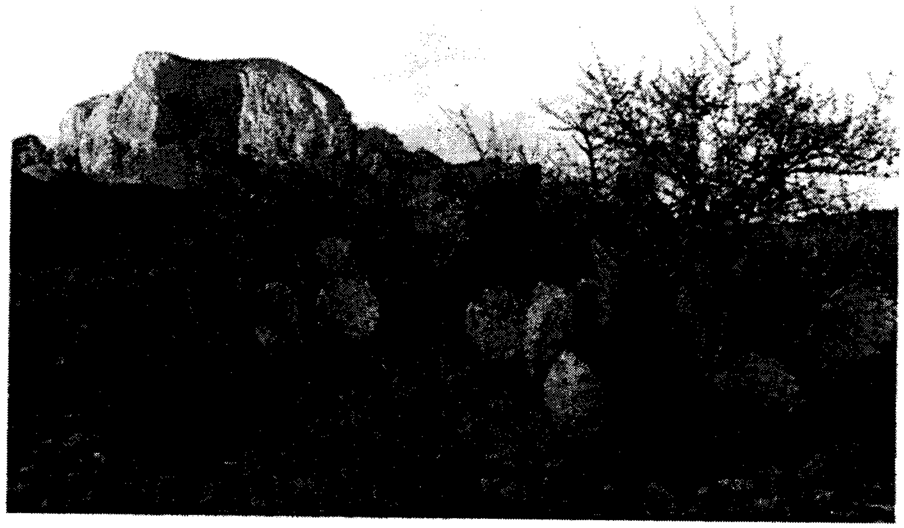

Water Resource Management Plan

Big Bend National Park
Texas

	Table of Conversions				
	Volume				
1	cubic meter	x	35.31467	=	cubic feet
1,000	cubic meters	x	0.81071	=	acre-feet
1	cubic foot/second • day	=	86,400 cubic feet	=	1.983 acre-feet
1	cubic meter/second • day	=	86,400 cubic meters	=	70.05 acre-feet
	Length and Area				
1	kilometer	x	.62137	=	mile
1	hectare	x	2.4711	=	acre

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Water Resource Management Plan

Big Bend National Park

Texas

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1996
National Park Service / U.S. Department of the Interior

Approved by: ______________________________ August 12, 1996

Superintendent, Big Bend National Park Date

Approved by: ______________________________ August 12, 1996

Superintendent, Big Bend National Park Date

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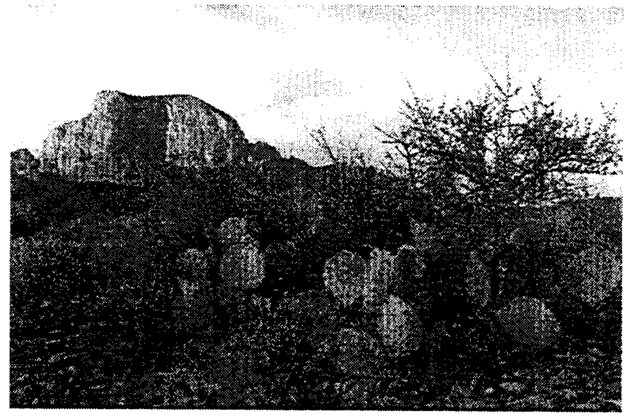
Executive Summary



Units of the National Park System are not required to develop a Water Resources Management Plan. However, where water resource issues or management constraints are particularly numerous, complex, or controversial, a Water Resources Management Plan is extremely useful in providing an identification and analysis of water-related information and issues, and presenting a coordinated action plan to address them. Big Bend National Park is a prime candidate for such a Water Resources Management Plan.

Big Bend National Park preserves some of the most representative Chihuahuan Desert ecosystem remaining in the United States. It is a land of dramatic contrasts as well as a land of limited water. The park's topographic extremes and diversity of habitat support a multitude of diverse flora and fauna including more than 40 species of plants and animals listed as "rare", "threatened", or "endangered. Along the southern boundary of the park, the Rio Grande (Rio Bravo del Norte), meanders through a portion of the Chihuahuan Desert cutting deep canyons through the nearly vertical walls of three mountain ranges, as well as supporting a ribbon of riverine and riparian environments that provide habitat for diverse populations of flora and fauna not commonly found in the desert environment. Between the river and the mountain, the open desert slopes and plains support a vast array of typical Chihuahuan Desert species.

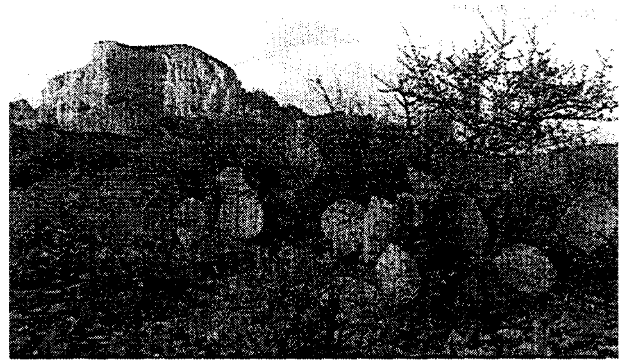
Water is an extremely important resource in terms of natural systems and providing for visitor use. Long term protection of the park's natural diversity depends at least partially upon the careful maintenance of the park's water resources and water-dependent environments (i.e., riparian zones, wetlands, etc.), and minimization of stresses which could affect these resources from both inside and outside the boundaries of the park. Situated in the northern Chihuahuan Desert, Big Bend National Park is subjected to the natural extremes of floods and droughts normal to such an environment. These natural stressors affect the water resources within the park, and require careful management to satisfy the park ecosystems as well as park personnel and visitors. Flow management strategies, coupled with flow control infrastructure in the upstream portion of the Rio Grande have combined to exacerbate the effects of climatic variation on the river, increasing the severity of flood waves, and extending the duration of droughts.

This Water Resource Management Plan was prepared cooperatively by the National Park Service and the Arizona Research Laboratory for Riparian Studies at the University of Arizona. The report provides an overview of existing resource conditions, identifies water-related management issues and develops alternatives addressing water resource issues and management in the park. In addition, the report presents a number of management recommendations, and includes 20 water-related project statements to guide park management in areas such as:

- establishing and maintaining an appropriate water resource data base;
- discussing the need for developing a water conservation strategy and improving the reliability of park water-related infrastructure;
- examining the need to evaluate present and historic flows of the Rio Grande and, where necessary, seeking alternatives to mitigate the historic effects of man on the flow regime;
- evaluating flood hazards in developed or frequently visited areas of the park; and,
- monitoring and managing water quality for the health and safety of park visitors.

This Water Resources Management Plan is complementary to and consistent with the park's General Management Plan. While similar in format to the park's Resources Management Plan, this Water Resources Management Plan further provides a thorough review of existing water resource information, an in-depth analysis of water resources issues, and the development of an action plan to address them.

Introduction
Chapter 1



Purpose of the Plan

Planning is an essential step in addressing the water resource issues faced by the Big Bend National Park. Planning, particularly in the face of the complexity of the hydrologic system in the park, and the relative scarcity of water in this northern Chihuahuan Desert environment, requires a comprehensive discussion of the issues. Further, it demands an inventory of existing supplies and uses, as well as the prospects for changing needs and uses in the future. This Water Resources Management Plan (WRMP) has been prepared to address the following issues:

- the assurance of adequate and safe water supplies for present and future needs of all facilities located in the park;
- transboundary water resource issues stemming from the reach of the Rio Grande river that comprises both the southern boundary of the park and the international boundary between the United States and Mexico;
- flood hazards and flood plain management;
- fisheries and biological resource management; and
- back country water resource monitoring and management.

The Water Resources Management Plan has four major sections. This first section (Chapters 1 and 2) introduces the water resources issues of Big Bend National Park, and provides necessary background information on the park.

Following the introductory material, a description of adjacent lands and their status, as well as information on laws, regulations, and policies applicable to the park are presented in Chapter 2. In addition, this section sets forth the objectives concerning the use and management of water in the park. The second section of the Water Resources Management Plan (Chapter 3) characterizes the hydrologic setting of the park and describes the current condition and status of the water resources. In addition to the extensive synthesis of previously published reports, this section includes analyses of unpublished data and other information that provide new insights into the hydrologic conditions in the park and serve as the foundation to the third section. The third section (Chapter 4) of the Water Resources Management Plan discusses water-related issues and management concerns while the final section (Chapter 5) presents an action program with recommendations and specific project statements necessary to address the water resources issues the park faces.

Purpose and Significance of Big Bend National Park

Big Bend National Park was authorized by the U.S. Congress in 1935 (49 Stat. 393), and was formally established in 1944. Today, the park preserves some of the most representative Chihuahuan Desert ecosystem remaining in the United States. Figure 1 shows the regional location as well as some of the important boundaries and developmental features of the park.

Big Bend National Park is a land of dramatic contrasts. The park has been described as "a mountainous topographic island lying buried in a sea of its own eroded alluvium, austere panoramas of open expanses of cactus and scrub brush, broken by rugged exposures of rocky terrain, towering pinnacles, and deeply etched canyons" (NPS, 1992a).

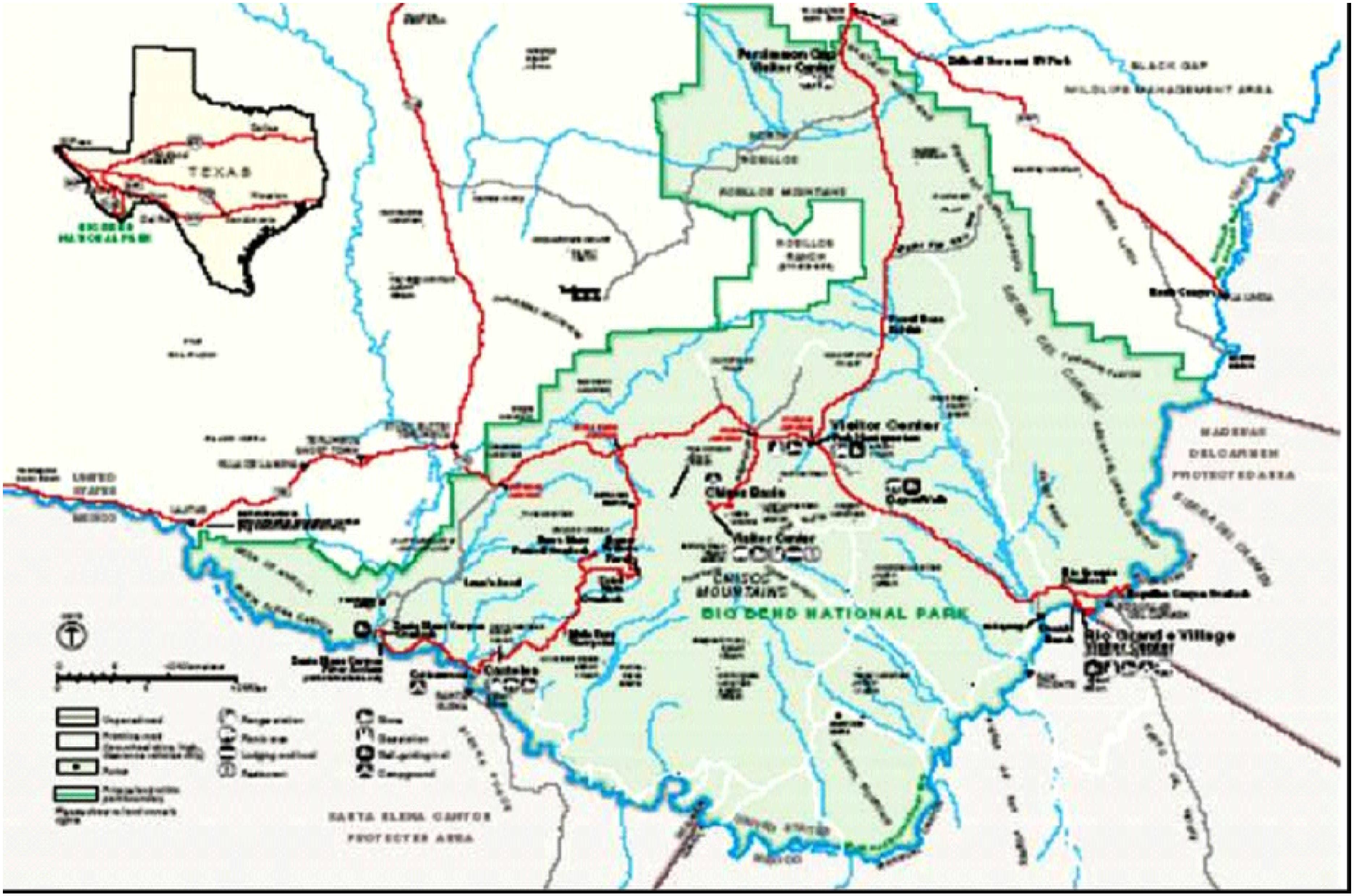
In the central portion of the park, the Chisos Mountains, rise to an elevation of 7,835 feet above sea level, creating a cool, moist montane environment which is a refuge for relict populations of late Pleistocene woodland species in an area that has been described as a "relict green island in a desert sea." Along the southern boundary of the park, the Rio Grande (Rio Bravo del Norte), meanders through a portion of the Chihuahuan Desert, cutting deep canyons through the nearly vertical walls of three mountain ranges, as well as supporting a ribbon of riverine and riparian environments that provide habitat for diverse populations of flora and fauna not commonly found in the desert environment. Between the river and the mountain, the open desert slopes and plains support a vast array of typical Chihuahuan Desert species. This unique combination of topographic extremes and corresponding diversity of habitats supports a multitude of species, including more than 40 species of plants and animals listed as "rare," "threatened," or "endangered." Many of these species occur nowhere else in the United States, and a few of these species occur nowhere else in the world (NPS, 1992a).

Big Bend National Park also contains numerous cultural resources, representing 10,000 years of more or less continuous human habitation. There are over 1,000 documented archeological sites, 15 of which have been designated as State Archeological Landmarks, and 14 historical properties (containing 73 historic structures) which have either been designated or nominated for the National Register of Historic Places. The park is also very well known for its exceptional paleontological resources (primarily of the Cretaceous and Tertiary periods), and its recreational opportunities which include river rafting, birding, mountain hiking, backcountry camping, and desert exploration.

The fact that Big Bend National Park has further been designated by the United Nations as an International Biosphere Reserve demonstrates its international significance as a biological research and environmental monitoring area.

Water Resources Management Objectives

Water is an extremely important resource in terms of natural systems and providing for visitor use in Big Bend National Park. Its topographical extremes and corresponding diversity of habitat allow the park to support a multitude of diverse flora and fauna. Maintaining this diversity depends at least partially upon the careful maintenance of the park's water resources and water-dependent environments (i.e., riparian zones, wetlands, etc.), and minimization of stresses which could affect these resources from both inside and outside the



TEXAS
BLACK GAP
WILDLIFE MANAGEMENT AREA
Persimmon Gap Visitor Center
Visitor Center
Chisos Basin
CHISOS MOUNTAINS
BIG BEND NATIONAL PARK
Rio Grande Village
Visitor Center
MADERAS DEL CARMEN
PROTECTED AREA
SANTA ELENA CANYON
PROTECTED AREA
UNITED STATES
MEXICO
Castolon

boundaries of the park. Sound management of the park's resources has been entrusted to the individual park managers who work in dose cooperation with appropriate state and federal regulatory authorities.

Specific management objectives pertaining to water resources and water-dependent environments within Big Bend National Park and the Rio Grande Wild and Scenic River include:

- establishing an up-to-date water resources baseline sufficient for determining the present condition of the park's water resources and detecting changing conditions and trends in surface water and groundwater;
- achieving an understanding of the impacts of upstream land use and water management upon the short-term and long-term flow conditions of the Rio Grande;
- fostering increased cooperation among the park, the International Boundary and Water Commission, the Rio Grande Compact Commission, the State of Texas, and the Government of Mexico in order to attain a Rio Grande flow regime that will protect aquatic resources, preserve the integrity of natural processes, and allow for recreational opportunities in the Rio Grande;
- fostering increased cooperation among the park, the International Boundary and Water Commission, the State of Texas, and the Government of Mexico in implementing programs to better understand, monitor, and maintain and/or restore the natural quality of waters within and adjacent to the park for purposes of protecting aquatic re-sources, encouraging water-oriented recreation, and providing a safe and adequate water supply;
- recognizing the significance of aquatic and riparian resources and managing them in a manner that will maximize their biological integrity and enhance habitat for fish, aquatic riparian, and other wildlife species;
- implementing a periodic inventory and monitoring program for determining long-term discharge patterns and water quality changes in riparian areas associated with desert springs;
- assuring that park development and operations do not adversely affect the park's water resources and water-dependent environments through the implementation of water conservation, sustainable design, and public education;
- protecting existing water rights, and where necessary, securing additional rights for the purposes of the park;
- assessing floodplain hazards and minimizing the flood hazards to facilities and to the public;
- maintaining habitat and providing adequate protection for the survival of the endangered Big Bend Gambusia; and,
- promoting public awareness of the importance of water resources in the Chihuahuan Desert environment and of current and potential human impacts upon these resources.

This Water Resources Management Plan will develop and evaluate management alternatives for achieving these objectives and provide a recommended course of management action.

Land Status, Uses, and Planning Relationships

Big Bend National Park consists of approximately 801,163 acres, of which 776,693 acres (96.8%) is currently in federal ownership. In addition, 23,283 acres of private lands and 2,601 acres of state lands occur within the authorized park boundary (NPS, 1994a).

Management Zones

Federally owned lands within the park have been classified into four zones in order to best achieve the overall purposes and management objectives of the park (NPS, 1992a).

The largest percentage of land within Big Bend National Park is managed as a "Natural Zone." National Park Service (NPS) Management Policies (NPS, 1988) require that natural resources and processes in the Natural Zone remain largely unaltered by human activity, except for approved development essential to the management, use, and appreciation of the area.

The historic districts, sites, and properties on the National Register of Historic Places, as well as State Archeological Landmarks and other important cultural resources are classified as "Historic Zones." These areas are protected and managed so as to enable public appreciation of their historic values. Physical development is minimized within the Historic Zone and is generally limited to actions needed to preserve, protect, and interpret their historic values. A listing of those areas designated as Historic Zones within Big Bend National Park is located in the park's Statement for Management (NPS, 1992a).

Areas of the Chisos Basin, Panther Junction, Rio Grande Village, Castolon, Maverick, Persimmon Gap, and roads and utility corridors where the natural or historic environments have been altered to provide for visitor or administrative uses, are classified as "Development Zones." These areas are managed to provide visitor services to relatively large numbers of park visitors and to support administrative activities required by the park.

"Special Use Zones" include all lands within the park boundary that are in private ownership. Currently, these lands are utilized for livestock grazing and recreational purposes.

Adjacent Land Use

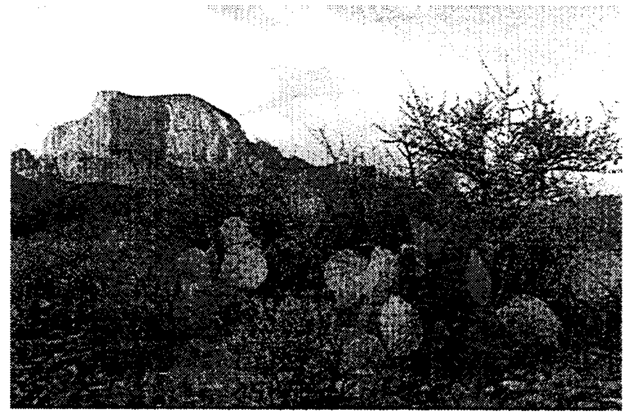
The traditional land use in the vicinity of Big Bend National Park is cattle ranching on large family-owned ranches. Although ranching continues to dominate these areas, recent years have seen it supplemented or replaced by a number of alternate land uses. Subdivision of these lands for residential development and recreational (primarily hunting) sites are the most notable activities.

Subdivisions occurring over large land areas north and west of the park, especially along State Highways 118 and 170 and an adjacent county road, have greatly intensified land use near the park. The Terlingua Ranch, joining the park's northwest boundary, consists of 120,000 acres of former ranch land that are being developed into 20 to 40 acre "ranchettes." A resort community exists at Lajitas, immediately adjacent to the western boundary of the park. Condominiums, single-family residences, approximately 60 motel units, and a 9-hole golf course have been developed in that area.

Land use on the Mexican side of the Rio Grande consists primarily of ranching, small-scale farming, and the limited mining of silver and fluorospar. There are also three minor, low-water border crossings in the park: Boquillas, San Vicente, and Santa Elena.

Regulatory Relationships

Chapter 2



Introduction

International treaties, interstate compacts, and numerous federal and state statutes and regulations, may all affect water resources management within Big Bend National Park. A number of those with the most direct application to the management of water resources affecting the park are presented below.

Enabling Legislation for Big Bend National Park (49 Stat. 393)

Big Bend National Park, a nationally significant representative area of the Chihuahuan Desert environment was established as a unit of the National Park System by an act of Congress in 1935 (49 Stat. 393). This act provided that "lands . . . as necessary for recreational park purposes . . . are hereby established, dedicated, and set apart as a public park for the benefit and enjoyment of the people." The act also stipulated that the provisions of the National Park Service Organic Act of 1916 (39 Stat. 535) apply. In accordance with the NPS Organic Act, the purpose of the park is to " . . . conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such a manner and by such means as will leave them unimpaired for the enjoyment of future generations ..."

The dual, and sometimes conflicting, mandates to preserve and protect resources while providing for their enjoyment by the public often complicates park management. Achieving a balance is at the heart of most decisions affecting the management of the park.

International Treaties and Agreements and Interstate Compacts

The Rio Grande Compact, the U.S. — Mexico Treaty of 1944, the La Paz Agreement of 1983, and the North American Free Trade Agreement (NAFTA) all play vital roles in the management of water resources of the Rio Grande near Big Bend National Park. The Rio Grande Compact plays the tremendously important role of determining how the waters of the Rio Grande are shared among the states of Colorado, New Mexico, and Texas. The U.S. - Mexico Treaty of 1944 specifies how the waters of the Rio Grande and its tributaries along the Texas-Mexico border are to be distributed between the United States and Mexico. The La Paz Agreement of 1983 lays the groundwork for cooperative agreements between the environmental protection agencies of Mexico and the United States. NAFTA provides several mechanisms for improving international trade between the United States and Mexico.

The Rio Grande Compact

The Rio Grande originates in Colorado and flows through the state of New Mexico before forming the international boundary between the United States and Mexico. The Rio Grande Compact of 1938 (New Mexico Statute Annotated § 75 (1992), Act of May, 1939, Ch. 155, 53 Stat. 785 (hereinafter Rio Grande Compact)) plays the vital role of apportioning the interstate waters among the three co-riparian states of Colorado, New Mexico, and Texas while providing the water allocated by international treaty to the sovereign nation of Mexico. This compact applies only to a region of the upper Rio Grande between San Luis, Colorado, and Fort Quitman, Texas.

The interstate compact that finally evolved had a long and torturous history of development. The source of conflict arises from the fact that the river has less water available than all of the demands that have grown upon it, and this amount of water is highly variable by season and year. On June 22, 1896, the government of Mexico filed a protest with the President of the United States citing immoderate uses of water by Colorado and New Mexico which, in turn, were creating a shortage of water in the Rio Grande at the frontier town of El Paso del Norte (now Ciudad Juarez/El Paso). The resulting investigation into the uses and distribution of water on the Rio Grande led to the Embargo of 1896 in which the Secretary of the Interior prohibited further development of irrigation works in Colorado and New Mexico. This embargo lasted until 1925, but the Rio Grande Reclamation Project of 1905 to build Elephant Butte Reservoir and the Convention of 1906 dividing waters of the Rio Grande between the United States and Mexico were directly linked to the original protest by the Mexican government (J. Hammond, 1996, Rio Grande Compact Commission, pers. comm.).

Elephant Butte Reservoir was completed in 1916. Discussions regarding the division of Rio Grande waters among the states continued by state legislative action in 1923 and resulted in the temporary Compact of 1929. This temporary Compact preserved a "status quo" intended to permit the states and the Presidentially-initiated Rio Grande Joint Investigation to conduct a thorough analysis of Rio Grande streamflow and engineering matters. Texas filed action against New Mexico on October 28, 1935 for violations of the Compact of 1929 (Texas v. New Mexico, 352 U.S. 991). Texas alleged that by building, filling and utilizing El Vado Reservoir, New Mexico seriously impacted Texas' deliveries under the Compact by diminishing flows and increasing salt content downstream.

Federal engineering investigations supported and contributed to negotiations that eventually led to the Rio Grande Compact of 1938. In addition to addressing the claims of both New Mexico and Texas against the deliveries of water by Colorado, the compact came in response to the protests of Mexico about the Elephant Butte Project and the Middle Rio Grande Conservancy District (MRGCD) and their emphasis upon irrigated agriculture and economic growth. These increases and diversions, said the bill in equity, violated Texas water rights under the general doctrines of the Supreme Court and the water law in the southwest (Clark, 1987).

In 1938, a critical juncture in the compact's development occurred when it became possible to establish with precision and accuracy both the relationship between major inflows to the San Luis Valley and outflows in the

Rio Grande across the state line of Colorado and New Mexico, and the relationship between the major inflows to the Middle Rio Grande Valley and the outflows to Elephant Butte Reservoir. These combined relationships were central to the agreement that led to a successful negotiation of a compact on the Rio Grande (Hill, 1974).

Streamflow variability in the Rio Grande precluded the establishment of rigid delivery schedules. Thus, flexible schedules dependent upon yearly runoffs and streamflows were developed. Information from stream gaging stations developed by the states form the basis for calculating deliveries. Two stations in Colorado (Del Norte and Los Sauces) are index stations for calculating the New Mexico deliveries, measured at Lobatos, a few miles south of the state line. Similarly, Otowi Bridge in Northern New Mexico is the index station for determining the entitlements south of Elephant Butte, measured at San Marcial, New Mexico. Smaller runoff in some years can be balanced against heavier runoffs in other years. The estimated average amount of water delivered to Elephant Butte is 790,000 acre-feet per annum (Clark, 1987).

In addition to flexible schedules for water delivery, the Compact provides for deviations, either by crediting the upper states for deliveries in excess of quotas or by debiting them for failure to meet their requirements. Other provisions allow for the adjustment of debits and credits in those years when the flow into Elephant Butte exceeds its capacity and for scaling down debits in years of abnormally light runoff. The Compact also provides for determining the proportionate evaporation loss chargeable against debit or credit waters. Miscellaneous provisions of the Compact apply to specific situations in the basin. With exceedingly complex rules and provisions, the Compact is not seen as providing principles and precedents for other interstate streams or as affecting the obligations of the United States to Mexico or as impairing the rights of Indian tribes.

Administration of the Compact is assigned to the Rio Grande Compact Commission. This commission is composed of the state engineers of New Mexico and Colorado and a governor-appointed commissioner for Texas. The President appoints a representative of the United States to serve as a nonvoting chairman of the Commission. Each state pays its own commissioner and shares equally in all other costs not borne by the federal government. Other than specifically granted powers, the Commission functions for the collection, correlation, and presentation of factual data, maintenance of records, and, by unanimous action, recommendations to the states connected with the Compact's administration. Every five years the Commission reviews nonsubstantive provisions which do not affect basic principles, but amendments must be ratified by the signatory states and approved by Congress (Clark, 1987).

The Compact deals specifically with surface flows in the stream channel. It does not deal with the ground water supplies in hydrologic connection with the stream, especially with the ground water in the Mesilla and Hueco Bolsons south of Elephant Butte Dam. These supplies have been the focus of major political and legal controversy between the states of New Mexico and Texas for nearly a decade.

U.S. – Mexico Treaty of 1944 and Related Conventions and Minutes

Although there is a 1906 Convention for the equitable distribution of the waters of the Rio Grande for irrigation purposes it is amplified by the U.S. – Mexico Treaty of 1944 (hereafter referred to as the Treaty of 1944). The Treaty of 1944 is the governing document for apportioning flows of the Rio Grande downstream of Fort Quitman, including those arriving at Big Bend National Park, between Mexico and the United States. The distribution and utilization of the waters of the Rio Grande is determined by Article 4 of the Treaty of 1944, entitled "Utilization of Waters of Colorado and Tijuana Rivers and of the Rio Grande" and dated February 3, 1944. Through this article, Mexico gained right to "all of the waters reaching the main channel of the Rio Grande ... from the San Juan and Alamo Rivers" as well as their irrigation return flows. The United States was allotted "all of the waters reaching the main channel of the Rio Grande ... from the Pecos and Devil Rivers, Goodenough Spring, and Alamito, Terlingua, San Felipe and Pinto Creeks." In addition to the primary allotments, each country was granted half of the Rio Grande flow below the lowest major international storage dam, and a specific formula was devised for distributing the flows of the Conchos, San Diego, San Rodrigo, Escondido and Salado rivers and the Las Vacas Arroyo between the two countries. Specifically, the treaty awards Mexico two-thirds of the flow reaching the main channel from the Rio Conchos and other specified streams, and one-half of all other unallotted flows occurring in the main channel including the contributions from all the unmeasured tributaries not named in Article 4 between Fort Quitman and the lowest major international dam. The treaty further provides, however, that Mexico must make available to the United States, a minimum of 350,000 acre-feet from the Mexican tributaries per year, averaged during a five-year cycle. The contributions from each of the six tributaries will vary depending upon local hydrological conditions in each of the six sub-basins identified above. Typically a majority of the flow is delivered from the Rio Conchos at its confluence with the Rio Grande at Ojinaga. The two reservoirs alluded to in Article 4 are Amistad Dam near Del Rio and Falcon Dam downstream of Laredo (both downstream of Big Bend National Park; see Figure 9 under "Major Rivers" heading in Chapter 3). A copy of Article 4 is presented in Appendix I.

The natural flow of the Mexican tributaries is such that a substantial proportion of the flow required from Mexico derives from the Rio Conchos and, thus, is available for use in the reach adjoining Big Bend National Park. On the other hand, under the prevailing climatological conditions, there may be some years, as in the past, in which flow by the park will be inadequate for sustaining normal river-rafting operations and riparian and aquatic biota, and other years in which uncontrolled flows will be high enough to inundate campgrounds or other facilities.

Since the Treaty of 1944 defines the distribution of the waters of the Rio Conchos on an annual and a five year cycle basis, the operation of the dams on the Rio Conchos (see discussion in Chapter 3 under "Major Rivers" for more information on these dams) appears to be entirely at the discretion of the *Comision National del Agua* (CNA) so long as the conditions stipulated in Article 4 of the Treaty are satisfied. Article 4 of the 1944 Treaty allocates one-third of the flow reaching the main channel of the Rio Grande from the Rio Conchos (and several other rivers) to the United States. This volume of water is to be measured as "an average amount in cycles of five consecutive years." The specific volume required from the Rio Conchos depends on the volumes released to the Rio Grande from the other rivers mentioned in paragraph B, section (c) of Article 4 of the 1944 Treaty (see Appendix I).

Water quality issues between Mexico and the United States can be addressed in certain ways under provisions of the Treaty of 1944 and Minutes pertaining thereto.

While the Treaty deals principally with quantitative utilization of the internationally shared waters, it provides in Article 3 that the two nations' governments would give preferential attention to the solution of all border sanitation problems. Articles 2, 3, and 24 of the Treaty contain authority for the International Boundary and Water Commission (IBWC), an international agency consisting of a United States Section and a Mexican Section, to meet this obligation.

Minute No. 261 (IBWC, 1979), entitled Recommendations for the Solution to the Border Sanitation Problems," defines a "border sanitation problem" as *"each case in which the waters that cross the boundary . . . have sanitary conditions that present a hazard to the health and well-being of **the** inhabitants of either side of the border or impair the beneficial uses of these waters."* Minute No. 261 recommends, among other things, that the International Boundary and Water Commission ". . . *give **permanent** attention to border sanitation problems and give currently existing problems immediate and priority attention"* (emphasis added).

In 1992, the International Boundary and Water Commission took note of Minute No. 261 and other instruments dealing with water quality, and adopted Minute No. 289, entitled "Observation of the Quality of the Waters Along the United States and Mexico Border." Among other things, Minute No. 289 grants approval to the "Joint Report of the Principal Engineer Relative to Determination of Presence of Toxic Substances in the Waters of the Rio Grande in its International Boundary Reach." That report set out a detailed two-year program of water quality sampling and monitoring which was duly carried out in 1992-94, and which resulted in the binational study report on toxic substances (IBWC, *et al,* 1994). The Rio Grande Toxic Substance Study is an EPA funded project coordinated by the Texas Natural Resource Commission and with field work done jointly with the Comision Nacional del Agua. The International Boundary and Water Commission serves as liaison to Mexico and assists with border logistics. Phase II of the toxic substances study was slated to initiate in December of 1995 (IBWC, 1995).

La Paz Agreement of 1983

The La Paz Agreement of 1983, formally the "Agreement Between the United States of America and the United

Mexican States on Cooperation for the Protection and Improvement of the Environment in the Border Area" (PL 89-497), initiated a broad-based plan of cooperation on environmental issues between the United States and Mexico. This long-term plan set up the framework for developing strategies to mitigate and prevent environmental crises along the international border, and provided for specific annexes to the agreement. It designated representatives from the U.S. Environmental Protection Agency (EPA) and from the Mexican Secretaria de Desarrollo Urbano y Ecologia (SEDUE) (now *Secretaria del Medio Ambiente, Recursos Naturales y Pescarias* (SEMARNAP)) as the coordinating authorities for the plan for the United States and Mexico, respectively.

Annex II of the Agreement deals directly with discharges of hazardous substances along the inland international boundary. In particular, this section outlines procedures for developing the "United States-Mexico Joint Contingency Plan" for handling pollution crises along the international border. In all cases, "the Border Area" is defined as a zone of 100 km (62.1 mi.) inland into each country from the border. This Annex provides for the detection and monitoring of polluting events along the border and the prompt notification of both countries' appropriate representatives of such an occurrence.

Industrial manufacturing and processing plants owned by U.S. companies and operating in the border area of Mexico known as maquiladoras appear to have been a driving force behind the La Paz Agreement. Understandably, the Mexican government expressed concern over the fate of the many hazardous and non-hazardous wastes generated by the maquiladoras' activities. The La Paz Agreement established a border zone of 100 kilometers (km) (62.1 miles) inland from the international boundary in each country along the entire Mexico/U.S. border. Article II of Annex III ("Regarding the Transboundary Shipments of Hazardous Wastes and Hazardous Substances") of the 1983 Agreement states that *"Each Party shall ensure ... that its domestic laws and regulations are enforced with respect to transboundary shipments of hazardous waste and hazardous substances... that pose dangers to public health, property and the environment."* In an apparent reference to maquiladoras, Article XI of the same Annex specifies that *"Hazardous waste generated in the processes of economic production, manufacturing, processing or repair, for which raw materials were utilized and temporarily admitted, shall continue to be readmitted by the country of origin of the raw materials in accordance with applicable national policies, laws and regulations."* In other words, all wastes generated by maquiladoras or similar industries within this zone would be the responsibility of the U.S.-based companies who owned the plants. As such, the wastes would be subject to all U.S. environmental regulations and must be permitted and disposed of accordingly.

An extension of the 1983 Agreement, The Integrated Border Environment Plan (IBEP; currently being revised and renamed to Border XXI (Rene Valenzuela, IBWC, 1996) stems from a joint presidential communique issued by Mexican President Salinas de Gortari and U.S. President Bush in November of 1990. This communique directed the SEDUE (now *Secretaria del Medio Ambiente, Recursos Naturales, y Pescarias* (SEMARNAP), Mexico's natural resources and environmental agency) and the U.S. EPA to cooperate in developing a comprehensive border environmental plan designed to solve environmental problems in the Border Area. The IBEP (1992-1994) marked "the commencement of a substantially increased cooperative binational effort for at least the next decade to promote environmental improvements along the border" (U.S. EPA, 1992).

The Border XXI Initiative comprises the follow-up to the IBEP. This initiative will continue the cooperative environmental efforts between the U.S. and Mexico for the period 1995 to 2000.

North American Free Trade Agreement

The North American Free Trade Agreement (NAFTA) went into effect on January 1, 1994 following approval by the legislative bodies of Mexico, the United States, and Canada. Through the trilateral environmental side agreement associated with NAFTA (United States, Canada, and Mexico, 1993), Mexico has committed itself to a high degree of external accountability in environmental enforcement. The environmental side agreement, formally the North American Agreement on Environmental Cooperation, authorized the two agencies described below. A third agency, the North American Commission on Environmental Cooperation, was also authorized, but is not pertinent to this Water Resources Management Plan.

Border Environmental Cooperation Commission (BECC) (United States and Mexico, 1993). The Border Environmental Cooperation Commission, based in Ciudad Juarez, Chihuahua, will evaluate (and certify for funding) border environmental infrastructure projects, focusing initially on wastewater treatment, water pollution, and municipal solid waste. The Border Environmental Cooperation Commission (BECC) has been created largely to provide public accountability to the North American Development Bank (NADBank) process. Theoretically, BECC may oversee and "certify" other financing projects beyond NADBank, such as World Bank loans for projects parallel to those of NADBank.

The Border Environmental Cooperation Commission has a 10-member (5 from each country) binational board of directors. These directors include the heads of U.S. Environmental Protection Agency and its Mexican counterpart, SEMARNAP *(Secretaria del Medio Ambiente, Recursos Naturales, y Pescarias;* formerly SEDESOL)[1], the two commissioners of the U.S. and Mexican sections of the International Boundary and Water Commission, and three other Presidential appointees from each country. The board is required to consult with an 18-member binational Advisory Council.

The Border Environmental Cooperation Commission's mandate is to work with affected states, communities, and localities in developing effective solutions to environmental problems in the border region. The commission's operation is meant to promote public participation, offering individuals from local communities the opportunity to comment on BECC's general guidelines and on applications for certification of projects.

To be eligible for BECC certification, projects must observe local environmental laws. Those with significant transboundary effects must provide an environmental assessment. Subsequently, the commission's Board, in consultation with affected states and localities, will determine that such projects meet the necessary conditions to achieve a "high-level" of environmental protection for the impacted area.

North-American Development Bank (NADBank) (United States and Mexico, 1993). Headquartered in San Antonio, Texas and Los Angeles, California, the NADBank will act as the lead bank in the financial packaging of Border Environmental Cooperation Commission-certified border projects. NADBank has been created to finance both environmental investments and NAFTA-related "community adjustments and reinvestment." Among its high-priority environmental projects are the provision of potable water, wastewater treatment, and municipal solid-waste disposal. "Community adjustments" are investments directed to communities anywhere in the United States or Mexico that suffer from NAFTA-related effects, such as the relocation of plants (Texas Natural Resource Conservation Commission, 1994). Ten percent of NADBank funding is slated to be spent on such social-adjustment programs, with areas most negatively affected by NAFTA (such as Chiapas) given priority.

NADBank, like the Border Environmental Cooperation Commission, has a unique design and governance structure. First, unlike other multilateral development banks, it will be able to finance only environmentally-approved projects. Second, its six-member board of directors is binational; the U.S. members include the Secretary of the Treasury, the Secretary of State, and the EPA administrator, while Mexico's representatives are the Secretary of Finance, the Secretary of Trade and Industry, and the Secretary of Social Development.

NADBank capitalization has been set optimistically at $3 billion, with the United States and Mexico each pledging to contribute $225 million in initial capital, divided into equal installments over 4 years. Each country has also agreed to contribute $1.275 billion in "callable" capital. NADBank funds are theoretically to be used to leverage other monies (appropriations, grants, bonds, fees, loans) in order to increase the actual value. For environmental-infrastructure projects, the expectation is that user fees will pay back the loans.

Although not entirely independent from their respective governments, these commissions will have a great deal more input from the public, and be able to fund, and

1. SEDESOL was superceded by the reaggregation of agencies known as SEMARNAP in February of 1996.

raise money for funding, projects for environmental protection and improvement.

Federal Legislation and Executive Orders

In addition to the Big Bend National Park enabling legislation and the National Park Service Organic Act (see discussion earlier in this chapter) which govern the establishment and management of Big Bend National Park, other important federal legislation directs much of the management of the water-related resources within the park. The Wild and Scenic Rivers designation for a large segment of the Rio Grande (within and outside the park) provides additional protection for the extraordinary natural and free-flowing condition of the river. The Federal Water Pollution Control Act set water quality goals for the nation's swimmable and fishable waters and protects them from any further discharge of pollutants. The National Environmental Policy Act requires environmental impact statements for federal approval of major actions which significantly affect the quality of human life and for which federal funds are expended. Two separate executive orders direct federal agencies to minimize flood risks (EO 11988) as well as to preserve wetland environments (EO 11990). In addition to other federal guidelines, the National Park Service has its own Management Policies and Guidelines which provide broad policy guidance for the management of National Park System Units.

Establishment of Rio Grande Wild & Scenic River (P.L. 95-625)

The Rio Grande Wild and Scenic River was created by the Omnibus Bill of 1978 (Public Law 95-625) which designated a 191.2 mile segment of the Rio Grande extending from the Chihuahua/Coahuila state line in Mexico (river mile 842.3) to the Terrell/Val Verde county line in Texas (river mile 651.1) as a Wild and Scenic River.[2] This designation includes a 68.6-mile segment of the Rio Grande which lies within Big Bend National Park, though the National Park Service also maintains responsibility for the management of the Rio Grande Wild & Scenic River downstream of the park's boundary (Figure 2). However, PL 95-625 specifically stated that this designation would not be in conflict with the 1944 Treaty which could permit the construction of one additional storage dam, potentially in the Wild and Scenic segments. However, construction of this dam could occur only with the concurrence of both nations.

The Wild and Scenic Rivers Act was established in order that ". . . *certain selected rivers of the Nation, which... possess outstandingly remarkable scenic, recreational, geologic, fish and wildlife, historic, cultural, or other similar values, shall be preserved in free flowing condition, and they and their immediate environments shall be protected for the benefit and enjoyment of present and future generations*" (United States Code, Title 16, Section 1271-1287).

Segments of the Rio Grande within Big Bend National Park designated as "wild" contain undeveloped shorelines, are free of impoundments and are generally inaccessible except by trail. Those river segments designated as "scenic" are again free of impoundments, generally contain only limited shoreline development, and may be accessible by road in a few locations.

Federal Water Pollution Control Act (Clean Water Act)

The Federal Water Pollution Control Act, more commonly known as the Clean Water Act, was first promulgated in 1972 and amended in 1977, 1987, and 1990. This law was designed to restore and maintain the integrity of the nation's waters. Goals set by the act were swimmable and fishable waters by 1983 and no further discharge of pollutants into the nation's waterways by 1985. The two strategies for achieving these goals involved a major grant program to assist in the construction of municipal sewage treatment facilities, and a program of "effluent limitations" designed to limit the amount of pollutants that could be discharged.

2. The IBWC has officially revised these numbers to river miles 853.22 and 657.52, respectively, for a total of 195.7 miles (N PS, 1980a).

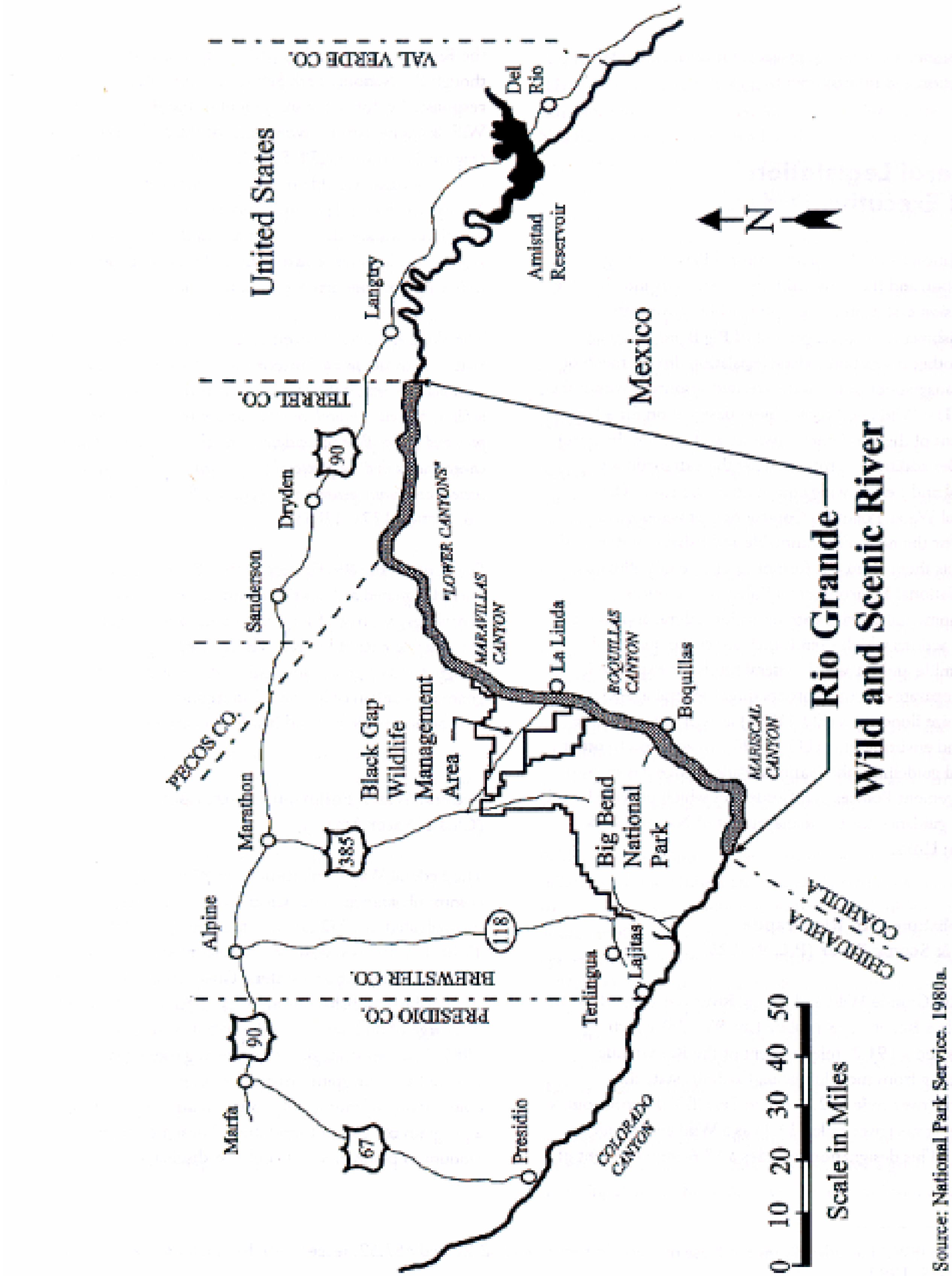


FIGURE 2. Rio Grande Wild and Scenic River

As part of the act, Congress recognized the primary role of the states in managing and regulating the nation's water quality within the general framework developed by Congress. All **federal agencies must comply with the requirements of state law for water quality management, regardless of other jurisdictional status or land ownership.** States implement the protection of water quality under the authority granted by the Clean Water Act through best management practices and through water quality standards. Best management practices are defined by the U.S. Environmental Protection Agency as methods, measures, or practices selected by an agency to meet its nonpoint control needs. These practices include, but are not limited to, structural and non-structural controls and operations and maintenance procedures. They can be applied before, during, and after pollution-producing activities to reduce or eliminate the introduction of pollutants into receiving waters. Water quality standards are composed of the designated use or uses made of a water body or segment, water quality criteria necessary to protect those uses, and an antidegradation provision which may protect the existing water quality.

Section 402 of the act requires that a National Pollutant Discharge Elimination System (NPDES) permit be obtained for the discharge of pollutants from any point source into the waters of the United States. The terms "point source," "waters of the United States," and "pollutants" are all broadly defined under the act, but generally all discharges and storm water runoff from major industrial and transportation activities, municipalities, and certain construction activities must be permitted by the NPDES program. The Environmental Protection Agency usually delegates NPDES permitting authority to a state.

The state, through the permitting process, establishes the effluent limitations and monitoring requirements for the types and quantities of pollutants that may be discharged into its waters. Under the antidegradation policy, the state must also ensure that 1) the approval of any National Pollutant Discharge Elimination System (NPDES) permit will not eliminate or otherwise impair any designated uses of the receiving waters; and 2) that the quality of any waters designated as an "Outstanding National Resource Water" must be protected and maintained.

In Texas, EPA Region 6 has the authority to issue NPDES permits. The Texas Natural Resource Conservation Commission (TNRCC) (formerly Texas Water Commission and Texas Department of Water Resources) issues its own permits for "minor" dischargers.[3] The Enforcement and Field Operations-Municipal Wastewater and Water Use Section and the Industrial Wastewater and Solid Waste Sections of TNRCC handle compliance and enforcement operations for the NPDES program (Texas Dept. of Water Resources, 1981a cf. Eaton and Anderson, 1987).

Section 404 of the Clean Water Act requires that a permit be issued for discharge of dredged or fill materials in waters of the United States including wetlands. The Army Corps of Engineers administers the Section 404 permit program with oversight veto powers held by the Environmental Protection Agency. The Environmental Protection Agency and the U.S. Fish and Wildlife Service provide advice on the environmental impacts of proposed projects. National Park Service activities associated with wetlands are managed in accordance with agency-specific guidelines called for by Executive Order 11990, which is discussed later in this section.

National Environmental Policy Act

Congress passed the National Environmental Policy Act (NEPA) in 1969. NEPA established a general federal policy for the responsibility of each generation as trustee of the environment for the succeeding generations. Specifically, NEPA requires that an environmental impact statement (EIS) be prepared as part of the review and approval process by federal government agencies of major actions which significantly affect the quality of human life and which involve federal funding. The primary purpose of an EIS is to ensure evaluation of the impacts of proposed projects and facilitate public review. An environmental assessment (EA) may be prepared prior to initiating an EIS in order to determine if the preparation of an EIS is required.

3. TNRCC is now applying for NPDES delegation from the U.S. EPA (G. Rothe, 1996, TNRCC, pers. comm.).

Regulations implementing NEPA require the cooperation of federal agencies in the NEPA process. The regulations also encourage the reduction of duplication through cooperation with state and local agencies including early efforts of joint planning, joint hearings and joint environmental assessments.

Floodplain Management (Executive Order 11988)

This executive order requires all federal agencies to "reduce the risk of flood loss, . . . minimize the impacts of floods on human safety, health and welfare, and .. . restore and preserve the natural and beneficial values weaved by floodplains" (Goldfarb, 1988). Federal agencies are therefore required to implement floodplain planning and consider all feasible alternatives which minimize impacts prior to construction of facilities or structures. Construction of such facilities must be consistent with federal flood insurance and floodplain management programs. To the extent possible, park facilities should be located outside these areas. National Park Service guidance pertaining to Executive Order 11988 can be found in Floodplain Management Guidelines (NPS, 1993).

Protection of Wetlands (Executive Order 11990)

This executive order requires all federal agencies to "minimize the destruction, loss or degradation of wetlands, and preserve and enhance the natural and beneficial values of wetlands" (Goldfarb, 1988). Unless no practical alternatives exist, federal agencies must avoid activities in wetlands which have the potential for adversely affecting the integrity of the ecosystem. National Park Service guidance for compliance with Executive Order 11990 can be found in Floodplain Management and Wetland Protection Guidelines, published in the Federal Register (45 FR 35916, Section 9).

National Park Service
Management Policies and Guidelines

The National Park Service Management Policies (1988) provide broad policy guidance for the management of National Park System Units. Topics include park planning, land protection, natural and cultural resource management, wilderness preservation and management, interpretation and education, special uses of the parks, park facilities design, and concessions management. Recommended procedures for implementing service-wide policy are described in the National Park Service guideline series. The guidelines most directly pertaining to actions affecting water resources include:

1) NPS-2 for the Planning process,

2) NPS-12, for Compliance with NEPA, including preparation of EIS's, EA's, and categorical exclusions,

3) NPS-75, for Natural Resources Inventory and Monitoring,

4) NPS-77, for Natural Resource Management, and

5) NPS-83 for Public Health Management.

Other Applicable Federal Laws

Endangered Species Act (1973)

The Endangered Species Act requires the National Park Service to identify and the promote the conservation of all federally listed endangered, threatened or candidate species within park or preserve boundaries. While not required by legislation, it is National Park Service's policy to also identify state and locally listed species of concern, and support the preservation and restoration of those species and their habitats.

Safe Drinking Water Act (1974)
and Amendments (1986)

The Safe Drinking Water Act is implemented by the state in order to ensure that public drinking water supplies are safe. The National Park Service must comply with state regulations regarding the construction, operation and monitoring of its public water supply systems.

Rio Grande Pollution Correction Act of 1987

The Rio Grande Pollution Correction Act of 1987 (Public Law 100-465) grants permission to the Secretary of State of the United States, working through the International

Boundary and Water Commission's Commissioner, to negotiate with "*the appropriate representative of the Ministry of Foreign Relations of Mexico for the purpose of correcting the international problem of pollution of the Rio Grande caused by discharge of raw and inadequately treated sewage and other wastes into such river from the border cities induding but not limited to Ciudad Acuna, Nuevo Laredo, and Reynosa, Mexico and Del Rio, Laredo, and Hidalgo, Texas.*"

The statute provides specific guidelines for the content of the agreements reached between the two countries. The agreements must provide detailed recommendations of "measures to protect the health and welfare of persons along the Rio Grande from the effects of pollution." In particular, the agreements specify the location, cost, distribution of costs between Mexico and the United States, and starting and completion dates for the construction of wastewater treatment plants.

Section 5 of the statute authorizes appropriations for the United States' share of the costs for construction and maintenance of the required treatment facilities. While this statute specifically names only cities downstream of Big Bend National Park, it clearly does not exclude upstream cities, such as Ciudad Juarez, El Paso, Ojinaga and Presidio.

Other Legislative Acts

Additional resource protection legislation decisions and actions must comply with the following existing legislation: the Antiquities Act of 1906; the Historic Sites Act of 1935; Executive Order 11593 of May 13, 1971 (which established procedures for complying with the National Historic Preservation Act of 1966); the Archeological and Historic Data Preservation Act of 1974; the Archeological Resources Protection Act of 1979; the Resources Conservation and Recovery Act of 1976 (amended in 1984); the Geothermal Steam Act of 1970; and the Wilderness Act of 1964.

Texas and Mexico Legislation, Regulations, and Programs

Legislation, regulations, and programs for Texas and Mexico that pertain to water resources management of Big Bend National Park include Texas Surface Water Quality Standards, Mexico Surface Water Quality Standards, Drinking Water Standards, and Texas water law pertaining to water allocation and administration of Texas's share of the Rio Grande River. Part A of Appendix II shows the surface water quality standards currently in effect in Mexico, the United States, and Texas. The Texas Clean Rivers Act addresses issues pertaining to nonpoint sources of pollution and marks Texas' first attempt to assess water quality by river basin. The Texas Natural Resource Conservation Commission, as directed by the Texas Water Code, determines state water rights. The Rio Grande Watermaster directs the allocation of all U.S.-owned Rio Grande water to water rights holders according to the rules of adjudication.

Texas Water Rights

Surface Water. Texas currently follows the Doctrine of Prior Appropriation in allocating its surface water rights. Under this doctrine, the person who first diverts water for a beneficial use (i.e., appropriates the water) has a prior right to use, against all other appropriators. This doctrine is commonly referred to as "first in time, first in right." An appropriative water right is a proprietary right in that it can be bought and sold, and its place of use, purpose, and point of diversion can generally be changed without loss of priority. It is also a right to the *use* of the water; the corpus of the water belongs to the public. A permit to appropriate is obtained by filing an application with the Texas Natural Resource Conservation Commission and by following the statutory provisions to place the water to beneficial use. In evaluating the application, loss of in-stream water uses and effects to bay and estuarine systems are considered (Skillern, 1991).

Prior to legislative adoption of appropriation statutes in the late 1800's, Texas courts generally followed the Riparian Doctrine to settle water disputes (Caroom, 1995). A riparian right is a right to the reasonable use of water by an owner of property adjacent to a watercourse (riparian land). The rights attach to riparian land patented between January 20, 1840 and July 1, 1895 (Caroom, 1995). Civil law rights, based upon grants of land from Mexico or colonial Spain prior to 1840, may also exist, where the grant expressly includes a grant of water with the land (Caroom, 1995).

Adjudications are the means by which the nature and extent of the various types of rights are set forth with certainty. Following a scheme established by the 1967 Texas Water Rights Adjudication Act, water users in an adjudication area were required to file water rights claims (Skillern, 1991). (Although not expressly exempted from appropriation in the statutes, domestic and livestock uses have generally been exempted from the water rights adjudication process (Caroom, 1995)). The adjudicated area encompasses a stream, river, watershed, or portion thereof. As the result of an adjudication, a decree is entered and certificates of adjudication are issued to water right holders (Hutchins, 1977). Riparian claims are limited, under the 1967 Act, to reasonable beneficial use of water during the four years prior to enactment of the statute, and any claim not filed in an adjudication would be extinguished (Hutchins, 1977).

Rio Grande Watennaster Operation. While most of the Rio Grande Basin has been fully adjudicated and is fully appropriated (overappropriated according to "paper" water rights (Matchus, 1995)), the Rio Grande in Texas above Ft. Quitman is currently undergoing adjudication (G. Rothe, 1996, TNRCC, pers. comm.). The Rio Grande Watermaster (RGWM), under the Texas Natural Resource Conservation Commission (TNRCC), is responsible for managing Texas' share of Rio Grande water below Ft. Quitman, Texas. After the International Boundary and Water Commission determines international ownership, the RGWM program controls all U.S.-owned water and is responsible for allocating the water to all Texas water rights holders according to the rules of adjudication. While this program began under the jurisdiction of the courts in the 1950's, the Texas Water Commission (now TNRCC) assumed responsibility for the program in 1971. The program operates under the authority established in Chapter 11, *Texas Water Code* and Commission Rule 30 Texas Administrative Code, Chapter 303 (TNRCC, 1994a).

Ground Water. While surface water is considered the property of the state, groundwater is considered the property of the overlying landowner. The use of groundwater is by the "rule of capture," wherein the landowner can pump unlimited quantities of groundwater irrespective of the impact to his neighbors' water supplies. This is the case even if the pumping were to affect a neighbor's right to the flow of a spring; the neighbor's right applies only after the water emerges from the ground (Caroom, 1995). In addition, the landowner can sell the groundwater for off-site use by another party (Caroom, 1995).

Limitations on the landowner include a bar on malicious use of water for the purpose of injuring a neighbor or in a manner that amounts to a wanton and willful waste of the resource (Caroom, 1995). In the case of artesian water, approval of withdrawals by the Texas Natural Resource Conservation Commission may be required in certain circumstances and special statutory provisions prohibiting waste apply (Caroom, 1995). Groundwater pumping within underground water conservation districts may be controlled by specific rules that can be enforced through judicial action (Skillern, 1995). The rules may apply to, for example, conservation, waste, recharge, and subsidence (Skillern, 1995).

Exceptions to the "rule of capture" are (1) groundwater that is the underflow of a surface watercourse (groundwater ". . . in a stream bed that is necessary for the stream's flow and thus is connected to, and part of, the surface water" (Skillern, 1995); often referred to as "subflow"), and (2) groundwater in a well-defined and known subterranean stream (Caroom, 1995). In the former instance, the groundwater is subject to allocation and use in the same manner as surface water (Caroom, 1995). In the latter instance, it must be proved that the underground water is flowing in a stream (Skillern, 1995), in which case ". . . the landowner's rights are the same as would apply to a surface watercourse" (Caroom, 1995).

Texas Water Quality Acts (Texas Water Code)

The Texas Water Quality Acts (see supporting document: Texas Codes Annotated (TCA), Water Code, Title 2, enacted 1967; latest amendment 1985) encompass a broad spectrum of measures under the jurisdiction of the Texas Natural Resource Conservation Commission designed to protect the quality of the state's waters. Chapter 5 outlines the specific duties and responsibilities of the Texas Natural Resource Conservation Commission (TNRCC). Chapter 26 (§26.001(5) and §26.127, TCA) provides the TNRCC with the authority to regulate water quality of waters in the state: surface water, ground water, and wetlands. Under this authority, the TNRCC has the sole authority to develop and amend water quality standards for the State (TNRCC, 1994a). Chapter 26 of the Texas Water Code also embodies the main rules and regulations pertaining to the discharge of waste into or adjacent to any state waters and the associated requirements for permits to do so. Regulations for private and public sewage treatment facilities are addressed in this title as well as in *Texas Wastewater Treatment Regulations* (see section below).

Chapter 30 of the Texas Water Code contains the text of the Regional Waste Disposal Act. The purpose of this act is to "*authorize public agencies to cooperatefor the safe and economical collection, transportation, treatment, and disposal of waste in order to prevent and control pollution of water in the state.*"

Texas Surface Water Quality Standards. Surface water quality in Texas is regulated by the federal Clean Water Act (CWA) (P.L. 9S-217) (see "Federal Laws and Regulations" earlier in this chapter) and Chapter 26 of the Texas Water Code. The CWA requires the U.S. EPA to set minimum standards. The individual states then have the right to adopt the federal standards or establish their own stricter standards (TNRCC, 1994a). Pursuant to Section 303 of the CWA, the Texas Surface Water Quality Standards (TSWQS) are subject to triennial review and approval by the U.S. EPA.

Texas Surface Water Quality Standards are defined in the Texas Administrative Code, Title 30, Texas Surface Water Quality Standards, Ch. 307 § 1-10, adopted June 14, 1995; effective July 13, 1995; promulgated under Texas Water Code § 26.023. They specify site-specific water quality criteria for individual stream segments of the Rio Grande and most other Texas rivers and their major tributaries. Site-specific standards provide upper and lower limits for the following water quality criteria:

- dissolved oxygen (DO)
- temperature
- pH
- total dissolved solids (TDS)
- fecal coliform bacteria, and
- toxic limits.

The water quality standards are specified for "uses to be protected" for each stream segment. These "designated uses" include:

- aquatic life habitat
- contact or non-contact recreation
- domestic water supply (public water supply
- and/or aquifer protection)
- navigation, and
- industrial water supply.

Table 1 lists the criteria for DO and fecal coliform that differentiate between the designated uses of contact versus non-contact recreation and the various levels of aquatic life habitat. Relative to aquatic life habitat, the Texas Surface Water Quality Standards contain both narrative and numerical criteria designed to protect each aquatic ecosystem as a whole. The Texas Surface Water Quality Standards define the terms of the attainable aquatic life uses of a given body of water through the use of dissolved oxygen and water toxics criteria. The process of setting the appropriate dissolved oxygen criterion is often based on physical or hydrological characteristics of a

Table 1. Texas Surface Water Criteria for Recreation and Aquatic Life Designated Uses

Parameter	Contact Recreation	Non-contact Recreation	Aquatic Life Habitat: limited	intermediate	high	exceptional
DO'			3	4	5	6
Fecal Coliform"	200 CFU/100 ml	2000 CFU/100 ml				

Source: Texas Surface Water Quality Standards (Texas Admin. Code, Title 30, Texas Surface Water Quality Standards, Chapter 307 § 1-10; adopted June 14, 1995; effective July 13, 1995).
' units of mg/l (milligrams per liter) for 24-hour average values
"values for 30-day geometric means (CFU = colony forming units)

Table 2. Texas Surface Water Quality Standards for Applicable River Segments of the Rio Grand Basin

Rio Grande Segment No.	Segment Name	Aquatic Life	Domestic Water Supply	Other Uses	Chloride°	Sulfate	TDS	D.O. Range	PH	Fecal Coliform°	Temp.
2306	**Rio Grande from 1.8** km (1.1 mi) downstream of Ramsey Canyon to Rio Conchos	H	PS	CR	300	**570**	**1550**	**5**	**6.5-9.0**	200	**93**
2307	**Rio Grande from Rio Concos to Riverside** Diversion Dam	H	**PS**	**CR**	300	**550**	**1500**	**5**[d]	**6.5-9.0**	200	**93**
2308	**Rio Grande from Riverside Diversion** Dam to International Dam	L		NCR	250	**450**	**1400**	**3**	**6.5-9.0**	2000	**93**

'Source: Texas Surface Water Quality Standards (Texas Admin. Code, Title 30, Texas Surface Water Quality Standards, Chapter 307 1-10; adopted June 14, 1995; effective July 13, 1995).
°all units in table are mg/1 unless otherwise noted
[b]pH units
units are number of colonies per 100 ml
[d]The DO criteria in the upper reach of Segment 2307 (Riverside Diversion Dam to the end of the channel below Fort Quitman) shall be 3.0 mg/L when the headwater flow over the Riverside Dam is less than 35 cubic feet per second (TSWQS, 1995).

Abbreviations: TDS = total dissolved solids; D.O. = dissolved oxygen; Temp. = **temperature** in **degrees Fahrenheit;** H = **high quality** aquatic habitat; L = limited aquatic habitat; PS = public water supply; CR = contact recreation; NCR = non-contact recreation

Table 3. Water Use classification of the Secretaria de Agricultura y Resoursos Hidraulicos

Class	Definition
DA	Domestic and industrial **water supply using disinfection treatment.Contact recreation.**
DI	Domestic and industrial water **supply using conventional treatment.**
DII	**Water** for **recreation,** conservation of flora **and fauna, or industrial use.**
Dill	**Water for agricultural or industrial use.**
DIV	**Water** for industrial use (excluding **food processing).**

Source: Eaton, D.J. and J.M. Andersen. 1987. The State of the Rio Grande/Rio Bravo. The University of Arizona Press, Tucson, AZ.

water body because little is known about the biological communities.

Site-specific water quality standards and designated uses for applicable segments of the Rio Grande (segments 2306, 2307, 2308; see Figure 20 in Chapter 3) are listed in Table 2.

The following excerpts from the Texas Natural Resource Conservation Commission's "1994 Regional Assessment of Water Quality in the Rio Grande Basin Including the Pecos River, the Devil's River, the Arroyo Colorado, and the Lower Laguna Madre" (TNRCC, 1994a) provide additional insight to the criteria applied to segments of the Rio Grande studied in this report.

"The designated uses for most segments of the Rio Grande include contact recreation and high aquatic life. The exceptions are two segments (2307 and 2308) near El Paso. A high aquatic life use, protected by a 24 hour average dissolved oxygen criterion of 5 mg11, has been established in Segment 2307. However, in the upstream reach of the segment (Riverside Diversion Dam to the

Table 4. FreshWater Parameter	Quality Mexico Aquatic Life Criteria°*	Texas Fresh Acute Criteria[b]~	Aquatic Texas Fresh Chronic Criteria°·
Aldrin	3	3.0	-
Aluminum	50	991	-
Arsenic	200	360	190
Cadmium	@exp(0.7852[In(hardness)]-3.490)	exp(1.128(ln(hardness)]-1.6774)	@exp(0.7852[In(hardness)]-3.490)
Chlordane	2	2.4	0.0043
Chromium (Hex)	10	16	0.041
Copper	@exp(0.8545[In(hardness)]-1.465)	@exp(0.9422[In(hardness)]-1.3844)	@exp(0.8190[In(hardness)]+1.561)
Cyanide**	5	45.78	10.69
4,4'-DDT	1	1.1	0.0010
Dieldrin	2	2.5	0.0019
Endosulfan	0.2	0.22	0.056
Endrin	0.02	0.18	0.0023
Heptachlor	0.5	0.52	0.0038
Hexachlorocyclohexane (Lindane)***	2.5	2.0	0.08
Lead	@exp(1.273[In(hardness)]-4.705)	@exp(1.273[In(hardness)j-1.460)	9exp(1.273[In(hardness)]-4.705)
Mercury	0.01	2.4	1.3
Nickel	@exp(0.8460[In(hardness)]+1.1645)	@exp(0.8460[In(hardness)]-3.3612)	@exp(0.8460[In(hardness)]+1.1645)
Total PCB's***	0.01	2.0	0.014
Parathion	0.04	0.065	0.013
Pentachlorophenol	0.5	exp(1.005(pH)-4.830)	exp(1.005(pH)-5.290)
Selenium	8	20	5
Silver, as free ion	@exp(1.72[In(hardness)]-6.52)	0.92	-
Toxaphene	0.0002	0.78	0.0002
Trichlorophen$	10	136	64
Zinc	@exp(0.8473[In(hardness)]+10.3604)	@exp(0.8473[ln(hardness)]+0.8604)	@exp(0.8473[In(hardness)]+0.7614)

° Source: International Boundary and Water Commission, 1994
b Source: Texas Surface Water Quality Standards, 1995.
' All values listed or calculated in micrograms per liter. Hardness concentrations are input as milligrams per liter.
" Amenable to chlorination.
Not found in 1989 Standards of Comision National del Agua.
$ 2,4,6-Trichlorophenol for Mexico criteria; 2,4,5-Trichlorophenol for Texas criteria.

end of the rectified channel downstream of Fort Quitman) a dissolved oxygen criterion of 3 mg11 applies when headwater, flow over the Riverside Diversion Dam is less than 35 cubic feet per second (c). This criterion is protective of a limited aquatic life use at these times.

A noncontact recreational use has been established throughout Segment 2308. The water quality standards for the upper reach of Segment 2307 and the entire length of Segment 2308 reflect the w e n t dominated characteristics that episodically exist in this area. "In addition to dissolved oxygen and fecal coliform bacteria, numerical criteria for chloride, sulfate, total dissolved solids, pH and temperature are assigned in the TSWQS to each Rio Grande segment to protect the designated uses. The TNRCC has not established numerical criteria for nutrient compounds (including ammonia and nitrate nitrogen and ortho and total phosphorus) or chlorophyll a and pheophytin a. However, the TNRCC does employ screening levels for these parameters in evaluating surface water quality monitoring data. They do not represent adopted state criteria and should not be considered as such."

The Antidegradation Statement (§ 307.5) of the Texas Surface Water Quality Standards lists specific policies used by the Texas Natural Resource Conservation Commission (TNRCC) in order to sustain the highest practical water quality in the surface waters of the state. Essentially, the TNRCC seeks to prevent any waste discharges into natural waters that would degrade the quality of those waters. Any waste discharges approved by the TNRCC must comply with federal and state laws, namely the Clean Water Act and the Texas Water Code.

Mexico Surface Water Quality Standards. In contrast to the United States' system of state-controlled standards, all surface water quality standards in Mexico are based upon the 1971 statute, *Ley Federal para Prevenir y Con trolar la Contamination Ambiental.* This statute delegated responsibility for the development and administration of surface water quality standards to the Secretaria de Agricultura y Recursos Hidriulicos (SARH) in cooperation with the Secretaria de Salubridad y Asistencia (SSA), which also has responsibility for drinking water protection. In 1973, SARH issued regulations which set standards for surface water quality and for industrial and municipal discharges into surface waters (Eaton and Andersen, 1987). Such standards are set according to the desired uses of the surface waters. Water use classification as set forth by SARH is shown in Table 3.

The Binational Study on Toxic Substances (IBWC, *et al,* 1994) selected screening levels, both general and site-specific, for various parameters of quality. The Mexican criteria for toxic materials relative to aquatic life protection are shown in Table 4. Results of the Binational Study are discussed later.

Texas Drinking Water Regulations. The Texas Natural Resource Conservation Commission, through the Water Utilities Division, enforces the Public Drinking Water Supervision program of the federal Safe Drinking Water Act and the National Primary Drinking Water Regulations. The Act and Regulations establish standards for chemical and microbiological quality for public water systems. Chapter 341 of the Texas Health and Safety Code gives authority for regulating public water systems and the authority to adopt rules to implement the necessary programs to the Texas Natural Resource Conservation Commission. The Rules and Regulations for Public Water Systems sets standards for construction, operation, and maintenance of water systems. The Drinking Water Standards Governing Drinking Water Quality and Reporting Requirements for Public Water Supply Systems sets standards for chemical and microbiological quality and is the state equivalent of the National Primary Drinking Water Regulations.

The Texas Drinking Water Standards (see supporting document: Texas Administrative Code (TAC), Title 30, §290.101-290.119) were developed to *"assure the safety of public water supplies with respect to microbiological, chemical and radiological quality and to further efficient processing through control tests, laboratory checks, operating records and reports of public water supply systems" (§* 290.101). These standards were designed to comply with the federal Safe Drinking Water Act (P.L. 93-523) and the U.S. EPA Primary Drinking Water Regulations. The following excerpt explains the categories of drinking water standards in Texas:

"The Drinking Water Standards are basically divided into two parts. The primary standards are standards set to protect the health of the consumers by setting Maximum Contaminant Levels (MCLs). These MCLs are set using data from animal studies and/or human epidemiological or occupational exposure data. In all instances, the Texas primary standards are set at the same level as the federal primary standards. The secondary standards are set at levels which, in most cases, prevent the waterfrom being aesthetically objectionable. In most instances, the secondary

standards in Texas are equivalent to thefederal secondary standards" (Texas Water Commission, 1992).

Texas Drinking Water Standards specify maximum contaminant levels for inorganic chemicals, fluoride, organic compounds (synthetic organic chemicals and volatile organic compounds), microbiological contaminants, and radiological hazards for "community" and "non-community" public water systems. Section 290.102 of the statute makes the following definitions:

community water system — public water systems with potential to serve at least 15 service connections year-round or at least 25 individuals year-round. Each single family residential unit, commercial, or industrial establishment to which drinking water is supplied is counted as one connection.

non-community water system — any public water system which is not a community water system.

The Texas Natural Resource Conservation Commission's permit system for public water suppliers is based on these water system designations. The permitted suppliers are required to report periodically on the methods and results of their water quality monitoring programs (TNRCC, 1994a). In addition to setting maximum limits for contaminants, the Texas Drinking Water Standards also specify sampling and monitoring procedures and schedules (§ 290.106-110). Appendix, II, Part B summarizes drinking water standards for the United States and Texas.

Mexico Drinldng Water Standards. In Mexico, the Secretaria de Salubridad y Asistencia (SSA) has responsibility for protection of drinking water. City governments are required to comply with the federal standards and to monitor the quality of public supply water.

Texas Clean Rivers Act

The Texas Clean Rivers Act (Senate Bill 818, 1991) amended Subchapter B, Ch. 26 of the Texas Water Code by adding § 26.0135: "Regional Assessment of Water Quality by Watershed/River Basin." By establishing this Watershed Assessment Program, this Act fostered a partnership between the Texas Natural Resource Conservation Commission (formerly the Texas Water Commission) and appropriate regional water resource management agencies to manage water quality on a watershed basis. The Texas Clean Rivers Act specifies that *"nonpoint sources of pollution will be addressed; cumulative water quality impactsfrom toxic substances and nutrients will be addressed; appropriate regional di$erences can be accounted for; and land, water, and coastal elements of the environment will be integrated by the assessments into holistic functional systems for evaluation and management planning"* (Texas Water Commission, 1992, p. 50). This act is the state of Texas' first attempt to assess water quality by river basin by using public input through local steering committees and funding from fees assessed to wastewater and water rights permits (TNRCC, 1994a).

In lieu of a river authority or special district in the Rio Grande Basin, the Texas Water Commission (TWC) conducted an in-house water quality assessment for the watershed (TWC, 1992). The 1992 report by the TWC and the 1994 Texas Natural Resource Conservation Commission reports entitled "Regional Assessment of Water Quality in the Rio Grande Basin" (TNRCC, 1994a) are the first and second in a series of biennial reports on water quality as mandated by the 1991 Texas Clean Rivers Act for all 23 major river basins in Texas.

Texas Wastewater Treatment Regulations

Title 31 of the Texas Administrative Code (Texas Natural Resources and Conservation Code, Ch. 319) spells out the monitoring and reporting requirements for holders of wastewater treatment permits. Details of monitoring schedules, and acceptable sampling and laboratory testing methods are given in Subchapter A. Subchapter B lists the allowable concentrations of each of the hazardous metals for discharge to inland as well as tidal waters.

The Hydrologic Environment

Chapter 3

Introduction

Situated in western Texas along the Rio Grande border with the Mexican states of Chihuahua and Coahuila, Big Bend National Park preserves a typical part of the desert, montane, and riverine environments found in the northern Chihuahuas Desert. Big Bend National Park, established in 1944, is the fifteenth largest unit of the National Park System and the eighth largest unit situated in the continental United States. Daily temperature variations may be extreme and water is commonly in limited supply in the Chihuahuan Desert.

Physiography

In the central part of the Park, the Chisos Mountains rise several thousand feet above the surrounding plain creating an "island" montane environment. The Rio Grande sustains a ribbon-like oasis along the southern boundary of the Park, and it supports riverine and riparian habitats not frequently found in the desert environment. Water performs critical functions in these arid environments, greatly controlling the distribution of biological communities and even the patterns of human settlement.

This ribbon of riverine and riparian environments provides a stark comparison to the adjacent desert. The river provides for water supplies and popular recreational activities including river-rafting and fishing. The connected riparian environments contribute essential habitat for wildlife and a migratory route for birds

(Wauer, 1977). Three canyons, Santa Elena, Mariscal, and Boquillas, carved through the limestone mesas along this reach of the Rio Grande, create some of the most exceptional scenic attributes of the park.

The principal surface water feature of the park is the Rio Grande (Rio Bravo del Norte), which forms the southern boundary of the park. The Rio Grande flows through New Mexico, from its headwaters in southern Colorado, curving southeast close to the New Mexico-Texas border. The Texas drainage area above the park is approximately 34,830 square miles (90,205 km^2). Historically, most of the Rio Grande's flow derived from runoff in the mountainous regions of southern Colorado and northern New Mexico. Streamflow losses, due in part to upstream reservoirs and diversions as well as natural and induced infiltration, leave the modern Rio Grande significantly depleted by the time it enters Texas. The Rio Grande is dry in many years from southeast of El Paso to Fort Hancock, TX. Saline ground water discharge supports a small discharge southeast of Fort Hancock. For the ensuing 185 miles (298 km), the Rio Grande trickles until the confluence with the Rio Conchos near Presidio, Texas. In this reach the river channel has narrowed and become choked with tamarisk and in its present condition would not be capable of conveying historic flows. In recent years (1932-1985), discharge emanating from the Rio Conchos' approximately 26,500-square mile (68,691 km^2) watershed has provided roughly 85% of the flow in the Rio Grande through Big Bend National Park (Saunders, 1987).

The surface waters of Big Bend National Park, aside from the Rio Grande, mainly include creeks produced by small headwater streams (or springs), and locally significant springs, seeps, and tinajas. These streams are generally ephemeral, losing their water to percolation or evaporation in relatively short distances. Occasional floods in these streams channels result from periodic heavy rainfall events and continue to carve wide, usually shallow arroyos. There are, however, four areas of perennial flow within the park. Terlingua Creek flows perennially for approximately 15 miles (24.1 km) before entering the Rio Grande near the mouth of Santa Elena Canyon. Perennial flows occur in Tornillo Creek for about 6 miles (9.7 km) from near McKinney Springs to just below Banta Shut-in, and in the final 0.2 miles (0.32 km) of Tornillo Creek just before it reaches the river. McKinney Springs flows for approximately 0.3 miles (0.48 km) as a perennial stream and Fresno Creek maintains year-round flow through approximately 1.5 miles (2.41 km) of its course. Oak Spring in the Chisos Basin, and springs at Boquillas supply most of the water for the needs of those communities.

Climate

Big Bend National Park lies in the northern Chihuahuan Desert and has a semi-arid climate. Rainfall records extending from 1958 through the present exist for Panther Junction, Rio Grande Village, and the Chisos Basin. Table 5 shows that the average annual precipitation over the period 1958-1995 ranged from 10.13 inches (257.3 mm) at Rio Grande Village to 19.33 inches (490.1 mm) in the Basin. In arid climates, short term averages can be misleading because they are strongly affected by extreme events. In terms of precipitation, a few severe storms that occur in the same month over several decades can make the average for that month appear high. The median value (defined as the middle observation when the sample population is ordered from smallest to largest) better represents "typical" conditions, because half the time there is more rain, and half the time there is less. Note that the median monthly and the average monthly (sum of all values for a given month divided by the number of years of record) precipitation values can vary by almost a factor of two (or 100%). The January and March values in Table 5 provide examples of these large disparities. Figure 3 shows the variability of monthly rainfall over the period of record for the station in the Chisos Basin. Patterns for the driest month (March), the wettest month (August), and a medium-wet month (October) are shown. The graphs clearly illustrate the four "wet" Octobers, and six "wet" March's that caused the wide disparities in the average and median values for those months over the thirty-nine years. The graphs also demonstrate that the largest percent variation from the mean (or average) precipitation for that month occurs in the driest month, and the smallest variation occurs in the wettest month. Thus, although August sees the largest absolute variation in measured rainfall, the relative variation from the average (or mean) value over the long term is smaller than in months with less precipitation.

Table 5 shows that the differences between the average annual rainfall (sum of all yearly precipitation values divided by the number of years of record) and the median annual rainfall (midpoint between the highest and lowest

Table 5. Monthly and Annual Rainfall for Three Locations in Big Bend National Park (inches) (1985)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Median	Annual Average
Chisos Basin														
Median	0.53	0.51	0.19	0.35	1.59	1.89	2.67	2.65	2.68	1.25	0.44	1.44	18.53	19.33
Average	0.73	0.67	0.37	0.60	1.70	2.31	3.43	3.43	3.12	1.73	0.62	0.63		
Panther Junction														
Median	0.30	0.42	0.19	0.35	1.11	1.38	1.66	1.76	1.82	1.20	0.36	0.42	13.68	14.07
Average	0.53	0.51	0.31	0.55	1.49	1.78	2.03	2.07	2.20	1.46	0.56	0.56		
Rio Grande														
Median	0.22	0.28	0.12	0.23	1.11	1.15	1.44	1.36	1.30	0.72	0.23	0.26	10.24	10.13
Average	0.44	0.37	0.20	0.40	1.26	1.34	1.47	1.34	1.36	1.15	0.37	0.44		

Source: Big Bend Notional Pork computerized database.
Note: 1 inch = 25.4 millimeters

yearly precipitation values) for the three stations are much smaller (betwee 1 and 4 percent) than the differences in the monthly values (1.5 to 100 percent). Thus, for long term trends, the choice of the average or the median as the point of reference becomes less significant. Figure 4 plots *annual* precipitation for the same three stations in the park for the period 1958-1995. The figure displays the departure of each station's annual precipitation from its mean (average) value expressed as a percentage of the mean value. Note while the mean *annual* rainfall (represented by the zero point on the y-axis) differs significantly between the stations, the pattern of departures is quite similar. This pattern supports the assumption that the percentage departure (relative change at each station) from the mean annual precipitation at that station is similar throughout the park. The data suggest a park-wide trend of increased annual precipitation that appears to start in the mid 1960's. Furthermore, the extreme departures from the annual mean value, both above and below, are larger and more frequent in the period following the mid 1970's.

When comparing precipitation data to springflow data, as discussed later in the section on springs and in Project Statement BIBE-N-554.001, cumulative (or additive) departure of precipitation from the monthly average is a good index of the hydrologic driving mechanism for springflow. That is, meteorological and/or climatic conditions that control discharges from springs are expressed in this measure of precipitation trends. Figure 5 plots the cumulative departure (sum of all differences up to that time) of precipitation from the average monthly rainfall (shown as the zero point on the y-axis) at the Chisos Basin station. The earlier discussion of Figure 4 noted an upward trend of precipitation starting in the 1960's.

Figure 5 shows that up until 1962, the cumulative departure was very small, but starting in 1962 and continuing through mid-1966, a sustained drought, with only a handful of months having more rainfall than the average, brought the total precipitation (relative to the average) to a deficit of 25 inches (635 mm) over a four year period. Following this drought, a wetter-thannormal last half of 1966 reduced the deficit by roughly 5 inches (127 mm). In the period between 1967 and mid-1980, the cumulative departure (net deficit) increased to over 30 inches (762 mm). Over the next two years, above normal rainfall in most months reduced the cumulative departure back to 10 inches (254 mm). The following years, from mid-1982 to mid-1984 were drier, and the deficit grew back to 20 inches (508 mm). From 1984 to 1986, precipitation was about average, and the cumulative departure remained unchanged. An unusually wet second half of 1986 reduced the long-term precipitation deficit to roughly 2 inches (50.8 mm).

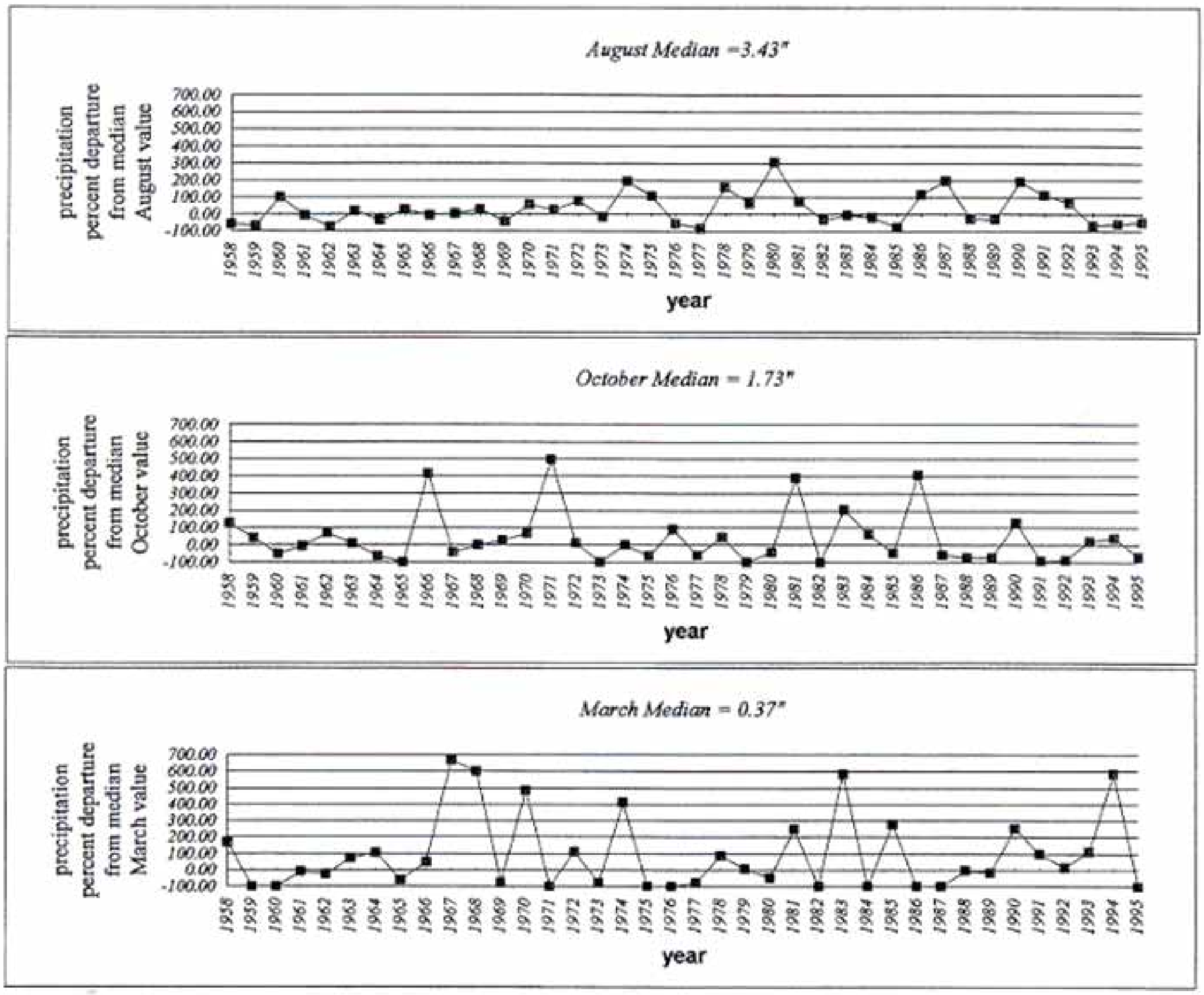


FIGURE 3. Wet, Medium, and Dry Precipitation Months at Chisos Basin
(precipitation in o/o departure from the monthly median value)

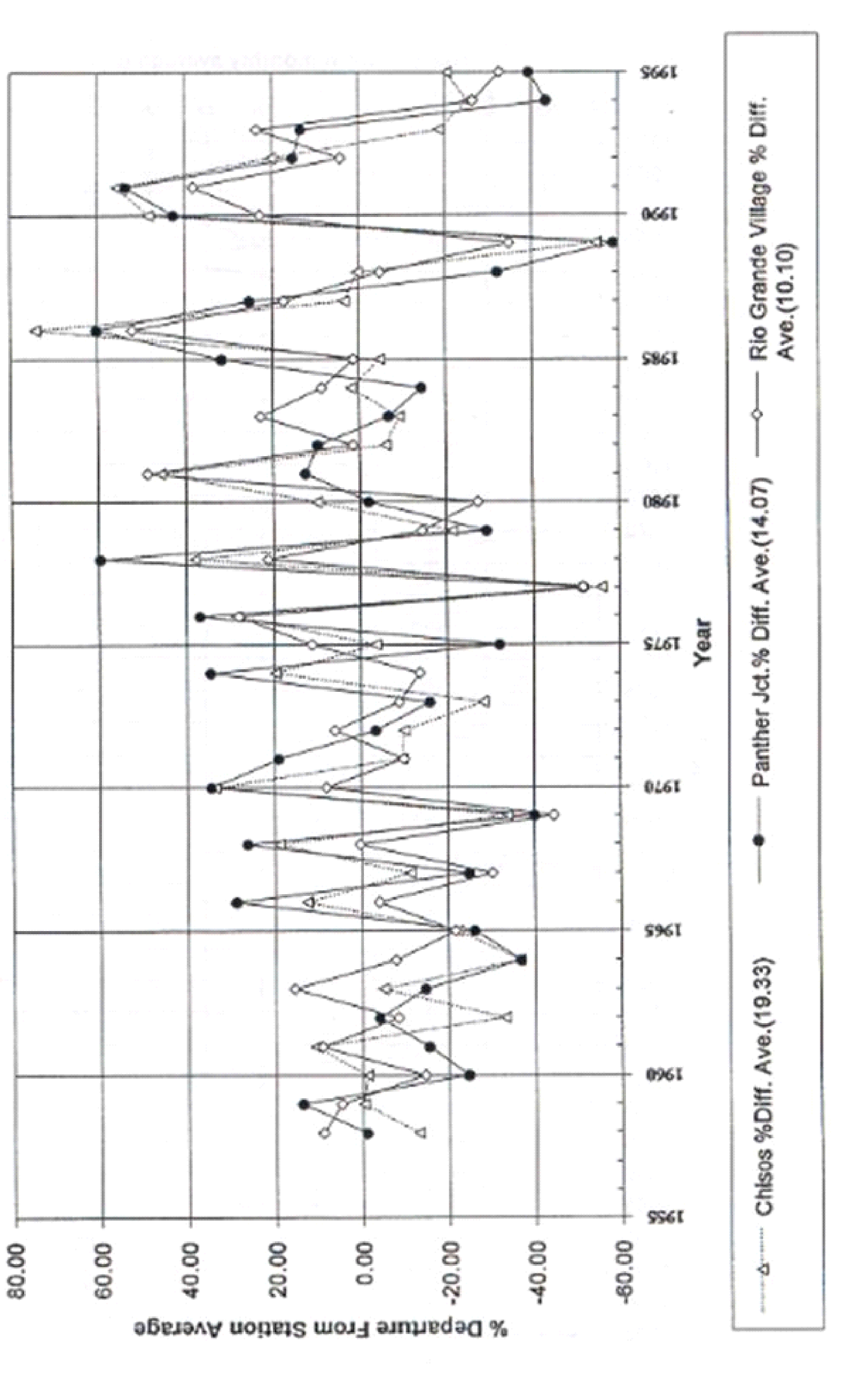


FIGURE 4. Variability in Precipitation at Three Locations in Big Bend National Park (1958-1995)

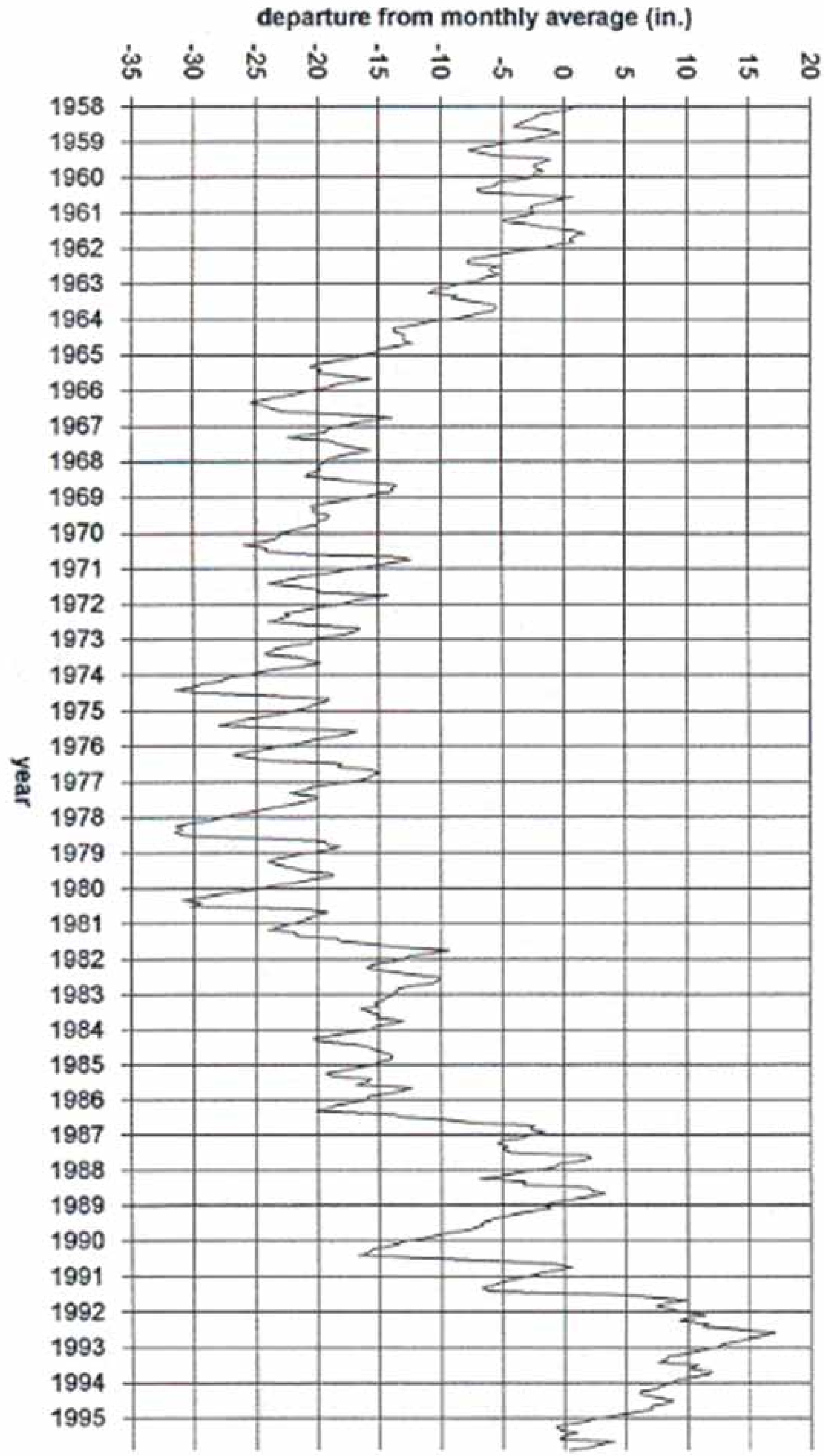


FIGURE 5. Cumulative Precipitation Departure from Average Monthly Value (in.), Chisos Basin

Rainfall values in 1987 and 1988 were near the average, with the net precipitation deficit hovering near zero over that time. A very dry 1989 followed by a very wet second halves of 1990 and 1991 brought the cumulative departure to 16 inches (406 mm) below average and then to 10 inches (254) above average by late 1991. Precipitation in 1992 left the long term precipitation in surplus, but by 1993, the trend began to fall again in a cycle remarkably similar to that seen for the period 1962-64.

Project Statement BIBE-N-566.001 provides guidance for an investigation of long-term precipitation characteristics based on the longest available precipitation records in the northern Chihuahuan Desert.

When completed, those results will permit evaluation of the significance of the short term records available for the park with respect to water resources dependent on rainfall.

Geology

The land forms within Big Bend National Park are typical of the Basin and Range Province of the western United States. In general, the area consists of part of a 40-mile wide block down-dropped between two major normal fault systems during Tertiary time. The Cretaceous clays, shales, and sandstones forming the main "floor" of the desert in Big Bend have been intruded and partially covered by Tertiary volcanic rocks which now form the Chisos Mountains. The huge alluvial fans now covering much of the sedimentary bedrock formed from subsequent erosion of those same igneous rocks (Archer, 1982). Table 6 summarizes the important geologic formations of the Big Bend area in a geologic time scale.

Most of the park is underlain by Cretaceous sedimentary rocks, Tertiary extrusive and intrusive (igneous) rocks, Tertiary or younger basin-fill deposits (some of which are as old as Early Miocene), and alluvium. The Persimmon Gap is the sole exposure of Paleozoic rocks in the park. The Big Bend region is unique for its great thickness of marine and continental Cretaceous deposits, bedded continental and extrusive Tertiary volcanic deposits, fossiliferous detritus deposits, and its wide variety of intrusive igneous rock (Maxwell and Dietrich, 1965).

Chisos Mountains

The Tertiary intrusive rocks that form the Chisos Mountains have been extensively eroded to form a rugged landscape of high peaks, ridges, deep narrow canyons, and broad depressions. In the process, bedrock ranging in age from Late Cretaceous to Miocene has been exposed. In some areas, Quaternary alluvium and colluvium (erosional products) cover the bedrock. Some stream channels have developed and these convey surface runoff and, in some areas, significant base flow. Some of the rock formations have become aquifers that supply water to springs and to a few wells (Baker, *et al,* 1993). In the basin area, the softer Cretaceous strata that were elevated by the igneous intrusion suffered accelerated erosion. Intermittent flow in stream channels that cross the geologic contact between the hard igneous rocks and the softer sedimentary rocks in upper Oak Creek has eroded the sediments to a near vertical surface. This type of erosion has resulted in spectacular waterfalls during periods of surface water flow. Some Tertiary igneous extrusive and intrusive rocks are exposed in the lower Oak Creek area, but most of the area is covered by Quaternary streambed deposits, alluvial fans, outwash gravel aprons, and colluvium consisting of talus and cliff debris with enormous boulders (Baker, *et al,* 1993).

Surface Water Resources

Surface water plays a critical role in maintaining the riparian habitats of Big Bend National Park as well as providing water for recreation and consumption to visitors and residents of the park. In Big Bend National Park, water occurs at the surface in seeps, springs, streams, and rivers as well as in small rainwater- holding depressions known as tinajas.

Backcountry Water Supplies

In the harsh desert environment of Big Bend National Park, the presence of natural springs, seeps, and tinajas are critical resources. They all provide support for the wildlife and vegetation where they occur, and may, at the same time provide for the water needs of park visitors. Over three hundred such sources exist within the park, but knowledge of the annual distribution of water availability and water quality of these important resources is poor.

Table 6. Summary of Geologic Units and Well Yields in Big Bend National Park

ERA	PERIOD	EPOCH	AGE (Million Years Ago)	Well Yields (gpm)*	Thickness (ft)	GEOLOGIC RECORD BIG BEND NATIONAL PARK
CENOZOIC	Recent					
	Quaternary	Pleistocene	3	5-500		Old Gravel (unconsolidated) and Alluvium deposits: clay, silt, SS, and conglomerate
		Pliocene Miocene	10 25			(unconformity)
	Tertiary	Oligocene	35		1000-1500	South Rim Fm: lava flows, ash beds, tuff, flow breccia, irregulary bedded SS and conglomerate
		Eocene	55		1500-2600 1170	Chisos Fm: indurated tuff interbedded with clay, sandstone, tuffaceous SS, ash beds, lavas, SS and conglomerate Canoe Fm: massive yellow SS overlain by tuffs and lavas (unconformity)
				25-30	350-770	Hannold Hill Fm: soft, gray and yellow-gray conglomeratic SS and varicolored and mottled clay
		Paleocene	65		> 850	Black Peaks Fm: varicolored clay, interbedded with ledge-forming buff to gray SS and lenses of conglomerate
MESOZOIC	Cretaceous	Gulfian	135	10-70	350-850	(unconformity) Javelina Fm: varicolored clay with thin SS layers; commonly bentonitic; fossil wood and dinosaur bones
					500-700 500-700	Aguja Fm: upper units nonmarine; lower units marine Upper: dark carbonaceous clay, silt and coal layers interbedded with yellow-brown SS, fossil wood and bones Lower: SS and silty clay, shelly SS at base (unconformity)
					220-600 350-400 475	Pen Fm: dark gray-blue gypsiferous marl and clay with LS concretions and layers of calc. sandstone (weathers yellow) Boquillas Fm: argillaceous, chalky flagstone, platy shale San Vicente Mbr.: gray chalk and buff argillaceous, flaggy LS Ernst Mbr: gray to yellow-brown LS with interbedded marl
		Comanchean		10-55	100 1-125 700-850 75 350-450 40-130 600	(unconformity) Buda Limestone: whitish, dense LS interbedded with marl Del Rio Clay: gray and yellow clay-shale and thin-bedded LS Santa Elena Limestone: massive, dense, heavy-bedded cherty LS Sue Peaks Fm: shale, marl, and thin marly, nodular LS ledges Del Carmen Limestone: massive, heavy-bedded cherty LS Telephone Canyon Fm: thin, nodular limestone and marl Glen Rose Fm: dense LS with calc. shale. Basal SS and conglomerate exposed at Persimmon Gap
	Jurassic		181			(unconformity) Prolonged period of erosion during which Paleozoic rocks were exposed in Marathon Basin, Solitario, and Persimmon Gap
	Triassic		230			
PALEOZOIC	Permian		280			
	Ordovician to Mississippian		500-340		300-7,000	(unconformity) Tesnus Fm: strongly folded black shale and sandstone; exposed at Persimmon Gap

Abbreviations and Symbols: (wavy line) unconformity

SS: sandstone LS: limestone Fm: formation calc.: calcareous

* Refer to Appendix IV for details on well locations and depths.

Tinajas. Tinajas are surface depressions in rocks of low permeability that serve as collectors for rain that falls on them and on the slopes above them. Most are small, exist only during, and for a short period of time after a rainfall event. They are used by wildlife as a water source when they contain water, but do not generally support vegetation because of their ephemeral nature. They are not reliable sources of water for park visitors because of their ephemeral nature as well as their vulnerability to contamination.

Seeps. Seeps include those springs whose discharge is diffuse, and their flows or discharges are generally not measurable as there is not defined channel or opening where their discharge is concentrated. The sources of the water supplying seeps may be very local, in which case the seep, like the tinaja, will respond rapidly to rainfall, or the absence thereof. Unlike the tinaja, seeps may also be the outlet for ground water that has travelled underground for long distances. Such seeps do not fluctuate rapidly in response to precipitation. Seeps with well established hydrophilic or phreatophytic vegetation around them are likely to be fed by distant sources. Seeps of this type are important for the vegetation they support, and in turn for the wildlife supported by the vegetation. Seeps of all kinds can be a source of emergency water supply to wildlife and to park visitors, for while the flow is generally small and diffuse, creating small depressions or troughs on the surface can allow enough water to collect to be useful.

Springs. Springs are a special class of seeps, and are characterized by well-defined flow path(s) which lend them to capture and development. Springs represent the most important source of water for wildlife and visitors in backcountry areas, and knowledge of their characteristics in terms of the temporal distribution of flow and their water quality is important. Like seeps, springs may be fed by bodies of permeable materials recharged by local precipitation, or fed through long, tortuous pathways from distant recharge points. The water quality of springs and seeps can be a good (though not certain) indicator of the distance to the source. Springs and seeps with highly mineralized waters, and/or temperatures higher than the mean annual air temperature are likely to be fed by distant sources, while springs with low mineral content are likely to be fed from local sources. The distance from the spring or seep to its source is important, because springs with distant sources will have significantly less fluctuation in flow in response to the variations in annual precipitation than will springs with local sources.

Occurrence of Springs in Big Bend National Park. In 1966-68, the U.S. Geological Survey (USGS) conducted a multiphase investigation into the water resources of Big Bend National Park (Garza, 1966; Leggat, et al, 1968). Phase I of the study consisted of an inventory of all sources of water in the central part of the park outlined in Figure 6. In addition, all known spring discharges were measured or estimated, and water samples were collected from selected wells and springs for chemical analyses. Findings from the USGS investigation are summarized below.

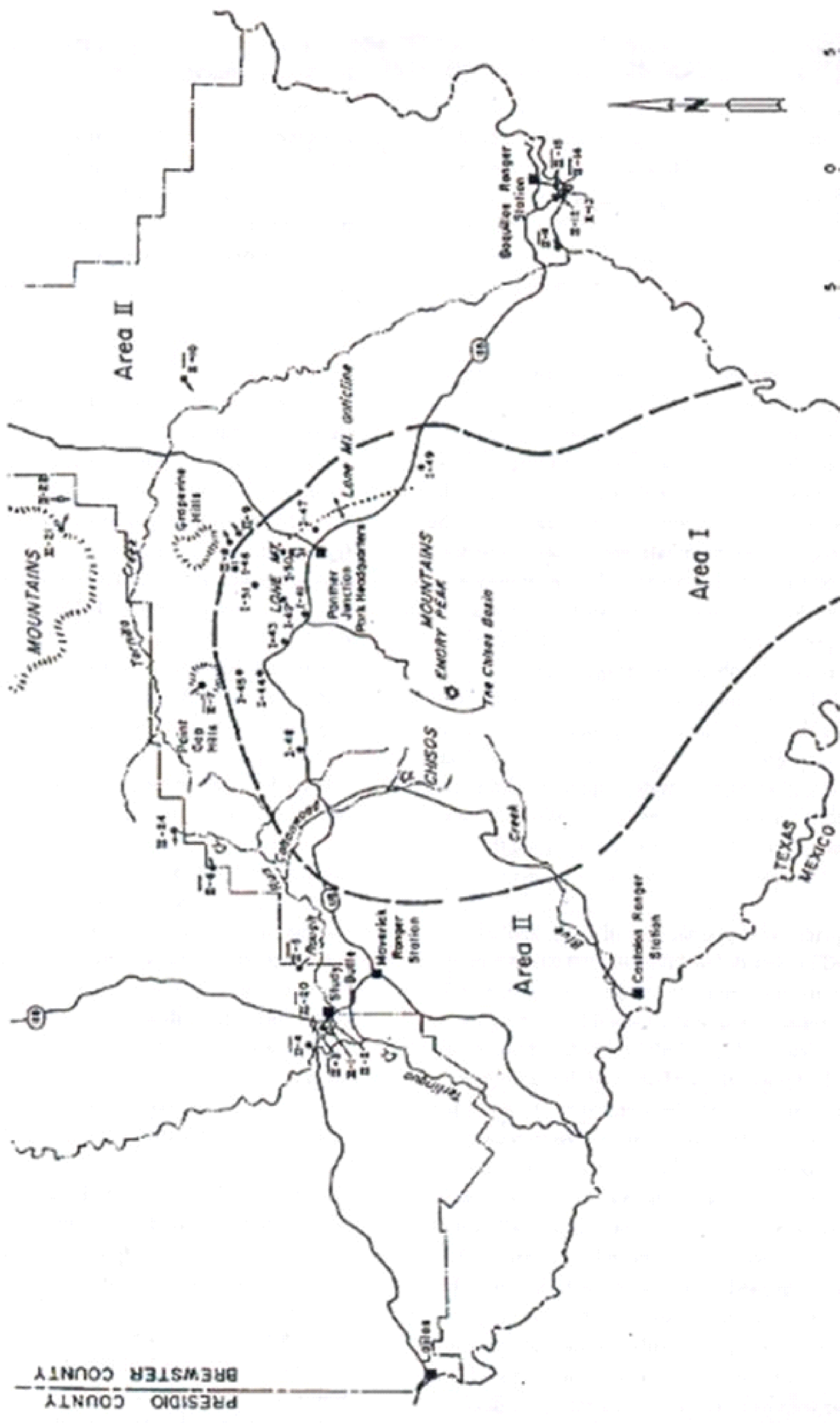
Area I. Water in Area I (study area for Phase I; shown on Figure 6) comes from three sources: springs, wells, and the Rio Grande. Twenty-six springs were inventoried in Area I, with the following results: 10 were dry; 12 had flows (seeps) less than 1 gallon per minute (gpm); 2 flowed 1-2 gallons per minute (gpm); and only two had significant discharge. Table 7 summarizes the findings for springs in Area I. The author cautioned that the discharges he observed should be considered less than potential flows because of the considerable loss to phreatophytes (willow, cottonwood, tile, and other vegetation) in the vicinity of the springs (Garza, 1966).

The quality of all of the springs' waters was good (above federal drinking water standards of 1962) except for Croton Spring, where the high sulfate content suggests contact with gypsum in the source rocks for that spring. Most of the springs had fluoride contents higher than 1 part per million (ppm) and generally low mineral content, reflecting either an environment of volcanic rocks or that the water-bearing unit crops out within a short distance of the spring (i.e., short distance from recharge to discharge areas). Aside from Oak and Cattail Falls springs, all of the springs served only the water needs of local wildlife and should not be considered as potential sources of water supply for the park (Garza, 1966).

Area II. The area of study for Phase II of the USGS investigation surrounds Area I to the west, north, and east, as shown in Figure 6, but the exact limits of the study area are ambiguous and appears to cover areas both within and outside the park boundaries. Most of the water supplies in this area derive from springs and wells. All creeks except for Terlingua Creek, which flows southward at the western edge of the park, and minor portions of Tornillo Creek, are intermittent (Baker, *et al,* 1993; B. Alex, Big Bend National Park, pers. comm., 1995). The low flow and poor quality of Terlingua Creek make it unsuitable as a water supply for the park.

Figure 6

Map of U.S. Geological Survey Areas for Phase I and II Investigations of Water Resources in Big Bend National Park



Source: Leggat, et al, 1968.

FIGURE 6. Map of U.S. Geological Survey Areas for Phase I and II Investigations of Water Resources in Big Bend National Park

Table 7. Springs in Area of U.S.			
Spring No. * (Name)	Appoximate Location	Discharge (gpm)	Quality
I-11 (Oak)	Chisos Basin	10	good
1-12 (Cattail Falls)	Chisos Basin	50	good
1-13, 1-14	- 5 mi. E. of Maverick Station, S. of Hwy 118	0-1	good
1-15 (Croton)	N. of Hwy 118, - 9 mi. E. of Maverick Station	0.1	high sulfate; very hard
1-16 through 1-18	N.W. flank of Chisos Mtns., - 2 mi. S. of Hwy 118 between Cottonwood Creek and Green Gulch	0-1	good
1-19	N. side of Hwy 118 just W. of Green Gulch (Government Spring?)	0-1	good
1-20 (Rock)	-3.5 mi. S. of Panther Junction, -1.5 mi. W. of Hwy 118	0	good
1-21 (Kibby)	unknown	0.2	good
1-22 (Yule)	-4.5 mi. S.E. of Maverick Station	0-1	good
1-23 (Burro)	- 6 mi. S.E. of Maverick Station, - 1 mi. W. of Castolon Hwy.	2	good
1-24 (Word)	W. flank of Chisos Mtns. at headwaters of Cottonwood Creek	1.5	good
1-25	unknown	0-1	good
1-26 (Chilicotal)	-7.5 mi. S.E. of Panther Junction, -2.5 mi. S. of Hwy. 118	0.2	good
1-27	-3.5 S.E. of Panther Junction, -1.5 mi. S. of Hwy. 118	0-1	good
1-28, 1-29 (Wasp)	Upper Blue Creek on W. flank of Chisos Mtns.	0-1,0.1	good
1-30 (Trap), 1-31 (Mule Ear), 1-32 and 1-33	- 6 to 9 mi. E. of Castolon, -1.5 to 5 mi. S.E. of Castolon Hwy.	0-1	good
1-34 (Glenn), 1-35 (Robbers Roose Spring well 5)	-12 to 13 mi. W. of Boquillas Ranger Station, - 7 mi. S. of Hwy. 118	0-1	good
1-36	-13 mi. S.W. of Boquillas Ranger Station, -12 mi. S. of Hwy. 118 (Mariscal Mountain?)	0-1	good

Source: Garza, S. 1966. Results of the Water Resources Investigation, Phase I, Big Bend National Park, Brewster County, Texas. U.S. Geological Survey memorandum (unpublished). 11 pp. plus fig.
'See Figure 6 for locations of springs

Area II springs are summarized in Table 8. The group of springs (II-11 through II-15) had flows from 50 to 200 gpm, and temperatures between 93 and 105° F (11-1 1 only). The high temperatures indicate that the ground water is affected either by the latent heat of igneous rocks that underlie the whole area or that water originates at considerable depths, possibly from the Georgetown or Edwards Limestone of Early Cretaceous age. In spite of moderate quality, this group of springs supplies water for the Boquillas Ranger Station and the Rio Grande Village camping area (Garza, 1966). Spring II-4 (referred to as Cedar Springs by the USGS author), 4.5 miles west of the Maverick Ranger Station, could potentially supply water for the Maverick Entrance if it were treated to reduce the

Table8. springs in Area II of Geological Survey Investigation (1965-66) of Big Bend National Park*			
Spring No. * (Name)	Appoximate Location	Discharge (gpm) .	Quality
II-, 11-2	Just W. of Study Butte, S. of Hwy 170	0-1	
11-3 (Moore)	Just W. of Study Butte, S. of Hwy. 170 (—4 mi. W. of Maverick Station)	4	extremely high sulfate (1130 ppm); very hard
11-4 (Cedar Spring well 1)	-4.5 mi. W. of Maverick Station, N.W. of Hwy. 170 junction with Hwy. 118 (E. of Terlingua Creek)	200 (July *1966)*	moderate (548 ppm sulfate; very hard)
11-5 (Indian Head)	-3 mi. N.E. of Study Butte, -1.5 mi. N. of Cottonwood Cr.	0.5	moderate (348 ppm sulfate)
11-6 (Christmas)	-8 mi. N.E. of Study Butte, -4 mi. N. of Hwy. 118		good
11-7 (Dripping)	-7.5 mi. N.W. of Panther Junction, -3 mi. N. of Hwy. 118		good
11-8, 11-9	-4 mi. N. of Panther Junction, -2 mi. W. of Hwy. 385 (Grapevine Hills?)		
11-10 (McKinney)	-3 mi. E. of Hwy. 385, -8.5 mi. N.E. of Panther Junction (—1.5 mi. E. of Tomillo Creek)	0	
II-11 (Hot Springs (72-49-401), 11-12, 11-13, 11-14 (Rio Grande Village Spr. no. 4), 11-15 (Rio Grande Village Spr. no. 1)	Along banks of Rio Grande near Boquillas Ranger Station	150 (50-200)	moderate (93-105°F) (34-41°C); 326-374 ppm sulfate; 881-932 TDS)
11-21 (Rosillos Ranch Spring)	S.E. side of Rosillos Mtns., 1 mi. outside park	15 (June 1967)	moderate (low TDS; veryhard)
11-23 (Buttrill Spring)	W. side of Rosillos Mtns., 11 mi. SW of Persimmon Gap Entrance	5-10**	good

Sources: Garza, 1966 and Leggat, et al, 1968
*See Figure 6 for locations of springs.
**the USGS document reports "several gpm"

which flows southward at the western edge of the park, and minor portions of Tornillo Creek, are intermittent (Baker, *et al,* 1993; B. Alex, Big Bend National Park, pers. comm., 1995). The low flow and poor quality of Terlingua Creek make it unsuitable as a water supply for the park. sulfate content. Aside from Cedar Springs, the Rosillos Ranch Spring, and the springs near Boquillas, the other springs in Area II have little or no discharge (Leggat, *et al,* 1968).

Two more recent and more comprehensive inventories of springs in the Big Bend area were conducted by the Park Service in 1985 (measurements made from 1984 to 1987) and 1990 (measurements made in 1990 and 1991). These inventories report discharges for over 300 water sources ranging from 0.001 to 90.0 gallons per minute (gpm). Table 9 provides a summary of the spring discharges measured during the two surveys. For presentation purposes, the springs are grouped by U.S. Geological Survey 7.5' quadrangle locations. Only those quadrangles with cumulative spring discharges totaling at least 10 gpm in either of the two inventory periods are presented. Figure 7 graphically summarizes the findings of the two inventories. Figure 8 illustrates the quandrangles with spring groupings described in Table 9 and Figure 7.

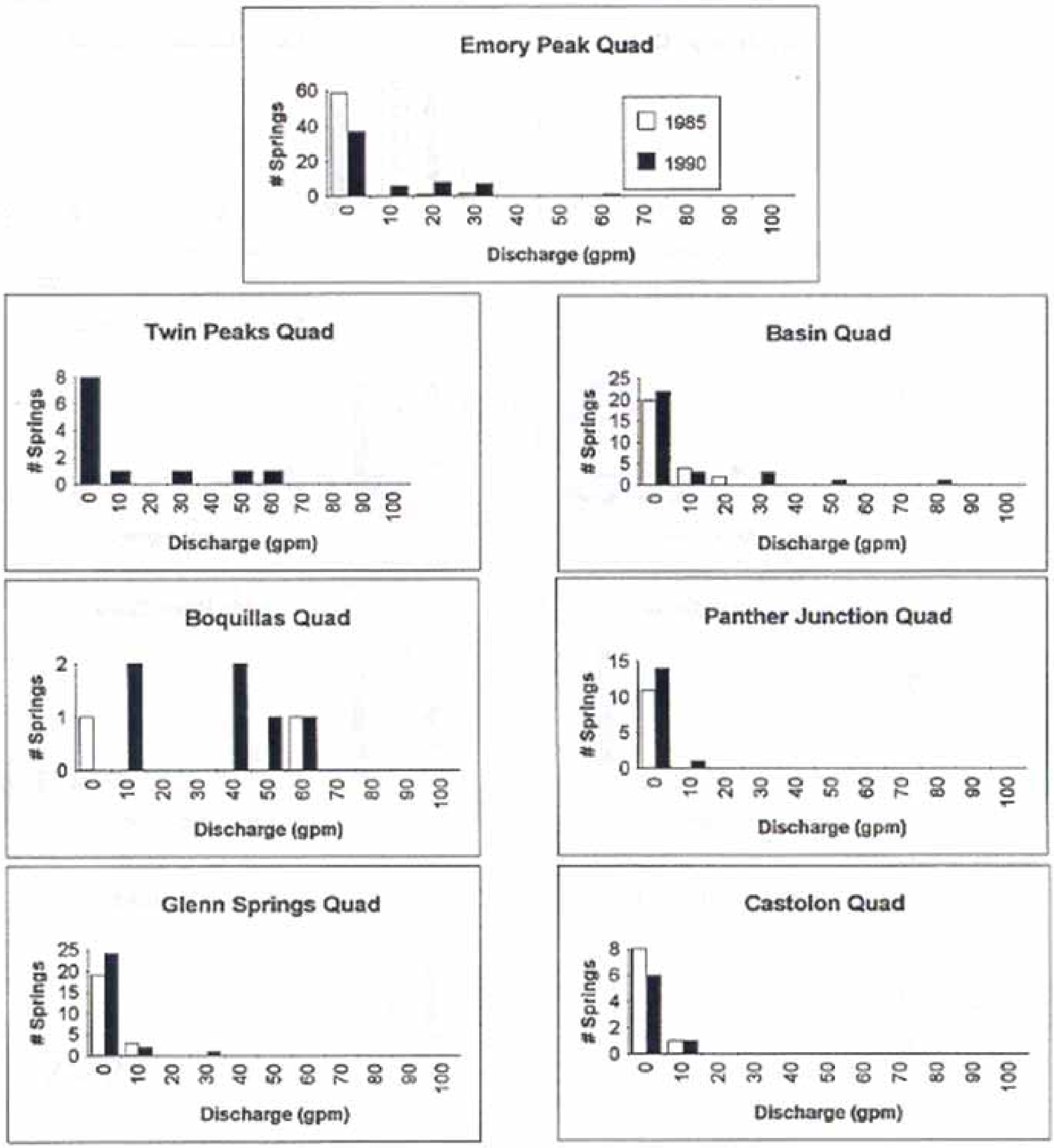


FIGURE 7. Summary of Spring Discharges Measured during 1985-86 and 1990 Surveys in Big Bend National Park

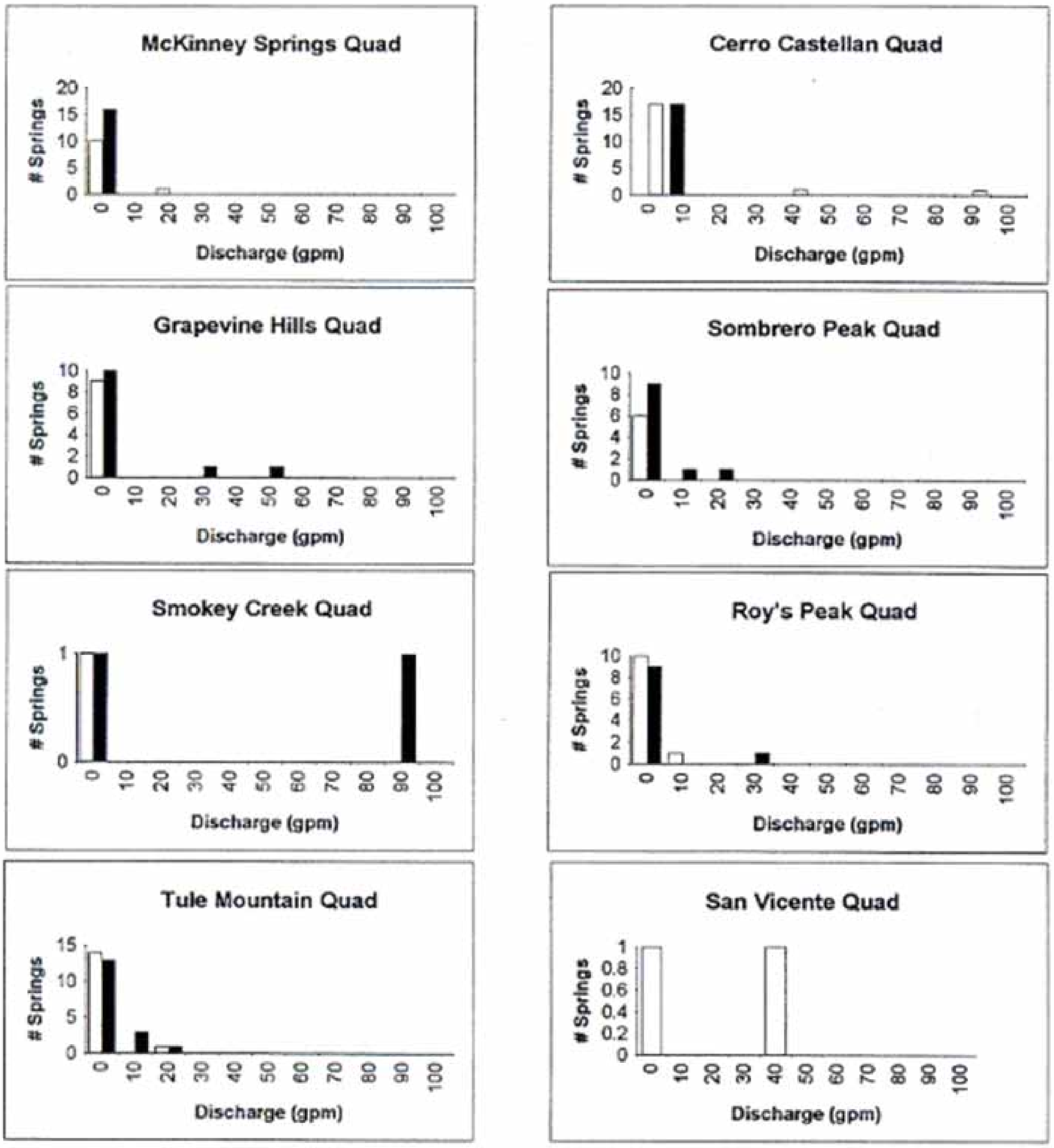
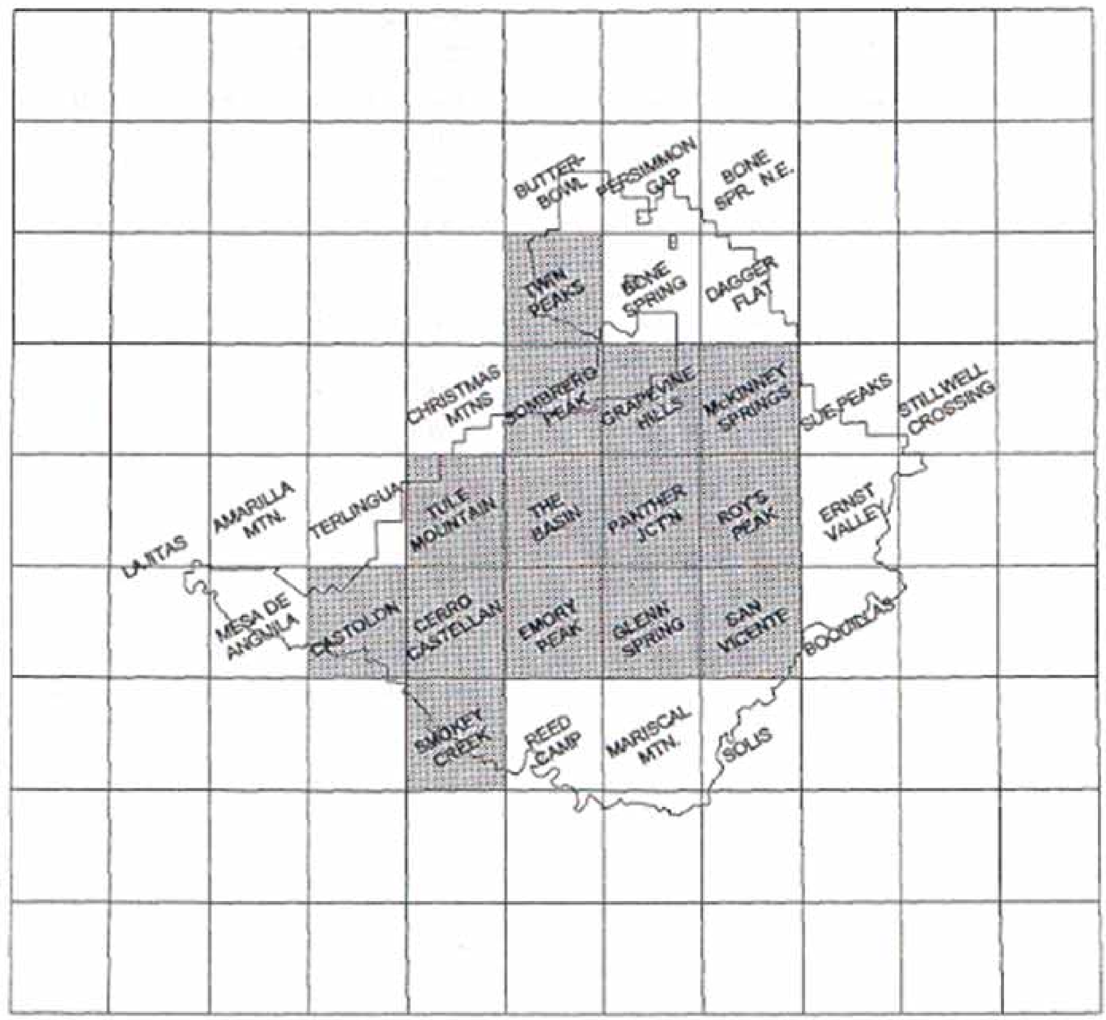


FIGURE 7. Summary of Spring Discharges Measured during 1985-86
and 1990 Surveys in Big Bend National Park (continued)



Adapted from Big Bend National Park Geographic Information System.

FIGURE 8. Location of U.S. Geological Survey Quadrangles in Big Bend National Park. Quadrangles with Major Springs are Shaded.

Table 9. Summary of Spring Discharge Measured During 1985-86 and 1990 Survey at Big Bend National Park

U.S.G.S. 7.5' Quadrangle Name[s]	No. of Springs		Discharge (gpm)							
			Maximum		Minimum		Mean		Total	
	1985-86	1990	1985-86	1990	1985-86	1990	1985-86	1990	1985-86	1990
Basin	26	31	20	80	0	0	4.8	9.5	124.9	284
Bone Spring	N/D	19	N/D	3	N/D	0	N/D	0.5	N/D	8.5
Boquillas	3	7	65	60	1.0	10	24.7	35.2	74.0	211
Castolon	9	8	10	11	0	0	2.0	2.8	19.2	19.2
Cerro Castellon	17	20	5	90	0	0	1.1	9.3	19.1	177
Emory Peak	62	60	30	60	0	0	1.9	10.2	117	602
Glenn Spring	22	28	15	30	0	0	2.7	4.0	60.2	108
Grapevine Hills	9	13	7	50	.001	0	2.7	7.4	24.2	88.6
McKinney Springs	11	17	5	6	0	0	2.4	1.6	26.5	26.3
Panther 1c'n.	12	16	3	11	0	0	0.6	2.5	7.2	37.7
San Vicente	5	N/D	40	N/D	0	N/D	9.0	N/D	45.0	N/D
Smokey Cr.	2	2	3	90	0.25	0.75	3.2	45.4	1.6	90.8
Sombrero Pk.	6	12	0.5	21	0	0	0.2	3.4	1.1	37.2
Tule Mtn.	15	18	25	20	0	0	2.3	4.2	34.5	71.6
Twin Peaks	N/D	13	N/D	60	N/D	0	N/D	12.8	N/D	154

Source: Big Bend National Park
'See Figure 8 for quadrangle locations

The histogram plots of number of springs vs. total discharge (Figure 7) allow a quick visual analysis of the types and numbers of springs in each area, and give considerable insight to the enormous temporal variability in discharges. For example, the 1985-86 values shown for the Emory Peak Quadrangle (Figure 7) indicate that nearly all of the springs measured (almost 60) had discharges of less than 10 gpm. By comparison, the 1990 graphs for Emory Peak Quadrangle springs show a distinct change in the nature of these springs since the previous (1985-86) inventory. In 1990, a much larger percentage of total discharge (for all of the springs inventoried) derived from springs with discharges of 10 to 70 gpm. Table 9 also demonstrates the difference in total flows between these two periods: 117 gpm in 1985 versus 602 gpm in 1990.

Some general observations can be made from the graphs in Figure 7. First, every major group of springs in Big Bend National Park exhibited larger discharges in the 1990 survey than in the 1985-86 survey. Reference to Figure 5 indicates that the "average rainfall" conditions which prevailed throughout 1984 and 1985 contributed to a lower total discharge representation for some spring groupings in the 1985 survey. The discharges measured in September 1990 through February 1991, on the other hand, followed six months of well "above average" rainfall. Second, two spring groupings stand out in their consistency between the two surveys: 1) Castolon Quad - total discharge increased only 1 gpm between 1985 and 1990 measurements and the distribution of discharges remains nearly identical; 2) McKinney Springs Quad - total discharge increased only 0.2 gpm from the 1985 to the 1990 survey, but more spring flow is attributable to smaller springs in 1990 than in the 1985 survey. Third, while 7 out of the 14 spring groups have springs with discharges exceeding 50 gpm in 1990, only 1 group (Boquillas) out of 14 had springs with discharges over 50 gpm in 1985. In general, the vast majority of the springs in the Big Bend area discharge less than 10 gpm, but a few important springs in the Chisos Mountains and in the Boquillas area yield significant discharges at certain times. The most important information gleaned from these graphs is that spring discharge in Big Bend is extremely variable in time. With this in mind, park management should be careful not to rely too heavily on these discharges for water supply.

Recommendations. While the few inventories of springs and seeps which were conducted over the past 30 years have been augmented with occasional estimates of discharge in the intervening years, no systematic effort has been made to evaluate variations in discharge that these springs may be expected to exhibit in response to variations in precipitation on monthly, seasonal, and annual scales. Basic hydrogeologic principles dictate that springs fed by small, shallow bodies of saturated material may be expected to have sharply varying rates of flow, and respond quickly (in days or weeks) to precipitation events. Springs and seeps whose source aquifers are larger in volume or more remote from the point of discharge will have a more subdued and delayed response. These predictions should be checked by field observations in order to gain a deeper understanding of the nature of spring flows in the park. Project Statement BIBE-N-554.001 provides guidance for the development of a systematic monitoring program which will yield a valuable data base that, along with climatic data, will enable park resource managers to reliably estimate spring flow conditions in the park.

Major Rivers

Figure 9 shows the major tributaries to the Rio Grande (Rio Bravo del Norte) in the United States and Mexico above La Linda, Texas. For the study area (El Paso to La Linda, Texas), the tributaries of interest in the United States include those of the Rio Grande in Colorado and New Mexico, plus Terlingua and Alamito Creeks in Big Bend National Park. The Rio Conchos and its tributaries in Mexico are major contributors to flow in the Rio Grande at Big Bend National Park.

Table 10 lists the drainage basin and the irrigated land areas contained therein for the gaging stations in the Rio Grande watershed within the study area of this report.

Rio Grande. In places below El Paso/Ciudad Juarez, the shallow streambed of the Rio Grande dries out completely (TNRCC, 1994a). Rainfall in its watershed is scarce, as little as eight inches (203 mm) per year in much of the basin, and when the rains come, they come in flood producing torrents. In the United States, all of the Rio Grande's natural runoff is controlled by dams, and supplemental supplies are piped in from the Colorado River. There are seven major dams along the river: the El Vado and Abiquiu dams on a tributary (Rio Chama) north of Santa Fe, New Mexico; the Cochiti Dam just southeast of Santa Fe; the Elephant Butte Dam in Truth or Consequences, New Mexico; the Caballo Dam north of Las Cruces, New Mexico; the Amistad Dam below the Big Bend National Park; and the Falcon Dam north of Brownsville, Texas. In addition, there are seven significant diversion dams between Caballo Reservoir and Fort Quitman which divert the vast majority of the flow for agricultural purposes, essentially dewatering the river.

The Rio Grande flows a total of 1,896 miles (3,051 km) from its headwaters in the San Juan Mountains of Colorado to the Gulf of Mexico. In total, the Rio Grande drains a total land area of 335,500 square miles ($mi.^2$) (867,600 square kilometers (km^2)). The drainage basin lies in three U.S. states (Colorado, New Mexico, and Texas) and five Mexican states (Chihuahua, Coahuila, Durango, Nuevo Leon and Tamaulipas). Since roughly half of this land area drains into closed basins (no outlet to the sea), the actual drainage area of the Rio Grande is only about 182,215 $mi.^2$ (471,909 km^2), with about half of that area lying in the U.S. (88,968 $mi.^2$; 230,413 km^2) and about half of the U.S. area occurring in Texas (48,259 $mi.^2$; 124,983 km^2) (TNRCC, 1994a). Two major U.S. tributaries to the Rio Grande, the Pecos and Devils rivers, join the Rio Grande downstream of Big Bend National Park, outside the study area for this report. Most of the waters of the Upper Rio Grande are diverted

Table 10. Drainage Basin and Irrigated Areas in the Rio Grande Watershed at IBWC Gaging Stations – El Paso to Johnson Ranch

Gaging Stations	Drainage Basin Area (square kilometers)**			Irrigated Areas		
	United States	Mexico	Total	United States	Mexico	Total
Above American Dam	75,812	0	75,812	33,807	0	33,807
American Dam to Acala Station	1,740	1,409	3,149	19,097	6,016	25,113
Acala Station to Fort Quitman Station	1,717	2,056	3,773	6,912	0	6,912
Fort Quitman Station to Above Presidio Station	4,263	3,652	7,915	75*	84	159
Above Presidio Station above Rio Conchos	83,532	7,117	90,649	59,891	6,100	65,991
Rio San Pedro above Francisco I. Madero Dam (Rio Conchose Watershed)	0	10,778	10,778	0	12,917	12,917
Rio Conchos above Boquilla Dam (Riio Conchos Watershed)	0	10,282	10,282	0	53,912	53,912
Boquilla Dam to Luis L. Leon Dam (Rio Conchos Watershed)	0	38,490	38,490	0	96,029	96,029
(Rio Conchos Watershed Total)	**(0)**	**(68,387)**	**(68,387)**	**(0)**	**(162,858)**	**(162,858)**
Alamito Creek above Gaging Station	3,895	0	3,895	0	0	0
Other tributaries	881	235	1,116	836	127	963
Above Presidio Station below Rio Conchos	88,308	75,739	164,047	60,727	169,085	229,812
Terlingua Creek above Gaging Station	2,771	0	2,771	0	0	0
Presidio Station below Rio Conchos to Johnson Ranch Station (excluding Terlingua Creek)	2,831	5,848	8,679	272	450	722
Above Johnson Ranch Gaging Station	93,910	81,587	175,497	60,999	169,535	230,534

* Total area irrigated from the Rio Grande at least once during the year; additional irrigations from this source dependent on availability of river water in this reach.
"Refer to conversion table inside the front cover of this document for conversion information.
Source: International Boundary and Water Commission, 1992. Flow of the Rio Grande and Related Data. Water Bulletin No. 62, p. 131.

Figure 9

Rio Grande Drainage Basin

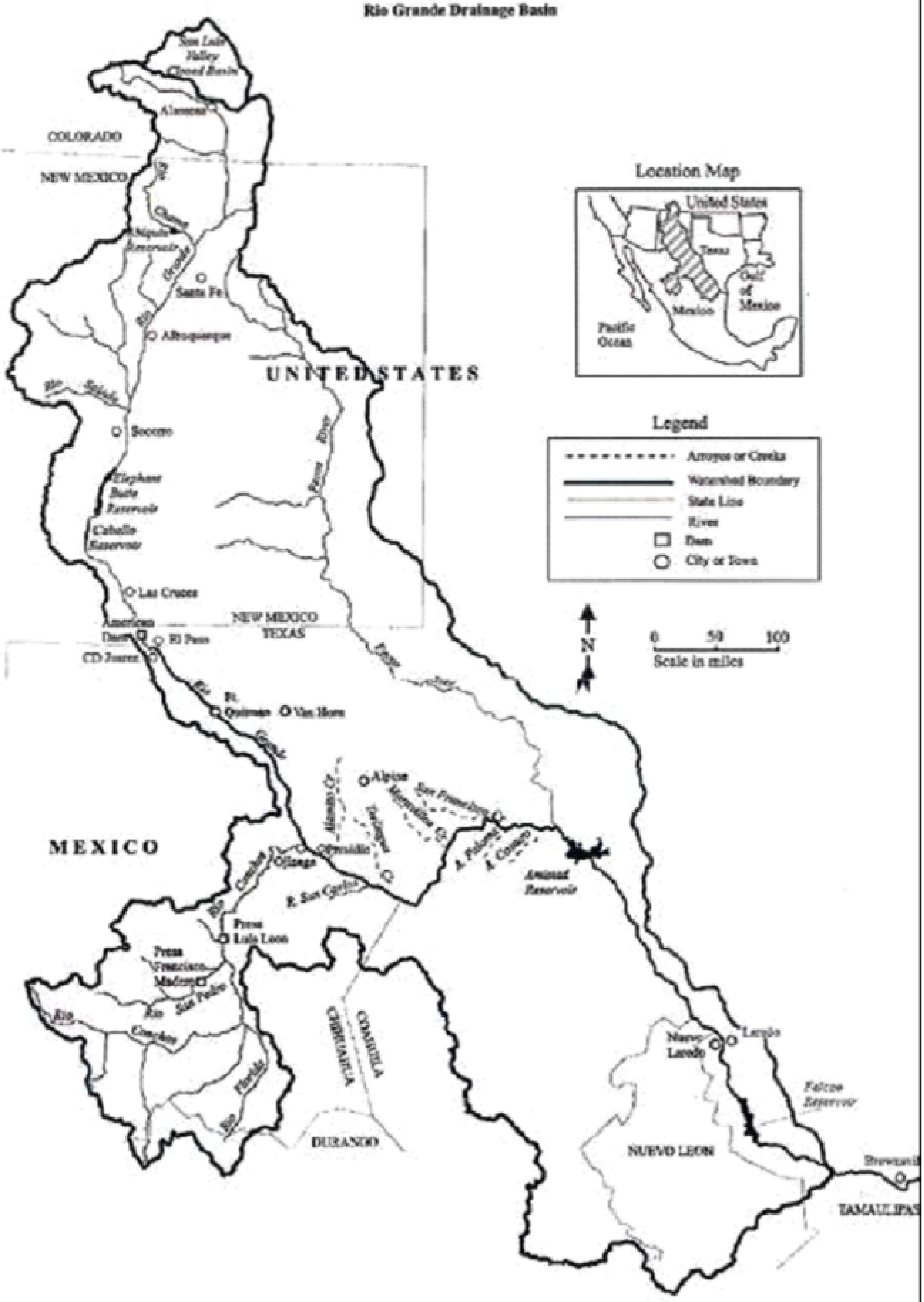


Table 11. Reservoirs in Operation on the Rio Conchos							
Name	State	Year Built	Function	Conservation Storage* (MCM**)	Flood Control Storage to Top of Spillway (MCM)	Maximum Surcharge Storage (MCM)	Spillway Capacity (M^3/s)
San Gabriel	Durango	1979	Irrigation	245	10	390	643
La Boquilla	Chihuahua	1916	Irrigation and Power	2,826	0	3,282	10,000
Francisco I. Madero	Chihuahua	1949	Irrigation	304	0	539	3,460
Chihuahua	Chihuahua	1960	Water Supply	24	0	40	300
El Rejon	Chihuahua	1976	Water Supply	7	0	10	80
Luis L. Leon	Chihuahua	1968	Irrigation and Power	360	464	877	7,000

* The IBWC (1992. Flow of the Rio Grande and Related Data. Water Bulletin No. 62, p. 83 reports the following total storage capacities (MCM): San Gabriel = 255.4; La Boquilla = 2,903.4; Francisco I. Madero = 348.0; Chihuahua = 31.9; El Rejon = unreported; Luis L Leon = 850.1

**MCM = million cubic meters

for irrigation and municipal uses at the American Canal in Texas and the Acequia Madre Canal in Mexico before they reach the cities of El Paso and Juarez.

Rio Conchos. More than half of the Rio Grande's drainage area lies within Mexico (87,365 mi.^{2}; 226,262 km^2). At 26,500 square miles (68,691 km^2), the Rio Conchos watershed comprises almost half of the entire Rio Grande watershed drainage area in Mexico. In many years, a large part of the flow of the Rio Grande arriving at Big Bend is from the Rio Conchos, the entire watershed of which is in the states of Chihuahua and Durango in Mexico. Six dams of various sizes currently operate on the Rio Conchos and its tributaries (see Figure 10), and two more small irrigation dams are under construction. The dams currently in operation are tabulated in Table 11. Of the six dams, only Luis Leon Dam has a gated spillway and significant flood control capacity (464 million cubic meters (MCM) (376,170 acre-feet) to the crest of the spillway gates).

From a practical viewpoint, the ungated dams on the Rio Conchos create five natural reservoirs in the river system which spill when the conservation levels are reached. Luis Leon Dam, on the other hand, benefits the Rio Grande during flood events by reducing the flood flows downstream from the junction of the Rio Conchos with the Rio Grande. The Presidio-Ojinaga Valley Flood Control Project was built to protect the agricultural lands in that area. The levee system functions as a mechanism to convey floods downstream. Thus, while it controls flooding on the lands it was designed to protect, it may exacerbate flooding in downstream reaches.

Historical Trends. The flow records at six gaging stations along the Rio Grande were analyzed to obtain an estimate of the water budget (gains and losses) during its flow to and around Big Bend National Park. The seven stations were chosen to coincide with those examined by Saunders (1987) and are shown in Figure 11. The six stations are listed in Table 12.

Table 13 expands Table 2 of the Saunders (1987) report to include annual flows of the Rio Grande from 1955 to 1991, and the same information is shown graphically in Figure 12. The last two rows of this table show mean annual flows for the two periods, 1961-85 (after Saunders, 1987) and 1955-1991. In the case of the Rio Grande above the Rio Conchos (River Mi. 963.7; River Km 1551), the mean annual discharge for the years

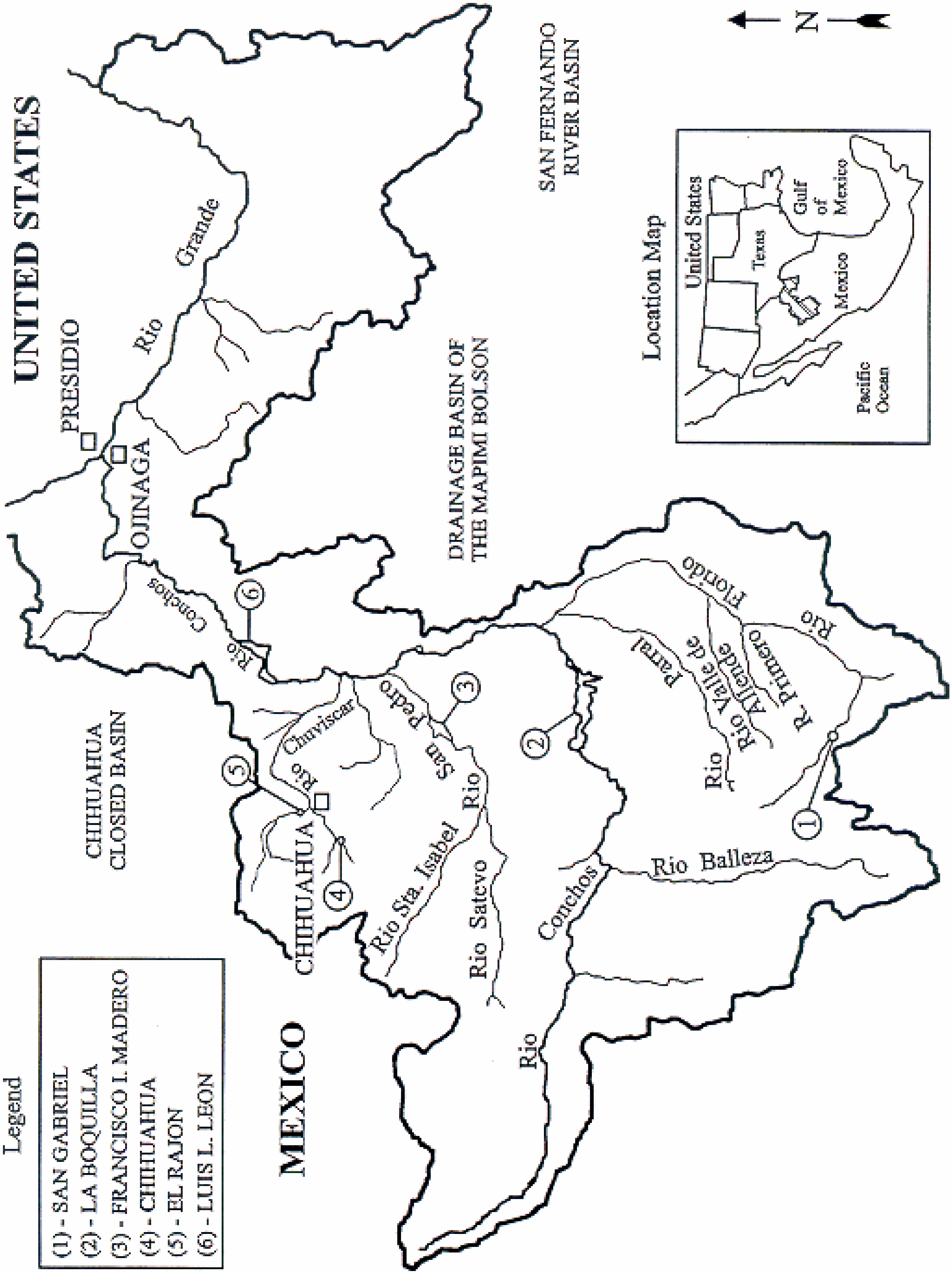
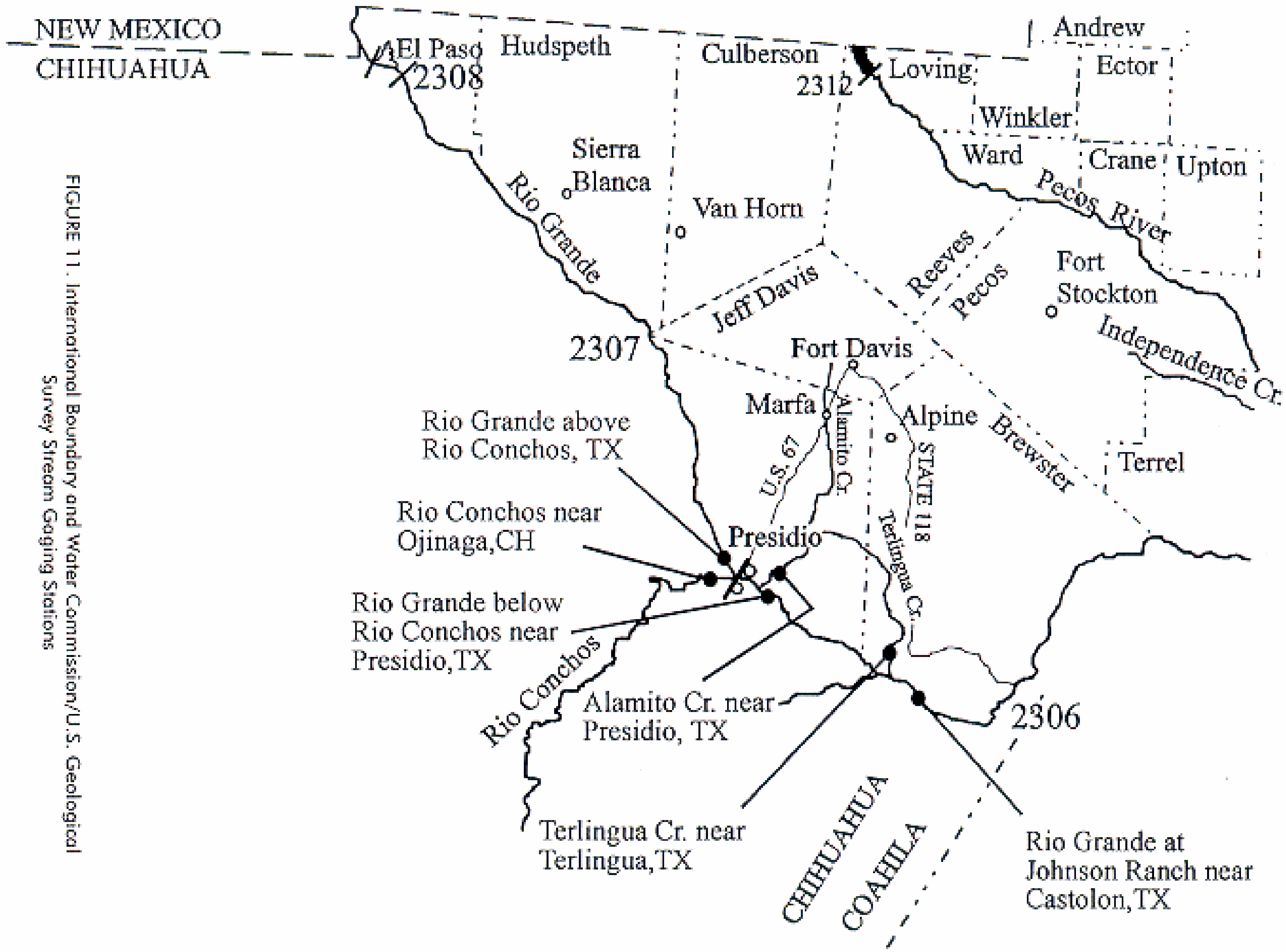


FIGURE 10. Dams in the Rio Conchos Watershed



Texas Water Commission (TWC). 1992. Regional Assessment of Water Quality In the Rio Grande Basin, Standards and Assessment division, Austin, TX. GP 92-02. 207 pp plus appendix

FIGURE 11. International Boundary and Water Commission/U.S. Geological Survey Stream Gaging Stations

Table 12. **IBWC** Streamgaging Stations in **Study** Area

Name	Station Number	River Kilometer	River Mile	Period of Record
Rio Grande Above Rio Conchos near Presidio, TX	08-3715.00	1551	963.7	1889-present
Rio Conchos near Ojinaga, Chihuahua	08-3737.00	1547	961.4	1968-present
Alamito Creek near Presidio, TX	08-3740.00	1529	950.1	1932-present
Rio Grande Below Rio Conchos near Presidio, TX	09-3742.00	1529	949.8	1955-present
Terlingua Creek near Terlingua, TX	08-3745.00	1425	885.2	1932-present
Rio Grande at Johnson Ranch near Castolon, TX	08-3750.00	1388	862.4	1936-present

Source: International Boundary and Water Commission. 1992. Flow of the Rio Grande and Related Data. Water Bulletin No. 62 pp. 15-21.

1961-1985 is 44,485 acre-feet (ac-ft) (54.87 million cubic meters (MCM)) whereas the mean for the expanded period (1955-1991) is 100,140 ac-ft. (123.51 MCM). This difference reflects the very high flows in 1988 and 1990 and the extremely high flows in 1986 and 1987 (these were very wet years as reported by the International Boundary and Water Commission). With similarly high flows from the Rio Conchos, the flows at all stations downstream were also high and, thus, considerably increased the values for the mean annual discharge for the larger period.

For a better picture of the water budget of the Rio Grande from above the Rio Conchos (River Mile (RM) 963.7) to Johnson Ranch near Castolon (RM 862.4), the mean monthly flows of the six stations for the period 1955-1991 were prepared and tabulated in Table 14. The flows are listed in ac-ft units to provide continuity with the Saunders (1987) report. Some pertinent units of conversion are provided in the table of conversions inside the front cover of this document.

The following example for the month of April illustrates the method used in calculating the water budget.

Example:

At RM 963.7 (Rio Grande above Rio Conchos)	5,040 ac-ft
Rio Conchos contribution	+36,690 ac-ft
Alamito Creek contribution	+244 ac-ft
Total of measured flows between RM *963.7* and 949.8	41,974 ac-ft
Flow measured at RM 949.8 (Rio Grande below Rio Conchos)	36,060 ac-ft
(Net change (loss) between RM 963.7 and 949.8	-5,914 ac-ft)
Terlingua Creek contribution	+1,434 ac-ft
Total of measured flows between RM 949.8 and 862.4	37,494 ac-ft
Flow measured at RM 862.4 (Rio Grande at Johnson Ranch-Castolon)	34,381 ac-ft
(Net change (loss) between RM 949.8 and 862.4	-3,113 ac-ft)
Total net reduction in flow due to channel losses, channel storage, diversions, legal and illegal withdrawals between RM 963.7 and 862.4	9027 ac-ft
Total of all measured flows between RM 963.7 and 862.4	43,408 ac-ft

Table 13. Rio Grande Annual Runoff by River Mile and Station Number (Acre-Feet)*

Year	RM 963.7* 08-3715.00	RM 961.4 08-3730.00	RM 950.1 08-3740.00	RM 949.8 08-3742.00	RM 885.2 08-3745.00	RM 862.4 08-3750.00
1955	23993	487501	16755	566160	35180	668993
1956	2448	190645	6089	205513	16746	209254
1957	6153	302434	13412	342213	26552	363561
1958	37512	1883837	35766	1866084	87526	2044275
1959	7153	530526	15413	553530	36633	614025
1960	32733	823274	11390	885655	56545	935225
1961	16292	488420	15201	543441	31993	585110
1962	35479	417726	29630	497984	37272	531792
1963	18161	402691	11294	446172	47785	512800
1964	952	361265	11671	392807	33684	422910
1965	2358	349635	11643	369698	22778	380825
1966	35192	1203968	23616	1116521	90343	1243367
1967	3390	541065	183670	563111	29272	603421
1968	16177	1082074	23661	1070488	40884	1125021
1969	3701	801363	9949	763757	25450	787569
1970	44472	564359	12787	594904	54831	671318
1971	24427	463888	37234	495642	82187	615314
1972	79385	868903	197890	917052	39282	970893
1973	6604	736600	24110	791006	20585	774898
1974	101377	1028525	70274	1238356	103989	1382081
1975	35181	663968	3668	735723	17057	761331
1976	57395	599583	7785	686064	43006	737296
1977	22297	465690	4215	483090	23808	501243
1978	84114	1698049	7427	1732512	60432	1801959
1979	22093	823045	5956	811184	32916	912389
1980	26725	551958	11925	601768	48195	716306
1981	116868	1164843	10853	1365812	62367	1396826
1982	24402	534253	2323	575964	21553	599393
1983	50065	356590	3039	435503	158656	404775
1984	151298	672107	14949	899124	44290	872078
1985	133730	527171	11639	681576	824578	713768
1986	710782	818910	18628	1766466	92530	1695761
1987	895082	724130	3577	1769422	48616	1676100
1988	289554	645828	4450	1042788	17804	999527
1989	131226	417928	2278	602220	21402	599612
1990	279720	1687913	27357	2113355	107586	2254584
1991	176700	2138562	23248	2507014	60447	2477526
Average 1961–1985	**44485**	**694710**	**16120**	**752370**	**44491**	**800987**
Average 1955–1991	**100140**	**757276**	**15713**	**892694**	**46482**	**934139**

***Source** of data for years 1961-1985: Saunders, G. P. 1987. Analysis of Streamflow of the Rio Grande: Big Bend National Park, Texas. Interim Research Report No. 2. Submitted to Office of Resource Management, Big Bend National Park, TX. 24 pp. plus app. and map.
Note: these values are the sums of daily flows.
Source for data for other years: International Boundary and Water Commission (IBWC). 1956-61, 1987-92. Flow of the Rio Grande and Related Data: 1955-60, 1986-91, Water Bulletin Numbers 25-30, 56-61 (El Paso: IBWC, U.S.Section).

Table 14. Average Monthly Runoff* and Channel Losses in the Rio Grande between Presidio and Castolon, Texas

RIVER MILE**	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SET	OCT	NOV	DEC	SUM
963.7	8245	5781	5097	5040	6075	7182	8633	11523	13567	14695	8390	8239	102467
961.4	35940	33278	38725	36690	39450	51049	60166	114490	177858	118364	41355	28961	776326
950.1	99	178	123	244	621	1761	2625	2712	5117	1660	179	123	15442
sum	44284	39237	43945	41974	46146	59992	71424	128725	196542	134719	49924	37323	894235
949.8	39844	35710	42734	36060	42426	54149	74277	134289	197673	145848	50638	39291	892939
loss/gain between 963.7 & 949.8	-4440	-3527	-1211	-5914	-3720	-5843	2853	5564	1131	11129	714	1968	-1296
885.2	191	283	220	1434	2970	6148	8356	9863	10949	4735	595	246	45990
sum 949.8+ 885.2	40035	35993	42954	37494	45396	60297	82633	144152	208622	150583	51233	39537	938929
862.4	39887	35327	41300	34381	45765	59623	80610	137609	203088	164418	52959	40520	935487
loss/gain between 949.8 & 862.4	-148	-666	-1654	-3113	369	-674	-2023	-6543	-5534	13835	1726	983	-3442

*Source: Saunders, G. P. 1987. Analysis of Streamflow of the Rio Grande: Big Bend National Park, Texas. Interim Research Report No. 2. Submitted to Office of Resource Management, Big Bend National Park, TX. 24 pp. plus app. and map.

**Refer to Table 12 for IBWC gaging station locations corresponding to river mileages in this table.

For the month of October, for the same river reach (RM 963.7 to 862.4), the river exhibits a net increase in flow of 24,964 ac-ft, or an 17.9% gain. Table 14 shows some interesting and obvious patterns. During low flow periods, the net changes in flow are negative, indicating net losses in the reaches due to channel losses and legal and illegal diversions. During the months of July, August, and September, net gains result from contributions of Alamito, Terlingua, and other ungaged washes. The mean annual values calculated from the water budget of mean monthly flows (last column in Table 14) show a net loss of 0.5% between RM 963.7 and 862.4. The water budget mean annual flow at RM 862.4 (Johnson Ranch near Castolon) is 935,487 ac-ft.

The mean annual flow of the Rio Grande at Johnson Ranch near Castolon is calculated as follows:

Rio Grande above Rio Conchos (RM 963.7)
102,467 ac-ft (= **10.9%)**

Rio Conchos (RM 961.4)
776,326 **ac-ft** (= **82.6%)**

Alamito Creek (RM 950.1)
15,442 ac-ft (= **1.6%)**

Terlingua Creek (RM 885.2)
45,990 ac-ft (= **4.9%) Total**
= **940,225** ac-ft (= **100%)**

(channel loss from RM 963.7 to 949.8) -
1296 ac-ft

(channel loss from RM 949.8 to 864.2) -
3442 ac-ft
Total = **935,487 ac-ft**

Thus, the 4738 ac-ft lost before RM 862.4 comprise 0.5% of the flow measured at RM 862.4. The water budget mean annual flow at RM 657.5 (Foster Ranch at Langtry) is 1,202,348, indicating a net annual gain of 266,861 ac-ft. This gain derives primarily from flood flow contributions from ungaged watersheds.

In an effort to detect any effect that the construction of Luis Leon Dam in 1968 might have had on the mean monthly flows of the Rio Conchos, the flow records were divided into periods of 1955-1968 and 1969-1991, and the average monthly flows calculated for each period.

Figure 13 shows the resulting graphs. The average monthly flows are greater for the period after 1968. This finding, however, could merely reflect the fact that the flows since 1968 have been greater than for the preceding period. No definite conclusion should be drawn from this analysis. One can only reiterate that the dams on the Rio Conchos watershed appear to have, in general, a minimal effect on the flows of the Rio Conchos at Ojinaga, except during extended periods of drought.

Figure 14 shows flood frequency (derived through Log Pearson Type III flood frequency analysis) and notable floods for the two mainstem gaging stations, Rio Grande below Rio Conchos near Presidio (RM 949.8) and Rio Grande at Johnson Ranch near Castolon (RM 862.4). Figure 15 shows the same type of information for the major tributary stations: Rio Conchos near Ojinaga (RM 961.4), Alamito Creek near Presidio (RM 950.1), and Terlingua Creek at Terlingua (RM 885.2). The reader should note that these studies are preliminary and should be used as general indicators.

Flow-Related Transboundary Issues

The natural flow conditions found in the RioGrande and its principal tributaries have been greatly altered due to the development of many significant storage and irrigation projects upstream of Big Bend National Park. Management of this flow is the responsibility of the Rio Grande Compact Commission and the U.S. Bureau of Reclamation. Flows in the Rio Grande between Elephant Butte Dam and the confluence with the Rio Conchos are affected by both storage and release schedules of the dam as well as by irrigation for agriculture between the dam and the park. Currently, most of the water flowing in the Rio Grande at Big Bend National Park derives from the Rio Conchos.

Those who live or operate facilities along the Rio Grande are unavoidably subject to periods of drought and floods for two reasons: first, because arid and semiarid regions commonly exhibit highly variable rainfall and runoff rates and volumes, and secondly, because the existing storage and flood control structures on the river system are not designed for controlling the waters in extreme events. More specifically, of all the storage and flood-control

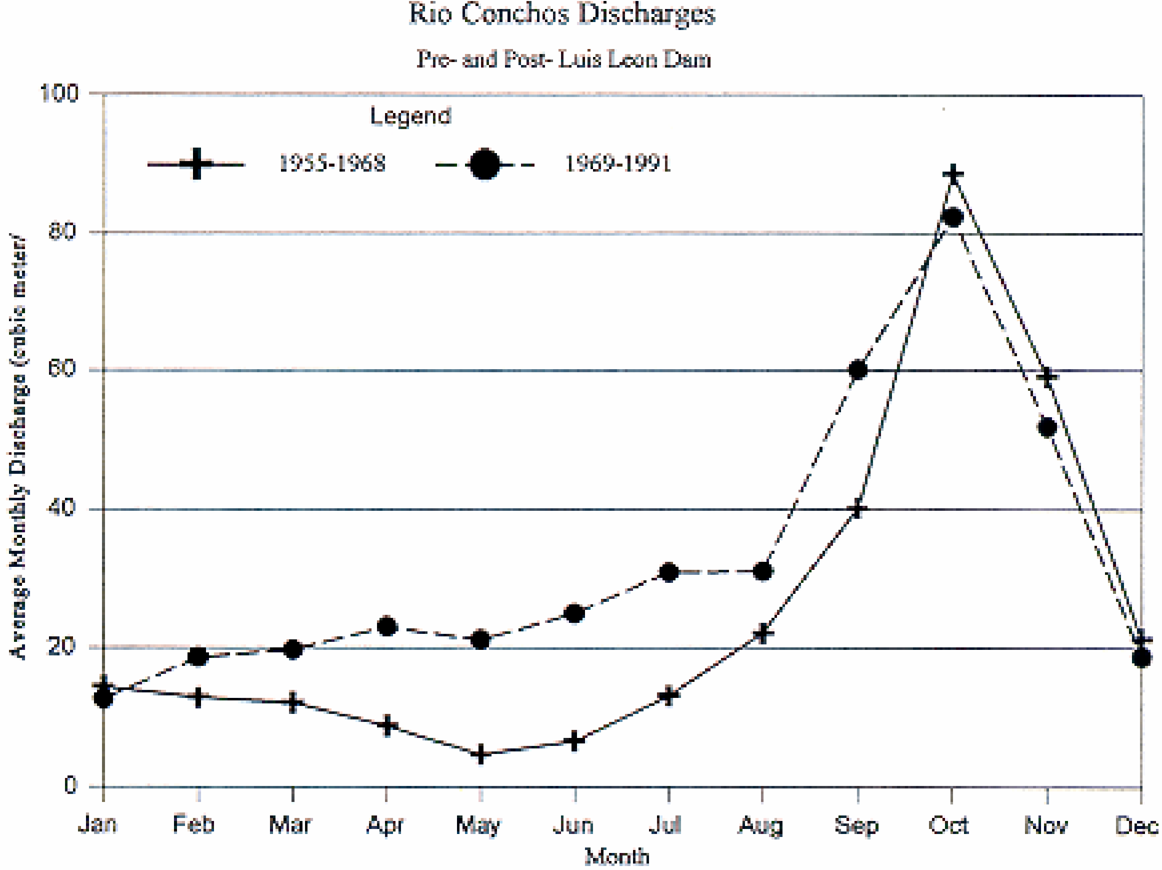


FIGURE 13. International Boundary and Water Commission Gaging Station on Rio Conchos near Ojinaga (near Rio Grande River Mile 961.4)

structures on the Rio Conchos, which is the source of almost all the flow reaching Big Bend National Park, only the Luis Leon Dam has control gates (see Table 11 and Figure 10).

Because the Rio Conchos supplies most of the flow in the Rio Grande at the park, the potential for large flood events in Big Bend National Park stems from precipitation in the Rio Conchos watershed. A very rare event could occur when extreme floods from Rio Conchos and either Alamito Creek or Terlingua Creek could arrive at Castolon at the same time, but the likelihood of such an event would be extremely small (refer to Project Statement BIBE-N-553.001).

The natural flow of the Mexican tributaries is such that a substantial proportion of the flow required from Mexico by the 1944 United States-Mexico Treaty derives from the Rio Conchos and, thus, is available for use in the reach adjoining the park. In keeping with National Park Service Management Policies (NPS, 1988), the National Park Service generally seeks to preserve natural flow variability, recognizing that aquatic and riparian ecosystems have evolved in harmony with this variability.

On the other hand, during periodic extreme droughts within the Rio Conchos watershed, flow to the Rio Grande is much reduced due to the need to store available water for use in Mexico. During these periods, flow reaching the park may be inadequate to support recreation such as river rafting, and the reduced flow may negatively impact indigenous aquatic and riparian species. Thus, it is recognized that there is a need for Big Bend National Park to develop a cooperative strategy for dealing with the irregular flow conditions typical of the modern Rio Grande within Big Bend National Park. This need is further addressed in Project Statement BIBE-N-557.001.

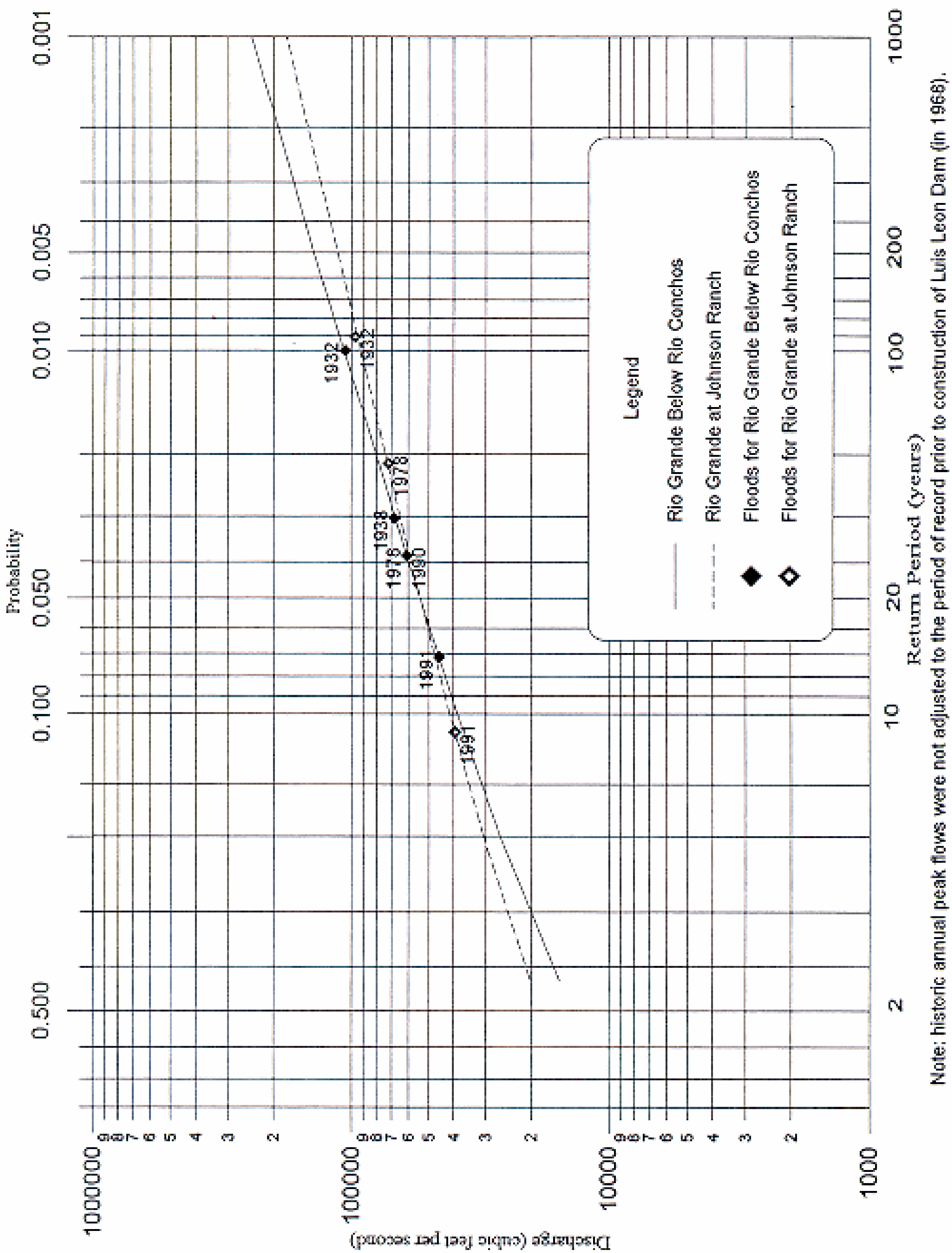
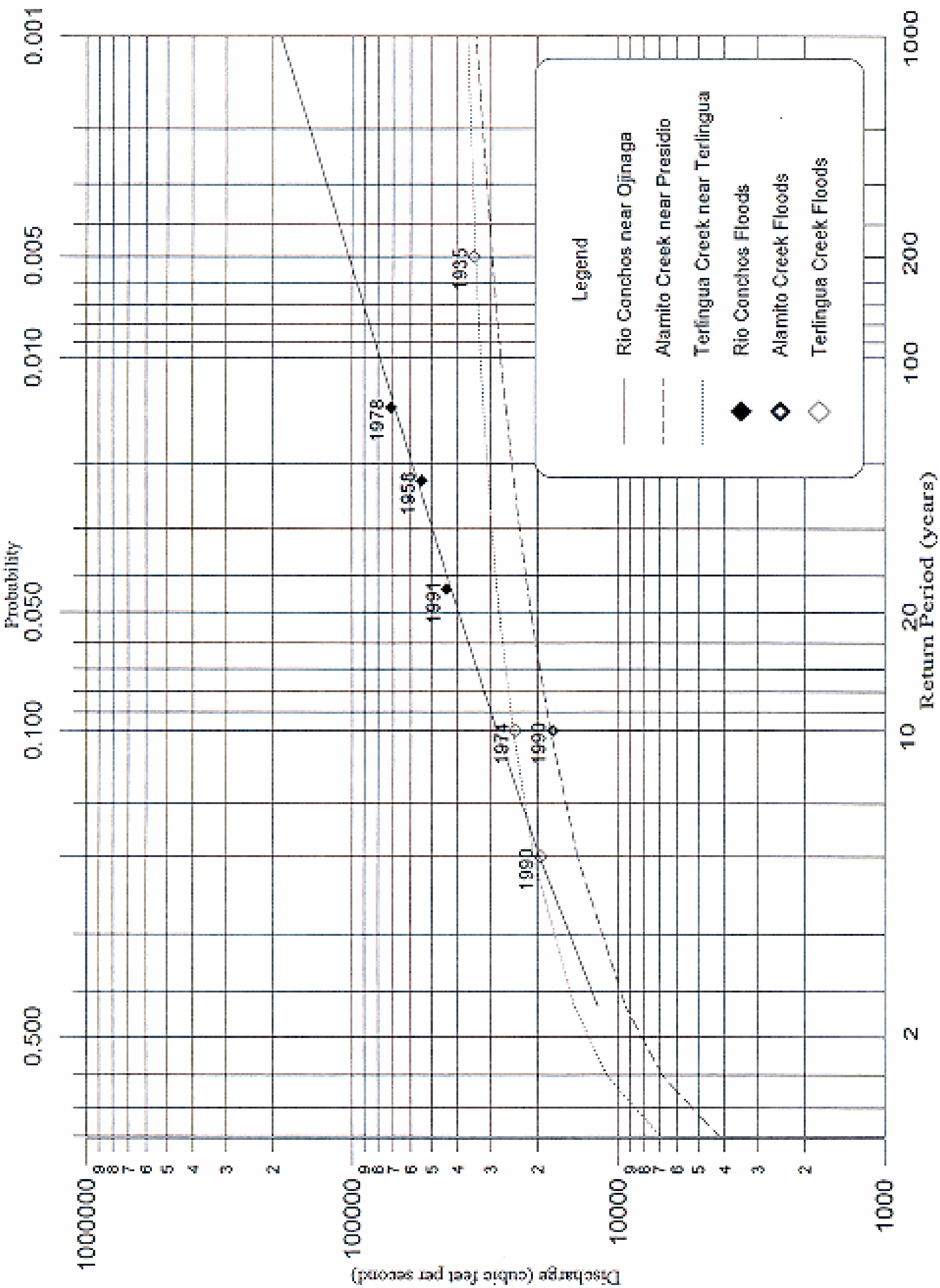


FIGURE 14. Flood Frequency Curves for Rio Grande Stations in Study Area



Note: IBWC (1996, pers. comm.) reports 100-year flood magnitudes for Rio Conchos near Ojinaga and for Alamito Creek near Presidio as 72,000 and 38,700 cfs, respectively.

FIGURE 15. Flood Frequency Curves for Three Major Tributaries to the Rio Grande

Recommendations. The following recommendations (see Project Statement BIBE-N-551.001) provide guidance for coping with unusually low flows:

- Distribute periodic information leaflets (or include in park literature) to raft operators, individual boat owners and other interested park visitors, warning that occasional low-flow periods are possible and citing the historical flow record as to their frequency and severity.
- Post signs at launching locations as a reminder to park users of the above conditions, and providing information on potential water quality problems at various thresholds of low flow.
- Establish and maintain liaison with the International Boundary and Water Commission (IBWC), such that during times of imminent drought or **serious** low-flow conditions, the IBWC can seek the Mexican operators' cooperation in maintaining minimal flows required to sustain aquatic and riparian ecosystems in the park, while satisfying the needs and operating rules of the Mexican water users on the Rio Conchos.

Flood Plain Management Issues

Risks associated with flooding represent a significant natural hazard in Big Bend National Park to visitors, staff, and infrastructure. Flash floods in tributaries often result from small intense rainstorms and, as such, can happen suddenly and without warning. Flash floods represent considerable hazard at low-water road crossings, campgrounds, and potentially to hikers crossing and hiking along arroyos. Floods in the Rio Grande itself typically occur as a result of longer term rainfall events covering areas of the U.S. and/or Mexico. High flows in the main river threaten boaters and buildings and other park facilities located in or along the river corridor. However, Rio Grande flooding on overbank areas presents less hazard to visitors, in general, than flashy tributaries because of the more advanced warning that is generally available with large scale storms and related flooding.

The National Park Service manages use of floodplains in accordance with Executive Order 11988 as presented in the National Park Service Floodplain Management Guideline (NPS, 1993). In summary, National Park Service floodplain policy is to restore and preserve natural floodplain values, avoid environmental impacts associated with use of floodplains wherever there is a practical alternative, and minimize risk to life and property utilizing nonstructural methods when possible. The Guideline permits use of the regulatory floodplain under certain conditions provided adequate mitigation is employed and a Statement of Findings is developed explaining the special circumstances and rationale for the decision to use the regulatory floodplain. The regulatory floodplain is determined on a site-specific basis and is defined in the Guideline as the "Extreme Floodplain" in areas subject to flash flooding, the 500-year floodplain in non-high hazard areas when critical actions (as defined in the Guideline) are involved, and the 100-year floodplain in all other situations. A greater discussion of the Guideline is beyond the scope of this report and the reader is referred to the Guideline, itself, for a complete description of protocols for floodplain management in National Park Service areas.

The pertinent regulatory floodplains to identify and use as the basis for management decisions at Big Bend National Park are the Extreme Floodplain for facilities near flashy tributaries, the 100-year floodplain for most activities in the Rio Grande corridor, and the 500-year floodplain for critical actions located in the river corridor. At present, no floodplains have been precisely delineated in Big Bend National Park and few studies of site-specific flood hazard have been completed. The Terlingua Abaja Campground along Terlingua Creek and the housing area in Panther Junction have been the subject of National Park Service Water Resources Division studies (Smillie and Martin, 1991; Martin, 1995), but no other studies are known to have been done. The cost associated with development of flood boundaries or other types of flood hazard determination for all developed locations in the park is prohibitive and probably not necessary. Therefore, a strategy is needed to provide a scheme by which it can be determined which areas should be the subject of flood hazard analysis. The following list outlines priorities for investigating flood hazard in the park that would prevent addition of new flood-related problems associated with new activities and emphasizes development of hazard information at existing facilities with greatest risk to humans.

- All new park facilities subject to the Guideline and potentially located in the regulatory floodplain of any stream or arroyo shall have a floodplain analysis performed by a qualified hydrologist or engineer.

- Existing facilities that present the greatest risk to humans will have high priority for flood hazard determination. Since flash flooding is considered the most significant hazard to humans, in general, facilities, especially overnight facilities, along tributaries should have highest priority.

- Overnight facilities and functions involving critical actions (as defined in the Guideline) along the Rio Grande should be the next highest priority.

Figure 14 shows flood frequency and notable floods for the two mainstem gaging stations, Rio Grande below Rio Conchos near Presidio (RM 949.8) and Rio Grande at Johnson Ranch near Castolon (RM 862.4). Figure 15 shows the same type of information for the major tributary stations: Rio Conchos near Ojinaga (RM 961.4), Alamito Creek near Presidio (RM 950.1), and Terlingua Creek at Terlingua (RM 885.2). In the interest of protecting public safety in Big Bend National Park, park officials should focus on the frequency distribution of the actual peak discharges at Castolon to plan some defensive measures. According to preliminary studies described in this report, the 100-year flow at Castolon has a peak discharge of 92,400 cubic feet per second. In lieu of more detailed studies, flood frequency data for Terlingua Creek and the Rio Grande at Castolon could be reasonably used to initiate flood plain mapping along both rivers.

Preliminary flood plain maps were prepared for this report (Figures 16, 17, 18, and 19). These maps were digitized into a Geographic Information System (GIS) and provided to Park Service personnel in digital format for inclusion in their GIS. The series of ortho-photo quadrangles prepared by the International Boundary and Water Commission from 1982 aerial photographs constituted the source of the digitized information. From the aerial photographs, only the active channel and the extent of historic flow can be determined. Detailed surveys of the reaches of concern will be required to delineate the various flood boundaries *(eg,* the areal coverage of the 100-year flood). Although such surveys can locate flood boundaries with reasonable accuracy, the accuracy depends heavily on the conditions existing at the time of the survey. Increases in vegetation, both in extent and density, can dramatically reduce the carrying capacity of the floodway and raise the level of the flood peak to inundate areas thought to be beyond a particular flood boundary. For this reason, floodplain conditions must be monitored after such a survey in order to trigger a resurvey or some other action when conditions affecting the carrying capacity of the river change significantly.

Recommendations. Project Statements BIBE-N-551.001, BIBE-N-552.001, BIBE-N-553.001, and BIBE-N-564.001 will provide useful information on how the Park Service can provide visitors and commercial river users advisories on extreme flow hazards. The following recommendations (also included in Project Statement BIBE-N-557.001) apply to preparation for high flows on the Rio Grande:

- Distribute periodic information leaflets to all park visitors (or include it in key park literature) warning of occasional flood flows and citing historical examples of such events.

- Post signs at campgrounds and other low-lying use areas as a reminder of such conditions.

- Survey floodplain zones in critical areas such as campgrounds. In 1991, Michael Martin of the National Park Service made such an evaluation for a site near the mouth of Terlingua Creek (Martin, 1991). Martin (1995) also completed a similar report for a housing area in Panther Junction in 1995. Project Statement BIBE-N-553.001 addresses this recommendation.

- Based on the results of the floodplain surveys, evaluate the need for, and feasibility of, taking nonstructural and low-cost structural measures to protect vulnerable areas *(eg,* campgrounds). Such measures may include bank protection, low levee upgrading, and/or site elevation in flood-prone areas. In keeping with the studies by Martin (1991 and 1995) each site must be individually evaluated for flood hazard based on its unique set of hydrologic conditions.

- Maintain communication with, or monitor broadcasts of, National Weather Service weather and flood hydrology conditions relative to Amistad Dam, and use this early-warning system to set in motion a set of prescribed precautions to be taken by park personnel.

- Train key park personnel in procedures to be taken in the event of imminent flood-flow conditions in the park.

Establish and maintain liaison with the International Boundary and Water Commission (IBWC), such that during times of imminent flood-flow conditions, the IBWC can seek the Mexican operators' cooperation in mitigating flows in the park area, to the extent possible within the structural capabilities and operating criteria along the Rio Conchos, so as to provide the most advanced flood warnings possible to visitors and residents along the river.

In addition to the actions listed above, the National Park Service should consider the following recommendations for improving the current level of understanding of flood wave propagation along the park boundary:

- Information should be compiled and analyzed to correlate water levels and corresponding discharges at the gaging stations Rio Grande below Rio Conchos near Presidio (RM 949.8), Terlingua Creek (RM 885.2), Rio Grande at Johnson Ranch at Castolon (RM 862.4), and the auxiliary staff gages at Castolon and Rio Grande Village campgrounds, and to determine the time of travel of the flood wave. Project Statement BIBE-N-552.001 addresses this recommendation.
- Studies should be undertaken to develop multiple-regression equations to estimate peak streamflow frequency for ungaged washes in Big Bend National Park. This exercise would permit better flood magnitude estimation for flash floods within the park, and thus provide park personnel with better flood warning capabilities with regard to ungaged streams within the park. Project Statement BIBE-N-564.001 addresses this recommendation.

Rio Grande Water Quality

The quality of the water in the Rio Grande affects many aspects of life and recreation in Big Bend National Park. The water supplies for residents and visitors of Castolon directly reflect the chemistry of the Rio Grande because of the immediate connection between the shallow ground water and the river systems there. Recreationists who come in direct contact with the waters of the Rio Grande should also be informed of the water quality conditions in the river for health reasons. Finally, faunal populations in and near the river may suffer immediate or long term effects from degenerating water quality conditions in the Rio Grande.

Existing Water Quality Information

The project team members have documented and reviewed available data and known information on water quality and contaminants along the Rio Grande from El Paso to La Linda, Texas. This 450-mile portion of the river includes the entire reach forming the southern boundary of Big Bend National Park (see Figure 1 in Ch. 1). This study includes the mainstem of the Rio Grande as well as tributary surface water sources.

Data Bases. Information on Rio Grande water quality, streamflow, and contiguous ground water features is contained in three principal computerized numerical data bases; in individual published reports which contain quantitative data collected for those particular investigations; and in other references, either published or unpublished, which deal with various aspects of river water quality, standards, use, or contamination. Sources of site-specific hydrologic and water quality information are listed in Appendix III.

The three primary computer data bases from which information on water quality were obtained are: (1) the U.S. EPA's STORET system; (2) the Texas Natural Resource Conservation Commission's Water Quality system database (which includes data submitted by the International Boundary and Water Commission); and (3) the U.S. Geological Survey's National Water Information System-1 (NWIS-1) database. STORET and NWIS-1 are both national databases. Several agencies, including the Texas Natural Resource Conservation Commission, contribute data to STORET and, although the EPA maintains the operation of the data storage system, any screening of the data is performed at the level of the contributing agency, and may therefore be of questionable integrity. The TNRCC screens water quality data before it enters the Texas Water Quality Data Base (Kolbe, 1996, TNRCC, pers. comm.) The U.S. Geological Survey screens all data entered into the NWIS-1 database, however, to ensure the quality of that system. In addition, the U.S. Geological Survey contributes water quality data processed from samples collected for the International Boundary and Water Commission to STORET. The degree of overlap in the various databases is not entirely

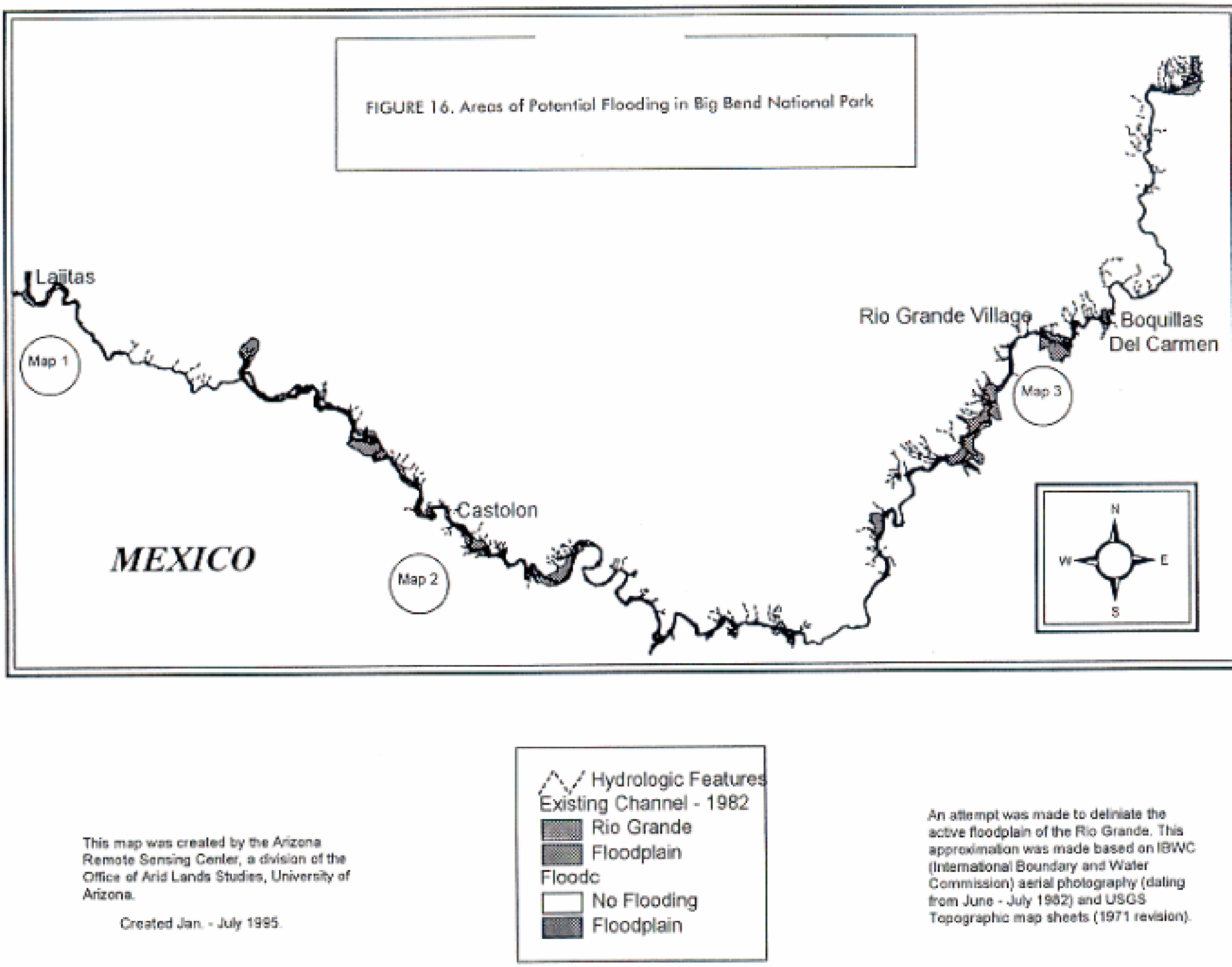


FIGURE 16. Areas of Potential Flooding in Big Bend National Park

This map was created by the Arizona Remote Sensing Center, a division of the Office of Arid Lands Studies, University of Arizona.

Created Jan. - July 1995.

An attempt was made to delinate the active floodplain of the Rio Grande. This approximation was made based on IBWC (International Boundary and Water Commission) aerial photography (dating from June - July 1982) and USGS Topographic map sheets (1971 revision).

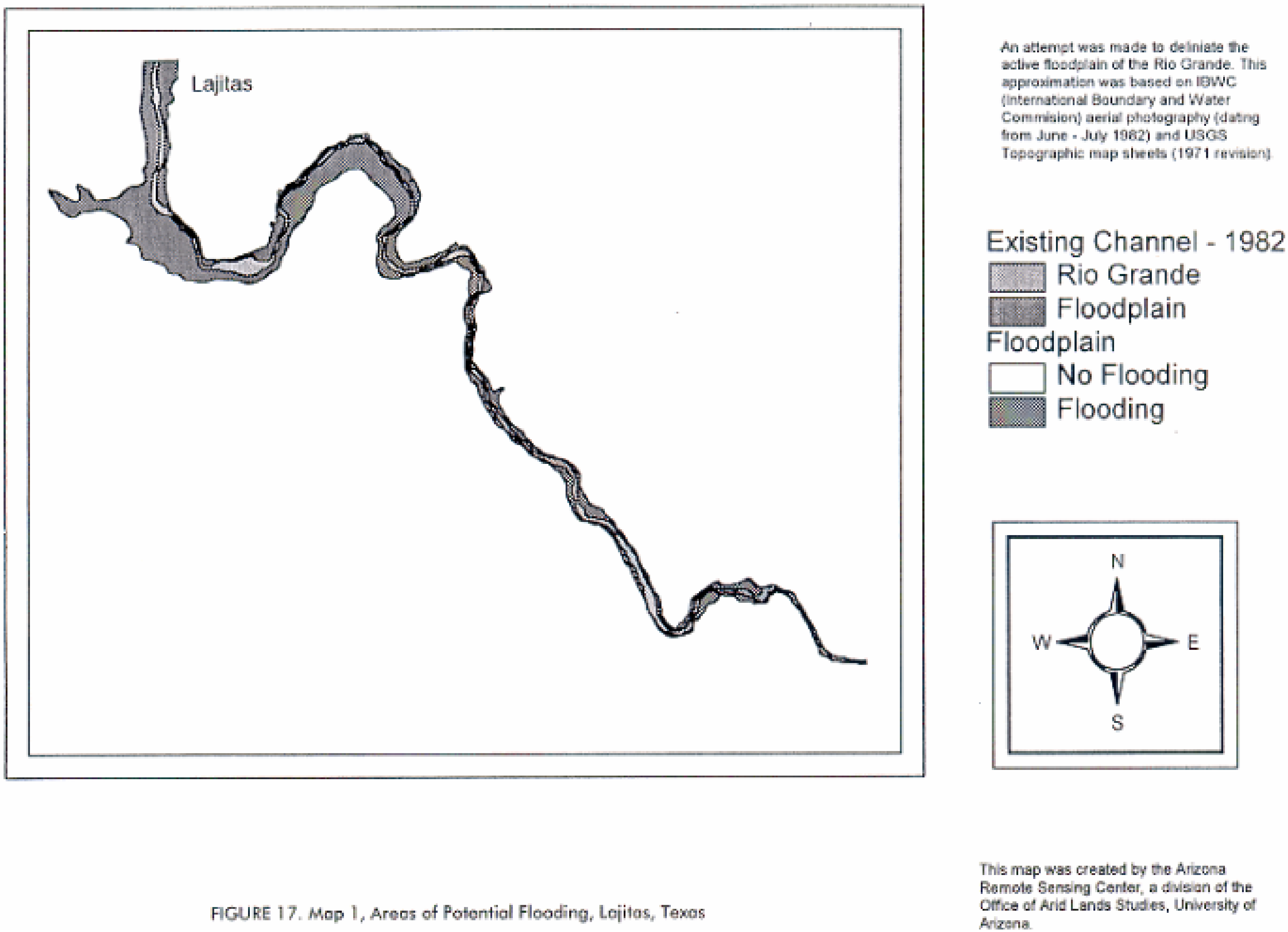


FIGURE 17. Map 1, Areas of Potential Flooding, Lajitas, Texas

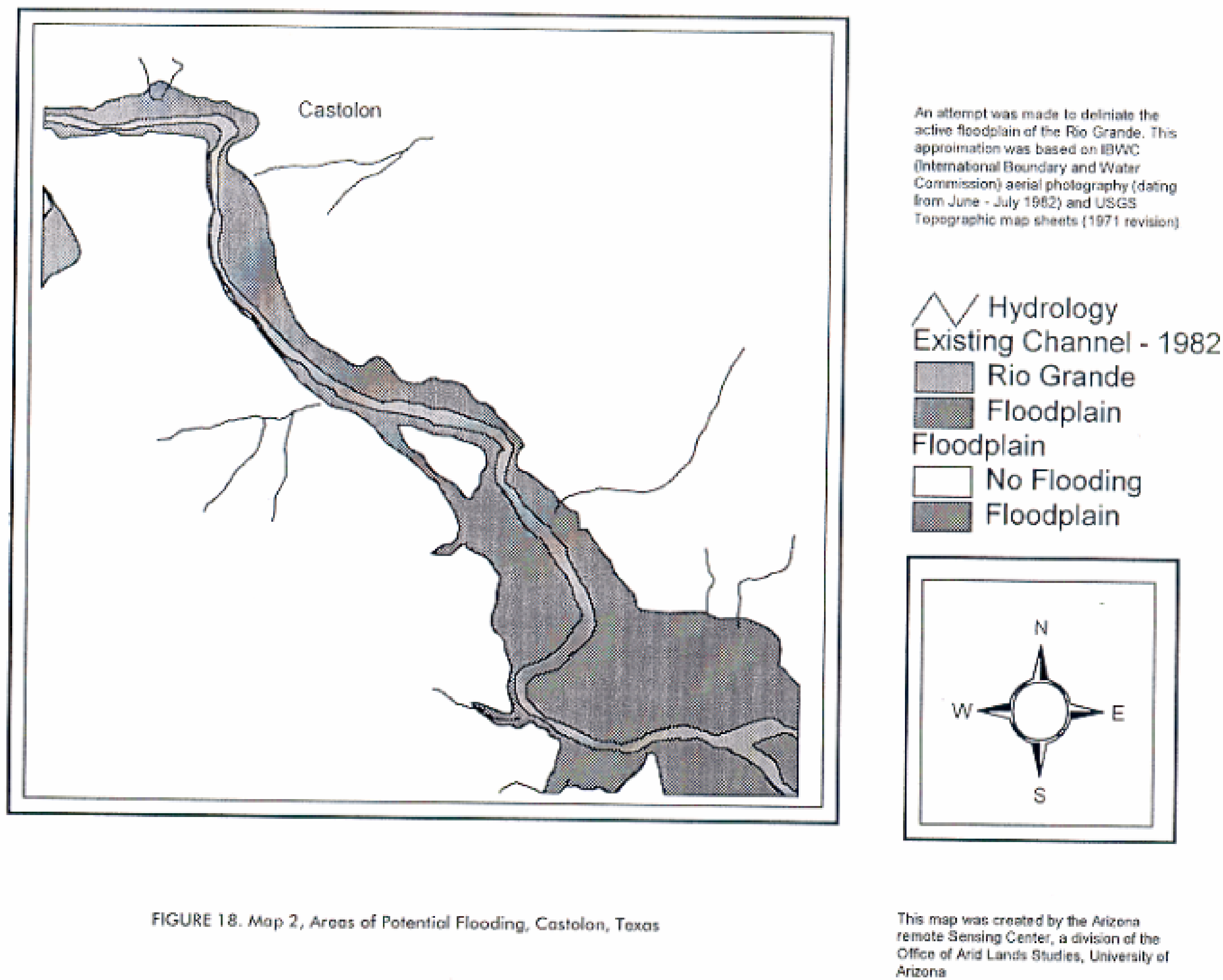
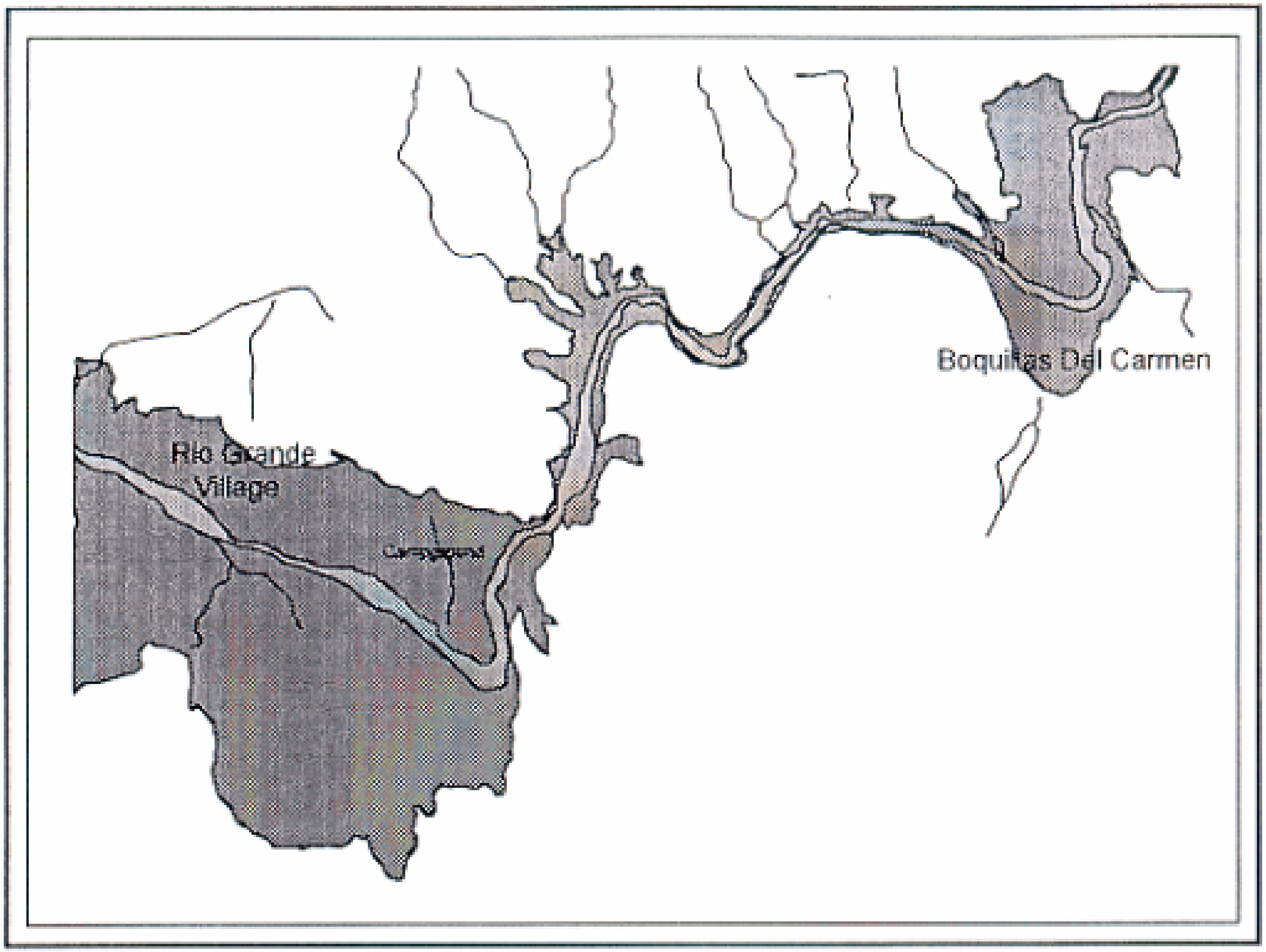


FIGURE 18. Map 2, Areas of Potential Flooding, Castolon, Texas



An attempt was made to delinate the active floodplain of the Rio Grande. This approximation was based on IBWC (International Boundary and Water Commission) aerial photography (dating from June - July 1982) and USGS Topographic map sheets (1971 revision).

Hydrologic Features
Existing Channel - 1982
Rio Grande Floodplain
Floodplain

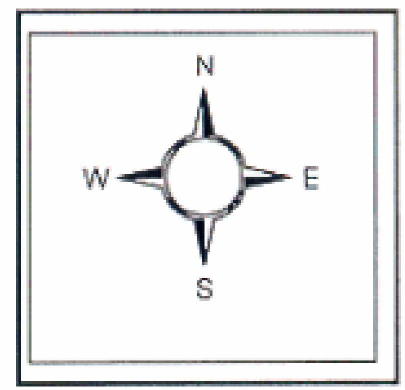


FIGURE 19. Map 3, Areas of Potential Flooding, Rio Grande Village, Texas

This map was created by the Arizona Remote Sensing Center, a division of the Office of Arid Lands Studies, University of Arizona.

discernable, but in general, information common to the various systems was found to be in reasonable agreement.

Additional Data. In addition to the three major computer databases noted above, many individual published reports, theses, dissertations, and other documents containing data for the reach of the Rio Grande covered in this study were reviewed. Although these studies generally do not provide an ongoing source of data, they do provide historical documentation of the water quality of the Rio Grande and its major tributaries and, therefore, are a valuable sources of information (see Appendix III).

One recently published report prepared jointly by both the United States and Mexico is of particular interest and importance. The study entitled "Binational Study Regarding the Presence of Toxic Substances in the Rio Grande/Rio Bravo and its Tributaries Along the Boundary Portion Between the United States and Mexico," began in 1992 and was completed in 1994. In addition to information on toxic chemical parameters, the study covers water quality data on ammonia, total organic carbon, total hardness, total suspended solids, total dissolved solids, chloride, sulfate, turbidity, pH, temperature, specific conductance, dissolved oxygen, and residual chlorine. The study also presents data on sediment particle size composition, total organic carbon, and acid volatile sulfide as well as on fish tissue tested for percent lipid content. Tests were made for 161 toxicants including priority pollutants as listed by U.S. Code of Federal Regulations except for dioxin and asbestos. Some 33 non-priority pollutants were also studied include: (1) 11 pesticides for which the State of Texas has established numerical criteria, (2) 19 compounds recommended for inclusion by the U.S. EPA, and (3) three additional compounds suggested in a study by Lewis, *et al* (1991).

The Rio Grande Toxic Substances study (IBWC, *et al*, 1994) noted that, within the area of interest for this study, the sampling sites in the mainstem of the Rio Grande with high potential for toxic chemical impacts were downstream from El Paso/Juarez, and those with slight to moderate potential were upstream from the Rio Conchos confluence near Presidio/Ojinaga. Tributaries which were found to have potential for toxic chemical impacts include El Paso Public Service Board Haskell Street Wastewater Treatment Plant (high), Ciudad Juarez Discharge Canal (high), and the Rio Conchos (slight to moderate).

The Texas Water Commission (1992) (now the Texas Natural Resource Conservation Commission) remarked that "*potential health risks from ingesting toxic substances in the water or fish of the Rio Grande are a major concern of residents in the basin,"* in its review of available toxic chemical data and potential instream aquatic toxicity for the 1992 assessment of water quality in the Rio Grande Basin. The segment-specific assessment section of that report presented a detailed discussion of these data and described historic impacts from pesticides derived from agricultural activities, primarily DDT and its metabolites. It also noted that recent sediment and water data indicate that such concentrations, and the corresponding possibility for adverse effects, are declining in the reach bordering Big Bend National Park.

A major evaluation of water quality for Big Bend National Park and vicinity was completed in 1995 by NPS-Horizon (1995). That analysis of STORET data covered some 18,551 observations for 300 parameters collected by U.S. EPA, U.S. Geological Survey, and the Texas Natural Resource Conservation Commission at 29 monitoring stations. The report and data are available on computer disk. Remarks on their findings are noted below in the section entitled "Evaluation of Surface Water Quality Conditions."

The Laboratory for Environmental Biology at the University of Texas at El Paso recently conducted another study (Carranza, *et al*, 1994). This preliminary study included invertebrate sampling and examined chemical and fecal coliform concentrations within the Rio Grande River in Big Bend National Park. Overall, the authors found that water quality of the river improved as it moved downstream within the park. They warned, however, that coliform contamination levels may threaten the river's suitability for both potability and contact sports. Carranza, *et al* (1994) expressed particular concern about the quality of water from Terlingua Creek. As discussed below, these concerns appear to be supported by results from NPS-Horizon (1995) and other data sources.

Current Water Quality Monitoring Programs Along the Rio Grande Adjoining the Park

The Texas Natural Resource Conservation Commission (TNRCC) and the U.S. Section of the International Boundary and Water Commission, participate in a cooperative surface water quality monitoring program for the Rio Grande. The result is that some mainstem stations are monitored monthly by the two agencies. Routine field measurements, flow measurements, and water chemistry analyses are conducted. Figure 20 shows the locations of these active sampling sites.

The first Binational Study on Toxic Substances in the Rio Grande and its Tributaries (IBWC, *et al,* 1994) resulted directly from the Integrated Environmental Plan for the Mexican-U.S. Border Area (First Stage, 1992-1994) (see Chapter 2 for details on this plan). In November of 1994, the International Boundary and Water Commission convened a binational technical meeting of responsible agencies (U.S. EPA, TNRCC, Comision National del Agua) in the U.S. and Mexico in El Paso, Texas to plan a second phase of the joint program. The group recommended that Phase II sampling and analysis be conducted at 32 of the Phase I sample stations, "excluding those which showed a low potential for toxic impact," and at 16 new stations not covered in Phase I. They also recommended that the parameters for the Phase II joint program be the same as those analyzed for during Phase I. These parameters include 153 toxic chemicals in water, 145 in sediment, and 140 in fish tissue; toxicity of water and sediment to aquatic organisms; and bioassessment of fish (IBWC, 1995). Sampling for Phase II was completed in December 1995. Table 15 lists the Phase II sampling stations (and compartmental coverage) between El Paso and Langtry, Texas. Stations not sampled during Phase I of the study are indicated with an "(N)" next to the station number.

The El Paso Water Utilities Board collect and analyze samples from several sites near El Paso. Their monitoring program is conducted to ensure that the quality of raw water supply from the Rio Grande is protected.

Several active citizen volunteer groups and/or individuals presently monitor water quality in the Rio Grande. Within the study area, one active volunteer monitoring program coordinates with Texas Watch and two active school related monitoring programs in place. The Texas Watch program is an invaluable adjunct to the Texas Natural Resource Conservation Commission monitoring network. Texas Watch contributes to volunteer monitoring efforts by providing technical training and support to the River Watch Network, a national volunteer monitoring program. A local group, self-named "Big Bend River Watchers," has organized to collect and analyze water samples on a quarterly basis from nine sites extending from Rio Grande Village to a point above the Rio Conchos confluence.

The Laboratory for Environmental Biology at The University of Texas at El Paso (UTEP) has conducted a series of water quality tests at ten sites along the Rio Grande in the vicinity of Big Bend National Park. Parameters tested in 1993 are noted in Appendix III, and results of the analysis are presented in a report by Carranza, *et al* (1994). That report noted an exceedingly high density of fecal coliforms at several locations.

Another school-sponsored environmental monitoring project in the Rio Grande Basin is Project del Rio. This program started in 1991 as a water quality project involving high school students in the United States and Mexico. Students from both sides of the border conduct field tests of water quality from the Rio Grande. Results are shared by computer network and the students collectively develop a water quality profile. The project culminates each year in a Student Congress at which students, teachers, and water resource professionals gather to discuss and respond to water issues. In 1991, a total of 12 high schools (seven in the United States and five in Mexico) participated (TWC, 1992; L. Laroque, Project Del Rio, pers. comm., 1994). Project del Rio is provided funds, equipment, and administrative support by numerous corporations and associations, both public and private, on both sides of the border.

Influences on Water Quality in the Rio Grande

Water quality in the Rio Grande between El Paso and La Linda, Texas is controlled by runoff from natural tributaries and overland flow, return flows from waters diverted for particular uses such as irrigation or industrial cooling, and by direct discharges of wastewater into the river. Pollution sources generally fall into the latter two categories, and these can be divided into "point" sources and "nonpoint" sources based on their origin and character.

Point Sources of Pollution.

***Wastewater** in Texas.* Direct wastewater discharges constitute the most common type of point source pollution in the Rio Grande between El Paso and La Linda. Under the authority of the Clean Water Act (see Chapter 2), the Texas Natural Resource Conservation

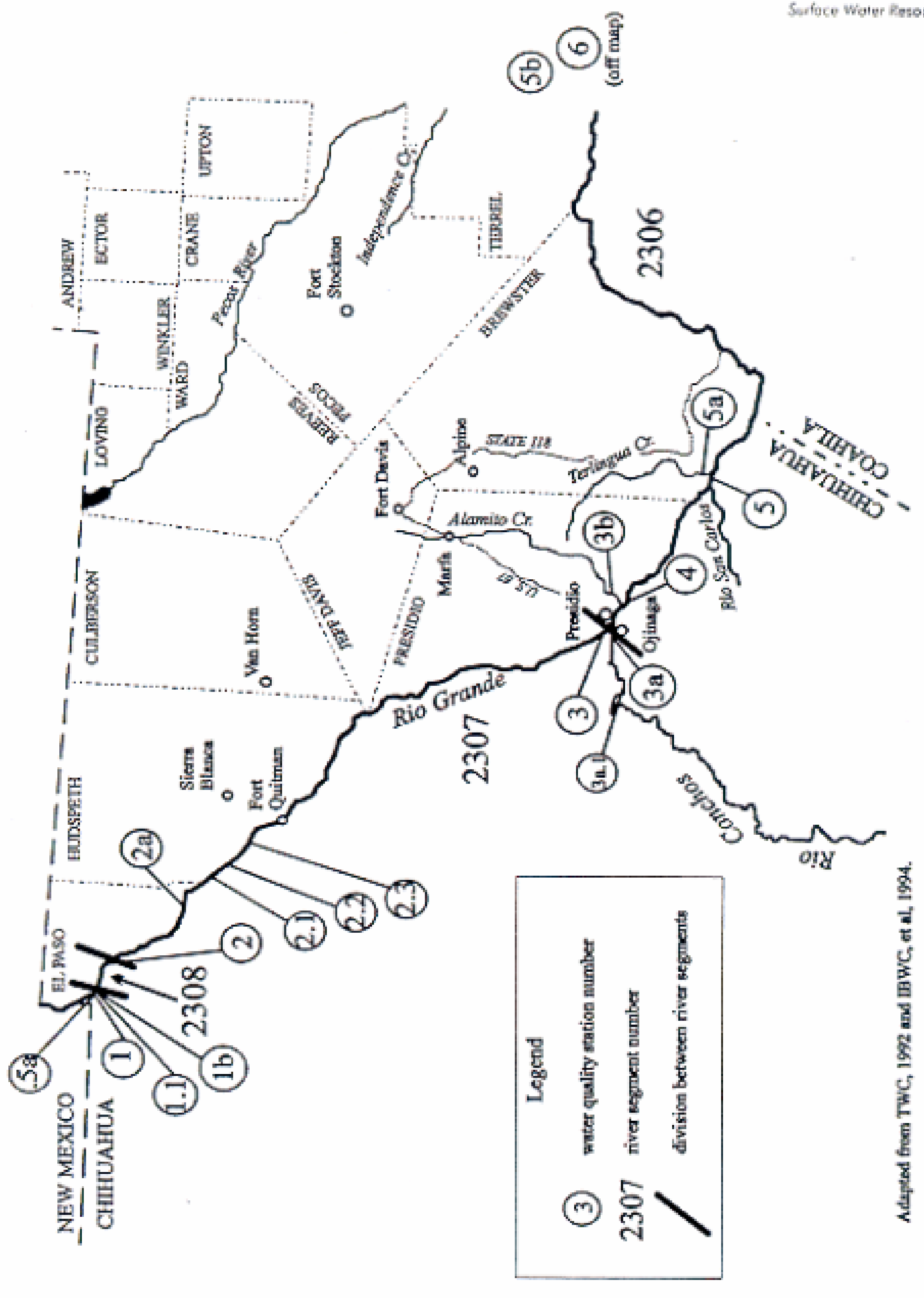


FIGURE 20. Sampling Sites In Phase I of the Toxic Substances Study

Table 15. Sampling Sites and Compartmental Coverage Planned for Phase II of the Binational Toxic Substances Study*

Station Description	Station No.	River Mile	Toxic Chemicals in Water	Toxic Chemicals in Sediment	Toxic Chemicals in Fish Tissue	Toxicity Testing Water & Sediment	Bio-assessment
Montoya Drain 0.4 km upstream from mouth	0.5a (N)		X	X		X	
Rio Grande/Rio Bravo at Courchesne Bridge in El Paso, 2.7 km upstream of Amer. Dam	1	1256	X	X	X	X	X
Rio Grande/Rio Bravo upstream from El Paso Haskell Street WWTP	1.1 (N)		X	X		X	
El Paso Haskell Street WWTP discharge	1a		X			X	
Rio Grande/Rio Bravo at Zaragosa International Bridge in El Paso/Ciudad Juarez	2	1238	X	X	X	X	X
Ciudad Juarez wastewater discharge canal, 2 km NE of Colonia Esperanza, Chih., Mex.	2a		X	X		X	
Rio Grande/Rio Bravo at Fort Hancock/Porvenir, approx. 2.5 km upstream of Int. Bridge	2.1 (N)		(salinity only)				
Rio Grande/Rio Bravo at Fort Hancock/Porvenir International Bridge	2.2 (N)		(salinity only)				
Rio Grande/Rio Bravo approximately 2.5 km downstream of International Bridge	2.3 (N)		(salinity only)				
Rio Grande Rio Bravo 5 km upstream from Rio Conchos confluence nr. Presidio, TX	3	964	X	X	X	X	X
Rio Conchos 0.2 km upstream from mouth	3a		X	X	X	X	X
Rio Conchos 20-25 km upstream from mouth	3a.1 (N)		X	X	X	X	X
Rio Grande/Rio Bravo 14.4 km downstream of Presidio/Ojinaga International Bridge	4	950	X	X	X	X	
Rio Grande/Rio Bravo at mouth of Santa Elena Canyon in Big Bend National Park	5	885	X	X	X	X	X
Terlingua Creek 0.2 km upstream of mouth'	5a		X	X	X	X	X
Rio Grande/Rio Bravo downstream from mouth of Lozier Canyon**	5b (N)	660	X	X	X	X	X
Rio Grande/Rio Bravo at Foster Ranch near Langtry	6	657	(salinity only)				

*Adapted from Table 1of International Boundary and Water Commission, United States and México. 1995. Joint Report of the Principal Engineers Relative to the Second Phase of the Program to Observe for the Presence of Toxic Substances in the Rio Grande/Rio Bravo in its International Reach. May 12. 5 pp. plus fig. and tables. (N) indicates station not sampled in Phase I of Toxics Substances Study.
'dry at time of sampling
**omitted during sample collection

Commission seeks to support Texas Surface Water Quality Standards and to protect designated uses for water bodies through its wastewater permit program. This program regulates all discharges of wastewater to state waters.

The wastewater permits issued to domestic and industrial dischargers restrict the quantity and quality of their effluent in terms of daily flow, daily loading of pollutants and maximum contaminant concentrations. Permittees that discharge directly into surface waters of the state must submit monthly effluent reports based on self-monitoring analyses (TNRCC, I994a). Table 16 provides the most recent published information on permittees for municipal and industrial discharges into the Rio Grande, including effluent limits and recent compliance history (TNRCC, 1994a).

Wastewater in Mexico. The *Secretaria de Agricultura y Recursos Hidrdulicos* (SARH), a federal agency, has primary control over point source water pollution in Mexico (Eaton and Andersen, 1987). A 1971 amendment to the Mexican Constitution *(Ley Federal para Preveniry Controlar to Contamination Ambiental,* Ch. 3, Articles 14-22) granted SARH the authority to regulate the quality of effluent discharges and the construction of municipal wastewater treatment facilities. Although local governments manage and construct wastewater treatment facilities, state offices play only a "minor cooperative role in control and enforcement activities" (Eaton and Andersen, 1987).

Under its constitutional authority, SARH enacted a set of regulations *(Reglamento para la Prevention y Control de la Contamination del Agua)* requiring all public or private establishments to a) register the wastewater emissions and characteristics with SARH, b) comply with effluent standards, and c) present plans for the control of settleable solids, oil, grease, temperature, and pH (Eaton and Andersen, 1987). SARH also coordinates registration of point discharges with the *Secretaria de Salubridad y Asistencia* (SSA). Dischargers are given three years after registration with SARH to comply with the terms of their permit, either through joint treatment with other industries and municipalities or with other suitable means of treatment (Eaton and Andersen, 1987). Unfortunately, a combination of heavy financial burdens, a shortage of skilled personnel within SARH and SSA, and a centralized system of water pollution control all force the border areas into competition with other regions of Mexico for funds and attention. Consequently, SARH, SSA, and other branches of the Mexican government are largely unable to enforce their regulations (Eaton and Anderson, 1987).

Felipe Ochoa and Associates (1978, cf. Eaton and Andersen, 1987) conducted a study on the municipal and industrial wastewater treatment facilities in Mexico for the *Secretaria de Agricultura y Recursos Hidrdulicos* in 1978. While the 1978 SARH study includes data on the actual quality of effluent, the point of discharge, types of treatment used, and percentage of population served, current data on municipal and industrial wastewater treatment facilities were not available (Eaton and Andersen, 1987). Eaton and Andersen (1987) were able to obtain information of twelve municipal wastewater treatment facilities along the Mexican side of the Rio Grande between Ciudad Juarez and the Gulf of Mexico. Of those, seven discharged directly to the Rio Grande, its tributaries, or connected irrigation drains, and five provide no treatment. According to a 1980 Mexican government census (Mexico, District Federale, 1980), 43.2% of all homes in the state of Chihuahua had no public drainage or septic tanks, compared with 43.6% in Coahuila, and 49.5% in Tamaulipas. 1970 census values for several cities indicate a higher rate of inadequate sewerage among rural homes than those in urban areas (Eaton and Andersen, 1987).

The same 1978 SARH study (Felipe Ochoa and Associates, 1978, cf. Eaton and Andersen, 1987) lists wastewater treatment facilities for eight major industries along the Texas,/Mexico border. Two of these eight provide primary treatment, four provide no treatment, and two do not describe their treatment processes. Four of the facilities discharge to the Rio Grande or its tributaries and two discharge for irrigation (Felipe Ochoa and Associates, 1978, cf. Eaton and Andersen, 1987).

Storage Tanks. Storage tanks containing petroleum or other substances with potential to pollute the environment constitute another type of point source pollution. In Texas, the Texas Natural Resource Conservation Commission (TNRCC) regulates the activities associated with such storage tanks. While the TNRCC has identified thousands of leaking or abandoned tanks in the Rio Grande Basin, neither the Texas Water Commission's 1992 report nor the TNRCC's 1994 report on Water Quality in the Rio Grande Basin assessed the impacts of underground and petroleum storage tanks (TWC, 1992; TNRCC, 1994a). Big Bend National Park

Table 16. Permitted Municipal and Industrial Discharges Into the Rio Grande/Rio Bravo del Norte[1]

Seg-ment	Permittee and Permit Number	Permitted Levels[a]						% Time Substantially Noncompliant[b]	Enforcement Action[c]
		Flow (MGD)	BOD_5 (lbs/d)	CBOD (lbs/d)	TSS (lbs/d)	NH_3-N (lbs/d)	DO (mg/l)		
2308	El Paso Water Util Pub Ser BD – 11WQ0010408-004	27.7	4620		4620		2		
	Segment Totals:	**27.7**	**4620**	**0**	**4620**	**0**			
2307	Clint Independent School District – 11WQ0013667-001	0.05	8.3		8.3		2		
2307	Cuadrilla Improvement Corp – 11WQ0013530-001	0.012	2		2		2		
2307	Socorro ISD – 11WQ0013437-001	0.01	1.7		1.7		2		
2307	San Elizario ISD – 11WQ0013380-001	0.04	6.7		6.7		2		
2307	El Paso County WA – 11WQ0010795-001	0.5	125		125		4		
2307	El Paso Water Util Pub Ser BD – 11WQ0010408-010	39	6509		6509		2		
2307	El Paso CO WCID 004 – 11WQ0010166-001	0.52	87		87		2	10.83	✓[d]
2307	Odom, Jerry L. DBA Aspen Properties – 11WQ0003050-	0.027	4.5		4.5			13.33	✓
2307	Petro, Inc. – 11WQ0003026-001	0.085	12.8		12.8				✓[d]
2307	Johnson, Wayne R., DBA – 11WQ0000516-001	0.038							
	Segment Totals:	**40.282**	**6757**	**0**	**6757**	**0**			
2306	US Dept of Interior – 11WQ0012865-001	0.055	9.2		9.2		2		
2306	Lajitas Utility Company, Inc. – 11WQ0012167-001	0.045	7.5		7.5		2		
2306	Gold Fields Mining Co – 11WQ0002297-002	0.025						10.83	e
2306	Gold Fields Mining Co – 11WQ0002297-001	0.025							
	Segment Totals:	**0.15**	**16.7**	**0**	**16.7**	**0**			

[1]**Source:** Texas Natural Resources Conservation Commission 1994. Regional Assessment of Water Quality in the Rio Grande Basin including the Pecos River, the Devils River, the Arroyo Colorado and the Lower Laguna Madre. Water Management Division, Austin, Tx. 337 pp.

[a]Blank indicates that permit does not include limits for the parameter.

[b]% time noncompliant is the ratio of number of months noncompliant to the total number of months (120 months) for the period of Jan. 1, 1982 – Dec. 31, 1991.

[c]Check mark indicates either historical or present enforcement action involving permittees noncompliant for 4 consecutive months during the period Jan. 1, 1982 – Dec. 31, 1991.

[d] Closed enforcement cases as of July 1994.

officials have removed all known underground petroleum storage tanks in the park (M. Fleming, Big Bend National Park, pers. comm., 1996).

Municipal-Industrial and Irrigation Return Flows. On the Texas side of the Rio Grande upstream of Fort Quitman, almost no data on return flows exist other than those for the El Paso region, and such data are reported to the Texas Natural Resource Conservation Commission on a voluntary basis by wastewater permit holders. Both municipal and industrial return flows carrying various concentrations of contaminants continue to increase along both sides of the border with the rapid growth in population and economic expansion.

Manufacturing or processing facilities located along the Mexican side of the border and linked to companies in the United States and other countries are known as maquiladoras. Maquiladoras are widely believed to contribute to the pollution of water in the Rio Grande Basin through illegal dumping of hazardous waste to water courses or other sites (Eaton and Andersen, 1987). Out of approximately 3,535 maquiladoras in Mexico, an estimated 635 maquiladoras are located along the Texas/Mexico border (TNRCC, 1994a). About 450 of these are registered with the Texas Natural Resource Conservation Commission (TNRCC). In 1990, about 200 were registered with the TNRCC, and an additional 100-125 maquiladoras have registered with TNRCC every year since then. The waste returned to Texas for disposal consists of a wide universe of chemicals, including solvents, paints, inks, liquids, solids, and heavy metals (TWC, 1992).

Irrigation return flow to the Rio Grande is not measured systematically. Irrigation return flows leaving the lower part of the El Paso region are recaptured for irrigation in Hudspeth County. Therefore, agricultural return flows from the El Paso-Ciudad Juarez area generally do not adversely affect the quality of water in the reaches adjoining Big Bend National Park. Agricultural return flows from irrigated areas along the Rio Conchos and in the Presidio area may, however, contribute residues of fertilizers and pesticides to the Rio Grande adjacent to the park. The Binational Study on Toxic Substances (IBWC, *et al,* 1994), discussed later in this chapter, has initiated monitoring of these potential pollutants.

Nonpoint Sources of Pollution. Nonpoint source water pollution originates from dispersed locations throughout urban and rural landscapes. Pollutants generated through innumerable actions are carried to receiving bodies of water by rainfall runoff, ground water leachate, and ground water infiltration (TNRCC, 1994a). Nonpoint pollution from agricultural runoff in the Rio Conchos and Presidio regions may impact the Big Bend National Park area. The Texas Natural Resource Conservation Commission (1994a) evaluated Big Bend National Park and the Rio Grande Wild and Scenic River (river segment 2306) in its "Nonpoint Source Water Pollution Assessment," and rated these areas with "concern" status due to problems with agricultural biocides and trespass livestock. In the same assessment, the TNRCC (1994a) reported the monitoring of river segment 2307 (from Presidio to just downstream of El Paso) for fecal coliform associated with sewage treatment facilities. This segment also received a status of "concern" in the assessment (TNRCC, 1994a).

Urban storm-water runoff is another significant source of nonpoint pollution. Urban runoff contributes contaminants from industrial activities, animal wastes, leaking sewer lines, fertilizers and pesticide application on residential yards, oil and gasoline from parking areas or service stations, and a number of other sources. In the Rio Grande Basin, the city of El Paso is the only area on the U.S. side large enough to require an NPDES permit for municipal storm-water discharges (TWC, 1992). While El Paso area is so distant from the park that little or no impact on the park is suspected from that source, future urban development along the Rio Conchos in Mexico or Presidio may pose a threat to Rio Grande water quality at Big Bend National Park.

On-site sewage disposal facilities in small communities such as Terlingua and Lajitas may also be sources of pollution in the Rio Grande. The State of Texas requires statewide permitting of on-site disposal facilities (see Chapter 2, "Texas Water Quality Acts"). Other than El Paso County, which has local authority, all of the counties in the portion of the Rio Grande Basin covered in this study fall under the authority of the Texas Natural Resource Conservation Commission for on-site sewerage facility permits. In 1993, Brewster County was listed as having 1,360 on-site sewerage systems and 3 permits. In the same year, Presidio County had 395 systems, with 4 permits.

Colonias (residential subdivisions lacking basic infrastructure such as paved roads, drainage and public utility services) on both sides of the border typically have owner-built, on-site sewerage facilities which rarely meet Texas Natural Resource Conservation Commission construction standards (TNRCC, 1994a). Surface application of untreated or partially treated wastewater is also common. The substandard design of these systems as well as the surfacing of wastewater from many of these facilities, small lot sizes, and proximity of many settlements to the Rio Grande, all contribute to nonpoint source pollution in the river which is manifested in elevated levels of fecal coliform (TNRCC, 1994a).

According to the Texas Water Commission (1992) (now the Texas Natural Resource Conservation Commission), standards are being amended to require more scientific methods for site and soil investigations, such as percolation tests. Presently there are no statewide subdivision standards on planning and construction of developments outside the Extraterritorial Jurisdiction (ETJ) of a municipality. Rules adopted in 1990 require developers to install water and wastewater systems as a condition of subdivision approval.

Current Land Uses as They Relate to Water Quality in the Rio Grande

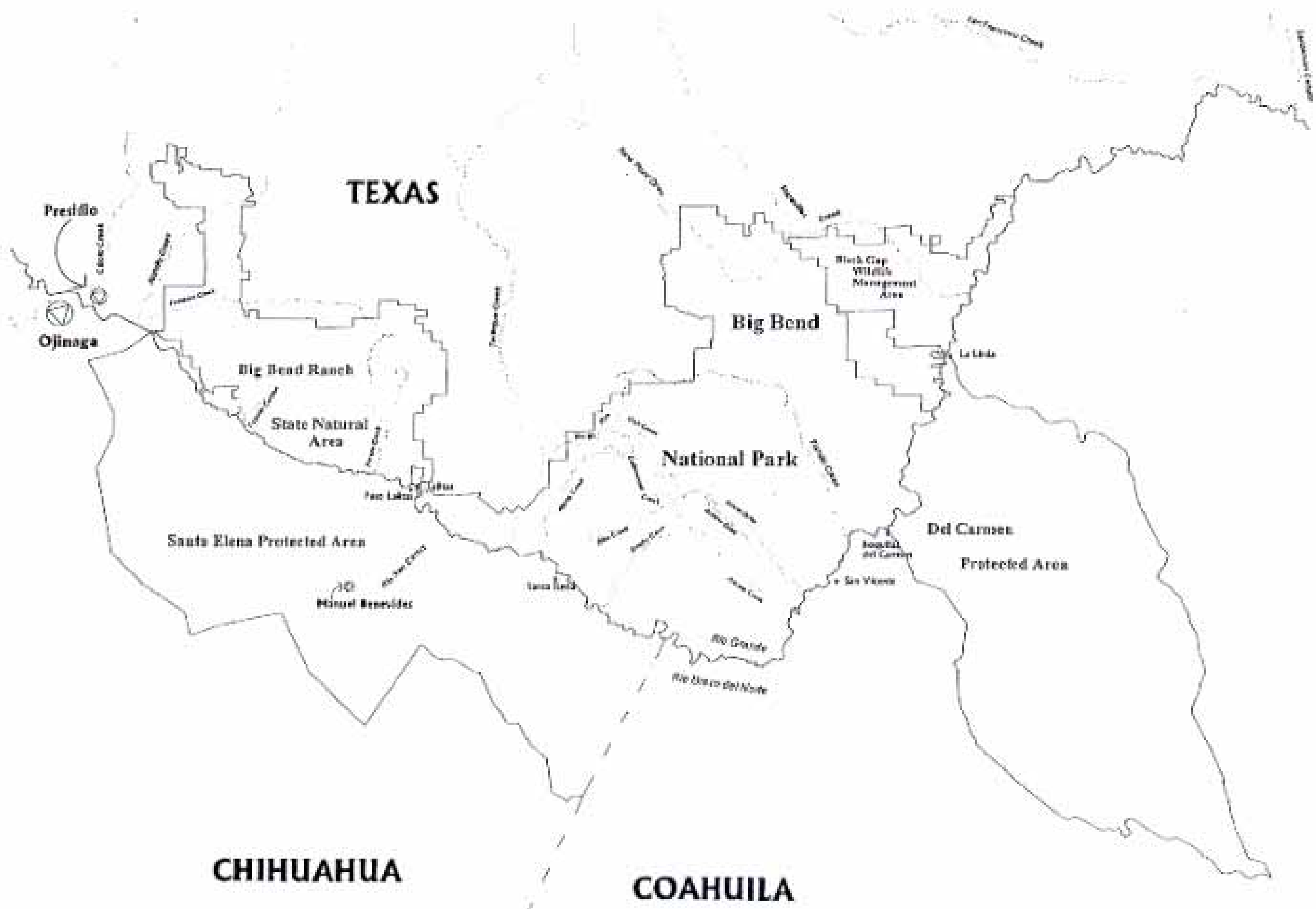
Land use in the region surrounding Big Bend National Park is illustrated in Figure 21. This figure shows that virtually the entire river reach from Presidio to La Linda is bounded by existing or proposed parks, reserves, or natural areas. The land use patterns upstream from the Presidio-Ojinaga area are much more diversified and utilized by private rather than public interests. Much of the land in the Rio Conchos Basin is dedicated to agriculture, but some mining and industrial uses also exist (J.C.Trevino Fernandez, *fete del Departamento de Ecologic,* Chihuahua, Mexico, 1995, pers. comm.).

Evaluation of Surface Water Quality Conditions

Evaluating available water quality data involves five interrelated factors: (1) time of sampling, (2) location of sampling, (3) source of water, (4) contaminant levels over time at a given location, and (5) the spatial variation of contaminant levels at a given time. Variations in period of record, number of samples taken, time of year, and numerous other factors complicate any comparison of water quality data from different sources. Because of such inconsistencies between data sources, the following summary of water quality data for the Rio Grande and its tributaries within the area of study presents a general discussion of existing water quality issues in these waters.

The Texas Natural Resource Conservation Commission (formerly the Texas Water Commission) in cooperation with the International Boundary and Water Commission water quality has monitored water quality in the Rio Grande for some 25 years. In addition, several independent groups monitor numerous water quality parameters along the Rio Grande. The staff at Big Bend National Park have expressed the following major concerns regarding the water quality of the Rio Grande: 1) the Rio Conchos' biocide (pesticide, herbicide, fungicide) contribution to the Rio Grande, 2) the need for a long-term comprehensive water quality monitoring program based on a frequency that would protect contract recreation uses, 3) a possible need to increase the dissolved oxygen standard, and 4) the need for reevaluating the existing water quality standards to protect the resources within Big Bend National Park (Kaiser, *et al,* 1994). Although Texas Surface Water Quality Standards set a standard of 5.0 mg(L dissolved oxygen (DO) for the Rio Grande adjacent to Big Bend National Park, they do not address the problem of nutrients in the water which may lead to suppressed DO levels. High nutrient levels and fecal coliform concentrations will likely remain a serious problem along the U.S./Mexico border until the wastewater discharges from sewers and sewage treatment plants on both sides of the border are more strictly regulated (C. Kolbe, Texas Natural Resources Conservation Commission, 1996, pers. comm.). Because these are complex issues requiring integrated, long-term solutions, this discussion will concentrate on selected parameters that have the greatest impact and for which there appear to be sufficient data to evaluate water quality. The area covered in this data review is that portion of the Rio Grande from El Paso to La Linda, Texas and includes Texas Natural Resource Conservation Commission river segments 2308 and 2307 and part of segment 2306. Although the most serious water quality problems in these segments generally occur in the El Paso vicinity, water quality concerns exist throughout the reach of the river covered by this review. The reader should note, however, that surface water in the El Paso/Ciudad Juarez area does not reach Big Bend National Park. By contrast, most of the water flowing through the Rio Grande at Big Bend National Park derives from the Rio Conchos in Mexico.

FIGURE 21. Location of National Parks and Reserves and Big Bend Ranch State Natural Area



Salinity has been, and continues to be, a general water quality concern, and high levels of fecal coliform have been measured at various times even in waters rated for contact recreation by the state of Texas (Kaiser, *et al*, 1994). Aside from hazards associated with direct consumption of saline water by humans and by livestock, plants irrigated with saline water experience reduced yields and soils are adversely impacted. Salinity also contributes to corrosion, impacting industry and homeowners. Some municipal areas also contribute industrial pollutants to the river. With increased manufacturing capacity being developed in the area, industrial effluent entering the river poses growing risks to humans and wildlife. Pesticides and other organics appear to be problematic in some areas. These contaminants can adversely impact the water uses (especially public water supply, aquatic habitat, and recreation) in the park and adjoining areas.

A recent NPS-Horizon (1995) assessment supports the findings listed above and defines additional water quality problems in the Rio Grande and its tributaries near Big Bend National Park. At stations identified as being located in the area reviewed by this report, the following parameters were sometimes found to exceed applicable criteria:

1) dissolved oxygen (5.0 m e , protection of freshwater aquatic life);

2) pH (6.5-9.0, EPA criteria for freshwater aquatic life);

3) turbidity (50 JTU/NTU, National Park Service, Water Resources Division [NPS/WRD] screening criterion);

4) sulfate (400 mg/l, drinking water criterion);

5) fecal coliform (400 CFU/100 ml, Texas Surface Water Quality Standards screening value);

6) lead (82 *µg/l*, acute freshwater aquatic life criterion, 5 tg(l, drinking water criterion); and

7) mercury (2.4µg/l acute drinking water criterion, 2.0 µgrl, drinking water criterion).

The NPS-Horizon (NPS, 1995) assessment also noted that, for other stations in its study area in and adjacent to the park but not pertaining to the present study, the following parameters showed concentrations exceeding standards for either drinking water or freshwater aquatic life: chloride, barium, cadmium, chromium, copper, nickel, and zinc. The NPS-Horizon (NPS, 1995) study reports that indicator bacteria (total and fecal coliform) concentrations and turbidity exceeded National Park Service-Water Resources Division screening limits for primary body contact recreation and aquatic life, respectively.

Data on maximum exceedences of water quality standards from the STORET database (maintained by the U.S. Environmental Protection Agency) and from the NWIS-1 database (maintained by the U.S. Geological Survey) indicate that fecal coliform, turbidity, chloride, and sulfate exceed screening level concentrations throughout the reach of the Rio Grande between El Paso and La Linda. Arsenic and mercury concentrations also were notably high at three mainstem stations between Fort Quitman and La Linda, and at tributary stations on the Ciudad Juarez sewage discharge canal and on Terlingua Creek. Terlingua Creek also exhibited high levels of other toxic metals. Values outside acceptable ranges for temperature, pH, and dissolved oxygen were also encountered in several areas. Toxic substances (other than metals) measured in excess of human health or aquatic life criteria were generally limited to samples taken near El Paso.

Arsenic and mercury are the most frequently occurring toxic substances in water samples from the Rio Grande and its tributaries in the area of study. Sites where high concentrations of toxic substances were found in fish tissue are shown in Figures 22 and 23. As the figures show, the Presidio-Ojinaga area and Santa Elena Canyon constitute the principal sites of concern for fish contamination.

Water Quality in River Segment 2308. Segment 2308 extends 15 miles (24 kilometers) from the International Dam to the Riverside Diversion Dam in El Paso. The designated uses for segments 2308 include noncontact recreation and limited quality aquatic life (see Table 2, Ch. 2). According to the Texas Natural Resource Conservation Commission (1994a), this segment below International Dam is listed under "waters of concern," due to the relatively high concentrations of phosphate-total, ortho phosphate, phosphorus-total, and phosphorus-dissolved. Ammonia-nitrogen, nitrate-

Source: International Boundary and Water Commission (United States and Mexico sections), et al, 1994.

FIGURE 22. Contaminants in Whole Fish

Source: International Boundary and Water Commission (United States and Mexico sections), et al, 1994.

FIGURE 23. Contaminants in Fish Fillets

nitrogen-total, and total dissolved solids (TDS) were listed as "possible concerns." Irrigation return flows are the principal source of elevated levels of TDS and phosphates in this river segment. Elevated nutrients, chlorophyll a, and instream aquatic toxicity have also been noted (TWC, 1992). The Texas Department of Water Resources (now the Texas Natural Resource Conservation Commission (TNRCC)) determined that violations related to a sewage treatment plant and to the discharge of municipal effluents occur in segment 2308 at El Paso (TDWR, 1981 cf. Eaton and Andersen, 1987). Toxic substances were also detected in several samples of water and sediment. Fecal coliform levels have frequently exceeded the allowable criteria, and for the period 1975-79, the Texas Department of Water Resources (now the TNRCC) reported between 15 and 80 percent of samples in violation of existing standards (TDWR, 1980 cf. Eaton and Andersen, 1987). In 1994, fecal coliform exceedences totalled 21% of 24 samples taken (TNRCC, 1994b). The TNRCC (1994b) summarized the results of its 1994 sampling program in segment 2308 as follows: *Fecal col form concentrations exceed the screening level in about one-fifth of the samples, but the non-contact recreation use is supported throughout the segment. Ammonia, nitrate, chlorophyll a and* ***phosphorus*** *levels are elevated above the screening levels. a wasteload evaluation completed for this segment recommends secondary treatment for wastewater discharges. An intensive survey for the segment was conducted in 1992 to provide a basis for revisions of the waste load evaluation.*

Water Quality in River Segment 2307. Segment 2307 extends 222 miles (357 kilometers) from Riverside Diversion Dam in El Paso to the confluence with the Rio Conchos near Presidio (see Figure 20). The designated uses for this segment include public water supply, contact recreation, and high aquatic life (Table 2, Ch. 2). Most of the flow arriving at El Paso is diverted for irrigation and municipal use in Mexico and Texas between El Paso and Fort Quitman. Although flow in this segment depends on releases from Elephant Butte and Caballo dams in New Mexico, portions of Presidio, Hudspeth, and El Paso Counties and small areas of Jeff Davis and Culberson Counties drain into this segment of the river. Most of this drainage area is characterized by desert mountains and sparse vegetation, with an average annual rainfall of about 8 inches. Ranching, irrigated agriculture, and tourism (as well as maquiladora plants in the El Paso area) are important to the economy of the area (TNRCC, 1994a).

The Texas Natural Resource Conservation Commission's (1994a) evaluation of water quality in segment 2307 categorized the following substances of "concern:" total Kjeldahl nitrogen (TKN), nitrate plus nitrite, phosphate-total, phosphorus-total, chlorides, sulfates and total dissolved solids. Constituents of "possible concern" include: nitrate-nitrogen-total, orthophosphate, phosphorus-dissolved, mercury-dissolved (human health criterion), and fecal coliform (at low-flow conditions).

Total dissolved solids (TDS) concentrations at Fort Quitman have historically been high (Mendieta, 1974 cf. Eaton and Andersen, 1987). In 1994, out of roughly 60 samples each, 91% of the samples exceeded chloride screening levels and 81% exceeded TDS screening levels (TNRCC, 1994b). The Texas Natural Resource Conservation Commission (1994b) summarized the status of segment 2307 as follows: *This segment is partially supporting the contact recreation use due to elevated fecal coliform levels.* ***Phosphorus,*** *nitrate, ammonia and chlorophyll a levels exceed the screening levels in the lower portion of the segment. River flow in the segment is reduced due to irrigation withdrawals in the El Paso area and evaporation throughout the segment. Average chloride, sulfate and total dissolved solids concentrations exceed the standard criteria.*

Little water flowing past Fort Quitman reaches Presidio, as it is lost through evapotranspiration, diversion, and channel seepage. Tributary streams below Fort Quitman contribute to occasional flows above Presidio, thereby reducing total dissolved solids (TDS) concentrations to below upstream levels. Most of the flow in the Rio Grande below Fort Quitman derives from tributaries flowing northward out of Mexico. The Rio Conchos joins the Rio Grande just above Presidio, Texas at the lower end of segment 2307. Overall, flows from the Rio Conchos dilute the total dissolved solids concentrations found in the Rio Grande (IBWC, 1981, cf. Eaton and Andersen, 1987). The available data on water quality in the Rio Grande below the Rio Conchos confluence permit only a limited characterization. Monitoring needs in this area are discussed in a later section.

Felipe Ochoa and Associates (1978, cf. Eaton and Andersen, 1987) cite an unnamed 1974 report from the Mexican *Secretaria de Agricultura y Recursos Hidrdulicos* (SARH) as listing high fecal coliform and sulfate levels in the Rio Conchos. The SARH report stated that total coliform levels were found as high as 24,000 colonies/100 ml, with a median of 13,200 colonies/100 ml (Felipe

Ochoa and Associates, 1978, cf. Eaton and Andersen, 1987). For the entire segment, the Texas Natural Resource Conservation Commission (1994b) reports that only 16% of the 62 samples collected exceeded fecal coliform screening criteria. According to the Texas Water Commission (1992), there are very few instantaneous dissolved oxygen measurements showing less than 5 mg/l for the reach of the river covered in this report. Most of the depressed levels that have occurred have been reported from the Ojinaga-Presidio area. Most of the river flow is diverted near El Paso for municipal and industrial supplies and agricultural irrigation purposes. The small river flow, slow velocities, and low physical recreation between El Paso and Presidio tend to naturally depress dissolved oxygen levels.

Water Quality in River Segment 2306. Segment 2306 extends 313 miles (504 kilometers) from the confluence of the Rio Conchos near Presidio to a point 1.1 miles (1.8 km) downstream from the confluence of Ramsey Canyon in Val Verde County. However, this study deals only with the portion of segment 2306 upstream of La Linda in Brewster County. The designated water uses for this segment are public water supply, contact recreation, and high aquatic life. This segment forms the southern boundary of Big Bend National Park and is therefore of prime concern for the management of the park.

Like segment 2307, segment 2306 of the Rio Grande has been deemed suitable for contact recreation by the Texas Natural Resource Conservation Commission upstream of Langtry (below Big Bend National Park). Downstream of Langtry, elevated fecal coliform bacteria, total phosphorus and DDE in sediment preclude a contact recreation rating (TNRCC, 1994b). With the exception of the Ojinaga-Presidio area, where the inflow from the Rio Conchos dominates water quality, the historical geometric means indicate water quality at all the downstream sites is not meeting the state's fecal coliform criterion (TWC, 1992). The reach below Terlingua Creek has also recently been found to have high levels of coliform bacteria (Carranza, *et al,* 1994). The persistently elevated fecal coliform levels suggest that the Rio Grande is not suitable for contact recreation and that individuals entering the river, particularly immediately downstream of each major border city, have an increased risk of becoming infected with water-borne pathogens. Carranza, *et al* (1994) reiterated this warning for waters in the Big Bend area, stating that water from hot springs as well as the river "should not be considered potable," and that recreationists should be warned that bodily contact with the water could be hazardous. Although bacterial levels are elevated, there are no visual indications to signal water quality problems in the Rio Grande (TWC, 1992).

The Texas watersheds that drain into this portion of the Rio Grande lie within Terrell, Brewster and Presidio counties in the northern portion of the Chihuahuan Desert. Annual rainfall in that area ranges from 12 to 14 inches. The landforms of the area include "semi-arid to desert mountains with deep canyons and rocky limestone soils" with sparse vegetation (TNRCC, 1994a). Other than recreational use by tourists to Big Bend National Park, sheep and goat rangelands constitute the principal land use in this sparsely populated area. Some irrigated agriculture does occur along the Rio Grande in the Presidio area, and oil and gas exploration in Terrell County is becoming increasingly important to the local economy. In addition to the usual land-based recreation activities, rafting and hot springs in this region attract many tourists.

The only "concern" level constituent listed by the Texas Natural Resource Conservation Commission (1994a) for this reach of the Rio Grande is phosphate-total. Out of 59 samples, 53 exceeded the screening level of 0.2 mg/l. Constituents of "possible concern" for segment 2308 include: nitrate-nitrogen-total, total Kjeldahl nitrogen, nitrite plus nitrate, phosphorus-total, fecal coliform, cadmium-dissolved (aquatic life criterion), hexachlorobenzene (human health criterion), and mercury-dissolved (human health criterion). In this segment, 13.3 percent of low-flow fecal coliform values and over 29 percent of high-flow fecal coliform values exceeded the screening level (400 colonies/100 ml). Low-flow conditions are defined as having less than the 10-year median flow value, and high-flows exceed the 10-year median flow value (TNRCC, 1994a).

Alamito Creek joins the Rio Grande in segment 2306 (Figure 20). Seventy-three percent of samples from the one water quality station on Alamito Creek did not meet the screening level of 5 mg/l dissolved oxygen (DO). While DO is the only "concern" listed for this station, Texas Natural Resource Conservation Commission (1994a) notes that most of these values were measured in mid summer (July 11 and 12, 1989). Mean concentrations of DO measured in the spring (mean 7.4 m e) were well above the spring mean criterion of 5.5 mg/l (TNRCC, 1994a).

Recommendations. The incidences of degraded water quality and high coliform levels noted above for the Rio Grande and some of the tributaries indicate a need for an investigation of the extent of the problems, and the identification of sources. Project Statements BIBE-N-550.001 and BIBE-N-563.001 have been included in this Water Resources Management Plan to address these issues.

Ground Water Resources

Regional Hydrogeology

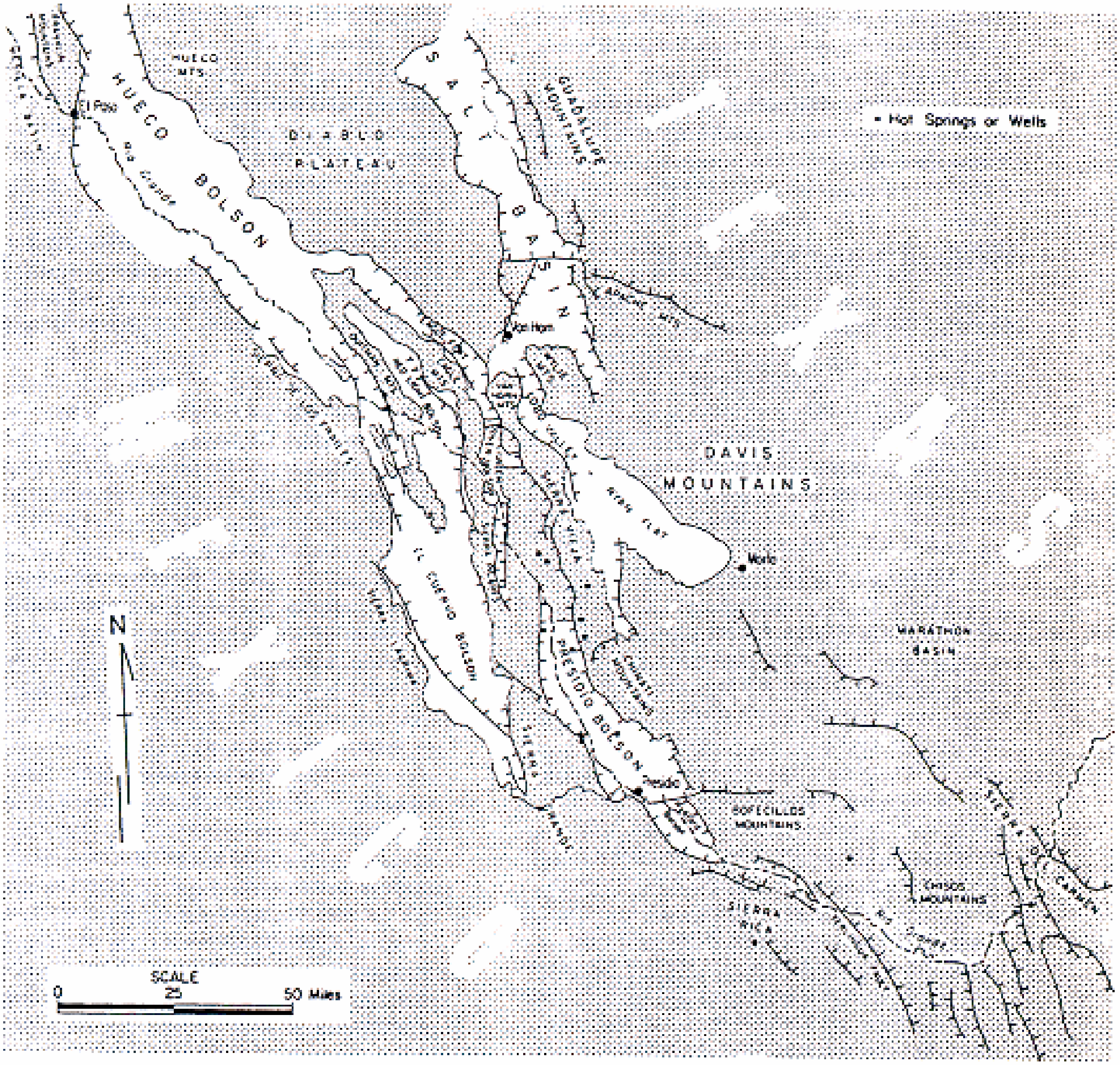
In the reach of the Rio Grande between El Paso and Presidio, the Rio Grande is underlain by a series of "bolsons" which are structurally-formed depressions containing sedimentary materials saturated with ground water at depth. Downstream from El Paso, these are identified as the Hueco, Red Light, Green River, Presidio, and Redford bolsons (Figure 24). These ground water reservoirs provide supplies for El Paso and other public water systems and for irrigation of crops in the river valley. Their zones of ground water occurrence, however, are generally at considerable depth with a significant vadose zone between them and any surface flow or ground water in the shallow alluvial deposits associated with the Rio Grande. The fact that water has been "mined" (ground water pumping rates exceeding natural recharge rates) has serious implications if delivery of additional Rio Grande water from the upper basin is contemplated. The existing ground water deficit in these drawn down reservoirs results in high vertical leakage rates fromsurface flows and produces a greater void to be filled by infiltrating groundwater before a saturated connection establishes between the two flow regimes. In other words, the higher the groundwater table, the sooner the zone between the surface water and groundwater systems becomes saturated. Once the groundwater mounds to a point near the surface, it may actually inhibit downward flow from a surface water source. In the case of the bolsons, however, maintaining an unsaturated zone between the surface and the groundwater may actually impede vertical leakage from the river to a certain extent because of the inverse relationship between hydraulic conductivity and soil water content.

Ground Water Occurrence

Information gleaned from inventories of springs and other surface water features in the park suggests that ground water provides the only reliable water supply for Big Bend National Park. Surface water flow in streams in the park occurs only after local storm events and is generally of very short duration. The exceptions to this rule include the perennially flowing Rio Grande and perennial and intermittent reaches of streams in the park which are sustained by ground water discharge. Examples of these small perennial reaches include portions of Terlingua, Tornillo and Fresno Creeks, McKinney Springs, and small washes fed by Chilicotal Spring(s).

The process of conveying water from the surface to a ground water aquifer is known as *recharge,* and it can be summarized as follows. Precipitation falls on the land surface during storm events. Once on the surface, it has an opportunity to infiltrate into the soil. If the precipitation is intense, and/or the soil is poorly permeable, a significant portion of the precipitation will become overland flow, and move down the slopes to a channel where the flow becomes concentrated and streamflow will start. After the storm has passed, evaporation from the wetted surfaces of the soil and from the wetted stream channels along with transpiration by vegetation will consume a significant volume of the precipitation. Water not lost to this evaporation/evapotranspiration (i.e., overland flow and streamflow) infiltrates into the soil. Depending on antecedent soil moisture conditions, most of this infiltrating water may go to satisfy the soil moisture deficit (to fill voids between soil grains). If the soil moisture deficit is small due to recent precipitation events, or if the amount of infiltrating water is large, water may percolate downward through the soil, eventually reaching the ground water table, which represents the top of the zone of saturation in the earth's crust.

Once in the zone of saturation, the water moves generally downward and laterally to a point of discharge, such as a spring, a stream, or a river. As water moves more easily in unconsolidated, porous material than in consolidated rocks, the most rapid ground water flow occurs in coarse, unconsolidated sediments, usually at or near the land surface. Water that finds its way through tortuous tiny fractures in consolidated rocks moves very slowly, and may travel many miles to its point of discharge.



Source: Henry, 1979.

FIGURE 24. Map of Bolsons Between El Paso and Big Bend National Park

These phenomena have important implications in the ground waters of the park. In terms of flow quantity, the ground water flow in the unconsolidated materials of the park is volumetrically important. Because of the relatively rapid flow in these aquifers, the water quality is generally very good, as the water does not have the opportunity to dissolve much mineral material in the aquifer. On the other hand, the proximity of these aquifers to the land surface makes them more susceptible to contamination by surface activities. Additionally, rapid travel time can lead to fluctuations in the ground water supply directly related to fluctuations in precipitation. This cause and effect phenomenon decreases in significance as aquifer volume increases, and as the distance the water must move from point of recharge to point of discharge increases. In Big Bend National Park, springs that lie at higher elevations in the Chisos Mountains, whether they derive from consolidated rock or unconsolidated materials, have generally good quality water, and their discharges fluctuate to varying degrees in response to fluctuations in the precipitation. In contrast, springs along the Rio Grande, particularly the warm springs, generally flow great distances through the consolidated rocks, and will generally fluctuate with multi-decadal or century-scale climatic fluctuations. Such springs do not fluctuate significantly in response to even several "wet" or "dry" years in a row.

Groundwater Occurrence in Big Bend National Park

Over 300 natural water sources within the boundaries of the park have been located including over 200 springs, as well as numerous seeps, tinajas, man-made water holes, stock tanks, etc (see previous discussion under "Surface Water Resources" heading). The significance of these natural water sources in furnishing local plant and wildlife habitat and as water supplies in this harsh desert environment cannot be over emphasized. In the developed areas of Castolon, Chisos Basin, Panther Junction, and even Persimmon Gap, wells have been drilled to develop water supplies. While such wells generally can produce sufficient quantities of water, and are relatively insensitive to droughts, the high degree of mineralization in the area associated with the emplacement of the igneous intrusive rocks (see Geologic Section in Table 6) often renders the quality of such waters unacceptable for potable uses.

During the same multiphase investigation whereby all of the springs in the Big Bend area were inventoried (see "Surface Water Resources" section above), the U.S. Geological Survey undertook a similar inventory of ground water resources (Garza, 1966; Leggat, *et al,* 1968). All known existing wells were inventoried and sampled, and a test drilling program was implemented to explore the possibility of further developing aquifer water supplies in the park, especially the Aguja Formation. Interest in the Aguja Formation as a ground water source dates back to Dr. Ross Maxwell's geologic mapping of the area in the early to mid-1960's. His interpretation of the geologic environment led U.S. Geological Survey scientists to believe that the portion of the Aguja Formation covering a 40-square mile area centered roughly on the Panther Junction area held the most promise for ground water development in the central region of the park (Garza, 1966). In their summary of the work entailed in six master's theses from Texas A&M University, Wilson and Schroeder (1984) reiterate the good potential for groundwater exploitation in the Panther Junction area. Specifically, they estimate that 1983 consumption rates in the Panther Junction area could likely be quadrupled with the available groundwater supplies there. While they acknowledge that the K-Bar wells may be insufficient for this level of production, they suggest that the Lone Mountain well field area may provide the additional water required (Wilson and Schroeder, 1984). Appendix IV lists the currently available information for existing wells in the Big Bend area.

Eleven test holes were drilled just north of the Chisos Basin as part of Phase II of the U.S. Geological Survey's spring investigation (see Figure 6 earlier in this chapter). The wells were drilled with the objective of testing the water supply potential of the Aguja Formation (Late Cretaceous age). The deepest test well was drilled to 600 feet. While all of the test holes were believed to have penetrated the Aguja, none penetrated the entire thickness of the formation. The authors describe the Aguja in that area as a "varicolored silty or sandy clay, sandstone, shale, and lignite" (Leggat, *et al,* 1968). *"The sandstone generally was moderately to well indurated and in places fractured. The poorly consolidated sandstone and the hard sandstone where it has been fractured are the main sources of water"* (Leggat, *et al,* 1968). The alluvium encountered during the test drilling varied from 0 to 110 feet in thickness, but because it was above the water table, it was not a source of water for the test wells. Water extracted from shallow alluvium in other areas is generally too mineralized for drinking (Leggat, *et al,* 1968).

Of the eleven test holes drilled, six were considered as potential producing wells. The six-inch steel casings were screened adjacent to sandstone beds, as interpreted from radioactivity or resistivity logs. Aquifer tests in these wells revealed that only three were apparently capable of producing a total of 95 gallons per minute (gpm) (135,000 gallons per day (gpd)) for a period of several days, or up to 140 gpm (200,000 gpd) for shorter periods of continuous pumping. The test data were insufficient to judge whether or not these discharges could be sustained for longer periods of time (a month or so) (Leggat, *et al,* 1968).

The authors of the Phase II study note that the most productive wells were in the part of the test area north and northwest of Lone Mountain and south of the axis of the Lone Mountain anticline or its northwestward extension. The quality of the water extracted from all of the test holes was generally good, with the exception of high fluoride contents (1.9 to 7.6 milligrams per liter (mg/l)). The temperatures of the waters pumped from the five producing test holes ranged from 24 to 36°C (75 to 93°F).

Appendix IV presents a complete catalog of wells in Big Bend National Park based on all available information. As indicated in Table 6, all of the ground water supplies in Big Bend National Park come from essentially three geologic formations: 1) Alluvium and Older Gravel (Pleistocene to Recent age), 2) the Hannold Hills Formation (Eocene age), and 3) the Aguja Formation (Late Cretaceous age). Most of the wells were drilled in direct response to increased human water supply needs, and are therefore located in populated areas of the park, such as the Chisos Basin, Castolon, Panther Junction, and Maverick Station.

Ground Water Quality

Ground water quality in Big Bend National Park is strongly influenced by the high degree of mineralization in the area associated with the intrusive and extrusive igneous rocks. High levels of fluoride are ubiquitous, with even shallow, alluvial/colluvial aquifers, such as the ones supplying water to the lower CCC wells and Oak Spring, having fluoride levels around 3 mg/l (see Appendix IV).

Wells obtaining water from sedimentary rocks of Tertiary and Cretaceous age commonly have sulfate levels in excess of 250 mg/I, total dissolved solids in excess of 500 m e , and fluoride levels over 4 mg/l. Prolonged use of high fluoride waters may cause the mottling of teeth in children. High sulfate waters may produce a mild laxatative effect initially, but acclimatization to the water should occur in a relatively short period of time with moderate concentration levels (Leggat, *et al,* 1968). While high concentrations of total dissolved solids, and occasionally iron, pose little or no health risk, they do have an adverse impact on the aesthetic quality and taste of the water.

Recommendations. While the available data on ground water quality are not sufficient for a thorough characterization, evidence indicates that the quality of ground water is highly variable throughout the park. Because of this high degree of variability, a large scale effort to characterize ground water quality would probably not be fruitful except as it pertains to drinking water supplies.

Due to the variety of mineralization sources and the lack of one major aquifer unit, recommendations for groundwater utilization in Big Bend National Park focus on point-of-use treatment as required (refer to "Castolon Water Quality and Special Needs" later in this chapter.)

Aquatic and Riparian Resources and Habitats

Along the Rio Grande within Big Bend National Park, the composition and extent of the riparian communities varies considerably. In addition to a variation in width that ranges from over a half mile to just a few feet, some of these riparian communities can be found in adjacent arroyos and streams where sufficient surface water, shallow ground water, or runoff exists to support a riparian plant community. A total of 64 riparian areas have been identified along the Rio Grande within the reach of the river between Lajitas and La Linda (Ditton, *et al,* 1977). Thirty-eight of these areas are accessible only from the river, while 8 of these areas are accessible by paved road, and 18 can be entered by primitive road (NPS, 1992).

Riparian plant communities, especially in arid areas such as those in Big Bend National Park, provide important wildlife habitat as well as a major recreational resource. At the park, these areas have been reported as supporting an important migratory corridor for birds (Waller, 1977) as well as some 30 species of mammals (Boeer and Schmidly, 1977).

Many factors can cause changes in these diverse and productive communities, including flooding, introduction of exotic species, cattle grazing, and recreational use. Site descriptions made in the mid-1970's from studies conducted in the 1940's indicate that significant changes have taken place in the vegetation of the riparian areas near the Johnson Ranch and at the mouth of Santa Elena Canyon (Boeer and Schmidly, 1977).

Several major visitor use areas in Big Bend National Park are located within the riparian zone of the Rio Grande. These developed facilities include Rio Grande Village, Cottonwood Campground, trailhead parking, and the take-out boat ramp at Santa Elena Canyon. Visitor activities in the riparian zone outside these developed areas include camping at primitive campsites, non-vehicular backcountry use, and boating including float trips.

Visitor use patterns, biological conditions, and selected recreational impacts such as trampling, litter, tree cutting and the presence of human waste were summarized by Fleming, *et al* (1995) and evaluated by Ditton, *et al* (1977). Ditton, *et al* (1977) found that biological health of the areas studied was not directly related to recreational impact. However, 25 percent of these sites were heavily impacted and these impacts reportedly decreased the aesthetic appeal of these locations for backcountry use. Trespass livestock impacts were found to mask the impacts caused by recreational visitors. Therefore, in order to fully understand the actual impacts caused by visitors, issues related to trespass livestock impacts must first be resolved.

Upstream dams, diversions, changes in land use, channelization have impacted the fisheries and aquatic biological resources of the Rio Grande within Big Bend National Park. Hubbs (1940) noted that as early as the 1930's reports documented the death of large numbers of fish killed by run-off, apparently due to contamination from the mercury and silver mines in the region.

Hubbs, *et al* (1977) conducted a fisheries inventory of the reach of the Rio Grande between El Paso and the confluence with the Pecos River. This study found that the fish species of the river could be divided into several faunal assemblages. The river reach upstream from the confluence with the Rio Conchos contains a saline faunal assembly consisting of widely distributed and salt tolerant species. Between the confluences of the Rio Conchos and the Pecos River, the Rio Grande is populated by species primarily of south Texas and Mexican origin. Tributary creeks are inhabited by Chihuahuan species and their derivatives for part or all of their life cycles. These last two assemblages are known to include rare and endangered species (NPS, 1992).

More recent inventories of the fisheries of the Rio Grande were conducted by Bestgen and Platania (1988) and Platania (1991). Platania is currently conducting additional work which will provide data on the fisheries for the Rio Grande (S. P. Platania, University of New Mexico, Albuquerque, pers. comm., 1994). Table 17 provides the most current information on fish species in the Big Bend National Park and the Rio Grande Wild and Scenic River.

A comparison of the more recent inventories (Bestgen and Platania, 1988) with the earlier survey by Hubbs, *et al* (1977) indicate that the icthyofauna of the Rio Grande upstream from the Rio Conchos have changed little since 1977 (NPS, 1992). The species of this community are resistant to the effects of reduced flows, high salinity, and temperature extremes. Since 1977, fish species diversity has decreased below the confluence of the Rio Grande with the Rio Conchos (Bestgen and Platania, 1988). Large amounts of black, anoxic silts, which often typify heavy organic loading, have been noted below the Rio Conchos (Bestgen and Platania, 1988).

In addition to the above studies, a limited amount of information on other limnological and aquatic resources of Big Bend National Park is also available. These studies provide some baseline chemical and biological data primarily on the water sources near Rio Grande Village and the springs and ponds that support the endangered Big Bend *Gambusia* (Lind and Bane 1979, 1975). Some chemical and biological information is also available for Lower Tomillo Creek, Hot Springs, Cattail Falls, Boquillas Canyon Warm Springs, Ernst Tinaja, and Boot Springs.

Table 17. Fishes of Big Bend National Park and the Rio Grande Wild and Scenic River

TAXA, COMMON NAME	**SCIENTIFIC NAME**	**ORIGIN**	STATUS
Sturgeon *(Acipenseridae)*			
Atlantic Sturgeon	*Acipenser oxyrhynchus*	Native	Very Rare FS-SC
Shovelnose Sturgeon	Scaphirhynchus platoynchus	Native	Extirpated
Gar *(Lepisosteidae)*			
Alligator Gar	*Atractosteus spatula*	Native	Extirpated
Spotted Gar	*Lepisosteus oculatus*	Native	
Longnose Gar	*Lepisosteus* osseus	Native	
Eel *(Anguillidae)*			
American Eel	*Anguilla rostrata*	Native	Extirpated
Shad *(Clupeidae)*			
Girard Shad	*Dorosoma cepedianum*	Native	
Threadfin Shad	*Dorosoma* petenense	Introduced	
Minnows *(Cyprinidae)*			
Mexican Stoneroller	*Campostoma omatum*	Native	US-2, TX-T, AFS-SC
Red Shiner	*Cyprinella lutrensis*	Native	
Blair's Red Shiner	*Cyprinella lutrensis blairi*	Native	Extirpated, US-3A
Blacktail Shiner	*Cyprinella* venusta	Introduced	
Common Carp	*Cyprinus carpio*	Introduced	
Roundnose Minnnow	*Dionda episcopa*	Native	
Silvery Minnow	***Hybognathus amarus***	Native	Extirpated, US-1, AFS-SC
Speckled Chub	***Macrhybopsis aestivalis***	Native	
Tamaulipas Shiner	*Notropis braytoni*	Native	
Chihuahua Shiner	*Notropis chihuahua*	Native	US-2, TX-T
Rio Grande Shiner	*Notropis* jemezanus	Native	US-2, AFS-SC
Phantom Shiner	*Notropis orca*	Native	Extirpated,TX-E, AFS-Ex
Bluntnose Shiner	*Notropis simus simus*	Native	Extirpated,TX-E, AFS-Ex
Fathead Minnow	*Pimephales promelas*	Native	
Bullhead Minnow	***Pimephales*** *vig lax*	Native	
Longnose Dace	*Rhinichthys cataractae*	Native	
Suckers *(Catostomidae)*			
River Carpsucker	*Carpiodes carpio*	Native	
Blue Sucker	*Cydeptus elongates*	Native	US-2, TX-T, AFS-SC
Smallmouth Buffalo	***Ictiobus bubalus***	Native	
Black Buffalo	*Ictiobus niger*	Native	
West Mexican Redhorse	*Moxostoma austrinum*	Native	
Gray Redhorse	*Moxostoma congest=*	Native	AFS-SC
Characins *(Characidae)*			
Mexican Tetra	Astyanax mexicanus	Native	
Catfishes *(Ictaluridae)*			
Blue Catfish	*Ictalunufurcatus*	Native	
Headwater Catfish	*Ictalurus lupus*	Native ?	US-3C, AFS-SC
Channel Catfish	*Ictalurus punctatus*	Native	
Flathead Catfish	*Pylodictis olivaris*	Native	
Killifishes ***(Cyprinodontidae)***			
Plains Killifish	*Fundulus* zebrinus	Native	

Table 17. Fishes of Big Bend National Park and the Rio Grande Wild and Scenic River (continued)

TAXA, COMMON NAME	SCIENTIFIC NAME	ORIGIN	STATUS
Livebearers *(Poecilndae)*			
Mosquitofish	*Gambusia affinis*	Native	
Big Bend Gambusia	*Gambusia gaigei*	Native	US-E,TX-E, AFS-E
Silversides *(Atherinidae)* Tidewater Silverside			
	Menidia beryllina	Introduced	
Temperate Basses *(Percichthyidae)* Bass White			
	Morone chrysops	Introduced	
Sunfishes *(Centrarchidae)* GreenWarmouth Sunfish Bluegill Redear Sunfish Largemouth Bass			
	Lepomis cyanellus	Introduced	
	Lepomis gulosus	Introduced	
	Lepomis macrochirus	Introduced	
Drums *(Sciaenidae)* Freshwater Drum	*Lepomis microlophus*	Introduced	
	Miaopterus salmoides	Introduced	
Cichlids *(Gchlidae)* *Blue Tilapia			
	Oreochromis aureus	Introduced	

TX = State of Texas Listed US = Federally Listed
AFS = American Fisheries Society

T = Threatened E = Endangered

1 = Category 1
2 = Category 2
NOR = Notice of Review
SC = Special Concern

SOURCES:

Stephen Platania, University of New Mexico, Albuquerque, pers. comm.
* Robert Edwards, University of Texas, Pan American, Edinburgh, pers. comm.

Several fisheries and aquatic biology-related issues still need to be addressed and are discussed in Project Statement BIBE-N-567.001. These issues include the following concerns: 1) determining the reasons for, as well as the implications of, the decrease in the species diversity within the Rio Grande below the Rio Conchos, 2) assessing the effects of runoff events from intermittent streams which may result in fish kills (especially carp) after extended dry periods (M. Fleming, Big Bend National Park, pers. comm., 1994), and 3) assessing the potential risks associated with consuming fish caught in the Rio Grande within the Big Bend National Park (NPS, 1992).

Developed Water Supplies

As the reader will observe in the following sections on hydrologic resource development in the various development zones in the park, there are some common problems that suggest an integrated solution might be preferable to piecemeal solutions for individual areas. The most obvious example is in the monitoring and management of the quality of potable water supplies. All the development zones in the park (with the exception of Panther Junction, but including the Chisos Basin deep wells) have or may expect to have (at West Maverick) water supplies with high levels of dissolved solids, fluorides, or other dissolved materials that necessitate treatment or at least render treatment desirable. In the past, the Park Service addressed this problem (at Castolon) by equipping each residence with "under the counter" reverse osmosis treatment units. The primary drawback to this approach is that each resident was responsible for servicing his own unit. Another reason for the failure may have been related to the mineralization of the source water. Manufacturers of similar reverse osmosis units, in reviewing the water quality data for Castolon, have indicated the operation of the units could be marginal unless the water were softened prior to treatment by reverse osmosis. In the case of Castolon, a very large and complex treatment system was installed, centralizing both the treatment and the maintenance of the system. The mismatch of system size and demand has led to a poor record of operation and high maintenance costs (both for equipment and material), as well as consuming about 75% of a dedicated technician's time.

One possible remedy to the park's water treatment problems might entail distributing treatment systems at or near points of use. By doing so, the maintenance could remain "centralized" in that one or two technicians could be tasked with maintaining all such units park-wide. Servicing of such distributed units in Castolon, Persimmon Gap, Rio Grande Village, and West Maverick should take no more than two or three days per month. The manpower savings would be significant, as the "centralized" maintenance of the distributed treatment system would require about 10% of the manpower currently devoted to the operation of the Castolon system alone. In this Water Resources Management Plan, a recommendation is made specifically for Castolon, though if local supplies are sought at Persimmon Gap and West Maverick, the same recommendation would apply to those areas.

Castolon

Nestled on the bank of the Rio Grande, in a broad valley just downstream from the mouth of Santa Elena Canyon, the Castolon Historic site is a National Register property that forms one of the major visitor attractions in the western part of Big Bend National Park. The site is nationally significant for its historic association with early 1900's development along the United States-Mexico border. It has additional state and local significance for its association with the Hispanic cultural influence on local architecture and for its association with early 20th century economic development of the Big Bend region.

The site contains structures that were built by the U.S. Army and were converted to commercial enterprises and residences beginning in the 1920's. The Castolon area is a destination for a large percentage of park visitors. In addition, Castolon serves as a popular "take-out" point for raft trips through Santa Elena Canyon.

Hydrogeology of the Castolon Area. Water occurs in the floodplain alluvium under water table conditions, and is hydraulically connected to the Rio Grande. The water in the aquifer is of poor quality, with high levels of fluoride, sulfates, total dissolved solids, and in one well, iron (NPS, 1980b). The quality of the ground water in this system suggests that water may be escaping from the underlying consolidated rocks as well, and thus the water in this system is a mixture of ground water from the underlying bedrock units and surface waters infiltrating from the Rio Grande. The prospects for finding a major local water supply with better quality water appear doubtful. Therefore, the recommended management options for the water supplies of Castolon will focus on feasible options for water supply, treatment, and monitoring.

Castolon Irrigation Project Water Right. The National Park Service holds a water right for diversion of water from the Rio Grande River in the Castolon and Rio Grande Village areas of Big Bend National Park. The right, under Permits 125 and 927, was recognized in a final decree of the 201st District Court of Travis County, Texas (Cause No. 245,154, *In Re: The* ***Adjudication*** *of Water Rights in the Upper Rio Grande and Tributaries of the Rio Grande Basin,* August 13, 1976), described in Certificate of Adjudication, No. 23-987, (issued August 18, 1977) and amended June 5, 1989 (Certificate No. 23-987 A).

The amended Certificate of Adjudication (Certificate No. 23-987 A) allows diversion in the Castolon and Rio Grande Village areas of (1) 530 acre-feet per year for municipal purposes and (2) 1,000 acre-feet per year for irrigation of 227 acres of land (campgrounds and peripheral areas) owned and operated by the National Park Service.

The priorities pertaining to the amendment are as follows:

- November 17, 1915 — for the first 750 acre-feet of the 1,000 acre-feet of water for irrigation purposes; and
- October 5, 1925 — for the next 250 acre-feet of the 1,000 acre-feet of water for irrigation purposes, and for the 530 acre-feet of water for municipal purposes.

The amendment is subject to the terms and conditions of the original Certificate of Adjudication (except as specifically amended), and ". . . all superior and senior water rights in the Rio Grande Basin" (Certificate No. 23-987 A).

Historical Development. The potable water supply at Castolon presently is derived from three wells (a fourth well has a collapsed casing and is no longer in use), as shown in Figure 25. The combined capacity of the wells is about 25-30 gallons per minute (gpm) and all are connected to the treatment facility for potable water supply. In addition, one irrigation well with a capacity of about 250 gpm currently satisfies irrigation requirements at the campground. The well water used for potable supply has been treated by an electrodialysis system in the past. This system, however, has failed and is presently not operational. Consequently, chlorination is the only treatment at the present time.

The potable water supply serves day visitors, the campground, resident staff, and the general store and apartments at Historic Castolon (see Figure 25). The Castolon area is frequented by many day visitors, with a high seasonal fluctuation and a peak in spring, around the time of spring semester break from colleges and universities (usually mid- to late March). The campground has no bath facilities or running water; vault toilets are used, and "drinking water only" is provided through spring-loaded faucets. Water for resident housing is stored in two 10,000-gallon tanks at the maintenance yard. Nine residents currently occupy the housing, which includes four single-family houses and two duplexes. Housing units currently are not equipped with water conservation devices. At Historic Castolon, two resident food-service personnel live in the apartments, and drinking water is provided at the historic area by means of spring-loaded faucets. Wastewater disposal is accomplished entirely by septic tanks and seepage pits.

Water Quality and Special Monitoring Needs. Table 18 shows examples of water quality analyses from the water supply wells. Data for wells no. 1, no. 2, and no. 3 for 1991 are drawn from a report prepared by the U.S. Public Health Service (Sacoman, 1991). Data from 1994 well samples (Figure 25 and Table 18) indicate excessive concentrations of the following constituents: alkalinity for Well No. 3; fluoride for Well No. 3; hardness and iron for Well No. 1; sodium for all wells; sulfate for all wells; total dissolved solids for all wells. Applicable water quality standards and Park Service guidelines are listed in Appendix H.

The quality of water pumped from wells at Castolon is essentially equivalent to that of the Rio Grande adjacent to the wells because the wells tap the alluvium that is in hydrologic connection with the river. Since the quality of the Rio Grande is highly variable and unexpected contaminants may readily appear in the river, the issue of monitoring the quality of water pumped from the Castolon wells is quite complex. Water quality monitoring of a supply for a specified use serves several purposes: (1) to establish a continuing baseline record of quality; (2) to determine changes, extreme values, and trends in values of the measured parameters; and (3) to identify concentrations of constituents that exceed criteria or standards for that use. A water quality monitoring program must determine (a) which parameters are to be monitored by sampling and analysis, (b) frequency of sampling, and (c) spatial distribution of sampling points. All of these variables directly affect costs. The recommended program must be sufficiently comprehensive to yield the requisite data to 1) protect the health and safety of National Park Service employees, their families as well as park visitors; and 2) assure compliance with Federal and State of Texas water quality monitoring requirements. At the same time, the program must be sufficiently constrained so as to remain feasible within the financial and other limits of the responsible agency.

In the instance of Castolon, even a rigorous water quality monitoring program may miss potential contaminants simply because they were not anticipated and therefore were not incorporated into the monitoring protocol.

Table 18. Water Quality in Castolon Wells

Constituent	Units	Well No. 1 1991 °	Well No. 1 1994[6]	Well No. 2 1991 °	Well No. 2 1994[b]	Well No. 3 1991 °	Well No. 3 1994[6]	Texas Drinking Water Standards`
Alkalinity **(dissolved** as $CaCO_3$)	mg/l	---	224	---	**364**	---	**508**	**N/A**
Alpha, dissolved	pc/l	---	<4.1	---	15±5.0	---	29±7.0	**N/A**
Aluminum, dissolved	pg/l	---	<20.0	---	**<20.0**	---	**<20.0**	**50-200**
Arsenic, dissolved	pg/l	---	**10.4**	---	**<2.0**	---	**6.4**	50
Barium, dissolved	pg/l	---	76	---	**55.4**	---	**43**	**2000**
Beta, dissolved	pc/l	---	**<4.3**	---	**15±4.0**	---	21 ±3.0	**N/A**
Bicarbonate	mg/l	---	**273**	---	**445**	---	**646**	**N/A**
Bromide, dissolved	mg/l	---	**0.49**	---	**0.33**	---	**0.3**	N/A
Cadmium, dissolved	pg/1	---	<0.5	---	<0.5	---	**<0.5**	5
Calcium	mg/l	---	**197**	---	**94**	---	**49**	**N/A**
Carbonate	mg/l	---	0	---	0	---	0	N/A
Chloride	mg/l	---	190	---	**125**	---	81	**300**
Chromium, dissolved	pg/l	---	**<10.0**	---	**<10.0**	---	**<10.0**	**100**
Copper, dissolved	pg/l	---	<4.0	---	**<4.0**	---	**<4.0**	**1000**
Conductivity	pmhos/cm	---	**1790**	---	**1766**	---	1871	N/A
Fluoride	mg/l	---	**0.8**	**0.5**	**3.3**	3.7	**5.5**	**4.0**
Hardness (as $CaCO_3$)	mg/l	**660**	**588**	---	281	---	147	N/A
Iron	mg/l	**0.8**	**0.849**	---	**0.0217**	---	**<0.010**	**0.3**
Lead, dissolved	pg/l	---	<5.0	---	**<5.0**	---	**<5.0**	**50**
Magnesium	mg/l	---	23	---	11	---	6	N/A
Manganese	mg/l	---	**0.847**	**0.26**	**0.0216**	---	**0**	**0.05**
Mercury, dissolved	pg/l	---	<0.13	**5.5**	<0.13	---	**<0.13**	2
Molybdenum, dissolved	pg/l	---	**23**	---	**<20.0**	---	**<20.0**	N/A
Nitrate	mg/l	---	<0.0	---	1.8	---	8.1	N/A
Nitrate-nitrogen,	mg/l as N	---	<0.01	---	0.41	---	0	10.0
Nitrite-nitrogen,	mg/l as N	---	<0.01	---	0.01	---	0	1.0
Nitrogen-ammonia,	mg/l as N	---	**0.05**	---	**0.03**	---	**0**	N/A
pH	**---**	---	**7.36**	---	**7.34**	---	7.5	z7.0
Potassium	mg/l	---	**8.9**	---	6.7	---	**4.5**	**N/A**
Selenium, dissolved	pg/l	---	<8.0	---	**<8.0**	---	<4.0	**50**
Silica	mg/l	---	32	---	**25**	---	**63**	**N/A**
Silver, dissolved	pg/l	---	<10.0	---	<10.0	---	**<10.0**	**100**
Sodium	mg/l	**233**	210	**183**	**308**	**310**	**396**	**N/A**
Strontium	mg/l	---	2.3	---	1.1	---	0.7	N/A
Sulfate	mg/l	**644**	510	**432**	**430**	---	**384**	**300**
Total Dissolved Solids	mg/l	**1436**	**1308**	**1090**	**1224**	1027	**1315**	**1000**
Vanadium, dissolved	pg/l	---	<10	---	**32.4**	---	67	N/A
Zinc, dissolved	pg/l	---	**29.8**	---	115	---	**50**	**5000**

° **Source:** Sacoman, M.J., 1991, **Report on Survey of Environmental** Health Facilities - **Big Bend** National Park, TX. **Prepared** for the National **Park Service by** the Public Health **Service,** Santa **Fe,** NM. 15 **pp.** plus **app.**
[b] **Source:** National **Park** Service **Database** for Big **Bend** Notional Park.
` Community standards shown here; see **Appendix** II for non-community standards.

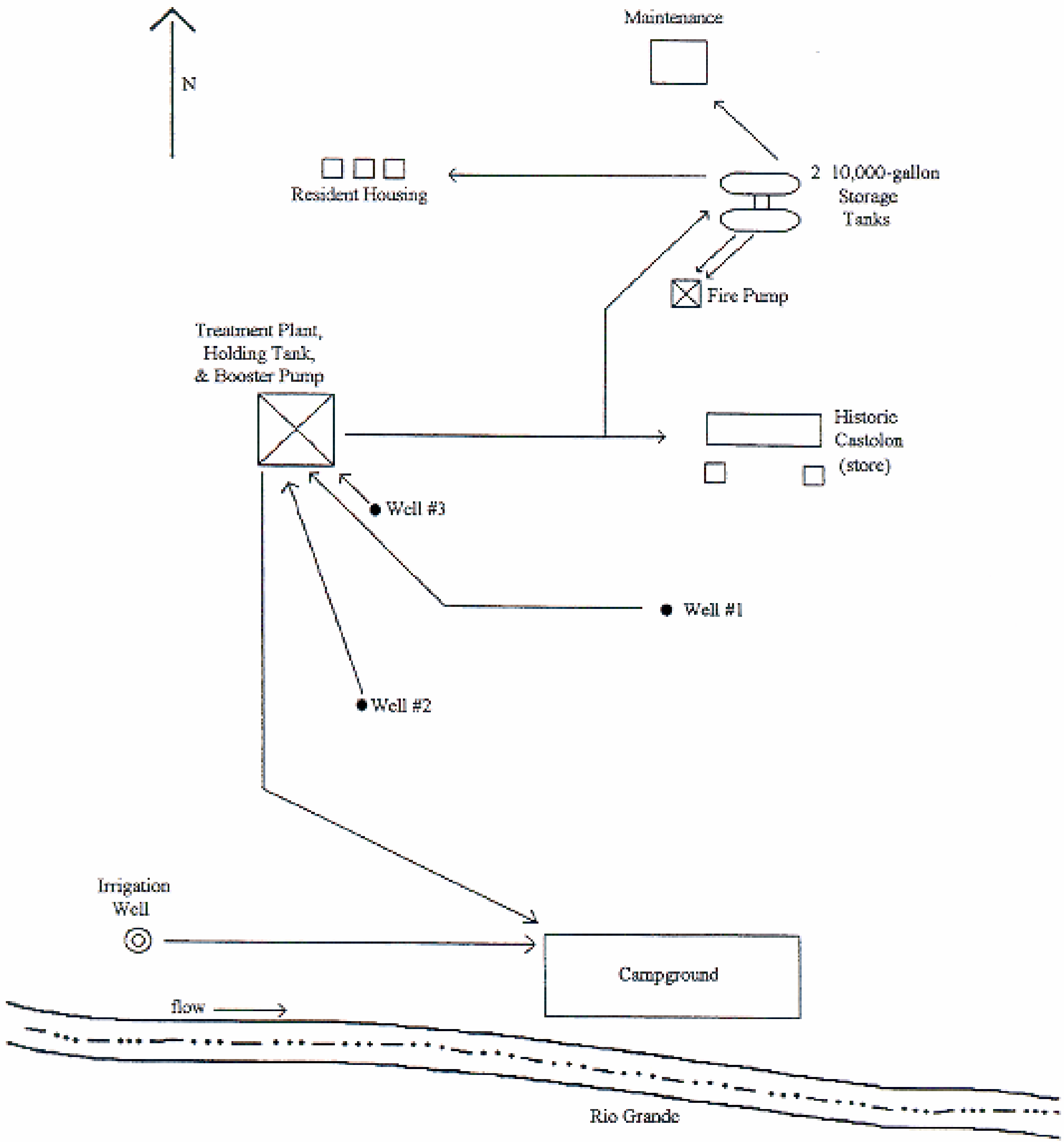


FIGURE 25. Schematic Diagram of Water System at Castolon

Thus, while a given sample of water from the Castolon wells may test below drinking water standards for specified constituents, the risk of the sample being unsafe for human consumption still exists. In order to assure public health in the absence of treatment to remove contaminants, a sufficient monitoring program would require well water sampling as frequently as bi-monthly, with the protocol including almost all substances known to pose any health hazard to humans. Obviously, such a program would entail enormous cost.

Table 19 presents the data on water quality in the supply system at Castolon after treatment. Sampling for disinfection treatment at Castolon is currently performed twice per month, which is adequate for the current "non-community" classification of the system.

Given the susceptibility of the water supply at Castolon to contamination from a broad spectrum of potential contaminants in the Rio Grande, the only reasonable options for potable water supplies are limited to treatment by distillation, reverse osmosis, or electrodialysis. The only other option is trucking water in from another source, but park personnel have indicated that this option is not acceptable (M. Fleming, Big Bend National Park, pers. comm., 1995).

Monitoring Program for Castolon. Maintaining the existing system (chlorination only) would require, at a minimum, monitoring of the following parameters:

Bacteriological: Two samples per month taken at equally spaced time intervals. All samples must be tested in laboratories certified by primacy agency.

Chemical: Groundwater analysis for primary constituents must be performed every three years. Secondary and general mineral analyses on ground water must be conducted every six years. However, since the ground water source in this instance is rapidly influenced by lateral migration of infiltrating stream flow from the Rio Grande, analysis for primary constituents should be made every year and analyses for secondary and general mineral constituents should occur every three years.

Organics: Public non-community transient systems must be sampled one time for pesticides, herbicides and PCB's. Samples from Castolon were tested for all volatile organics listed in the Public Health Management Guideline NPS-83 (NPS, 1993a) by January 1994 and additionally on a case by case, as-needed basis.

Repairing the electrodialysis system or replacing it with either centralized or distributed treatment systems using reverse osmosis or distillation would eliminate the requirements (and associated costs) for monitoring water quality in the water source to protect health and safety of the residents at Castolon.

Until an effective treatment system for the potable water supply at Castolon is operational, either truck potable water in from Panther Junction, or implement an aggressive bimonthly sampling program for the supply well analyzing for the entire spectrum of hydrophyllic contaminants that have appeared in the Rio Grande. Project statement BIBE-N-558.001 outlines the alternatives for obtaining a safe drinking water supply for Castolon. The recommended treatment system consists of water-softening systems at the residential area and in Historic Castolon which serve "point-of-use" distillation treatment units. Water from the Castolon wells should be adequate for non-potable uses.

Chisos Basin

The Chisos Basin lies in the heart of the Chisos Mountains in the central part of the park. The rugged and forested Chisos Mountains rise several thousand feet above the desert floor to form a natural focal point in stark contrast to the surrounding plains. The basin is a topographic and structural depression in the northwestern part of the Chisos Mountains surrounded by high peaks and ridges (Baker, et al, 1993). The cultural development in the basin consists of a motel, cabins, lodge and restaurant, store, ranger station, campground, horse corral, and sewage-treatment plant and lagoons. Development the basin is shown schematically in Figure 26.

Hydrogeology. The Chisos Basin looks, to a casual observer, very much like a volcanic crater which has been eroded to some degree. The western and northern parts of the "rim" are formed by intrusive igneous rocks of late Tertiary age that are all believed to be connected to a large deeply buried pluton. The southern and eastern parts of the "rim" consist of non-intrusive igneous and closely associated sedimentary rocks of an earlier Tertiary

Table 19. Water Quality in Treated Water Supply System at Castolon*

Constituent	Units	1990	1993	Texas Drinking Water Standards (Community)
Alkalinity (as $CaCO_3$)	mg/l	307	ND	N/A
Aluminum	mg/l	ND	<0.020	0.05-0.2
Antimony	mg/l	ND	<0.0020	0.006
Arsenic	mg/l	0.02	0.0041	0.05
Barium	mg/l	0.041	0.0168	2.0
Beryllium	mg/l	ND	<0.0003	0.004
Bicarbonate	mg/l	375	ND	N/A
Cadmium	mg/l	<0.005	0.0002	0.005
Calcium	mg/l	53	ND	N/A
Carbonate	mg/l	0	ND	N/A
Chloride	mg/l	112	ND	300
Chromium	mg/l	<0.02	<0.0040	0.1
Conductivity	pmhos/cm	1877	ND	N/A
Copper	mg/l	0.1	0.0793	1.0
Fluoride	mg/l	3.7	ND	4.0
Hardness (as $CaCO_3$)	mg/l	155	ND	N/A
Iron	mg/l	0..05	0.0955	N/A
Lead	mg/l	<0.0200	ND	0.05
Magnesium	mg/l	5	ND	N/A
Manganese	mg/l	<0.02	0.0024	0.05
Mercury	mg/l	0.0002	<0.00013	0.002
Nickel	mg/l	ND	<0.0050	0.1
Nitrate-nitrogen	mg/l	0.45	ND	10.0
Alkalinity (as $CaCO_3$)	mg/l	0	ND	N/A
pH	--	8.3	ND	z7.0
Selenium	mg/l	<0.002	<0.0020	0.05
Silver	mg/l	<0.010	<0.0030	0.10
Sodium	mg/l	310	ND	N/A
Sulfate	mg/l	354	ND	300
Total Dissolved Solids	mg/l	1027	ND	1000
Zinc	mg/l	0.08	0.613	5.0

'**Source:** Texas Department of Health, Division of Hygiene. 1991 and 1993. Water Analysis Report, Castolon Maintenance Area, Big Bend National Park.

ND: no data

N/A: no applicable standard

age. These rocks, in turn, overlie Cretaceous rocks which are primarily fine-grained sedimentary rocks. In the center of the structural basin, the non-intrusive igneous and sedimentary rocks of Tertiary age have been stripped, and the basin floor is primarily rock of Cretaceous age.

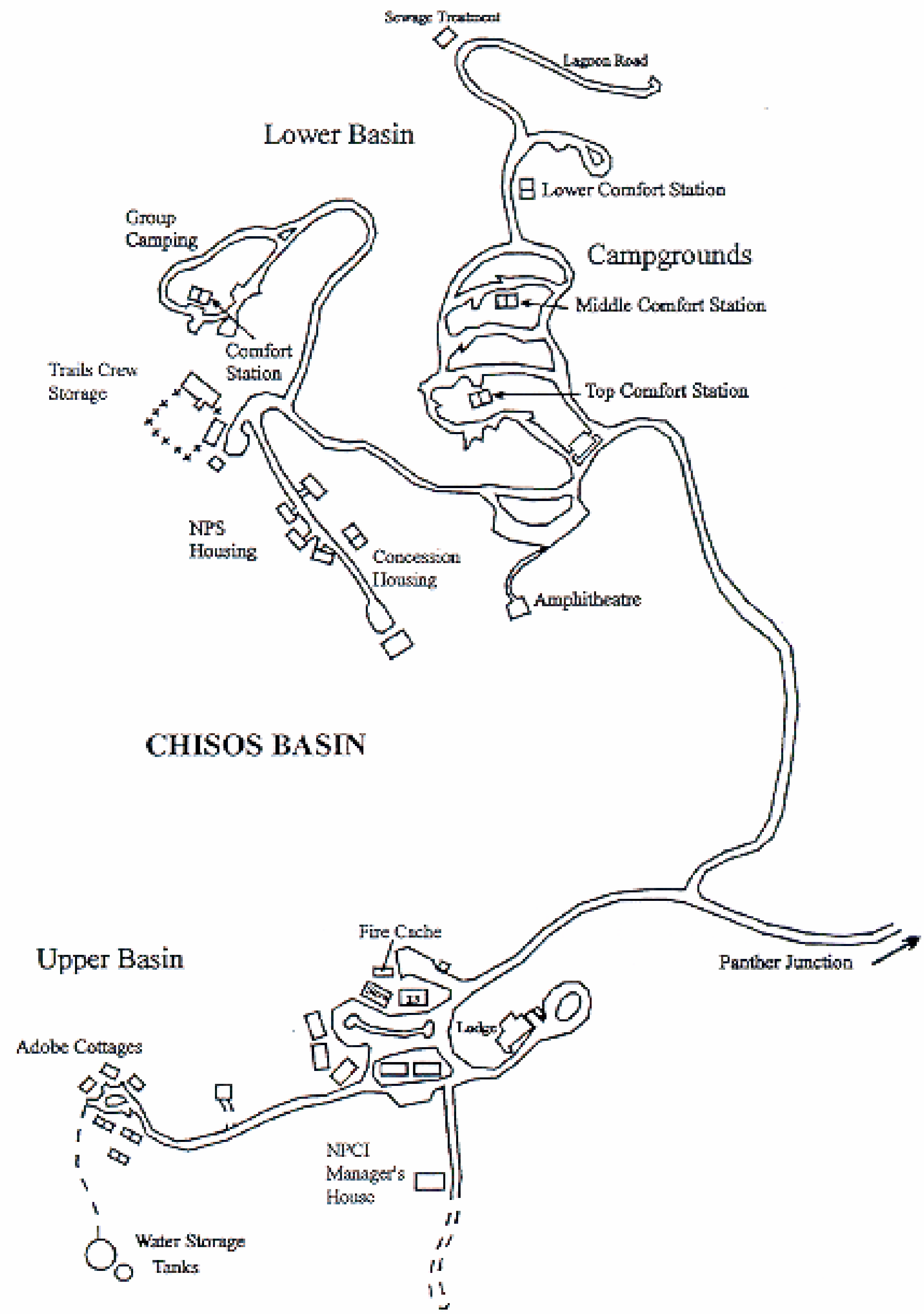
Talus, colluvial, and alluvial sediments of Quaternary and Recent age cover most of the surface, concealing the Cretaceous formations below. This mantle ranges in thickness from 0 to perhaps 100 feet, with the thickest areas most likely to be found along the natural drainages, such as upper Oak Creek. Baker, et al (1993) estimated the thickness of this unit at 50 feet in the vicinity of the lower CCC well. While all the rock units mentioned above are capable of yielding usable quantities of water in places, the "in places" qualification argues against classifying any of these formations as aquifers. Of the units discussed, the non-intrusive igneous and related sedimentary rocks of Tertiary age, and the Quaternary "mantle" offer the best opportunities for well development. The CCC wells along the course of upper Oak Creek probably obtain water from the saturated base of the "mantle" units. Baker, *et al* (1993) discussed this mechanism as their second hypothesis, preferring the hypothesis that the CCC wells penetrated an aquifer in the Aguja formation underlying the colluvial/talus mantle at that location. Since their seismic survey could not differentiate a thin saturated colluvium from the bedrock, and hand-dug wells like the CCC wells do not typically penetrate bedrock units, we prefer their second hypothesis. The Chisos Basin's surface drains to the west, and ground water in the deeper parts of the colluvial/alluvial mantle also drains in that direction. This ground water is the most likely source of the water for Window Spring.

Where saturated parts of the colluvial/alluvial mantle overlie the non-intrusive igneous rocks, water may move from the mantle downward into permeable layers in the eastward-dipping early Tertiary units and subsequently drain to the east, leaving the Chisos Basin in the subsurface, and perhaps contributing flow to springs in the drainages to the east such as Juniper and Pine canyons. Oak Spring, which is presently the water supply for the basin, is not hydraulically connected to the Chisos Basin, as the late Tertiary intrusive igneous rocks form a barrier to the westward movement of ground water from the basin. Baker, *et al* (1993) conducted a detailed evaluation of the Oak Spring system and concluded that Oak Spring was water discharging from a sandstone unit in the early Tertiary non-intrusive igneous and related sedimentary units that dip to the east and abut the intrusive igneous rocks. They postulate that the water reaching Oak Spring derives from a combination of waters from the Window pour-off and from precipitation falling on the talus/colluvium mantling the early Tertiary units with both waters percolating downward and laterally to discharge at Oak Spring.

Historical Development. This Chisos Basin Water System riparian water right (No. 38185) permits the detour of water from Cottonwood Creek through infiltration pipes in the stream bed below Cattail Falls and from Oak Spring by means of a collection box placed over the spring. A significant part of the flow of Oak Spring is gathered, stored in storage tanks, and pumped to the Chisos Basin for municipal purposes. Water is not being diverted from Cottonwood Creek at present. At the present time, water pumped from Oak Springs supplies the Chisos Basin demand (a schematic drawing of the basin area is provided in Figure 26). The spring is 2.47 miles west-north-west of the Chisos storage facilities. The spring's water is collected in a "capture box" equipped with a V-notch weir. Four pipes penetrate the Oak Spring mountain side and convey the spring discharge into the capture box. After passing through the weir, the water discharges through two outlet pipes. The south-facing pipe discharges the overflow and supplies water to the riparian vegetation in the valley below. The other pipe gravity feeds water west into the 25,000 gallon storage tank.

From the first storage tank, the water gravity feeds into the second (500,000 gallon) tank. Only half of the larger tank fills because the elevation of its top is ten feet higher than the overflow from the 25,000 gallon tank. Normally, the spring discharge exceeds the daily demands of the Chisos Basin, and the overflow from the 25,000 gallon tank drains into the stream channel of Oak Creek. Water from the 500,000 gallon storage tank is piped into the Oak Springs pumping station where two forty-horse-power pumps alternate lifting the water a total of 1,458 feet to the basin. They operate manually and are turned on whenever the water storage level in the Chisos Basin drops to 14 or 15 feet. The water is metered and recorded as it departs from the station.

Once the water is pumped from the station, the output pipe carries it east through a physiographic feature referred to as the Window. From there, the pipeline



Adapted from NPS, 1974.

FIGURE 26. Schematic Diagram of Chisos Basin

travels east-south-east until it arrives at the Chisos Basin storage facility. At this point the "upper" 500,000 gallon storage tank fills and the arriving water is metered and recorded. A second storage tank with a capacity of 100,000 gallons exists at this location but is not currently in use. From this storage facility, the water is gravity fed into the distribution system of the Chisos Basin.

The 500,000 gallon storage tank at Oak Springs is presently half full and the 100,000 gallon tank in the Chisos Basin is not in use. The pumping rate from Oak Springs required to satisfy the worst case scenario (120% of historic peak monthly demand) is 16.5 gpm (see Table 20). During times of drought, the spring's output has dropped to levels near this number. A peak demand period longer than one month would further reduce the water in storage, and at some point, would not be adequate for municipal supply and fire protection needs. To avoid this hazardous situation, the National Park Service would need to enact those elements of the "Water Conservation and Drought Contingency Plan" (Appendix V) that would impact Chisos Basin visitation and use.

Recommendations. Long periods of drought and high demand rates have been experienced in the park. Some action must be taken to ensure the normal operation of Chisos Basin and a water supply for the Oak Springs vegetation during these times. Simple and inexpensive modifications to incorporate available, but currently unused, storage capacity in the system can reduce the worst case monthly demand rate by 20% to 13.3 gpm. Project Statement BIBS-N-562.001 discusses this possibility.

Reactivating the upper and lower CCC wells, and incorporating them into the Chisos Basin supply could provide significant financial benefits, provided the wells suffer no contamination due to development in the Chisos Basin. While these wells are not drought proof, and the Oak Spring supply needs to be maintained, use of these wells in normal times can reduce the electrical power required for the Chisos Basin water supply by 50%. In 1993, the electric power cost for delivering Oak Spring water to the basin exceeded $12,000, so the potential savings is significant. Further, the CCC wells may be made more drought resistant. Project Statement BIBE-N-559.001 provides guidelines to:

- re-incorporate the CCC wells into the Chisos Basin water supply,
- evaluate the potential for deepening the CCC wells during a future drought,
- locate, test, and consider reincorporation of upper basin well #1 in the Chisos Basin supply.

Table 20. Worst Case Demand for Chisos Basin	
Maximum Distribution Demand Recorded (gallons per minute = gpm) (this value was recorded during the leak of 1993)	19.5
Assume peak demand at 120% of historic peak monthly demand (gpm)	23.4
Peak demand quantity for one month, 31 days (gallons)	1,045,000
Current Storage Potential Half of the 500,000 gallon tank at Oak Springs Full 25,000 gallon tank at Oak Springs Full 500,000 gallon tank in the basin Total Current Storage Available (gallons)	 250,000 25,000 500,000 775,000
Difference between demand and available storage	270,000
60% of storage tanks capacity (amount needed in tanks at end of month)	465,000
Total Deficit (gallons)	735,000
Pumping rate required from Oak Springs (gpm)	16.5

Maverick (Planned Entrance Station)

Big Bend National Park's General Management Plan calls for the development of a secondary entrance station located at the western boundary of the park (NPS, 1981). This development is likely to consist solely of an entry station and possibly a single residence. Such a facility would enhance the National Park Service's ability to provide public information and monitor visitation in the western portion of the park.

Hydrogeology. The Aguja Formation is the most likely source of a reliable water supply for the Maverick entrance station. In the mid-1960's, the U.S. Geological Survey conducted a water resources investigation and a test drilling program in concert with the National Park Service (Garza, 1966; Leggat, et al, 1968). Three wells, drilled to depths of 347 to 823 feet, were located near the Maverick station (see Appendix IV). All the wells yielded highly mineralized water, and thus any well drilled for the entrance station is likely to require some treatment to attain potable water standards. Wells finished in the Aguja Formation in this area have reported yields in the 10-gallon-per-minute range, far in excess of the anticipated demands at an entrance station. Rough Run, an alluvium-filled channel within three miles of the station, is another possible source of water. A number of known springs in the headwaters of this drainage, and the presence of phreatophytic vegetation in some reaches of this channel, suggest that a small amount of water may move through the alluvium at its base. Pumping the water over the distance from Rough Run to the entrance station would probably make this the most expensive alternative in terms of up-front capital costs, but the potential for obviating treatment may make this alternative the most cost effective one in the long term.

Recommendations. The development of a water supply for the Maverick Entrance Station to supply restroom facilities and drinking water for visitors and a domestic supply for the Park Service personnel manning the station (one household) would require a dependable supply of about two gallons per minute. Project Statement BIBE-N-556.001 addresses the potential location of a suitable water supply. If the recommended exploration in Rough Run is not successful, a well could be drilled at the entrance station. In that case, the culinary/drinking water supply coming from such a well would most likely require treatment (see previous discussion of recom-mended treatment system for Castolon). Alternatively, this supply could be trucked in and stored on site for use, as is presently done at the Persimmon Gap Entrance Station.

Panther Junction (Park Headquarters)

Panther Junction is the largest developed zone in the park in terms of resident population, and though not included in the scope of work for the development of this Water Resources Management Plan, project statement BIBE-N-560.001 has been prepared for the future evaluation of the water resources available in the area.

Persimmon Gap (Entrance Station)

The Persimmon Gap Entrance Station and a Visitor Contact Station are located at the northern extremity of the park, some 26 miles north of Panther Junction. The station has on-site housing for visitor station personnel, though at the present time, the station is unmanned a significant part of the time.

Hydrogeology. The oldest geologic formation exposed at the surface in Big Bend National Park is the Paleozoic Tesnus Formation. The overlying Cretaceous rocks are primarily of marine origin, and the water they contain is likely to be highly mineralized. The site schedule for a well (BK-73-23-801) drilled at the Persimmon Gap Entrance Station showed the well was drilled to a depth of 122 feet, and was believed to draw water from the Aguja Formation. Chemical analyses done on water from this well in August and December of 1953 show total dissolved solids (TDS) at about 5000 parts per million (ppm), with sulfate at about 3000 ppm. Another well (BK-73-23-802) was drilled into alluvial materials about 100 feet north of the channel in Santiago Draw, and about a mile to the south and west of the Entrance Station. This well was abandoned after penetrating a black shale at about 30 feet, and without encountering any saturated material in the alluvium. The best opportunities for discovering a water source with total dissolved solids, sulfate, etc. in acceptable ranges for drinking water without treatment probably lie along the thickest parts of the alluvium in the valleys. Searching for the deepest part of the alluvium along Santiago Draw might locate a source that is not too distant from the station. A better location would be along Nine Point Draw, close to its intersection with Highway 385. While this area is nearly four miles from the entrance station, the size of that drainage and the fact that its headwaters are in the Rosillos Mountains suggest it is more likely to have water (and in larger quantities) moving through the basal zones of the alluvium than would be expected in Santiago Draw.

Historical Development. The Persimmon Gap Entrance Station has historically been supplied with water trucked in from Panther Junction. The 52-mile round trip for the tank truck constitutes an incentive to find a local supply source. Earlier attempts, as in the cases of the two wells described above, have been unsuccessful. Although the deeper of the two wells might have a sufficient yield, the water would require treatment to achieve potability.

Recommendations. Explore the alluvium-filled draws for possible water supplies. Use of shallow seismic and/or resistivity equipment to make profiles crossing the washes at right angles would quickly locate the deepest part of the alluvium, and could possibly determine the degree of saturation. The Project Statement BIBE-N-556.001 addresses the issue of locating a suitable water supply. In the event that this effort is unsuccessful, treat the water from the existing well at Persimmon Gap using the same technology that is employed in the Castolon distributed system for culinary/drinking water.

Rio Grande Village (Boquillas)

Rio Grande Village (Figure 27) lies on the extreme southeast boundary of Big Bend National Park, roughly 20 miles from Panther Junction. Its facilities include a visitor center, residences, Class A and B campgrounds totaling 300 sites, a picnic area, a sewage treatment plant, a group campground, an amphitheater, a 25-site concession-operated RV campground, a store, and a gasoline station (NPS, 1992a). Located on the banks of the Rio Grande Wild and Scenic River, the village sits just a few river miles upstream from the mouth of the impressive Boquillas Canyon. The community's potable water supply comes from a partial diversion of Spring No.4, which also supports an important marsh ecosystem adjacent to the Rio Grande. Irrigation water for the village area is obtained from the Rio Grande by direct intake pumps and from two wells penetrating alluvium near the river (NPS, 1992). A refuge pond for the endangered *Gambusia gage;* is maintained by water from Spring No.1 (see Figure 27)

Hydrogeology. Rio Grande Village lies on unconsolidated sediments that have been deposited by the Rio Grande River and tributary drainages entering Rio Grande in a graben structure between what appear to be two northeasterly trending faults, one at the mouth of Hot Springs Canyon, and another just south of the campground. The eastern fault may be the conduit for the waters supplying the four springs on the eastern side of the Boquillas area, with thermal springs No. 1, No. 2, and No. 4 on the main fault plane and Spring No. 3 on a branch off the main fault. Spring No. 1, the source for the Gambusia Refugium, is the northernmost and highest elevation of the four springs. The long narrow ridge to the east of the Gambusia refuge pond appears to be a sliver of rock between the main fault plane and the branch plane. The driller's log for the "Gambusia Well" shows that the unconsolidated materials in this structure are at least 150 feet thick. Because the spring flows must rise up through the thick layer of unconsolidated sediments, their discharge zones are diffuse and actual openings are difficult to locate.

C.M. Fleming (Big Bend National Park, personal communication, 1994) indicated that Spring No. 2 and possibly Spring No. 3 had disappeared, possibly due to flooding by the Rio Grande, or possibly because of the diffuse nature of their discharge zones and the almost impenetrable vegetation they support. No data were found regarding the flow rate or water quality of Spring No. 2, but Leggat, *et al* (1968) reported a combined yield for springs No. 1, No. 2, and No. 4 as 150 to 200 gpm, and the site schedules for springs No. 3 and No. 4 show that S. Garza of the U.S. Geological Survey visited both springs in 1966 and estimated the flows of 50 gpm for Spring No. 3 and 30 gpm for Spring No. 4. Obtaining accurate discharge figures for these springs is probably impractical, but exact knowledge of the discharges may not be critical as the estimated discharge ranges far exceed the present needs of Rio Grande Village and the threatened Gambusia. The high temperature of the water (86-96°F) and the degree of mineralization (Table 21) suggest that the source of recharge is distant, and therefore, the fluctuation of springflow in response to even long term climatic fluctations will be subdued. This conclusion is further supported by Sepulveda (1984), who age-dated the spring waters and found them to be between 18,700 and 29,000 years old and of meteoric origin.

Historical Development. The Wedin Spring riparian water right (No. 5820) encompasses Springs No. 1 and No. 4 in the Rio Grande Village region, a small distance from the Rio Grande. Spring No. 4, the chief source for municipal and irrigation purposes, fills a 400,000 gallon storage tank. Water from Spring No. 1 is pumped to a small pond which provides habitat for the endangered Big Bend Gambusia. The outflow of Spring No. 4 supports another pond of the Big Bend Gambusia. Both populations need tepid water from the springs for their survival during cold weather (NPS, 1992).

In 1983, the "Gambusia Well" was drilled a few tens of yards northwest of the Gambusia refuge pond. The well was drilled with the expectation that the conduit feeding the springs would be encountered and that the head in that conduit would be high enough to cause the well to flow naturally, without having to pump water, to the refuge pond. While the concept is valid, the well might have been better located along the fault trace which could be approximated by a line connecting springs No. 1 and No. 4. Spring No. 4 is used as the supply for all non-irrigation use in Rio Grande Village, with the exception of the Barker House Research Station which has its own well. The supply provided by Spring No. 4 is pumped to a storage tank on a hill north of the Gambusia Refugium and distributed by gravity to all points of use in the Rio Grande Village. The water pumped from Spring No. 4 is metered at the pumphouse, and meters are installed at most points of use in the village. However, the addition of three in-line meters, as suggested in Project Statement BIBE-N-555.001, would be very useful in isolating leaks when they occur.

The National Park Service has a right to divert water from the Rio Grande River in the Castolon and Rio Grande Village areas (a total of 1,000 acre-feet for irrigation and 530 acre-feet for municipal purposes) described in Amended Certificate of Adjudication No. 23-987A. For a more detailed description of the amended certificate, please refer to the section entitled *Castolon Irrigation Project Water Right* earlier in this chapter. Irrigation supply is drawn directly from the Rio Grande at a pumping station below the mouth of Hot Springs Canyon. The high silt load of the Rio Grande has caused many problems for the Park Service, ranging from frequent pump servicing due to high wear rates on pump impellers to problems of disposing of the silt that rapidly accumulates in the settling ponds.

Recommendation. Irrigation supply should be obtained by refurbishing two existing wells, and if additional supply is needed, by drilling either a new well or constructing an infiltration gallery near the Rio Grande. The problems encountered with the existing system will continue, and there are simply no alternatives to reduce their impact as long as the irrigation supply is drawn directly from the river. Project Statement BIBE-N-561.001 address the problems with the irrigation supply.

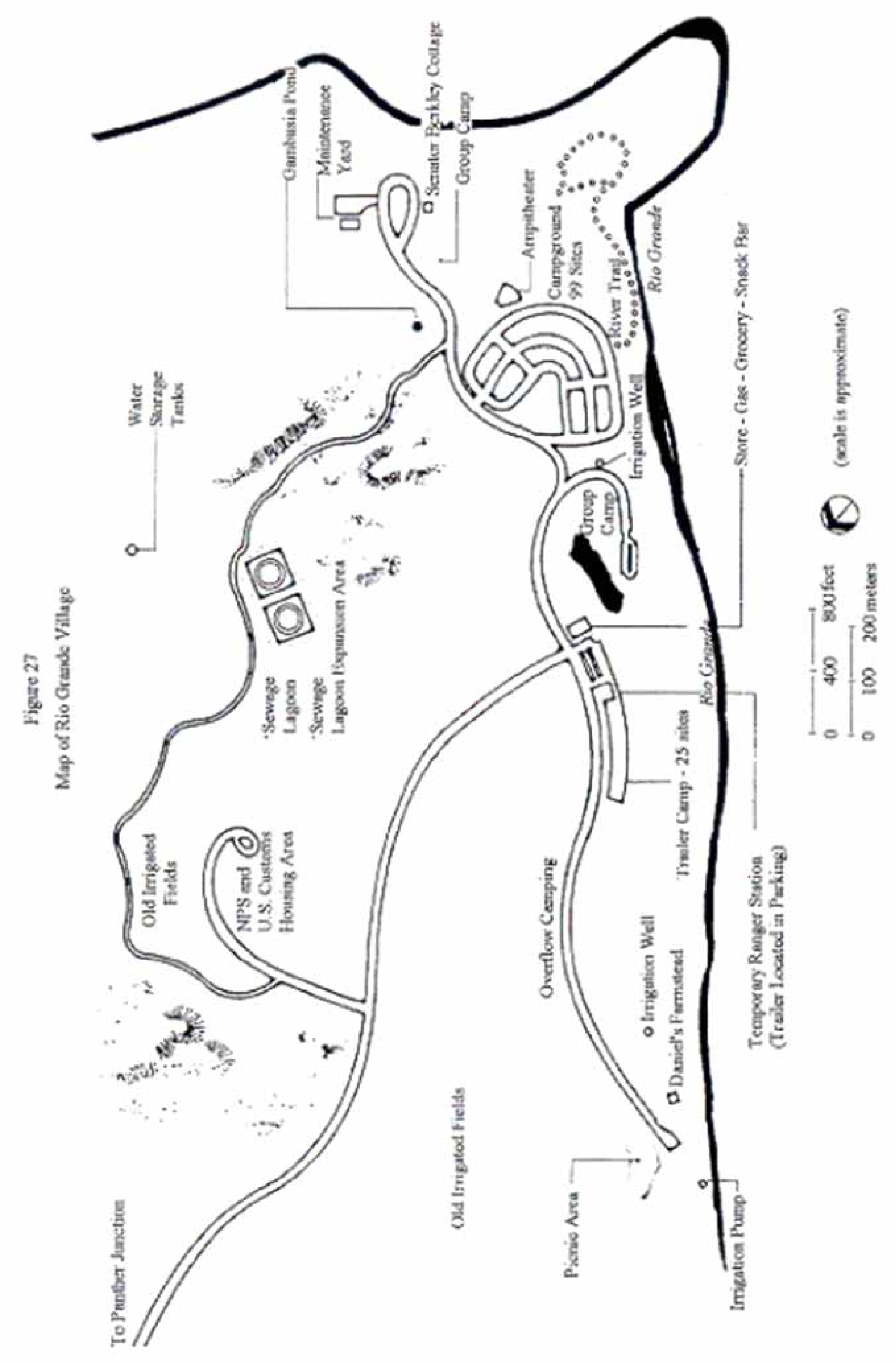


FIGURE 27. Map of Rio Grande Village

Table 21. Water Quality Data for Springs at Rio Grande Village/Boquillas										
Parameter	**Spring #1**		**Spring #3**		**Spring #4**					**Hot Spring**
Date	**7/13/60**	**6/5/87**	**6/15/64**	**3/12/65**	**7/18/56**	**7/13/60**	**6/15/64**	**3/12/65**	**6/5/87**	**8/15/53**
Flow (gal/min)	--	--	40	50 gpm	--	--	40	30	--	100+
Temperature	--	96 F	86 F	55 F?	--	--	84 F	55 F ?	96 F	--
pH	--	8.1	7	7.3	7.4	7.0	7.4	7.4	8.1	8.5
Report Units	ppm	mg/l	ppm	ppm	ppm	ppm	ppm	ppm	mg/l	ppm
Total Dissolved Solids	881	838	845	839	--	831	807	842	834	909
Specific Conductance	1200	1500	1150	1250	1220	1210	1100	1240	1503	1310
SiO_2	22	24	23	22	--	22	23	23	24	26
Fe	--	--	0.03	0.06	--	--	0.04	0.03	--	--
Ca	122	125	128	129	--	126	114	132	124	129
Mg	36	37	36	36	--	36	35	34	37	37
Na	--	99	--	96	--	--	--	96	96	--
K	--	6	--	6.1	--	--	--	6.0	6.0	--
Na+K	95	--	102	--	--	100	102	--	--	209
CO_3	0	0	0	0	0	0	0	0	0	16
HCO_3	268	267	270	269	264	266	222	268	267	499
SO_4	326	346	352	346	--	344	352	348	346	372
Cl	67	66	67	68	65	69	68	68	66	70
F	1.8	1.9	2.1	2.0	2.0	1.9	2.0	2.0	1.8	2.8
NO_3	1.8	1.8	1.5	1.2	--	1.5	1.5	1.1	1.8	0.8
Hardness as ($CaCO_3$)	452	465	468	473	460	462	428	468	462	474
Hardness (non-carbonate)	233	218	246	250	--	244	246	248	219	65

Source: Leggat, *et al*, 1968.

Water Resources Issues and Management

Chapter 4

Park-Wide Water Quantity and Flow Issues

The location of Big Bend National Park, in the heart of the Chihuahuan Desert climate regime and along the banks of one of North America's major continental drainage systems, predisposes it to periods of both drought and flooding. Like the natural ecosystems that survive in the park, the human population must adapt to the uncertainty of the climate. By planning for circumstances of both extremes, National Park Service managers can sustain an adequate water supply for both residents and visitors to the park.

While this Water Resources Management Plan deals primarily with water management issues within Big Bend National Park, the Project Statement BIBE-N-565.001 provides guidance for evaluating water use and supply outside the park in the Maverick and Persimmon Gap areas.

As part of an ongoing analysis of water resources within the Big Bend National Park, park personnel should routinely enter all water resources data acquired from field measurements (such as spring flow, well water quality analysis, precipitation, etc.) into the NWIS- I database maintained by the U.S. Geological Survey. Project Statement BIBS-N-569.001 recommends an appropriate course of action in this area.

Water Conservation

Water is a precious resource in the desert environment of Big Bend National Park and its frugal use is important in maintaining the park in as natural a condition as possible and in meeting the needs of park visitors and residents. True conservation involves the minimization of evaporative losses of water. For an environment like that in Big Bend National Park, conservation means minimizing outdoor uses of water. Xeriscape landscaping, dirty automobiles, the absence of gardens, lawns or swimming pools, and the treatment and reuse of waste water are direct evidence of water conservation in practice, whether purposeful or not. Reducing demand is frequently construed as conservation, though if the results of demand reduction do not reduce evaporative losses, they achieve little in support of water conservation.

Drought contingency planning should be considered a normal part of existence in any desert environment. The first step of preparing for a water shortage is conservation in times of plenty. Many of Big Bend National Park's human residents and visitors come from humid climates, where water is relatively plentiful. Consequently, they have come to the desert southwest with a culture and associated habits that are not compatible with the desert's limited water availability. Few are aware of the limited amount of ground water recharge that occurs, and view reservoirs tapped by wells and springs as "inexhaustible supplies." In fact, regardless of the size of the reservoir, outflow eventually and inevitably will be limited to the amount of inflow. In order to provide the greatest number of people an opportunity to enjoy the park's spectacular beauty, education of both residents and visitors on the practice of water conservation is essential. For residents, economic incentives and disincentives also may be utilized in concert with educational efforts to promote water conservation.

Additional (and important) conservation can be achieved through careful analysis of meter data in the water distribution system, and frequent inspection of campground and other visitor-accessible facilities to detect leaking faucets, toilets, etc. The 1993 leak in the Chisos Basin system was detectable from the meter data and approximated a 3-gallon-per-minute loss. Though finding the leak would have been difficult without more inline meters to segment the distribution system, just knowing that a leak of that magnitude existed would have increased the awareness of park personnel. A similar analysis of the 1994 data for Panther Junction would reveal the magnitude of a leak which plagued that system for an undetermined time.

Recommendations for Promoting Water Conservation. The "Water Conservation and Drought Contingency Plan" included as Appendix V in this Water Resources Management Plan provides a five phase program of conservation and drought contingency planning. In addition to the routine conservation practices outlined in Phase I of the Water Conservation and Drought Contingency Plan, the following recommendations may be used to enhance conservation efforts.

1. Education:

a. Obtain the series of water education posters produced by the American Water Resources Association and the U.S. Geological Survey and solicit local school districts to incorporate these training devices in the elementary grades.

b. Incorporate water conservation reminders and tips in internal periodic publications such as newsletters for National Park Service residents.

c. Prepare brochures on water conservation for visitors, including suggestions on how they can practice conservation and encouraging them to promptly report leaks in water facilities.

d. Place conservation reminder placards in all pubic access water facilities.

e. Prepare records of water use at residences to demonstrate patterns and quantities of use.

2. **Economic Incentives:**

a. Establish rate structures that increase the cost of water as the amount used per capita increases.

b. Offer rewards for water saving suggestions that are implemented and do save water.

c. Offer discounts on water bills that demonstrate a reduction from the historic use levels (see part `e' in section 1 above).

d. Offer to subsidize innovative water harvesting investments made by residents.

3. Management Policy

a. Eliminate irrigated landscaping from all official Park Service facilities.

b. Retrofit facilities to separate grey waters and harvest roof runoff for vehicle washing and other essential but non-potable outdoor uses, including recharge basins.

c. Discourage, or mandate the elimination of, lawns and other non-native vegetation in landscaping at residences and concessions.

d. Discourage or strictly limit outdoor gardening.

Monitoring Flows on the Rio Grande

The Rio Grande attracts a large number of park visitors with river related recreation interests. The flow of the river can vary widely, with high flows creating hazardous situations for river users, and low flows creating portaging problems. In addition, the quality of the river water varies considerably, with low flows being of such poor quality that bodily contact may, on occasion, be unadvisable. The park maintains stage gages at Castolon and Rio Grande Village which are read daily. These data, along with data from the International Boundary and Water Commission (IBWC) at Presidio, Terlingua Creek, Lajitas, Johnson Ranch and Dryden, are made available from the park to the public and commercial river users. While the present system does not provide the ability to advise river users on the time of arrival of flood peaks moving down from the upstream stations, nor provide any information on how "high" the peak flow will be in the park, the U.S. Section of IBWC may be able to assist in this matter U. Robinson, U.S. Section IBWC, 1996, pers. comm.).

Areas along the Rio Grande are unavoidably subject to periods of drought and floods because of highly variable rainfall and runoff rates and volumes. Although the Rio Conchos is the source of almost all the flow reaching Big Bend National Park, only one of the six storage and flood-control structures on that river system has control gates. The levee system of the Presidio-Ojinaga Valley Flood Control Project, built to protect agricultural lands in that area, provides a mechanism for conveying flood waters out of the Rio Conchos valley but provides no mitigation of flooding downstream from the project.

Recommendations Related to Irregular Flows on the Rio Grande. Potential strategies for coping with irregular flows on the Rio Grande at Big Bend National Park include actions that can be implemented by the National Park Service or that the Park Service can persuade others to institute on a cooperative basis. These actions, summarized here, are discussed in greater detail in Project Statement BIBE-N-551.001.

- Educate public on low-flow and flood hazards through information leaflet distribution and with posted warning signs at boat launch sites and popular recreation areas.
- Communicate and cooperate with the International Boundary and Water Commission to maintain minimal flows at the park during low-flow periods.
- Survey floodplain zones in critical areas such as campgrounds (see Project Statement BIBE-N-5 5 3.001)
- Take nonstructural and low-cost structural measures to protect flood-prone high use areas.
- Monitor National Weather Service severe weather and flood warning broadcasts for Amistad
- Reservoir and use as an early warning system for the park.
- Train park personnel for flood contingency.
- Use U.S. Geological Survey National Water Information System data from telemetered stations upstream of the park (as far as the Rio Conchos) in conjunction with studies of flood wave propagation along the park boundary to correlate water levels and corresponding discharges at key gaging stations between Presidio and Rio Grande Village (see Project Statement BIBE-N-552.001).
- Develop multiple-regression equations to estimate peak streamflow frequency for ungaged washes in Big Bend National Park (see Project Statement BIBE-N-564.001).

Park-Wide Water Supply Issues

Maintaining potable water supplies for the Chisos Basin, the Persimmon Gap Entrance Station, the planned entrance station at West Maverick, the Gambusia Refugium at Rio Grande Village, and Castolon is a fundamental concern for National Park Service management. All of the existing systems are vulnerable to failure, and in most cases, water trucked in from other areas constitutes the only emergency supply available. Even small leaks, such as in 1993 at Chisos Basin and in 1994 at Panther Junction, can strain the normal resources.

Recommendation for Monitoring Supply / Distribution Systems. The parkwide implementation of an effective water use monitoring program will reap important benefits in leak detection and will allow results of water conservation programs to be analyzed. When coupled with visitor use data, the monitoring program will also enable projections of trends in demand leading to *a priori* mitigation programs to modify such trends. Project Statement BIBE-N-555.001 has been developed to address this issue.

Site-Specific Water Supply Issues

Chisos Basin. The Chisos Basin supply and distribution system is the most vulnerable to failure in the park due to its age, the length of the pipelines, and the lack of an alternative supply on site. Further, due to the very high power costs for lifting water from the source at Oak Spring, even small leaks can be very expensive.

Recommendations for the Chisos Basin Supply. The problem at Chisos Basin can be addressed by utilizing presently available storage and water sources, and by making improvements to those sources in the future (see Project Statement BIBE-N-562.001). The utilization of existing storage facilities is an inexpensive part of the solution. By itself, this process will reduce the required Oak Spring discharge by almost 30% while leaving the storage facilities at 60% full after a peak monthly demand 20% greater than historically experienced. Utilization of existing supplies, in particular the CCC wells in the lower basin, and perhaps Well No. 1 in the upper basin, would dramatically reduce the power costs (by 50%) involved with the Oak Spring supply. Provided that the quality of water from these sources is suitable, this process would provide the added benefit of creating some redundancy in the supply. Such redundancy is particularly important given the distance water is piped from Oak Spring and the problems of affecting speedy repairs in the event of a failure. In the event of drought, efforts to deepen the CCC wells to make them more drought resistant, and to improve the efficiency of the capture box at Oak Spring, should be considered. Project Statement BIBE-N-559.001 has been prepared to outline the steps to implement these improvements.

Entrance Station Supplies. Similar problems affect the two entrance stations. Aquifer zones that have been tapped in formations at or near those sites produce highly mineralized water that would require treatment to achieve potable standards. While sufficient quantities of water can be produced to meet the minimal needs of the entrance stations (1/2 gallon per minute will produce 770 gallons per day) the water would have to be softened prior to treatment by reverse osmosis or distillation. Since reverse osmosis produces 3 gallons of waste for every gallon of treated water, if the yield of the well is marginal for meeting the needs at the station, treatment by distillation would be the preferred alternative. The possibility of finding better quality water in washes within four miles of the entrance stations does exist. While the cost of running a pipeline form these potential sources would be a large capital investment, obviating the need for treatment could make the long term cost lower.

Recommendation for Entrance Station Supplies. As the maintenance of any water treatment system represents a continuing long term cost in dollars and employee time, we recommend that a source of water that can be used without treatment be sought as a preferred solution. Project Statement BIBE-N-556.001 outlines a series of steps to take in evaluating a solution to the supply problem. In the event that such a supply is not obtainable, the treatment option may be revisited.

Rio Grande Village Supply Issues. Two primary water supply concerns affect Rio Grande Village. The first concern stems from the susceptibility of the supply mechanism for the Gambusia Refugium to mechanical and electric power failures. In 1983, a well was drilled to try to tap the source of Spring No. 1 (which supplies the Gambusia Refugium) in the hope that the hydrodynamic head of the well would be high enough to supply the refugium by gravity flow. The attempt was unsuccessful, and the supply to the refugium pond must be pumped from the springbox to the pond. The second issue at Rio

Grande Village involves the problems associated with direct diversion of irrigation water from the silt-laden Rio Grande. The centrifugal diversion pumps must be within 16 to 18 vertical feet of the water surface in the Rio Grande in order to pump water. Because the stage of the Rio Grande can vary over even a larger vertical range, the pumps are at risk of inundation when flood flows come down the Rio Grande. The high silt content of the Rio Grande flow quickly wears out the pump impellers in addition to creating a disposal problem as the settling ponds rapidly fill with the silt.

Recommendations for Rio Grande Village Supply Issues. While locating a well closer to the trace of the fault that conveys water to Springs No. 1, No. 2, and No. 4 to supply water to the refugium by gravity might still be a solution, a more direct solution could involve deepening, or developing, a new refugium pond whose water surface is lower in elevation than the water level in the springbox at Spring No. 1.

The recommended solution for the silt-plagued irrigation supply is to refurbish existing wells drawing water from the alluvium in hydraulic connection with the Rio Grande, or to drill a new well, or an infiltration gallery, if addition water is needed. Project Statement BIBE-N-561.001 addresses this issue.

Castolon. Water is supplied to Castolon from shallow wells which draw groundwater from the river alluvium of the Rio Grande. This magnitude of this supply is more than adequate for the needs of the residents of, and visitors to, Castolon, but the quality of the water limits its use for human consumption. Hence, the only issue concerning water supply at Castolon is that of providing sufficient potable water. Implementation of appropriate potable-water treatment systems at Castolon is discussed in the following section on water quality issues.

Park-Wide Water Quality Issues

Existing Water Quality Concerns and Contaminant Sources in the Rio Grande and Tributaries

Along both sides of the Rio Grande, diverse patterns of land and water use, particularly for irrigation and livestock watering, and locations of municipal and industrial water-using facilities, all contribute to a complex mosaic of water quality impacts in the region. Institutional controls on wastewater discharges, monitoring, and analysis share some common traits on the two sides of the border, but they also exhibit some notable differences in procedure and practice. The Rio Grande Basin suffers a strong need for upgraded or additional new treatment facilities as the population and industrial activity increase. The combination of an international boundary, the presence of a national park, and multiple federal and state agency jurisdictions pose a unique regulatory problem along the Rio Grande. Pollution cannot be confined by political boundaries; and effective monitoring and control requires international cooperation. Wastewater treatment facilities, water quality monitoring, and enforcement programs must be continually improved on both sides of the river.

In 1990 alone, approximately 200 spills and releases of toxic or hazardous compounds were reported to the Texas Water Commission in counties along the United States-Mexico border. Problems in the border counties include lack of awareness of environmental regulations and lack of resources to manage waste. Clandestine dumping of hazardous and nonhazardous wastes is common in the area. Historical contamination is widespread in agricultural areas of the Rio Grande Basin due to pesticide use. Landowners who have purchased contaminated property are often unwilling or unable to clean up sites. Pesticides left in place often impact both surface and ground water (TWC, 1992).

Nonpoint pollution from agricultural runoff in the Rio Conchos and Presidio regions may impact the Big Bend National Park area in terms of agricultural biocides and fecal coliform from trespass livestock and sewage treatment facilities. While urban storm-water runoff from El Paso probably has little or no impact on the park, future urban development along the Rio Conchos in Mexico or in the Presidio, Texas area should be monitored in this regard. On-site sewage disposal in small communities such as Terlingua and Lajitas, may also be a source of nonpoint pollution into the Rio Grande.

On-site sewerage facilities in colonias and other small settlements along the border between Presidio and La Linda pose a potential threat to water quality in the Rio Grande near the park. The substandard design of these typically owner-built systems, combined with the common practice of applying untreated or partially treated wastewater to the surface, and the proximity of many settlements to the Rio Grande, all contribute to elevated levels of fecal coliform in the river.

Out of approximately 3,535 maquiladoras in Mexico, an estimated 635 maquiladoras are located along the Texas/Mexico border (TNRCC, 1994a). About 450 of these are registered with the Texas Natural Resources Conservation Commission. The waste returned to Texas for disposal consists of a wide universe of chemicals, including solvents, paints, inks, liquids, solids, and heavy metals (TWC, 1992). Suspected illegal dumping and/or improper handling of hazardous wastes from these operations poses a significant threat to water quality in the Rio Grande at Big Bend National Park.

Based on an assessment of existing data, Table 22 summarizes the principal water quality contaminants of concern at key sampling sites along with their probable sources. This information sets forth general conclusions and recommendations for action that would work toward mitigation or solution of known and suspected water quality problems.

Potential Risks of Exposure
Based on Available Water Quality Data

The extent to which contamination of the Rio Grande from both the Mexican and United States sides of the river contributes to the overall cause of waterborne disease in the Rio Grande Basin is unknown. Data on infectious diseases in the border states probably represent only a fraction of the true incidences of disease. The available surveillance information also often lacks the specificity needed to distinguish diseases. Every measure must be taken to prevent existing and future contamination of the river from all sources. Water in the river will be easier to treat to the level of drinking water standards when contamination is low (IWC, 1992).

Water-related diseases remain a major problem in the Rio Grande Basin. Water-borne diseases in the area may be related in part to the large fraction of people living in houses without piped water and adequate sewage disposal systems. Improvements in wastewater facilities and public education are important in the eradication of water-related diseases. The United States and Mexico must place special emphasis on the protection of the quality of surface and underground waters in the basin and early detection of water-borne disease outbreaks in order to prevent their spread (Eaton and Andersen, 1987).

High fecal coliform levels in water are unacceptable for public water supply, recreation, and irrigation, especially of food crops. The health hazard risk increases significantly as the geometric mean of fecal coliform levels reaches or exceeds 2,000 colonies/100 milliliters of water. Water exhibiting fecal coliform concentrations above 1,000 colonies/100 milliliters may adversely affect human health when used to irrigate crops which would be consumed by humans. The Texas Surface Water Quality Standards for "contact recreation" in the Rio Grande list a limit of 200 colonies/100 milliliters (see Table 2 in Chapter 2). The extent of toxic substances and pesticide contamination in the Rio Grande are only recently being studied and documented in a comprehensive way (IBWC, *et al,* 1994). It is generally agreed, however, that the occurrence of these substances in water used for public water supplies, livestock watering, and irrigation can be harmful depending on the level of the concentrations found.

Impact of Rio Grande Water Quality on
Faunal Composition

Human activity is also increasingly shaping the faunal composition in the Rio Grande Basin. According to Edwards and Contreras-Balderas (1991), a combination of decreasing stream flow, increasing water pollution, and the proliferation of exotic species has resulted in a change in the ichthyofauna of the international portion of the Rio Grande. Reservoirs on the Rio Conchos and the Rio Grande have led to a loss of stream habitat, an increase in pooled habitats which often are unavailable for colonization, and additional impacts which influence the fish communities of much of the Rio Grande. The loss of the flood/drought cycle in the river could account for the new preponderance of exotic species; the occasional disruption being a condition to which native species had adapted and that might have kept non-native species in check (Edwards and Contreras-Balderas, 1991).

Several fish species have been extirpated due to habitat alterations (see Table 18 in Chapter 3), including the endangered silvery minnow *(Hybognathus amarus)* and the Rio Grande bluntnose shiner *(Notropis simus simus).* Although no longer found in Big Bend National Park, the Rio Grande bluntnose shiner *(Notropis simus simus)* was

Table 22. of Water at Key Stations

Location (IBWC Station)	Contaminants of Concern	Probably Source of Contaminant	Recommendations Data Needs/Actions
Rio Grande upstream from Rio Conchos (3)	Fecal coliform Turbidity Cl SO4 Toxic substances Nutrients	Human/animal fecal waste Soil runoff Natural deposits and runoff Natural deposits Industry Sewage treatment/disposal	
Rio Conchos upstream from mouth (3a)	Toxic substances As Nutrients	Natural deposits, smelters, and other industry Industry Sewage treatment/disposal	Additional data collection efforts
Rio Grande downstream from Rio Conchos (4)	Fecal coliform Turbidity SO4 As Hg Toxic substances Nutrients	Human/animal fecal waste Soil runoff Natural deposits Natural deposits, smelters, and other industry Natural deposits, crop runoff, and electrical components Industry Sewage treatment/disposal	Additional data collection efforts
Rio Grande at mouth of Santa Elena Canyon (5)	Fecal coliform Turbidity SO4 Nutrients	Human/animal fecal waste Soil runoff Natural deposits Sewage treatment/disposal	Additional data collection efforts
Alamito Creek (3b)	Fecal coliform DO[1] Nutrients	Human/animal fecal waste High nutrient levels Sewage treatment/disposal	
Terlingua Creek (5a)	Fecal coliform Hg Nutrients	Human/animal fecal waste Natural deposits, crop runoff, and electrical components Sewage treatment/disposal	Additional data collection efforts[2]

Data from Texas Natural Resource Conservation Commission, 1994a.
[2] Recommended by the authors of this report for additional monitoring because of uncertainty of effects of coliform from development along Terlingua Creek on water quality in the park.

found in the upper Rio Grande near El Paso. While these extinctions cannot be tied to one particular cause, they probably result from a combination of factors including loss of habitat due to reservoirs, channelization, irrigation practices, loss of spawning habitat and competition with introduced species led to their extinction. Springs of the Rio Grande Basin often produce spring pool habitats with a high degree of endemism. Reduced flow or cessation of flow in many of these springs is likely the result of increased ground water pumping. At present, several species endemic to spring systems of the Rio Grande Basin are classified as federal- or state-listed endangered or threatened species.

Another species of concern is the peregrine falcon *(Falco peregrinus)*, which resides permanently in Big Bend National Park. A study by Irvin (1989) reported the presence of DDE, a byproduct of the breakdown of pesticide DDT, in the tissues of insects, fish and birds in the Rio Grande Basin. Migratory birds may be exposed to DDT in Latin American countries where it is still used. Tributaries from Mexico, however, may be the primary avenue for the delivery of pesticides into the Rio Grande. Reports of raw sewage, poorly treated sewage, and industrial wastes being dumped into the river threaten the continued recovery of the peregrine falcon within the Rio Grande Basin (Irwin, 1989).

Current Water Quality Monitoring Programs for the Rio Grande

Population growth and industrial development have occurred over the last several years on both sides of the Rio Grande without adequate investment in the infra structure necessary to control the resulting pollution. Growth is straining the ability of local entities to fund pollution abatement or adequate water quality monitoring programs. The North American Free Trade Agreement promises to accelerate this growth, as does the shift from an agricultural to an industrial economic base (TWC, 1992).

Routine water quality monitoring in the Rio Grande and its tributaries has traditionally been limited in scope, and has been designed to detect violations of numerical water quality criteria and to measure long-term trends in conventional water quality parameters. Pollutant loading may have changed in the last few years. Today, a great potential for contamination exists, especially from the expanded manufacturing and development on both sides of the river. Manufacturing generates a wide array of wastes that can threaten water quality, including organic compounds and solvents (TWC, 1992).

Recommendations for Improving Water Quality in the Rio Grande at Big Bend National Park. The sources of water pollutants affecting Big Bend National Park include: (1) the Rio Grande from the El Paso-Ciudad Juarez area to upstream of Presidio, Texas, with contributions from both the United States and Mexico; (2) the Rio Conchos watershed, lying entirely within Mexico; and (3) the drainage areas of a few tributaries entering downstream from Presidio and upstream from the park, including considerable private land. Consequently, neither Big Bend National Park nor the National Park Service is in a position to control, or change appreciably, the activities of polluters in those areas through regulatory, coercive, or incentive devices; only cooperative and negotiative processes can be employed.

The principal water quality databases and individual reports, as cited earlier in this paper and in Appendix III, have documented numerous instances in which water quality does not meet standards (see "Evaluation of Surface Water Quality Conditions" in Chapter 3). In total, however, the existing body of data and information is insufficient to comprehensively assess the measures needed to bring all water quality parameters up to the established standards for the desired uses of water in the park. What the National Park Service *can* do is:

(1) work through or with other entities to ameliorate known water quality problems;

(2) promote, with the assistance of other agencies, the development of pretreatment programs for existing and new maquiladora facilities along the Rio Grande and Rio Conchos; and

(3) press for continued and expanded monitoring to fulfill the database requirement and thus reveal any unknown problems.

These topics are further addressed below.

Recommendations for Transboundary Cooperative Monitoring Activities. Achieving and maintaining water quality in the Rio Grande in accordance with established state standards for the designated uses of the river system is central to the purpose of Big Bend National Park (NPS, 1992). The growing development of industry on both the Mexican and United States sides of the Rio Grande and the preliminary data on toxic substances in the river (IBWC, *et al,* 1994) indicate that the strong need for rigorous monitoring of water quality on both sides of the border to track any increases in the level of these compounds which will adversely impact river water quality. The Binational Study on Toxic Substances (IBWC, *et al,* 1994) may provide one avenue for continuing surveillance of water quality conditions at key locations upstream from Big Bend National Park. This study recommends that the park maintain close liaison with the International Boundary and Water Commission, the Texas Natural Resources Conservation Commission, and the U.S. Geological Survey regarding any such further monitoring efforts and their results, and regarding any proposed remedial action to mitigate impacts and/or preserve water quality in the river system. The park should request to be provided, on a continuing basis, the results of ongoing quality monitoring by these agencies for stations between

El Paso and La Linda (TNRCC river segments 2308, 2307, and 2306). It is critical that the National Park Service communicate and work with these agencies prior to any future studies to establish appropriate screening levels to ensure the usefulness of data for park management of public water uses in Big Bend National Park.

If park management desires to initiate a monitoring program in which Big Bend National Park would have a great measure of control and responsibility, we recommend that the National Park Service explore the possibility of obtaining funding either singly or in a cooperative program with one or more of the currently monitoring groups, through provisions of the North American Free Trade Agreement (NAFTA) (see Chapter 2 for a more detailed description of these agreements and agencies).

Recommendation for Cooperative Regional and Local Monitoring Activities. The park should also maintain close contact with non-governmental monitoring groups to take maximum advantage of their findings, and to engage them in cooperative monitoring efforts with Big Bend National Park where appropriate. In particular, these groups include, but are not limited to, the following:

1. Texas Watch,
2. The UTEP monitoring group, and
3. Project Del Rio.

These organizations and their current and proposed activities are discussed in Chapter 3 under the heading "Current Water Quality Monitoring Programs Along the Rio Grande Adjoining the Park." Project Statement BIBE-N-568.001 also suggests approaches that may assist in this effort.

Recommendation for a Microbiological Monitoring Program for the Rio Grande. The water resources management objectives of Big Bend National Park should dictate the design of a much needed monitoring program. First and foremost, these objectives include maintaining water quality consistent with the park's uses (public water supply, recreation, and habitat for fish and wildlife). A review of available data reveals concerns related to all of these activities (see Table 23 in this chapter). The authors of this study recommend that the National Park Service work with the Texas Natural Resources Conservation Commission, the U.S. Geological Survey, and the International Boundary and Water Commission to establish a monitoring program to determine if there is a hazard related to biological contamination of the Rio Grande in Big Bend National Park from a human health perspective. This testing should be conducted, as noted in Table 23, for fecal coliform, and we suggest that additional studies be made to determine possible problems with parasites such as *cryptosporidium* and *giardia* sp., as well as viruses. Project Statement BIBE-N-563.001 address this issue in further detail.

Site-Specific Water Quality Issue

Castolon Water Supply

Because of potential hazards to health and safety of residents, concessionaires, and visitors, the water supply at Castolon may be the single most pressing concern with respect to water quality in Big Bend National Park. The concern stems from the fact that the aquifers supplying water to the wells in Castolon are in immediate hydrologic connection with the Rio Grande. This means that whatever contaminants are present in the Rio Grande are likely to show up in the water supply at Castolon. A large treatment system was installed to overcome this problem, but the mismatch of system size and load, coupled with the complexity of its operation, have resulted in its being inoperative for long periods of time. When the system is not in operation, the only treatment the water receives is chlorination. While chlorination is effective against bacterial contaminants, it does not offer protection from the broad spectrum of biocides and industrial chemicals that have been detected in the waters of the Rio Grande and/or its tributaries upstream from the park.

Recommendation for Castolon Water Supply. It is imperative that an effective system of water treatment be developed for Castolon's water supply. The present chlorination-only treatment of water is adequate for domestic uses that comprise the largest portion of total water use, it is not acceptable for drinking and culinary use. Since the total water demand for drinking and culinary use is currently less than 100 gallons per day, and is distributed to fewer than twelve points of use, a distributed treatment strategy is recommended. Project Statement BIBE-N-558.001 provides guidance for mitigating this health hazard by the use of distributed distillation treatment systems for culinary/drinking water supplies at points of use.

Water Resources Project Statements

Chapter 5

The twenty specific project statements listed below are provided in the standard format of National Park Service programming documents. They are not listed in priority order, as park priorities are likely to change as tasks are completed, more is learned about the water resources of the system, and as decisions are made internally and *externally* which affect the relative urgency of the various issues. However, current (1996) park-wide resource management priorities are provided as part of each project statement.

It should be noted that each project budget represents estimated costs associated with equipment, supplies, temporary employees and/or contract work needed to complete the respective recommended actions. The full-time equivalent (FTE) costs of ONPS-funded personnel are not included within the project budgets.

These project statements are both planning tools used to identify problems and needed actions, and standardized programming documents used within the National Park Service to compete with other park projects for funds and staff.

BIBE-N-550.001
Monitor Water Quality Degradation, Rio Grande

BIBE-N-551.001
Monitor Rio Grande, Flow

BIBE-N-552.001
Research Rio Grande, Flow

BIBE-N-553.001
Map Floodplain

BIBE-N-554.00 1
Monitor Water Sources, Springs - Seeps (cyclic)

BIBE-N-555.001
Research/Monitor Water Use, Developed Areas

BIBE-N-556.001
Research Water Potential, Park Entrance Stations

BIBE-N-557.001
Investigate Alternatives for Altered Flows

BIBE-N-558.001
Develop Safe Water Supply for Castolon

BIBE-N-559.00 1
Incorporate Wells in Basin Water Supply System

BIBE-N-560.001
Expand Panther Junction Water Supply

BIBE-N-561.001
Evaluate Irrigation Supply, RGV

BIBE-N-562.001
Utilize Available Storage, Chisos Basin

BIBE-N-563.00 1
Investigate Coliform Hazard in Rio Grande

BIBE-N-564.00 1
Mitigate Flashflood Hazard

BIBE-N-565.001
Evaluate New Area Water Sources

BIBE-N-566.001
Research and Analyze Precipitation Records

BIBE-N-567.001
Assess Aquatic and Riparian Habitat

BIBE-N-568.00 1
Support Other Water Quality Monitoring Activities

BIBE-N-569.001
Enter Water Data into USGS Data Base

Project Statement		
BIBE-N-550.001		
Last Update: 03/26/96	**Priority: 6**	**Initial Proposal: 1995**
Title: Monitor Water Quality Degradation, Rio Grande **Sub-title: Water Resources**		
Funding Status:	**Funded: 0.00**	**Unfunded: 135.00**
Servicewide Issues: N11 (WATER QUAL-EXT)		
N-RMAP Program Codes: Q00 (Water Resources Management), Q01 (Water Resources Management)		

Problem Statement

Population growth and industrial development have occurred in recent years on both sides of the Rio Grande without adequate investment in the infrastructure necessary to control resulting pollution. Growth is straining the ability of local entities to fund either pollution abatement or adequate water quality monitoring programs. The North American Free Trade Agreement promises to accelerate this growth, as does the shift from an agricultural to an industrial economic base in the border area (TWC, 1992).

The limited routine water quality monitoring in the Rio Grande and its tributaries has traditionally been designed to detect violations of numerical water quality criteria and to measure long-term trends in conventional water quality parameters. With recent population increases and development along the border, pollutant loading may have changed in the last few years. Today, a great potential for contamination exists, especially from the expanded manufacturing and development on both sides of the river. Manufacturing generates a wide array of wastes that can threaten water quality, including organic compounds and solvents (TWC, 1992).

The Texas Natural Resources Conservation Commission (TNRCC) and the U.S. Section of the International Boundary and Water Commission (IBWC), participate in a cooperative surface water quality monitoring program for the Rio Grande. The result is that some mainstream stations are monitored monthly by the two agencies. This monitoring consists of routine field measurements, flow measurements, and water chemistry analyses.

Unsatisfactory water quality has become evident within the reach of the Rio Grande flowing through Big Bend National Park. As stated by Kaiser, et al (1994), "Known water quality problems on the 2306 segment [below Presidio] include elevated fecal coliform bacteria levels so that a portion of the segment does not meet swimmable criteria. The 2307 segment has experienced elevated levels of chloride, sulfate, and dissolved solids from natural causes. Chloride levels along this segment exceed the Texas Department of Health drinking water criteria."

Similar results have been reported by TWC (1992), TNRCC (1994), IBWC, et al, (1994), and NPS-Horizon (1995). In addition, changing water use patterns may have generated point source and/or nonpoint-source water quality problems which have not yet been fully documented. Concern is growing over fear that pollutants associated with newly developed sources could further deteriorate the existing water quality in the park. These sources include potential contamination from industrial plants, agricultural runoff, and septic tanks.

While a program to monitor all possible impacts from these sources would be extremely costly, the recently completed Phase I Binational Toxic Substances Study (IBWC, et al, 1994) has identified several water quality concerns that require management awareness. These concerns include the long-term trends due to impacts of development along the Rio Conchos and the Rio Grande near Presidio. That same report recommended follow-up monitoring designed to provide a more complete and ongoing assessment of water quality at sites of potential concern (those on the Rio Grande and Rio Conchos just above Presidio), as well as "intensive surveillance" on the Rio Conchos, which supports significant aquatic life habitat. In order to ensure subsequent hydrologic data collected in the park are comparable Big Bend National Park should pursue the development of a Quality Assurance Project Plan (QAPP). A QAPP will provide written guidelines to assure that the hydrologic data collected are statistically representative of hydrologic and chemical conditions in the park.

Available data suggest a possible correlation between flow volume and water quality. Undoubtedly, the lowest flows in the river coincide with the poorest quality water. An analysis of the water quality parameters of concern versus flow may reveal that, above certain flow thresholds, specific water quality parameters pose little or no hazard. While the variability of inputs to the river, both of contaminants and flow, prevents certainty in any prediction of contaminant levels based on flow, the recommended analysis would permit the dissemination of advisories warning of the increased possibility of contamination in excess of some standard when flows fall below a certain level.

Literature Cited

International Boundary and Water Commission (IBWC) (United States and Mexico sections), the National Water Commission of Mexico, and the U.S. Environmental Protection Agency. 1994. Binational Study Regarding the Presence of Toxic Substances in the Rio Grande/Rio Bravo and its Tributaries along the Boundary Portion Between the United States and Mexico. 250 pp.

Kaiser, R.A., S.E. Alexander, and J.P. Hammill. 1994. Protecting the National Parks in Texas Through Enforcement of Water Quality Standards: An Exploratory Analysis. Technical Report NPS/NRWRD/NRTR-94/18. Prepared for the U.S. Department of the Interior, National Park Service by Texas Agricultural Experiment Station Texas A&M University, College Station, TX. 96

PP.

National Park Service. 1995. NPS-HORIZON — Baseline Water Quality Date Inventory and Analysis. Technical Report

NPS/NRWRD/NRTR-95/S 1. National Park Service Water Resources Division, Fort Collins, CO.

Texas Natural Resources Conservation Commission (TNRCC). 1994. Regional Assessment of Water Quality in the Rio Grande Basin Including the Pecos River, the Devil's River, the Arroyo Colorado, and the Lower Laguna Madre. Watershed Management Division, Austin, TX. 337 pp.

Texas Water Commission (TWC). 1992. Regional Assessment of Water Quality in the Rio Grande Basin Including the Pecos River, the Devil's River, the Arroyo Colorado, and the Lower Laguna Madre. Standards and Assessments Division, Austin, TX, GP 92-02, November. 207 pp. plus app.

Description of Recommended Project or Activity

***Recommended** Actions:*

1. Establish an operational agreement whereby the timely results of all such continuing monitoring by IBWC, TNRCC, and the U.S. Geological Survey will be promptly furnished to Big Bend National Park. This activity will be accomplished "in-house" by the park's base-funded hydrologist (0.1 FTE).

2. Evaluate the scope and frequency of monitoring by other agencies for parameters of concern to the park, particularly those contaminants that would render the water unsafe for human contact. The design should strive to capture sufficient data to develop a correlation between flow rates and unsafe water quality. This activity will be accomplished by a one year contract estimated to cost approximately $75,000.

3. If parametric scope and/or temporal frequency of existing monitoring programs are insufficient for park purposes, negotiate with other sampling agencies to modify their sampling procedures to meet the park's needs. $20,000 per year is programmed in years 2-4 of this project to augment activities of the sampling agencies. Big Bend National Park, in coordination with other agencies engaged in sampling activities on the Rio Grande, should develop and implement a QAPP for the Upper Basin of the Rio Grande (El Paso to Amistad Dam) similar to the QAPP developed by the TNRCC for the Clean Rivers Program in the Middle Basin of the Rio Grande.

BUDGET AND FTEs				
		Funded		
	Activity	Fund Type	Budget . ($1000s)	FTEs
		Total:	0.00	0.00
		Unfunded		
Year 1:	RES	One-time	75.00	0.10
Year 2:	MON	Recurring	20.00	0.10
Year 3:	MON	Recurring	20.00	0.10
Year 4:	MON	Recurring	20.00	0.10
		Total:	135.00	0.40

Alternative Actions / Solutions and Impacts

The no-action alternative consists of continuing to rely on the other sampling agencies' compliance with state and federal regulations regarding parametric coverage and sampling frequency to satisfy the purposes of the park.

Another alternative would be to institute an in-house sampling program to meet the parks' needs. This alternative would probably cost more, in dollars and employee time, than the recommended alternative.

Compliance codes:

EXCL (CATEGORICAL EXCLUSION)

Explanation:

516 DM6 APP. 7.4 E(2)

Project Statement		
BIBE-N-551.001		
Last Update: 03/26/96	**Priority: 0**	**Initial Proposal: 1995**
Title: Monitor Rio Grande, Flow **Sub-title: Water Resources**		
Funding Status:	**Funded:**	**Unfunded: 0.00**
Servicewide Issues: N12 (WATER FLOW)		
N-RMAP Program Codes: Q00 (Water Resources Management), Q01 (Water Resources Management)		

Problem Statement

The Rio Grande attracts a large number of park visitors with river-related recreation interests. The flow of the river can vary widely, with high flows creating flooding and hazardous situations for river users, and low flows creating portaging problems. In addition, the quality of the river water varies considerably, with low flows being of such poor quality that bodily contact may, on occasion, be unadvisable. The park maintains stage gages at Castolon and Rio Grande Village which are read daily. These data, along with data from the International Boundary and Water Commission (IBWC) at Presidio, Terlingua Creek, Lajitas, Johnson Ranch and Dryden, are made available from the park to the public and commercial river users. The present system does not provide the ability to advise river users on the time of arrival of flood peaks moving down from the upstream stations, nor provide any information on how "high" the peak flow will be in the park.

Those who live near or operate facilities along the river are unavoidably subject to periods of drought and floods for two reasons: first, because arid and semiarid regions commonly exhibit highly variable rainfall and runoff rates and volumes; and second, because the existing storage and irrigation on the river system greatly influence natural flow patterns. Of all the structures on the Rio Conchos, which is the source of almost all the flow reaching Big Bend National Park, only the Luis Leon Dam has control gates. The levee system of the Presidio-Ojinaga Valley Flood Control Project, built to protect agricultural lands in that area, is insufficient to provide downstream mitigation for the largest floods, as was demonstrated during the 1990 and 1991 flood periods.

Description of Recommended Project or Activity

Actions that can be instituted cooperatively by the National Park Service and other water users in the basin include the following:

1. Relative to low flows:

   Distribute periodic information leaflets (or include in Park literature) to raft operators, individual boat owners and other interested Park visitors, warning that occasional low-flow periods are possible and citing the historical flow record as to their frequency and severity.

   Post signs at launching locations as a reminder to Park users of the above conditions.

   Establish and maintain liaison with the International Boundary and Water Commission, such that during times of imminent drought or serious low-flow conditions, the IBWC can seek the Mexican operators' cooperation in maintaining minimal flows essential for maintaining aquatic and riparian ecosystems in the park while satisfying the needs and operating rules of the Mexican water users on the Rio Conchos.

2. Relative to high flows:

   Distribute periodic information leaflets to all park visitors (or include it in key park literature) warning of occasional flood flows and citing historical examples of such events.

Post signs at campgrounds and other low-lying use areas as a reminder of such conditions.

Make surveys of floodplain zones in critical areas such as campgrounds (see Project Statement BIBE-N-553.001).

Take nonstructural and low-cost structural measures to protect campgrounds, such as bank protection, low levee upgrading, and/or site elevation in flood-prone areas.

Maintain communication with, or monitor broadcasts of, National Weather Service weather and flood hydrology conditions relative to Amistad Dam, and use this early-warning system to set in motion a set of prescribed precautions to be taken by park personnel.

Train key park personnel in procedures to be taken in the event of imminent flood-flow conditions in the park.

Establish and maintain liaison with the International Boundary and Water Commission (IBWC), such that during times of imminent flood-flow conditions, the IBWC can seek the Mexican operators' cooperation in mitigating flows in the park area, to the extent possible within the structural capabilities and operating criteria along the Rio Conchos, to provide the most advanced flood warnings possible to visitors and residents along the river.

In General:

1. Continue present practice of daily observation of stage gages until the completion of work prescribed in Project Statement BIBE-N-552.001. In addition, negotiate with the IBWC to install satellite relay telemetry on existing gages on Alamito and Terlingua Creeks to permit capture of near-real-time data from these stations.

2. Utilize the U.S. Geological Survey (USGS) National Water Information System (NWIS) to obtain near-real-time data from all telemetered stations upstream of the park as far as the mouth of the Rio Conchos, and use the correlations made in BIBE-N-552.001 to estimate the arrival times of peak flows. An alternative to obtaining the data from the USGS data base that would provide faster and "fresher" data would be to obtain a PC-based ground station at the park to capture the data directly from the National Weather Service broadcasts.

3. Continue to observe the stage gages at Rio Grande and Castolon, but only to verify the arrival time of peak flows and their maximum stages. This process would serve to increase the data base and verify it over a wider range than was obtained during the continuous stage record collection in BIBE-N-552.001. When no peaks are expected, the stage need not be observed as park staff can use the correlations to provide estimates of stage for river users.

BUDGET AND FTEs

Funded				
	Activity	**Fund Type**	**Budget ($1000s)**	**FTEs**
1995:	**MON**	**Recurring**	**4.00**	**0.10**
1996:	**MON**	**Recurring**	**4.00**	**0.10**
1997:	**MON**	**Recurring**	**4.00**	**0.10**
1998:	**MON**	**Recurring**	**4.00**	**0.10**
		Total:	**16.00**	**0.40**
Unfunded				
		Total:	**0.00**	**0.00**

Compliance codes:

EXCL (CATEGORICAL EXCLUSION)

Explanation:

516 DM2 APP. 2, 1.6

Project Statement		
BIBE-N-552.001		
Last Update: 03/26/96	**Priority: 26**	**Initial Proposal: 1995**
Title: Research Rio Grande, Flow **Sub-title: Water Resources**		
Funding Status:	**Funded:** 0.00	**Unfunded:** 42.00
Servicewide Issues: N12 (WATER FLOW)		
N-RMAP Program Codes: Q00 (Water Resources Management), Q01 (Water Resources Management)		

Problem Statement

Flows in the Rio Grande have changed as a result of the construction of reservoirs on the main stem and important tributaries upstream from the Park Data have been collected in the form of daily stage readings at Castolon and Rio Grande Village, but no analyses of these data have been performed, the data being provided primarily for river recreationists. There are continuous record stations on the Rio Grande below the mouth of the Rio Conchos and Alamito Creek near Presidio (RM 949.8), at Johnson Ranch (RM 862.4), and also at Terlingua Creek (RM 885.2) maintained by the International Boundary and Water Commission (IBWC). If a continuous record of stage were available at Castolon and Rio Grande Village, the continuous records from the IBWC stations could be used to derive estimates of stream flow at Rio Grande Village and Castolon. These continuous stage records can also be used in estimating the different travel times of flood waves through the reach of river adjacent to the park over a range of flood discharges.

Description of Recommended Project or Activity

Recommendation I

Install an orifice in the channel of the Rio Grande connected to a bubbler/transducer system with a recorder at Castolon and Rio Grande Village. Operate these stations until a sufficient variety of flood peaks have been captured (probably about 5 years).

Recommendation 2

a. Analyze the continuous stage and discharge records from the three IBWC stations to obtain estimates of peak discharges passing Lajitas, Castolon, and Rio Grande Village.

b. Correlate the continuous stage records at Rio Grande Village with the peak discharge estimates to obtain a stage/discharge relation at Rio Grande Village and Castolon.

c. Determine the travel time of flood peaks over a range of discharges to develop a stage/travel time relationship between Castolon and Rio Grande Village.

Recommendation 3.

Prepare a brochure/fact sheet presenting the information developed for park visitors, and particularly for the river recreationists.

BUDGET AND FTEs				
Funded				
	Activity	**Fund Type**	($1000s)	
		Total:	**0.00**	**0.00**
Unfunded				
Year 1:	RES	One-time	5.00	0.10
	MON	One-time	5.00	0.10
		Subtotal:	10.00	0.20
Year 2:	RES	One-time	5.00	0.10
	MON	One-time	5.00	0.10
		Subtotal:	10.00	0.20
Year 3:	RES	One-time	5.00	0.10
	MON	One-time	5.00	0.10
		Subtotal:	10.00	0.20
Year 4:	RES	One-time	5.00	0.10
	MON	One-time	5.00	0.10
	INT	One-time	2.00	0.10
		Subtotal:	12.00	0.30
		Total:	**42.00**	**0.90**

Alternative Actions/Solutions and Impacts

The no-action alternative would continue present operations of providing data on stage to the river recreationists. No information on either discharge or the travel times of peak discharges through the reach of the Rio Grande bounding the park could be derived from this data.

A second alternative would be to place crest-stage gages at Castolon and Rio Grande Village, this would reduce the cost of equipment as the crest-stage gages are simple vertical tubes with cork particles in them that stick to the tube walls at the highest stage the river reaches between readings. Frequent (perhaps weekly) inspection would provide data from which stage/discharge estimates could be derived, though the travel times of flood peaks could not be determined.

Compliance codes:

EXCL (CATEGORICAL EXCLUSION)

Explanation:

516 DM6 APP. 7.4 E(2)

Project Statement		
BIBE-N-553.001		
Last Update: 03/26/96	**Priority: 25**	**Initial Proposal:**
Title: Map Floodplain **Sub-title: Water Resources**		
Funding Status:	**Funded: 0.00**	**Unfunded: 90.00**
Servicewide Issues: N20 (BASELINE DATA)		
N-RMAP Program Codes: Q00 (Water Resources Management), Q01 (Water Resources Management)		

Problem Statement

Flood events on the Rio Grande pose a risk to some facilities in Castolon and Rio Grande Village. These risks lead to public safety concerns at both sites and at popular camping locations used by river runners. The historic flows of the Rio Grande have been dramatically altered by upstream dams, with almost no flow originating above the Elephant Butte reservoir reaching the park at the present time. Most of the flows in the Rio Grande originate from the Rio Conchos, although large tributaries can contribute significant flow during floods. In order to protect facilities and safeguard lives, the current flow regime needs to be quantified to determine flows with return periods of one hundred years and five hundred years. The Water Resources Management Plan (WRMP) for Big Bend National Park gives preliminary estimates of the one-hundred year flood for the Rio Grande as 92,400 cubic feet per second (cfs) and the five-hundred year event as 147,000 cfs. The preparation of maps delineating flood prone areas, and depth of flooding in those areas, would greatly facilitate the development of protective measures for those regions. The International Boundary and Water Commission (IBWC), as noted in the WRMP is presently contracting for a flood frequency determination for the Rio Grande stations, and the project proposed herein could start when the new figures become available. While the final results will undoubtedly differ from the estimates provided in the WRMP, the difference will likely be small and result in negligible change to the flood boundary locations.

Literature Cited

National Park Service. 1993. National Park Service Floodplain Management Guideline. National Park Service, Washington, DC. 14 pp.

Description of Recommended Project or Activity

1. Contract with an appropriate entity for the development of flood-plain maps of the type prepared for flood insurance purposes for Big Bend National Park.

2. Based on the maps developed under Recommendation 1, evaluate the potential damage to facilities such as the Gambusia Refugium, irrigation wells and pumps, campgrounds, trailer/RV parks, etc., and determine the level of risk the Park Service is willing to accept. The assistance of floodplain management specialists from the NPS Water Resources Division would be sought to complete this task

3. Develop mitigation or protection strategies for those facilities with unacceptable levels of risk associated with the status quo. This recommendation includes the publication of maps/brochures to provide information on flood hazards to visitors. (NB: Costs and environmental compliance activities associated with any recommended structural changes will be determined on a future case-by-case basis.)

BUDGET AND FTEs				
Funded				
	Activity	Fund Type	Budget ($1000s)	FTEs
		Total:	**0.00**	**0.00**
Unfunded				
Year 1:	RES	One-time	35.00	0.20
Year 2:	RES	One-time	35.00	0.20
	MIT	One-time	20.00	0.10
		Subtotal:	55.00	0.50
		Total:	**90.00**	**0.50**

Alternative Actions / Solutions and Impacts

The no-action alternative is to proceed without knowledge of the degree of risk to existing facilities at Rio Grande Village and Castolon. With the current effects of upstream dams, the long recurrence-interval floods are significantly smaller than during pre-dam times. Visual evidence of the higher pre-dam floods exists in the form of the floodplain margins. Post-dam floods with similarly long recurrence intervals will not reach the edge of the current floodplain.

Compliance codes:

EXCL (CATEGORICAL EXCLUSION)

Explanation:

516 DM6 APP. 7.4 E(2)

Project Statement		
BIBE-N-554.001		
Last Update: 03/26/96	**Priority: 45**	**Initial Proposal: 1995**
Title: Monitor Water Sources, Springs — Seeps (cyclic) **Sub-title**: Water Resources		
Funding Status:	**Funded: 40.00**	**Unfunded: 130.00**
Servicewide Issues: N12 (WATER FLOW)		
N-RMAP Program Codes: Q00 (Water Resources Management), Q01 (Water Resources Management)		

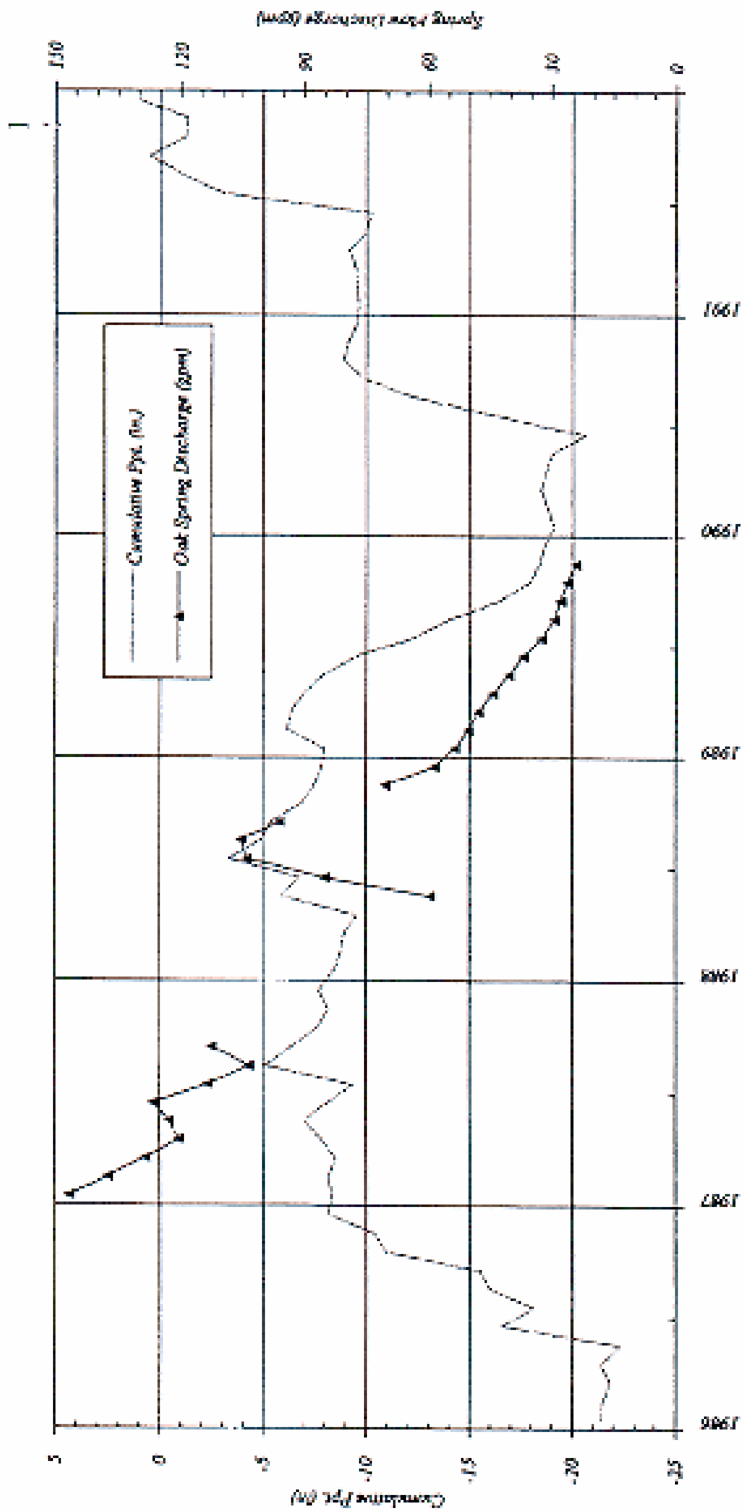
Problem Statement

Springs are important water sources in Big Bend National Park. Back country springs support important riparian and wildlife habitat, as well as being used by backcountry visitors as destinations when hiking and/or camping. The principal water supply for the Chisos Basin is a spring, and the current back-up supply also depends on springflow. Springs represent an "overflow" from a groundwater reservoir, and the rate of springflow thus tied to the rate of recharge to the groundwater reservoir as well as to the size of the reservoir. Climate-induced variations in the ground water recharge rate produce subsequent variations in the flow rates of the springs fed by the groundwater reservoir. The size of the ground water reservoir, and the length of the flow paths from the point of groundwater recharge and spring discharge, modulate the climatic forcing function. Thus, the smaller the groundwater reservoir and the shorter the flow path, the more rapid and dramatic will be the springflows' response to climatic fluctuations. For important springs, the park should develop information on the response of springs to climatic variation in order to be able to estimate the flow of springs without visiting them. As the first step in this task, the climatic forcing function (precipitation) and the responses of the springs should be monitored over a minimum of one year's time. The attached figure illustrates one such curve for precipitation (as cumulative departure from mean over period of record 1950-1992) in Chisos Basin and discharge at Oak Spring. This monitoring will help determine the amplitude of the springs' variation and the lag-time between rainfall and peak spring discharge. Once this information is available, park personnel can estimate the flow of such springs by analyzing climatic data. Subsequent fluctuations in climate that exceed the range experienced in the initial monitoring period should initiate a visit to each of the springs to extend the range of climatic conditions for which confident estimates of springflow can be made.

Description of Recommended Project or Activity In the first eighteen months:

1. Identify, and arrange in priority order, all springs for which the Park Service desires the capability to confidently estimate springflow based on climatic data. Of the more than 300 springs in the park, only about 30 have had measured or estimated flows of 10 gallons per minute or more. These springs, and an equal number of smaller springs distributed over the park, would provide a good basis for the springflow monitoring program.

2. Visit all sixty springs and evaluate the best method of monitoring the springflow (i.e., weir, flume, etc.) at each site. For many springs, measurement of all flow will be impractical, but useful data can be acquired by measuring as large a portion of the flow as is reasonably practical and estimating the unmeasured portion. Since it is highly probable that the proportions of measured and unmeasured flow are systematically related, estimates of the unmeasured component made on monthly visits to service the gage recorders can be used to develop estimates of total flow over the range of flows measured during the year of monitoring.



Precipitation plotted as cumulative departure from mean value (y-axis) for period 1950-1992.

Relationship between Cumulative Precipitation at Chisos Basin to Spring Flow at Oak Spring

3. Using the prioritized listing, and the type of measuring device required for each spring, group the springs into six groups of ten, with the objective of minimizing the total number of each type of measuring device.

After the first eighteen months:

Acquire and install the measuring devices on the first group of ten springs and begin recording data. After six months of record have been acquired, plot the springflow hydrograph for each spring along with the rainfall data from the nearest precipitation station (daily or even weekly total rainfall data would be sufficient), and evaluate the response of the springflow to the rainfall. For springs with large groundwater reservoirs, and/or distant sources of recharge, the lag time in the response may preclude such evaluation. For such springs, data must be acquired for a longer period of record, and for these springs, data collection should continue. Note that as the lag time increases, the period of record for corresponding rainfall data should also increase. As the lag time increases to a month or more, the rainfall data should be plotted as cumulative departure from the monthly, quarterly, or annual average values. Revisit this analytical procedure at six month intervals, and cease data collection at each site as soon as the lag time has been determined. When data collection is discontinued at a site, the equipment should be moved to a spring in the second group of ten, and the cycle started again at the new site.

This process would continue for seven to ten years, depending on the number of long lag-time springs in the sixty-spring sample.

BUDGET AND FTEs

	Activity	Fund Type	Budget ($1000s)	FTEs
Funded				
1995	MON	Cyclic	40.00	0.60
		Total:	**40.00**	**0.60**
Unfunded				
Year 1:	RES	One-time	50.00	0.50
Year 2:	RES	One-time	15.00	0.15
	MON	One-time	35.00	0.00
		Subtotal:	50.00	0.15
Year 3:	RES	One-time	15.00	0.15
Year 4:	RES	One-time	15.00	0.15
		Total:	**130.00**	**0.95**

Alternative Actions/Solutions and Impacts

The park could continue with periodic inventories of springflow at about five year intervals. This scenario would preclude estimating springflows from climatic data, but it would, over time, produce a database which would allow some evaluation of springflow variability for each spring for which data is obtained.

Compliance codes:

EXCL (CATEGORICAL EXCLUSION)

Explanation:

516 DM6 APP. 7.4 E(2)

Project Statement

BIBE-N-555.001

Last Update: 03/26/96	**Priority:** 21	**Initial Proposal:** 1995
Title: Research/monitor Water Use, Developed Areas **Sub-title:** Water Resources		
Funding Status:	**Funded:** 32.00	**Unfunded:** 35.00
Servicewide Issues: N19 (CONSUMPT USE)		
N-RMAP Program Codes:		

Problem Statement

All facilities having water supply and distribution systems require monitoring to enable managers to evaluate system performance and to identify trends in use. These trends permit managers to project necessary expansion, repairs and/or policy modifications to mitigate adverse effects. The more extensive the system, the more important the monitoring program. In 1993, a leak of approximately 3 gallons per minute (gpm) developed in the distribution system in the Chisos Basin. The leak remained undetected for several months, during each of which approximately 134,000 gallons escaped. As 3 gpm represented about 20% of the average annual demand rate, over $2,000.00 of the 1993 power costs for lifting the water from Oak Spring went toward water that seeped into the ground. More recently, a leak was discovered in the Panther Junction distribution system, and while the cost per gallon of water lost was much lower than for the Chisos Basin leak, the strain that the leak placed on the system's delivery capacity caused strong concern in the park (K. Yarborough, personal communication, 1994). To counter these problems, the park needs a monitoring system that incorporates a strategic placement of metering devices and a data capturing system that: 1) compiles data on water use close to point of use, 2) automatically generates reports on trends in use, and 3) automatically identifies inconsistencies in metered data. Strategically placed in-line meters in a distribution system divide the system into sections. Each distribution system in the park should have such meters, placed with a goal of having no section of the system account for more than an average total demand rate of 5,000 gallons per day at points of use within that section. Additionally, in-line meters should be used to monitor critical segments of the system with no points of use (eg, the pipeline from the water source to the reservoir system, or long runs of pipeline between significant points of use).

The attached figure is a schematic diagram based on the distribution system at Rio Grande Village. The water source is Spring #4, and the water leaving the spring is metered at the spring. The water then travels to the storage reservoir. From the storage tank, the distribution line splits near the tank. An in-line meter placed on each of the two pipelines would isolate leaks in line Section 1 (leading from the spring to the reservoir) or the reservoir itself. The shorter distribution line serves Section 2, where leaks would be detected by comparing the in-line meter with the sum of the point-of-use meters in that section. The longer distribution line should be broken into two sections by another in-line meter dividing Section 3 (a long run of pipeline with few points of use) from Section 4 (a short length of pipeline but a large number of points of use). Use (and leaks) in Section 3 would be tracked by subtracting the sum of the point-of-use meters in that section as well as the "downstream" (Section 4) in-line meter. Use and leaks in Section 4 would be tracked by subtracting the sum of the point-of-use meters from the in-line meter.

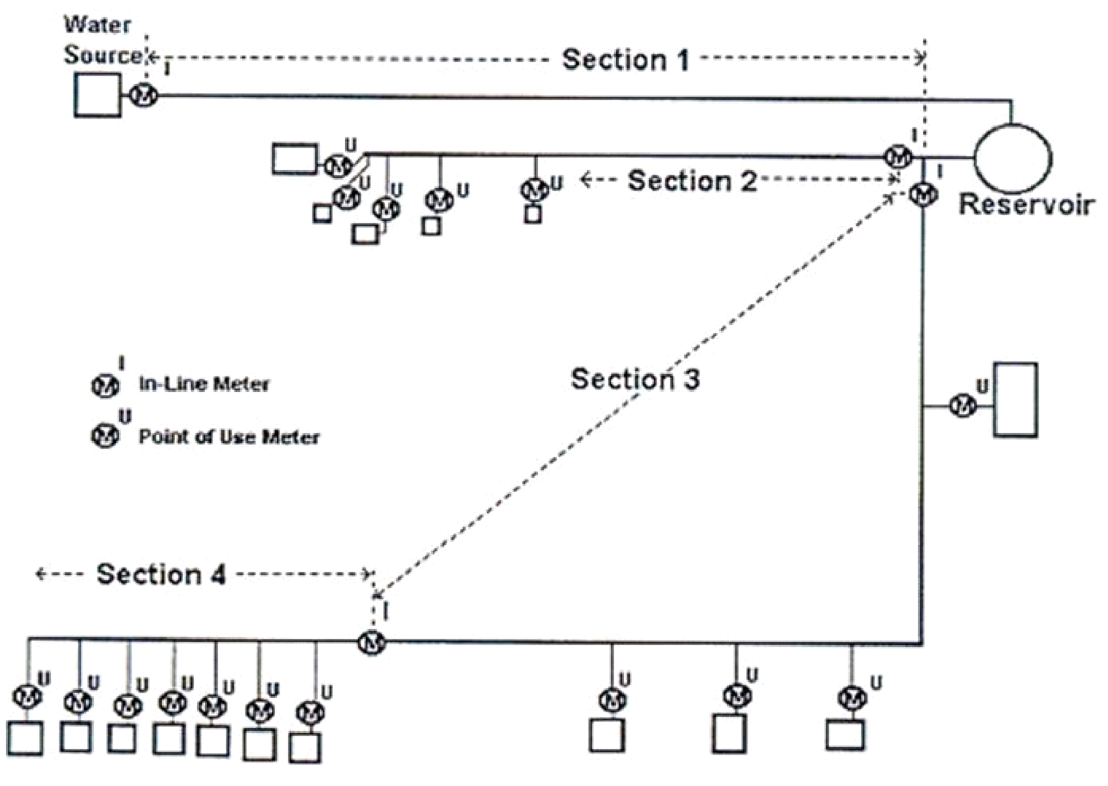
Description of Recommended Project or Activity

1. Take an inventory of all metering devices presently installed in each supply and distribution system. The order of priority would be Chisos Basin, Panther Junction, Castolon, Rio Grande Village. The systems at the entrance stations may be done last. In conjunction with this effort, map locations of meters and lines and digitize into Big Bend National Park Geographic Information System (GIS).

2. Prepare schematics of each supply and distribution system and identify points where meters should be placed. Refer to the above figure for placement strategies. If the inventory of available meters reveals that their number is not sufficient, additional meters should be purchased and installed. Meters should be read monthly.

3. Develop a spreadsheet program with the following attributes:

   - data entry can be done by the meter reader in the field using a laptop, or preferably, data may be entered from field notes which should be preserved;
   - for each meter, the meter reading along with date and time of reading are entered;
   - for each monthly period, number of park visitors is entered and stored;
   - meter data are computed and stored as average gallons per minute for the period between current and previous reading;
   - for each meter, the average gallons per minute over the approximate monthly interval between meter readings, and the change for that monthly value compared to the previous month and to the same month in the previous year, are compute and displayed;
   - the differences in these values between all in-line meters, including any point-of-use meters between the in-line meters for the same time frames identified above are computed and displayed;
   - the total use rate at point of use, and the comparison of that value with the in-line meter closest to the point of supply (again for the same time frames) is computed and displayed;
   - monthly and annual summaries of water use by residences, lodges, campgrounds, group campgrounds, trailer / RV parks, remudas, and facilities (maintenance yards, stores, etc.) for each area, and for the park as a whole, are computed and graphically displayed;



Schematic Diagram of Water Distribution System at Rio Grande Village

■ visitor-impacted per capita use on a monthly and annual basis, for use categories impacted by park visitors (eg, lodges, campgrounds, etc.), is computed and displayed.

4. Review monthly summaries each month. Differences of more than 0.5 gpm between supply and point-of-use rates in any system should prompt an immediate investigation as to cause. Similarly, differences of more than 5% in per capita use rates in visitor-impacted points of use should prompt investigation as to cause.

BUDGET AND FTEs				
Funded				
	Activity	Fund T ~e	Budget ($1000s)	FTEs
1995	MON	Recurring	8.00	0.20
1996	MON	Recurring	8.00	0.20
1997	MON	Recurring	8.00	0.20
1998	MON	Recurring	8.00	0.20
		Total:	32.00	0.80
		Unfunded		
Year 2	RES	One-time	35.00	0.00
		Total:	35.00	0.00

Alternative Actions / Solutions and Impacts

The no-action alternative would be to continue monitoring existing meters. With no schematics of distribution lines presently available, leaks may be detected by careful analysis of total system use and system supply. In the absence of visible evidence of a leak, pin-pointing the probable location of leaks will continue to be very difficult.

Compliance codes:

EXCL (CATEGORICAL EXCLUSION)

Explanation:

516 DM6 APP. 7.4 E(2)

Project Statement

BIBE-N-556.001		
Last Update: 03/26/96	**Priority: 5**	**Initial Proposal: 1995**
Title: Research Water Potential, Park Entrance Stations **Sub-title: Water Resources**		
Funding Status:	**Funded: 0.00**	**Unfunded: 186.00**
Servicewide Issues: N22 (VIS USE-DIN ZN), N18 (VIS USE-BCTRY)		
N-RMAP Program Codes: Q00 (Water Resources Management), Q01 (Water Resources Management)		

Problem Statement

The Persimmon Gap Entrance Station currently obtains water for Park Service personnel manning the station and for park visitor use by trucking water in from Panther Junction, 26 miles to the south. A similar entrance station is planned for West Maverick, which is almost as far from Panther Junction as Persimmon Gap. The entrance stations are projected to need a maximum of 3,000 gallons of water per day to satisfy all demands. Any water source that can produce a little over two gallons per minute (gpm) can meet that demand (2 gpm = 2,880 gallons per day), provided the supply system includes an appropriately sized storage tank. In both areas, the consolidated rock unit most likely to yield adequate quantities of water is the Aguja Formation. Unfortunately, hydrologic data suggest that the water in both areas is likely to be highly mineralized. A well drilled at Persimmon Gap (BK-73-23-801) had total dissolved solids (TDS) levels of 5,000 parts per million (ppm), with sulfate at 3,000 ppm. Three wells near the Maverick Entrance Station (II-1, II-2, and II-20) were reported by Leggat, et al (1968) to have penetrated the Aguja Formation to depths ranging from 347 feet to 823 feet. The wells yielded an estimated 10 gpm, and the water from well II-20 contained 1,460 ppm sulfate and 2,100 ppm TDS. The water from well II-2 reportedly was high in hydrogen sulfide and was not suitable for drinking. Waters of this degree of mineralization would require treatment by reverse osmosis or distillation to be rendered potable.

Literature Cited

Leggat, E.R., R.D. Reeves, and C.R. Follett 1968. Results of Water-Resources Investigation of the Big Bend National Park, Phase II. U.S. Geological Survey Administrative Report (unpublished), 17 pp. plus fig.

Description of Recommended Project or Activity

1. Conduct geophysical exploration in nearby washes whose headwaters lie in mountainous terrain, including Nine Point Draw south of Persimmon Gap, and Rough Run to the north and west of Maverick. The exploratory geophysical work, using shallow seismic and/or resistivity equipment would help determine the crossectional profile of the alluvium in these valleys in an effort to ascertain its thickest point, and further to determine if there is significant saturation in the basal sediments. Santiago Wash could be another candidate for such a survey as it is closer to Persimmon Gap than Nine Point Draw. The principal drawback of Santiago Wash is that its drainage area is much smaller than Nine Point Draw, and it does not originate in as mountainous terrain. (Estimated contract cost $12,000.)

NOTE: If this work is done, it would be cost effective to do the geophysical work recommended at the Lower Basin CCC wells at the same time (see BIBE-N-559.001).

2. Based on the information gained in the geophysical exploration, drill wells to penetrate the alluvium. At each site, three shallow wells should be drilled, with two to serve as observation wells when an aquifer test is done by pumping the third well. The water level

data from these wells and the hydrologic parameters derived from the aquifer tests can be used to estimate the amount and flow rates of water moving downstream in the alluvial materials. If the wells in the alluvium yield sufficient quantities of water of acceptable quality, construct a pipeline from the wells to the entrance stations. If the well water is not sufficient in quantity and/or quality, proceed with Recommendation 3, below. (Estimated cost for wells $40,000, estimated cost for pipeline $80,000, 8 miles)

3. The remaining alternative for developing a water supply for the entrance stations consists of obtaining water from the Aguja Formation and treating it to potable standards. For the Persimmon Gap Entrance Station, the existing well should be tested to ascertain if its yield is sufficient in quantity, and if so, install a treatment system on the potable points of use, and use untreated water for everything else. (Estimated cost $2,000 per treatment site)

The Maverick Entrance Station will require that a new well be drilled, perhaps to a depth of 700-800 feet. There is very little chance that the water from such a well will be potable without treatment, and a system similar to the one described for Persimmon Gap should be installed.

BUDGET AND FTEs				
Funded				
	Activity	Fund Type	Budget ($1000s)	FTEs
		Total:	0.00	0.00
Unfunded				
Year 1	RES MIT	One-time One-time	12.00 174.00	0.10 0.00
		Subtotal:	186.00	0.10
		Total:	186.00	0.10

Alternative Actions/Solutions and Impacts

The no-action alternative is to continue to truck water to the existing and new entrance stations from Panther Junction.

Another alternative is to truck only potable-use water from Panther Junction, and use local supplies of poor quality water for all non-potable uses at the entrance stations. Necessary plumbing to accommodate this alternative could be designed into the new entrance station, but the station at Persimmon Gap would require some retrofitting.

Compliance codes:

EXCL (CATEGORICAL EXCLUSION)

Explanation:

516 DM6 APP. 7.4 E(2)

Project Statement		
BIBE-N-557.001		
Last Update: 03/27/96	**Priority: 3**	**Initial Proposal: 1996**
Title: Investigate Alternatives for Altered Flows **Sub-title: Water Resources**		
Funding Status:	**Funded: 0.00**	**Unfunded: 110.00**
Servicewide Issues: N12 (WATER FLOW), N13 (WATER RIGHTS)		
N-RMAP Program Codes: Q00 (Water Resources Management), QOI (Water Resources Management)		

Problem Statement

Upstream control of flows in the Rio Grande and its tributaries presents a major impediment to achieving natural flow conditions in the Rio Grande along the Big Bend National Park boundary. Those who live near or operate facilities along the river are unavoidably subject to periods of drought and floods for two reasons: first, because arid and semiarid regions commonly exhibit highly variable rainfall and runoff rates and volumes; and second, because the existing storage and flow control strategies on the river system can exacerbate the adverse impacts of extreme events.

For example, while the 1995 snowpack in the upper Rio Grande watershed was well above average, maintaining high levels of storage of this runoff has resulted in no ameliorating effects on extreme low flow conditions in Big Bend National Park brought about by extended drought conditions in southwestern Texas and northern Mexico. Conversely hydrologic effects of upstream flood protection projects exacerbated downstream flooding in Big Bend National Park during high rainfall episodes in 1978, 1990, and 1991.

Description of Recommended Project or Activity

1. Undertake activities to better understand the current and historic flow conditions, upstream infrastructure, and institutional arrangements influencing the flow of the Rio Grande in the vicinity of Big Bend National Park.
2. Investigate what possible alternatives, if any, exist for the National Park Service to secure an improved flow regime for the Rio Grande in the vicinity of Big Bend National Park.

	BUDGET AND FTEs			
	Funded			
	Activity	**Fund Type**	**Budget ($1000s)**	**FTEs**
		Total:	**0.00**	**0.00**
		Unfunded		
Year 1:	**RES**	**One-time**	**110.00**	**0.50**
		Total:	**110.00**	**0.50**

Compliance codes:

EXCL (CATEGORICAL EXCLUSION)

Explanation:

516 DM6 APP. 7.4 B(10)

Project Statement		
BIBE-N-558.001		
Last Update: 03/27/96	**Priority: 11**	**Initial Proposal: 1996**
Title: Develop Safe Water Supply for Castolon **Sub-title: Water Resources**		
Funding Status:	**Funded: 0.00**	**Unfunded: 65.00**
Servicewide Issues: N22 (VIS USE-DEV ZN)		
N-RMAP Program Codes: Q00 (Water Resources Management), Q01 (Water Resources Management)		

Problem Statement

The water supply at Castolon is from wells that are in hydraulic connection with the Rio Grande, and prospects of locating alternate supplies that are not in connection with the river appear slim. The only alternative to trucking water in from Panther Junction is to treat the water to the point that it is safe for human consumption. The treatment can be applied to the entire water supply, as the presently installed but inoperative system was, or a much smaller treatment system can process only water that is used for culinary purposes and drinking. Treating water that is used elsewhere, both inside and outside buildings, even for fire protection, beyond chlorination is unnecessary. The higher the level of treatment required by the raw water supply, the more expensive and unnecessary (except for human ingestion) treating such water becomes.

For the purpose of determining the potable water needs at Castolon, the stable resident population is considered to be 10 individuals, with 5 additional residents at Historic Castolon, for a total of 15 permanent residents. A drinking/culinary water allotment of 5 gallons per person per day should be adequate. Therefore, the total estimated drinking/culinary water requirement at Castolon is approximately 75 gallons per day.

The electrodialysis method used in the presently installed centralized treatment system is designed for a much larger distribution system. Because of its minimal use, the iron content of the raw water supply appears to interfere with the efficiency of membrane stacks. The high costs of maintenance and operation of this system, both in dollars and employee time, have precluded a high level of reliable performance. At the present time, the system is "down," and the only treatment is chlorination. Bringing the electrodialysis system back into operation would be costly. Park Service personnel estimate that replacing pads would cost $18,000, and that additional costs would be incurred for new valves and other parts and chemicals required to clean the system in order to restart operations. The cost of supplies to operate the system and annual inspection and servicing by the manufacturer is estimated at several thousand dollars per year. Operation of the Aquamite 3 electrodialysis reversal system involves $800 for muriatic acid to clean the system's pipes, $300 in sodium hypochlorite for chlorination, and several thousand dollars in spare parts (J. Gibson, Maintenance Supervisor, Pecos National Historical Park, National Park Service, pers. comm., 1994). Repairing and restoring this system to operation is not recommended.

Prior to the installation of the electrodialysis system, individual household treatment units of the reverse osmosis type had been installed. These systems treated only the water used for consumption and cooking, leaving the present chlorinated supply for all other purposes. The National Park Service relied on residents to maintain the point-of-use systems, which require filter changes at approximately monthly intervals. Relying on residents to service the systems, coupled with the highly mineralized water, ultimately resulted in failure of the potable drinking water system. While a distributed system is the recommended alternative, the water should be softened prior to treatment at the point of use, and it is imperative that the system maintenance be performed by assigned NPS staff.

The special water quality concerns at Castolon mandate consultation with a water treatment specialist (probably the manufacturer) to ensure that the selected system can accommodate the typical constituent loads (especially total dissolved solids, hardness, iron, and sulfate) of Castolon well water. Reverse osmosis (R.O.) units , produce about three gallons of waste for each gallon of treated water. This waste could be a significant problem if all water in the distribution system were to be treated, but the waste generated from treating only the culinary/drinking supply should not present a large concern. This consideration also pertains to the issue of standardizing treatment systems throughout the park. RO. units would only be suitable for a limited-supply environment (eg, Chisos Basin) if they were used only as under-sink units and not for treating the entire water supply for the area. Thus, if the Park Service wishes to have only one type of treatment system for the entire park (in order to minimize training of maintenance personnel, for example), then R.O. would be acceptable for drinking water/culinary-only treatment systems. R.O. units require monthly filter changes, while distillation units need filters changed annually and require monthly cleaning (although there are self-cleaning units on the market). Distillation units produce no waste (other than for cleaning of the distillation chamber), but they are initially more expensive. Both units will require a softener in their supply line to operate efficiently.

The essential considerations for choosing between reverse osmosis and distillation are: 1) moderate initial cost for reverse osmosis units but higher long-term maintenance costs, or 2) high initial costs for distillation units but lower maintenance costs in the long term.

Regardless of the option chosen, without adequate personnel time, training, and established procedures, no treatment option is likely to work for any extended period. Dedication of sufficient personnel and establishment of written operation and maintenance procedures are vital to the success of the treatment units. In addition, the NPS must maintain an adequate stock of replacement parts and maintenance materials at all times.

Description of Recommended Project or Activity

1. While initially more expensive, we recommend distillation units as they produce a safer product from a health standpoint. Some distillation units are self-cleaning, requiring only an annual change of pre-and post-filters as routine maintenance. A unit which produces 12 gallons per day (sufficient for a household) costs approximately $1,600. We recommend that a water softener ($1,200 for a dual tank demand system) be housed in one of the buildings at the water storage tanks. Water from the present distribution system would be connected to the intake of the softener, and the discharge would be piped to distillation units in the residences, with one softener serving all units in the residential area. A similar system would be installed to serve the concession and housing at historic Castolon. Maintenance on the water softeners, and the annual filter changes on the distillation units, should be performed by assigned and trained Park Service staff. This system would not require storage tanks and post-treatment chlorination.

2. Train two staff (at least one of which lives in Castolon) in the operation and maintenance of the system. The lead staff should be licensed in the operation of the system.

3. Maintain a complete inventory of spare parts and supplies for the system.

The costs of equipment, training and a supply inventory, and including the installation of pipe and plumbing is estimated at a one time cost of $25,000. Maintenance and supplies are estimated at $10,000 per year as a recurring cost.

BUDGET AND FTEs				
Funded				
	Activi	**Fund Type**	**Budget ($1000s)**	**FTEs**
		Total:	**0.00**	**0.00**
Unfunded				
Year 1:	**MIT** **ADM**	**One-time** **Recurring**	**25.00** **10.00**	**0.20** **0.20**
		Subtotal:	**35.00**	**0.40**
Year 2:	**ADM**	**Recurring**	**10.00**	**0.20**
Year 3:	**ADM**	**Recurring**	**10.00**	**0.20**
Year 4:	**ADM**	**Recurring**	**10.00**	**0.20**
		Total:	**65.00**	**1.00**

Alternative Actions / Solutions and Impacts

1. Use two centralized systems, one in the residential area, and one in historic Castolon. Both systems would require softeners, storage tanks, and pipelines to the residences. A distillation unit of sufficient capacity will cost about $15,000, while an R.O. system would cost $1,000. With a total demand of about 75 gallons per day, a system could be installed at the present storage site with a 1000-gallon tank and new distribution pipes to points of use in the residential area. A second, smaller system could be installed for serving the Historic Castolon facilities with a tank capacity of 500 gallons and new distribution pipes to points of use. According to John Gibson (1995), Chief of Maintenance at Pecos National Historic Park in New Mexico, storing water treated by reverse-osmosis in holding tanks will likely require the installation of a post-R.O. chlorinator. As an additional safeguard, the storage-tank strategy would also allow the flexibility of trucking in potable water to the smaller tanks in the event of system failures. Gibson favors "system" treatment units over point-of-use treatment based on his experiences with both types of R.O. units. He holds that, while initially more expensive than the point-of-use treatment option, the potential problems and parts costs associated with maintenance of several smaller units would likely make the central system option less costly over time. Gibson also notes that questions of liability involving sample logs, post chlorination logs, and other quality tests could best be addressed by assigning maintenance tasks to official park staff. He further suggests that the park consider having the assigned maintenance personnel licensed in the operation of the selected treatment unit.

2. Repair and operate the electrodialysis system, at a cost of approximately $22,000.

3. The no-action alternative of continuing the present chlorination-only treatment is not acceptable given the potential for contaminants from the Rio Grande reaching the wells at Castolon.

Compliance codes:

EXCL (CATEGORICAL EXCLUSION)

Explanation:

516 DM2 App 1.7

Project Statement

BIBE-N-559.001		
Last Update: 03/27/96	Priority: 41	Initial Proposal: 1996
Title: Incorporate Wells in Sub-title: Water Resources		
Funding Status:	Funded: 0.00	Unfunded: 50.00
Servicewide Issues: N22	(VIS USE-DEV ZN)	
N-RMAP Program Codes: Q00 (Water Resources Management), Q01 (Water Resources management)		

Problem Statement

At the present time, the Chisos Basin facilities are totally dependent upon the Oak Spring supply system. While the facilities of the Oak Spring system are in reasonably good condition, the age and the length of the supply pipelines pose some risk of failure. In the event of failure, the Chisos Basin facilities would likely depend on some emergency supply with severe use restrictions for a potentially lengthy period of time. There are several existing wells in the Chisos Basin which could be incorporated into the basin supply that would provide redundancy to mitigate a system failure in the Oak Spring supply. Two of the wells, the Lower Basin CCC wells, were once a part of the supply for the basin, but were abandoned when the Oak Spring supply was developed. While these wells are relatively shallow dug wells, and cannot presently be deemed a reliable supply in times of drought, the water quality of these wells is comparable to the Oak Spring supply (Baker, et al, 1993), and they would make an excellent primary supply except during time of drought. The benefits of their incorporation in the basin supply are: 1) providing a redundant supply system for the basin, and 2) reducing the lift costs by about 50% (the lift from Oak Spring to the basin storage facility is 1458 feet, and the lift from the CCC wells is 720 feet). K. Yarborough (Big Bend National Park, pers. comm., 1994) reported that in FY 93, power for the Oak Spring supply cost $12,834.45. There are two drilled wells, # 1 and #2, in the Upper Basin, which have reported yields of 70 and 25-30 gpm, respectively (NPS, 1974). Maxwell (1985) reported that the #2 well failed after 4 months and was abandoned. The fate of the #1 well is unknown, but if still usable, could serve as an emergency supply. The Development Concept Plan (NPS, 1974) showed in Table 3 that in 1942, the water from this well had total dissolved solids of 614 ppm. While this value exceeds the EPA secondary maximum contaminant level, fluoride content was very high (6 ppm), which exceeds the EPA maximum contaminant level. Blending with waters from other sources could bring the fluoride below the maximum contaminant level, but not below the secondary maximum contaminant level.

Literature Cited

Baker, E.T., Jr., P.M. Buszka, and D.G. Woodward. 1993. Hydrogeology, Geochemistry, and Quality of Water of the Basin and Oak Spring Areas of the Chisos Mountains, Big Bend National Park, Texas. U.S. Geological Survey, Water-Resources Investigation Report 93-4112, 76 pp.

Maxwell, 1985, Big Bend Country: Big Bend Natural History Association, Big Bend National Park, Texas, 88p.

National Park Service. 1974. Environmental Assessment for the Chisos Basin Development Concept, Big Bend National Park, Texas. U.S. Department of the Interior, Denver Service Center. December. 125 pp.

Description of Recommended Project or Activity

1. Perform a pumping test on each of the CCC wells to determine their yield. (The Development Concept Plan (NPS, 1974) for the Chisos Basin shows reported yields of 5 gpm for each well.)

2. Inspect, replace and/or repair, as necessary, the existing pipeline leading from the upper and lower

CCC wells to the Chisos Basin storage facilities, and install pumps capable of lifting the yields determined in 1. against a head of approximately 800 feet on each of the lower CCC wells.

3. Investigate the feasibility of deepening the lower CCC wells to both increase their yield as well as render them more drought resistant. This investigation would be accomplished by a detailed seismic survey in the immediate vicinity of the wells to ascertain the thickness of the saturated materials that supply water to the wells.

NOTE: if this work is done, it would be cost effective to combine the geophysical work for BIBE-N-556.001 (Entrance Station Water Supply Exploration) at the same time.

4. If the thickness of saturated material below the present well bottoms is three or more feet, deepening the wells by hand during drought, or by machine at the Park Service's convenience, would substantially improve the drought resistance of the lower CCC wells.

5. Locate, and retest Upper Basin well # 1 for yield and water quality. If the reported values are confirmed, plumb the well into the basin supply system as an emergency potable source, as well as a source for fire control.

BUDGET AND FTEs				
Funded				
	Activity	Fund type	Budget ($1000)	FTEs
		Total:	0.00	0.00
		Unfunded		
Year 1:	MIT	One-time	50.00	0.00
		Total:	50.00	0.00

Alternative Actions / Solutions and Impacts

The no action alternative would be for the Chisos Basin to rely solely on the continuing integrity of the Oak Spring supply facilities. The park would continue to underwrite the power costs for lifting the water from Oak Spring. In the event of system failure, water would be trucked in from Panther Junction, but severe use restrictions would be necessary, perhaps closing the Chisos Basin to all but park residents and day use activities until repairs could be effected.

Compliance codes:

EXCL (CATEGORICAL EXCLUSION)

Explanation:

516 DM6 App. 7.4 C(11)

Project Statement		
BI BE-N-560.001		
Last Update: 03/27/96	**Priority: 44**	**Initial Proposal: 1996**
Title: Expand Panther Junction Water Supply **Sub-title: Water Resources**		
Funding Status:	**Funded: 0.00**	**Unfunded: 140.00**
Servicewide Issues: N19 (CONSUMPT **USE), N22 (VIS USE-DEV ZN)**		
N-RMAP Program Codes: Q00 (Water Resources Management), Q01 (Water Resources Management)		
10-238 Package Number :		

Problem Statement

Panther Junction is the headquarters of Big Bend National Park and has more permanent residents than all other developed areas of the park combined. There have been several investigations of water availability in the vicinity of Panther Junction (Abbott, 1983; Archer, 1982; Gibson, 1983; and others) and test wells were drilled with the U.S. Geological Survey's assistance (Leggat, et al, 1968). Yields of the existing wells, including the test wells, range from less than 10 gallons per minute (gpm) to about 40 gpm, with most of the wells finished in coarse sand and gravel beds in the continental facies of the Aguja Formation (Leggat, et al, 1968, and Garza, 1966). As Panther Junction is the most populous developed area in the park, and because it also serves as an emergency source of trucked water for other developed areas, it is important to determine whether the present water supply can be expected to support anticipated future needs. It should be noted that in previous studies, Wilson and Schroeder (1984) felt that the addition of the Lone Mountain wells to the Panther Junction supply system could support a substantial increase in water availability.

Literature Cited

Abbott, C. L. 1983. Bedrock Aquifer Geometry in the Panther Junction Area of Big Bend National Park, Texas. Master of Science Thesis, Dept. of Geology, Texas A&M University.

Archer, J.A. 1982. A Hydrogeological Evaluation of Alluvial Fans in Northern Big Bend National Park, Texas, Using Geophysical Methods. M.S. Thesis, Texas A&M University.

Garza, S. 1966. Results of the Water Resources Investigation, Phase I, Big Bend National Park, Brewster County, Texas. U.S. Geological Survey memorandum (unpublished). 11 pp. plus fig.

Gibson, J. L. 1983. Ground-Water Hydrology of the Panther Junction Area of Big Bend National Park, Texas. M. S. Thesis, Dept. of Geology, Texas A&M University.

Leggat, E.R., R.D. Reeves, and C.R. Follett. 1968. Results of Water-Resources Investigation of the Big Bend National Park, Phase II. U.S. Geological Survey Administrative Report (unpublished), 17 pp. plus fig.

Wilson, M. P. and Schroeder, M. C. 1984. Ground Water Investigation in an Area of Big Bend National Park, Texas, Final Report, Dept. of Geology, Texas A&M University, 22 pp.

Description of Recommended Project or Activity

1. Review the literature, particularly Wilson and Schroeder (1984) and other the aquifer test analyses (see Big Bend National Park files on existing wells and original well logs, aquifer tests, etc.), to assess the potential for existing wells to meet anticipated future demands.

2. Analyze historic water level data on all wells in the area, and assess the performance of the aquifer in response to historic stresses, both climatic and man caused (i.e., ground water withdrawals). It is estimated that recommendations 1 and 2 would cost $20,000.

NOTE: If Recommendations 1 and 2 are followed, and the resulting conclusion is that existing wells can meet anticipated demands, and the aquifer has achieved, or appears to be approaching, an equilibrium condition under current stress, drop Recommendation 3 and move to Recommendation 4.

3. Design and implement the facilities required to bring water from the Lone Mountain wells to provide new water supplies for Panther Junction. This element is estimated at $100,000.

4. Establish a water level and water use monitoring program that tracks the static and pumping levels of all wells in the system, as well as nearby unused wells. The goal of the monitoring program is to detect changes in the aquifer's response to stress. Monitoring should be done on a monthly basis, and an annual review of the data should be made by a hydrologist. This element would cost $5,000 per year on a recurring basis.

BUDGET and FTEs

		Funded		
	Activity	**Type**	**($1000s)**	**FTEs**
		Total:	**0.00**	**0.00**
		Unfunded		
Year 1:	**MON** MIT	Recurring One-time	**5.00** **120.00**	**0.10** **0.10**
		Subtotal:	**125.00**	**0.20**
Year 2:	**MON**	Recurring	**5.00**	**0.10**
Year 3:	**MON**	Recurring	**5.00**	**0.10**
Year 4:	**MON**	Recurring	**5.00**	**0.10**
		Total:	**140.00**	**0.50**

Alternative Actions / Solutions and Impacts

1. No action; continue present operations with no additional effort to demonstrate sufficient water for Panther Junction's future needs. In view of previous studies, if little additional growth in demand at Panther Junction is anticipated, this alternative does not appear to carry high risk.

2. Treat present waste water for reuse in Panther Junction. The reuse could be direct if dual supply lines were used: one for potable water supplied only to inside taps (including showers and tubs), the other for treated water supplied to outside taps, toilets, and washing machines, etc. Treated waste water could also possibly be used to encourage infiltration upgradient from the present supply wells to recharge the aquifers they tap.

Compliance codes:

EXCL (CATEGORICAL EXCLUSION)

Explanation:

516 DM6 App. 7.4 C(11)

Project Statement		
616E-N-561.001		
Last Update: 03/26/96	**Priority:** 27	**Initial Proposal: 1996**
Title: Evaluate Irrigation Supply, RGV **Sub-title: Water Resources**		
Funding Status:	**Funded: 0.00**	**Unfunded: 115.00**
Servicewide Issues: N19 (CONSUMPT USE)		
Cultural Resource Type:		
N-RMAP Program Codes: Q00 (Water Resources Management), Q01 (Water Resources Management)		
10-238 Package Number :		

Problem Statement

Irrigation water for the Rio Grande Village area is currently drawn by pumping water directly from the Rio Grande at the mouth of Hot Springs Canyon. The pumps are threatened by high flows in the river (they were flooded in October 1991), and by the high sediment load in the water they pump. The sediment causes excessive rates of wear on the pumps, and a settling pond must be used to remove the sediment before irrigation. The rapid accumulation of sediment in the ponds requires that the ponds be periodically emptied of sediment. Together, all the elements of the irrigation supply for the Rio Grande Village make it an expensive operation.

Description of Recommended Project or Activity

1. Test pump the two existing irrigation wells at Rio Grande Village. One well is located near the group campground and one is located about 100 yards downstream of the pumping station. Although we found no information on the yields of these wells, the sizes of the unused pumps sitting on them suggest they may well be capable of supplying sufficient water for the irrigation needs at Rio Grande Village. (This would be a categorically excluded project.) If refurbishing and using these wells cannot supply sufficient water, then proceed with Recommendation 2.

2. Using a backhoe with sufficient span to dig a trench seven to ten feet below the bed of the stream, construct an infiltration gallery. These galleries consist of a horizontal screened section buried in alluvial materials a few feet below the bottom of, and parallel to, the stream channel. A vertical riser attached to the horizontal screened section houses the pump column. The cost of such a well is strongly influenced by the length of the horizontal screened section required to achieve a desired yield, and this, in turn, depends on the transmissive quality of the alluvial deposits. Such a well effectively eliminates all the problems caused by sediment in the present irrigation supply, and the vertical riser can be sufficiently high to protect the pump mounted on it from high flows in the river. While drilling a series of test borings would enable the design of a gallery, it can be constructed without expensive preliminary testing. Simply dig the trench, and during the digging process, test pump the trench. Alternate digging and pumping until the trench supplies the amount of water desired for irrigation purposes. When a sufficient supply is captured, complete the installation by installing the horizontal screen section and connecting it to the vertical riser. (This activity would require an EA and perhaps a 404 permit, and NPS wetlands policy compliance).

BUDGET AND FTEs				
Funded				
	Activity	**Fund Type**	Budget. ($1000s)	**FTEs**
		Total:	**0.00**	**0.00**
		Unfunded		
Year 1:	**RES**	One-time	15.00	0.10
Year 2:	**MIT**	One-time	100.00	0.40
		Total:	**115.00**	**0.50**

Alternative Actions / Solutions and Impacts

The no-action alternative would continue the operation of the present system, accepting the risks of the pumps being inundated during floods on the Rio Grande, and the costs associated with the sediment problems. These costs include both rapid wear on the pumps and the problem of disposing of, or managing, the sediment accumulations in the settling ponds.

A second alternative might be explored if the combined yield from the two existing wells does not quite satisfy the irrigation supply need. This alternative would replace the expensive infiltration gallery with another well drilled in the alluvium similar to the two present wells. This project would cost about half as much as the infiltration gallery.

Compliance codes:

See description of recommended activity.

Project Statement		
BIBE-N-562.001		
Last Update: 03/27/96	**Priority: 22**	**Initial Proposal: 1996**
Title: Utilize Available Storage, Chisos Basin **Sub-title: Water Resources**		
Funding Status:	**Funded: 0.00**	**Unfunded: 10.00**
Servicewide Issues: N22 (VIS USE-DEV ZN)		
Cultural Resource Type:		
N-RMAP Program Codes: Q00 (Water Resources Management), Q01 (Water Resources Management)		
10-238 Package Number :		

Problem Statement

The Chisos Basin in Big Bend National Park is the most frequently visited region of the park for overnight stays. Visitors, park employees, and the concessionaire generate the water demand in the basin. Water pumped from Oak Spring, 2.467 miles away and 1458 feet lower, supplies the demand. The Chisos Basin Water System contains four storage tanks, two at Oak Spring, and two in the basin. Two of the four storage tanks have the capacity to store more water, with one capable of holding 100,000 gallons in the basin, and an unused space of 250,000 gallons in the 500,000 gallon tank at Oak Spring. During normal demand and precipitation conditions, this system, in its present configuration, provides a sufficient quantity of water for the Chisos Basin needs. However, in times of drought and peak demand, officials at Big Bend National Park feel that Oak Spring may not provide the water needed for normal park operations.

The highest average monthly use rate in Chisos Basin (19.6 gallons per minute) occurred in June 1993. Although the distribution system had a significant (approximately 3 gpm) leak at that time, the Park Service's concern over inadequate water supplies stems from Oak Spring's history of variable discharge (flow fell to as little as 19.9 gpm on June 18, 1990 (NPS, 1992)). Based on data from 1990 through 1992, water use in the Chisos Basin averages about 11 gpm over the year, with monthly demands ranging from 7.6 gpm to 16.1 gpm. Table 20 in the Water Resources Management Plan provides an analysis of water use data and minimum Oak Spring flow rates required to satisfy a demand 20% greater than the highest recorded rate and leave the storage system filled to at least 60% of full capacity. This analysis shows that Oak Spring could flow as little as 16.5 gpm using present storage configuration, 14.2 gpm if the 500,000 gallon tank at Oak Spring were fully utilized, and as low as 13.3 gpm if the 100,000 gallon tank in the basin were utilized as well.

Description of Recommended Project or Activity

1. Install a pump between the 25,000-gallon and 500,000-gallon storage tanks at Oak Springs. (This effort was previously planned; in a letter dated January 16, 1992, then Superintendent Arnberger refers to pumps purchased for this purpose being stored in the pumphouse at Oak Spring.) This effort would increase the quantity of stored water for the Chisos Basin by 250,000 gallons. The installed pump would lift the water 10 ft. into the 500,000-gallon tank. The increase in electrical operation cost associated with the 10-foot lift would be minimal because the resulting Oak Springs- to-Chisos Basin lift is reduced by 10 feet. The only new continuing cost would go toward maintaining the small pump.

2. The second recommended course of action would be to reconnect the Chisos Basin 100,000-gallon storage tank into the system. This alternative would raise the storage capacity of the system by 100,000 gallons which would, in turn, decrease the necessary Oak Springs recovery rate by almost 1 gpm. The

significant increase in efficiency could support a larger demand rate or a longer peak demand time.

Personnel would only be required for a few hours of plumbing and for electrical expertise needed to replumb the storage tanks in the Basin and at Oak Spring, and to install the pump to lift water to fill the 500,000-gallon tank at the spring . After the plumbing changes and pump installation, maintenance and operations of the additional facilities would be an insignificant addition to present operations and maintenance already performed at the two sites.

The only cost associated with these recommendations is the cost of pipe and plumbing fittings with which to incorporate the additional storage capacities of the system in the Basin and at Oak Spring. In the event that the pumps referred to in the Arnberger letter cited above have been utilized for other purposes, the additional cost of a pump(s) would be incurred.

BUDGET AND FTEs				
Funded				
	Activity	FunTyped	($1Budget 000s)	FTEs
		Total:	0.00	0.00
		Unfunded		
Year 1:	MIT	One-time	10.00	0.20
		Total:	10.00	0.20

Alternative Actions / Solutions and Impacts

A no-action alternative would continue the use of the present configuration of storage in the Chisos Basin supply system. As the Oak Spring flow rate requirements were based on a 20% increase in a peak monthly demand which included the effect of an approximate 3 gpm leak, the estimates are very conservative. The supply would not be as resilient to diminished flow from Oak Spring, and would not have the additional 100,000 gallons on hand in the Basin storage facility for fire protection, and as additional reserves if the delivery system from the spring were to suffer a failure.

Compliance codes:

EXCL (CATEGORICAL EXCLUSION)

Explanation:

516 DM6 App. 7.4 C(18)

Project Statement	
BIBE-N-563.001	

Last Update: 03/27/96	Priority: 28	Initial Proposal: 1996
Title: Investigate Coliform Hazard in Rio Grande Sub-title: Water Resources		
Funding Status:	Funded: 0.00	Unfunded: 70.00
Servicewide Issues: N11 (WATER QUAL-EXT), N16 (NEAR-PARK DEV)		
Cultural Resource Type:		
N-RMAP Program Codes: Q00 (Water Resources Management), QO1 (Water Resources Management)		
10-238 Package Number :		

Problem Statement

The Rio Grande flows along the southern boundary of Big Bend National Park. Flow of this reach of the river comes primarily from the Rio Conchos in Mexico and tributaries such as Terlingua and Alamito Creeks. Known discharges to the river include industrial and municipal effluent from both sides of the United States/Mexico border, and possible pathogen contributions may originate from sewage systems in housing developments on both sides of the border.

Data presented by TNRCC (1994) presented cause for concern with fecal coliform levels with nearly 30 percent of the samples exceeding the 400 colonies/100 ml screening level in high flow conditions, and 13 percent of samples exceeding the screening level in low flow conditions.

Kaiser, et al (1994) noted in their recent exploratory analysis of water quality issues related to Big Bend National Park that elevated coliform bacteria levels found in a portion of Rio Grande River segment 2306 result in parts of the river not meeting swimmable criteria. In addition, Carranza, et al (1994) presented data that indicated the presence of elevated fecal coliform.

While the source of possible bacterial contamination has not been determined, it may be related to the wildlife and trespass livestock that occur in the area. However, there is also the possibility of septic leachate emanating from increasing private home development on both sides of the border.

Literature Cited

Carranza, C., M. Carias, M. del C. Monarrez, M. Tarango, W.P. Mackay, R. Mena, N. Hallerud, and E. Ruiloba, Jr. 1994. Evaluation of Water Quality of the Rio Grande in Big Bend National Park, Texas, 43 pp. (unpublished report)

Kaiser, R.A., S.E. Alexander, and J.P. Hammill. 1994. Protecting the National Parks in Texas Through Enforcement of Water Quality Standards: An Exploratory Analysis. Technical Report NPS/NRWRD/NRTR-94/18. Prepared for the U.S. Department of the Interior, National Park Service by Texas Agricultural Experiment Station Texas A&M University, College Station, TX. 96

PP-

Texas Natural Resources Conservation Commission (TNRCC). 1994. Regional Assessment of Water Quality in the Rio Grande Basin Including the Pecos River, the Devil's River, the Arroyo Colorado, and the Lower Laguna Madre. Watershed Management Division, Austin, TX. 337 pp.

Description of Recommended Project or Activity

A two-year intensive study is proposed to evaluate the extent of bacterial contamination and possible sources of contamination within the Big Bend National Park. Monitoring would consist of: 1) bimonthly monitoring for fecal coliform and Enterococci bacteria at appropriate surface water sites along the Rio Grande as well as in Terlingua and Alamito Creeks, 2) implementing appropriate laboratory verification techniques to identify the sources as human or wildlife related, and 3) based on the data for the first year, undertaking a comprehensive sanitary *survey* to identify possible sources of bacterial contamination.

Sampling sites on the Rio Grande should include, but not necessarily be limited to:

1. at or near the Presidio/Brewster County line
2. at the head of Santa Elena Canyon
3. at the mouth of Santa Elena Canyon above Terlingua Creek
4. at the Johnson Ranch gaging station
5. at Solis Landing
6. at the Hot Springs
7. at the head of Boquillas Canyon.

If additional funding is available, the survey should be expanded to include other pathogen organisms such as Giardia, Cryptosporidium, and viruses. Should contamination be found and sources identified, appropriate mitigation alternatives could be implemented for U.S. sources, and negotiated for Mexican sources.

The projected cost for the coliform monitoring is about $40,000 with about $10,000 in additional funding for a sanitary survey. An additional $20,000 is required to include Giardia, Cryptosporidium, and viruses.

BUDGET AND FTEs				
Funded				
	Activity	FunTyped	($1 Budget	FTEs
		Total	0.00	0.00
		Unfunded		
Year 1:	RES	One-time	30.00	0.10
Year 2	RES	One-time	40.00	0.10
		Total:	70.00	0.20

Compliance codes:

EXCL (CATEGORICAL EXCLUSION)

Explanation:

516 DM2 APP. 2, 1.6

Project Statement		
BIBE-N-564.001		
Last Update: 03/26/96	**Priority: 56**	**Initial Proposal: 1996**
Title: Mitigate Flashflood Hazard **Sub-title: Water Resources**		
Funding Status:	**Funded: 0.00**	**Unfunded: 40.00**
Servicewide Issues: N12 (WATER FLOW)		
Cultural Resource Type:		
N-RMAP Program Codes: Q00 (Water Resources Management), Q01 (Water Resources Management)		
10-238 Package Number :		

Problem Statement

Flash flooding on normally dry streams poses a danger to park visitors. People unfamiliar with the dangers of flash floods may be unpleasantly surprised when a wall of water one to three feet high suddenly moves down a dry stream bed somewhat faster than a person can run. This danger is perhaps most significant in large drainages such as Tornillo and Terlingua Creeks and the tributary to Stilwell Creek in the northern part of the park. The large areal extent of these drainages creates the potential for an intense storm to create a flash flood that can travel a long distance from the storm area. Thus, a person might not even notice the storm producing the flood that may imperil him/her some hours after the rain actually fell.

Most of these floods are caused by high-intensity short-duration storms. For example, many storms exceeding two inches per hour, and some exceeding three inches per hour, have been recorded by the National Weather Service stations in Brewster and surrounding counties. Most of these storms lasted two hours or less.

Many investigations have shown that large peak discharges in the area are not uniformly distributed temporally or areally. A recent investigation by Slade, et al (1995) presents an example of temporal clustering for peak discharges. For the investigation, the U. S. Geological Survey identified all Texas stream gaging stations with at least fifty years of peak-discharge data from natural basins (basins where discharges are not strongly affected by urbanization, diversions, or regulation). For each station, the peak data base was separated into two data sets representing the first and second half of the period of record. For each data set, a peak-flow frequency analysis was performed. For the 47 stations that met the selection criteria, the analysis indicated that the mean difference for the 2-year (return period) peak discharge was 35% between the two periods, while the mean difference for the 100-year peak discharge was 37%. The analysis indicated a non-uniform temporal distribution in peak discharges for most stations, even those with long-term records.

This and other investigations indicate that peak-flow frequency is best quantified when peak data for many pertinent stations are included in the analysis. A multi-regression technique - - an analysis that relates peak discharge to drainage basin and precipitation characteristics - - is recommended for such investigations. Several such studies in Texas, including Schroeder and Massey (1977) and Slade, et al (1995), have produced regression equations relating peak discharge to such basin characteristics as contributing drainage area,
main-channel slope, main channel length, and a basin shape factor. The precipitation characteristics used include mean annual precipitation and the 2-year, 24-hour maximum precipitation.

Slade, et al (1995) performed this kind of analysis in Hays County, Texas. The regression equations proved quite reliable, with the mean error of prediction about 20%, and the standard error about 30%. The U.S. Geological Survey is currently conducting a similar investigation for streams discharging to the Highland Lakes on the

Colorado River. A similar analysis for streams in the Big Bend National Park area would provide reliable equations for predicting the recurrence interval (return period) for peak discharges for natural streams in the area.

About 20 existing stations in the vicinity of Big Bend National Park have a minimum of 8 years of peak discharge data, have less than ten percent of their area covered by impervious material, and have less than 10 percent of their drainage area controlled by reservoirs (R.M. Slade, U.S. Geological Survey, pers. comm., 1994). There are additional stations on the Rio Grande, and on tributaries larger than 3,000 square miles, but these stations are not typical of the kinds of smaller basins that are of concern to the park, so they would not be included.

Literature Cited

Schroeder, E. E. and B. C. Massey. 1977. Technique for Estimating the Magnitude and Frequency of Floods in Texas. U.S. Geological Survey Open-File Report 77-110, 22 pp.

Slade, R. M., Jr., Asquith, W. H., and G. D. Tasker. 1995. Multiple-Regression Equations to Estimate Peak-Flow Frequency for Streams in Hays County, Texas. U.S. Geological Survey, Water-Res. Invest. Report 95-4019, prep. in coord. with Federal Emergency Management Agency and U.S. Army Corps of Engineers, Austin, Texas (map).

Description of Recommended Project or Activity

1. Prepare an information pamphlet for visitors on the dangers of flash floods. The pamphlet should provide a general description of flash floods, the times of year when they are most likely to occur, and precautions visitors may take to avoid risk. Specific information should be provided on storm areas that can produce flash floods on the larger tributaries (eg, to the north and northwest in Tornillo Creek, and to the west on the Stilwell Creek tributary.)
2. Produce a video tape for display in visitor centers that shows flash flood events and gives advice on how to avoid them. This might be combined in a general presentation on hazards in the park such as bear and/or mountain lion encounters, poisonous snakes, river rafting, back country hiking/camping precautions, etc.
3. Post permanent signs at the closest points of vehicular access to Tomillo and Terlingua creeks and the Stilwell Creek tributary warning of flash flood hazard, and the-need to be alert for even distant storms.
4. Develop an agreement with the Texas District of the U.S. Geological Survey to produce a report for the Big Bend National Park area similar to the Slade, et al (1995) report. With the capability of estimating the peak discharge for ungaged sites for various recurrence intervals, flood hazard mapping could be done in areas of concern under an extension of this agreement.

Public awareness and mitigation aspects of recommendations 1 through 3 can be implemented in the first year of this project. Completing a research study to estimate peak discharge at ungaged sites (recommendation 4) would likely be a two year research project.

BUDGET AND FTEs				
Funded				
	Activity	Fund Type	Budget ($1000s)	FTEs
		Total:	0.00	0.00
Unfunded				
Year 1:	RES MIT	One-time One-time	20.00 10.00	0.50 0.10
		Subtotal:	30.00	0.60
Year 2:	RES	One-time	10.00	0.10
		Total:	40.00	0.70

Alternative Actions / Solutions and Impacts

The no-action alternative would result in continuing the present practice in the park regarding flash flood warning. The current practice consists of providing general information at visitor centers stating that flash flood hazards exist in the park.

A second alternative would be to develop flash flood warning devices in areas where park visitors are likely to recreate in washes susceptible to flash floods caused by distant storms. This alternative would be costly to put in place, and even more costly to guarantee its proper operation. By providing such a warning system the National Park Service would assume liability for its operation.

Compliance codes:

EXCL (CATEGORICAL EXCLUSION)

Explanation:

516 DM2 APP. 2, 1.6

Project Statement

BIBE-N-565.001

Last Update: 03/27/96	**Priority:** 57	**Initial Proposal: 1996**
Title: Evaluate New Area Water Sources **Sub-title: Water Resources**		
Funding Status:	**Funded: 0.00**	**Unfunded:** 35.00
Servicewide Issues: N20 (BASELINE DATA)		
Cultural Resource Type:		
N-RMAP Program Codes: Q00 (Water Resources Management), QOI (Water Resources Management)		
10-238 Package Number :		

Problem Statement

The boundaries of Big Bend National Park have expanded over the years as adjacent lands were acquired and incorporated into the park. While the National Park Service has acquired water resources and related data for areas within the former park boundary, such data have not been systematically collected on the recently acquired additions to the park.

Description of Recommended Project or Activity

1. Expand and populate all layers in the Big Bend National Park's GIS system to include the boundary expansion. In the process of populating well and spring water source layers, site schedules should be prepared so that the data may be entered into the U.S. Geological Survey's NWIS- 1 data base. Larger springs and all wells that can be pumped to obtain samples should be tested for common ions, with springs being additionally tested for coliform. Estimated cost of $15,000.

2. Install a meteorological station to record all climatic data presently being captured by the stations at Chisos Basin, Panther Junction, Persimmon Gap, Castolon, and Rio Grande Village. A station is recommended for the northern part of the park, and another for near the western edge. National Weather Service maintains all meteorological data collection sites.

3. Include the springs in the new lands in the systematic flow evaluation recommended in Project Statement BIBE-N-554.001. Estimated cost $3,000.

4. Review all information on the new lands and develop plans for the utilization of these lands in a Development Concept Plan as well as the Master Plan for Big Bend National Park. Depending on envisioned uses, further investigations may be required to assess flood hazards in high visitor use areas near washes, and to assess the availability of water suitable for any desired development. The estimated cost of a Development Concept Plan is $17,000.

BUDGET AND FTEs				
Funded				
	Activity	**Fund Type**	Budget ($1000s)	**FTEs**
		Total:	**0.00**	**0.00**
Unfunded				
Year 1:	**MON**	Cyclic	**3.00**	**0.10**
	RES	One-time	15.00	**0.20**
	ADM	One-time	**17.00**	**0.20**
		Subtotal:	**35.00**	**0.50**
		Total:	**35.00**	**0.50**

Alternative Actions / Solutions and Impacts

The no-action alternative would be to gather no new data on the new lands as a field effort, but to incorporate existing available data into appropriate data bases.

Compliance codes:

EXCL (CATEGORICAL EXCLUSION)

Explanation:

516 DM2 APP. 2, 1.6

Project Statement

BIBE-N-566.001		
Last Update: 03/27/96	**Priority:** 37	**Initial Proposal: 1996**
Title: Research and Analyze Precipitation Records **Sub-title: Water Resources**		
Funding Status:	**Funded: 0.00**	**Unfunded: 7.00**
Servicewide Issues: N20 (BASELINE DATA)		
Cultural Resource Type:		
N-RMAP Program Codes: Q00 (Water Resources Management), Q01 (Water Resources Management)		
10-238 Package Number :		

Problem Statement

An analysis of precipitation records for Big Bend National Park beginning in the late 1950's shows a gradual trend downward in the annual precipitation that starts in the mid 1960's (see Figure 4 in Chapter 3). In addition, the frequency of extremes in the record, both of "wet" and "dry" years, appears to increase after the mid 1970's. While continuation of these trends could have serious implications for the water resources of the park, particularly in places like the Chisos Basin where the water supply depends on the flow of Oak Spring, these trends must be put in the context of the long term variability of climate in this region. Analyzing and comparing very long term rainfall records for stations in both the Mexican and United States portions of the northern Chihuahuan Desert with records from the park stations could provide insight into the significance of the recent trends seen in the park station records.

Description of Recommended Project or Activity

1. Search the literature and the databases of the National Weather Service and its Mexican counterpart to obtain precipitation data from stations with the longest period of record.

2. If the literature does not contain such an analysis, compare the precipitation variability within records for the long term stations to test the uniformity of these variations over the northern Chihuahuan Desert region.

3. Analyze the overlapping records for long term stations and the park stations to put the park precipitation record in perspective, and take appropriate action if the continuation of present trends seems likely.

This analysis would make an excellent topic for a Masters' thesis, and could be done in about 6 months, at a cost of about $7,000.

BUDGET AND FTEs				
Funded				
	Activity	Fund Type	Budget ($1000s)	FTEs
		Total	0.00	0.00
		Unfunded		
Year 1:	RES	One-time	7.00	0.05
		Total:	7.00	0.05

Alternative Actions / Solutions and Impacts

The no-action alternative would be to continue on in ignorance of how recent precipitation patterns relate to long term records. If current conditions are near normal for the region, a continued trend toward less precipitation might threaten the water supply from Oak Spring. Advance knowledge of the probability of such a circumstance would allow management to pursue alternative supplies.

A second alternative would be for park staff to perform the literature and database search and prepare the analysis in-house. This alternative would require .1 FTE of technical or scientific background.

Compliance codes:

EXCL (CATEGORICAL EXCLUSION)

Explanation:

516 DM2 APP. 2, 1:6

Project Statement		
BIBE-N-567.001		
Last Update: 03/27/96	**Priority: 12**	**Initial Proposal: 1996**
Title: Assess Aquatic and Riparian Habitat **Sub-title: Water Resources**		
Funding Status:	**Funded: 0.00**	**Unfunded: 165.00**
Servicewide Issues: N12 (WATER FLOW)		
N-RMAP Program Codes: Q00 (Water Resources Management), Q01 (Water Resources Management)		

Problem Statement

Big Bend National Park, located in an increasingly stressed ecosystem along the United States/Mexico border, requires essential baseline data sets for effective resource management. The North American Free Trade Agreement (NAFTA) is expected to contribute to expanded development along the U.S./Mexico border. To achieve a balance between economic growth and protection of the area's biological resources, the United States and Mexico need a clear understanding of the impacts of changes in the near and distant future.

Big Bend National Park suffers from a critical lack of information on its riparian/wetlands areas (NPS, 1992). Habitat maps for wetland and aquatic areas, combined with inventories of flora (eg, species composition and structure) and fauna (eg, fish and aquatic invertebrates) within those areas, are needed for the park. Given detailed maps and inventories, resource managers will be able to detect the responses of wetlands and riparian zones to various natural and human-induced disturbances. A mapping and inventory effort will be necessary to address the following resource management objectives:

1) measurement of the response of wetland and riparian zones and their faunal components to intensive grazing by trespass livestock and to recreationalists;

2) measurement of the response of rare wetland-dependent biota and associated habitat to water quality and hydrological stresses;

3) understanding and prediction of changes in wetland boundaries and community structure in response to natural/animal-related (eg, floods, wind-produced canopy gaps, grazing, fire, etc.) and human-induced (eg, water withdrawals, ground water level changes, water quality degradation, sedimentation, etc.) factors; and

4) provision of a baseline for effective visitor use planning (eg, placement of visitor facilities, design of interpretive walks, etc.).

When the wetland and riparian zone assessment is coupled with aquatic surveys (eg, fishes and invertebrates), water quality monitoring, livestock population monitoring, and upland vegetation surveys, resource managers will have many of the data sets necessary to make well-informed resource protection decisions.

Changes in the community structure of the Rio Grande riverine biota have been documented. Population surveys show a decline in distribution and abundance of some native fish species (of 35 native species, 14 are considered extirpated or have a threatened status) including the Rio Grande silvery minnow while hardier species such as the red shiner (Cyprinella lutrensis) are increasing. Changes in water quantity and quality are possible factors, but no specific causes have been identified (Edwards and Contreras-Balderas, 1991).

The segment of river between Presidio and Boquillas is a potential area for studying the effects of water quality on aquatic communities. The area's special biological status is reflected in its designation as National Park, Wild and Scenic River, and Man and the Biosphere Program.

The University of New Mexico Ichtyofaunal Studies Program and Texas Parks and Wildlife maintain databases on the fishes of the area. In addition, the endangered species recovery team for Chihuahuan desert fishes (whose members include the U.S. Fish and Wildlife Service, as well as New Mexico, Texas, and Mexico agencies and universities) are currently surveying the fish populations (S.P. Platania, University of New Mexico, Albuquerque, pers. comm., 1994).

Literature Cited

Edwards, R.J. and S. Contreras-Balderas. 1991. Historical Changes in the Ichthyofauna of the Lower Rio Grande (Rio Bravo del Norte), Texas and Mexico. The Southwestern Naturalist, vol. 36, no. 2. pp. 201-202.

National Park Service. 1992. Big Bend National Park Water Resources Scoping Report. National Park Service, Water Resources Division and Big Bend National Park Technical Report NPS/NRWRD/NRTR - 92/08, Washington, DC. 31 pp.

Description of Recommended Project or Activity

1. Inventory the fish fauna and associated habitat. Estimated cost $25,000.

2. Inventory the wetland/riverine invertebrate fauna. Estimated cost of $40,000.

3. Map the distribution of various wetland/riparian habitats, and assimilate information into the parks GIS. Estimated costs of $40,000.

4. Monitor human caused impacts to riparian wetland system (ie, water removals, grazing, fire, etc) via a quantitative photo point assessment. Estimated costs of $15,000 per year.

BUDGET AND FTEs				
Funded				
	Activity	Fund Type	Budget ($1000s)	FTEs
		Total:	0.00	0.00
Unfunded				
Year 1:	RES MON	One-time Recurring	105.00 15.00	0.20 0.10
		Subtotal:	120.00	0.30
Year 2:	MON	Recurring	15.00	0.10
Year 3:	MON	Recurring	15.00	0.10
Year 4:	MON	Recurring	15.00	0.10
		Total:	165.00	0.60

Compliance codes:

EXCL (CATEGORICAL EXCLUSION)

Explanation:

516 DM2 APP. 2, 1.6

Project Statement		
BIBE-N-568.001		
Last Update: 03/27/96	**Priority: 42**	**Initial Proposal: 1996**
Title: Support Other Water Quality Monitoring Activities **Sub-title: Water Resources**		
Funding Status:	**Funded: 0.00**	**Unfunded: 40.00**
Servicewide Issues: N11 (WATER QUAL-EXT)		
N-RMAP Program Codes: Q00 (Water Resources Management), Q01 (Water Resources Management)		

Problem Statement

The continuing popularity and growth of recreational use of the Rio Grande in Big Bend National Park by river rafters and others, as well as growing concerns for fish and wildlife habitat and health, necessitates the development of a comprehensive and continuing water quality monitoring program at selected sites along the river and local tributaries. Considering costs of water sampling in the field, laboratory analyses, and data interpretation, storage, and retrieval, the annual funding and human resources available to the park may not be adequate for conducting such a program in-house. In light of this fact, the park should make maximum use of monitoring efforts by others. Cooperative activity with local groups can be conducted at relatively low cost, can be directed toward known or suspected water quality problems, and can serve to supplement data collected by state and federal agencies. These activities can also provide early warning indicating needs for focused study of specific water quality parameters

Description of Recommended Project or Activity

Cooperative activity in water quality monitoring has already been initiated in Big Bend National Park through the Texas Watch program and related activities. The group called "The Big Bend River Watchers" assembled in 1994 with the following stated goals:

> "To restore and preserve the Rio Grande as a drinkable, fishable, and swimmable waterbody."
>
> "To sustain the Rio Grande as a waterbody that attracts and supports tourism."

The group includes student bodies and citizen volunteers and ". . . is very committed to monitoring and is willing to travel long distances to reach sampling sites" (August , 1994 Meeting Notes). cooperators include Sul Ross State University, Presidio High School, Lajitas Waste Water Treatment Plant, Far Flung Adventures, Outward Bound, the Texas Natural Resource Conservation Commission, and Big Bend National Park.

We recommend that the park provide the physical and human resources necessary to make the following contribution:

1) Assign specific personnel to participate in, and act as liaisons to, the group monitoring activity;

2) Organize and sponsor regular meetings of the group as needed;

3) Provide training and technical assistance in the collection, preservation, storage, and analysis of water samples;

4) Provide office/file/computer space for the ongoing storage and processing of all data acquired under the program.

Compliance codes:

EXCL (CATEGORICAL EXCLUSION)

Explanation:

516 DM2 App. 2, 1.6

BUDGET AND FTEs				
Funded				
	Activity	Fund Type	Budget ($1000s)	FTEs
		Total:	0.00	0.00
Unfunded				
Year 1:	MON	Recurring	10.00	0.25
Year 2:	MON	Recurring	10.00	0.25
Year 3:	MON	Recurring	10.00	0.25
Year 4:	MON	Recurring	10.00	0.25
		Total:	40.00	1.00

Project Statement		
BIBE-N-569.001		
Last Update: 03/27/96	**Priority:**	**Initial Proposal:** ***1996***
Title: Enter Water Data into USGS Data Base **Sub-title: Water Resources**		
Funding Status:	**Funded: 0.00**	**Unfunded: 30.00**
Servicewide Issues: N11 (WATER QUAL-EXT), N12		**(WATER FLOW)**
N-RMAP Program Codes: Q00 (Water Resources		**Management), QOl (Water Resources Management)**

Problem Statement

The water resources data base for Big Bend National Park is highly fragmented. Some data, such as precipitation is available in electronic form, some, but not all, streamflow data is available in electronic form, and only a few ground water data sites are available in electronic form. Many records exist for ground water and spring sites, and a large percentage of the ground water data is partially recorded in data entry format. The U. S. Geological Survey has a data base (NWIS) which will accommodate all of the Parks water data, and the Texas District Office of the USGS Water Resources Division has expressed a willingness to accommodate Big Bend National Park data on that data base. The advantages of utilizing this data base include professional management of an automated data base, utilization of an extensive analytical and report generating library, QA/QC on data entered, training of park staff on data collection and processing procedures, analytical tools, and report generation.

Description of Recommended Project or Activity

1. Develop an agreement with the U.S. Geological Survey Texas District Office to gain access to the NWIS data base. Access would be by high speed modem until such time as the Park has access to the Internet. This agreement should address:
   — access and use of the data base
   — USGS acquisition and incorporation of IBWC Rio Grande data in the NWIS data base
   — training on data entry and data base operation
   — training on data collection and processing
   (training may be on-site, at the Texas District, or at the USGS National Training Center in Denver)

2. Using the files on wells and springs organized in the preparation of the Water Resources Management Plan, complete population of the ground water data base.

3. Prepare complete site schedules for those wells and springs not included in 2. above, and enter these site data in the data base.

4. Develop a procedure for updating the information in the data base as new data become available.

The initial data base construction would be undertaken by a 0.3 FTE seasonal position. Continual implementation of this project would be undertaken by the base-funded park hydrologist, in cooperation with the USGS.

BUDGET AND FTEs				
Funded				
	Activity	**Fund Type**	**Budget ($1000s)**	**FTEs**
		Total:	**0.00**	**0.00**
Unfunded				
Year 1:	**ADM**	**Recurring**	**15.00**	**0.30**
Year 2:	**ADM**	**Recurring**	**5.00**	**0.10**
Year3:	**ADM**	**Recurring**	**5.00**	**0.10**
Year 4:	**ADM**	**Recurring**	**5.00**	**0.10**
		Total:	**30.00**	**0.60**

Alternative Actions / Solutions and Impacts

The no-action alternative would be to continue to collect and store water data in a highly fragmented fashion. Following this alternative would lead to heavy front-end costs on any analyses of water resource issues, with the added risk of data loss through lack of uniform procedures and practices in collection, processing, and management.

Compliance codes:

EXCL (CATEGORICAL EXCLUSION)

Explanation:

516 DM6 APP. 7.4 E(2)

Environmental Compliance

This Water Resources Management Plan is categorically excluded from the NEPA process. This determination is based on the guidelines provided in the United States Departmental Manual:

> 516 DM6, Appendix 7.4 B(4) — This plan would only involve nondestructive data collection, inventory, study, research, and monitoring activities.

Any activities involving disturbance to park lands will involve appropriate environmental and cultural review and compliance.

Copies of this plan have been provided to those agencies, organizations, and individuals listed under the section entitled "Copies Distributed for Review." Their review and comments on the draft report were considered in the preparation of this final Water Resources Management Plan.

Review Comments

Comments received were generally supportive of the plan. The suggested changes are summarized below:

Alice Johns of the NPS-WRD clarified several points relating to Texas water law and how it affects Big Bend National Park.

Christine Kolbe and Gail Rothe of the Texas Natural Resource Conservation Commission recommended (and assisted with) reference to current water quality standards and water quality data for the Rio Grande.

Gary Smillie of the NPS-WRD supplemented the discussion on floodplain concerns.

Jack Hammond of the Rio Grande Compact Commission clarified several points regarding the history of the distribution of Rio Grande water between the United States and Mexico.

James Robinson of the IBWC (U.S. Section) and Rebecca Lambert of the USGS-WRD in San Antonio, Texas, provided detailed comments and corrections and proposed actions that the National Park Service may explore in the future.

Keith Yarborough (NPS) provided a detailed review of the plan with several useful comments.

Mike Sacoman (US Public Health Service) reviewed and complimented the plan's suggestions for water supply improvements.

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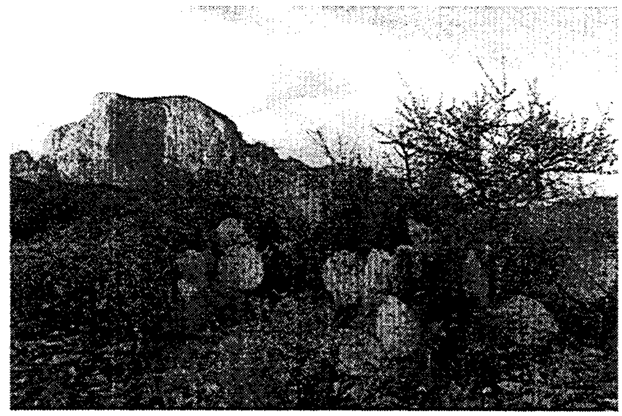

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