco mexicanus*), were present primarily during summer. Cooper hawks (*Accipiter cooperii*) were detected about equally during all four seasons. The remaining raptor species occurred in the valley during migration, sometimes being observed between June and August as late spring or early fall migrants.

The large birds consisted of herons and egrets, waterfowl, cranes, shorebirds and ibis, ring-necked pheasant, greater roadrunner, belted kingfisher, and miscellaneous species such as grebes, cormorants, gulls, and rails. The large population of sandhill cranes (*Grus canadensis*) and Canada geese (*Branta canadensis*) in winter accounted for a sizeable part of the high counts of large birds.

Census routes (per 16 km [10 mi]) having high numbers of raptors also tended to have high numbers of herons, ducks, and other species, and the number of species observed was correlated with the number of observations per 16 km (10 mi); i.e., greater observation numbers yield higher numbers of species. Also, the census routes least affected by urbanization had the highest numbers and species of raptors and large birds, and their numbers increased with increasing distance from Albuquerque, the major urban center.

Bald eagles have become common winter residents in many locations in the middle valley, particularly in the Albuquerque to Cochiti Dam reach of the Rio Grande and in the vicinity of Bosque del Apache NWR. The increased presence of bald eagles from Cochiti Dam south to Albuquerque is likely due to an increasing population of bald eagles and increased prey availability resulting from the creation of Cochiti Lake and its downstream effects on the Rio Grande. The combined presence of Cochiti Lake and Jemez Canyon Reservoir has also increased the presence and numbers of birds associated with aquatic or semiaquatic habitats in the upper reaches of the middle valley. Increased numbers of bald eagles at Bosque del Apache NWR are due to increased numbers of snow geese as prey.

Large numbers of sandhill cranes, with a small number of whooping cranes (*Grus americana*), winter in the middle valley from October and through February. Principal areas are south of Albuquerque with large concentrations in the general vicinity of Belen and Casa Colorada waterfowl areas and Bosque del Apache NWR. Most feeding occurs in agricultural fields and night roosting on river sandbars.

Fifteen species of ducks were recorded with the most abundant species being mallards, green-winged teal, blue-winged teal, cinnamon teal, and American widgeon. Only mallards, cinnamon teal, and possibly blue-winged teal bred in the valley. The two common species of geese using the valley—the snow goose (*Chen caerulescens*) and Canada goose (*Branta canadensis*)—were present only during the winter. Since Hink and Ohmart's study the number of waterfowl in the valley has apparently increased, including more summer residents and a small number of geese.

Of the eight species of shore birds detected, six occurred only during migration. Killdeer were present throughout the year, and spotted sandpipers were summer residents. Of the wading birds, six species of herons and egrets were detected on census routes. Of these six, only great blue herons were normally present during winter. Snowy egrets, black-crowned night-herons, and green-backed herons were most numerous during summer and bred in the study area. Flocks of white-faced ibises (*Pelagadis chihi*) were observed during spring and fall migration. Sandbars are important to shorebirds for roosting and foraging especially during migration.

American coots, pied-billed grebes, and belted kingfishers were present throughout the year along drains. Ring-necked pheasants and greater roadrunners, commonly seen on levee roads, were also present year-round.

Recent Changes.—Changes in bird species composition and number are inherent in most ecosystems. These changes can be a result of many factors (e.g., climate and human influence) occurring locally, regionally, or even globally. Also, they may occur over a period of a few years or over an extended period of time. Recent examples in addition to those already discussed include the invasion of the middle valley by European starlings (*Sturnus vulgaris*), indigo buntings (*Passerina cyahea*), and common and great-tailed grackles (*Quiscalus quiscula* and *Q mexicana*); expansion in the range and/or numbers of white-winged doves (*Zenaida asiatica*), downy woodpeckers (*Picoides pubescens*), American crows (*Corvus brachyrhynchos*), and black-capped and mountain chickadees; declines in red-headed woodpeckers (*Melanerpes erythrocephalus*) and eastern kingbirds (*Tyrannus tyrannus*); and expansion/decline in Mississippi kites (*Ictinia mississippiensis*; J.P. Hubbard, in litt.).

Summary of Bird Data.—In addition to being used by large numbers of bird species, cottonwood-dominated community types were also preferred habitat for a large proportion of these species. This was especially true during the breeding season. Bird densities appeared to be strongly related to density of foliage, regardless of species composition of the plant community type. For some seasons, bird densities were higher in stands of nonnative trees and shrubs. Marshes, drains, and areas of open water contributed to the diversity of the riparian ecosystem as a whole because of the strong attraction these areas have for water-loving birds. At various times of the year, these areas supported the highest bird densities and species numbers in the study area.

Invertebrates

Except where indicated, the following review is based on many personal observations by M.C. Molles and C.S. Crawford. The review emphasizes arthropods, which are the main contributors to the biodiversity of the Middle Rio Grande riparian zone, and focuses on communities of invertebrates in well-defined habitats.

Forest Trees.—Recent studies using standard yellow sticky traps hung from trees at the Rio Grande Nature Center and Bosque del Apache NWR suggested that aerial/arboreal arthropods (mainly insects) are more abundant in cottonwood canopies than in either Russian olive or salt cedar canopies (Molles and Crawford 1992, Ellis et al. 1993). If this is true, and if cottonwood regeneration relies mainly on overbank flooding which now seldom occurs, then eventual domination of the northern and southern Middle Rio Grande bosque by Russian olive and salt cedar, respectively, will decrease the biomass of canopy arthropods available to birds. Such a decrease could be significant because insects and other arthropods have much higher protein contents than plants (Mattson 1980).

Many different types of arthropods, in particular sucking and chewing insects and spiders, occur in bosque tree canopies. Among the most obvious of these, between early June and mid-October, is a widespread species of floodplain cicada, *Tibicen marginalis* (Homoptera: Cicadidae). The loud chorusing of male cicadas is heard nearly every day during that period, especially right after sunset (Crawford and Dadone 1979). Many birds feed on these large, abundant insects. Much smaller and in higher densities, leafhoppers and aphids (also homopteran insects) pierce the leaves of cottonwood, willows, and other bosque trees and ingest their carbohydrate-rich fluids. Larvae and adults of the widespread elm leaf beetle, *Pyrrhalta luteola* (Coleoptera: Chrysomelidae), in contrast, chew and often decimate the leaves of introduced Siberian elms. Flattened larvae of tiny flies, wasps, and moths chew characteristic tunnels in the leaves of the bosque's woody vegetation.

Caterpillars of the fruit-tree leafroller moth, *Archips argyrospilus* (Lepidoptera: Tortricdae), a common pest of orchard crops, tie and eat leaves of cottonwood, willows, Russian olive, salt cedar, false indigo, and white clover. This insect, together with larvae of a more cottonwood-specific leafroller, *Anacampsis innocuella* (Lepidoptera: Gelechiidae), caused the premature drop of a about 9% of the leaves in each of eight cottonwoods at the Rio Grande Nature Center during 1992 (T-H. Yong, pers. comm.).

Surfaces other than leaves are also used by arthropods, which are in turn encountered by gleaning birds. Twigs and small branches, for example, are microsites for the deposition of moth (Lepidoptera) and katydid (Orthoptera: Tettigoniidae) eggs, while crevices in bark are used by tiny predaceous pseudoscorpions (Arachnida: Pseudoscorpionida). Beneath the bark, beetle (Coleoptera) larvae tunnel as they consume cambium and wood. Deeper in the wood of cottonwoods are larvae of several kinds of boring beetles and large horntail wasps (Hymenoptera: Siricidae). Woodpeckers hunt these insects.

Tree trunks provide conduits for ants (Hymenoptera: Formicidae) that nest on the ground and forage in the canopy, where they harvest high-protein arthropod prey as well as sugar-rich honeydew secreted by aphids. Of all the insect groups in the bosque, the many species of ants are likely to move the most nutrients—and soil. That evaluation is consistent with their recognized role in most terrestrial environments (Höldobler and Wilson 1990).

Canopies that overhang water in the bosque have a different association with aerial arthropods than do canopies in the forest. This was documented at a small seep (ground-water drain) at the Nature Center. Sticky traps (each 13 × 18 cm [5 × 7 inches]), hung from Russian olive branches extending over the water, caught up to 800 midges (Diptera: Chironomidae) per card in 48 hours during the winter, when there was very little insect activity in forest trees. Insect numbers in the two places equalized in the warmer months.

Cottonwood provides a special resource for arthropods that is not found in Russian olive (but is present in Siberian elm), namely sap fluxes at wound sites. In wet years especially, sap collects in pockets where branches have broken off from main stems. Bacteria quickly colonize the oozing fluid, and are in turn consumed by the larvae of small flies (Diptera) which then become potential food for other animals.

Forest Understory.—Information on invertebrates inhabiting the woody and herbaceous understory of the bosque is very limited. Leaves of woody species such as coyote willow and false indigo are consumed—sometimes to the point of causing serious damage—by the same widespread leaf-tying caterpillar that eats the leaves of the major trees (T-H. Yong, pers. comm.). White clover and other legumes such as the introduced red bladderpod (*Sphaerophysa salsula*) and native loco weed (*Astragulus* spp.) are important ground cover in relatively wet years. These nitrogen fixers serve the nutritional needs of many insects, including species of often abundant grasshoppers, as do common composites such as goldenrod (*Solidago* sp.), horseweed (*Conyza canadensis*), and asters (*Aster*, *Macheranthera*), as well as other plants such as western tansy mustard (*Descurainia pinnata*). Birds and spiders are probably the main predators of these insects. Ants tend aphids (Homoptera: Aphididae) and related species on the understory plants.

Open Area Vegetation.—Four-wing saltbush (*Atriplex canescens*) and sand sage (*Artemisia filifolia*) are fairly common woody shrubs in bosque open spaces. Many insects and spiders use them for food and shelter. Patches of purple sage (*Dalea scoparia*) sometimes occur in sandy soils; when in bloom they attract many native, ground-nesting bees (Crawford 1981) as well as introduced honeybees. Snakeweed (*Gutierrezia sarothrae*), a subshrub promoted by disturbance, is widespread here even beneath sparse stands of cottonwood; it is a resource for many kinds of arthropods (Foster et al. 1981). Flowering Rocky Mountain bee plants (*Cleome serrulata*) and groundsel (*Senecio multicapitatus*) attract a diversity of pollinator moths and bees, in addition to many herbivorous insects. Other common herbs used extensively by arthropods in bosque openings are globe mallow (*Sphaeralcea* spp.), hidden flower (*Cryptantha* spp.), and several mustards (family Cruciferae).

Patches of Indian ricegrass (*Oryzopsis hymenoides*) and several species of dropseed grasses (*Sporobolus* spp.) tend to occur separately from patches of snakeweed in these places. The grass fauna is similar to, but does not completely overlap, that of snakeweed. Tiny leaf-rasping thrips (Insecta: Thysanoptera) and somewhat larger leafhoppers are extremely common in both patch types, as are spiders, ants, and grasshoppers.

Forest Floor.—This is the bosque habitat about which most is known when it comes to arthropods. Spiders, ants, beetles, and isopods (Crustacea: Isopoda) are its characteristic groups, which is similar to litter of other temperate forests (Wallwork 1976). All spiders and many beetles here are carnivores; other beetles are omnivorous detritivores, many being specialists on fungi. An assortment of ants, which collectively have broad diets, can be found almost anywhere on the forest floor, except in winter. All these arthropods form assemblages that vary, in any given location, with the dominant tree species at that location.

Introduced crustacean isopods are surely the most abundant macrodetritivores on the forest floor. Two species of European origin are widespread in the Middle Rio Grande riparian zone. One, a pillbug (*Armadillidium vulgare*), develops more successfully on Russian olive leaf litter than on cottonwood leaf litter—at least in the laboratory (F. Heinzelmann, pers. comm.). Great numbers of both species (the other is the woodlouse, *Porcellio laevis*) are found in deep leaf litter and beneath logs during the colder months. They coexist in some parts of the bosque but not in others.

An unexpected relationship between the isopods and colonies of the most common harvester ant (*Pogonomyrmex occidentalis*) in the bosque was recently discovered (F. Heinzelmann, pers. comm.). These large red ants construct conspicuous mounds and surround them with zones cleared of vegetation. As abundant and wide-ranging seed harvesters, they impact seed germination in the forest and open areas alike although their actual effects in the bosque have not been documented. They also impact isopods, which they sting and then harvest like seeds as they carry the protein-rich carcasses into their nests. Later, they haul the white, calcified exoskeletons of the isopods back out and scatter these around the mounds. Whether other bosque animals are significant predators of the isopods is not known.

Omnivorous native crickets (*Gryllus* spp., Orthoptera: Gryllidae) can also be abundant on the forest floor. Their distribution seems even more patchy than that of the isopods. Underground at the Nature Center, in the tunnels of pocket gophers, omnivorous camel crickets (*Ceuthophilus gertschi*, Orthoptera: Rhaphidophoridae) have surprisingly high densities.

Pitfall trap collections beneath cottonwood and Russian olives at the Nature Center reveal a possible connection between moisture, leaf litter nutrients, and the activity of ground-dwelling arthropods. In the dry summer of 1990, approximately equal numbers of these species were trapped beneath each kind of tree. However, in the wet summers of 1988 and 1991, greater numbers were trapped beneath Russian olive. Molles and Crawford (1992) proposed that Russian olive leaf litter, which is significantly higher in nitrogen and phosphorous than is cottonwood leaf litter (M.C. Parker, pers. comm.), supports higher levels of activity but only during wet summers when water is not a limiting factor. Microarthopods such as mites and springtails (Insecta: Collembola) are always abundant in moist leaf litter and soil.

Finally, termites (Isoptera) must not go unmentioned, even though they are seldom seen in the bosque. A widespread subterranean species (*Reticulitermes tibialis*) begins to decompose woody litter by consuming it from below. Its role as a consumer of below-ground organic matter has not been studied in the forest. A larger-bodied species, *Zootermopsis laciteps*, has been found in cottonwood logs, where carpenter ants (*Camponotus* spp.) also excavate galleries.

Open Area Surface.—Ants, spiders, and beetles dominate the soil surfaces of bosque open areas. Despite some overlap with the arthropod fauna of the forest floor, the species differences between the two ground-surface habitats are strong. This is particularly true for beetles, most of which are detritivores, in the open areas. Further differences include much better representation of predaceous "velvet ants" (Hymenoptera: Mutillidae) and other ground-dwelling wasps and bees in open areas.

Cutworms disperse over open area soils in large numbers during the spring of certain years. They eat the new shoots and leaves of low-growing plants, including clover. Robins, rufous-sided towhees, and other ground-feeding birds are well served by their presence.

The absence of isopods in open areas illustrates the need for resident arthropods either to be tolerant of heat, cold, and dryness, or to be able to escape these stresses. Strong differences in arthropod community composition between forest and open habitats reflect steep microclimatic differences between these landscape elements (Molles and Crawford 1992).

The same regionally widespread species of subterranean termite found under wood in the forest also consumes surface litter of all kinds in bosque open areas. As long as moisture levels are high and temperatures beneath potential food items are moderate, these insects account for the disappearance of considerable detritus. In terms of nutrient flow, they may well be among the most important organisms in the riparian zone.

Banks of Channels, Ponds, and Marshes.—The banks of flowing and stationary waters present a set of highly confined habitats, each with a community of ground-dwelling arthropods that differs in diversity from the others. In contrast to the extensive banks of the Rio Grande, those of non-river sites appear to be refugia for species once far more widespread around marshes and ponds. Some of the more subtle, bank-specific differences are as follows:

- River: carnivorous tiger beetles (Coleoptera: Cicindellidae) and toad bugs (Hemiptera: Gelastocoridae) are restricted to damp bank shorelines free of vegetation.

- Seeps and riverside drains: ground-dwelling beetles and spiders are much more abundant and diverse at the Nature Center seep than at the riverside drain about 50 m (164 ft) distant (N.L. Runyan, pers. comm.).

- Ponds and marshes: although only one comparison has been made (M.C. Molles, pers. comm.), banks at a constructed Los Lunas pond had more species (65) after 1 year than banks along Isleta Marsh. The marsh, however, produced greater numbers of individuals.

Soil.—Soils of the forest have deeper organic horizons than soils of open areas, which seldom have horizons other than those provided by cryptogamic crusts. Herbivorous invertebrates in both places should include root-feeding nematodes and a variety of small arthropods.

In forest soils, tree-root fluids are imbibed by the nymphs of floodplain cicadas, which after spending an unknown number of years underground emerge to spend the last few months of their lives in the canopy above. Roots of shrubs, forbs, and grasses are eaten by a variety of insects, including the larvae of weevils (Coleoptera: Curculionidae).

Earthworms are common in relatively moist, loamy forest soils where they are of potential importance in decomposition and soil turnover and aeration. The largely fungus-feeding larvae of small flies are abundant at the soil/litter interface in the forest (M.C. Parker, pers. comm.). Therefore they too may have significant rate-controlling effects on decomposition, especially in wet years when the adults emerge in relatively great numbers from decomposing matter on the forest floor.

Decomposer Communities

The Rio Grande riparian zone is a mosaic of forests (the bosque) and open areas (forest openings, agricultural fields). Everything that lives and dies there ultimately decomposes. Decomposition, which is a general term describing the breakdown of organic matter, depends mainly on inputs from dead leaves, wood, and roots. Other contributors include dead herbaceous vegetation and animals, as well as animal waste products (e.g., molted skins and cuticles, urine, and feces). Collectively, these items serve as the substrate ("detritus" or "litter") that supports the "decomposer food web." Organisms making up the web appear to control the supply of nutrients needed for plant growth in forest ecosystems (e.g., see Whitkamp and Ausmus 1975). A simplified picture of the structure and dynamics of that web, as it applies to the bosque, is presented in Fig. 32.

In the bosque, a diversity of relatively large, scavenging invertebrate "detritivores" feeds on most of the items mentioned above. These animals are in turn preyed upon by many kinds of invertebrates (carnivorous beetles, ants) and vertebrates (insectivorous mice, birds, lizards, toads). The detritivores in question consist mainly of native and introduced earthworms, introduced isopods (pillbugs and woodlice), and the following mostly native insects: termites, crickets and camel crickets, and larvae of many flies as well as larvae some adults of certain families of beetles (C.S. Crawford and M.C. Molles, unpubl. data). Ants that scavenge dead material can be added to the list. Much of the detritus eaten by this assemblage is colonized by

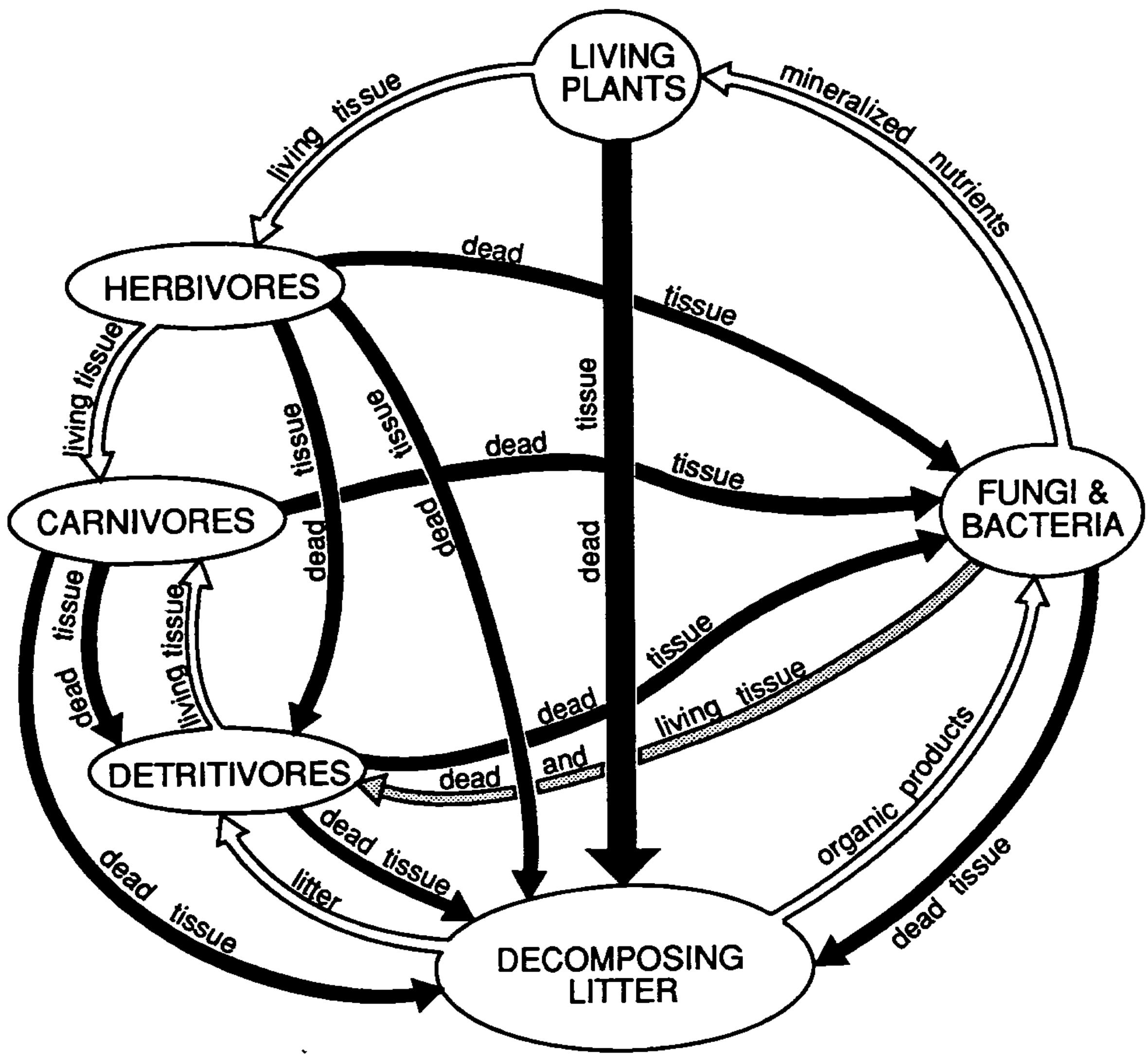

Fig. 32. Simplified decomposer food web. Widths of arrows emphasize presumed relative importance of interactions in the Middle Rio Grande riparian zone.

microorganisms that prepare it for consumption by breaking down certain hard-to-digest compounds. Detritivores also consume soil, and in doing so ingest bacteria and fungi that are essential for the breakdown of complex compounds such as the cellulose and lignin in wood. Simple carbohydrates are made available to the detritivores by this process.

Detritivores forage and defecate as they move through their habitats. Thus soil and litter microbes ingested by them in one location are deposited in another, ensuring continuous dispersal of these important organisms. Because detritivore feces are physically fragmented, compared with detrital food prior to ingestion, they present a relatively great surface area. This increases the potential for further colonization by decomposer microorganisms. Detritivore feces are often consumed by other detritivores thereby enhancing the rate of eventual mineralization (Lodha 1974).

Enormous numbers of smaller soil and litter invertebrates add to the food web's complexity. Most of these animals are mites, springtail insects (collembolans), or tiny free-living nematodes. Some mites are true detritivores, while others, as well as the springtails, eat fungi. Still other mites are predators (Wallwork 1970, 1976). Soil nematodes tend to be nutritional specialists on one of the following: bacteria, fungi, organic detritus, or other small invertebrates (Swift et al. 1979).

Despite the great variation in their ecology and behavior, the overall role of invertebrates in the bosque's decomposer food web is that of *indirect* regulation of decomposition rates. Regulation occurs at countless points in the web, which means that many kinds of decomposition controls are acting simultaneously. Examples include predation on detritivores by mice and spiders, and modification of the soil-litter environment by soil-moving earthworms and wood-fragmenting carpenter ants. Much regulation is accomplished through interactions of detritivores and nematodes with fungi and bacteria, which collectively in forest ecosystems appear to have much greater biomass than invertebrates (e.g., see Ausmus et al. 1975). By their regulatory effects on microorganisms, microarthropods and nematodes can significantly influence rates of nitrogen mineralization in leaf litter and soil organic matter (Anderson et al. 1985). Likewise, different densities of woodlice exert differential regulation of bacterial and fungal populations; in other words, woodlice can influence rates of leaf litter decomposition (Hanlon and Anderson 1980).

It is the fungi and bacteria, however, rather than other components of the decomposer food web, which *directly* account for the main biogeochemical transformations of dead organic matter into compounds that can be taken up by plant roots (Schlesinger 1991). The microorganisms do this by releasing extracellular enzymes that further degrade (i.e., mineralize) materials originally attacked by detritivores or by fungi. Energy for the growth and activity of the microorganisms comes from organic carbon in the detritus. As they decompose the organic substrate, these microbes concentrate ("immobilize") nitrogen, phosphorous, and other elements in their own tissues (Swift et al. 1979). Then, as the fungi and bacteria die in the litter and soil, they release the mineralized compounds which then become available for plant nutrition. The uptake of such compounds, assisted in most cases by root-associated mycorrhizal fungi (Swift et al. 1979, Anderson et al. 1985), allows them to be transported to metabolically active structures, such as leaves and roots. Eventually, these plant parts die and are added to the detrital biomass which continues to fuel the decomposition process.

5. Habitats

Wildlife inventories conducted by Cole (1978), Raitt et al. (1981), Hink and Ohmart (1984), Hoffman (1990), and Campbell (1990) have confirmed the rich assemblage of vertebrate species along the Middle Rio Grande. Information on species associations with riparian vegetation types is in preceding sections of this document.

Diversity, Patchiness, and Mosaics

While the term "diversity" has a broad application, we have defined it in several ways. Alpha diversity refers to species numbers and distribution of numbers of organisms within a given unit, e.g., the plant community type defined by Hink and Ohmart (1984). At a larger scale, beta diversity refers to the rate of species turnover when moving between one patch (or community type) to another. Gamma diversity is a consequence of the alpha diversity of the communities or habitats and the beta diversity among them. On a regionwide or landscape scale, gamma diversity would refer, for example, to the contrast between the arid and semiarid uplands and the more mesic riparian zones along the Rio Grande (Whittaker 1972). We have also followed Hink and Ohmart (1984) in using the word diversity to describe differences in structure in vegetation types. We believe that concepts of diversity, ranging from species numbers, differences in community types, to structural differences in canopy cover, can be appropriately applied in the determination of management goals.

Related to concepts of diversity and plant communities are the ideas of environmental "patchiness" and "mosaics." In an ecological sense, patchiness refers to the discontinuities in the environment that are important to any given organism or set of organisms. These discontinuities may exist in both time and space and may determine the distribution of organisms dependent on their resources. A mosaic of patch types refers to the grouping of patch types in a given area. The critical factor in analyzing and defining patches and mosaics is to clarify what organisms are using these patches (Wiens 1976). For example, a vole or small rodent would use different resources and patches than would a bald eagle. As with diversity, concepts of patchiness and mosaics are dependent on scale, and scale varies depending on the organisms that are being studied.

Our concerns for this plan are wide-ranging and focus, for the most part, on groups of organisms rather than on individual species. Consequently, our discussions of diversity, patchiness, and mosaics will be broad and primarily descriptive. Maintenance of native species in plant communities (or patches) in the riparian zone is one of our primary goals. We assume that patchy environments that include native plant communities (producers) will also include native species (consumers) using those patches, but we realize that the presence of some introduced species (both producers and consumers) is probably inevitable in many cases.

Habitat Value

The value of riparian habitat is well known to resource managers because of the high diversity and abundance of animal species which rely on the ecosystem for its unique plant community types, hydrologic features, soil, topography, and other environmental features that do not exist in adjacent upland habitat. Many species are obligate (depending entirely on the immediate riparian zone) while most are facultative (occurring in riparian habitat as well in other habitat types).

The ecological attributes that contribute to the high value of riparian habitat and that should be maintained to preserve the value to wildlife include the following (from Brinson et al. 1981):

- Heterogeneity of plant communities and structure
- Predominance of woody plant communities
- Presence of surface water, soil moisture, and high water table
- Continuous, unfragmented corridors of habitat
- Sustainability

Heterogeneity of Plant Communities Types and Structure

Patchiness.—Under natural conditions, riparian ecosystems provide a mosaic of habitat components. As a result of floods, other disturbances, varying ground-water levels, and soil conditions, riparian forests become interspersed with a range of plant community successional (seral) stages, marshes, meadows, ponds, and openings. This creates a variety of habitat niches leading to high species diversity. Riparian habitat supports species which are attracted to edges or which require a combination of adjacent vegetation types and habitat features.

For optimal habitat value, a balance must be achieved between large stands of habitat and those with a mosaic of plant communities and structural types. Habitat types must be large enough and spaced close enough to support viable populations of desired species.

Seral Stages.—Species populations often undergo nonseasonal, directional, and continuous patterns of colonization and extinction in areas subject to disturbance (Daubenmire 1968, Begon et al. 1986). These changes are called "succession." Fire, flooding, and grazing are common successional processes and can also be used to maintain transitional ("seral") stages. In the northern reach of the bosque, fire is replacing flooding as the major successional process. In native riparian habitats, livestock have been used to achieve different seral stages contributing to diversity and heterogeneity (Bryant 1985, Thomas 1991). Livestock can also be used to control seedling and sapling stages of salt cedar (M.K. Wood, pers. comm.).

Edge Effect.—Edges between the riparian vegetation types and adjacent aquatic, wetland, upland, and agricultural areas are high value wildlife habitat. Edges have long been known to be associated with abundance of wildlife, as well as with species diversity (Leopold 1933). Odum (1974) stated that edges between adjoining community types often support greater population densities and a higher number of species than the adjacent communities.

Along the Middle Rio Grande, Hink and Ohmart (1984) found that edges, especially the edges of cottonwood stands adjacent to levees, had the greatest concentrations of vertebrates. Examples of bird species with a strong preference for edges of cottonwood stands include Gambel's quail, hairy woodpecker, yellow-billed cuckoo, western kingbird, mountain chickadee, blue grosbeak, and white-crowned sparrow.

The edges between agricultural fields and the riparian zone have value for certain species. Conine et al. (1979) found high densities of birds along the riparian-agricultural edge along the lower Colorado River in Arizona, Nevada, and California. Species such as white-crowned sparrow, Gambel's quail, loggerhead shrike, yellow-rumped warbler, and Brewer's sparrow had higher densities along the edge than in the adjacent riparian or agricultural fields for most of the year. This effect was most pronounced where agricultural conversions occurred in salt cedar because species diversity and densities were usually higher in native riparian communities than along their agricultural edge. Certain management implications were drawn from this study:

- Although agricultural conversions are detrimental for riparian birds, a different assemblage of birds is attracted to agricultural areas.
- Strips of riparian vegetation left within agricultural conversions would increase species diversity and density.

There is apparently a limit to the value of edge effect. Martin (1992) recommended that wildlife managers consider the habitat requirements of each species of concern prior to management actions that create openings and edges in homogeneous forest habitats. For example, certain bird species are significantly impacted by cowbird nest predation when there is an increase in edge to patch size ratio (Brittingham and Temple 1983, Airola 1986). There is a great need for studies of the basic ecology and demography of many wildlife species in order to predict the effects of creating edges in habitat (Verner 1986). Hink and Ohmart (1984) found that certain bird species showed a strong preference for the interior of cottonwood stands (great horned owl, western wood-peewee, yellow-breasted chat, and indigo bunting).

Foliage Density.—Foliage density is a measure of the total surface area of leaves and stems per unit area. Species and abundance of birds, especially insectivores, increase with higher foliage density in the middle and upper canopy layers (Ohmart and Anderson 1986).

Foliage Height Diversity.—Foliage height diversity is a measure of the distribution of foliage in vertical layers in the riparian forest. The vegetation structural types developed for the Middle Rio Grande Biological Survey (Hink and Ohmart 1984) were based on foliage height diversity. High foliage height diversity results when foliage density is nearly the same in all vertical layers of vegetation (Ohmart and Anderson 1986). These layers provide a variety of niches for wildlife.

Predominance of Woody Plant Communities

The predominance of woody vegetation in riparian ecosystems provides an important habitat value, especially near grasslands, deserts, and farmlands where extensive forests are lacking (Brinson et al. 1981). Riparian forest habitats have considerable vertical structure, foliage height diversity, and foliage density which contribute to wildlife diversity and abundance. Tree foliage, bark, and ground litter are important foraging substrates, especially for birds and invertebrates. Birds nest in tree canopies, dead limbs, snags, and dense understory vegetation. Dense cottonwood forests with understory vegetation increase humidity, lower temperatures, and provide shade that attracts certain wildlife species.

Presence of Surface Water, Soil Moisture, and High Water Table

Surface water is a requirement of many wildlife species such as shorebirds, waterfowl, fish-eating birds, beaver, and muskrat. Several species of amphibians have adapted their breeding cycles to seasonal inundation of floodplains. Hink and Ohmart (1984) found high densities of vertebrates in moister areas with dense understory shrubs and herbaceous vegetation.

High water tables support marshes and wet meadows that provide habitat for a high diversity and density of wildlife including some of the rarer and declining species. Ohmart and Anderson (1986) discussed changes in riparian habitat that are occurring throughout the Southwest from ground-water withdrawal.

Continuous, Unfragmented Corridors of Habitat

Linear riparian corridors provide migration and dispersal routes and serve as connectors between upland habitats (Brinson et al. 1981). Trees and shrubs are used as cover by animals traveling through otherwise open areas. Many species of migratory birds depend on riparian vegetation, marshes, sandbars, and adjacent agricultural areas for food and cover during rest stops.

The width of the riparian corridor can be limiting. Species associated with edges, such as belted kingfisher or song sparrow, can establish territories in relatively narrow riparian forests. Other species such as great blue heron, Cooper's hawk, and yellow-billed cuckoo require larger territories and appear to be declining in Southwest riparian areas; they are found only where the riparian corridor is at least 100 m (328 ft) wide (Gaines 1974).

If habitat is fragmented into isolated patches, any given patch may not be large enough to support the home range of certain wildlife species. Long distances between patches may preclude an area from supporting viable populations of desired species. The end result of fragmentation is that smaller habitat fragments have fewer animal species than larger ones (Verner 1986). Fragmentation of habitat has become one of the main issues of wildlife management of the late 20th century. Loss of habitat heterogeneity is a consequence of fragmentation because even a seemingly uniform expanse of habitat has some form of heterogeneity (Soulé 1986).

Compared with riparian habitat downstream of Elephant Butte Reservoir, upstream of Velarde, and on other southwestern rivers, the overall riparian zone along the Middle Rio Grande is relatively wide, intact, and unfragmented. Along many rivers throughout the west, riparian zones have been fragmented into separated patches isolated by many miles of farmland or residential areas built-up right to the river's edge.

Fragmentation is occurring on the Middle Rio Grande at the plant community level. Marsh and wet meadow habitat has been fragmented and reduced in size, thereby causing a reduction of wildlife species that depend on this habitat (i.e, leopard frog, New Mexican jumping mouse). The anticipated continued decline in Rio Grande cottonwood-willow communities would lead to significant loss and fragmentation of this plant community in the foreseeable future. Fragmentation of the entire riparian ecosystem by private residential development is a concern.

Wilcove et al. (1986) summarized the management implications of fragmentation with the following conclusions: "Finally, we believe that over the long run virtually all temperate zone reserves will require active management to prevent or overcome the ecological imbalance created by fragmentation and human activity. Good reserve design will lessen but rarely eliminate the need for management.... Such management may take several forms, including controlled treatment of the vegetation to preserve particular successional stages...; the elimination of foreign species...; or the culling of populations of 'nuisance' animals (cowbirds...). Conservationists must realize that the battle is not over once the land has been saved. Indeed, it has just begun."

Sustainability of Plant Communities

Sustainability is a function of the ability of a dynamic riparian ecosystem to resist the long-term effects of fragmentation, species introduction, pollution, and human disturbance. The ecosystem must be able to persist in supporting desired species diversity and population levels. Management needs to understand natural processes to conserve biological diversity. Natural process in the riparian ecosystem has three basic parameters—composition, structure, and function (Samson 1992).

Composition.—Composition is the diversity of plant and animal species that are interrelated and dependent on physical and ecological processes that may differ in time and space. The composition of the riparian community is closely related to flooding, ground-water level, soils, dispersal of plants, and movements of animals.

Structure.—Structure in the riparian ecosystem is the arrangement of plant community types and habitat components discussed above. Both the structure and composition in riparian communities are linked to flooding and other disturbances. Loss of such disturbances leads to biosimplification (loss of species diversity, productivity, aesthetics, and sustainability).

Function.—Riparian areas function to dissipate the energy of high water flows. This serves to reduce erosion, improve water quality by filtering sediments and contaminants, aid floodplain development by capturing bedload, improve ground-water recharge by retaining flood waters, stabilize riverbanks with root masses, and provide habitat to support biodiversity (U.S. Bureau of Land Management 1993). Riparian systems are ever changing but self-sustaining as a result of the interaction among surface and ground water, soils, geology, and vegetation.

Habitats Interspersed with Riparian Forests

Marshes and Wet Meadows.—Species found in cattail marshes are notable for their high numbers and their restriction to that habitat. Species commonly associated with marshes of the Middle Rio Grande include pied-billed grebe, Virginia rail, sora, yellow-headed blackbird, American coot, mallard, marsh wren, song sparrow, swamp sparrow, chorus frog, bullfrog, tiger salamander, musk rat, Great Plains spiranthes, catchfly gentian, Pecos sunflower, and Parish's alkali grass.

Wet meadows, once much more extensive in the area, provide habitat for some rare and declining species including New Mexican jumping mouse, white-faced ibis, long-billed curlew, common black-hawk, and leopard frog. Other than the state and federal wildlife management areas discussed previously, limited acreages of marshes and wet meadows exist in the Middle Rio Grande Valley (Fig. 33). Known existing or potential wetlands with wildlife value are listed in Table 22 (U.S. Bureau of Reclamation 1992). Little is known about several of these areas which may provide excellent mitigation and enhancement opportunities.

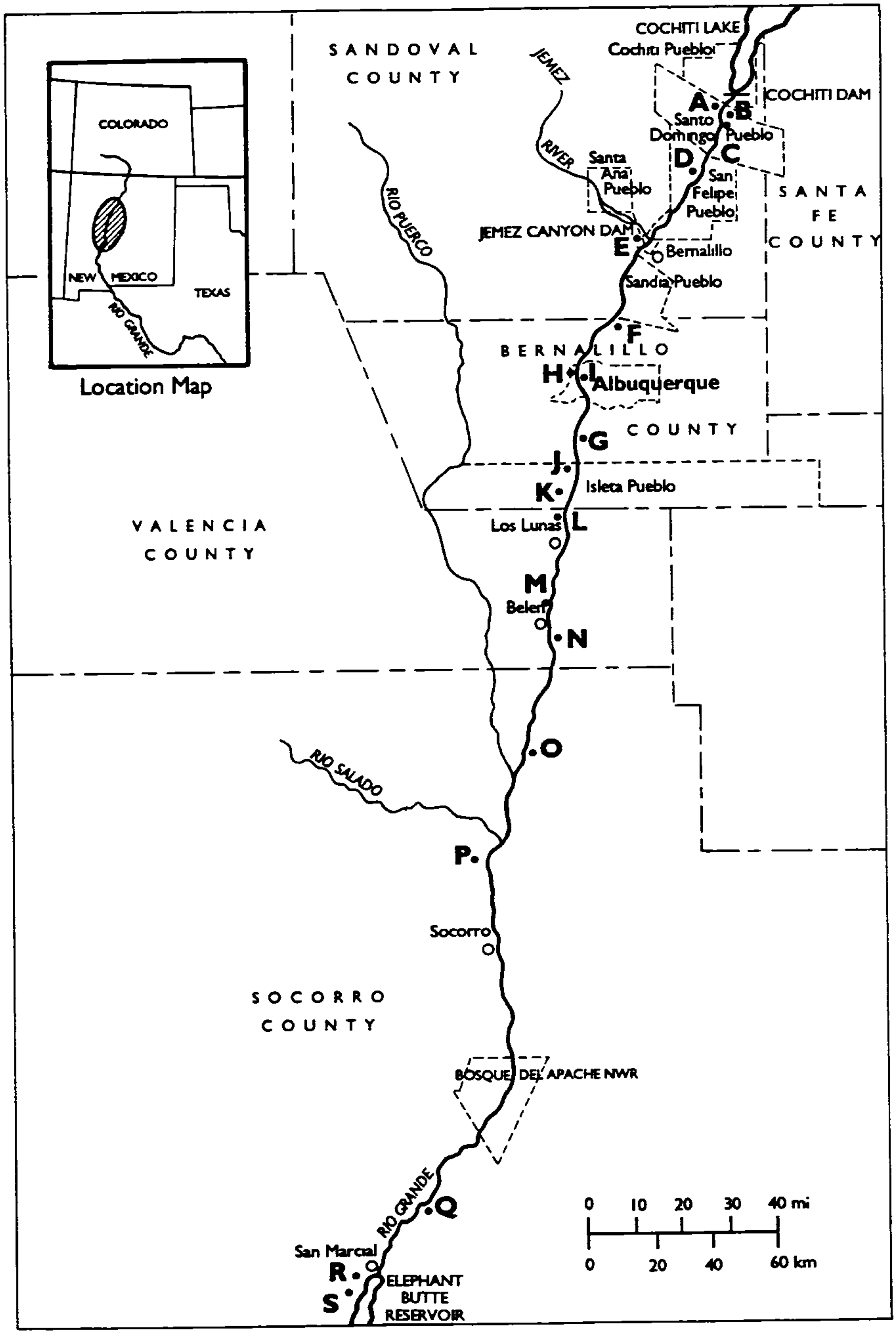

Fig. 33. **Locations of some existing and potential wetlands. See Table 22 for description of locations.**

Table 22. Some existing and potential wetland areas within the Middle Rio Grande Valley (U.S. Bureau of Reclamation 1992). Letters in parentheses refer to location in Fig. 33.

Area Name		Location	Remarks
Channel wetlands	(A)	Cochiti Reach: west side of river 4.5 km (2.8 mi) downstream from Cochiti Pueblo	Needs biological inventory and evaluation
"Nudist Ponds"	(B)	Cochiti Reach: east side of river 5.5 km (3.4 mi) downstream of Cochiti Pueblo	Waterfowl and aquatic life, needs evaluation
Wet meadows	(C)	Cochiti Reach: east side of river 3 km (1.9 mi) upstream of bridge at Santo Domingo Pueblo	Jumping mouse and leopard frog habitat
Leopard frog habitat	(D)	Cochiti Reach: west side of river 2.7 km (1.7 mi) downstream of San Felipe Pueblo	Old unmaintained riverside drain; needs to be preserved
Channel wetlands	(E)	Middle Reach: west side of river between Jemez River and Hwy 44 Bridge	Cattail marsh and ponded water, used by waterfowl
Seasonal wetlands	(F)	Middle Reach. Albuquerque North Diversion channel	Created by city runoff
Seasonal wetlands	(G)	Middle Reach: Albuquerque South Diversion channel, Rio Grande Valley State Park	Created by city runoff
Oxbow Marsh	(H)	Middle Reach: Rio Grande Valley State Park	Designated a "Special Protection Area" with unique ecological values (City of Albuquerque Parks and Recreation Department 1987)
Conservancy Lagoon (Tingley Beach)	(I)	Middle Reach. downstream of Central Avenue Bridge	Heavy fishing use
North Isleta Marsh	(J)	Middle Reach: immediately north of railroad bridge	Cattail marsh with deep water
Isleta Marsh and adjacent wet meadows	(K)	Middle Reach: west side of river south of Isleta	High value wetlands with high species richness and density; jumping mouse habitat
COE Experimental Wetland	(L)	Middle Reach: west side of river near Los Lunas	Example of man-made wetland
Fishing Pond	(M)	Middle Reach: west side of river near Belen	Man-made pond used for fishing waterfowl use
Madrone Ponds	(N)	Middle Reach east side of river, north of Turn	Waterfowl, leopard frogs, turtles, heavy hunting, and fishing

Table 22, continued.

Area Name		Location	Remarks
Wet Meadows	(O)	Middle Reach east side of river, north of Bernardo Bridge	Leopard frogs and possible jumping mouse habitat
Cattail Marsh	(P)	Socorro Reach: west side of river along drain, north of San Acacia Diversion Dam	Needs biological inventory and evaluation
Abandoned Conveyance Channel	(Q)	San Marcial Reach. a 6-km (4-mi) length below Tiffany	Sparse emergent vegetation, no standing water and heavy grazing; enhancement opportunity
Intermittent Wetlands	(R)	Elephant Butte Reach Ft. Craig area	Adjacent to conveyance channel on west side
Mulligan Gulch Wetland	(S)	Elephant Butte Reach· near end of conveyance channel	Status unknown—submerged; about 8.1 ha (20 acres) of marsh maintained by flows from conveyance channel, high use by waterbirds

Salt Cedar Stands.—Hink and Ohmart (1984) found a distinct assemblage of summer resident birds in salt cedar stands that included mockingbird, lark sparrow, western meadowlark, black-throated sparrow, blue-gray gnatcatcher, and crissal thrasher. Raitt et al. (1981) found that bird density and diversity were higher in native vegetation than in salt cedar stands in the head of Elephant Butte Reservoir. Crissal thrasher was the only bird species found to breed in stands of salt cedar. However, certain birds show fidelity to salt cedar during migration and in winter, including house wren, Virginia's warbler, MacGillivray's warbler, Lincoln's sparrow, and song sparrow. The study predicted that clearing monotypic stands of salt cedar would create openings to benefit vermilion flycatcher, lark sparrow, American kestrel, ladder-backed woodpecker, western bluebird, loggerhead shrike, and horned lark. Revegetation with native trees following clearing would increase the value of habitat parameters (i.e., foliage density, patchiness, foliage height diversity) necessary for increased bird density and richness.

Gravel Bars and Riverbank Habitat.—Common fish-eating birds that forage in the river from riverbank perches include greenback heron, black-crowned night heron, bald eagle, and belted kingfisher. Other birds that use the riverbank habitats include spotted sandpiper, killdeer, great blue heron, water pipit, and mountain bluebird. Large trees with overhanging limbs, dead and downed woody material, dense understory vegetation, and emergent wetland vegetation greatly add to the fish and wildlife value of riverbank habitat.

Hink and Ohmart (1984) found that gravel bars and dry river channels are characteristically low in wildlife compared with other habitat in the project area. However, gravel-bar habitat had the most diverse and abundant populations of reptiles and amphibians. Coyotes, raccoon, beavers, and muskrats often use gravel bars for foraging. Wintering sandhill crane flocks use gravel bars for night roosting especially in the southern reaches of the Middle Rio Grande.

Mallards, the most common resident waterfowl in the project area, breed in the riparian zone adjacent to the river. Large groups of mallards occur along the river in the winter. Other common waterfowl species that use the riverine habitats include green-winged teal, cinnamon teal, and ruddy duck.

Snags.—Standing dead trees (snags) and live trees with dead limbs are known as wildlife cavity trees. This decadent portion of the riparian forest supports many species of plants, invertebrates, birds, and mammals. For example, fungi, mosses, and lichens use the decayed wood as a growth substrate. Invertebrates use spaces under loose bark for cover and foraging. Birds use cavities for nesting or roosting and snags for foraging substrates, perches, and nest supports. Snags are extremely important as roost and hunting perches for bald eagles. Mammals use cavities for dens or escape cover. Certain species, mostly woodpeckers, excavate their own cavities (primary excavators). Most species either use natural cavities, cavities excavated by other species, or spaces under loose bark (secondary cavity users).

The formation of cavity trees is part of the natural successional process within cottonwood forests in the bosque. As stands mature and become more decadent, snags and dead limbs become more numerous, and in time, gradually deteriorate. Cottonwood snags in loose, sandy soils remain standing for a relatively short period.

Historically, many cottonwood stands, especially those nearest the main river channel which succumbed to erosion, did not attain maturity. Usually the more mature stands with large cavity trees were very spotty or concentrated near the outer edge of the floodplain. Recently, because of a more controlled river, cavity trees have the potential to be more evenly distributed throughout the bosque. However, our observations have noted a paucity of snags in many areas of the bosque. Apparently many snags are felled by firewood cutters. The MRGCD and other management agencies may have an effect on the numbers of trees felled by their policies for permitting fuelwood cutting (New Mexico State law requires permission of landowners to cut wood [68-2-22 NMSA 1978]).

In the Middle Rio Grande bosque, at least 16 bird and 12 mammal species are known to use cavities in snags for nesting and shelter (Tables 23 and 24). Cavities are mostly used in dead, partly dead, or live cottonwood trees, or to a lesser extent in tree willows and juniper. The use of Russian olive, Siberian elm, and salt cedar by cavity nesters has not been observed and may be much less. Hink and Ohmart (1984) found that most cavity nesting bird species preferred cottonwood/Russian olive over cottonwood/coyote willow—presumably due to the concentration of larger, more mature cottonwood trees in cottonwood/Russian olive habitats. We, as well as Cole (1978), noted that use of snags by native cavity nesters, especially woodpeckers, is impacted by competition with European starlings.

Cavity nesting species have specific requirements for minimum diameter of trees and limbs they select for nesting, as well as height of their cavity (Tables 23 and 24). Although, these

Table 23. Bird species known to use cavity trees in riparian forests and estimated nesting requirements; d.b.h. = diameter at breast height (1.5 m [4.5 ft]; from Thomas et al. 1979).

Species	Minimum d.b.h. centimeters (inches)	Minimum Nest Height meters (feet)
Wood duck	50.8 (20)	1.8 (6)
Common merganser	50.8 (20)	1.8 (6)
American kestrel	30.5 (12)	4.6 (15)
Barn owl	50.8 (20)	4.6 (15)
Screech owl	30.5 (12)	4.6 (15)
Lewis woodpecker	30.5 (12)	9.1 (30)
Red-headed woodpecker	30.5 (12)	9.1 (30)
Ladder-backed woodpecker	unknown	unknown
Hairy woodpecker	25.4 (10)	4.6 (15)
Downy woodpecker	15.2 (6)	4.6 (15)
Northern flicker	30.5 (12)	1.8 (6)
Ash-throated flycatcher	25.4 (10)	4.6 (15)
Black-capped chickadee	10.2 (4)	1.6 (6)
Mountain chickadee	10.2 (4)	1.6 (6)
White-breasted nuthatch	30.5 (12)	4.6 (15)
House wren	25.4 (10)	1.8 (6)
European starling	25.4 (10)	1.8 (6)

nesting requirements were determined for birds in cottonwood floodplains in eastern Colorado (Sedgwick and Knopf 1986, 1990) and for animals in the Blue Mountains of Oregon (Thomas et al. 1979), they can be used as a general guide for snag management in the bosque. There is a direct relationship between nest site availability and abundance and number of species of birds and mammals dependent on them (Brush et al. 1983).

The number of cavity trees required to maintain optimal populations of woodpeckers per acre of riparian forest was estimated by Sedgwick and Knopf (1986) and Thomas et al. (1979). Generally, an average of 750 cavity trees is required per 100 ha (300 per 100 acres). Optimally,

Table 24. Mammal species known to use cavity trees in riparian forests and estimated nesting requirements; d.b.h. = diameter at breast height (1.5 m [4.5 ft]; from Thomas et al. 1979).

Species	Minimum d.b.h. centimeters (inches)	Minimum Nest Height meter (feet)
Opossum	50.8 (20)	1.8 (6)
Yuma myotis	30.5 (12)	1.8 (6)
Little brown myotis	30.5 (12)	1.8 (6)
Pallid bat	30.5 (12)	4.6 (12)
Colorado chipmunk	25.4 (10)	1.8 (6)
Deer mouse	25.4 (10)	1.8 (6)
White-footed mouse	25.4 (10)	1.8 (6)
Southern plains woodrat	38.1 (15)	1.8 (6)
White-throated woodrat	38.1 (15)	1.8 (6)
Raccoon	50.8 (20)	1.8 (6)
Long-tailed weasel	30.5 (12)	1.8 (6)
Striped skunk	50.8 (20)	1.8 (6)

about 50% of these cavity trees should be over 15.2 cm (6 inches) diameter at breast height (d.b.h.), 17% over 25.4 cm (10 inches), and 33% over 30.5 cm (12 inches). Dead limbs 15-30 cm (6-12 inches) in diameter are preferred for cavity excavation. Since woodpecker cavities are used by other species, maintaining the optimum number of cavity trees for woodpeckers would benefit the wide variety of other species that use snags.

In cottonwood bottomlands, Sedgwick and Knopf (1986, 1990) found the following:

- Dead limbs on live cottonwood trees are as important as snags for cavity nesters.
- Dead limbs 10 cm (4 inches) in diameter are the minimum size required by cavity nesters; those over 14 cm (6 inches) are preferred.
- Cavity trees over 54 cm d.b.h. (21 inches) are preferred.
- Clusters of cavity trees are important, especially for bird species that require secondary nest sites.

Thomas et al. (1979) discussed the following biological considerations for cavity tree management.

- Several species of cavity nesters will use the same tree.
- Birds of the same species will not usually nest in the same tree.
- Large cavity trees can be substituted for smaller ones, but not the reverse (when the requirements of species that need the cavity trees of the largest d.b.h. class are met, the requirements of the species needing smaller size trees would be met).

Dead and Downed Woody Material.—Dead and downed woody material on the forest floor has important ecological implications for mineral cycling, nutrient immobilization, nitrogen fixation, fire, and habitat for invertebrates and vertebrates. In the bosque, the value of dead and downed material from an ecosystem perspective can be impacted by flooding, firewood gathering, and burning. This can affect both decomposition processes and biodiversity.

As fallen logs and other woody debris decompose, nitrogen concentration increases and the debris often serves as a nursery for seedlings of a variety of plants. Eventually fungi will colonize and nutrients will begin to accumulate. Mycorrhizal fungi, symbionts with vascular plants, contribute to the process of nitrogen concentration. In addition, fungi are an important food source for both invertebrates and vertebrates.

During decomposition, fallen logs lose density and become more available for burrowing small mammals and other wildlife. Size of log relates to the species and number of individuals that can use it. Larger logs are of greater value to a higher number of species, and logs that are well distributed over the forest floor are also of greater value. Vertebrate species use logs for feeding sites, protection from predators, reproduction dens, and thermal cover. Downed logs in the river are of value to aquatic species.

Habitats for Special Status Species

Currently there are about 20 species of plants and animals in the management area that, because of their apparent rarity or declining population trend, have state and federal designations such as "endangered" and "threatened." In addition, there are several species which are designated as candidates for federal listing or have been determined by us to need special management considerations. Tables 25 and 26 summarize information on these special status species plants and animals, respectively, which are known to occur in the Middle Rio Grande Valley.

The federally listed species are protected by the Endangered Species Act (Act). The initial stated purpose of the Act is "to provide a means whereby the *ecosystems* upon which endangered species and threatened species depend may be conserved." Likewise a goal of listing State of New Mexico endangered species, under the Wildlife Conservation Act, has been to protect habitats. Although most of the focus of implementing these Acts has been toward individual species, the overall long-term intent is to protect national and regional biodiversity.

This plan can look beyond individual species to the ecological units that sustain them. Conceivably, by working with the entire Middle Rio Grande riparian ecosystem, managers can protect several species. Table 27 organizes special status species by the area's biological communities to reinforce this concept.

Table 25. Special status plants of the Middle Rio Grande (C1 = federal candidate category 1; C2 = federal candidate category 2; S1 = state-listed endangered; S2 = state-listed sensitive.

Species	Status	Special Habitat Requirements
Great Plains spiranthes (*Spiranthes magnicamporum*)	S1	Occurs in wet meadow and marsh edge habitat; found recently near Isleta Marsh (Sivinski et al. 1990)
Giant helleborine (*Epipactis gigantea*)	S2	Riparian habitats; has been found in mature cottonwood forests with sparse understory within the Albuquerque Reach (Sivinski et al. 1990)
Catchfly gentian (*Eustoma exaltatum*)	S2	Wet meadows, ditchbanks, and streamsides
Pecos sunflower (*Helianthus paradoxa*)	C1, S2	Saline and alkaline meadows
La Jolla prairie clover (*Dalea scariosa*)	S2	Loose sandy soil; found on terraces and on alluvial sands deposited by arroyo flooding in the floodplain
Parish's alkali grass (*Puccinellia parishii*)	C2, S2	In wet meadows with alkaline soils

Ecosystem management can protect habitat for existing listed species and can help avoid future listings. However certain species may require specific management strategies that address their needs. Therefore, ecosystem management can complement, but does not replace, recovery and management planning for special status species. Appendix III contains life-history information on listed species which can be used in management planning. The management recommendations have incorporated habitat requirements of special status species. Further research and monitoring may indicate the need for specific management actions.

Table 26. Special status animals of the Middle Rio Grande (E = federally endangered; T = federally threatened; P = federally proposed for listing; C1 = federal candidate category 1; C2 = federal candidate category 2; S1 = state-listed endangered; S2 = state-listed sensitive; * = Biological Interagency Team species of concern).

Species	Status	Special Habitat Requirements
Rio Grande silvery minnow (*Hybognathus amarus*)	P, S1	Adults encountered most frequently in shallow, braided, and sandy bottom sections of the river and backwater pools
Phantom shiner (*Notropis orca*)	S1	Probably extirpated
Rio Grande Bluntnose shiner (*Notropis simus simus*)	S1	Probably extirpated
Northern leopard frog (*Rana pipiens*)	*	Wet meadows with shallow clear pools
Olivaceous cormorant (*Phalacrocorax olivaceus*)	S2	Known to breed at Elephant Butte Marsh, uses partially submerged snags
White-faced ibis (*Phegadis chihi*)	C2	Marsh and flooded riparian areas
Bald eagle (*Haliaeetus leucocephalus*)	E, S2	Riverbanks with large overhanging branches, submerged snags
Northern goshawk (*Accipiter gentilis*)	C2	Mature cottonwoods during migration and winter
Common black hawk (*Buteogallus anthracinus*)	C2, S2	Nests in mature cottonwoods in Middle Rio Grande Valley; forage in nearby shallow wetlands
Ferruginous hawk (*Buteo regalis*)	C2	Open areas including agricultural fields
Peregrine falcon (*Falco peregrinus anatum*)	E, S1	Forages over wide area during migration
Mountain plover (*Charadrius montanus*)	C2	Open areas
Piping plover (*Charadrius melodus*)	T, S1	Rare spring migrant on sandbars and shorelines
Snowy plover *Charadrius alexandrinus nivosus*	C2	Sandbars
Interior least tern (*Sterna antillarum athalassos*)	E, S1	Sandbars
Loggerhead shrike (*Lanius ludovicianus*)	C2	Wet meadows and agricultural areas
Southwestern willow flycatcher (*Empidonax traillii extimus*)	P, S2	Dense understory riparian vegetation near water; proposed critical habitat has been identified Alameda Bridge south to the I-25 crossing

Table 26, continued.

Species	Status	Special Habitat Requirements
Bell's vireo (*Vireo bellii*)	S2	A summer vagrant in Middle Rio Grande Valley
Occult little brown bat (*Myotis lucifugus occultus*)	C2	Forages over wetlands and river
Spotted bat (*Euderma maculata*)	C2, S2	Riparian woodlands and a variety of upland habitats
Tawny-bellied cotton rat (*Sigmodon fulviventer*)	*	Wet meadows
New Mexican jumping mouse (*Zapus hudsonius luteus*)	C2, S2	Wet meadows and vegetated canal banks

Table 27. Community associations of special status species of the Middle Rio Grande.

Community Association	Species	
Mature cottonwood forest	Giant helleboine Bald eagle Common black hawk	Northern goshawk Yellow billed cuckoo Cavity nesting birds
Understory riparian shrub	Willow flycatcher Bell's vireo	New Mexican jumping mouse
Marsh	Olivaceous cormorant Long-billed curlew	Willow flycatcher Little brown bat
Wet meadow	Parish's alkali grass Great Plains spiranthes Catchfly gentian Pecos sunflower	Northern leopard frog White-faced ibis New Mexican jumping mouse Tawny-bellied cotton rat
Aquatic riverine	Rio Grande silvery minnow Bluntnose shiner Phantom shiner	White-faced ibis Bald eagle
Sandbar	Whooping crane Least tern	Piping plover Snowy plover
Other	Mountain plover Peregrine falcon Ferruginous hawk	Common ground dove Loggerhead shrike La Jolla prairie clover

V. FUTURE CONDITIONS WITH NO ACTIVE CHANGE IN BIOLOGICAL MANAGEMENT

The purpose of this section is to project the future of the Middle Rio Grande ecosystem with no changes in its biological management. So far, in this document, we have presented evidence that external factors, such as flood control and introduced species, are producing major changes in the appearance and function of the river and the bosque. Moreover, it is now clear that simply protecting the boundaries of the riparian zone will not freeze it in its current condition. Therefore, we expect the scenario that follows to (1) serve as a basis for the management plan's biological resource recommendations and (2) assist managers in deciding to what extent individual recommendations are appropriate for their specific needs. The scenario is preceded by a set of assumptions about human population growth and resource use as these relate to the Middle Rio Grande ecosystem. The assumptions are based on our best estimates of trends documented by information in this plan.

A. ASSUMPTIONS

1. Population

The population in the Middle Rio Grande Valley will continue to increase. The Bureau of Business and Economic Research (1991) predicted that the four-county (Bernalillo, Sandoval, Valencia, and Socorro) population will grow by 41% between 1990 and 2020. About half of this growth will occur in Bernalillo County, but both Valencia and Sandoval counties are predicted to double their 1990 populations. County by county, the population projections are:

County	2020 Population	Increase	Percent Increase
Sandoval	128,996	65,155	102%
Bernalillo	614,265	132,576	27%
Valencia	91,831	46,286	102%
Socorro	21,216	6,412	43%
Total	**856,308**	**250,429**	**41%**

2. Land Use and Management

We assume that, in the absence of a revised agenda, current land managers will continue to exercise their existing authorities and levels of management. This assumption is of particular importance when predicting what influence the expanding population will have on the bosque.

- The trend of converting agricultural lands, including grazing lands, to primarily residential uses will continue. This conversion will be greatest in those areas serving the Albuquerque metropolitan area (Bernalillo through the South Valley and Bosque Farms to Belen).

- Currently undeveloped and privately owned lands in the floodplain will be increasingly converted to residential uses. The greatest proportion of privately owned lands in the riparian zone is located in Socorro County.

- Grazing will continue to be a common use of riparian zone lands in those areas currently grazed and not converted to other uses.

- Recreational use of the Rio Grande and the bosque will increase proportionally with the population increase. This will result in a greater human presence especially in and near the population centers. The City of Albuquerque will implement its *Bosque Action Plan* which identifies specific environmental and recreational improvements for the Rio Grande Valley State Park (City of Albuquerque Parks and General Services Department 1993). There will be increased disturbance to levee edge and drain habitat.

- The frequency of fires in the riparian zone will increase proportionally with population, and fire suppression will continue at its current level of effectiveness.

- Unmanaged firewood cutting in the bosque will increase proportionally with the population except in the Rio Grande Valley State Park. There will be a general reduction of snags and dead and downed wood by firewood cutters.

- Illegal dumping in the bosque will not only keep pace with the increasing population, but the problem will be exacerbated by the closing of local landfills.

- Numbers of feral dogs and cats will increase.

- Attention to improving land management activities in the principal watersheds will continue.

3. Water Management

Hydrology

As with land management future scenarios, we assume that the current water management institutional framework will remain largely unchanged. New Mexico's administration of water rights will remain intact, and international and interstate obligations will continue to be honored. This does not mean that we believe that changes within this framework are impossible.

- The current physical water management infrastructure (water supply and flood control facilities) will remain in place for the foreseeable future although modifications to some facilities are possible.

- The maximum combined releases from Cochiti and Jemez Canyon dams will decrease due to development within the floodway.

- Levee rehabilitation will occur in various reaches of the river, extending from Corrales to Elephant Butte Reservoir.

- The San Juan-Chama Project will continue to divert approximately 100,000 acre-feet into the Rio Grande Basin. All water will be contracted to water users.

- The City of Albuquerque will have to release more of its contracted San Juan-Chama water through the Albuquerque reach to offset the effects of ground-water pumping on the Rio Grande.[1]

- The City of Albuquerque's wastewater discharge into the Rio Grande will increase proportionally with its population.

- River channel and floodway maintenance activities will continue for the purposes of water conveyance and flood control. The nature of these activities, however, will continue to evolve in response to changing "technologies" and public needs.

- The Low Flow Conveyance Channel will continue to be operational. It is possible that the operating criteria will be modified in response to additional public needs.

- Additional urban runoff control facilities will be constructed not only in Rio Rancho and the City of Albuquerque but in other communities as well.

River Morphology

In general, the morphological processes currently set in motion in response to the hydrology of the Rio Grande will continue.

- The elevational degradation of the Rio Grande's channel bed will continue downstream at least to the confluence with the Rio Puerco, and possibly as far as San Acacia, before reaching equilibrium. The rate and magnitude of change will diminish with distance downstream.

- Where riverbank vegetation is not well established, and where bank stabilization measures are not implemented in the Cochiti Reach, bank sloughing will continue.

- Riparian vegetation will further stabilize the riverbanks, especially in the Albuquerque and Bernardo reaches.

- The overall configuration of the Rio Grande—slightly sinuous with straight reaches—will not change appreciably. Its sinuosity may increase locally between the levees.

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[1]Using the New Mexico State Engineer's current formula, the City of Albuquerque will have to use its entire 50,000+ acre-feet of San Juan-Chama Project water to offset surface-water losses in the year 2030 (Summers 1992)

- The tectonic uplifting in the Socorro area will continue, slightly decreasing the slope of the river upstream in the Belen Reach and slightly increasing its slope downstream in the lower portion of the Socorro Reach.

- The Rio Puerco will remain the primary sediment contributor to the Middle Rio Grande. It is unknown whether the recent trend of decreasing sediment loads will continue.

- Sediment loading from urban runoff facilities will increase.

- Sediment plugging at the Rio Grande's outfall into Elephant Butte Reservoir will continue to occur during near-full or full reservoir conditions.

Water Quality

- The volume of urban point source and nonpoint source discharges, including storm-water runoff and treated municipal water, will increase proportionally with population growth.

- The nonpoint discharges from irrigated agriculture will decrease because of the incorporation of more efficient irrigation methodologies and the conversion of agricultural lands to other uses.

- Water quality standards will continue to be more stringent.

- Ground-water pollution resulting from high concentrations of septic tanks/fields in the larger urban areas will decrease due to creation and expansion of municipal sewage treatment facilities.

Ground Water

- The City of Albuquerque and other municipalities will increase ground-water pumping in response to growing population and industrial needs.

- Agricultural activities will continue, but at a decreasing level. The associated water delivery/drain system will remain in place.

- Deep-rooted riparian vegetation will filter nitrogen and phosphorous from contaminated ground water provided that the vegetation is located between discharge sites and the river.

- The Rio Grande will remain hydrologically connected to the shallow ground-water system. This is predicated on the assumption that water management institutions will implement active changes in ground-water extraction activities should this hydrologic connection be threatened. The hydrologic connection, however, will be relatively static with regard to nutrient mobilization in riparian forest soils because of continually restricted overbank flooding.

B. AQUATIC ENVIRONMENT

1. Trends for Hydrologic Conditions and Aquatic Resources under Current Management Conditions

A policy of no active change in the biological management of the Middle Rio Grande would proliferate the hydrologic trends introduced in the previous section. Above the Rio Puerco, the river would continue to become narrower and deeper, as banks stabilize and channel degradation continues. This would affect riverine species that require warm, shallow reaches. Opportunities for the formation of wetlands (with attendant aquatic communities) would also diminish as conditions for overbank flooding and ground-water seepage also decline.

2. Habitat

The distribution of available habitat will continue to adjust with upstream channel degradation and downstream aggradation. The preferred range of native, warmwater fishes would be reduced as some endemic warmwater habitat is replaced by cool-water habitat due to channel degradation. The narrowing of the river channel (approximately 50% since 1935; see Maps 1-4) due to the effects of water regulation will also result in the loss of aquatic habitat.

Current river channel maintenance activities, as discussed in previous sections, would continue to cause localized loss and fragmentation of habitat (e.g., shoreline). Local fish and invertebrate populations will be subjected to increased mortality during construction. The cumulative impacts of channel maintenance activities, such as an increased continuity of stabilized banks, could impact fish movement and affect overall longitudinal distribution of native fish. Minimizing the number of bank stabilization projects and developing environmentally sensitive channel maintenance activities would help alleviate habitat and species impacts.

Main channel dams and diversions will function as physical barriers separating habitat types and associated fish populations. Habitat intermittency during low flow will continue to fragment habitat for extended periods and would result in the loss of habitat until flows increase.

Other potential future conditions and their effects on aquatic habitat are as follows:

- Damping of runoff peak flows due to factors such as decreased downstream channel capacity would limit available high flow habitat including wetlands.

- Reactivation of the Low Flow Conveyance Channel would increase the potential for habitat fragmentation and loss in the Socorro Reach during low flow. Diversion of water into the conveyance channel would force fish into suboptimal habitat. Conveyance channel habitat will not support viable populations of many species including the Rio Grande silvery minnow.

- The downstream extension of the channel bed degradation will result in the loss of warmwater aquatic habitat.

- Increased maintenance of irrigation system drains and wasteways would diminish associated habitat values for fish and macroinvertebrates.

Wetlands have been the aquatic habitats most impacted heavily by drainage, conversion to agriculture, and conversion to urban uses. These aquatic refugia for frogs, fish, and invertebrates will continue to decline in area and numbers if no management steps are taken to prevent loss and to create new wetland locations.

3. Water Quality

As urban populations increase, storm-water runoff and municipal wastewater discharges will increase, while nonpoint discharges from agriculture will decrease. Urban discharge will continue to include oil and gasoline contaminants from streets and parking lots as well as nitrogen and ammonia compounds from sewage treatment plants.

Ground-water quality may be improved by reduction of inputs from septic systems although this may be offset by increases in discharges from sewage treatment plants. Leaking gasoline storage tanks, contamination by toxic waste dumps, and other, long-standing sources of contamination would continue to be a problem.

Contaminants may also enter the system from sources in the watershed upstream of the middle valley or from tributary streams. These include mining wastes as well as natural sources of toxic materials.

Depending on the identity of contaminants in surface and ground water, aquatic and terrestrial organisms associated with the riparian ecosystem may be affected directly or indirectly. Changes in pH, water temperature, and the presence of toxic compounds may affect aquatic organisms directly. These changes may also indirectly affect terrestrial organisms through reduced numbers of prey or may affect predators by bioaccumulation of toxic materials.

Population expansion in the Middle Rio Grande Valley (and also within the watershed) will increase the effects of sewage and runoff on water quality.

4. Consumers

The composition of fish and macroinvertebrate communities in the Middle Rio Grande would change in response to the current baseline of natural and human perturbations and the addition of new stressors. The status and structure of fish communities will be influenced by water regulation, changes in water quality, and introduction of nonnative species. Increased regulation of water delivery throughout the Middle Rio Grande would impact natural processes such as reproduction, migration, competition, and survival. Spatial habitat intermittency associated with low flow will have a large impact on fish populations. Habitat intermittency may fragment populations. Extended periods of desiccation due to increased water regulation would significantly impact populations and restrict recolonization. Fish confined to isolated habitats during low flow would be exposed to increased levels of predation, pollution, and disease. Extended, static high flow periods, as associated with reservoir releases, may impact the duration and extent of spawning. Edwards and Contreras-Balderas (1991) predicted that rivers with a reduced instream flow, such as the Rio Grande, will experience a concurrent reduction in fish abundance and diversity.

Main channel dams and diversions will continue to limit the upstream migration of fish and thus impact their distribution. The Rio Grande silvery minnow may continue to concentrate below San Acacia Diversion Dam. The inability of this portion of the population to recolonize upstream reaches will limit opportunities to enhance the current distribution of this species. Rio Grande silvery minnow populations would also remain fragmented throughout the range of the species. The trend of decreasing abundance of this species would continue. Also, the continued increase in the dominance of a limited number of species, such as red shiner, to the possible detriment of nonnative and special status species may continue under current management practices.

Native fish would continue to tolerate natural fluctuations in baseline physical water quality parameters (e.g., temperature, pH, total dissolved solids). Extreme variation in these parameters will impact fish survival. An increase in point source discharges, especially during periods of low flow, would lead to population fragmentation and a decline in fish abundance within a reach. The long-term impacts of nonpoint source pollution in the Middle Rio Grande are unknown. However, there will be the potential for increased bioaccumulation of contaminants.

The trend toward an increased abundance of nonnative fish species would continue. Interdrainage translocation of nonnative fish to the Middle Rio Grande would greatly reduce the native fish assemblage. Regulations governing the use and commercial sale of bait minnows will likely change. The NMDGF may attempt to prohibit the interdrainage transport of baitfish. The limited system of effective checks and balances relative to nonnative species introductions and native fish would minimize the combined benefits of these two fisheries. Nonnative fish would continue to emigrate downstream and displace native fish.

The potential introduction of zebra mussel would impact both fish and invertebrate populations. Zebra mussels could outcompete native invertebrates and affect fish, especially young-of-year, by impacting their food base (McNabb 1993). As a result, young-of-year mortality would be high and numbers of older and larger fish would be gradually reduced (McNabb 1993)

Edwards and Contreras-Balderas (1991) concluded that maximizing the use of water for human and cultural activities in rivers in the Southwest results in the decline and loss of native fish populations. This trend appears very applicable to the Middle Rio Grande and its aquatic communities. The Rio Grande silvery minnow is the last of a guild of four short-lived cyprinid fish that were endemic to the Rio Grande in New Mexico. The guild represents species that are vulnerable to human perturbations of the physical environment (B. Montoya, in litt.). The Rio Grande silvery minnow may be an indicator of the integrity of the native fish community and may influence future water management.

C. TERRESTRIAL ENVIRONMENT

1. Trends for Hydrologic and Riparian Conditions under Current Management Conditions

Northern (Cochiti and Albuquerque) Reaches of Middle Rio Grande

These reaches will continue to be sediment-poor because of Cochiti and Jemez Canyon dams. The continued restriction of high flows would prevent major floods from scouring large areas and removing vegetation. Bank stabilization by vegetation would continue causing the channel to continue to deepen rather than to broaden. Bed armoring has been observed along some stretches of river in the north, indicating that equilibrium between sediment input and sediment load has been attained. There would be little or no recruitment of native plant species that require open substrate and periodic flooding for germination and growth. There would continue to be senescence and death of cottonwoods and tree willows, with exotic species such as Russian olive, Siberian elm, white mulberry, and others that have potential for germination in the understory, becoming dominant species. Native species in the northern reaches of the Middle Rio Grande Valley would eventually be replaced by Russian olive, Siberian elm, and other nonnative trees.

Southern (Belen and Socorro) Reaches of Middle Rio Grande

This part of the system would continue to be sediment-rich because of input from tributary streams. Because of water controls upstream, there will be a lack of high flows to move those sediments downstream. There will be continued aggradation of the stream channel, resulting in formation of substrate for native and introduced species and burial of young colonies by sediments. Depending on time of high water, native or introduced species will become established on the open substrate. While this area has the highest potential for large-scale recruitment of new cottonwood and willows, it also has high potential, under current water management, for the continued expansion of salt cedar.

Presence of Surface Water, Soil Moisture, and High Water Table

Continued withdrawal of ground water in the floodplain, particularly in the heavily urbanized Albuquerque area, could potentially lower the high water table in the riparian zone and decrease surface water and soil moisture. This drying of the riparian zone could affect marshes, wet meadows, areas with lush herbaceous understory, and even the cottonwoods and willows. Changes in the hydrologic processes described above would reduce populations of a significant variety of vertebrate and invertebrate species, including some of the rarer species which depend on riparian habitats.

2. Habitat Use by Animals within the Plant Communities

Invertebrates

A policy of no active change in management would affect terrestrial invertebrates via shifts in the structure and composition of bosque vegetation, reductions of wetland habitats, and introductions of new species of plants and animals. As cottonwoods continue to die faster than they are replaced, and as introduced trees take their place, there would be a significant decline in the abundance of canopy arthropods. (Studies cited earlier in this document give the strong impression that cottonwoods house a greater number of arthropods than do introduced trees.) The decline in numbers means that the amount of tree-associated high-protein food for foraging vertebrates—in particular birds—will also drop. Thus, if birds and other vertebrates are now food-limited by the availability of canopy arthropods, they are likely to be even more food-limited in the future.

Cottonwood replacement by several other tree species in the same area (e.g., Russian olive, Siberian elm, tree-of-heaven) would provide a more diverse arthropod diet for vertebrates than replacement by a monoculture (e.g., a solid stand of salt cedar). Whether or not the overall diversity of canopy arthropod species will increase or decrease with cottonwood replacement, it will certainly change. What that will mean cannot be easily predicted.

The abundance of ground-dwelling arthropods, on the other hand, would not change appreciably if the expected trajectory of tree distribution continues in the Middle Rio Grande riparian zone. This conclusion is also based on results of studies cited earlier. The species diversity of ground-dwelling arthropods would, as with canopy arthropods, undergo some change. How this would affect vertebrates that forage in leaf litter is unclear.

Continued wetland disappearance would lead to local, if not actual, extinctions of invertebrate species inhabiting their banks. Currently, some of these species seem to be in relict status; at one time they must have been much more broadly distributed in the riparian zone.

Finally, the possibility of new introductions of invertebrate species is very real, as it is for other kinds of organisms. How such introductions would affect the functioning of the ecosystem as a whole remains to be seen. Given past patterns of introductions in the bosque, it is reasonable to expect additions to the diversity of presently existing plant species. That should at least promote herbivore diversity and therefore might have a positive effect on insectivorous vertebrates. On the negative side, arthropods introduced with new plants have the potential to damage established vegetation.

Vertebrates

The continued evolution of the bosque would result in a decrease in cottonwood gallery forest especially in the northern reach. The spatial heterogeneity previously produced by its interspersed successional stages, diverse community types, wetlands, and associated edges and openings would decrease. This decrease would result in a commensurate reduction of species diversity and abundance especially of certain birds. Where salt cedar replaces cottonwood the resulting forest will be more spatially homogeneous, have fewer interior edges shared with other plant communities, particularly wetlands, and have fewer openings. Where several other introduced species replace cottonwood the opposite may be true.

As human use of the bosque increases, the number of human-caused fires would increase. While burning has replaced flooding as the main disturbance factor that creates patches, replacement vegetation will likely be trees other than cottonwood. Therefore, the effects of burning should accelerate the conversion of cottonwood-dominated bosque to one dominated by introduced species.

A loss of spatial heterogeneity could decrease the abundance and diversity of small mammals by reducing in size the following areas (see Table 19):

- Young successional stages of dense herbaceous and shrub vegetation.
- Edges with dense vegetation.
- Areas adjacent to wetlands.

Evaluation of Hink and Ohmart's (1984) findings, which are summarized in Tables 17, 18, and 19 can be used to make general predictions about the future trend of small mammal populations. Abundance and species numbers will remain high in those areas with dense growths of Russian olive and salt cedar particularly when associated with a lush herbaceous understory, near water, and adjacent to upland habitats. The reduction of marshes, wet meadows, and dense willow thickets could reduce populations of tawny-bellied cottonrats, jumping mice, and harvest mice. With the reduction there could be a corresponding increase in populations of white-footed mice. Areas with widely scattered trees and little understory would support small mammal populations with low numbers and with relatively few species.

Cottonwood-dominated forest is preferred habitat for a significant number of bird species. Many of these are summer residents and breeders. Loss or significant reduction in vegetation structure (foliage height diversity) due to the loss of the cottonwood canopy layer, should result in a corresponding decrease in the number of foliage layers that provide varied habitats for birds. Also, the canopy of mature cottonwood forests probably has a higher foliage density and structure than forests of introduced tree species and supports an abundant and diverse biota that is adapted to its particular components. Its reduction would result in a decrease in the abundance of birds that are forest specialists (e.g., cavity nesters), those that are associated with the forest canopy and open understory, and perhaps even those that are associated with a shrub understory.

Because the cottonwood canopy supports a sizeable association of birds, studies suggest that it has a greater number of arthropods that provide high protein for foraging birds than introduced trees do. The association of birds and arthropods in the cottonwood canopy layer is only partially understood. If there is a close association of birds with arthropods in the cottonwood canopy layer, then the diversity and abundance of birds that are attracted by this food source would decline. Bats would also be affected since they also forage in or above the canopy.

Wetlands are extremely limited in the middle valley and have experienced the greatest decline of any floodplain plant community at least since the early 1900's. Wetlands support high numbers of individuals of a particular species, e.g., red-winged blackbirds, and the greatest number of species dependent on any one habitat type (Hink and Ohmart 1984). In addition, this declining habitat supports the greatest number of rare and relict vertebrate species in the Middle Rio Grande Valley including several species of rare plants, leopard frogs, white-faced ibis, black hawks, New Mexico jumping mice, and tawny-bellied cotton rats. Without efforts to maintain them, there would be a continued reduction of wet meadow and marsh habitat for dependent plants and animals as well as the diversity of habitats in the riparian zone and the high use wetland/forest edge.

As cottonwood trees mature and become decadent there would be a temporary increase in snags that provide nesting cavities. This would increase productivity of a variety of cavity nesting birds. However, if the trend for intense fuelwood cutting continues, a large portion of this habitat component will be rapidly removed. Eventually, with the reduction of the cottonwood forest, the number of snags would decrease. Russian olive and Siberian elm stands may not provide the variety of size and height classes of snags to which the present assemblage of cavity nesters has adapted and has available.

Beaver habitat quality would decline in areas where their preferred forage species of young willow and cottonwood is replaced by dense stands of Russian olive, elms, salt cedar, and others. In certain areas beavers would also put more pressure on future dwindling cottonwood/willow trees. Beavers may use Russian olive and other introduced riparian trees, but the forage quality may be lower (Allen 1983). The interior of dense stands of trees would become mostly unavailable for beavers to fell.

3. Disturbance and Fragmentation

Disturbance from flooding has been reduced or eliminated by the man-made, physical constraints in place along the Middle Rio Grande, as well as by management decisions regarding timing and amount of water released from upstream reservoirs. In the northern reach of the river, the deepening channel also reduces opportunities for overbank flooding. Riparian vegetation remains essentially undisturbed by flooding throughout the Middle Rio Grande, particularly in the northern reach above Isleta. Other disturbances, however, do take place. Construction of roads, bridges, and various developments has occurred both inside and outside the levees.

Habitat fragmentation has resulted from much of this disturbance, although certain types of disturbances are more detrimental to plant and animal communities than others. Clearing vegetation for powerlines, for example, allows for a certain amount of regrowth of plants and reuse of the area by animals. Residential development, agricultural conversion, and construction of bridges and roads result in permanent loss of all habitats in the developed area, disruption of animal and plant movement and dispersal, and creation of a continual disturbance that affects plant and animal communities in the adjacent, fragmented portions of the bosque. Habitat fragmentation resulting from these types of development is the most serious.

Burning is another type of disturbance resulting in habitat fragmentation with serious short- and long-term consequences for bosque habitats. Fires in the bosque usually result in the death of cottonwood trees and subsequent invasion by exotic tree and shrub species, including tree-of-heaven, Siberian elm, Russian olive, and salt cedar. The sensitivity of cottonwood trees to fire suggests that the bosque did not evolve under a fire regime. Contrary to conditions found in high-elevation montane forests, where fire (primarily from lightning) has a significant role in ecosystem processes, lower-elevation cottonwood forests are not adapted to survive fires. Most fires in the bosque are the result of human activities, and, like other human-made disturbances, cause habitat fragmentation and disruption. The effects of disturbance by fire, however, are exacerbated by the ability of exotic species to rapidly take over the area where a fire has occurred. Because humans have also interrupted the flooding regime necessary to establish native species in a disturbed area, exotic species will almost inevitably dominate areas that have burned. Lack of flooding has also promoted the build-up of dead material on the forest floor, combined with the invasion of high density salt cedar which is highly flammable, increasing the potential for hotter, more destructive fires (G. Fitch, pers. comm.). Burning fragments the cottonwood bosque, with considerably reduced habitat values for native animal communities.

The cumulative effects of continued fragmentation of the riparian zone would combine with natural cottonwood mortality and reduction of wetlands to reduce diversity, biomass, and productivity of riparian plant and animal communities. Fragmentation of riparian habitat would directly affect those vertebrate species that require large territories. The habitat may be reduced to a size that could no longer support viable populations, thus reducing species diversity. Fragmentation would also reduce the carrying capacity of habitat with a corresponding reduction in species abundance.

Migratory and breeding birds that have adapted to use riparian habitat, especially cottonwood/willow, would be affected. For declining neotropical birds, the connection of riparian habitat in the Southwest, wintering habitat in the tropics, and breeding habitat further north is undoubtedly important, but only partly understood. Any significant reduction of the width of the riparian corridor may have such deleterious effects as increasing the vulnerability of breeding birds to nest predation by brown-headed cowbirds or increasing competition for nesting cavities with European starlings.

4. Ecological Processes

Lack of active change in management would continue to affect a number of ecological processes, including decomposition and nutrient cycling. As stated earlier in this report, introduced Russian olive fixes nitrogen and produces leaf litter that has significantly more nitrogen than cottonwood leaf litter. As a result, soils beneath Russian olive contain more nitrogen than soils beneath cottonwood. A nearly complete takeover of the northern bosque by Russian olive would therefore add increased nitrogen to the apparently nitrogen-limited decomposer community in the non-flooded riparian forest there, and increase the amount of nitrogen available for plant life.

Continued absence of overbank flooding in the northern reach of the Middle Rio Grande riparian zone would allow litter build-up to continue. This would have several consequences. One will be enhancement of fire potential particularly in dry years and decades. Another will be the continued build-up of a soil horizon with an increasingly deep layer of leaf litter above it. While horizon buildup will enhance that habitat for many invertebrates, it will also inhibit the germination of seeds covered over by dead leaves as is now the case.

Another consequence of the lack of flooding would be the continued limiting of storage water in the riparian forest soil (Reily and Johnson 1982 cited in Scott et al. 1993) and recharge of the alluvial aquifer (Johnson et al. 1976 cited in Scott et al. 1993). This will continue to affect the decline of native riparian vegetation.

A further consequence of flooding cessation would be the continued reduction of nutrient transport into the forest by flood waters. This would be less important in the southern reach where flooding would continue to occur due to an aggrading riverbed. Moreover, assuming urban growth in the northern reach causes increasing amounts of nitrogen and phosphorous to enter the river, there could actually be an enrichment of river water below Albuquerque, which could supply nutrients to parts of the bosque that might be flooded to the south. Yet, if the Rio Puerco is dammed, the decline in nutrient-carrying sediments below that river's entry into the Rio Grande ought to offset any such nutrient benefits from the "Albuquerque effect."

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VI. BIOLOGICAL MANAGEMENT RECOMMENDATIONS

A. INTRODUCTION

Having explored and described the historical and existing state of the Middle Rio Grande riparian ecosystem, and having considered the future of the ecosystem if no active change in management takes place, we believe that a comprehensive yet flexible management strategy is necessary to preserve—and to some extent restore—its biological and physical diversity. This assessment goes beyond thinking of the system in purely functional terms. In the foreseeable future there will no doubt continue to be a river channel conveying water that supports riparian vegetation and wildlife. But that simple scenario ignores what most concerned biologists, managers, and citizens in general wish to see maintained, namely the **biological quality** and **ecosystem integrity** of the Middle Rio Grande Valley ecosystem.

As we use the term, biological quality refers to the diversity and abundance of species—especially native species—together with the processes and environments that sustain them. High biological quality, in this sense, describes situations in which relatively large numbers of species occupy a mosaic of patch types over a wide range of spatial scales and for ecologically long periods of time. Many, if not most, of these species should be native to the region (i.e., they would have been present as community components for thousands of years). Periodic natural disturbances such as floods and droughts are expected to disrupt short-term community stability in this situation, but are nevertheless predictable events in the long term. Using these descriptions as criteria, we conclude that comparatively few "high quality" environments presently occur along the middle reach of the Rio Grande. In contrast, "low quality" environments prevail in many places. These are situations in which smaller numbers of native species exist in landscapes characterized by ecological sameness and/or by unnatural disturbances. A heavily cut, burned, and grazed cottonwood forest with little in the way of native understory vegetation or an extensive stand of uninterrupted salt cedar would be examples of a low quality environment.

There are serious constraints to the preservation of cottonwood and other native species along the Middle Rio Grande. Among the most significant of these is the combined effect of past management practices that have altered both the morphology and the hydrology of the Middle Rio Grande. These practices, discussed in detail earlier in this document, were put in place for reasons associated with optimizing human use and management of the river and its resources. Utility and flood protection, not aesthetics or ecology, were the underlying criteria at the time. The long-term ecological consequences of these practices, especially as they applied to the survival of native species, were rarely known, much less considered. Now, however, with increased knowledge, these consequences are of greater concern. In our recommendations, we will not necessarily suggest elimination of such constraining management practices; rather, we will propose sometimes creative modifications that can be implemented with few effects on flood control, irrigation, and ground-water drainage.

Another constraint is the introduction of nonnative species. Without question, much of the present diversity of plants in the bosque and fish in the river, is due to the presence of introduced species. To exterminate even a small number of these species would be economically prohibitive and ecologically disruptive. Besides, they are now functional components of the ecosystem and add to its biodiversity, regardless of how people feel about them. The important point here is that some of them (e.g., salt cedar, bullfrogs) need to be managed, while others (e.g., white clover, terrestrial isopods) probably do not. An important criterion for management should be whether or not the introduced organisms negatively impact native species such as cottonwoods and leopard frogs.

Finally, and perhaps most importantly, institutional constraints must be considered. Human institutions manage the Middle Rio Grande riparian ecosystem and human communities populate its floodplain. From the standpoint of maintaining biological quality, human beings, most of whom are recent introductions, are the ecosystem's dominant element. It is with human institutions, therefore, that all management recommendations must ultimately deal. Our Bosque Biological Management Plan takes this approach.

B. RECOMMENDATIONS

The team foresees the boundaries of the Middle Rio Grande bosque as not only being protected from development but also expanded in the future. In addition to protection, the restoration and maintenance of ecosystem processes are fundamental to this biological management plan. We envision a perennial Rio Grande whose flows mimic the natural hydrograph to the maximum extent possible, and a river channel that is permitted maximum freedom within the floodway. The attainment of these basic conditions will facilitate the achievement of all other recommendations to enhance the biological quality and ecosystem integrity of the bosque.

Hydrology

Water is the key variable that drives the processes of the riparian ecosystem. Prior to the extensive human changes in the river system, water performed the work of providing habitat, moisture, and nutrients for riparian organisms' reproduction and survival. We believe that water can be managed to allow it to continue to do as much of this work as possible with minimal human interference. Whenever water cannot do its work, people will have to attempt to replace vital, missing functions and processes in the ecosystem. The following three recommendations are closely interrelated and deal with management of surface and ground water in the Middle Rio Grande:

1. Coordinate Rio Grande water management activities to support and improve the bosque's riverine and terrestrial habitats, with special emphasis placed on mimicking typical natural hydrographs.

2. Implement measures to allow fluvial processes to occur within the river channel and the adjacent bosque to the extent possible.

3. Reintroduce the dynamics of surface-water/ground-water exchange, manage ground-water withdrawal, and restrict contamination.

Aquatic Resources

Recommendations about aquatic resources overlap and are related to those for hydrology, but focus on communities and species that are primarily dependent on the presence of surface water either throughout or at critical times during their life history. Water must also be of high enough quality to enable organisms ranging from single-celled to more complex plants and animals to use the resource without toxic effects. In addition to this, recommendations relating to aquatic resources consider habitat and the introduction of nonnative species into the waters of the Rio Grande and associated wetlands. The recommendations are as follows:

4. Protect, extend, and enhance the structure of the aquatic habitat to the benefit of native communities.

5. Protect and enhance surface-water quality.

6. Integrate management of nonnative and native fish species in all aquatic environments in the Middle Rio Grande riparian ecosystem including wetlands, canals, and drains.

Terrestrial Resources

Recommendations affecting terrestrial resources in the riparian ecosystem focus on protection, enhancement, and restoration of communities and habitats in the riparian zone and the floodplain. Human activities have severely impacted these portions of the riparian ecosystem. The effect of water in important ecosystem processes (e.g., disturbance, nutrient cycling, reproduction of native species, etc.) has been reduced by dams and levees that protect a highly developed floodplain. In addition, introduced species have entered plant and animal communities and become major components of the ecosystem. It is in the terrestrial portion of the ecosystem that there are the most visible needs for management, in order to replace the ecosystem processes that have been eliminated or diminished in force and scale and to protect the remaining communities from detrimental human activities. The following recommendations address management needs:

7. Protect the geographic extent of the Rio Grande bosque and avoid fragmentation of the riparian ecosystem and component habitats.

8. Protect, extend, and enhance riparian vegetation in noncontiguous areas in the floodplain.

9. Manage the buffer zone of the contiguous bosque to protect ecosystem processes, enhance wildlife habitat values, and maintain rural and semirural conditions.

10. Manage livestock grazing activities in a manner compatible with biological quality and ecosystem integrity.

11. Manage activities that remove dead wood in a manner compatible with biological quality and ecosystem integrity.

12. Manage recreational activities in the bosque in a manner compatible with biological quality and ecosystem integrity.

13. Prevent unmanaged fires in all reaches of the bosque.

14. Use native plant species and local genetic stock in vegetation establishment and management efforts throughout the bosque.

15. Protect, enhance, and extend (create) wetlands throughout the Middle Rio Grande riparian zone.

16. Sustain and enhance existing cottonwood communities, and create new native cottonwood communities wherever possible throughout the Middle Rio Grande riparian zone.

17. Contain the expansion of existing large stands of nonnative vegetation in the Middle Rio Grande riparian zone. At the same time, study the ecology of these stands and develop creative ways of maximizing their biological values.

Monitoring and Research

Monitoring to determine the effects of management actions is vital to the implementation of all recommendations included in this document. In addition, monitoring studies are needed to assess the ecological trends in the bosque over a long period of time as well as to provide information about the life histories of individual species. Monitoring information can be used in developing research goals that specifically address management problems. Research related to management questions should be pursued, but research addressing purely scientific goals should also be encouraged. Both research approaches will generate information that can be applied to management issues. We have made two recommendations relating to these topics:

18. Develop a coordinated program to monitor biological quality (with emphasis on diversity and abundance of native species) and ecosystem integrity (with emphasis on restoring the functional connection between the river and riparian zone) of the Middle Rio Grande ecosystem.

19. Develop a coordinated research program to study the ecological processes and biotic communities that characterize the Middle Rio Grande riparian ecosystem.

Implementing and Revising the Biological Management Plan

Management of the Middle Rio Grande as an ecosystem requires an integrated approach. The key factors in this approach are communication among agencies and other management entities and coordination of activities that have to do with the river, riparian zone, and floodplain. Monitoring and research generate data that need to be compiled and analyzed for application to future management activities, management plan revisions, and guidance for research.

20. Regularly review and update the Middle Rio Grande Ecosystem: Bosque Biological Management Plan.

The Middle Rio Grande—Part of a Larger Riparian System

The Middle Rio Grande is only a portion of the total river system, and includes a small fraction of the entire watershed. This part of the river is dependent on what enters the system upstream, and how we manage our section affects the river downstream. While we have attempted to take an ecosystem approach to management of the Middle Rio Grande, we recognize that to be truly comprehensive, the whole river and its watershed should be included. The final recommendation deals with how this management plan could be readily adapted to fit into a larger management scheme for the entire Rio Grande.

21. Integrate resource management activities along the Rio Grande and within the contributing watersheds to protect and enhance biological quality and ecosystem integrity.

Guide to Issues and Recommendations

Table 28 includes generalized issues and the recommendations that address those issues. The table can be used as a guide to the particular recommendations that address issues of concern to the reader. The reader can also use the table as a rough guide to the contents of a particular recommendation. Within each recommendation is a listing of agencies, municipalities, businesses, groups, or individuals with expertise or information relating to that recommendation. Addresses for these organizations are found in Appendix IV.

Table 28. Guide to issues and recommendations.

RECOMMENDATIONS	ISSUES: Water Releases	Surface/Ground-Water Relations	Surface-Water Quality	Flooding	Native Fish Communities	Sportfish	Protection of Bosque	Agriculture	Buffer Zone	Grazing	Firewood	Recreation	Vehicular Traffic	Revegetation	Wetlands	Nonnative Plant Species	Monitoring	Research	Plan Revisions	Future Directions
1 Mimic Natural Hydrographs	X	X		X	X									X		X	X	X		
2 Allow Fluvial Processes	X	X		X	X									X	X	X	X	X		
3 Restore Surface/Ground-water Dynamics	X	X	X	X				X	X						X	X	X	X		
4 Protect Structure of Aquatic Habitats	X				X												X	X		
5 Protect/enhance Surface-water quality			X		X	X	X	X	X	X				X	X		X	X		
6 Integrate Native/Nonnative Fish Management	X		X		X	X											X	X		
7 Protect Extent/Avoid Fragmentation of Bosque		X	X				X		X	X	X	X	X			X	X	X		
8 Protect/Extend Non-contiguous Bosque		X	X				X	X	X	X	X	X	X	X		X	X	X		
9 Manage Buffer Zone		X	X	X			X	X	X	X					X	X	X	X		
10 Manage Livestock Grazing			X					X	X	X				X		X	X	X		
11 Manage Dead Wood Removal				X			X				X		X	X			X	X		
12 Manage Recreation							X		X			X	X				X	X		
13 Prevent Fires							X				X	X	X	X		X	X	X		
14 Use Native Species/Local Stock in Revegetation							X							X	X	X	X	X		
15 Protect/Extend Wetlands	X	X	X	X											X	X	X	X		
16 Sustain/Create Cottonwood Communities	X	X	X	X			X							X		X	X	X		
17 Contain Expansion of Nonnative Species	X			X										X			X	X		
18 Develop Coordinated Monitoring	X	X	X	X	X		X		X	X	X	X	X	X	X	X	X		X	X
19 Develop Coordinated Research	X	X	X	X	X	X	X		X	X	X	X		X	X	X		X	X	X
20 Review and Update Plan																	X	X	X	X
21			X					X		X						X	X	X	X	X

RECOMMENDATION 1: Coordinate Rio Grande water management activities to support and improve the bosque's riverine and terrestrial habitats, with special emphasis on mimicking typical natural hydrographs.

Need: As documented in this plan, there has been a decline in abundance and diversity of native species in the Rio Grande riparian ecosystem. The reproductive strategies of riparian species are strongly linked to the river's natural hydrograph—its characteristic rise and fall. The decline of riparian species has coincided with the increasing control over water in the river, which has resulted in changes in amount of peak runoff, duration of high water periods, summer and autumnal spikes in response to thunderstorms, and perennial flows. There is a need to restore or mimic, to the extent possible, the natural hydrograph that was characteristic of the Rio Grande prior to construction of dams in the watershed in order to support the continued survival of river-dependent organisms.

Description of Recommendation: Water management releases from Cochiti and Jemez Canyon dams should continue to follow the spring runoff, with gradual decline after the peak (see sections on hydrology, current hydrological regime and its effects on the riparian vegetation, and aquatic organisms and habitat). Using runoff as the annual cue for releases of water from Cochiti and Jemez Canyon dams allows the present water management system to mimic the natural flows that existed prior to dam construction. These should be tied each year to existing runoff conditions. Releases of water from Cochiti and Jemez Canyon dams during periods not associated with high natural flows, such as winter releases, should be avoided, if possible, or managed to minimize unseasonal impacts on downstream terrestrial and riverine communities.

Opportunities and Constraints: It is fortunate that Cochiti and Jemez Canyon dams are operated for the purposes of flood control rather than for water storage and generation of hydroelectric power. Hydroelectric generation requires release of stored water, with daily and seasonal fluctuations based on need for electric power. The resulting river flows are distinctly different than the natural flows of most western rivers, which respond to seasonal runoff and precipitation. As presently operated, water releases from Cochiti and Jemez Canyon dams allow the river to partially resemble its pre-dam condition although changes in peak flows, duration of runoff, and presence of high water in winter have altered the riverine and riparian systems.

Benefits which may result from operating dams in a manner that reflects the runoff are seasonal flooding along some parts of the river, contributions to the seasonal recharge of ground-water tables throughout the middle valley, and seasonal movement of sediments and shifting of channels. These peaks of water availability and physical changes in the river channel influence riparian species' survival and the composition of riparian communities. Species and communities, ranging from those found in the hyporheic zone through native fishes to those in terrestrial habitats, should also benefit from this type of water management.

There are serious constraints on the present water management system that prevent full realization of recreating the natural hydrograph in rate of flow and duration. Because of development in the floodplain of the Rio Grande, construction of levees, and restrictions in the river channel, the capacity of the existing waterway to transport large floods (>10,000 cfs) is greatly diminished. Thus, the ability of the river to scour portions of the floodplain and to transport large sediment loads to new locations is also diminished as are opportunities for overbank flows. Because of this, creation of new habitats for native aquatic and terrestrial organisms has decreased.

Operational criteria for the COE dams are set forth in federal law. Some operational latitude is allowed contingent upon endorsement by the Rio Grande Compact Commission. Should any significant alteration of the COE's operational regime be recommended to enhance biological values, it is likely that a change in federal legislation would be required. Likewise, the delivery of San Juan-Chama Project water must be in accordance with federal law, contracts between water users and BOR, state water laws, and terms of the Rio Grande Compact. Within these confines, however, there is some flexibility for adjusting deliveries.

Implementation Considerations: The COE currently releases flows from Cochiti and Jemez Canyon dams which mimic the natural hydrologic regime of the river to a certain extent. Operation of the dams under existing mandates and constraints requires this type of release. We recommend that this practice be refined and continued. Releases not coordinated with runoff may have a negative effect on the native fish fauna if the time, magnitude, and duration of the releases do not mimic natural, seasonal flow events.

Action: We recommend that water be released from Cochiti and Jemez Canyon dams in such a way as to mimic natural flows in the river. This includes coordinating releases with inflows from upstream runoff. Length of peak flow and amount of release should continue to be adjusted to runoff. The stepdown of releases from peak flow to maintenance flow should be incremental, based on amount and duration of runoff, as well as comparison to monthly averages of discharge at Otowi Bridge for duration of measurement (see hydrology and geomorphology in the Existing Conditions section).

At a minimum, channel capacity should be maintained at 8,000-10,000 cfs and increased if possible. Further restrictions on channel capacity should be avoided. Development in the floodplain adjacent to the river (e.g., the residence recently built within the 2-year floodplain near Socorro) will increase the risk of damage to human lives and properties from uncontrolled flooding due to tributary sources and will seriously diminish management options for controlled releases from upstream dams.

Prior to the late 1800's, when increased diversions for agriculture caused portions of the river to dry up (see Historical Conditions section), the Rio Grande probably flowed year-round. Since the 1800's, the river has continued to be dry in some areas during irrigation season in some years (see U.S. Bureau of Reclamation 1977). Opportunities to maintain perennial flows in the Middle Rio Grande should be actively pursued, and agreements negotiated and signed. A recent example of this type of action is the agreement reached between the City of Albuquerque and the MRGCD to maintain over the next 10 years a minimum flow of 250 cfs as measured at the Albuquerque gauge during irrigation season.

Monitoring and Research: The greatest need is to develop an interactive hydrologic model for the Middle Rio Grande that can be used in developing and evaluating water management alternatives. The model should be designed so that it can be adapted to multiple uses and be compatible with other hydrologic models in the Rio Grande Basin. The relationship of discharge to channel depth, overbank flooding, ground-water depth and recharge, evaporation, transpiration, and other relevant characteristics should be included in future studies. The relationship between river flows and native fish species and their habitat should be studied (see Recommendation 4 on aquatic habitats).

Agencies Currently Investigating Rio Grande Flow Regimes and/or Involved in Hydrologic Modeling:

City of Albuquerque Department of Public Works
New Mexico Bureau of Mines and Mineral Resources
New Mexico Interstate Stream Commission
U.S. Geological Survey
U.S. Bureau of Reclamation, Albuquerque Projects Office
U.S. Army Corps of Engineers, Albuquerque District Office
U.S. Fish and Wildlife Service, Region 2
U.S. Fish and Wildlife Service, National Ecology Research Center

RECOMMENDATION 2: Implement measures to allow fluvial processes to occur within the river channel and the adjacent bosque to the extent possible.

Need: The Rio Grande is highly controlled and physically altered in the Middle Rio Grande Valley. The normal fluvial processes that maintained the aquatic and riparian communities of the Rio Grande in the past, such as flooding, channel meandering, and sediment transport and deposition, have been diminished or eliminated by water management structures and activities. The Rio Grande should be allowed to recreate fluvial processes as much as possible; because whatever work the river cannot do to support ecosystem process and riparian communities, we will have to attempt to provide.

Description of Recommendation: In the full range of the management spectrum, possibilities include placing virtually no controls on the river to converting the river into a riprap lined, straightened channel. This recommendation tends to deal with those options and possibilities that are somewhere in the middle of this spectrum.

In some areas, levees could be moved or removed to expand the influence of the river. Building new levees in areas where none now exist should be avoided. Development should be restricted in areas that are likely to flood, and lands should be acquired (from willing sellers only) in the floodplain adjacent to the river. These areas could then be managed as riparian zone and floodplain habitat for native riparian plant and animal communities. The most likely possibilities for these management options are in the Belen and Socorro reaches of the Rio Grande. There, sediment input from major tributaries (and other factors) has caused the river to become broader and shallower than in the other reaches of the river, and in some areas there are no existing levees on the east side of the river.

In areas where it is not possible to expand the influence of the river outside the existing levee system, the Rio Grande should be allowed to find its own course within the floodway to the greatest extent possible. Ongoing management could be modified to encourage disturbance and instability inside the levees, thereby creating suitable sites for the reproduction of native riparian plant species. Potential modifications to management include ceasing to use jetty jacks for channel modification and stabilization, and using vegetation stabilization instead of riprap where feasible at erosional points. Sediment plugs or portions of them could be allowed to remain in place to provide sediment for riparian processes.

Constricting or inhibiting flows during construction of new facilities and modification of existing ones should be avoided. Existing structures (e.g., railroad embankments, bridges, headgates, etc.) that restrict the amount of water released into the channel should be moved or modified to allow higher peak flows to be released from dams without damage.

River and land management activities continue to affect the sediment inflow to the Middle Rio Grande, which in turn directly influences the channel morphology. The upper reaches, especially Cochiti, now have an incised river channel partly due to the capturing of sediment behind dams. This has greatly reduced the potential for overbank flows from controlled releases. The San Acacia Reach in the south, on the other hand, is experiencing significant sediment loading, primarily from the Rio Puerco. This contributes to decreased channel capacity, which influences maximum flows the channel can handle.

The effects of sediment inflows on the fluvial processes and the adjacent bosque vegetation need to be included in sediment and river channel management decisions. The Middle Rio Grande historically has been an aggrading river. This systematic aggradation provided conditions for the bosque to fluctuate both spatially and temporally in the middle valley. Recent water and river management has stabilized the depth of the river channel in the Cochiti Reach. This stabilization is proceeding through the Albuquerque Reach and may continue on through a portion of the Belen Reach. Below the confluence with the Rio Salado, the riverbed continues to aggrade. In the Socorro Reach, no river management activities should be undertaken to reverse channel aggradation although aggradation likely will have to be managed. In addition, the benefits of specific sediment management decisions on the Rio Grande have to be balanced with the needs of the contributing watersheds. We recommend that sediment be managed in the upper reaches in such a manner as to allow *localized* channel instability.

Wetlands can be created or constructed either inside or outside the levees. In the past, fluvial processes caused wetlands in old oxbows, areas of high water table, and side channels which carried water during flood stages. Allowing fluvial processes to take place in the floodway and in areas without levees may increase wetlands and aquatic habitat without human intervention.

The BOR's Low Flow Conveyance Channel is designed to direct 2,000 cfs of water from the river in the Socorro and San Marcial reaches under certain flow conditions. We recommend that the purpose of construction and use of the channel be reevaluated in the context of concerns about the Rio Grande riparian ecosystem.

Ultimately, it may be possible to develop a biological management plan that includes the establishment of areas where, by a combination of land acquisition (from willing sellers) and modifications of existing management, the river will be allowed to run its course in portions of the floodplain. Removal or repositioning of levees in some areas and strengthening of them (and other structures) in areas where flooding would be destructive to lives or property would be major factors in the accomplishment of such a plan.

At one extreme of the management spectrum, we could recommend that all restraints on the river, including levees and dams, be removed. This would allow the river to influence the riverine, riparian, and floodplain zones as it did in the past. It would mean removing farms, houses, businesses, roads, and other infrastructure elements from the river's path on the floodplain, or accepting their presence there at great risk. Wetlands and bosque would be allowed to slow and absorb flood waters and release them gradually into the river. Allowing the floodplain to accommodate seasonal flooding may be the best way to live with a major river. However, this option would require changes in our society's values and commitment of significant resources to managing development on the floodplain rather than following current courses of action.

Opportunities and Constraints: Water managers at the federal, state, and local levels have authority to determine the feasibility of these ideas and to implement the options included in this recommendation. Some options could be addressed on an experimental basis to assess their practicality for use on the river. The constraints in the system are private property rights, public safety, and the need to fulfill water obligations to users.

Implementation Considerations: Should the feasibility of implementing some of the structural solutions, such as relocating levees, be established, monetary costs may become a constraint. Ultimately it would be societal values and willingness to publicly finance such endeavors that would decide whether or not to proceed.

Action: Agencies should review their current management guidelines and identify opportunities that allow fluvial processes to occur without, or with reduced, interference. They should also review upcoming rehabilitation and maintenance activities that may provide opportunities to remove impediments to high peak flows. Efforts to identify areas with potential for flooding should begin. Depending on ownership, these areas could be targeted for conservation easements, or acquisition (where indicated). Agencies should also complete a reevaluation of the Low Flow Conveyance Channel to determine its compatibility with the concepts of riparian ecosystem management.

Monitoring and Research: Agencies can begin conducting experimental removal of jetty jacks in some areas (perhaps in some places where vegetation has not become densely intertwined) to see if water will cause disturbance and consequent recolonization of native species. Experiments using material such as root wads and vegetation plantings for bank stabilization, instead of riprap, should begin. Experiments with high release flows (most recently up to 7,500 cfs) should continue; these could be coordinated with river profile studies to predict areas of highest potential for overbank flooding and the locations where the infrastructure of river controls is weakest. Any proposal to modify the degree of sediment loading in the Middle Rio Grande would require a comprehensive evaluation not only of the implications for the river channel and the riparian ecosystem but also of impacts on the contributing watersheds. Models predicting the river's sinuosity within existing constraints should be developed. This will provide information needed for future comprehensive river and floodplain management that will allow the river as much freedom as possible in affecting its ecosystem.

Agencies with Experience in Managing River Channel Characteristics:

U.S. Army Corps of Engineers
U.S. Bureau of Reclamation
The Nature Conservancy, Boulder, Colorado

RECOMMENDATION 3: Reintroduce the dynamics of surface-water/ground-water exchange, manage ground-water withdrawal, and restrict contamination.

Need: There is a need to reestablish the historic association between ground water and overbank flooding in order to assure availability of water and to promote nutrient availability for bosque vegetation. Recent evidence indicates that the bosque may be severely nitrogen-limited when not flooded for decades. Overbank flooding appears to oxygenate ground water and generate an energy source (dissolved organic carbon in rapidly rising ground water) that allows soil nitrogen to be mobilized.

Another need is to restrict ground-water withdrawal unless rapid recharge is assured. In the Albuquerque area, ground-water withdrawal for municipal use has already reversed the direction of its flow in some areas; and increased withdrawal by a swelling population is likely to lower the water table in the floodplain. Native trees and shrubs in the riparian zone are more susceptible to the lowering of ground-water levels than are nonnative species. Thus a lowered water table in the bosque could negatively affect the already unfavorable relationship between native and introduced woody vegetation. It could also jeopardize the existence of the few remaining wetlands in the riparian zone.

An additional need is to restrict ground-water contamination from point and nonpoint sources throughout the inner valley. Such contamination tends to increase in proportion to the size of the human population, which gives the problem added urgency. Because of the nature of the valley's topography and soils, movement of contaminants in ground water can be rapid. These materials have potentially degrading effects on terrestrial and aquatic communities.

Description of Recommendation: Localized (spot) flooding should be considered as a management tool in order to mobilize nutrients, via elevated ground water, in the bosque. Diversion and/or drain water can be used for this purpose, as can water channelled from the river during periods of high flow. Appropriate use of ditches and groin dikes with stop-log structures controls flows and backs up water to create flood conditions. During low flows, flood water can be channelled back to the river from flooded areas if so desired.

No additional ground-water withdrawal programs should be undertaken that lower ground-water levels in the riparian zone until a comprehensive assessment of the biological impacts has been completed. Special care needs to be taken that municipal water supply systems and irrigation delivery systems do not lower ground-water levels in the bosque and wetlands. Management of local ground-water levels to the benefit of native riparian vegetation and wetlands should be considered in conjunction with wastewater treatment and agricultural practices.

The effects of urban turfgrass watering on ground-water levels needs to be studied. The enormous amount of water currently used in Albuquerque for turfgrass watering needs to be reconsidered in light of the area's potential for xeriscaping parks and residences.

Existing federal, state, municipal, pueblo, and local controls on protecting ground-water quality should be rigorously enforced, especially in the floodplain where ground water is most vulnerable to contamination. Adequate alternatives to septic tank/field systems currently serving high density residential areas should be developed and put in place.

An integrated system of observation wells should be established in the riparian zone to monitor ground-water levels and quality. This system should take full advantage of existing wells. Additional research addressing the impacts of agriculture on ground water, similar to that sponsored by the Resource Conservation and Development Council and the BOR in the Las Nutrias area, should be encouraged.

Opportunities and Constraints: Opportunities to initiate spot flooding are greatest in areas where water delivery can be readily arranged within the existing framework of water allocation along the Rio Grande. Experienced personnel at Bosque del Apache NWR can give expert advice on the subject. However, earth moving and dike construction are not inexpensive matter and involve the use of heavy equipment. New Mexico State Parks and Recreation Division has used above-ground irrigation pipe to supply water to areas at the Rio Grande Nature Center.

There are readily available opportunities to expand our understanding of the inner valley's shallow ground-water system. Currently, a number of agencies and entities (e.g., City of Albuquerque, New Mexico Bureau of Mines and Mineral Resources, USGS, BOR, FWS, UNM) are studying various aspects of this system throughout the Middle Rio Grande Valley. The challenge is to expand the present ad hoc forums and to provide a practical long-term mechanism for these groups to coordinate their activities and secure funding for those aspects not being addressed.

The MRGCD's existing irrigation water delivery and drain infrastructure presents the best immediate opportunity to manage shallow ground-water levels. The challenge is to balance the management of this system with other traditional and nontraditional needs.

Implementation Considerations: State water law would have to be considered in any activity that deviates from current management practices.

Action: Agencies should evaluate current management practices for opportunities to use flooding at the appropriate time of year in order to enhance ecosystem processes.

Monitoring and Research: Monitoring of the response of ground water to flow releases from upstream dams should begin. This monitoring should continue at intervals throughout the year and consider seasonal changes in ground water. Flow release information should be coordinated with ground-water information. Research on the hyporheic zone and its possible dependence on ground-water recharge from all sources should begin. This information should be part of data collection for the interactive hydrologic model called for in Recommendation 1.

Agencies with Experience in Surface-water/Ground-water Relationships:

Middle Rio Grande Conservancy District
New Mexico State Parks and Recreation Division
U.S. Fish and Wildlife Service, Bosque del Apache National Wildlife Refuge

U.S. Fish and Wildlife Service, National Ecology Research Center
U.S. Bureau of Reclamation
U.S. Geological Survey
The Nature Conservancy, Boulder, Colorado
City of Albuquerque

RECOMMENDATION 4: Protect, extend, and enhance the structure of aquatic habitat to the benefit of native communities.

Need: Loss of riverine habitat, especially native aquatic habitat, is a major problem in warmwater streams of the Southwest. The complexity of aquatic habitat in the Middle Rio Grande has been impacted by human perturbations such as main channel storage and diversion structures, flow regime alterations, and channel maintenance activities. Loss of habitat equates directly with a decrease in carrying capacity and a concomitant reduction in diversity and abundance of aquatic communities. The current noncontiguous distribution of the Rio Grande silvery minnow suggests a reduction and fragmentation of aquatic habitat in the Middle Rio Grande. The replacement of native habitat with disturbance-induced habitat often selects against native species. The preservation and enhancement of native aquatic habitat are critical in maintaining viable native aquatic communities.

Description of Recommendation: *Prevent the loss of native aquatic habitat*—Recent studies (Platania 1993) have attempted to quantify the distribution of aquatic habitat in the Middle Rio Grande by river reach. Research is also underway to identify the fish use of aquatic habitat throughout the Middle Rio Grande. Currently, however, we do not know all the habitat requirements of all native fish (e.g., Rio Grande silvery minnow). Invertebrate use of specific aquatic habitat is only generally known. Native aquatic organisms have likely adapted to and thrive in selected native aquatic habitats. It is therefore important to preserve the integrity of native aquatic habitat to the greatest extent possible because the magnitude of impact of habitat loss on native communities is unclear.

Habitat loss can occur from physical disturbances or changes in hydrology. Habitat loss due to human or natural disturbance is generally more apparent. However, as mentioned, changes in flow patterns can have both short- and long-term impacts on available aquatic habitat. Thus, water management agencies should attempt to maintain the spatial and temporal availability of native aquatic habitat by maintaining the patterns and variability of the natural hydrograph.

Channel maintenance activities should be minimized and directed to maintain and expand aquatic habitat conditions. Cessation of pilot channeling in the 1980's significantly reduced degradation of the aquatic ecosystem. The extent of current bank stabilization should be restricted to high priority areas to alleviate potential cumulative impacts. Environmentally sensitive and innovative methods of bank stabilization should be considered.

Enhance and create aquatic habitat where appropriate—In some cases, physical modifications are required to restore aquatic habitat that has been lost to channel perturbations. These opportunities should be pursued with consideration of species and life stage selectivity and community equilibrium. The riparian ecosystem will respond differently to modifications due to a new environmental baseline based on both natural and human stressors. For example, even the restoration of a native habitat type may now favor nonnative species. Backwaters created in the Cochiti Reach seasonally support abundant populations of nonnative, predatory white crappie. Habitat enhancements should be designed to meet habitat needs of native species while selecting against nonnative species.

Opportunities and Constraints: Opportunities include the management of flows to meet both aquatic and terrestrial needs. High flows that are needed to benefit riparian areas also provide critical habitat for various life stages of aquatic communities. The timing and duration of different flow regimes will affect habitat utility (see Recommendation 1 on mimicking natural hydrographs).

Bureau of Reclamation river maintenance activities provide an opportunity to integrate the goals of efficient sediment transport, floodplain protection, and habitat enhancement. The use of environmentally sound maintenance techniques that benefit native species should be encouraged.

Current river management objectives often conflict with the preservation and maintenance of aquatic habitat. Habitat should be created and maintained through natural processes whenever possible. However, when artificial modifications to the system occur, priority should be assigned to protection of native aquatic habitat and species.

Implementation Considerations: Cumulative effects of channel maintenance activities must be considered. The benefits of bank stabilization must be balanced with potential costs, such as localized loss and/or fragmentation of shoreline habitat.

Current enhancement practices, such as construction of groins, boulder groupings, backwaters, etc., provide additional aquatic habitats but must be continually assessed relative to their effectiveness in supporting native communities. Also, the longevity of these structures should be monitored. Alternative techniques, such as using natural material (e.g., trees and root wads) in bank stabilization, should be explored.

Relationships need to be developed between varying flow regimes and availability of aquatic habitat. The appropriate level of resolution of this analysis must be considered and should account for reach-specific and seasonal variability. Water management agencies will require some level of predictability when attempting to benefit native aquatic habitat and species with management activities.

Management goals should be continually reevaluated to identify areas of flexibility within which aquatic habitat can be protected. Physical creation of habitat should be approached cautiously to assure that needs of the target species, population, or community are met. Consultation with a qualified aquatic biologist is important prior to any modification or enhancement.

Prior to any channel maintenance or enhancement activities, all sites should be evaluated for occurrence of the Rio Grande silvery minnow, a species proposed for listing under the Endangered Species Act. Consideration should be given to the Rio Grande silvery minnow, as appropriate, when protecting and enhancing aquatic habitat.

Action: Agencies should develop aquatic habitat enhancement and creation guidelines for specific reaches of the river. The guidelines should encourage activities that are appropriate for local aquatic habitat conditions and that will support existing native communities.

Monitoring and Research: Studies are currently being developed to identify habitat requirements of the Rio Grande silvery minnow. This ongoing research will further quantify the availability and use of aquatic habitat and should be supported. Long-term monitoring of aquatic habitat in the Middle Rio Grande should be established to assess temporal and spatial variations in habitat, especially as environmental baseline conditions change over time. This could be a multiple agency/entity effort.

An additional monitoring priority will be the long-term evaluation of specific construction sites to assess impacts of management actions and mitigation efforts on aquatic habitat and species. The BOR and COE could be lead agencies in this effort.

Research opportunities are as follows: (1) develop relationships between varying flow regimes and aquatic habitat availability, (2) quantify the habitat use of all native fish species, especially the Rio Grande silvery minnow, (3) study invertebrate use of different habitat types, (4) quantify the vegetative component of aquatic habitat when applicable, and (5) study short- and long-term impacts of physical habitat enhancement and creation. Specific consideration should be given to species and life stage selectivity and community equilibrium.

Agencies with Aquatic Habitat Protection and Enhancement Experience:

New Mexico Department of Game and Fish
U.S. Fish and Wildlife Service, New Mexico State Ecological Services Field Office
U.S. Bureau of Reclamation
U.S. Army Corps of Engineers

RECOMMENDATION 5: Protect and enhance surface-water quality.

Need: Surface-water quality in the Middle Rio Grande has been altered over the last century due to mainstream dams and diversions, watershed development, and point and nonpoint sources of pollution. Surface-water quality is a key component of the riparian ecosystem affecting not only riverine resources but also influencing the riparian zone, wetlands, and ground-water chemistry.

Current baseline surface-water quality levels appear to be within the tolerance limits of most aquatic communities; however, extreme conditions may subject organisms to increased stress and possibly mortality. Wastewater treatment facility discharges, increasing urban runoff, and discharge of agricultural waters via drains have the potential to create suboptimal conditions for aquatic communities. Nonpoint sources of urban storm-water runoff have been shown to increase loading of coliform fecal bacteria and total suspended solids within the Albuquerque Reach (Tague and Drypolcher 1979). Also, wastewater effluent may contain elevated concentrations of ammonia, chlorine, and other constituents. Contaminant levels of irrigation return water are unknown. These potential water quality problems may also be exacerbated during periods of low flow.

Description of Recommendation: *Provide sufficient flows in critical reaches of the river during specific times of the year to alleviate water quality problems*—Water quality is a special concern during periods of low flow when the river becomes spatially intermittent and fish are confined in isolated pools. Concentration of pollutants and extreme fluctuations in physical water quality parameters, such as temperature and dissolved oxygen, elevate stress levels in aquatic organisms and reduce survivability. Baseflows that would maintain a continuous wetted channel in critical reaches during specified time periods could alleviate water quality problems.

Develop a model to simulate spatial and temporal variation in water quality parameters—The water quality model should incorporate both natural and human influences and should be responsive to varying flow regimes. A water quality model is an essential component of a larger system-wide operations/hydrology model. The model should also be interactive and capable of answering "what if" management questions.

Consider the use of riparian forests and/or wetlands as buffers to reduce the impacts of point and nonpoint pollution—Recent studies have shown that riparian forests can remove large amounts of dissolved nitrates and phosphorous from surface runoff (Chauvet and Décamps 1989, Gregory et al. 1991). Studies to determine the utility of these natural ecosystem components in the treatment of effluent discharges should be encouraged. These and other proactive strategies may help prevent further degradation of surface-water quality.

Integrative water quality based programs should be supported—The FWS has created the Biomonitoring for Environmental Status and Trends (BEST) program to evaluate, anticipate, and minimize the effects of environmental contaminants on natural resources. The City of Albuquerque is conducting a Use Attainability Analysis (UAA) to assess the factors affecting the attainment of designated uses of surface water in the Middle Rio Grande. The USGS National Water Quality Assessment (NAWQUA) program is designed to inventory and monitor the quality of the nation's water resources. All of these programs use a holistic, "ecosystem," approach to water quality monitoring, integrating both physical habitats and biological resources.

Evaluate the limited warmwater fishery use designation for Section 2-105 of the New Mexico Water Quality Standards—The reach of the Middle Rio Grande from Alameda Bridge to the headwaters of Elephant Butte Reservoir, Section 2-105, is designated to support a limited warmwater fishery. A warmwater fishery use designation usually represents an associated sportfishery. The sportfishery interpretation does not apply to the reaches of the Middle Rio Grande below the Cochiti Dam tailwater. Current state and federal management activities within this reach address native warmwater fisheries.

Opportunities and Constraints: Factors influencing water quality in any river system are very complex. Attempting to analyze system variability and specific sources of system inputs to determine impacts is a difficult task. Knowledge of all sources of input to the system, as required in a water quality model, is critical when determining causative agents of localized impacts. A comprehensive approach to water quality management provides the opportunity to address the interrelatedness of all activities on water quality.

Given the water management infrastructure of the Middle Rio Grande, including storm-water diversion channels and irrigation system drains and wasteways, most nonpoint sources of pollution enter the river through point discharges. This allows for a reasonably high level of analysis and potential control of many complex system inputs.

The need to provide some form of instream flows (in this case to lessen water quality problems) is a common element in several recommendations focusing on protection and enhancement of bosque biological resources. Integrating these needs and recommendation affords an opportunity to better manage the Middle Rio Grande system for the benefit of multiple resources. Designing and implementing flow strategies will require a significant amount of time and resources from a variety of entities, both public and private. Effective coordination between all parties is critical so that goals and objectives for the resource and its users can be attained.

Altering the magnitude or composition of system inputs, such as wastewater effluent, storm-water runoff, and irrigation returns, is generally technically feasible but cost limiting. Identifying the most cost effective alternatives to minimizing deleterious inputs to the Rio Grande system is important.

The potential for using riparian forests and/or wetlands as a buffer for point and nonpoint sources of pollution presents an opportunity to both manage water quality and extend and enhance riparian vegetation, aquatic habitat, and wetlands within the bosque.

Implementation Considerations: It is important to fully identify and quantify the needs and requirements of all system users and resources before attempting to initiate an improvement to the system. Initiatives such as NAWQUA, UAA, and BEST are important first steps. Approved and proposed pueblo stream standards for the Middle Rio Grande must be integrated with state standards when analyzing system needs and requirements.

Consideration should be given to evaluating the effectiveness of designating the Rio Grande from Alameda Bridge to the headwaters of Elephant Butte as a single reach for water quality standard purposes.

Timing is an important consideration in providing flows to alleviate water quality problems. Native fish species are often more tolerant of low flow periods than nonnative species. However, unseasonal periods of high flow may negatively affect native species. Therefore, artificial baseflows need to be carefully integrated with the natural hydrograph to maximize the benefits to native species.

As mentioned in the wetlands recommendation (Recommendation 15), the design of wetlands to serve as buffers for water quality benefit must also consider the diversification of wetland function and configuration.

Action: Water quality modeling must be integrated or at least compatible with hydrologic modeling efforts. Coordination should occur early in the development process. Consideration should be given to determining the most important parameters to model. To effectively represent water quality impacts on aquatic communities, the model should consider natural diel fluctuations in certain parameters (e.g., temperature and dissolved oxygen). The time step of the model is also important.

Current water quality standards define a warmwater fishery as a stream reach "suitable for the support and propagation of warmwater fishes such as largemouth black bass, small-mouth black bass, crappie, white bass, bluegill, flathead catfish, or channel catfish." This definition allows for flexibility in characterizing a warmwater fishery as it would best apply to the Middle Rio Grande aquatic resource. Either a more appropriate interpretation or a redefinition of the Middle Rio Grande warmwater fishery should be considered. The initiation of a UAA offers a good opportunity to analyze the appropriateness and attainability of the designated uses of the Middle Rio Grande.

Monitoring and Research: A major research need is the analysis of specific water quality impacts on various components of the riparian ecosystem. For example, an understanding of the specific impacts of wastewater effluent discharge on native fishes is important, especially with the proposal to list the Rio Grande silvery minnow as an endangered species.

As mentioned previously, laboratory research has been conducted to study the impacts of pesticides on the aquatic resource. Further laboratory-controlled exposure studies with all life stages of selected and/or surrogate fish species would provide valuable additional data. No in situ research has been conducted to date. Caged fish studies is one technique for quantifying species specific water quality impacts. Quantification of the environmental concentrations of pollutants in irrigation return waters is also a research need.

As a component of the modeling effort, sources of point and nonpoint pollution should be monitored both short and long term to quantify the magnitude and variability of their influence on water quality.

The impact of main channel dams and diversion on organic input to the Middle Rio Grande needs further study. Research could be conducted to quantify energy input and energy transportation throughout the system.

Agencies and Municipalities with Surface-Water Related Experience:

U.S. Geological Survey
City of Albuquerque
New Mexico Department of Health and Environment, Surface Water Quality Bureau
U.S. Fish and Wildlife Service
U.S. Bureau of Reclamation
U.S. Corps of Engineers
Albuquerque Metropolitan Arroyo Flood Control Authority
Middle Rio Grande Conservancy District
All Indian Pueblo Council

RECOMMENDATION 6: Integrate management of nonnative and native fish species in all aquatic environments in the Middle Rio Grande riparian ecosystem including wetlands, canals, and drains.

Need: Increased human activity in warmwater streams in the Southwest has generally led to a concomitant reduction in native fish populations (Edwards and Contreras-Balderas 1991). The native fish community of the Middle Rio Grande has declined in both abundance and diversity of species. Changes in flow regimes and aquatic habitat are significant factors contributing to the decline of native fish species. However, purposeful and accidental (e.g., bait bucket) introductions of nonnative fish species also negatively impact native species through predation, hybridization, and competition for resources.

Sportfish management in New Mexico is under the control of the NMDGF. Native species management in the Middle Rio Grande is beginning to be integrated with the policies and management practices for nonnative species. However, without an extensive system of biological checks and balances relative to species introductions, nonnative fish in the Middle Rio Grande will continue to affect native species.

The Rio Grande silvery minnow, a species proposed for listing under the Endangered Species Act, occurs exclusively in the Middle Rio Grande. Fish management activities in the Middle Rio Grande currently address the protection and expansion of this species' distribution, abundance, and habitat. As a potential indicator of the health and status of the native fish community, the Rio Grande silvery minnow is a critical component of all aquatic resource issues and activities, such as nonnative fish management.

Description of Recommendation: *Develop an implementation plan integrating management of nonnative sportfish and native fish in the Middle Rio Grande*—The current system of sportfish management in New Mexico is driven by both biologic and economic factors. Anglers purchase fishing licenses that partially support the stocking of sportfish. Also, federal funding to states for fishery management focuses on sportfish restoration. Often, nonnative fish stockings are assessed only for their viability to support a recreational fishery and not for interactions with and impacts on the native aquatic ecosystem.

The NMDGF should continue to develop and implement strategies to manage sportfish in concert with native fish. The biology of the system should be the driving force within a sportfish management program to ensure the continued existence and success of associated native fish and other biological components of the ecosystem.

Enhance methods to regulate, control, and enforce accidental introductions of nonnative fish—Accidental introductions of nonnative fish are the most difficult to control and may have the most devastating effects on the native ecosystem. As mentioned previously, bait bucket introduction of the plains minnow to the Pecos River led to extirpation of the Rio Grande silvery minnow from that drainage. A similar introduction to the Middle Rio Grande could lead to extinction of the Rio Grande silvery minnow. Strict regulations, enforcement, and penalties are critical to managing this problem. The NMDGF should continue to attempt to both regulate the use and commercial sale of bait minnows and prohibit the interdrainage transport of baitfish.

Opportunities and Constraints: Management of nonnative introductions is a component of many native and endangered species management and recovery plans. The NMDGF should continue its coordination with other management and resource agencies (e.g., FWS, BOR, COE) in developing creative and integrative management strategies for the Middle Rio Grande. A proactive strategy integrating the management of these species will greatly reduce the threat to the existing native aquatic community.

The current proposal to list the Rio Grande silvery minnow as federally endangered will likely lead to establishment of an interagency team to protect, stabilize, and recover Rio Grande silvery minnow populations and the associated native fish community of the Middle Rio Grande. Future management, research, and coordination of nonnative fish issues will likely be carried out within the framework of the Endangered Species Act activities but with an ecosystem focus.

Constraints on these recommendations are the political and economic considerations of altering sportfish management policies and the logistical problems with regulating and enforcing accidental nonnative fish introductions. The initial constraint should be manageable within the purview of the NMDGF. Fish stockings using federal funding are subject to Endangered Species Act consultations. Program goals and objectives may need continued redefinition. However, the integration of native and nonnative fish management strategies should reflect the changing attitudes of the general public in supporting nongame programs.

Implementation Considerations: An interagency team should be established to address native fish management. As mentioned above, the team could be established within the existing and future framework of the Rio Grande silvery minnow endangered species process. This process should provide the forum for key entities to work cooperatively. All entities with landownership along the Middle Rio Grande, including the pueblos, should be involved with this process so that the system can be considered as a whole. It will be critical to maintain an ecosystem focus for the development of a management plan within the single species environment of the endangered species process.

Action: As a component of an integrative management plan for nonnative and native fishes, water management activities associated with Cochiti Lake should attempt to benefit reservoir fisheries (considering such issues as storage ration, water retention, and seasonal storage) while minimizing negative impacts on the downstream native fish community. In all actions, priority should be given to native communities.

Increased biological sampling in the Middle Rio Grande has raised the question of data comparability. The use of various study designs, sampling techniques, and collection management practices increases the difficulty of comparing data from different studies. The importance of aquatic resource data in management decisions affecting the Middle Rio Grande requires that all data meet some level of acceptability. Biologists and policymakers should agree on appropriate levels of standardization and/or data compatibility. The scientific collecting permit processes employed by the NMDGF and FWS may provide the institutional framework to accomplish this goal.

Monitoring and Research: Fish research in the Middle Rio Grande currently addresses the Rio Grande silvery minnow but, by design, also studies the distribution and abundance of the entire fish community, including nonnative fishes. The research will also address the impacts of nonnative species on native fish during periods of low flow.

Additional research needs are as follows. (1) Study short- and long-term movements of nonnative fish into and within the Middle Rio Grande. (2) Further quantify the impacts of nonnative fish on the native fish and invertebrate community. Additional sampling specifically for nonnative species might enhance the understanding of their distribution, abundance, and habitat associations in the Middle Rio Grande. (3) Experiment with techniques to limit the emigration of nonnative fish from stocking locations. For example, methods of limiting downstream passage of fish during Cochiti Dam releases should be explored.

Long-term monitoring of the entire fish community is critical to understanding native/nonnative fish community dynamics. This data is essential for developing appropriate management actions. Monitoring also plays a critical role in the regulation and, hopefully, control of accidental introductions.

Agencies and Groups with Middle Rio Grande Nonnative/Native Fish Experience:

New Mexico Department of Game and Fish
U.S. Fish and Wildlife Service, New Mexico State Ecological Services Field Office
University of New Mexico, Ichthyofaunal Studies Program
New Mexico State University, Department of Fisheries and Wildlife Sciences
U.S. Bureau of Reclamation
U.S. Army Corps of Engineers

RECOMMENDATION 7: Protect the geographic extent of the Rio Grande bosque and avoid further fragmentation of the riparian ecosystem and component habitats.

Need: The Rio Grande floodplain has been used for habitation and for agriculture since prehistoric times. More recently, population growth and associated development have expanded into previously unoccupied and unused areas and caused losses of riparian bosque and wetlands. Development in the vicinity of Albuquerque and other urban areas threatens the extent of the riparian plant communities and includes both reduction of the bosque area by housing, shopping centers, and agriculture as well as fragmentation of contiguous bosque habitat by powerlines, bridges, transportation corridors, and other projects that cross the riparian zone. Large-scale (in terms of kilometers or miles) fragmentation of a narrow, linear ecosystem like the riparian has serious implications for natural resources. Interruption of riparian habitats for long distances separates populations of plants and animals, disrupts migration and dispersal of some species (e.g., neotropical migrants), and may reduce species richness and diversity within the remaining fragments. On a smaller scale, fragmentation of the component parts of the ecosystem (i.e., community types or habitats) may disrupt the lives of a different set of organisms supported by the system.

Description of Recommendation: The remaining riparian habitats in the Middle Rio Grande Valley should be protected from development and fragmentation. This could be accomplished by management policies, land purchases, zoning, cooperative agreements with private landowners, and other methods.

Opportunities and Constraints: Recent national and regional concern over the future of the Rio Grande has brought an awareness of riparian ecosystem issues to land and water managers and to the public. The remnant riparian ecosystem of the Rio Grande is recognized by national groups, municipalities, agencies, and private citizens as an asset to our cities, to our state, and to our region. Thus, the time is right for these entities to begin to work together to provide protection to water and lands that contain surviving riparian communities.

Ownership and management responsibilities for the Middle Rio Grande riparian zone include MRGCD, pueblos, New Mexico State Parks and Recreation Department, NMDGF, FWS, BOR, various municipalities, and private individuals. Constraints on the accomplishment of this recommendation include the need for municipalities and agencies to meet essential goals that may have nothing to do with protection of riparian ecosystems. The rights of private landowners to use and dispose of their property as they see fit (within the guidelines of state, county, or municipal regulations) must be recognized. However, these constraints should not prevent protection and conservation of many riparian areas where landowners and land managers are willing to participate in such activities.

Implementation Considerations: Because of the mixed ownership status of bosque lands and the lack of certainty of ownership in some cases, defining and clarifying land status in the riparian zone are necessary prerequisites for protection planning. Riparian habitats of high quality (those with native species as dominants within the plant community) should be selected for cooperative agreements or acquisition (only from willing sellers). The Nature Conservancy, the New Mexico Natural Lands Protection Committee, the FWS "Partners for Wildlife," and other private lands programs also work with private citizens and nonfederal groups or agencies to protect and sometimes acquire lands of biological importance.

It is also important to recognize that disturbances in the bosque vary. Projects that are large in scale and involve clearing many acres of cottonwood habitat for residential, business, or agricultural development are clearly destructive to plant and animal communities. Activities in these developed areas may have continued effects on adjacent bosque in the form of noise, air, and water pollution. Powerlines or pipelines require removal of vegetation. The narrow nature of these types of disturbances, however, may not be sufficient to disrupt dispersal or migration. Bridges are another form of disturbance that may not be extensive enough in area to interrupt dispersal or migration, but the disturbance resulting from their construction and use is intensive and continuous. The physical damage, the constant noise, and the access points to previously interior woodland areas are serious disruptions to some wildlife species. Agriculture does have some benefits to wildlife (see Recommendation 9 on buffer zone).

Because of these deleterious effects, we recommend that clearing and fragmentation of habitats and of the linear riparian ecosystem be avoided by protecting the geographic extent of the existing bosque and by minimizing the number and extent of projects that cut across the slender band of woodland. Transportation, pipeline, and powerline corridors should be combined to restrict impacts.

Action: Develop a definitive ownership map of the riparian zone in the Middle Rio Grande Valley so that protection by appropriate entities can be extended to the bosque whenever possible.

Pueblos, agencies, and municipalities should review their policies for operation, development, and management that are related to riparian issues. Appropriate policies could be revised or new ones developed to protect riparian habitats. These policies could be coordinated with other management entities through a state riparian task force and/or riparian coordinators (see Recommendation 20 on plan review and update).

Federal and state agencies and other entities involved in planning, implementing, and reviewing projects in the riparian zone should include fragmentation issues when considering projects and mitigation measures in the bosque.

Private citizens (and nonfederal agencies and municipalities) should be made aware of programs such as "Partners for Wildlife" and other cooperative agreements with the FWS that support the protection, enhancement, and creation of wildlife habitat, including habitats found in the riparian zone. They should also be made aware of conservation easements, acquisition programs, and other options with The Nature Conservancy and the New Mexico Natural Lands Protection Committee. No riparian sites are currently on an acquisition list; future coordinating groups should work with the New Mexico Energy, Minerals, and Natural Resources Department to nominate sites that qualify under the Natural Lands Protection Act (78-5-1 et seq. NMSA 1978).

Monitoring and Research: Fragmentation of ecosystems and habitats is a poorly understood topic. There is little information on minimum size of habitat units needed to support the full range of species in riparian communities. The Rio Grande ecosystem has not been adequately studied in this regard. We recommend that research on the consequences of fragmentation of the bosque habitats be undertaken as soon as possible, so that information on this important topic can be incorporated into riparian management plans.

When disturbances of bosque habitats are unavoidable, the effects should be monitored. Baseline, or predisturbance information, should be gathered, and postdisturbance data should be collected at regular intervals. Monitoring should include assessments of plant and animal community composition. This information should be evaluated and incorporated into management plans for future activities. (See Recommendations 18 and 19 on monitoring and research for additional guidance on these topics.)

Agencies and Municipalities with Existing Plans for Riparian Management:

U.S. Bureau of Land Management
City of Albuquerque, Open Spaces Division

Agencies and Groups with Funds and Resources Available for Habitat Improvement:

New Mexico Natural Lands Protection Committee
New Mexico State Forestry and Resources Conservation Division
U.S. Fish and Wildlife Service, Private Lands Coordinator
The Nature Conservancy, Santa Fe
Tree New Mexico
Soil Conservation Service, Plant Material Center

RECOMMENDATION 8: Protect, extend, and enhance riparian vegetation in noncontiguous areas in the floodplain.

Need: Most of the native riparian plant communities are restricted to areas between the riverbanks and levees alongside the river, but there are also stands of cottonwood trees and other native species outside of these boundaries in the surrounding floodplain. These may be remnant stands of native communities left from previous riverine processes, or the result of suitable environmental conditions and seed availability at these locations. Native plant communities outside the contiguous bosque increase the wildlife habitat beyond the narrow band along the river and provide islands of shelter and resources for resident, migratory, or dispersing animals. Development in the floodplain most often affects riparian communities outside the levees; the effects of development range from complete clearing to removal of understory with a few mature trees left to enhance the landscaping.

Description of Recommendation: Existing riparian communities outside the levees should be protected from development. Riparian habitat in these locations could be extended to link up with the river bosque, to form larger islands of habitat, or to join isolated patches of bosque with each other. The value of existing stands could be enhanced by providing buffer areas around them, by supplementing the stand with plantings of native species, and by controlling nonnative species within and around the stand.

Opportunities and Constraints: Opportunities include the current existence of riparian vegetation in the floodplain and overall site suitability (soils, ground water, agriculture, and water distribution system). Opportunities also include the current awareness of the value of riparian habitat for wildlife use and human enjoyment. Agencies and many private interests involved in development often recognize the value of native plant communities (especially cottonwood bosque) and are willing to protect it as much as possible during project planning and construction. Techniques for enhancement of the bosque by pole planting and planting of native species of shrubby understory are well developed and widely practiced. Constraints include the large amounts of privately owned land and the availability of suitable sites for establishment of new riparian communities.

Private lands in the floodway are especially valuable in urban areas because they are easy to develop and because of their semirural atmosphere. Development of these lands may conflict with the ideals of bosque protection, enhancement, and extension. However, development does not necessarily preclude carrying out these ideals; indeed, especially for housing developments, the presence of cottonwood woodlands enhances the monetary value of residential properties. Various state, federal, and private programs, including those of the New Mexico Natural Lands Protection Committee, FWS, and The Nature Conservancy are available for protection and enhancement of cottonwood habitats by willing landowners.

Other constraints are mainly related to changes in physical conditions that allow regeneration of cottonwoods and other native species in the floodplain away from the existing river channel. Because the river has shifted its bed frequently in the past (prior to the construction of levees and other river training devices), existing stands of mature cottonwoods outside the levees were probably created when the river was nearby and when it provided adequate moisture for germination and establishment of trees. Once established, their roots were able to reach water even after the river channel was shifted away from them. Now, however, ground water may be too deep to supply pole plantings or seedlings with adequate moisture for survival. For this reason, extension and enhancement of outlying stands of cottonwood bosque (or other riparian species) should be attempted only after studying local conditions to assess the likelihood of success.

Implementation Considerations: Implementation of plans to protect, enhance, and extend noncontiguous native riparian species in the floodplain of the Rio Grande is dependent on the location and identification of areas where such bosque occurs, and also on landownership status.

Other considerations for protection, enhancement, and extension of these vegetation types can be found in Recommendation 16 on protection and enhancement of the contiguous cottonwood forest, Recommendation 9 on buffer zone, and Recommendation 17 on removal on nonnative species. These include site assessment for suitability, site preparation, and techniques for revegetation.

Action: Develop detailed site location and ownership maps for noncontiguous cottonwood bosque and other native communities in the Middle Rio Grande Valley; in conjunction with this, develop land status ownership maps so that owners or managers will have the opportunity to protect, enhance, and extend the riparian forest. A set of criteria, including biological and social considerations, should be developed to rank noncontiguous areas in terms of need for preservation, enhancement, and establishment.

Landowners and managers should be made aware of the resources and the opportunities for protection and enhancement of riparian communities by using state, federal, and private sources, including the New Mexico Natural Lands Protection Act, FWS private lands programs, and The Nature Conservancy.

Lands with high value (based on species composition, size, and condition) riparian habitat should be acquired for protection and management by appropriate municipality, state, or federal agency.

Programs specifically for riparian habitat protection, enhancement, and extension should be developed by state, federal, and private entities.

Monitoring and Research: Any enhancement or restoration efforts should be accompanied by monitoring studies, including acquisition of baseline information on location and extent of the riparian forests for comparison to future changes. Research on these noncontiguous riparian community areas may provide information on size of fragment or patch and number and type of associated animal species. Estimates of minimum fragment or patch size necessary to support and sustain native animal communities could be developed from these studies (see Recommendations 18 and 19 on monitoring and research).

Research on size, configuration, vegetation species composition, juxtaposition to other areas, etc., should be completed as required to develop the biological ranking criteria.

Agencies and Groups with Funds and Resources Available for Habitat Improvement:

New Mexico Natural Lands Protection Committee
New Mexico State Forestry and Resources Conservation
U.S. Fish and Wildlife Service, Private Lands Coordinator
Tree New Mexico
Soil Conservation Service, Plant Materials Center

RECOMMENDATION 9: Manage the buffer zone of the contiguous bosque to protect ecosystem processes, enhance wildlife habitat values, and maintain rural and semirural conditions.

Need: Agricultural activities in the floodplain surrounding riparian areas have created what could be called a buffer zone between the bosque and adjacent urban development in many areas in the middle valley. Undeveloped uplands that extend into the floodplain and the bosque may also form part of the buffer zone. This buffer zone provides protection from some forms of urban human disturbances and provides food and resting areas for migratory waterfowl and other wildlife. The combination of water, cover, and feeding areas presented by the juxtaposition of river, bosque, and agricultural fields is extremely valuable to sandhill cranes, snow geese, Canada geese, and other species. In addition, this combination of attributes is particularly pleasing and important to people in the area who value rural and semirural ways of life typical of the Middle Rio Grande Valley.

Irrigation agriculture also provides, to a certain extent, replacement of the riverine floodplain functions; these include spreading out of flood waters and the recharge of sediments, nutrients, and ground water on floodplain lands. Ditches and canals that carry water to fields in the floodplain provide water and emergent vegetation that supports wildlife, including waterfowl, other bird species, muskrats, and beavers, throughout the floodplain.

Undeveloped upland areas that come very close to the river provide a different habitat type within the floodplain as well as access to water and riparian food sources for upland animal species.

The buffer zone is particularly important in maintaining the high wildlife value of the bosque and associated communities, as well as maintaining the rural atmosphere and character of the Middle Rio Grande Valley. Population is expanding in the floodplain of the middle valley, and there is a steady conversion of these buffer zone agricultural lands to residential uses.

Description of Recommendation: This recommendation encourages the continued agricultural use of floodplain land by maintaining property tax relief for agriculture (e.g., Bernalillo County's "green belt" policy) in municipalities where it exists now and for instituting similar programs in areas lacking such policies. Landowners should be encouraged with economic incentives to continue farming. Zoning laws, even though they are unpalatable to many small municipalities, would help to keep developed land parcels large (minimum size 0.4-1.2 ha [1-3 acres]), with access to irrigation, so that buffer zone functions can continue and rural values be maintained as much as possible.

Opportunities and Constraints: The buffer zone in Bernalillo County is supported by the green belt policy; land holdings of 0.4 ha (1 acre) or more that are in agricultural production are taxed at a lower rate. The county land-use plan requires 0.4 ha (1 acre) zoning in many areas outside the City of Albuquerque boundaries. Counties and municipalities outside the urban influence of Albuquerque have the opportunity to institute green belt policies and zoning regulations that would allow growth but in ways that will help sustain bosque values for both wildlife and humans.

Albuquerque zoning policies allow for denser development on floodplain lands (now protected by levees) within the city boundaries. Density of development in both city and county jurisdictions is also dependent on availability of services, such as water and sewage, which are regulated by the New Mexico Environment Department. Existing zoning regulations may be a constraint on protection of the buffer zone but, with changes, could easily become an opportunity for maintaining that protection.

There are economic constraints on carrying out this recommendation. As population in the Middle Rio Grande Valley grows, development is inevitable, and floodplain land under agriculture increases in its potential value for development. However, economic assistance for farmers and control of the nature of development can provide some opportunities for implementing this recommendation.

Irrigated farmlands can be managed to provide suitable crops for wildlife. Land could be leased or acquired for the purposes of growing agricultural crops that are beneficial to wildlife.

Implementation Considerations: Counties, municipalities, and pueblos have the local control necessary to develop and implement policies and regulations for growth in ways that preserve agricultural, wildlife, and rural values.

Action: Counties, municipalities, and pueblos should develop and implement policies for protection of riparian buffer zone lands for their wildlife and human values.

Land leasing and acquisition from willing owners could be undertaken to grow crops such as corn, milo, and other grains that support migratory and resident bird species. Personnel at the Rio Grande Nature Center and Candelaria Farms in Albuquerque and at Bosque del Apache Wildlife Refuge have experience in farming and managing irrigated lands to attract and maintain wildlife.

Monitoring and Research: Use of buffer zones by wildlife should be quantified; information on species using these areas, numbers of individuals, and seasonality of use should be collected.

Counties with Property Tax Provisions for Agriculture:

Bernalillo County

Agencies with Programs for Farming for Wildlife:

New Mexico Parks and Recreation Division
U.S. Fish and Wildlife Service, Bosque del Apache National Wildlife Refuge
City of Albuquerque, Open Space Division
New Mexico Department of Game and Fish

RECOMMENDATION 10: Manage livestock grazing in a manner compatible with biological quality and ecosystem integrity.

Need: Livestock grazing in the Rio Grande bosque and floodplain needs to be managed so that its detrimental effects on riparian habitats are minimized while its beneficial effects on habitat diversity are promoted. Livestock grazing has removed much of the undergrowth in cottonwood stands in parts of the Middle Rio Grande bosque. These stands now exhibit structural simplicity and are not expected to have high biotic diversity. Also, livestock have, over historic time, eaten back cottonwood and willow seedlings and saplings along the river. This has inhibited the regeneration of native vegetation and reduced resultant community biological quality. Heavy grazing in Rio Grande watersheds has contributed, via erosion, to high sediment loads in the river. Likewise, in those watersheds that are contributing high sediment loads to the Middle Rio Grande, livestock grazing practices should be reviewed and improved if necessary.

Description of Recommendation: In order to allow regeneration and areal expansion of native bosque vegetation, grazing should be controlled in severely damaged parts of the ecosystem.

On the other hand, if managed carefully, livestock grazing can be used to increase the diversity of bosque habitats, as well as the diversity of plants and animals in those habitats. Increased diversity can be achieved by using livestock to create and maintain a variety of successional stages. Stocking rates and graze-rest cycles must be monitored in such operations. Livestock can be used to control introduced vegetation. Seedlings and saplings of salt cedar in particular can be controlled this way.

Grazing should be more creatively managed on those lands not held in private ownership (e.g., MRGCD lands). Management entities should develop and enforce comprehensive grazing plans that incorporate riparian biological values. Incentives for modifying grazing activities on privately owned lands in and adjacent to the bosque should also be developed. These could be in the form of tax incentives, payments, or easements. Finally, the existing governmental cooperative services that provide advice to agricultural interests should expand their riparian grazing programs.

Opportunities and Constraints: Livestock grazing, if planned carefully, can play an important role in ecosystem management along the Middle Rio Grande. This is most likely to be the case where land users do not rely entirely on financial returns from their land. Such individuals may have greater flexibility to use different pasture sizes, mixtures of plant species, and different kinds of livestock, stocking rates, and grazing schemes than land users who depend more completely on grazing for a living.

Resource managers should anticipate opposition by farming and ranching communities to activities perceived to be attempts to limit grazing. Hence the need, referred to above, for sound riparian grazing education programs. Managers should also recognize that working with ranchers using nonprivate lands, as opposed to those on private lands, can produce results affecting relatively large blocks of land. On the other hand, working with private landowners has the value of being voluntary (on their part) and allowing for the development of incentive packages resulting in both short- and long-term economic benefits.

Implementation Considerations: Most of the necessary information is already known and most of the technology has already been developed to use livestock to enhance the riparian areas along the Rio Grande (Clary and Webster 1990). This knowledge should be used by management agencies and landowners to make management decisions. Transfer of this knowledge and technology can be accomplished through an extensive education program for public and private land users. Grazing pressure should be monitored, and duration and season of use should be determined to achieve desired plant communities.

Action: There is no simple solution to the problem of overgrazing in the riparian zone. Incentives (e.g., payments to not graze or to modify grazing) may be an alternative for private landowners who otherwise may not restrict their livestock from entering sensitive areas. Another approach might be for a government agency, or private organization such as The Nature Conservancy, to develop conservation easements for riparian areas with landowners, or to purchase and restore overgrazed riparian land. Passage of legislation that tightens controls on grazing practices is yet another approach; it might be tied to the use of incentives.

The benefits of improving habitat diversity by carefully managed livestock grazing should be publicized, and the practice should be encouraged where feasible. Livestock owners who use their animals to control introduced vegetation, especially salt cedar, should be rewarded for doing so, particularly if the control is carried out on public land. This type of action should be made part of a coordinated program of salt cedar management.

Agencies that manage public lands along the Middle Rio Grande should work together to develop guidelines for livestock grazing on those lands. Once this is done, those agencies should routinely monitor grazing practices and habitat responses over long periods in order to make recommendations and/or enforce changes.

Monitoring and Research: Public and private land users should be instructed on how to monitor plant, soil, water, and animal resources. Some relatively quick, simple, and inexpensive methods can be used to indicate seral status and trends (Range Improvement Task Force 1981). Photography points and range inventory plots should be established to monitor vegetation changes.

Field experiments should be undertaken to further test the effectiveness of livestock grazing on creation of riparian habitat diversity and biodiversity. Results should be compared against those from similar but ungrazed control sites. The use of livestock to control introduced vegetation such as salt cedar should also continue to be tested.

Agencies with Riparian Protection Programs and Grazing Management Responsibilities:

U.S. Bureau of Land Management
U.S. Forest Service

Individuals with Expertise on Grazing Management:

Dr. Karl Wood, New Mexico State University

RECOMMENDATION 11: Manage activities that remove dead wood in a manner compatible with biological quality and ecosystem integrity.

Need: A variety of animals reproduce, forage, and find shelter in tree cavities. For example, in cottonwood riparian habitats, cavity-nesting birds comprise 32-43% of the breeding birds (Sedgwick and Knopf 1986). Cavity trees are standing dead trees (snags) and trees with dead limbs. Both provide the majority of substrate for animals that use cavities. Dead and downed logs also provide a valuable biological component. Snags and dead limbs of cottonwood and willows have more value for cavity nesters than do some introduced tree species (Brush et al. 1983). The value of Siberian elm and Russian olive to cavity nesters in the bosque is unknown.

Firewood cutting is the major current threat to snags or live trees with dead limbs. Demand for wood in the future may increase this threat. A secondary threat could be indiscriminant removal of snags and dead limbs for safety or appearance considerations. In addition, in an aging cottonwood forest without adequate concurrent regeneration, there would be a eventual decline in large, mature trees with dead limbs as well as a decline in numbers of snags.

While snags and fallen dead wood are important to a healthy forest, the absence of flooding in the Rio Grande bosque for the last 30-50 years has caused a build-up of dry, woody combustible material in some areas on the forest floor. This material burns with intense heat that is lethal to cottonwoods. There is a need to determine the appropriate balance between the desirable amount of dead material available for forest processes with maintaining low fuel loads to prevent high intensity fires.

Description of Recommendation: *Cavity trees*—To support a diversity of plants and animals associated with snags, riparian forest habitats should include a component of dead and decadent standing trees. In general, a cottonwood-willow tree community with a wide range of tree heights, diameters, and age classes would accommodate the entire community of cavity dependent species. The following are general guidelines to maximize the value of the riparian forest habitats for cavity nesting animals.

For maximum diversity and abundance of cavity nesting species, an average of 7.5 cavity trees per hectare (3 per acre) should be present in mature forest habitats. The minimum density should be 2.3 cavity trees per hectare. These trees should be as large as possible with at least 6 cavity trees per hectare (2.5 per acre) at least 30 cm (12 inches) d.b.h. An occasional cavity tree should be at least 54 cm (21 inches) d.b.h. Retain cavity trees with dead limbs greater than 14 cm (6 inches) in diameter. As a general rule, larger trees and limbs are more valuable because they meet the requirements of a greater number of species.

Cavity trees should be well distributed throughout forest stands to meet the territorial requirements of different species. It is also important to protect areas with clusters of cavity trees to maintain habitat for species that require secondary nest sites.

Areas without adequate density and distribution of cavity trees should be closed to wood cutting. Fuelwood cutters should be restricted from cutting all standing dead or decadent cottonwood and willow trees greater than 54 cm (21 inches) d.b.h. Access roads to selected riparian forest stands should be closed to vehicular traffic to discourage woodcutting.

In mature riparian forests with a low density dead wood component, snags could be created by girdling selected trees and limbs, or nest boxes could be provided for selected species. This type of management should be approached with caution because primary excavators may not always use such created snags, nor do the primary excavators use nest boxes.

Snags or dead limbs near water that have potential for rookeries or perch sites for fish-eating birds should be protected.

Dead and downed woody material—To maintain a healthy riparian forest ecosystem the dead and down component must be maintained. Firewood gathering and burning should be coordinated with plans for maintaining dead, woody material on the forest floor.

Firewood gathering should be monitored to ensure that large stands of bosque are not completely cleared of downed logs. A minimum average of least 5 downed logs per hectare (2 per acre) should be maintained in riparian forests. Areas identified as "wildlife areas" should contain a greater density of downed logs in different stages of decomposition well distributed over the riparian forest floor.

Downed logs on the riverbank and in the water should not be removed to the extent possible. Prescriptions for controlled burns should contain measures to maintain larger downed logs.

Opportunities and Constraints: The requirement for permitting fuelwood harvesting provides an opportunity to coordinate firewood collecting and maintenance of dead and downed material. Constraints is lack of staffing for proper monitoring and enforcement.

Implementation Considerations: Management of cavity trees should be incorporated into an integrated firewood management plan. Alternative sources of firewood could be provided such as felling of exotic trees or thinning of dense intermediate-aged stands of cottonwood. Retention of minimum snag densities should be considered in burned forest habitats before cutting of standing burned trees.

Because firewood cutting requires a permit under state law (68-2-22 NMSA 1978), coordination of management of fuelwood harvesting should include the New Mexico Forestry and Resources Conservation Division.

A public education program should include awareness of the value of snags and dead and downed trees to the ecosystem.

Action: Agencies, municipalities, and landowners should develop guidelines that maintain desired densities of cavity trees and downed logs in concert with management plans and activities. Examples of specific actions include:

- Vehicle access restrictions may be required in areas where cutting of dead and decadent trees (both standing and downed) may be impacting cavity nesters. Alternative sources of firewood could be provided.

- Minimum densities of standing burned trees and downed logs should be left in burned areas when cleared for revegetation or in areas targeted for prescribed burns.

- Efforts should be made to identify and protect cavity trees, roosting trees, and downed logs during rehabilitation and maintenance projects in riparian forests.

Monitoring and Research: Inventories of cavity trees should be conducted throughout the bosque. Areas of high value to cavity nesters should be identified. Cavity tree management goals should be established in areas where firewood is collected.

Research on this recommendation should be coordinated with experiments on controlled burns (see Recommendation 13 on fire prevention) and with restoration of flooding in the bosque (Recommendation 3).

Firewood gathering should be monitored to ensure that desired densities of snags are maintained and large stands of bosque are not completely cleared of downed logs.

As stands of introduced trees such as Russian olive and Siberian elm mature and become senescent, research is needed to compare the use by cavity nesters of these trees with cottonwood and willows.

Agencies and Municipalities with Responsibilities that Involve Removal of Dead Wood:

City of Albuquerque, Open Space Division
U.S. Fish and Wildlife Service, Bosque del Apache National Wildlife Refuge
New Mexico Department of Game and Fish
New Mexico Parks and Recreation Division
New Mexico Forestry and Resources Conservation Division
Pueblo Governments: Isleta, Sandia, Santa Ana, San Felipe, Santo Domingo, Cochiti
U.S. Bureau of Reclamation
U.S. Army Corps of Engineers

RECOMMENDATION 12: Manage recreational activities in the bosque in a manner compatible with biological quality and ecosystem integrity.

Need: The Rio Grande and its riparian forest have provided recreational opportunities for humans since their presence in the middle valley. The river has also served as a focal point for social and community activities. In an arid and sparsely vegetated region, the riparian corridor is an oasis providing shade and opportunities for hunting and fishing, picnicking, aesthetic appreciation, nature observation, education, and exercise. With increasing population densities there is a commensurate increase in recreational use of the bosque with concomitant demands on its resources and disturbance of its ecosystem. Recreational use of the bosque is heaviest in urbanized areas, decreasing with distance from population centers.

Uncontrolled vehicular access (on- and off-road) as well as some forms of recreational use and access are adversely affecting vegetation, wildlife habitat, and sensitive plant and animal species. Uncontrolled access is promoting the dumping of waste, firewood cutting, fires, poaching, and use of all-terrain vehicles. These activities not only physically destroy and degrade wildlife and wildlife habitat, but the accompanying disturbance also adversely affects wildlife presence and behavior. There are higher value plant communities and animal species that are sensitive to disturbance or are rare, or both, that can be adversely affected. Also, there are periods (e.g., the breeding season) during which some species are particularly sensitive to disturbance. Unrestrained dogs harass and kill wildlife and can be a public safety hazard. Unmanaged access also promotes the indiscriminant use of firearms. The continuing intensification of public use will correspondingly intensify impacts from uncontrolled access.

Commensurate with the increasing attractiveness and enjoyment of the bosque is a need to maintain an awareness of how recreational use can affect the well-being of those biological attributes that are found so desirable and to plan recreational use and development so as to preserve those desirable qualities. The need to manage these uses and to maintain the biological and associated recreational quality of the bosque is exemplified by management plans and measures instituted in the Rio Grande Valley State Park and by the Village of Corrales.

Description of Recommendations: *Directed access of motorized vehicular traffic*—Managed access of motorized vehicular traffic is the single most important management tool that eliminates much habitat degradation and wildlife disturbance and promotes improved recreational quality. This measure can be achieved (and has been implemented in certain reaches) by managing access to levee roads, primarily at bridge crossings and at a few intervening roads that cross the drains. Also, the degree to which control is needed may be dependent on the potential intensity of use—more control may be necessary in urbanized areas and less in rural areas.

Access (and egress) to the riparian corridor and river for recreational use is paramount and must be preserved. Motorized vehicular traffic should be redirected to formally developed parking sites. These sites may be in the riparian zone near bridges, sites landward of the riverside drains/canals, or at the mouths of tributary arroyos. Pedestrian access to the bosque would be required from parking sites landward of the riverside drains/canals. Pedestrian bridges over water features would be necessary in many cases. Parking sites within the bosque would have to be defined to restrict further access into the bosque. This basic concept of controlling vehicular access to the bosque should also be employed in areas without a levee or riverside drain.

Vehicular access to the levee or bosque for hunting should be allowed in rural areas where hunting is permitted during designated seasons. The existing levee should be widened at approximately 1.6-3.2 km (1-2 mi) intervals to provide parallel parking. Widened levee sections should be incorporated in levee rehabilitation measures planned by the COE.

Siting of formal parking areas and access and egress points should be planned to avoid adverse impacts to a particularly valuable plant community, such as wetlands, young cottonwood forest, habitat for animal species of concern, or a particularly important nesting site. Surveys of species or habitats of concern should be accomplished during plan formulation to guide placement (see City of Albuquerque Parks and General Services Department 1993). To the extent possible, these areas should be placed adjacent to a variety of plant communities that exemplify the diversity of habitat that comprises the bosque.

Use of motorized craft on the river should be managed for safety and rescue use only. The interior of the riverine corridor provides seclusion and isolation for a large number of wildlife species, and this isolation should be preserved. Use of canoes and rafts is generally a compatible activity although increasing intensity of use should be monitored to ensure that the level remains compatible with the goal of sustaining biological resources.

Location of developed recreation areas and level of development—In general, major recreational development should be located outside of the bosque, with only limited development (e.g., trails, observation blinds, etc.) within the bosque proper. An integrated public access and trail plan should be developed that allows a variety of recreational opportunities (e.g. hiking, biking, equestrian, nature study in relative solitude). This would require restrictions in certain sensitive areas such as strategic trail routing and closures. Certain access points should be provided with information/interpretive signs and other facilities. Conflicts with private land use should be addressed. Fencing or explanatory signs, or both, should be considered to protect sensitive habitats.

Again, the biological value of a particular plant community is an important consideration in plan formulation. As a general planning concept, and to the extent feasible, significant recreational development should be concentrated in or near areas of urban development, particularly in currently used areas. This concept would reserve greater areas with less disturbance, thereby enhancing wildlife use.

The landward levee edge is a zone of high wildlife use, particularly intermediate aged cottonwood and dense, shrubby vegetation. These edge community types should be preserved to the extent feasible. Edges without vegetation, or sparsely vegetated edges, could be used. Trails should be placed on the levee crest or elsewhere rather than on the river side (or toe) that typically has a distinct community type and provides higher wildlife use.

Although developed trails should be limited within the bosque, it is important from an educational and aesthetic perspective that some be placed in a variety of plant communities (again avoiding high use and sensitive areas). Priority areas would be in already disturbed and urbanized areas.

Avoidance of fragmentation—As discussed, the size and integrity of a particular plant community/structure type are of significant importance to a number of animal species. Not only can physical division occur due to developmental features, but activity and noise also can divide in a like manner. Therefore, planning for recreational development and use should strive to locate these areas near the edges of plant communities.

Hunting within the riparian zone—Hunting along the river has been a favorite recreational activity for generations of sportsmen and continues with even greater demand. Hunting should remain a priority use of bosque resources, recognizing that safety, especially in heavily urbanized and developed areas adjacent to the bosque, should govern where hunting is to be allowed.

Uncontrolled pets—Develop and distribute a handout for pet owners adjacent to the bosque to inform about impacts of dogs and cats on wildlife. Enforce leash laws in the bosque, and control feral dogs and cats.

Opportunities and Constraints: Recreation management measures are being implemented and planned in the Rio Grande Valley State Park to preserve and enhance biological values. Because a significant portion of the remainder of the bosque is under the administration of a public or tribal governing body, implementation of this plan has a high potential for success. A challenging element of this recommendation is acquisition of property and development of formal vehicular/pedestrian access points. An integrated vehicle and recreation plan would require coordination and cooperation of the MRGCD, land management agencies, private landowners, and pueblos.

The City of Albuquerque has developed a management plan that contains a recreation-vehicle plan for the Rio Grande Valley State Park and could serve as a model. Wherever possible, existing roads should be used. Also, site selection should consider potential disturbance to any adjacent private landowners.

Cochiti Lake has expanded opportunities for sportfishing in the Rio Grande to at least Angostura Diversion Dam and perhaps farther downstream. Access to a significant length of the river above Albuquerque, as well as egress, is restricted by tribal ownership. Any future public access and egress through pueblo lands for fishing or other water-based recreational activities (e.g., hunting, canoeing, and rafting) should be based on management objectives by the individual or collective pueblos.

There is an appreciable demand for nearby recreational fishing; Sandia, Shady, and Isleta lakes and Tingley Beach are examples of developed and managed sportfishing facilities within or near the riparian zone. Several of these areas have been developed with a sensitivity toward preserving riparian vegetation. A very real constraint could be a perception by some that recreational management would be another limitation of their use of the bosque. Conversely, an urban population may be very likely to endorse management and be willing to pay for it.

Implementation Considerations: A major consideration in implementing this recommendation is the willingness and ability of management entities to actively develop and manage recreational activities. After these are established then the ability to fund these activities becomes a significant element, followed by planning and associated public involvement. Planning considerations include the following: (1) landownership/administration; (2) land acquisition and trusts; (3) community education/partnership; (4) site location-relationship to adjacent plant communities, Rio Grande, and floodplain development; (5) biological planning information-identification of community/structural type, associated animal use and abundance, areal extent, edge, sensitivity, adjacent biological communities, etc.; (6) soils; (7) existing recreational use; (8) light versus heavy recreational use; (9) access; and (10) minimize vegetation clearing with an emphasis on retaining native species.

Action: Implement a coordinated, comprehensive access and use management plan among involved federal and state agencies, municipalities (including pueblos), and associated landowners.

Monitoring and Research: All recreational areas should be continually monitored for any deterioration of habitat or changing biological conditions that may require a change in recreational use. A prime example is the increasing population of wintering bald eagles along the Rio Grande, especially in the Albuquerque area. Because of their seasonal presence, a heavy recreational use designation may need to be changed to light use. Also, intensive recreational use may cause soil compaction or vegetation abuse that may require that an area be temporarily withdrawn from use to allow restoration.

There is a need to inventory and map the following: (1) sensitive wildlife habitats where public access should be restricted, (2) existing roads that should be closed and revegetated, (3) existing trails to be closed and revegetated, (4) access points for recreation opportunities, (5) potential routes of trails, and (6) area(s) that could support off-road vehicle use. Again, the Rio Grande Valley State Park plan is a good example.

Monitoring would be necessary, and adjustments to the plan would be made when habitat disturbance is documented or further recreational demand requires additional developments.

Agencies and Groups with Experience and Information in Recreational Management:

There are ample information, experience, and examples to manage recreational activities in the bosque in a manner compatible with biological values. Sources include the following:

City of Albuquerque Open Space Division
New Mexico Parks and Outdoor Recreation
New Mexico Department of Game and Fish
U.S. Fish and Wildlife Service, Bosque del Apache National Wildlife Refuge
U.S. Army Corps of Engineers
U.S. Bureau of Reclamation
Pueblo Governments: Sandia and Isleta

An appreciable number of entities would play a role in implementation of this recommendation, key among which would be the MRGCD. Each municipality, pueblo, county, and element of federal or state government would play a vital role.

RECOMMENDATION 13: Prevent unmanaged fires in all reaches of the bosque

Need: Human-caused fires have especially deleterious effects on the bosque's cottonwood communities because these communities are less fire adapted than other forest types. Salt cedar, Russian olive, and other exotic species quickly invade after fires in cottonwood communities. High intensity fires usually kill cottonwood trees, which rarely regenerate following a fire. Conversely, salt cedar and Russian olive quickly sprout new growth from their root crowns. With the loss of periodic flooding, which removes accumulated litter, fuel densities and fire intensities have greatly increased. Cottonwood stands with dense understories (type I) are the most flammable, while those with sparse understory (type II) appear to be more resistant to catastrophic fires (Sivinski et al. 1990).

There is a high frequency of human-caused fires in the bosque. Many of these fires, especially those in dense, mature stands, are resistant to suppression due to high fuel loads and salt cedar-induced fire storms. A large amount of cottonwood forest is at risk from future fires.

The New Mexico State Forester has identified two major preventable causes of wildfires. These are spring ditch burning and Fourth-of-July fireworks (Sivinski et al. 1990).

Description of Recommendation: Increased fire prevention in the bosque should be accomplished by public awareness programs and access restrictions. Control of fireworks and spring ditch burning would reduce the frequency of wildfires. Fire contained in charcoal grills or campfires should be discouraged within the bosque.

An integrated fire management plan needs to be developed to improve fire suppression in the bosque. This would involve coordination with New Mexico Forestry and Resources Conservation Division, pueblo fire-fighting organizations, municipal and rural fire departments, and federal interagency fire organizations. There is need for funding, training, and equipment (G. Fitch, pers. comm.). Access to remote areas of the bosque, use of heavy equipment, and dispersal of standing burned cottonwood trees are actions that need biological input. The plan also needs biological input on rehabilitation of burned groves, snag removal, and location and design of fire breaks.

Fire hazards could be reduced by establishing fire breaks and control of accumulated litter. Fire breaks should be 4.5-6.0 m (15-20 ft) wide (Sivinski et al. 1990). Fire breaks up to 75 m (246 ft) wide have been used successfully at Bosque del Apache NWR (J. Taylor, pers. comm.). These breaks should be located in vegetation without mature cottonwoods. Wetlands could be designed and constructed to retard the spread of fires. Strips could be cut into large salt cedar stands or in younger growth cottonwood stands. Accumulated litter could be managed by controlled burning and flooding. Removal of dead wood for firewood may be a potential tool for reducing fuel loads (see Recommendation 11 on dead wood removal), but this should be balanced with the need to have dead, woody material and litter for ecosystem processes.

Opportunities and Constraints: Increased prevention, suppression, and control of wildfires in the bosque would require coordination with the agencies and organizations mentioned above. The New Mexico Forestry and Resources Conservation Division is developing joint powers agreements with federal, municipal, and county governments for wildfire protection. There is opportunity to both control wildfires and enhance the biological value of the bosque with well-designed fire breaks.

Implementation Considerations: There is a need for a central land management agency to coordinate a biologically sound wildfire prevention, suppression, and rehabilitation program specifically for the bosque.

Action: An integrated fire management plan needs to be developed for the bosque. The New Mexico Forestry and Resources Conservation Division could be the coordinating agency. Input would be required from pueblo fire-fighting organizations, municipal and rural fire departments, and the U.S. Bureau of Land Management.

To ensure that biological values are considered, the fire management plan would also require biological input from entities such as the Middle Rio Grande Coordinating Council and/or the Middle Rio Grande Bosque Coordinator (see Recommendation 20). Biological aspects of the plan would include design and location of fire breaks, use of heavy equipment in sensitive habitats, and retention of minimum snag densities in burned areas.

Monitoring and Research: Research should be concerned with the effectiveness of fuel breaks and revegetation techniques in burned areas. Studies of induced vegetative reproduction (suckering) should be conducted in burn-killed cottonwood stands.

There is also a need to determine whether low-intensity fires could be used to prevent build-up of fuel load in the understory without killing cottonwood trees. Research on burning should be coordinated with that for dead wood removal (see Recommendation 11).

Monitoring is needed to document the areal extent of burns, the subsequent loss of native plant species, and the spread of exotics and the effects of fragmentation. Revegetation efforts need to be monitored and replanted when necessary.

Agencies and Groups with Fire Prevention and Suppression Responsibilities:

New Mexico Forestry and Resources Conservation Division
Pueblo Fire-fighting Organizations: Sandia, Isleta, San Felipe, Santa Ana, Santo Domingo, Cochiti
Municipal and Rural Fire Departments: City of Albuquerque, Bernalillo County
U.S. Bureau of Land Management
U.S. Fish and Wildlife Service, Bosque del Apache National Wildlife Refuge
City of Albuquerque, Open Space Division

RECOMMENDATION 14: Use native plant species and local genetic stock in vegetation establishment and management efforts throughout the bosque.

Need: Nonnative plant species have been used for erosion control, ground cover, and ornamentals in the southwestern United States since Europeans arrived. Other species have been introduced accidentally in forage or crop seeds. Many of them have escaped and become troublesome weeds or pests; the most notorious of these are salt cedar, Russian olive, summer cypress (*Kochia scoparia*), tumbleweed (*Salsola kali*), goathead stickers (*Tribulus terrestris*), and cheat grass (*Bromus tectorum*). Both purposeful and accidental introductions have often resulted in the proliferation of nonnatives at the expense of indigenous species, particularly in the riparian ecosystem where salt cedar and Russian olive have replaced native plants and are now the dominant or subdominant species in many areas. In order to mitigate the effects of these and future introductions, native species should be used in revegetation projects and riparian management in the Rio Grande bosque. By native species, we mean those that are indigenous to the Middle Rio Grande Valley and the life zones and floristic provinces through which the river flows.

Description of Recommendation: Species for revegetation should be native to the region and selected from those that occur in the area from sites of similar elevation, soil type, and moisture regime. Local genetic stock should be used, when possible, in all revegetation projects. In any given area, material should be collected from a variety of sources; for example, cuttings should be taken from more than one or two trees. This will ensure that plants adapted to local conditions of soil, moisture, and temperature (or to some unknown but critical environmental factors), and that have the full array of genetic characteristics, will be used.

Opportunities and Constraints: Native species have been used in revegetation projects by various agencies, including the BOR, COE, FWS, and the City of Albuquerque. Native species are adapted to the southwestern climate and environmental conditions, and most (if not all) revegetation requirements can be fulfilled with plant species from this region. Local genetic stock is usually readily available and can be used if there is adequate time allowed for collection and preparation of the material. Cottonwood or willow poles, for example, can be collected from the local area and used in plantings to revegetate burned areas or in other projects. The BOR has adjusted its mowing schedule on the riverbanks (for maintaining a 183-m [600-ft] floodway) to allow the growth of cottonwood and willow seedlings to a size suitable for pole planting. These are collected and used in BOR revegetation projects. Seedling trees or shrubs may require longer term planning. Seeds should be collected from species within the local area and held for direct planting (some seeds require a period of dormancy before germination), or they should be grown in a greenhouse until they are large enough to plant.

Implementation Considerations: If agencies and municipalities expect to plant native species, they should either have the expertise and facilities to acquire their own native planting material, or, ideally, use another organization such as the SCS Plant Materials Center to help them with collection and use of this material. The Plant Materials Center has assisted agencies in collection and production of poles and seedlings. However, the Center has lacked funding for research and development of the use of native species and local genetic stock for revegetation and restoration projects. For this reason, materials for use in some projects, especially constructed or created wetlands, have sometimes been acquired from out of the region.

Action: Agencies and municipalities should develop or expand revegetation and restoration guidelines that require the use of native species and local genetic stock to prevent ecological disasters (such as the invasion of salt cedar and Russian olive) caused by introductions of nonnatives and to reestablish (to the degree possible) native riparian plant communities.

Monitoring and Research: Monitoring the success of revegetation or restoration of riparian and wetland sites is critical to developing effective management techniques. All such efforts should be monitored for a long enough time period to evaluate success. Baseline information should be collected for comparison to future data; this baseline should include records about date of planting, source of material, species and numbers of planting, and some quantification of size. Additional data should be collected at regular intervals and used in an assessment of the success or failure of the project. This information should be made available to interested parties.

The SCS Plant Materials Center is a source for cottonwood and willow poles, as well as for shrub seedlings. Funding should be provided to the Plant Materials Center to study the genetic characteristics of cottonwoods and willow in particular and how these characteristics may affect revegetation success.

The Plant Materials Center should also be provided funding and, if necessary, additional personnel, to investigate the suitability of other native species for revegetation, including shrubs, herbaceous forbs and grasses, and wetland plants. Suitable species for restoration and revegetation could be kept on hand, or techniques could be developed for collection and preparation for planting of local material, that would minimize or eliminate the need for using nonlocal and nonnative species.

Agencies and Municipalities with Related Experience:

City of Albuquerque, Open Space Division
U.S. Fish and Wildlife Service, Bosque del Apache National Wildlife Refuge
U.S. Army Corps of Engineers
U.S. Bureau of Reclamation
Soil Conservation Service, Plant Materials Center
Tree New Mexico
New Mexico State Forestry and Resources Conservation Division
New Mexico Parks and Recreation Division

RECOMMENDATION 15: Protect, enhance, and extend (create) wetlands throughout the Middle Rio Grande riparian zone.

Need: Wetlands consist of marshes, wet meadows, drains, and seasonal ponds that typically support water loving plants such as cattails, bulrush, sedges, rushes, saltgrass, pondweed, milfoil, and watercress. Wetlands are an integral component of the bosque ecosystem, not only increasing its diversity but also enhancing the value of surrounding plant communities for wildlife. They provide habitat for a high diversity and abundance of wildlife, many of which are rare and declining. A significant portion of the animal community is dependent on wetlands, including waterfowl, shore- and wading birds, muskrats, beaver, frogs, kingfishers, turtles, and a multitude of aquatic invertebrates. The interface of wetlands with other plant communities provides increased habitat diversity and is reflected in higher animal species and abundance. Wetlands are also a potentially important factor in maintenance and improvement of water quality.

Wetlands are important to many special status (considered rare, threatened, or endangered by state or federal agency) species. In addition to the more common species, special status species will benefit from wetland protection and creation. Protecting, enhancing, and creating wet meadows and marsh habitats and communities would protect meadow jumping mice and tawny-bellied cotton rats, as would maintaining herbaceous vegetation along drains. The creation of additional ponds and/or marshes could potentially benefit both the leopard frog and the painted turtle, as well as other species associated with wet habitats. Planting willows directly adjacent to wetlands would enhance nesting habitat for southwestern willow flycatchers.

Wetlands have experienced the greatest historical decline of any floodplain plant community and are currently limited to relic and human-made or caused wetlands, e.g., Santo Domingo Marsh, North and South Diversion channel outfalls, Oxbow Marsh, Isleta Marsh, Madrone Ponds, Bernardo and La Joya waterfowl areas, and Bosque del Apache NWR (see Table 22 for a more comprehensive list). There are also several small, scattered wetlands throughout the bosque. From 1918 to the present, wetlands (represented by marsh, open water, saltgrass meadow, and alkali) have been reduced from about 21,052 ha (52,000 acres) to about 1,498 ha (3,700 acres)—a 93% reduction. The majority of human-developed or caused wetlands that are currently being managed will likely be perpetuated. However, wetlands such as Santo Domingo and Isleta marshes and Madrone Ponds will continue to mature and progress toward more mesic terrestrial communities.

Among the greatest needs of the riparian ecosystem are the preservation of existing wetlands, management of these wetlands for optimum benefit, and expansion or creation of additional wetlands. These measures would aid in restoring some of the biological values historically lost and in enriching the habitat value of the bosque ecosystem. Also of significant importance in the expansion or creation of wetlands is the need to emphasize local genetic stock and native species.

Description of Recommendation: *Protection of existing wetlands*—The limited area of wetlands places a high value on those remaining. Existing landowners and administrators not presently managing wetlands located on their land need to consider implementing measures to ensure the future preservation of biological values. Existing landowners or administrators currently managing wetlands should continue to emphasize wetland values. Planning studies in areas of known or potential wetlands need to locate these areas and formulate alternatives that preserve this resource.

Enhancement of existing wetlands—There are several measures that can be taken to enhance the value of unmanaged wetlands. These include management of human use, grazing, water, vegetation, depredation, and sedimentation. Existing riverside drains represent one of the largest wetlands in the middle valley, and inclusion of biological values as an integral part of their management would make an appreciable contribution toward enhancing not only wetland values but also wildlife use of the adjacent bosque. An assessment of current management practices may demonstrate opportunities to benefit wildlife use of this important existing resource. Often, minor changes in existing practices can produce large improvements in wetland values.

Expansion of wetlands—There are numerous opportunities for expanding wetlands and enhancing wetland values in the Middle Rio Grande Valley. While all reaches of the middle valley would benefit from wetland creation, the Belen and Socorro reaches historically had more wetlands, and wetland restoration should be emphasized in these reaches. The use of constructed wetlands has a high potential for accomplishing this recommendation and can be achieved in several ways. These are as follows:

(1) Ground-water wetlands. The presence of a high ground-water table in the riparian zone (and in various areas in the adjacent floodplain) offers the opportunity to create wetlands by excavating into the water table. This proven method does not require water containment, control, or supply facilities; employs simple construction methods and a minimum of construction equipment; can be constructed at a moderate cost or in conjunction with other construction projects requiring borrow; and requires very little maintenance. Wetlands of this type, however, may be affected by restoration of peak flow regime (i.e., by sedimentation). Examples are the COE wetland at Los Lunas and the State of New Mexico's wetland at the Rio Grande Nature Center. This technique can also be used to convert sand and gravel pits located within the riparian zone or adjacent floodplain into productive wetlands. The Albuquerque to San Acacia reach has a relatively high water table that would favor this type of wetland development. However, other reaches also have favorable sites.

(2) Drain return flows. The Oxbow Marsh is an example of wetland development at the discharge point of a riverside drain into the Rio Grande. Excavation of depressions of diverse sizes, configurations, and depths at the discharge points could be achieved easily, at moderate cost, with few if any structural facilities, and with minimal maintenance Drain discharges should not contain significant amounts of sediment acquired from irrigation water.

(3) Floodplain wetlands (small scale). Similar to excavated riparian wetlands, depressions can be excavated within the floodplain. Examples of these wetland types are at the Rio Grande Nature Center and Bernardo Waterfowl Area. If the minimum water table is not high (above about 2 m [6 ft]), an alternate water supply is required for filling and to compensate for evapotranspiration losses. This alternate water supply can be provided by pumping or by diversion. A waterproof liner (Polyolefin, PVC, Hypalon, Permalon, clay, or bentonite) is required to prevent water loss if the wetland bottom is in porous substrate. The Rio Grande Nature Center uses a liner in their primary wetland and Sandia Lakes uses both liners and

bentonite. Initial investment costs are higher than those of ground-water wetlands, and operation and maintenance costs are also involved.

(4) Floodplain wetlands (large scale). Impoundments can be created by excavation, berms, dikes, or a combination of measures to form large wetlands, such as those at La Joya Waterfowl Area and Bosque del Apache NWR. Water is obtained by diversion or pumping and controlled by gates and weirs. Sandia Lakes utilizes water diverted from the riverside drain. Engineering design and construction can range from simple to complex, and construction and maintenance costs vary according to complexity. This wetland design is quite adaptable for treating wastewater, storm runoff, and irrigation return flow from large and small population centers. This wetland creation measure would generally be on a scale too large to be compatible with riparian segments of limited width. However, this concept could be adapted on a smaller scale to large openings, areas of sparse vegetation, or vegetation with a demonstrated low wildlife use (e.g., salt cedar).

(5) Storm-water conveyance channels. The outfall channels of the AMAFCA's North and South Diversion channels are good examples of how wetlands can develop from trickle flows in unlined, storm-water conveyance channels. These flows can be high in pollutants which can be substantially reduced by wetland plants and microbial action before entering the Rio Grande. However, major runoff events present engineering challenges for treatment and sediment loading. Also, the infrequent nature of precipitation and the discharge of large volumes of water in the span of 1 or 2 hours are major concerns.

Special status species—Protection of wetlands and incorporation of certain design elements into constructed wetlands will benefit the special status species. Following is a brief description of requirements for leopard frogs, southwestern willow flycatchers, and meadow jumping mice:

Leopard frog—to maximize the habitat value of marshes to leopard frogs and painted turtles, Applegarth (1983) recommended the following features be incorporated into wetland design:

- Provide a combination of wet meadow with shallow, clear ponds holding water in April.
- Provide shallow ponds at least 1 km (0.6 mi) away from deeper ponds.
- Ponds should range form 10-100 m (33-328 ft) wide by 100-1,000 m (328-3,281 ft) long—the longer ones should parallel the river to resemble old river channels.
- Excavate depressions for ponds halfway to average annual low water table or excavate in winter to top of winter water table.
- Ponds should not have steep side slopes.
- Ponds should be a variety of shapes, sizes, and depths.

Southwestern willow flycatcher—plant willows directly adjacent to wetlands to provide the overhanging cover required for nesting habitat.

Jumping mouse—intensive human activities, such as construction gravel operations, off-road vehicle use, and grazing, can cause serious damage to sensitive habitats. If located in or near jumping mouse habitat, these activities could alter the area's vegetation, microclimate, and hydrology; disrupt breeding, nesting, and hibernation activity; and destroy cover vegetation, food sources, and nesting materials.

Dredging permanent ditches and clearing, moving, or burning ditchside willow/grass/forb vegetation could alter or destroy jumping mouse habitat. These activities could remove vegetation, decrease abundance of preferred plant species, and destroy nests.

To avoid or minimize impacts and disturbances from the various agencies' construction or operation and management activities, the following measures should be implemented:

- Prior to initiating any activities, all potential work sites would be evaluated to identify any areas of jumping mouse preferred habitat of permanent marsh, wet meadow, or willow/grass/forb ditchside habitats. Potential habitat would then be evaluated by a qualified biologist to determine the occurrence of the subspecies.

- Selection of sites for projects and associated features such as access roads, dredge spoil disposal, borrow pits, temporary equipment and material storage yards, vegetation control and planting, and other related activities would be made with full consideration to protect potential jumping mouse habitat.

- Major disturbances along both sides of ditches that remove significant amounts of bank vegetation and along large continuous areas of willow/grass/forb ditch habitat should be avoided. Cleaning and dredging activities that steepen ditchbanks should be avoided. Mowing of willow/grass/forb vegetation close to the water along ditches should be scheduled in alternate years. Ditch maintenance activities at sites determined to be in or adjacent to nesting habitat should be deferred until fall or winter, when juveniles are out of the nest and able to move away from maintenance equipment.

- Efforts should be made to regulate flows so that occasional controlled flooding of ditchbanks and meadow areas can occur. Growth of plant species preferred by jumping mice should be enhanced by seeding and periodically cutting back tall willows that shade out grasses and forbs.

If wetland areas are created or restored, wet meadows with vegetation preferred by jumping mice should be a part of the design. Efforts should be made to reintroduce jumping mice into such created wetlands.

Opportunities and Constraints: The protection, extension (creation), and enhancement of wetlands are the most achievable recommendations in this plan. Most of the major wetlands are under some form of governmental control, and if not directly protected and managed for wetland values, the potential to do so is present. Isolated wetlands in private ownership need to be located and owners encouraged to protect and enhance their wetlands. Creation of wetlands is highly achievable, and the technology is available. Creation of wetlands can be accomplished in concert with planned construction measures to rehabilitate the existing levee system in the Albuquerque, Belen, and Socorro reaches. Table 22 and Fig. 33 list some areas with potential for wetland protection, enhancement, and creation. Also, the expansion of agency missions, both federal and state, to restore the extensive, historic loss of wetlands would provide a positive method for directly focusing on the creation, expansion, and management of wetlands.

Potential constraints are considered to be manageable. As with all recommendations, landownership/administration is a primary consideration. Several wetland creation measures involve diversion of water (including exposing ground water), and acquisition of water rights would be a major consideration. Alteration of land management practices, either in conjunction with enhancing existing wetlands or creating new ones, would have to be addressed by the managing agency or individual(s).

Implementation Considerations: There is little published literature regarding wetland creation and enhancement in western and semiarid landscapes. However, there are several governmental agencies and private entities with knowledge and experience in this subject area. The NMDGF, New Mexico State Parks and Outdoor Recreation, COE, FWS, and the SCS are local governmental agencies with expertise and experience in wetland creation. Some fundamental considerations are as follows:

Preservation of Existing Wetlands: (1) identification, (2) landownership, (3) laws and regulations, (4) partnership, (5) incentives, (6) acquisition, (7) planning objectives, and (8) water supply.

Enhancement of Existing Wetlands: (1) grazing management, (2) open water/emergent vegetation ratio, (3) strategy for management of riverside drains, (4) vegetation management, (5) human-use management, and (6) water supply.

Creation of wetlands—A major design concept to be emphasized in wetland design is the diversification of wetland function and configuration. This diversity will optimize both the diversity of plants and animals. Also, the design should consider target species such as the leopard frog, the painted turtle, the southwestern willow flycatcher, and other wetland species whose numbers have declined as a result of wetland drainage. Although just about any size wetland will have some benefits, wetlands 0.8 ha (2 acres) and larger will achieve the greatest benefits. The concept of "bigger is better" applies to wetlands. Factors that should be considered in the planning and designing of wetlands include the following: (1) goals; (2) landownership/administration and management; (3) site location—relationship to adjacent plant communities, Rio Grande, channel configuration, and floodplain development; (4) site attributes—soils, vegetation, biological values, ground-water depth, and ground-water fluctuation regime; (5) monitoring of ground-water fluctuation for wetland design; (6) design options—optimum shallow/deep water diversity, wet meadow, seasonal flooding/permanent water, open water/emergent vegetation ratio, sideslope ratio and variability, and enhancement of species of concern; (7) public use; (8) access—construction and any public use; (9) preference for native species (same genotype) for planting; and (10) size.

Action: *Creation of wetlands*—Develop site suitability maps based on biological value of plant communities to be displaced, relationship to biological value to adjacent plant communities and floodplain development, soils, ground-water depth, and annual fluctuation, locations that offer maximum protection from flood-flow scouring and sedimentation, and water quality.

Develop a comprehensive plan of wetland development and design that not only emphasizes diversity within each wetland developed, but also diversity among a system of wetlands redeveloped along the entire length of the middle valley.

Pursue wetland development in conjunction with planned levee rehabilitation efforts from the Village of Corrales to San Marcial, in conjunction with storm-water or wastewater treatment plans, and consider sand and gravel needs. This strategy takes advantage of measures that strongly lend themselves to wetland creation with minimal direct costs for wetland features.

Wetland creation as a specific goal should also be pursued, particularly in areas where there are none, where they existed historically, or where there are no foreseeable opportunities for their creation. Monies for their creation should likewise be budgeted for this purpose.

Address possibility of expanding agency missions to include wetland restoration.

Existing wetlands—Existing wetlands should be identified as areas of high biological value as well as areas of high potential for enhancement of these values. Many wetlands are not managed for their intrinsic values, and even small management efforts can be of significant value. Existing wetlands should be evaluated for their existing biological use and for factors that limit their full potential; measures should then be developed to optimize biological values. Human and livestock management, water management, vegetation management, and judicious dredging are measures that can appreciably increase these values. As with creation of wetlands, the possible expansion of agency missions to address wetland management should be pursued.

The MRGCD holds title to a significant amount of the riparian zone, including the drains, and has excavation capability. Because of these features, the MRGCD will play a major role in wetland creation and management.

Monitoring and Research: All actions taken to enhance and create wetlands should be monitored to evaluate the effectiveness of management actions and the development of wetland plant and animal communities, respectively. Wetlands developed for treatment of wastewater should be monitored for effectiveness and possible high levels of various elements and compounds including any bioaccumulation.

Research is needed to develop native stocks of wetland plants that can be used in the creation of wetlands (see Recommendation 14 on native plant species). Currently, there are no developed sources of local or regional wetland plants.

Long-term research into wetland design for optimum development of wetland plant and animal communities should be undertaken by local, state, and federal agencies and regional universities

Agencies or Entities with Implementation Roles and Related Experience:

Middle Rio Grande Conservancy District
All Municipalities, including Pueblos

U.S. Army Corps of Engineers
U.S. Bureau of Reclamation
New Mexico Department of Game and Fish
Ducks Unlimited
New Mexico Energy, Minerals, and Natural Resources
U.S. Fish and Wildlife Service
Soil Conservation Service
New Mexico Parks and Outdoor Recreation
Hydra, Inc.

RECOMMENDATION 16: Sustain and enhance existing cottonwood communities, and create new native cottonwood communities wherever possible throughout the Middle Rio Grande riparian zone.

Need: Restriction of the river between levees and reduction of scouring flows have reduced the number of sites and opportunities for the establishment of native riparian vegetation, especially cottonwoods. Nonnative species, many of which have reproductive strategies that allow them to reproduce under existing conditions, have become established in the riparian zone and often are the dominant members of plant communities or form a significant part of them. As the native cottonwoods age and die, these nonnatives will become more abundant and may eventually entirely replace native species. In order to protect the geographic extent of the bosque and avoid fragmentation, steps should be taken to preserve the existing cottonwood forest. However, preservation is not enough. There is also a need to sustain existing cottonwood communities and to create new communities where possible. The biological benefits from following this recommendation are not restricted to maintaining plant communities; riparian zones and the native species which compose them support diverse and abundant populations of wildlife, especially in contrast to adjacent upland areas.

Description of Recommendation: Sustaining and enhancing the bosque require providing suitable sites and conditions for germination and establishment and also the presence of adequate ground water to support new and existing stands (see Recommendations 1-3 on maintaining natural hydrograph, fluvial processes, and ground-water levels). Creating new cottonwood communities in appropriate locations will maintain populations of native species in the bosque and prevent those areas from being colonized and dominated by nonnatives.

Opportunities and Constraints: As currently managed, water releases from Cochiti Dam somewhat resemble the natural hydrograph (see Recommendation 1 on the natural hydrograph). Peak flows provide a pulse of water at approximately the same time as conditions prevalent before dams were constructed on the main river stem and its tributaries. This type of flow, presumably, supports to a certain extent existing plant communities (and other riparian organisms) by providing ground-water replenishment at optimum times during the year.

There are also opportunities to manage water in such a way that conditions for germination and establishment could be produced during a specific year. In a year of abundant runoff, water could be stored until cottonwood and willow seed dispersal begins, and then released at maximum capacity. In areas where overbank flooding is possible, and where suitable open spaces are naturally available or created (especially in the Belen and Socorro reaches of the river, below the confluence of the Rio Puerco), new cottonwood communities could become established. Since there are relatively few sites where overbank flooding takes place under the present reservoir management regime, this strategy will probably have limited success, especially in the Cochiti and Albuquerque reaches. However, locations where overbank flooding does not take place, but where damp soils are produced by seepage and rising ground water in open areas, may also be sites for new cottonwood communities. A significant constraint to overbank flooding is the limited channel capacity due to the poor condition of spoilbank levees (except in the Albuquerque Reach).

In addition to the presence of spoilbank levees, there are other constraints preventing establishment of new stands of cottonwoods along the northern reaches of the Rio Grande. There, the river channel is degrading rather than aggrading, or building up. Vegetation has grown along the banks of the river channel in some areas, thus stabilizing the channel and enhancing the tendency for degradation rather than bank erosion and channel shifting. Stabilization and deepening of the channel (the result of natural processes and the implementation of a bank stabilization program) have reduced lateral movement of the river and resulting erosion and scouring effects. Established stands of cottonwoods are not being eroded and removed by flooding but are remaining in place. Consequently, there are few open areas available for younger generations of cottonwood and other native species, even if moisture conditions were made suitable by flooding. It is critical to the future of the bosque that disturbed areas be revegetated with native cottonwoods; it may also be necessary to institute forestry practices (including purposeful clearing of senescent cottonwood stands) to sustain the bosque over a long period of time.

Active land and vegetation management will be required to supplement in some cases, or replace in others, the Rio Grande's hydrologic and fluvial processes that are favorable to the support and creation of cottonwood communities. The human "energy" investment could vary from mechanically preparing a site for natural spring flooding, to artificially applying water to particular sites, or to planting acres of individual cottonwood trees.

Fires in the bosque present both opportunities and constraints. High intensity fire is a major disturbance, resulting in the death of cottonwood trees of all ages. Fires may clear out old trees, but unless something is done after the conflagration, the burned areas will be invaded almost entirely by nonnative species such as salt cedar, Russian olive, mulberry, and Siberian elm.

As with the protection of the bosque recommendation (Recommendation 7), landownership is an important factor in enhancement of existing native species communities and creation of new ones. Land management agencies and private landowners have the potential for managing their lands for the benefit of native plant species. There are state, federal, and private sources with economic assistance for these purposes.

Implementation Considerations: Because of mixed ownership status of bosque lands and lack of certainty of ownership in some cases, defining and clarifying land status in the riparian zone would be useful for planning. Ownership/management of riparian habitats of high quality could be identified, and owners/managers would have the option of protecting and enhancing those areas. Ownership/management of areas of high potential for revegetation could also be identified, and the owners/managers would then have the opportunity to replant with native species.

Personnel at the Bosque del Apache NWR, BOR, COE, the SCS Plant Materials Center, and the City of Albuquerque have experience in establishing cottonwood, willow, and native shrubs. Research on the hydrological regime required for germination of cottonwoods has been conducted by the FWS National Ecology Research Center in Fort Collins, Colorado.

Flooding of particular areas along the bosque, in all reaches, could be accomplished with the construction of headgates to enable the use of irrigation canals to carry water to specific locations, pumping from the river or ditches, or the use of inflatable dams across the river. This kind of "spot flooding" would produce germination of native species if done at the appropriate time of year and if open substrate is available.

Preparation of a site for receiving seeds and moisture is very important. If the site is occupied by dense vegetation, cottonwood seedings will not be successful. Use of heavy equipment to plow up the soil in advance of flooding should create suitable conditions for germination. This is now being investigated at Bosque del Apache NWR.

Until additional research shows how low intensity fire might be used in management of the bosque, we believe that fire suppression is extremely important to prevent the deaths of large numbers of trees. If a fire does take place, the dead trees should be removed (leaving some snags and dead wood) and regeneration of cottonwoods and other native species should be attempted. Pole planting has been the predominant method used, but methods such as planting seedlings or saplings have been used successfully in other areas (see Appendix V for methods and information sources). Post-fire seeding and flooding may also provide effective reestablishment.

Action: Develop an ownership map of the riparian zone in the Middle Rio Grande Valley so that protection, enhancement, and revegetation can be extended where possible to the bosque by the appropriate entities.

Develop site suitability maps for revegetation based on topography, known ground-water levels, soil characteristics (especially salinity), and other relevant features of the landscape. These maps could then be used as a guide for revegetation plans along the Middle Rio Grande Valley. Until these detailed maps are developed, it may be possible to achieve successful revegetation based on individual assessments of particular areas to establish the appropriate species and revegetation techniques (see Appendix V for additional information on species, techniques, and sources of material).

Revegetation by seed—Recently exposed or deposited sediments that may be suitable for establishment of riparian vegetation by means of flooding are found mostly below the confluences of the Rio Puerco and the Rio Salado with the Rio Grande. Spot flooding to create similar conditions could be used in open areas along the river reaches north of the Rio Puerco. If flooding occurs at the appropriate time (during dispersal of cottonwood seeds), the combination of exposed, bare areas and suitable moisture conditions may produce new stands of cottonwood trees.

Revegetation by pole planting—Areas suitable for revegetation by pole planting include disturbed locations and areas in the river reaches above the confluences of the Rio Puerco and Rio Salado that are not likely to be affected by overbank flooding.

Revegetation by planting rooted saplings—Planting rooted cuttings is an alternative to using pole plantings. Successful projects have included using "deep tillage." Like pole planting, deep tillage requires an auger, which is used to drill holes to the water table. The auger should be of a large diameter (30.5 cm [about 12 inches]) to create a cylinder of loosened soil into which roots can spread. After planting, the rooted cuttings are irrigated for varying lengths of time, depending on local conditions. (See Appendix V for additional details.)

Areas suitable for revegetation—Figure 28 shows locations of burned areas that could be targeted for surveys and assessment of suitability for revegetation by using any of the above techniques.

Vegetative reproduction-root sprouting—Judging from size-class distributions of cottonwood on several sites along the Middle Rio Grande, root sprouting occurs in the absence of overbank flooding. This form of reproduction could be enhanced by mechanical means although this appears not to have been well studied. Places where cottonwood roots have been impacted by heavy equipment definitely show evidence of root sprouting. This form of revegetation should be considered in the future pending the results of research (see Recommendation 19 on research) especially in parklike areas with native stands and little or no understory and in burned locations.

Agencies and municipalities are encouraged to review operation, development, and management policies that are related to riparian issues especially cottonwood regeneration. Appropriate policies could be revised or new ones developed to protect and enhance riparian habitats. These policies could be coordinated with other agencies and municipalities through a state riparian task force and/or riparian coordinators.

Private citizens (and nonfederal agencies and municipalities) should be made aware of programs such as "Partners for Wildlife" and other cooperative agreements with the FWS that support the preservation and creation of wildlife habitat, including habitats found in the riparian zone. They should also be made aware of conservation easements, acquisition programs, and other options with The Nature Conservancy and the New Mexico Natural Lands Protection Committee all of which could be used to protect, enhance, or create cottonwood communities.

New federal, state, and private programs providing incentives for improving cottonwood habitats should be initiated and developed.

Monitoring and Research: Any revegetation effort in the bosque should be accompanied by monitoring so that an assessment of the success of the project can be made and the resulting information and conclusions applied to future plans. Baseline information on species, numbers, and sizes of plants should be collected. The same information should be collected at regular intervals to determine success of the project.

Research into forestry practices should begin in order to determine effective ways to establish new stands of cottonwoods. This is especially applicable in areas where the bosque is contiguous for long distances and where disturbance is not likely to take place from fluvial processes. These practices may include removal of senescent stands of trees to allow juveniles to become established and removal of extensive stands of nonnative species and replanting with natives.

Studies of controlled burns should begin to see if low temperature fires could be used to prevent build-up of a substantial fuel load and to control the understory in order to protect existing cottonwood stands from high intensity fires. Dead wood removal and flooding (see Recommendations 2, 3, and 11) may help maintain appropriate amounts of dead wood.

Research on methods of revegetation by pole planting, rooted cuttings, and seeds should be continued, including planting season, plant size, relationship of origin of poles, cuttings, and seeds to successful establishment, soil characteristics (especially salinity), and other relevant topics. Existing information on many of these topics may not have been documented; and in some cases, additional work is needed to verify or quantify perceived trends. This research should be linked to that discussed in Recommendation 14 on using native plant species and local genetic stock in revegetation. Studies should investigate the potential for generating significant numbers of new cottonwood trees in existing cottonwood forest from root sprouting. Research should also examine salinity tolerance of native and introduced species.

Agencies and Municipalities with Existing Plans for Revegetation:

City of Albuquerque, Open Space Division
U.S. Fish and Wildlife Service, Bosque del Apache National Wildlife Refuge
U.S. Bureau of Reclamation
U.S. Army Corps of Engineers

Agencies and Groups with Funds or Resources Available for Habitat Improvement:

New Mexico Natural Lands Protection Committee
U.S. Fish and Wildlife Service, Private Lands Coordinator
New Mexico State Forestry and Resources Conservation Division
Tree New Mexico
Soil Conservation Service, Plant Materials Center

RECOMMENDATION 17: Contain the expansion of existing large stands of nonnative vegetation in the Middle Rio Grande riparian zone. At the same time, study the ecology of these stands and develop creative ways of maximizing their biological values.

Need: If the decline of cottonwood forests along the Middle Rio Grande continues, Russian olive will become the dominant tree in the north and salt cedar will increase its dominant position in the south. Both trees, salt cedar in particular, form large, homogeneous stands with relatively low-diversity undergrowth (however, the numbers and kinds of animals that inhabit these stands can be impressive).

Large cottonwood stands cannot easily be maintained if correspondingly large stands of nonnative trees close to them are not brought under control. So far, such control has proven especially difficult with salt cedar, but the effort needs to be continued. Russian olive and salt cedar stands are here to stay, and therefore must be regarded as integral parts of the bosque. As such, they can be used to enhance the bosque's biological diversity. Clearly, there is a need to study these relatively new ecosystems and to experiment with ways of managing them.

Description of Recommendation: Containment of the spread of large stands of nonnative trees is possible using combinations of bulldozing and root ripping, at least in the case of salt cedar. This has proved successful at Bosque del Apache NWR, where herbicides have also been used. Since the side effects of herbicides are not always apparent, we hesitate to recommend them. Containment of Russian olive stands may seem less of a problem now, but the species spreads rapidly and does well in the absence of shade. Even in the semishade of a cottonwood forest, Russian olive contributes a significant understory. Both species seem to survive burning better than cottonwood; therefore, that form of control should be used with extreme care, if at all.

Because eradication is unrealistic, and because both trees have much to offer wildlife (see earlier discussions), it is sensible to manage them for the enhanced diversity of consumer organisms. This can be done in several ways. One way is to break up large stands mechanically, creating increased forest edges in the process. If cleared areas are near the river and subject to flooding, the clearings could, with correctly timed flood drawdown, be converted to cottonwood/willow stands. This is now being attempted at Bosque del Apache NWR.

Another way of managing these stands for diversity is to create wetlands, cottonwood stands, and open spaces (grasslands, shrublands) inside them. Again, these procedures are best done mechanically. Discussion elsewhere in this document considers wetland establishment in landscapes dominated by native and nonnative forests.

Opportunities and Constraints: Now is the best time to prevent further intrusion of cottonwood forests by expanding stands of nonnative trees. As the years go by the opportunity to contain the intrusion will diminish, especially if cottonwood reestablishment is not vigorously promoted.

Likewise, the existence of large homogeneous stands of nonnative trees now presents an excellent opportunity to experiment with creation of habitat and species diversity within those stands. Establishing "islands" and "corridors" of wetlands, cottonwood forests, and open areas within these often great expanses of exotic vegetation, tends to help keep them under control.

Implementation Considerations: Although implementation of this recommendation applies to stands of both Russian olive and salt cedar, the latter are more extensive and uniform. For the time being, therefore, enhancing the diversity of vegetation would be most practical in areas dominated by salt cedar. Lessons learned could then possibly be applied in Russian olive stands, which now are located mainly between the riverbank and interior forest with good cottonwood representation.

As implied above, use of heavy equipment is the key to diversifying vegetation and creating habitats. Since operation of earth moving machinery is expensive, initial efforts at implementing this recommendation would best be accomplished on public lands, such as those in the Socorro Reach, and by large agencies such as the FWS, BOR, and MRGCD. An example of collaboration between the first two of these is seen at Bosque del Apache NWR, where acre-size plots along the Rio Grande were removed in the spring of 1993 in an attempt to establish cottonwood after overbank flooding. Following that example, cottonwood germination could be promoted by extensive mechanical removal of salt cedar on both banks of the river (levees exist only on the west bank in that area) shortly before expected overbank flooding in late spring.

Wide fire breaks in large salt cedar stands at Bosque del Apache NWR are created with heavy earth moving equipment. When maintained, these are good examples of salt cedar containment. During the growing season, they are rapidly colonized by Russian thistle and summer cypress which are annuals and can be easily plowed under. Similar newly bared expanses could be planted with grasses and native shrubs (information available from the SCS Plant Materials Center) to create open spaces throughout the salt cedar forests.

Such open spaces could also be used to create wetlands, perhaps fringed with cottonwood planted on shallow banks as poles or cuttings, or separate stands of cottonwood. Excavation to the water table (2-4 m [6-13 ft] deep) in the old riverbed should be considered. Emergent vegetation should be planted soon after to improve habitat diversity.

Action: Maps charting the expansion of major nonnative trees along the Middle Rio Grande are available in this document and from the FWS National Ecology Research Center in Fort Collins, Colorado. These maps should be examined for information leading to decisions about where to perform the above-mentioned manipulations. They show, for example, the location of large tracts occupied by salt cedar.

Activities such as those being undertaken at the Bosque del Apache NWR should be continued and expanded. Other public agencies should inventory their land; and where large expanses of salt cedar are present, they should seek funding and implement vegetation diversity programs.

Monitoring and Research: Any actions under this recommendation should include monitoring over a length of time sufficient to determine the success or failure of the projects. The effects of mature salt cedar stands on surficial soil chemistry (with a focus on salts and boron), which may inhibit or prevent germination and establishment of native species, should be investigated.

Agencies and Other Organizations with Related Experience:

U.S. Bureau of Reclamation
U.S. Fish and Wildlife Service, Bosque del Apache National Wildlife Refuge
U.S. Army Corps of Engineers
U.S. Fish and Wildlife Service, National Ecology Research Center
Hydra, Inc.

RECOMMENDATION 18: Develop a coordinated program to monitor biological quality (with emphasis on the diversity and abundance of native species) and ecosystem integrity (with emphasis on restoring the functional connection between the river and riparian zone) of the Middle Rio Grande ecosystem.

Need: Insufficient long-term data exist for managers of the ecosystem to develop the kind of comprehensive management strategy described in the introduction to this section. Systematic, coordinated monitoring of key ecological variables and indicators of ecosystem integrity along the Middle Rio Grande is needed to provide this kind of information. Monitoring will be useful for testing assumptions, improving predictions, and identifying cause and effect relationships. All of these are important to ecosystem management. The program should minimize interagency overlap and maximize information return to a central, management-related data base.

Description of Recommendation: As discussed in the next section of this document, a broad-based interagency management unit consisting of a central coordinator and agency coordinators should first be created as a framework for storage and exchange of monitored data and other relevant information. The central coordinator should call for a series of meetings in which all interested and involved organizations (federal, state, municipal, pueblo, private) would address development of a comprehensive, long-term monitoring program for the Middle Rio Grande. This would be done in conjunction with development of a long-term research program (see Recommendation 19) because both functions have close ties. We recommend that the monitoring program focus on critical aspects of riverine hydrology and morphology, aquatic ecology, and terrestrial ecology.

It is true that certain of these critical features are presently monitored by a number of organizations, which are generally willing to release their data. However, such monitoring tends to be mission-specific (directed, for example, at flood control or bird migration) and not driven by a need to consider the health of the entire ecosystem. It can also involve several organizations monitoring the same thing (e.g., ground water). Therefore, we propose that special emphasis be placed on the coordinated monitoring of factors that affect the broad question of biological quality and integrity of the Middle Rio Grande ecosystem.

Specifically, we propose that the following be monitored in a standardized manner at designated points along the reach: (1) changes in the morphology of the river; (2) transport of particulates and dissolved compounds that influence the viability of aquatic and riparian communities; (3) changes in ground- and surface-water levels, soil moisture, and soil salinity and their relationship to river flows; (4) cycling of nutrients in riparian communities; (5) changes in structure and composition of plant and animal communities in the bosque, the river, and wetlands; (6) recruitment and establishment of cottonwoods and willows; (7) changes in distribution and abundance of populations of plants and animals highly sensitive to disturbance; (8) changes in the rate of incursion and population growth of introduced species; (9) changes in seasonal and annual meteorological conditions in diverse forest habitats; (10) frequency and effects of fires; (11) intensity and effects of livestock grazing; and (12) extent and effects of recreational use.

Monitoring of these factors will help analyze the effects of regularly occurring events such as seasonal changes in plant and animal communities, disturbance events such as wildfires, and management practices such as cottonwood reintroduction. Baseline monitoring should be started as soon as possible where disturbance and management effects are likely to occur.

Opportunities and Constraints: Managing an ecosystem as complex as the Middle Rio Grande requires (1) an appreciation of its ecology, (2) an ability to monitor ecological functions as they relate to management goals, and (3) a mechanism to coordinate such monitoring among managing agencies. The first of these is widespread, although it needs to be nurtured. The second can be found in agencies that manage aspects of the Middle Rio Grande ecosystem; however, development of skills and techniques relative to the monitoring of nutrient fluxes could be improved. It is the coordination of monitoring that needs the most emphasis. Ecological monitoring along the Middle Rio Grande currently lacks the level of coordination needed for a comprehensive management strategy. Additional coordination would reduce monitoring redundancy, allow all parties to monitor with full knowledge of current and past information, and contribute to a long-term data base available for ecosystem management.

Implementation Considerations: Development and implementation of a centralized monitoring clearinghouse and planning function will require the cooperation and good will of the various agencies that presently manage the Middle Rio Grande's resources. It will also require funding to create a computerized network for information transfer and storage. Coordination costs to the agencies concerned will probably be minimal if they assign existing employees as agency coordinators. The main expense is expected to fall on the central coordinator, who may need to subcontract some or all coordination and information storage functions to another source.

The monitoring program will serve the ecosystem's managers. Its authority will be credible only if it has the continued support of the associated federal agencies and strong backing of the pueblos and state government, the state's congressional delegation, and the agencies that now manage the Middle Rio Grande.

Action: The recommended monitoring program should address the following questions: Which agencies or other organizations should do what monitoring? When and where should that monitoring occur? How should monitored data be coded, transmitted to the central coordinator, and ultimately made available to managers and other users? Ideally, many of the critical factors listed above should be monitored at each of the four distinct reaches identified in this document.

Agencies or Entities with Potential for Involvement in Monitoring:

All those agencies and entities listed in Appendix IV with appropriate biological or hydrological expertise.

RECOMMENDATION 19: Develop a coordinated research program to study the ecological processes and biotic communities that characterize the Middle Rio Grande riparian ecosystem.

Need: It is difficult to predict the effects of management on an ecosystem without having a thorough understanding of the processes that drive it and the biotic communities that inhabit it. When early resource managers in the Middle Rio Grande riparian ecosystem began to practice large-scale water management, they could not foresee that their operations would lead to the conditions that produced the need for this biological management plan.

Even today, because our understanding of how the Rio Grande functions as an ecosystem is far from complete, we are unsure of the long-term consequences of current management practices. For example, while the effect of flooding on cottonwood regeneration seems obvious and is often taken for granted, how flooding actually influences nutrient cycling and the lives of many key organisms in the aging cottonwood bosque is largely unexplored. Yet until these basic features are illuminated through carefully planned research, the consequences of implementing many of our present recommendations will remain unclear.

Many agencies and groups are now conducting research in the Middle Rio Grande riparian ecosystem and larger watersheds. Although there is admirable coordination among many of these activities, it is not comprehensive. As with the ongoing monitoring programs, rarely are ecosystem-level issues being addressed although they could be incorporated into the ongoing research.

Description of Recommendation: We recommend establishment of a long-term, integrated program of ecological research that will interact, where possible, with independent research activities along the Middle Rio Grande. As with the monitoring program (see Recommendation 18), this effort should also minimize interagency overlap and maximize information return to a central, management-related data base. In addition, the research program should interact with other national and international programs that study the ecology of large floodplain river systems.

It is important that all researchers involved be aware of what others are investigating in order to avoid unnecessary duplication of effort. Therefore, a series of meetings, not unlike those suggested for the monitoring program, should be an effective way to organize a comprehensive research program. Ongoing and completed studies (referenced and discussed earlier in this document) could provide a partial basis for the ultimate design of the program.

Whenever feasible there should be a close association of the research program with the recommended monitoring program. Likewise, as with the monitoring, the research should focus on critical aspects of and connections among hydrology, aquatic ecology, and terrestrial ecology. Strong emphasis should be placed on the relationship of hydrological regimes and fluvial dynamics to community-level regeneration and successional trajectories. Another strong emphasis should be placed on the dynamics of ground-water/surface-water interactions, which are clearly related to nutrient cycling and therefore to the productivity and diversity of riparian communities. An important related goal should be to understand—and possibly model—the relationship of Rio Grande flow regimes to water levels and water quality in wetlands, irrigation channels, and ground-water drains.

Terrestrial research should emphasize relationships among nutrient cycling (which is a fundamental process driven by hydrology and climate), primary and secondary production, and community dynamics. Although these interactions are broad and complex, a balanced program could examine specific, management-directed questions including the following: (1) Can a study of the genetics of dominant native and nonnative plants be used to create more salinity-tolerant cottonwood forests? (2) What are the effects of bosque fragmentation on key populations and communities? (3) What kinds of bosque habitats lead to optimal wildlife diversity?

The impacts of various forms of disturbance are also in need of study. Examples of pertinent questions here are: (1) How do native and nonnative organisms respond to air and water pollution? (2) Do bridges across the Rio Grande have demonstrable effects on dispersal of small mammals? (3) Can burning, even though it usually kills cottonwood, be used as a management tool?

We know little, at present, about conditions that lead to the establishment and maintenance of adjacent, but very different, communities in the bosque. Knowledge of these conditions will help us understand and predict the success of created wetlands and artificially established native vegetation within stands of introduced vegetation.

Some aspects of aquatic ecology research (e.g., fish population dynamics in the river) are ongoing. However, the causes of fish population changes are imperfectly understood. Aquatic invertebrates (potential fish food, among other things) are often highly responsive to changes in water quality and could tell us a great deal about pollution effects. Yet, the diversity of such organisms, to say nothing of the diversity of floating and emergent plant life in the region's aquatic systems, remains poorly known.

Opportunities and Constraints: The opportunities for useful research in the Middle Rio Grande riparian ecosystem are endless. For one thing, the natural history of most organisms inhabiting the zone is a virtual blank. Natural history is not cutting-edge science and does not command big budgets. Nevertheless, its study yields information that managers need in order to understand how the pieces of an ecological puzzle fit together. Natural history can be studied by amateurs, as well as by professionals. Organizations such as the Rio Grande Nature Center, the New Mexico Museum of Natural History, the Albuquerque Public School system, and the UNM Continuing Education program could promote natural history studies. Perhaps the New Mexico Riparian Council or the Museum of Natural History could be used as a clearinghouse for the results of these studies.

Major, somewhat interrelated, constraints to setting up a coordinated program of research include inertia and lack of funds. Inertia may involve a reluctance to depart from traditional research practices in which an organization (university department, federal or state agency) considers itself the recognized authority. The concept of "turf" plays a role here. However, interagency cooperation will be indispensable if any kind of coordinated program is to become a reality.

Environmentally related research funds are not easy to obtain at any level. But this constraint could be surmounted to some extent by organizing the research program in such a way that those agencies already active in special fields (e.g., pollution control, fish population biology) would continue to concentrate in those fields. Thus, a premium would be put on efficiency and lack of overlap. Much valuable research in outdoor environments can be done at little expense.

Agency scientists have their own internal sources of funding; however, such resources may not at first be sufficient to support the coordinated program we envision. Scientists who wish to contribute independently to riverine and riparian research, and who require funding to conduct their studies, will have to apply for grants and contracts from a variety of sponsoring organizations ranging from the National Science Foundation to the New Mexico Water Resources Institute.

Implementation Considerations: Implementation of a coordinated research program that interacts with more independent research studies and utilizes natural history information generated by amateurs and professionals should be promoted by the newly created coordinating council. It will be up to the council's membership to set the agenda. We recommend that this biological management plan be carefully read prior to setting the research agenda.

Action: The same interactive coordinating structure recommended to handle monitoring should decide on research priorities, and it could suggest research assignments for organizations wishing to be involved in the coordinated program. The assignments could be based in part on monitoring data and ongoing research. As with monitoring, similar questions should be asked, and similar approaches taken where possible, for all four of the Middle Rio Grande reaches delineated in this document. At the same time, because management needs vary along the Middle Rio Grande, the program will have to allow for a certain amount of flexibility.

Academic institutions have an important potential role to play in Middle Rio Grande ecosystem research as do management agencies and private organizations. These groups should consider interacting at the national level with the newly formed Sustainable Biosphere Initiative, which has taken a particular interest in environmental management of the entire Rio Grande Basin.

Communication among researchers will be critical to success of the program. They should be strongly encouraged to publish research results in the open literature, whether or not these results are also submitted as agency reports. Finally, researchers should be encouraged to participate in local, regional, national, and international conferences, and to confer with other scientists studying large floodplain river systems.

Agencies with Potential for Involvement in Research:

All Indian Pueblo Council
University of New Mexico
New Mexico State University
U.S. Fish and Wildlife Service
U.S. Geological Survey
U.S. Army Corps of Engineers
U.S. Bureau of Reclamation

New Mexico Department of Game and Fish
New Mexico Forestry and Resources Conservation Division
New Mexico Museum of Natural History
All others with appropriate biological or hydrological expertise

RECOMMENDATION 20: Regularly review and update the Middle Rio Grande Ecosystem: Bosque Biological Management Plan.

Need: This biological management plan requires regular review and update if it is to realize its potential for influencing management decisions that affect the Middle Rio Grande riparian ecosystem. More and more Middle Rio Grande management entities are consulting with one another, sharing resources, and addressing biological considerations when planning and implementing programs. The community of "cooperators" needs to be expanded, and the consistency of cooperation needs to be enhanced in order to achieve integrated ecosystem management. This plan can provide the focal point to reach the next level of cooperation and implementation of the plan. In addition, there is a need for a central repository of information applicable to the Middle Rio Grande riparian ecosystem. As it is now, data, analyses, and reports are generally retained by the agencies that generated them. Distribution is fragmented and incomplete.

Description of Recommendation: We recommend formation of a Middle Rio Grande Coordinating Council. It should be composed of a Middle Rio Grande Bosque Coordinator, riverine and riparian managers, and other interested parties. The Middle Rio Grande Bosque Coordinator should set up a clearinghouse for management-related information and arrange for meetings of the Council.

Primary duties of the Council would be to review and update the biological management plan and to make recommendations for monitoring and research in the Middle Rio Grande. The Council would also serve to provide opportunities for managers to discuss implementation of the plan and to develop cooperative agreements for broad-based management actions.

Opportunities and Constraints: There is a strong public interest at this time in the Rio Grande bosque and its future. Management agencies such as the BOR, COE, and FWS have taken an active interest in cooperative management. The formation of the Coordinating Council will make this cooperation more formal and bring other management entities into the process.

Implementation Considerations: The Middle Rio Grande Bosque Coordinator, with appropriate interagency and public participation, should prepare an annual progress and status report to be distributed to all interested agencies, entities, and persons. The annual report should include, at a minimum, summaries of recent management, monitoring, and research activities, and progress made on accomplishing specific recommendations. In addition, the present plan should be revised and updated every 5 years, the first update to be completed in 1998. The update should include the incorporation of new information and the review of (and modifications to, if determined appropriate) all recommendations. The Middle Rio Grande Coordinating Council should determine who should update the plan and should identify the source of funding.

Action: The FWS (or some other agency with substantial funding and support) should take the lead by selecting a Middle Rio Grande Bosque Coordinator and convening a conference of potential coordinating council members. The current biological management plan will provide a focus for the first conference, where the participants could address implementation of the plan and the mechanism for updating it. (Additional details for this recommendation are to be found in the next section of this document.)

Agencies with Potential Contributions to the Middle Rio Grande Ecosystem:

All agencies and entities listed in Appendix IV.

RECOMMENDATION 21: Integrate resource management activities along the Rio Grande and within the contributing watersheds to protect and enhance biological quality and ecosystem integrity.

Need: The Rio Grande through the middle valley is influenced by all the events and activities that occur upstream and upslope in its drainage area. The Rio Grande is the spout and the watersheds are the funnel. The amount of snowfall in the San Juan or Sangre de Cristo mountains largely determines the amount of water that will be in the system. Urbanization in the Albuquerque metropolitan area affects ground-water quantity and quality, runoff patterns and discharge points, and surface-water quantity and quality. Past mining activities in the Rio San Jose drainage (tributary to the Rio Puerco) affect water quality, and land management in the Rio Puerco watershed impacts sediment deposition in the Rio Grande. The total drainage area for the Rio Grande above San Marcial is 64,150 km^2 (24,760 mi^2); the direct tributary drainage area for the Middle Rio Grande is about 33,160 km^2 (12,800 $mi)^2$. The Rio Puerco alone constitutes 15,180 km^2 (5,860 mi^2). The 71,939 ha (177,689 acres) of bosque are indirectly or directly affected by the entire area.

Description of Recommendation: Ultimately, integrated management of all of the watersheds that collectively make up the Rio Grande drainage is required to manage the bosque. All studies and resultant actions to improve conditions upstream on the Rio Grande and in the tributaries and their watersheds should be actively supported by bosque management interests. In addition, activities in the watersheds should be monitored for their potential impacts to the bosque. Bosque interests need to be represented in the decision-making process for those which are considered to be of particular importance. Likewise, where bosque managers identify watershed conditions to be deleterious to the biological well-being of the bosque, they need to promote appropriate studies or actions to reduce or eliminate the problems.

In addition, bosque managers have responsibilities to those resource managers and users downstream from them, whether in the middle valley, or in Las Cruces, New Mexico, or in Texas or México. We must also consider what our management actions may have on them, and solicit their inputs to our proposed actions.

Opportunities and Constraints: New forums are not necessarily required for integrated management of the drainage. Numerous formal/informal groups and comprehensive study efforts already exist. These include, but are not limited to:

- U.S. Geological Survey's National Water Quality Assessment
- All-Indian Pueblo Council
- New Mexico Water Resource Research Institute's annual water resource management conferences
- Rio Grande Consortium
- Rio Grande Joint Initiatives sponsored by the COE, BOR, and FWS
- Rio Puerco Watershed Work Group led by BLM
- Albuquerque Basin ground-water research cooperators coordinated by the City of Albuquerque
- Sustainable Biosphere Initiative

Participation in these groups by Middle Rio Grande bosque managers and researchers is of paramount importance to maximize communication to effect beneficial changes throughout the watershed.

Implementation Considerations: The challenge, obviously, is the breadth of the physical and human landscape. There are innumerable private, Native American, and governmental forces at work throughout the 64,000 km^2 of watersheds. There is no easy answer on how to coordinate interests and activities. Constant communication is the key, and bosque managers need to invest the necessary resources.

Agencies Active in Rio Grande Basin Watershed-oriented Management, Research, and Monitoring:

U.S. Soil Conservation Service
U.S. Bureau of Land Management
U.S. Forest Service
U.S. Bureau of Indian Affairs
U.S. Geological Survey
New Mexico Bureau of Mines and Mineral Resources
U.S. Bureau of Reclamation
U.S. Army Corps of Engineers
U.S. Fish and Wildlife Service
All Indian Pueblo Council
Sustainable Biosphere Initiative

VII. FUTURE DIRECTIONS FOR THE BOSQUE BIOLOGICAL MANAGEMENT PLAN

Taken together, the recommendations in this Bosque Biological Management Plan argue for a major shift in long-term management policy for the Middle Rio Grande bosque ecosystem. This central point must be appreciated if the plan is to be an effective guide for resource managers. We strongly urge them to pursue their management objectives in an ecosystem context, no matter how specific the objectives.

Because the plan emphasizes an **integrated** approach to management of the bosque and the rest of the Middle Rio Grande ecosystem, we propose that its key operational words should be "communication" and "coordination." From our standpoint, it follows that implementing the plan's recommendations will require (1) a central coordinating structure and (2) an active, representative council of managers and concerned citizens. Positive interaction between the central structure and the council will be crucial; it will make possible sharing of management-related information and coordination of management-related activities among the council's participants.

We believe that this interacting structure—call it for now the "Middle Rio Grande Coordinating Council"—should be simple, flexible, and well funded. This is how it might get started:

- Because federal funds for the Middle Rio Grande bosque initiative are available from the U.S. Fish and Wildlife Service Region 2, the Regional Director could provide initial leadership by (1) appointing a Middle Rio Grande Bosque Coordinator and (2) convening a conference of riverine and riparian managers and other interested parties (the Council).

- The Middle Rio Grande Bosque Coordinator need not but could be a Fish and Wildlife Service employee, and could have a salary and staff paid for by the above-mentioned funds. The role of the Middle Rio Grande Bosque Coordinator would be to (1) set up a clearinghouse for receiving, transmitting, and storing management-related information; (2) arrange for semiannual meetings of the Council's participants—call them "Riparian Coordinators;" (3) create and distribute a newsletter updating and summarizing all ongoing and planned management activities along the Middle Rio Grande; and, (4) prepare and distribute an annual report.

- At the initial meeting, the participants could consider the Bosque Biological Management Plan, deciding also on a mechanism for updating it and its recommendations. We feel the plan should be reviewed and updated every 5 years.

- At subsequent, semiannual meetings of the Council, the Riparian Coordinators could address questions of communication and coordination. In doing so they should (1) make recommendations concerning monitoring and research in the Middle Rio Grande bosque ecosystem, (2) discuss how to incorporate monitoring and research information into revised and updated biological management plans, and (3) make every effort to enhance the flow of management-related information among managing organizations.

If this broad, integrated approach is acceptable, specific approaches taken by the Council can be worked out by its membership. Whatever the case, implementation of the plan will have to be backed by strong leadership and active participation. The future of the Middle Rio Grande bosque is at stake.

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APPENDIX I.

RIO GRANDE BOSQUE CONSERVATION COMMITTEE FINAL REPORT

RIO GRANDE BOSQUE CONSERVATION COMMITTEE

Part of the Conservation Initiative of U.S. Senator Pete V Domenici
625 Silver SW, Suite 120
Albuquerque, New Mexico 87102
(505) 292-1291

June 30, 1993

The Honorable Pete V Domenici
427 Dirksen Building
Washington, D.C. 20510-3101

Dear Senator Domenici:

It is my privilege to transmit to you the final report of the Rio Grande Bosque Conservation Committee, which you appointed and charged in September, 1991.

At a meeting in Albuquerque on May 26, 1993, the Committee completed its work on the document, incorporating numerous suggestions and ideas gained from public comment on an earlier draft. Having finished our labors, the members of the Committee then present, who included Hector Gonzales, Dorothy King, Hanna Lattman, J.C. Sanchez and myself, voted unanimously to approve the entirety of the report, including all of its recommendations. Other members, who for reasons of illness or distance had been unable to attend the meeting and who included Rowena Baca, Paul Risser, and Lynne Scott, subsequently voted by telephone to approve and give full endorsement to the report.

Thus we present to you the result of nearly two years' hard work, which also represents the good efforts of dozens of institutions, public and private, and hundreds of private citizens who participated in the Committee's public involvement program

We are grateful to you for the confidence you placed in us to undertake this task, for your support and guidance throughout the course of our efforts, and especially for your commitment to restore and protect the vigor of the Rio Grande Bosque and preserve the many benefits it provides to the people of New Mexico

We hope that we have been able to contribute positively toward that end.

Sincerely,

William deBuys
Chairman

WdB.dlp
Enclosure

THE RIO GRANDE BOSQUE CONSERVATION COMMITTEE

RECOMMENDATIONS FOR CONSERVATION OF THE MIDDLE RIO GRANDE BOSQUE

June, 1993

EXECUTIVE SUMMARY

After consultations with diverse interests and a lengthy series of public meetings, the Rio Grande Bosque Conservation Committee concludes that.

- The Middle Rio Grande Bosque is undergoing rapid ecological change which endangers the future existence of native biological communities, especially riparian gallery forests of cottonwood and willow
- The value of the Bosque is greater than the sum of its uses and benefits People value it for its own sake.
- People demand stronger management of the Bosque, including enforcement of existing ordinances
- People don't want greater governmental complexity
- People recognize the importance of flood control, irrigation, and drainage but agree that the river and the bosque should not be managed for these ends alone. The public wants a balance of compatible goals and activities, including maintenance of a healthy, diverse ecosystem and provision of clean water and recreational opportunities

The Committee developed ten recommendations based on the comment and information it received

1 A biological management plan for the Middle Rio Grande should be developed as a first step toward restoring the Bosque's health.

2 The institutional structure that currently manages the Middle Rio Grande should be redesigned, expanding management's mission to include, in addition to irrigation, flood control and drainage, ecosystem management, recreation management and the balancing of compatible uses of the Bosque. This task of redesign should be undertaken by a task force authorized by the New Mexico State Legislature.

3. Local governments should become more involved in the protection of Bosque resources within their jurisdictions, especially through improved enforcement of existing ordinances and regulations

4 Constructed wetlands should be considered for treatment of effluent. Such wetlands will also increase habitat for Bosque wildlife.

5 Efforts to control erosion in upland areas, especially the watershed of the Rio Puerco, need to be strengthened

6. Development of Best Management Practices for a wide range of activities can help control nonpoint source pollution

7 Use of drains for conveying irrigation water causes valuable bosque, agricultural, and residential lands to become water logged. The MRGCD should find alternatives to this practice.

8 Agencies involved in Bosque fire control and prevention need to strengthen coordination among themselves

9 A broad-based effort to improve public education on bosque-related topics should be launched.

10 Structures should be developed to direct private charitable giving toward Bosque protection efforts.

PREAMBLE

This report culminates nearly two years of work by Senator Pete Domenici's Rio Grande Bosque Conservation Committee. This work included public meetings, meetings with the relevant government agencies and pueblo governors, preparation of proposals, fact sheets, and communiques, on-site tours, many hours of Committee meetings, and much more. Having invested its best efforts, the Committee earnestly hopes that the recommendations contained in this report be implemented. The major proposals herein are for the most part interdependent. The ultimate value of each is dependent on the implementation of the others.

PURPOSE OF THE COMMITTEE

The Rio Grande and its Bosque are the lifeblood of central New Mexico New Mexicans recognize that the river and the Bosque provide a foundation for agriculture as well as for many other vital economic activities They also value the Bosque as a place to walk, bicycle, ride horses, or just sit and enjoy It enhances the quality of our lives and our communities. Ask yourself:

What would central New Mexico be like without the river and its riparian areas?
Would you have chosen to live here?
Would the communities still exist?
Would the area's history or the diversity of its people be as rich?
Would anyone have chosen to locate farms or industries here?
Would our economic future be as bright?

And then ask.

What will the river and its Bosque be like in the year 2000 In 2025? In 2050? Will the Bosque, as we know it now, still exist?

Will the river corridor still enhance the quality of our lives and communities, and will it still attract visitors, new residents, and businesses to our region?

What do we need to do to assure a healthy future for the river and its bosque so that they will continue to anchor our region environmentally, culturally, and economically, as they do today?

These are some of the questions that led Senator Pete Domenici to appoint the Rio Grande Bosque Conservation Committee in September, 1991 He asked the Committee's nine citizen members to examine the problems affecting the Bosque, to solicit broad public involvement, and to make recommendations for the long term protection of the Bosque and continuation of the many benefits it provides

PRINCIPLE CONCERNS EXPRESSED BY THE PUBLIC:

The Rio Grande Bosque Committee functioned under the premise that the public's concerns and desires regarding the Bosque were of primary importance. Following are some of the major points of agreement expressed at public meetings

1 The value of the Bosque is greater than the sum of its uses and benefits People everywhere value it for its own sake. They are glad "just knowing it is there." This widespread sense of connection to the Bosque is especially intense among the six Middle Rio Grande Pueblos, who maintain strong spiritual ties to the river and its corridor

2. People badly want stricter enforcement of ordinances prohibiting trash dumping and vandalism in the Bosque.

3 People don't want greater government complexity They want local governments and existing agencies to work together to protect and manage the Bosque.

4 People don't think the river and its corridor should be managed just for flood control, drainage and irrigation While those activities are of utmost importance, they also want a healthy, diverse ecosystem, clean water, and recreational opportunities They want to see a balance of compatible goals and activities They agree, however, that vehicular access in the Bosque should be determined in accordance with local use plans

BASIS FOR THE COMMITTEE'S RECOMMENDATIONS

The Committee gathered data and public comment and arrived at a number of important conclusions

1 The Rio Grande Bosque is nationally, regionally, and locally significant Ninety-five percent of native riparian habitat in the Southwest has been lost in historic times Much of the best cottonwood-willow bosque that remains is to be found along the Middle Rio Grande

2. People value the Bosque highly People from all walks of life and representing all kinds of interests—farmers, hunters, birders, hikers, etc.—were virtually unanimous in saying the Bosque is important to them Further, the Bosque provides myriad benefits and opportunities. It is important for recreation, religious ceremonies, irrigation, education, wood gathering, hunting, and enjoyment of solitude—its uses are as numerous and diverse as the people of central New Mexico

3 The River and the Bosque are in decline. Water quality continues to deteriorate, native tree species continue to lose ground to introduced species, trash dumping, vandalism, and other problems continue to impair the health of the bosque and the ability of people to enjoy it.

4 The river and the bosque are inseparable. Problems affecting one also affect the other

5 Private ownership of land and water rights must be respected.

6. While dealing with city and county governments, the Committee also noted the sovereignty of the Pueblos and their authority over the Bosque within their jurisdiction. The Committee acknowledges that the Indian communities have been an integral part of attempting to preserve the Bosque, and appreciates their continued cooperation.

SPECIAL NOTE WITH REGARD TO WATER QUALITY

Water quality is an issue of vital importance. It affects human health, agricultural productivity, and the ecological health of the entire river system.

In public meetings to review draft versions of these recommendations, the Committee was repeatedly asked why it made no recommendation relating to the establishment of new and stringent water quality standards by Isleta and other Pueblos.

Processes already underway involving litigation and negotiation between Isleta Pueblo, the City of Albuquerque, and various state and federal agencies should resolve many key water quality issues and establish important precedents for dealing with others The Committee hopes and urges that these processes be speedily completed and result in fair treatment for all parties and in overall improvement of the biological health of the Rio Grande and its Bosque

FINDINGS AND RECOMMENDATIONS

Three of the Committee's recommendations involve detailed planning efforts, one of which is already underway These plans will complement each other (A diagram showing how the plans fit together is appended to this report.) The Committee's other recommendations involve actions that can be taken in the immediate or near future, without complex authorization or a great deal of additional planning.

We begin our recommendations with those involving the three complementary plans

I BIOLOGICAL MANAGEMENT

FINDING: The Bosque, as we know it, is in a state of rapid biological change Some native species, cottonwood in particular, are failing to regenerate Introduced species like russian olive and tamarisk increasingly dominate the riparian corridor

Because New Mexicans greatly value native cottonwood and willow ecosystems, the impending loss of these communities means that, from a sociological if not also a biological point of view, the Bosque is in a state of crisis. Although a great deal of information is available about the ecology of the Bosque, this information is not well assembled or integrated into management.

RECOMMENDATION A Task Force, led by a Biology professor from the University of New Mexico, consisting of professional scientists from the U S Fish and Wildlife Service, U S Army Corps of Engineers, and the Bureau of Reclamation, and drawing on the advice and skills of the widest possible range of experts, should develop a Biological Management Plan for the Middle Rio Grande. The Plan should include, but not be limited to

Identification of a desired mosaic of biological communities,

Identification of methods by which the desired biological diversity can be maintained and/or established, including plans of action to assure regeneration of key species

ACTION: Funding for the task force has been obtained and the planning process is currently underway The findings of the task force will be available by the Fall of 1993 for consideration by agencies responsible for managing the river and the Bosque.

II. INSTITUTIONAL MANAGEMENT STRUCTURE

FINDING: The Rio Grande Bosque is a valuable resource with a variety of uses and users As such, its management requires a structure that

— involves the public in consideration of key issues, and provides a forum for continued public input,

— produces a comprehensive and integrated plan for management policies and practices,

— recognizes the multiple uses and users,

— incorporates an adaptive management strategy that is capable of change as new information becomes available, and that is capable of evaluating and monitoring its own performance.

RECOMMENDATION: The current matrix of governance and administrative structure does not adequately satisfy these criteria, and thus changes will be useful to better coordinate management resources and responsibilities. That changes are required is not surprising, since the initial management structures were designed before the wide range of uses and users was recognized, and before much of the current knowledge about the Bosque was available. Therefore, such change would be a natural consequence of increasing demand and need for sophistication of managing natural resources and public involvement in the decision-making processes

Possible Models for Management: The Committee has identified three possible models to better meet current needs

First, the responsibilities and jurisdictions of the existing agencies could be adjusted to meet the necessary requirements for managing the Bosque.

Second, a new comprehensive agency could be created, designed specifically to meet the requirements of the Bosque as they are understood today

Third, the existing agencies could be retained, but additional coordination mechanisms could be formed to meet the integrated needs of management policies and practices relating to the Bosque.

Role of the Management Structure: Regardless of the actual governance and administration model implemented, this structure will play several roles

First, it will be necessary to describe a common vision for the future of the Bosque. This vision should recognize that the Bosque is an integrated system of biological, physical, social and cultural components Because of these multiple components, the administration must recognize the many values of the Bosque, that there are many current and future users, and that not all reaches of the Bosque should be managed in the same way nor for the same priority uses

Second, because the Bosque is a public resource, the governing body must include representatives from the constituencies who benefit from and use the Bosque. Although this structure must have the responsibility for promulgating management policies and practices, the public should also be involved in offering advice on key topics, having opportunities to respond to proposed management alternatives, and reviewing the actions of the governing body

Third, regardless of the selected management model, there must be clear lines of jurisdictional responsibility This clarity is required to ensure that the responsibilities of each entity are known by all those charged with managing the Bosque, to ensure that issues are not neglected by simple omission, and to provide the public with an opportunity to evaluate the performance of those responsible for the management policies and practices of the Bosque.

Fourth, the management structure must recognize existing rights and privileges, such as land and water rights held by land owners, and those retained by the Pueblos.

Fifth, the management structure must include sufficient powers and resources to implement and enforce the necessary management policies and practices within the Bosque itself, to encourage compatible management of the areas surrounding the Bosque where these areas have significant influences on the Bosque, and to arbitrate possible conflicts among jurisdictions

Sixth, increased funding will be required to manage the Bosque and to improve its values for the broad community of users In designing the sources of these funds, it must be recognized that current MRGCD rate-payers receive specific values from the Bosque. However, in addition to its local significance, the Bosque is also a regional, state and national resource, and current rate-payers should not be expected to bear the costs alone.

Seventh, the structure must accommodate the principles of adaptive management. The Bosque is a living system, hence its condition must be constantly evaluated. As new information becomes available, management practices may have to be changed. Thus, the administrative structure must explicitly include mechanisms for gathering new information and incorporating this new knowledge into the management policies and practices

ACTION: The Committee believes that each of the three models for management structure set out earlier is reasonable and could serve the functions enumerated above. The Committee further believes that the existing agencies and the public should have ample opportunity to study and to comment on each alternative. Designing the structure necessary for managing the Bosque in a more integrated manner will require a deliberate, thoughtful approach. Thus, this work of design should be undertaken by a legislatively-mandated, non-partisan task force, whose membership must include representatives from the agencies currently managing the Bosque, all levels of government from local to federal, and the many and varied constituencies of the Bosque In formulating its final recommendation, the task force should consider the recommended roles for the governing body as described by this Committee and the information provided during the public hearings The task force should also consider and suggest ways in which the federal agencies can operate more effectively toward the goal of preserving the Bosque.

III. LOCAL GOVERNMENT

FINDING. On a range of issues from trash dumping and groundwater pollution to recreation and law enforcement, local governments need to become more involved in the protection of the Bosque Toward that end they need assistance in assessing and addressing Bosque issues under their jurisdiction

RECOMMENDATION Provide funds to a Coordinating Agency (the agency could be state or federal, the National Park Service, for example, has authorization for programs of this sort) so that the Agency might make grants to counties, municipalities, and pueblos to hire professional planners for up to two years to develop Bosque Plans Participation by local governments in this program of grants would be entirely voluntary The program would begin with a limited number of pilot grants and would be subject to revision depending on the success of initial efforts

The Coordinating Agency would be responsible for-

1) hiring or assigning its own "coordinating planner" to direct this program,

2) assisting local governments with selection of their planners,

3) developing standards and goals, and assuring compatibility of the plans with each other, and with the Bosque Biological Management Plan to the extent feasible,

4) providing support, facilitating inter-county communication, and assuring quality control throughout the planning process.

Topics (at a minimum) which the local plans should address:

1) A plan for assuring public safety in the Bosque and enforcing applicable ordinances, including those relating to dumping, firearms, trespass, and road closures, vandalism, etc.

2) A strategy for solid waste disposal to alleviate dumping.

3) A land use plan for the Bosque and immediately adjacent property, addressing building in flood zones, standards for septic tank and well permits, groundwater protection, runoff, appropriate zoning, building standards, etc.

4) Recommendations for controlling erosion from development activities.

5) A plan for Bosque-related activities, including recreation. This plan should address local access and use issues

6) Procedures for appropriate consultation with all agencies whose activities impact the Bosque.

Upon completion, a plan which met the original standards set forth by the Coordinating Agency could be submitted to appropriate public boards and commissions for approval. Projects that advance approved plans would be eligible for federal matching grants through, possibly, the 'state-side' grants program of the Land and Water Conservation Fund.

ACTION. Seek funding and commitment from the National Park Service's Rivers, Trails and Conservation Assistance Program to undertake the needed program.

OTHER RECOMMENDATIONS:

IV EFFLUENT MANAGEMENT

FINDING Constructed wetlands have been found to benefit areas similar to the Bosque in two important ways 1) effluent and other kinds of contaminated waters can be cleaned before entering rivers, and 2) additional habitat for birds and other wildlife can be created

RECOMMENDATION The Committee recommends that funding be identified and secured for research to determine the impacts, both positive and negative, of constructed wetlands on the Bosque ecosystem. In addition, the Committee recommends that pilot projects utilizing constructed wetlands be considered for use where water treatment is needed, and that such constructed wetlands be carefully located to avoid damage to existing Bosque. The Committee understands that these efforts should be carried out in close coordination with the Biological Management Task Force, and other agencies responsible for water quality and environmental protection in the Bosque.

V. WATERSHED IMPROVEMENT

FINDING Siltation resulting from erosion in the uplands is a problem in some reaches of the river. For instance, the Rio Puerco, which since 1974 has contributed 66% of the silt entering Elephant Butte Reservoir, has been declared an impaired watershed by the New Mexico Environment Department because of nonpoint source pollution in the form of high sediment levels. In view of the large sums spent annually to remove sediment from the channel of the Rio Grande, it is possible that increased government expenditures to control upland erosion would result in a net savings to the taxpayer in addition to providing benefits locally in upland areas

RECOMMENDATION The Rio Puerco Watershed Project, a cooperative effort led by the Bureau of Land Management and involving 13 public agencies and local communities, should receive steady, dependable funding Additionally, all agencies with land management responsibilities should evaluate the efficacy of their erosion control programs and structures

VI. NON-POINT SOURCE POLLUTION

FINDING Widespread concern exists over contamination of the river and the bosque from various non-point sources, such as storm run-off from streets, lawns, and fields

RECOMMENDATION The Committee recommends that public agencies dealing with activities that can lead to nonpoint source pollution should consult with private citizens and the scientific community to develop Best Management Practices (BMPs) for those activities Such BMPs would address irrigation methods, burning and clearing of ditches, use of pesticides and fertilizers, including residential, municipal, and other non-agricultural use, and other matters The Committee further recommends that these Best Management Practices be communicated to the public and adopted

VII WATER LOGGING OF LANDS

FINDING· Concerns exist, particularly among Pueblos, about the use of drains for conveyance of water This practice has caused valuable bosque, agricultural, and residential lands to become water logged. It also diminishes the wildlife habitat value of drain corridors and contributes to water pollution when septic drain fields become saturated with water during irrigation season

RECOMMENDATION. The Committee recommends that the Middle Rio Grande Conservancy District re-evaluate its use of drains as water conveyances and urges the MRGCD to find alternatives to this practice wherever possible

VIII. FIRE CONTROL

FINDING Fire protection and prevention is extremely important within the bosque. The New Mexico State Division of Forestry and various municipal fire departments have primary fire-suppression responsibilities on State and private lands within the Bosque.

RECOMMENDATION: The Committee recommends that all available fire-fighting organizations including the U S Forest Service, BLM, and the Pueblo fire fighters explore strengthening their existing cooperative agreements with agencies bearing primary responsibility for Bosque fire protection and prevention.

IX. EDUCATION

FINDING: Public understanding of the Bosque and its dynamics must be enhanced to help motivate activities to protect the Bosque and balance its uses

RECOMMENDATION: The New Mexico Museum of Natural History should take the lead in forming a coalition of appropriate educational and natural resource entities and institutions for the purpose of developing a Water Resources/Bosque Education Program This program could include public service announcements, school programs, exhibits, adult education, TV programs and announcements, etc. Topics could cover information about the dynamics of the Bosque and how it works, its history, and the value of the Bosque on a local, regional, and national level

ACTION: The New Mexico Museum of Natural History has initiated a process of consultation with educators from a variety of institutions for the purpose of designing a broad-based program for bosque education

X. PRIVATE FINANCIAL SUPPORT

FINDING. Willingness exists in the private sector to contribute toward protection of the Bosque.

RECOMMENDATION: Explore alternatives for directing increased private sector charitable contributions to bosque-related needs and projects.

ACKNOWLEDGEMENTS

The Rio Grande Bosque Conservation Committee would like to thank the following people and organizations for their generous donation of time, facilities, and effort Senator Pete V Domenici, Middle Rio Grande Conservancy District, Pueblos of Cochiti, Isleta, Sandia, Santa Ana, San Felipe, and Santo Domingo, All Indian Pueblo Council, U S Fish and Wildlife Service, U S Bureau of Reclamation, U.S. Army Corps of Engineers, National Park Service, National Fish and Wildlife Foundation, The Conservation Fund, State Engineer's Office, Western Network, City of Albuquerque, Open Space Division, Bernalillo, Sandoval, Socorro, and Valencia Counties; Alameda Community Center; University of New Mexico, Sevilleta National Wildlife Refuge, Rio Grande Nature Center; New Mexico Museum of Natural History; 542nd Transportation Squadron, Kirtland AFB

The Committee would like to add a special thanks to everyone who attended its public meetings and who shared their views on Bosque issues

HOW THE COMMITTEE WORKED

September, 1991 Senator Domenici appointed a nine-member citizen task force—the Rio Grande Bosque Conservation Committee. In its first months of operation, the Committee conducted various field trips and meetings to familiarize its members with the Bosque and related issues

January-February, 1992 Focusing first on the biology of the Bosque ecosystem, the Committee hosted a round-table discussion with federal, state, and local agencies involved in the management of the Rio Grande. In cooperation with Western Network, a Santa Fe-based non-profit organization specializing in facilitation and mediation, the Committee also began planning a public involvement program

March, 1992 Following discussions with the State Engineer, the Army Corps of Engineers, the Bureau of Reclamation, the U S Fish and Wildlife Service, the Middle Rio Grande Conservancy District (MRGCD), biologists at the University of New Mexico, and the City of Albuquerque, the Committee formulated a proposal for an "Inter-Agency Biological Management Plan"

April, 1992 Senator Domenici, the Committee, and the members of the public met at the Rio Grande Nature Center to witness the formal signing of a Letter of Intent between the U S Fish and Wildlife Service, U S Army Corps of Engineers, and U.S. Bureau of Reclamation. The letter expressed the agencies' agreement to cooperate in preparing a Biological Management Plan for the Middle Rio Grande. Congress provided the necessary funding at Senator Domenici's request.

May - July, 1992 The Committee prepared materials for its Public Involvement Program, including a questionnaire, fact sheet, and newsletter The Committee also met regularly to discuss other topics including conservation education, the Biological Management Plan, and other issues.

August, 1992 Senator Domenici and the members of the Bosque Committee held public meetings in Socorro, Los Lunas, and Alameda, facilitated by Western Network. Approximately 240 citizens attended, offering their views on scores of issues relating to use and management of the Bosque and the river At these meetings, the Committee distributed and collected a questionnaire which provided valuable additional information.

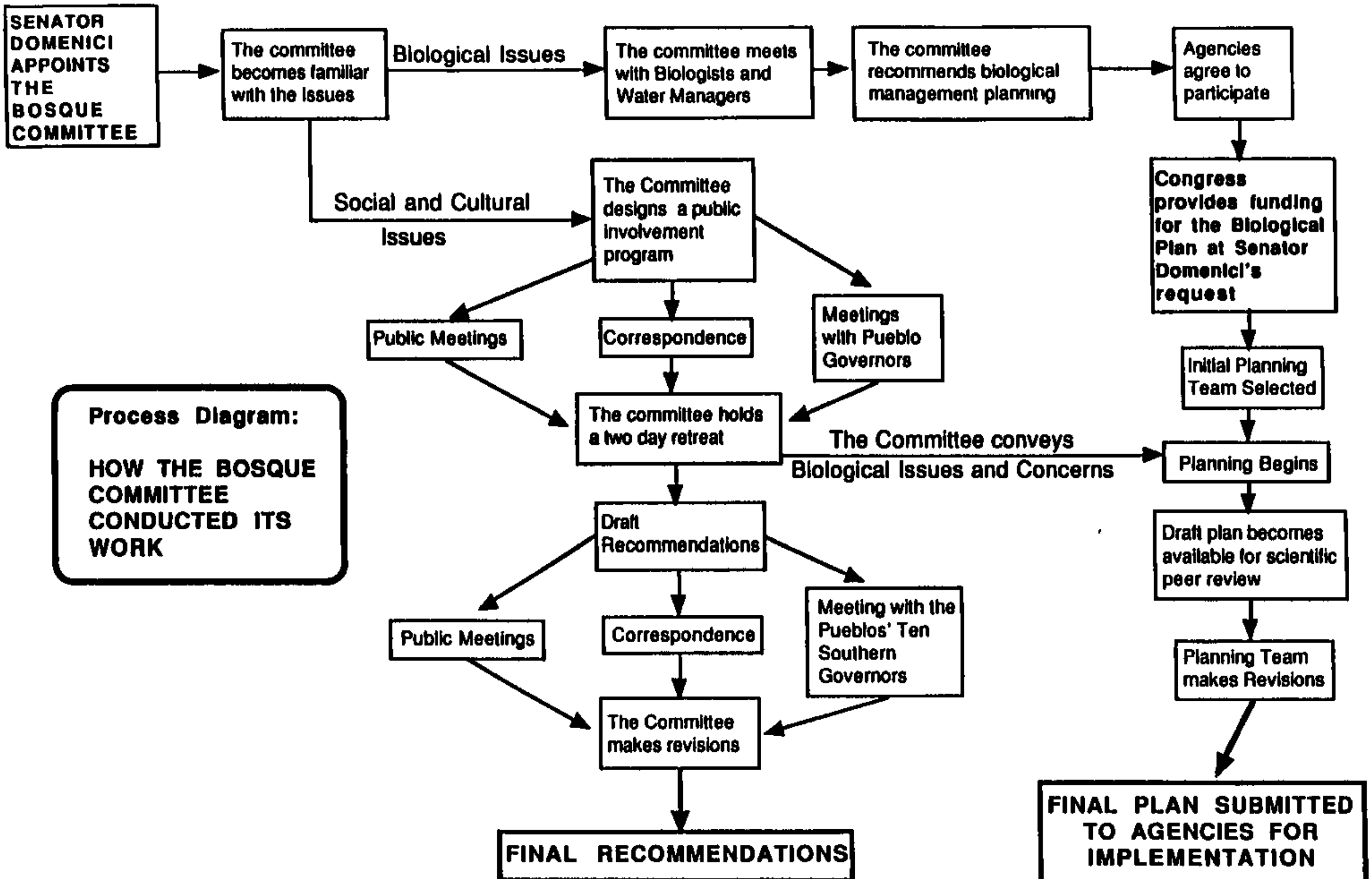
September - October, 1992. Members of the Committee, a representative from Senator Domenici's Office, and a Western Network facilitator discussed bosque conservation with leaders of each of the six Pueblos along the Middle Rio Grande. The Committee mailed summaries of the comments received at the public meetings to all the people who attended them, as well as to the Pueblos. With help from the U.S Fish and Wildlife Service, the Committee reviewed issues relating to the possible listing of the Southwestern Willow Flycatcher and the Rio Grande Silvery Minnow as endangered species.

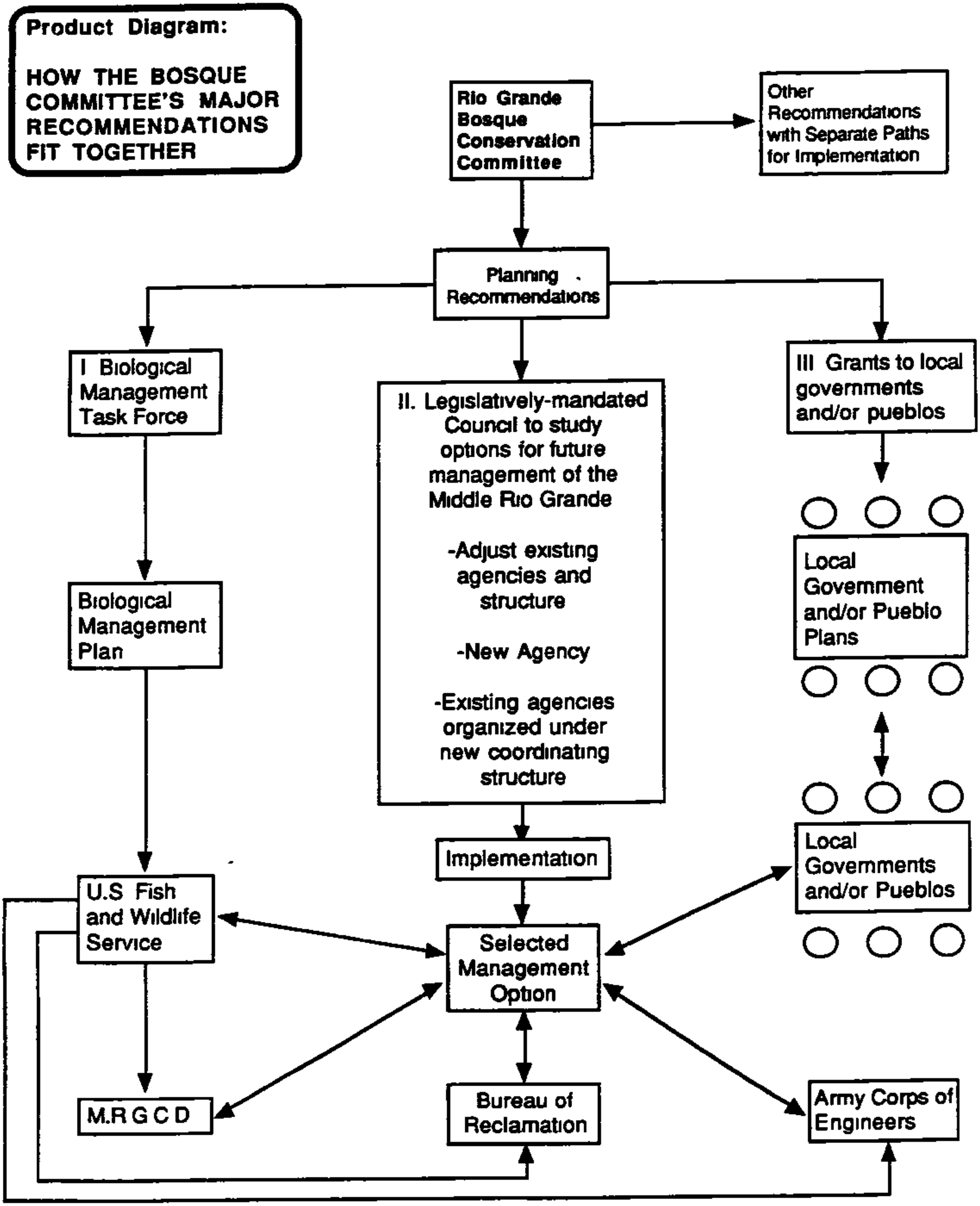
October 31 - November 1, 1992. The Committee conducted a retreat at Sevilleta National Wildlife Refuge to study and discuss the information gathered at the public meetings and to formulate draft recommendations for conservation of the Middle Rio Grande Bosque.

February, 1993 Senator Domenici and the Committee held public meetings in Bernalillo, Isleta Pueblo, and Socorro for public review and comment on the draft recommendations

March, 1993 the Committee Chair presented the draft recommendations to the Ten Southern Pueblos' Governors Council.

May and June, 1993 the Committee revised its draft recommendations in light of public input and submitted its revised report to Senator Domenici


SENATOR DOMENICI APPOINTS THE BOSQUE COMMITTEE
The committee becomes familiar with the issues
Biological Issues
The committee meets with Biologists and Water Managers
The committee recommends biological management planning
Agencies agree to participate
Congress provides funding for the Biological Plan at Senator Domenici's request
Initial Planning Team Selected
Planning Begins
Draft plan becomes available for scientific peer review
Planning Team makes Revisions
FINAL PLAN SUBMITTED TO AGENCIES FOR IMPLEMENTATION
Social and Cultural Issues
The Committee designs a public involvement program
Public Meetings
Correspondence
Meetings with Pueblo Governors
The committee holds a two day retreat
The Committee conveys Biological Issues and Concerns
Draft Recommendations
Public Meetings
Correspondence
Meeting with the Pueblos' Ten Southern Governors
The Committee makes revisions
FINAL RECOMMENDATIONS
Process Diagram:
HOW THE BOSQUE COMMITTEE CONDUCTED ITS WORK


Product Diagram:
HOW THE BOSQUE COMMITTEE'S MAJOR RECOMMENDATIONS FIT TOGETHER
Rio Grande Bosque Conservation Committee
Other Recommendations with Separate Paths for Implementation
Planning Recommendations
I Biological Management Task Force
II. Legislatively-mandated Council to study options for future management of the Middle Rio Grande
-Adjust existing agencies and structure
-New Agency
-Existing agencies organized under new coordinating structure
III Grants to local governments and/or pueblos
Biological Management Plan
Local Government and/or Pueblo Plans
Implementation
U.S Fish and Wildlife Service
Selected Management Option
Local Governments and/or Pueblos
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APPENDIX III.

A. HABITAT INFORMATION ON FEDERAL THREATENED, ENDANGERED, AND PROPOSED SPECIES

Rio Grande silvery minnow (*Hybognathus amarus*). The widespread decline of the Rio Grande silvery minnow has been attributed to several factors including competition and hybridization with nonnative species. In the Rio Grande portion of its original range, factors relating to water development are thought to have been responsible for its decline. Evidence strongly suggests that the Rio Grande silvery minnow has not responded well to habitat and flow alterations associated with reservoir construction, channelization, irrigation diversion, or to point and nonpoint pollution (New Mexico Department of Game and Fish 1988, Bestgen and Platania 1991, Federal Register 1993a).

Despite the Rio Grande silvery minnow's disappearance from 95% of its original range (Bestgen and Platania 1991), the species still occurs in scattered populations throughout the Middle Rio Grande. In 55% of the collections taken by Bestgen and Platania (1989) in 1987 and 1988, the Rio Grande silvery minnow was either the most abundant or second-most abundant species taken. Platania (1991b, pers. comm.) suggested that the species' widespread occurrence in the 1987-88 collections may have been an anomaly—the result of 2 successive years of above-average river flows beginning in 1987. In 1992 surveys, the Rio Grande silvery minnow comprised approximately 4% of the total catch (Lang and Platania 1993).

The biology and life history of the Rio Grande silvery minnow are not thoroughly understood. Adults appear to be encountered most frequently over shallow, braided, low-velocity, sandy-bottomed runs, and backwater pools over sand-silt substrates, although specimens have been collected from a number of other habitats. Subadult Rio Grande silvery minnows occupy primarily shallow, low velocity backwaters with sand-silt substrates (Platania and Bestgen 1988, Bestgen and Platania 1991, U.S. Bureau of Reclamation 1990).

Habitat for the Rio Grande silvery minnow is of varying quality and is frequently disjointed and ephemeral, dependent on the timing and duration of seasonal and storm-related inflows, reservoir releases, and agricultural demand.

Bestgen and Platania (1991) reported that the species appears to move upstream into habitat below diversion dams during periods of low flow, apparently to escape desiccated areas. During periods of higher flows and in winter, densities below diversion structures generally decrease to levels similar to up- and downstream reaches.

Bald eagle (*Haliaeetus leucocephalus*). Annual bald eagle surveys of the Rio Grande, from Española south to Caballo Reservoir conducted by the NMDGF, consistently find wintering eagles concentrated around Cochiti, Elephant Butte, and Caballo reservoirs. Only a few bald eagles are observed in riverine habitats away from the reservoirs.

Key habitat components for bald eagles are trees with large horizontal branches bordering on open areas, especially on the edges of rivers or lakes. Eagles often perch on the tallest trees available that have branches overlooking a food source. They often habitually use certain preferred trees and branches. In the Cochiti area, the large cottonwood trees that line the river channel are frequently used (Sifuentes 1989).

The few nests reported in New Mexico have been in trees and on cliffs (New Mexico Department of Game and Fish 1988). Two known nesting sites in the Rio Grande Valley are adjacent to, but not located within, the project area. Bald eagles within the Rio Grande Valley are most likely to nest in adjacent canyons or in canyons that drain into major reservoirs. The breeding period for southwestern bald eagles is roughly November through April.

Whooping crane (*Grus americana*). Currently there are only a few whooping cranes wintering with their foster-parent sandhill cranes in the Middle Rio Grande Valley. At Bosque del Apache NWR, all areas within the floodplain, including riverine and riparian zones, are considered critical habitat for the whooping crane. During winter, whooping cranes are known to use sandbars in the Rio Grande within the Bosque del Apache NWR and isolated areas outside the refuge (e.g., near the San Acacia Diversion Dam) for night roosting (U.S. Army Corps of Engineers 1990). Because of recent sightings of sandhill cranes in Albuquerque's north valley, the possibility exists for whooping cranes to occur in this area (U.S. Army Corps of Engineers 1992).

Peregrine falcon (*Falco peregrinus*). The only known breeding territory along the Middle Rio Grande for the peregrine falcon is in the canyons above Cochiti Reservoir. Their hunting territory includes the bosque below the reservoir. Otherwise, the peregrine falcon is a spring and fall migrant in the Middle Rio Grande Valley.

Interior least tern (*Sterna antillarum athalassos*). The interior least tern's breeding areas range from California, South Dakota, and Maine to Chiapas and the Caribbean. The major inland population resides in the Mississippi River Basin. Its winter range continues southward from the Pacific Coast of México and the Gulf Coast. It was never common in New Mexico, which is on the western periphery of its range. In New Mexico, terns breed in the vicinity of Roswell including Bitter Lake NWR in the Pecos River Basin, which is the key habitat area of the state. The species migrates through Eddy County and is occasionally seen in Española, Bosque del Apache NWR, near Glenwood, Las Cruces, and Alamogordo (New Mexico Department of Game and Fish 1988). Sightings of a single tern were recorded at Bosque del Apache NWR in 1989, 1991, and 1993 (J. Taylor, pers. comm.).

The least tern is a colonially nesting waterbird, nesting on the ground, typically on sites that are sandy and relatively free of vegetation. In New Mexico and other parts of the southern Great Plains, alkali flats provide nesting areas. The least tern's decline and range reduction can be traced primarily to the elimination and degradation of nesting habitat. Fluctuating water levels in rivers are not conducive to nesting.

Southwestern willow flycatcher (*Empidonax traillii extimus*). This bird species was proposed for listing in July 1993. The final decision on listing will be made within a year of that date. It is a common migrant throughout the bosque, resting and feeding in riparian understory vegetation. There are probably a few nesting pairs each year in dense willows overhanging wetland habitat. Nest parasitism by brown-headed cowbirds (*Molothrus ater*) is contributing to the decline of willow flycatchers throughout the Southwest. Proposed critical habitat includes the Middle Rio Grande in Bernalillo County from Alameda Bridge downstream to the I-25 crossing. It includes the main river channel and all associated side channels, backwaters, pools, marshes, and areas within 100 m (328 ft) of the surface water (Federal Register 1993b).

B. HABITAT INFORMATION ON SOME OF THE FEDERAL CANDIDATES AND OTHER SPECIES OF CONCERN

Parish's alkali grass (*Puccinellia parishii*). This species occurs in isolated locations near seeps, springs, and wet alkaline areas. It grows with *Triglochin* sp., yerba del manso (*Anemopsis californica*), saltgrass (*Distichlis stricta*), rushes (*Juncus* sp.), and other species. Parish's alkali grass is not known to be in the Middle Rio Grande Valley but is suspected due to potential habitat and is being considered for listing.

Pecos sunflower (*Helianthus paradoxus*). Occurs in saline wet meadow habitat with cordgrass (*Spartina pectinata*), saltgrass, sea lavender (*Limonium limbatum*), burroweed (*Allenrolfea occidentalis*), scratchgrass (*Muhlenbergia asperifolia*), and other species. The Pecos sunflower has not been found in the Rio Grande drainage, but there is potential habitat.

Rio Grande bluntnose shiner (*Notropis simus simus*). Although the Rio Grande bluntnose shiner has probably been extirpated from the Rio Grande Basin, the subspecies has been listed as endangered (Group I) on the New Mexico State List of Endangered Species. The subspecies' last documented collection was in 1964 near Peña Blanca (Sandoval County), New Mexico (Bestgen and Platania 1987, New Mexico Department of Game and Fish 1988).

Phantom shiner (*Notropois orca*). The phantom shiner was endemic to the Rio Grande Basin. It was known to have inhabited the main channel of the Rio Grande from the vicinity of Isleta, New Mexico, downstream to the Gulf of México, but it is believed to have been extirpated from New Mexico some time after 1939, perhaps as late as 1949. The last known collection of the species (a single specimen) was in 1975 near Ciudad Diaz Ordaz, Tamaulipas, México (New Mexico Department of Game and Fish 1988, Bestgen and Platania 1990).

Although recent extensive sampling in a broad area of its original range failed to locate a single remaining specimen (Bestgen and Platania 1987), the species has been listed as endangered (Group I) on the New Mexico State List of Endangered Species.

White-faced ibis (*Plegadis chihi*). Flocks of up to 70 birds occur regularly during spring and fall migration. There are no breeding records for the area. They forage and rest in marshes, wet meadows, irrigated fields, and backwaters. An unusual occurrence of about 600 ibis was recorded in late April 1993. These birds were concentrated in a recently burned riparian area which had been flooded to encourage willow growth (J. Taylor, pers. comm.).

Ferruginous hawk (*Buteo regalis*). Small numbers occur in open areas, especially around agricultural fields in winter and during migration.

Swainson's hawk (*Buteo swainsoni*). This hawk is an uncommon breeding species in mature cottonwood trees. Known nesting sites are near Bosque Bridge and between Los Lunas and Belen (Hink and Ohmart 1984).

Long-billed curlew (*Numenius americanus*). This species inhabits grasslands, lakeshores, rivers, mudflats, and marshes. Optimum habitat is wetlands adjacent to grasslands. A few individuals occur during migration in agricultural areas near the riparian edge.

"Western" yellow-billed cuckoo (*Coccyzus americanus occidentalis*). This species breeds in "healthy" mature and mixed-aged cottonwood stands in the bosque. Although it has been removed from the candidate list because of lack of evidence of subspecies status, it is of management concern due to its regional importance. This species is declining throughout the west. The Middle Rio Grande bosque may support the largest local population of yellow-billed cuckoos in the west (Hoffman 1990).

Occult (little brown) bat (*Myotis lucifugus occultus*). This bat is a summer resident foraging over open water. It breeds near water and roosts in buildings and possibly under bridges. Loss of roosting sites is a major concern for this species.

Spotted bat (*Euderma maculatum*). This species, one of the rarest bats in North America, is a very rare migrant in the area.

New Mexican jumping mouse (*Zapus hudsonius luteus*). Once thought to have been common throughout the river valley's marshlands and wet meadows, jumping mice populations decreased when the valley's marshes and wet meadows were drained in the 1930's. Today, comparatively few acres of marshland and wet meadow habitat remain in the Middle Rio Grande Valley. Individual sites are discontinuous and often small (Morrison 1988).

Suitable wet meadow habitat in the bosque area occurs at slightly higher elevations than cattail marshes and usually has saturated soils that are occasionally inundated by periodic flooding. It is this regular flooding that results in growth of the diverse vegetative species that characterize meadow jumping mouse preferred habitat (Morrison 1988). Coyote willow overstory appears to be an important habitat component that creates a suitable wet microclimate.

Specific sites where the New Mexico jumping mouse has been found include Bosque del Apache NWR, wet meadows on the Isleta Pueblo, three sites north of Española, and the Casa Colorada Waterfowl Area.

Certain ditches and drains appear to offer suitable habitat of undisturbed willow/grass/forb vegetation. Ditches and drains where jumping mice have been found include the Socorro Main Ditch and the Elmendorf Drain in the northern part of Bosque del Apache NWR, an unnamed ditch in the southern part of the refuge, the Casa Colorada Drain near the town of Turn, and the Isleta Drain in the vicinity of Isleta Marsh. As would be expected, the species has not been found in highly disturbed ditchside habitats.

Occasionally, isolated areas of preferred habitat occur, but small habitat size, isolation from other breeding populations, and exposure to periodic catastrophic flooding likely prevent colonization or continuous use. Still, it is possible that a few small, isolated populations may persist among these unlikely areas.

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APPENDIX IV.

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APPENDIX V. REVEGETATION TECHNIQUES

A. TECHNIQUES FOR ESTABLISHING NATIVE SPECIES IN THE MIDDLE RIO GRANDE VALLEY

By: Regina Dello Russo

INTRODUCTION

The reestablishment of native vegetation along the Rio Grande is now being implemented by various agencies. Research into various planting techniques is ongoing. The following information was gathered to aid individuals and agencies interested in revegetation. This is an overview of some of the current techniques. It is not a comprehensive listing of all techniques being applied in the field. The information is supplied to serve as a starting point; as more information becomes known, an update of current techniques used along the Rio Grande will be made available.

SITE SELECTION

The choice of a site may be governed by many variables such as ownership, damage to the area, and final product desired. Study of a proposed area prior to site selection is important. Extensive study of the selected site is necessary prior to site preparation.

Specific site study techniques can be recommended. Preparation of a detailed scale map which includes the following information, will greatly aid in plant selection and survival. Noting the location of the exotics to be removed may be helpful to avoid planting directly on top of old roots (B.T. Ellison, pers. comm.). An extensive survey of all existing vegetation should be accomplished prior to removal of unwanted species. Include adjacent plant community types as well. At least 1 year prior to planting, water table measurements should be taken at regular intervals to establish the lowest water table during any particular season. Soil salinity measurements at 10 inches below the ground surface and just above estimated planting depth are recommended for canopy species determination (J. Taylor, pers. comm.). For example, it was found that soil salinity levels of over 2,000 ppm caused a dramatic decrease in cottonwood pole survival. General trends in soil textures throughout the planting area should also be noted on the site map. As soil textures become finer, mean growth in trees decreases (Anderson and Ohmart 1985). All of the above information will aid in choosing the community types to be created.

SITE PREPARATION

Once background information on the site has been completed, site clearing can begin. Methods vary from complete clearing of the area with heavy equipment to hand clearing with chain saws. The method of least disturbance to the site is preferred wherever possible (Hink and Ohmart 1984; Baird 1989; B.T. Ellison, pers. comm.). Minimal disturbance ensures: (1) keeping organic material important to the nutrient cycle of the site in place; (2) keeping mycorrhizal organisms in place; (3) not increasing surface erosion at the site; and (4) keeping surface temperatures low, thereby decreasing evaporation. This method of clearing is labor intensive, but may save in maintenance costs later in the project (B.T. Ellison, pers. comm.). In areas of compacted soils or clays, tillage can increase the performance and survival of cottonwood and willow saplings (Anderson and Ohmart 1985). If machine clearing is chosen, leave natural topographic differences intact, or create mounds and depressions after clearing. This will increase temporary water catchment after rains.

Clearing should be done between the months of October and March to minimize disturbance to birds and mammals during breeding seasons (Hink and Ohmart 1984). If clearing includes removal of salt cedar, be sure to remove the root crown found just below the soil surface to decrease the chance of later sprouting. After clearing is complete, bring in leaf litter from areas surrounding the site in order to import fungal spores helpful to soil establishment (Baird 1989). Also, importing dead wood may be necessary for long-term incorporation of nutrients in the soil, as well as for stabilization of the substrate (Minckley and Rinne 1985). Specific preparation requirements will be covered in more detail in later sections.

PLANTING PATTERNS

A list of native species to be included in the project should be compiled (including information on their salinity tolerance, water requirements, shade requirements, soil preferences, etc.). Once this list is complete, the techniques included below for establishment of canopy and understory species, as well as methods of planting grasses and establishing wetlands, can be followed.

Canopy Species Establishment

The following procedures recommended by the Soil Conservation Service (SCS) Plant Materials Centers in Los Lunas, New Mexico, and Tucson, Arizona, have been widely employed by workers in the Rio Grande Valley (G. Fenchel, pers. comm.). After a listing of general procedures, specific techniques used by different sources are included along with a discussion of results. The canopy species referred to in this section are Rio Grande cottonwood and Goodding willow.

(1) Harvest and transport poles carefully. Select healthy, fairly straight, rapidly growing trees 4 years old or less, with a base diameter of 2.5-10 cm (1-4 inches).

(2) Poles should be cut when completely dormant, prior to bud break. Length of pole will depend on planting depth necessary to reach a stable water table. Select poles of a length which allows 1.2-1.8 m (4-6 ft) to be above the soil surface.

(3) Soak poles within 2 hours after harvesting and until planting. Minimize soaking time. See the discussion below for results from different techniques used.

(4) Dig holes to depths of the lowest anticipated water table. Methods applied are discussed later Avoid sites where the water table will be within (30 cm) 1 ft of ground surface during the growing season.

(5) Plant poles as soon as possible after harvesting and/or soaking and transporting to the site. Set the butt of the pole below the lowest annual water table elevation.

(6) Back fill the holes carefully to avoid leaving air pockets. The use of dry surface material is recommended.

(7) Place tree guards around the poles if animal damage is anticipated. Protection 1.2 m (4 ft) above ground level will be necessary in areas with beaver populations. Types of protection include chicken wire and tree wrap.

(8) As buds begin to swell, usually in April or May, remove them from the lower two-thirds of the pole to reduce water loss by transpiration.

Discussion of Techniques

The following suggestions are from field techniques established by different agencies active in revegetating the Rio Grande Valley. Documentation of results by agency personnel is unpublished at this time. References are included to allow those interested to contact individuals if more information is desired.

Hole digging.—The depth of the planting hole is determined by the depth to a stable water table. The type of machinery required to reach that depth is usually determined by soil type. The following agencies have had success with various techniques.

The U.S. Bureau of Reclamation's (BOR) Socorro Field Division developed a system using a water pump, a water truck (if a water source is not convenient), and a back hoe. Water from the truck is jetted through a long stem of steel pipe. A tree pole is pushed down beside the pipe as the hole is being jetted. This method has been very successful when used in sandy soils. One benefit from this technique is that the soils around the pole are supplied with a substantial amount of water at the time of planting, helping the pole to get established. A scaled down version of this method, perhaps using less machinery, is now being worked on by the BOR (N. Umbreit, pers. comm.).

Bosque del Apache National Wildlife Refuge (NWR) personnel have used auger rigs, mounted on trucks or back hoes, to plant poles. This method works well in more compacted soils. The contact for information on this planting technique is John Taylor.

Pole Preparation.—Site conditions may determine which of the following methods of pole preparation would be best to use.

The Plant Materials Center in Los Lunas recommends cutting all branches off poles prior to planting (G. Fenchel, pers. comm.). This aids in transport and planting, and decreases stress on poles during root establishment. After harvest, poles are soaked for 10 to 14 days, then transported to the site for planting. Root stimulants do not aid plant establishment. Other agencies, such as the U.S. Fish and Wildlife Service (FWS) and the BOR, use similar techniques to those described above.

Workers at the Open Space Division of the City of Albuquerque found that trimming all branches to a height of approximately 1.8 m (6 ft) from ground level was sufficient when planting a tree (B.T. Ellison, pers. comm.). This leaves a canopy of branches on the tree. They also prune dead branches. The butt end of the tree is cut at a sharp angle prior to planting, exposing the greatest amount of surface area to soil and water. The cambium is exposed by using a hatchet to cut shallow notches into the tree 53 cm (21 inches) from the base. This increases exposure of the cambium to water and soil. After some backfilling, the tree is pulled up slightly to force dirt into the notched areas. Increased root growth has been observed in trees following this preparation technique.

A major factor in the success rate of poles planted by the City of Albuquerque could be that workers cut and plant poles immediately (within the same day) with no soaking. Planting occurs in March and April, when the pole will immediately begin to draw water from the ground.

Costs of Revegetating Canopy Species.—Costs of revegetating canopy species depend on the size of the project and on costs of clearing and revegetating. Bosque del Apache NWR has been reestablishing cottonwoods and willows within the refuge for a number of years. Costs for salt cedar control, impoundment/irrigation system development, and revegetation (including site survey, revegetation, and maintenance) are reported for each project. This information, as well as information on survival rates and average growth, is available to agencies and individuals.

On a smaller scale, the City of Albuquerque Open Space Division, which uses mostly manual labor for site clearing, collection of poles, and planting, estimates a cost of approximately $12.00 per pole if harvested by city personnel and $16.00 per pole if the pole is purchased from an outside source. More information about costs incurred in revegetation projects is available upon request.

Other information on costs associated with revegetating riparian areas is available from *The Restoration of Rivers and Streams, Theories and Experience* by James A. Gore. Chapter 3 of this book deals with riparian revegetation.

Other methods of revegetating areas suitable for cottonwood are under experimentation at Bosque del Apache NWR. These include clearing of salt cedar prior to spring runoff thus allowing for natural regeneration of cottonwoods. This of course, is being accomplished on the river side of the levee. Another method involves flooding large plots of cleared land by irrigation prior to seed dispersal. If necessary, seed material is imported in the form of branches pruned from trees near the site. Monitoring of these methods will show if they are feasible techniques to follow at appropriate locations.

Understory Species Establishment

Rainwater catchment systems have proven to be an effective method for planting of understory species in the Rio Grande Valley. The method is as follows:

(1) Form a shallow "V" ditch with a center depth of 25 cm (10 inches) and a total width of 3 m (10 ft). A grader can be used to create this ditch, with a single chisel plow being used to till the center of the ditch in hard soils.

(2) Plants are then set in the center of the ditch at appropriate spacing for the species involved.

(3) Line the ditch with Permalon. Sheets are laid out on one side of the ditch covering the top of the slope and extending down to the center, next to the plants. Landscape staples, 20-25 cm (8-10 inches) long, are used to secure the Permalon to the ground. The other side is similarly laid out with 30 cm (1 ft) of overlap at the center of the ditch. In order to fit around the plants, notches are cut in the Permalon at plant locations.

(4) Water at the time of planting. If necessary, water again after 1 week. Additional watering should not be necessary, but monitoring is advisable.

Discussion of Techniques

The Bosque del Apache NWR and the U.S. Army Corps of Engineers (COE) have had very good success using the above techniques. The following discussion is included for further information.

Lining Materials—Tests of different lining materials were performed at the Bosque del Apache NWR. Permalon has proved to be the most effective material to use as a lining. Ordinary black plastic breaks down too quickly and is not recommended as a substitute for Permalon. There was concern over removal of the Permalon after plants were established. At an older site at the refuge, dirt blown into the ditch has covered the lining and grass has begun to grow over it, suggesting that removal might not be necessary.

Other techniques for establishing understory species are being tested. One method uses plant stock raised in a greenhouse environment. The plants are grown in 5-10 cm (2-4 inches) diameter PVC tubes from 36 to 76 cm (14 to 30 inches) long. This should allow the roots, when planted, to reach a lower water table. Information on the success of this and other techniques will be available in the future. Sources of information include the Plant Materials Center in Los Lunas, Tree New Mexico in Albuquerque, and the Bosque del Apache NWR.

Costs for Establishing Understory Species.—Costs for establishing understory species are available from the Bosque del Apache NWR and the COE. Additional information on understory species planting methods is currently being compiled by Tree New Mexico. This information should be available in the near future.

SUMMARY

The most appropriate methods for revegetating native species in the bosque along the Rio Grande is a topic of current research by several agencies with jurisdiction in the area. Future information from the monitoring of current methods and from results of methods being developed now will increase the amount of information available.

The scale of revegetation project varies from very small to very extensive. It is hoped that the above information can be useful to persons involved in the important task of maintaining and reestablishing this ecosystem.

LIST OF SPECIES

A partial listing of native species, indigenous to the Rio Grande Valley, is included below. This list should aid persons selecting species for revegetation. Information on salinity tolerances, water requirements, shade requirements, etc., can be obtained from Tree New Mexico, the Plant Materials Center, the New Mexico State Forestry and Resources Conservation Division, the FWS, and other agencies (see Appendix IV).

Common Name		Scientific Name
	Trees	
Rio Grande cottonwood		*Populus fremontii*
Goodding or black willow		*Salix gooddingii*
Peachleaf willow		*S amygdaloides*
	Shrubs	
New Mexico olive		*Forestieria neomexicana*
Coyote willow		*Salix exigua*
False indigo		*Amorpha fruticosa*
Golden currant		*Ribes aureum*
Anderson wolfberry		*Lycium andersonii*
Willow baccharis		*Baccharis salicina*
Seepwillow baccharis		*B. glutinosa*
Fourwing saltbush		*Atriplex canescens*
Threeleaf sumac		*Rhus trilobata*
Sand sage		*Artemisia filifolia*
Screwbean mesquite		*Prosopis pubescens*
	Grasses	
Western wheatgrass		*Agropyron smithii*
Alkali sacaton		*Sporobolus airoides*
Sand dropseed		*S. cryptandrus*
Indian ricegrass		*Oryzopsis hymenoides*

This is only a partial list of species; both government and private sources should be consulted about available species and their suitability for particular projects. Additional plants may be brought into cultivation and used in the future, and the list of available species may be expanded.

B. SUMMARY OF "DEEP TILLAGE" REVEGETATION METHOD

INTRODUCTION

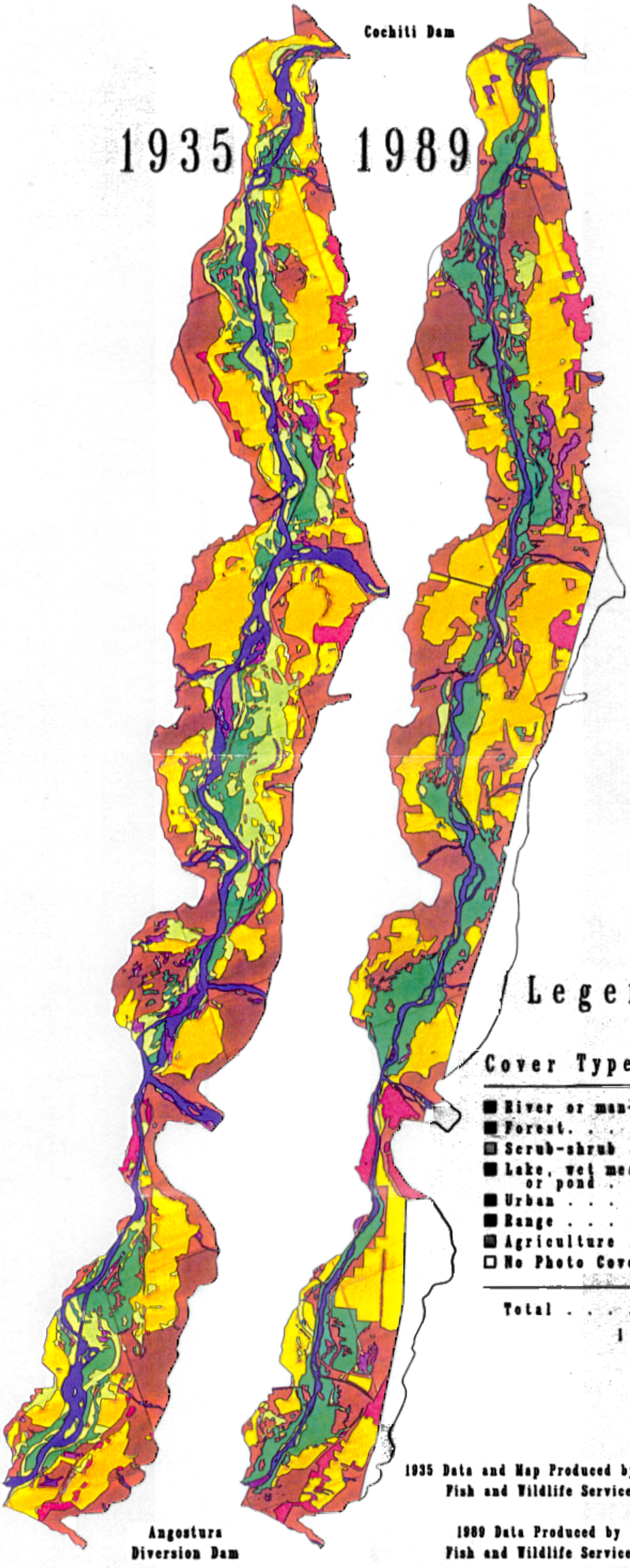
The concept of "deep tillage" was developed by the Revegetation and Wildlife Management Center in Blythe, California. This technique, using rooted cuttings, has been incorporated into revegetation projects along the lower Colorado and Kern rivers (Anderson 1988, Anderson and Laymon 1989). As is the case with the pole planting methods described above, the important factor is to dig a hole for the plant that is deep enough to reach the water table.

DESCRIPTION OF METHOD

Cuttings 0.3-0.4 m (12-16 inches) long and 1.0-1.3 cm (0.4-0.5 inches) in basal diameter were taken from local sources and rooted in a greenhouse. Cuttings were treated with a rooting hormone and placed in 4 l (4 qt) pots with sandy soil, peat moss, and perlite or vermuculite. At the planting area, holes were drilled with a bit 30.5 cm (12 inches) in diameter, to the water table or to just above it. The augured material was mixed with time-release fertilizer (20N:3K:3P) and replaced in the hole when the rooted cuttings were planted. Cuttings were irrigated and weeded to promote survival and growth. (Length of irrigation time depended on precipitation, temperature, and other local environmental factors.) Along the Colorado River, irrigation was provided for an average of 210 days (precipitation averages about 8.75 cm [3 inches] per year, with a water table about 3 m [10 ft] below the surface). Along the Kern River, cuttings were irrigated for approximately 90 days (precipitation averaged about 34.7 cm [13 inches] per year and depths to water table varied from 1.3 m-2.1 m [4-7 ft]).

RESULTS

At the two experimental sites, the application of rooting hormone enhanced and sped up the formation of roots in treated cottonwood and willows. Rooted cuttings survived and grew better than pole plantings. Continued monitoring of planted cuttings indicates that irrigation and weeding have a significant beneficial effect on the establishment, growth, and long-term survival of the cuttings.



Cochiti Reach

Middle Rio Grande Ecosystem:
Bosque Biological Management Plan
October 1993

Scale 1:86,000

KILOMETERS
0 1 2 3

MILES
1 0 1 2

Legend

Cover Type	Area in Hectares 1935	Area in Hectares 1989
River or man-made channel	767	417
Forest	888	1,441
Scrub-shrub	1,213	156
Lake, wet meadow, marsh, or pond	257	134
Urban	164	304
Range	2,610	2,589
Agriculture	2,285	2,320
No Photo Coverage	0	824
Total	8,185	8,185

1 Hectare = 2.47 Acres

Map 1

1935 Data and Map Produced by the National Ecology Research Center
Fish and Wildlife Service, U.S. Department of the Interior

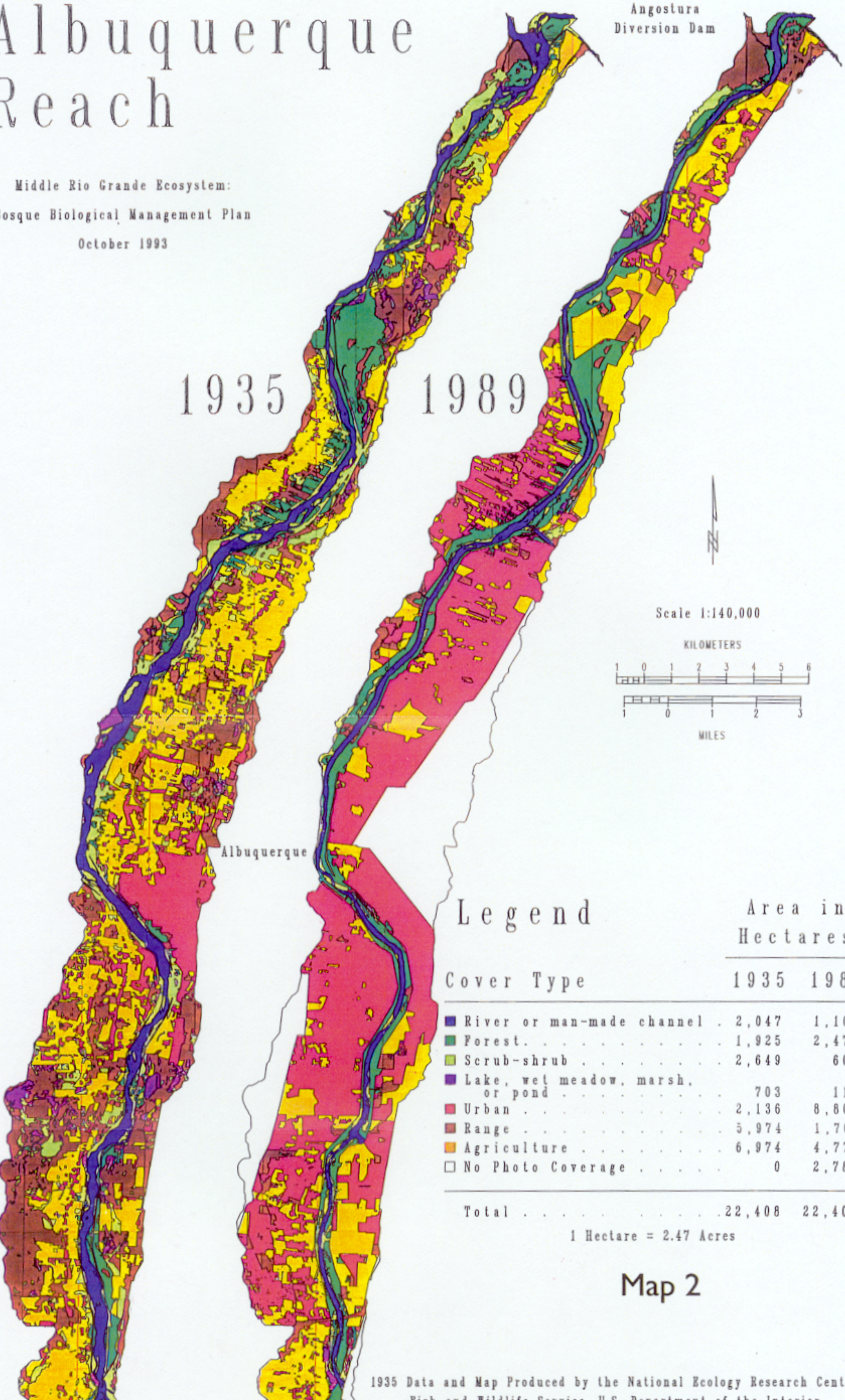
1989 Data Produced by the National Wetlands Inventory
Fish and Wildlife Service, U.S. Department of the Interior

Albuquerque Reach

Middle Rio Grande Ecosystem:

Bosque Biological Management Plan

October 1993



Legend

Cover Type	Area in Hectares 1935	Area in Hectares 1989
River or man-made channel	2,047	1,100
Forest	1,925	2,472
Scrub-shrub	2,649	600
Lake, wet meadow, marsh, or pond	703	117
Urban	2,136	8,803
Range	5,974	1,763
Agriculture	6,974	4,772
No Photo Coverage	0	2,781
Total	22,408	22,408

1 Hectare = 2.47 Acres

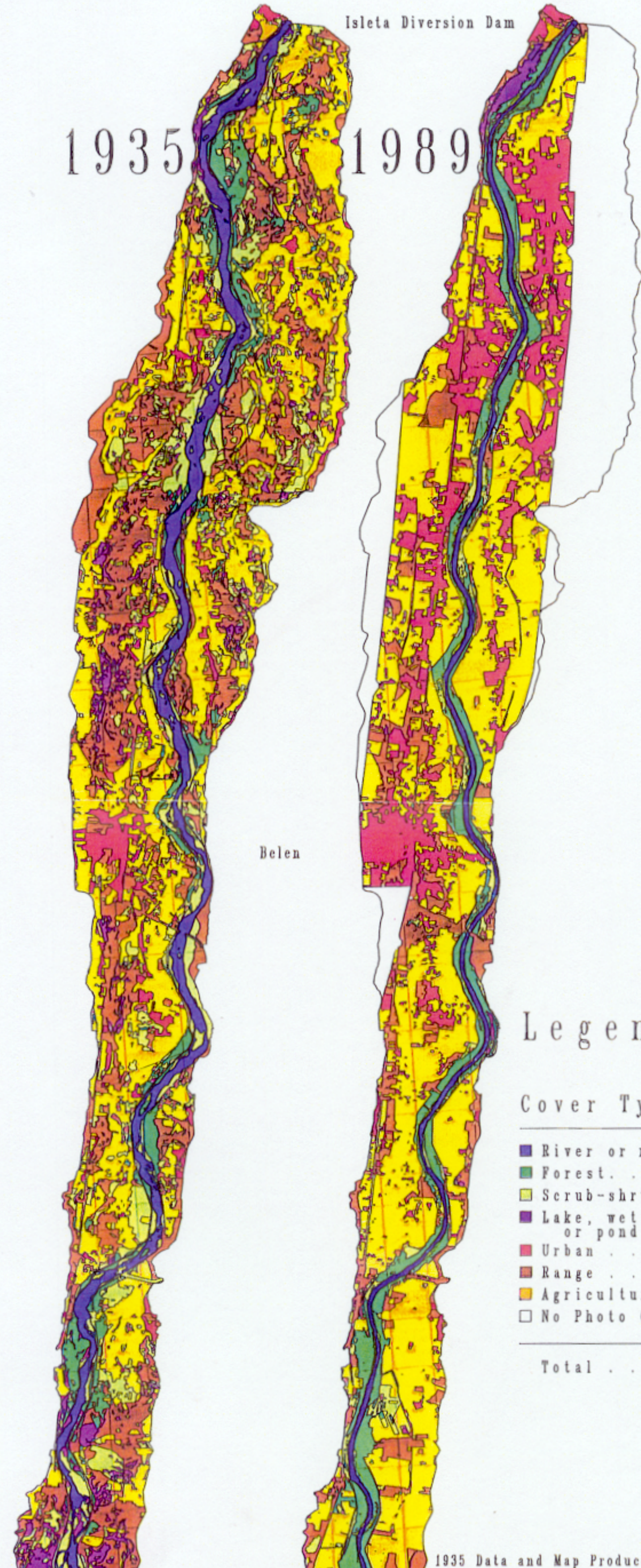
Map 2

1935 Data and Map Produced by the National Ecology Research Center
Fish and Wildlife Service, U.S. Department of the Interior

1989 Data Produced by the National Wetlands Inventory
Fish and Wildlife Service, U.S. Department of the Interior

Belen Reach

Middle Rio Grande Ecosystem:
Bosque Biological Management Plan
October 1993



Scale 1:147,000

KILOMETERS

1 0 1 2 3 4 5 6

1 0 1 2 3

MILES

Legend

Cover Type	Area in Hectares 1935	Area in Hectares 1989
River or man-made channel	1,934	930
Forest	1,749	2,376
Scrub-shrub	4,076	1,097
Lake, wet meadow, marsh, or pond	1,161	229
Urban	1,184	3,856
Range	7,870	3,218
Agriculture	8,295	10,071
No Photo Coverage	0	4,493
Total	26,269	26,269

1 Hectare = 2.47 Acres

Map 3

1935 Data and Map Produced by the National Ecology Research Center
Fish and Wildlife Service, U.S. Department of the Interior

1989 Data Produced by the National Wetlands Inventory
Fish and Wildlife Service, U.S. Department of the Interior

Socorro Reach

Middle Rio Grande Ecosystem:
Bosque Biological Management Plan
October 1993

Scale 1:210,000

KILOMETERS 2 0 2 4 6 8

MILES 1 0 1 2 3 4 5

Legend

Cover Type	Area in Hectares 1935	Area in Hectares 1989
River or man-made channel	4,225	1,898
Forest	4,020	1,545
Scrub-shrub	6,107	7,447
Lake, wet meadow, marsh, or pond	1,998	1,157
Urban	252	920
Range	3,785	4,015
Agriculture	2,887	6,164
No Photo Coverage	0	129
Total	23,275	23,275

1 Hectare = 2.47 Acres

Map 4

1935 Data and Map Produced by the National Ecology Research Center
Fish and Wildlife Service, U.S. Department of the Interior

1989 Data Produced by the National Wetlands Inventory
Fish and Wildlife Service, U.S. Department of the Interior