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Development of Water Quality Analyses for the Shared Waters of the United States and Mexico

Prepared for:

United States Environmental Protection Agency
Office of Wastewater Management
Washington DC, 20460

Prepared by:

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[1] RTI International is a trade name of Research Triangle Institute.

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Acknowledgments

The U.S.-Mexico Shared Waters project represents a unique effort to bring together organizations and individuals from both sides of the U.S.-Mexico border to help with the design and creation of the first prototype version of the U.S.-Mexico Border Waters Repository and the Mexico Border Reach File (MBRF). This effort has developed a baseline of what water quality information is available on both sides of the U.S.-Mexico border, generated useful products based on this information, and identified ways to build up on what has been done so far towards developing a binational water quality dataset that can be used to establish baseline border water quality conditions and measure future progress towards improving water quality conditions for this important resource.

One of the most important accomplishments of this project has been to identify current and future key players involved with U.S.-Mexico border environmental issues and to gain their cooperation towards establishing a baseline data set. Many of these organizations have been working for years on important environmental problems in the region and have vast experience dealing with water resources and water quality issues along the U.S.-Mexico border. The following organizations contributed data, comments, and recommendations to this project; their expertise and guidance on border issues was fundamental to completing this report:

- U.S. Environmental Protection Agency (EPA) Region 6 and Region 9
- Comisión Nacional del Agua (CNA), México Distrito Federal, México
- Comisión Internacional de Límites y Aguas (CILA), Juárez, México
- International Boundary and Water Commission (IBWC), El Paso, TX
- Southwest Consortium for Environmental Research and Policy (SCERP), San Diego, CA
- University of Texas at Austin (UTA)
- U.S. Geological Survey (USGS), Austin, TX.

Future cooperation and coordination with these entities must be included in planning for subsequent phases of this project and will be critical towards the continuing success of the border water data collection efforts.

In addition, this report builds upon earlier work on this project conducted by Parsons Engineering Science, Inc. (A Unit of Parsons Infrastructure & Technology Group Inc.). In particular, that work contributed significantly to the description of the study area in Section 2 and Appendix A of this report.

This work was led and directed by Alfonso Blanco, Office of Wastewater Management, U.S. EPA Office of Water. The work was done under task order contract by RTI International. Eric Solano was the RTI technical lead and Robert Truesdale was the RTI task order leader.

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List of Acronyms and Abbreviations

BASINS	Better Assessment Science Integrating Point and Nonpoint Sources
BECC	Border Environment Cooperation Commission
BFCC	U.S.-Mexico Border Field Coordinating Committee
BITF	Border Indicators Task Force
BOD	biological oxygen demand
CILA	Comisión Internacional de Límites y Aguas
CNA	Comisión Nacional del Agua
COD	chemical oxygen demand
CU	cataloging unit
DO	dissolved oxygen
DOI	U.S. Department of the Interior
DPSIR	driving forces-pressure-state-impact-response
EPA	U.S. Environmental Protection Agency
ESAR	Environmental Sampling, Analysis, and Results
GIS	geographic information systems
GNEB	Good Neighbor Environmental Board
GNIS	Geographic Names Information System
GPS	global positioning system
IBWC	International Boundary and Water Commission
ITFM	Interagency Task Force on Monitoring
MBRF	Mexico Border Reach File
NAD	National Assessment Database
NADB	North American Development Bank
NAFTA	North American Free Trade Agreement
NHD	National Hydrography Dataset
NWIS	National Water Information System
OMB	Office of Management and Budget
PSR	pressure-state-response
QA/QC	Quality Assurance/Quality Control
RIT	Reach Indexing Tool
RTI	RTI International
SCERP	Southwest Consortium for Environmental Research and Policy
SEMARNAT	Secretariat of Environment and Natural Resources
SNICA	Sistema Nacional de Información de la Calidad del Agua
SQL	structured query language
STORET	EPA’s STOrage and RETrieval data repository
TCEQ	Texas Commission on Environmental Quality
TDS	total dissolved solids
TN	total nitrogen
TSS	total suspended solids
U.S.	United States
USGS	U.S. Geological Survey
UTA	University of Texas at Austin

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1.0 Introduction

The U.S. Environmental Protection Agency's (EPA's) Office of Wastewater Management initiated this project, entitled *Development of Integrated Water Quality Analyses for the Shared Waters of the United States and Mexico* (U.S.-Mexico Shared Waters), to support specific objectives of the Border 2012: U.S.-Mexico Environmental Program (Border 2012) that require assessment and management of water quality data along the U.S.-Mexico border. In support of these objectives, the U.S.-Mexico Shared Waters project

- Assembled, centralized, and standardized in one repository existing water quality data from both sides of the border
- Developed a watershed approach that can be used to analyze water quality issues on the U.S.-Mexico border
- Created a prototype of a hydrographic data set, the Mexico Border Reach File (MBRF), and described its potential use for assessing and managing water quality data towards improving water conditions in the border region.

The U.S.-Mexico Shared Waters project created a U.S.-Mexico Border Waters Data Repository, populated this Repository with U.S. and Mexican data, and reviewed the assembled data to identify data gaps. Additionally, common water quality analysis methodologies, such as water quality status and trends analysis, were investigated as examples of potential uses of the repository.

1.1 Background

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*, also known as the La Paz Agreement, was signed by the United States and Mexico at La Paz, Baja California, in August 1983 and entered in force in February 1984 (U.S. EPA, 2004). The La Paz Agreement is the legal basis for the creation of Border 2012.

Border 2012—a 10-year, results-oriented environmental program that serves as the main legal framework within which the United States and Mexico can pursue solutions for improving the environmental conditions along the border—is the latest multiyear, binational planning effort to be implemented under the La Paz Agreement. It succeeds Border XXI, a 5-year program that ended in 2000 (U.S. EPA, 2005a). Border 2012 was designed to empower the federal environmental authorities in the United States and Mexico to undertake cooperative initiatives. The U.S. EPA and Mexico's Secretariat of Environment and Natural Resources (SEMARNAT) serve as national coordinators for these initiatives.

One of the goals of Border 2012 is to reduce water contamination by building on infrastructure projects initiated by the Border Environment Cooperation Commission (BECC) and the North American Development Bank (NADB). Since 1995, BECC and NADB, both created by North American Free Trade Agreement (NAFTA), have had the primary role of working with communities to develop and construct infrastructure projects. The main objectives of Border 2012, which build on those early projects, are as follows:

- **Objective 1.** By 2012, promote a 25 percent increase in the number of homes connected to potable water supply and wastewater collection and treatment systems.
- **Objective 2.** By 2012, assess significant shared and transboundary surface waters and achieve most of the water quality standards currently being exceeded in those waters.
- **Objective 3.** By 2006, implement a monitoring system for evaluating coastal water quality at the international border beaches. By the end of 2006, establish a 2012 objective toward meeting both countries' coastal water quality standards.
- **Objective 4.** By 2005, promote the assessment of water system conditions in 10 percent of the existing water systems in the border cities to identify opportunities for improvement in overall water system efficiencies.

In support of these objectives, in particular objectives 2 and 3, EPA initiated the U.S.-Mexico Shared Waters project to provide the information and tools needed to help determine indicators for measuring program progress and assessing environmental and health changes in the region.

The U.S.-Mexico Shared Waters project is consistent with observations and recommendations presented in the Good Neighbor Environmental Board's (GNEB) recent report on water quality for the border region (U.S. EPA, 2005b). This eighth report by GNEB to the President and Congress reiterates GNEB's 1995 recommendation that environmental data gaps and data accessibility be addressed as a high priority. Specifically, GNEB's Recommendation 2 in the report is

> "Develop and sign formal U.S.-Mexico border-region water resources data agreements. Such agreements should support the collection, analysis, and sharing of compatible data across a wise range of uses so that the border region water resources can be more effectively managed."

To support this recommendation, the GNEB report goes on to describe that border water data are needed by water resource managers to help them understand "overarching forces that continue to affect the fate of the regions water resources (such as current and projected land use) in managing water quantity, quality, and use. The 2005 GNEB report also references the 2003 report of the U.S.-Mexico Binational Council as stating that "…an accurate and harmonious system of data collection would serve as a fundamental starting point for cross-border management."

The GNEB report identifies several remaining barriers to adequate border water quality data, which this project has helped to overcome:

- **Barrier 1. Data gaps on water quantity and quality.** The U.S.-Mexico Shared Waters project has identified surface water data gaps (Section 3.2.2) and provides recommended next steps to fill them (Section 6).

- **Barrier 2. Different methods, inability to compare.** As described in Section 3.1, the project has brought data from both sides of the border into a common format to promote and inform ongoing binational discussions towards developing and applying standardized, comparable measures and protocols.

- **Barrier 3. Inaccessibility of data.** The U.S.-Mexico Border Waters Data Repository provides a standardized format and database structure that can be interfaced with Web-based systems that (1) enable data-providing organizations to upload, review, and maintain data and (2) access data through map-based and tabular queries. Because the Repository was designed and built as a cooperative effort between U.S. and Mexican agencies and organizations (Section 1.2), the project has built the capacity and trust needed for prompt availability and access of data collected on both sides of the border.

- **Barrier 4. Limited, ad hoc data exchange systems.** In recommending next steps for establishing an annual U.S.-Mexico water quality data exchange, page 27 of the GNEB report specifically endorses this project and its subsequent phases as a collaborative, cross-border effort that should be strongly supported.

As described in Section 3.1, the U.S.-Mexico Border Waters Data Repository is designed to efficiently assemble data from existing U.S. and Mexican data systems into a common system to enable cross-border sharing and comparison of data, and through the cooperation of Mexican and U.S. agencies and organization, has been populated with most of the readily available water quality data in the border region.

1.2 Stakeholder Workgroup

The U.S.-Mexico Shared Waters project has provided a unique opportunity to bring together organizations and individuals from both sides of the U.S.-Mexico border to help with the design and creation of the first version of the U.S.-Mexico Border Waters Repository and the MBRF prototype. When planning this project, EPA and RTI recognized that the expertise and guidance of stakeholders and experts on both sides of the border would be essential to accomplishing the objectives of this project, from designing a robust and maintainable data repository to populating it with U.S. and Mexican data. To meet this need, we worked with the following key players involved with U.S.-Mexico border environmental issues:

- Angel Kosfizer, U.S. EPA Region 6
- Eugenia McNaughton, U.S. EPA Region 9
- Eric Gutiérrez López, Carolina Molina Segura, Comisión Nacional del Agua (CNA), México Distrito Federal, México
- Antonio Rascón, Comisión Internacional de Límites y Aguas (CILA), Juárez, México
- Carlos Peña, International Boundary and Water Commission (IBWC), El Paso, TX
- Rick Van Schoik, Southwest Consortium for Environmental Research and Policy (SCERP), San Diego, CA

- Daene McKinney and Carlos Patiño, University of Texas at Austin (UTA), Austin, TX
- Jean Parcher, U.S. Geological Survey (USGS), Dallas, TX.

These individuals and others in their organizations represent vast experience dealing with water resources and water quality issues along the U.S.-Mexico border. Many of them have been working for years on important environmental problems on the border region. Through meetings, conference calls, and e-mail, the stakeholders contributed data, comments, and recommendations at every stage of this project. Specific input was solicited and used for the following aspects of the project:

- Selection of the study area basins (Section 2)
- Agreement on the water quality parameters to be addressed in the project (Section 3)
- Design of the data repository (Section 3)
- Collection of the data to be incorporated in the Repository, especially for the Mexican side of the border (Section 3)
- Review of the draft final report
- Recommendations for activities to be included in the next phase of the study (Section 6).

Building this work group was critical to the completion of this report, and EPA thanks each individual and organization for their valuable contributions to the project.

The future cooperation of these stakeholders will be essential in planning the subsequent phases of this project. For example, recent (November and December 2005) meetings have confirmed the value of this effort to all parties and their commitment and desire to continue the work. The next meeting of the group, to be held in February 2006, will focus on developing common, standardized binational measures and benchmarks that can be used to focus future data collection efforts and allow regular assessment of water conditions in the border region. Topics will include finalizing system requirements (e.g., for data sharing and updates) and identifying resources for continuing the effort.

1.3 Document Content and Organization

This report documents the following activities that RTI performed in support of this project:

- Collected and centralized in one repository a significant amount of existing water quality data on both sides of the U.S.-Mexico border
- Standardized the format in which water quality data on both sides of the border are collected and stored
- Facilitated the integration of existing and future water quality data with other repositories, such as EPA's STOrage and RETrieval system (STORET) and the National Water Information System (NWIS)

- Identified data gaps in the water quality indicators for which data are being collected at the monitoring stations along the border
- Provided a watershed approach to analyzing water quality issues on the U.S.-Mexico border
- Developed a prototype of the MBRF and described its potential benefits for water quality analysis.

The rest of this document is organized as follows:

- **Section 2, Study Area**, defines the study area and provides a brief overview of the major basins in the transboundary region.
- **Section 3, Data Repository**, describes the methodology used to develop the data repository and the findings from the data collected so far.
- **Section 4, Developing Effective 2012 Water Quality Indicators for the U.S.-Mexico Border**, provides background and recommendations for developing an effective set of indicators that can be used to assess the quality of the shared waters of the United States and Mexico.
- **Section 5, Mexico Border Reach File**, describes the prototype reach file developed for the U.S.-Mexico border region.
- **Section 6, Future Work**, describes future enhancements or analyses that could build upon the work described here.
- **Section 7, References**, lists the works cited in this report.

2.0 Study Area

The border region was defined in the La Paz agreement (Article 4) as the area located within 100 km on either side of the inland border between the United States and Mexico. Figure 1 shows the border region with this 100-km buffer (outlined in red). The border region includes territory in four U.S. states (California, Arizona, New Mexico, and Texas) and six Mexican states (Baja California, Sonora, Chihuahua, Coahuila, Nuevo Leon, and Tamaulipas).

Figure 1. U.S.-Mexico border study area.

The 100-km buffer encompasses eight basins that were defined in the mid-1990s by a U.S. Department of the Interior (DOI) committee—the U.S.-Mexico Border Field Coordinating Committee (BFCC)—that was created to promote and facilitate coordination among the DOI bureaus and the U.S.-Mexico border organizations. The BFCC, which is no longer active, proposed a new definition for the U.S.-Mexico border, using hydrologic and hydrogeologic criteria to delineate the extent of the border area (Woodward and Durall, 1996).

These basins do not, of course, coincide perfectly with the 100-km buffer, nor do state and international lines coincide with the basins. Consequently, it makes sense to discuss the border waters and their status and trends from a shared-waters perspective. This report is organized around such a shared-waters perspective. For simplicity, we combined some of the eight DOI basins that had similar hydrologic and physiographic characteristics to define five "transboundary regions" (shown outlined in black in Figure 1):

- Pacific/Salton Sea Basins (DOI Basin 1)

- Colorado River/Sea of Cortez Basin (DOI Basin 2)
- Central Desert/Closed Basins:
  - Mexican Highlands Basin (DOI Basin 3)
  - Mimbres/Animas Basin (DOI Basin 4)
- Upper Rio Grande Basin:
  - Rio Grande I—Elephant Butte Reservoir to above Rio Conchos Basin (DOI Basin 5)
  - Rio Grande II—Rio Conchos to Amistad Reservoir Basin (DOI Basin 6)
  - Rio Grande III—Below Amistad Reservoir to Falcon Reservoir Basin (DOI Basin 7)
- Lower Rio Grande Basin (Basin 8).

Table 1 summarizes the characteristics of each of these transboundary regions, including the DOI basins of which they are composed. The remainder of this section provides a brief description and a more detailed map for each of the transboundary regions. Appendix A describes the geography and hydrology of each of the transboundary regions in more detail.

Table 1. Transboundary Basin Characteristics

Transboundary Region	DOI Basin	DOI Basin Name	Total Area		Area in Mexico		Area in U.S.	
			sq. mi.	km^2	sq. mi.	km^2	sq. mi.	km^2
Pacific/Salton Sea Basins	1	Pacific Basins/Salton Sea	14,000	36,000	4,870	13,000	9,130	24,000
Colorado R./Sea of Cortez Basin	2	Colorado R./Sea of Cortez	22,590	59,000	8,370	22,000	14,220	37,000
Central Desert/ Closed Basins	3	Mexican Highlands	21,840	57,000	5,395	14,000	16,445	43,000
	4	Mimbres/ Animas	12,450	32,000	6,185	16,000	6,265	16,000
Upper Rio Grande Basin	5	Rio Grande I	28,940	75,000	5,760	15,000	23,180	60,000
	6	Rio Grande II	34,630	90,000	13,910	36,000	20,720	54,000
	7	Rio Grande III	12,910	33,000	7,840	20,000	5,070	13,000
Lower Rio Grande Basin	8	Lower Rio Grande	10,240	27,000	6,155	16,000	4,085	11,000
Total U.S.-Mexico Border area			157,600	408,000	58,485	151,000	99,115	257,000

Source: Woodward and Durall (1996)

2.1 Pacific/Salton Sea Transboundary Basins

The Pacific/Salton Sea Basins drain an area of 14,000 square miles (36,000 km^2), to either the Pacific Ocean or inland seas. These basins have a very dry, semiarid climate with few fresh water resources. The most important watersheds are the San Diego, Cottonwood-Tijuana, and Salton Sea. Except for the Salton Sea watershed, flow is primarily from east to west, with stream flows originating from precipitation in the mountains flowing toward the Pacific Ocean. The flow in these streams is controlled through a series of hydraulic structures, including reservoirs. Land use varies considerably, ranging from urbanized to agricultural to wilderness. The Salton Sea watershed includes the fertile Imperial Valley and the manufacturing center of Mexicali.

From MODIS-TERRA Satellite/Sensor System, NASA

Pacific/Salton Sea Basins.

The Tijuana River is one of the main streams in the basin and one of the City of Tijuana's major natural resources. The river flows northwest through the city of Tijuana before crossing into California near San Ysidro and then flowing into the Pacific Ocean. Figure 2 shows the Pacific/Salton Sea Basins and their most important characteristics.

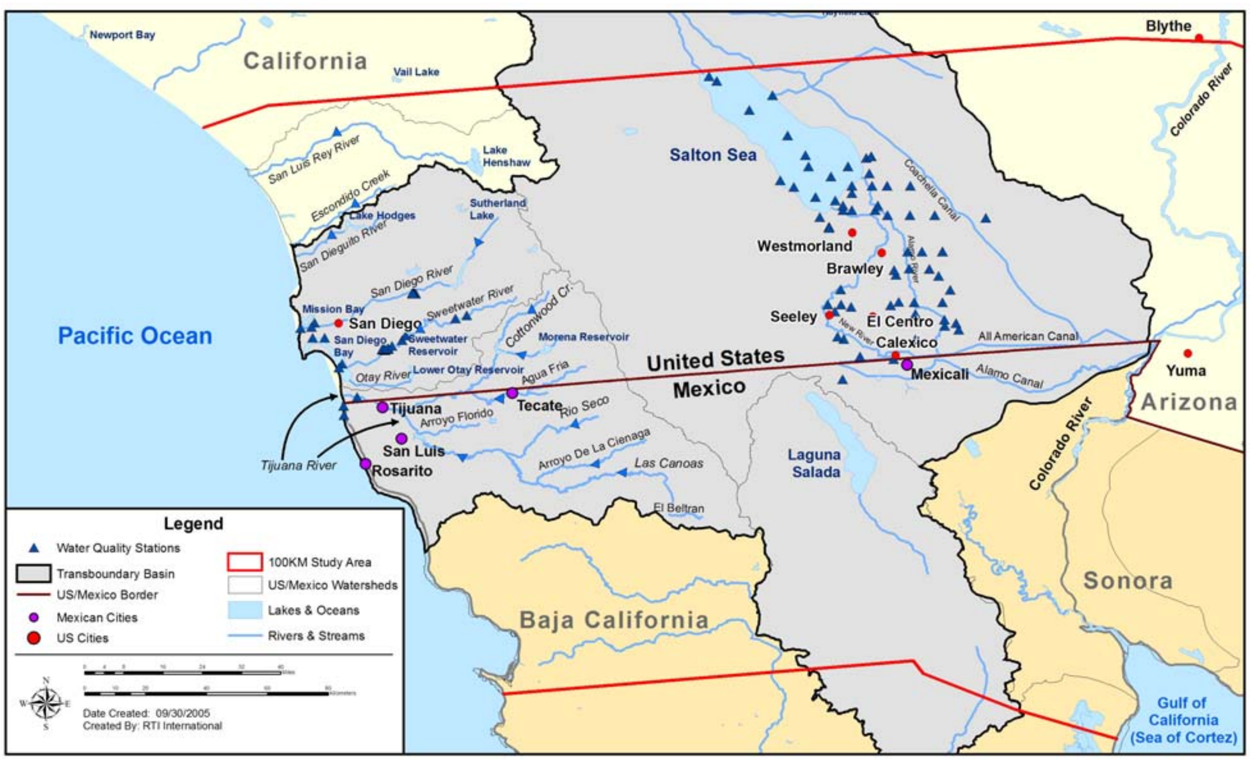

Figure 2. Pacific/Salton Sea Basins.

2.2 Colorado River/Sea of Cortez Transboundary Basins

The Colorado River/Sea of Cortez Basins contain watersheds that drain either to the Colorado and Gila Rivers, or directly to the Gulf of California (Sea of Cortez). These basins drain 22,590 square miles (59,000 km^2) and cover portions of the states of Arizona and Sonora. Land use is primarily agricultural and grazing, although there are important wildlife refuges and wilderness areas, along with urban areas such as Yuma and San Luis Rio Colorado.

Photo courtesy Bureau of Reclamation

Lower Colorado River.

The Colorado River flows into the basin through heavily urbanized areas near Yuma and San Luis Rio Colorado and then through wetlands before flowing into the Sea of Cortez. Currently, most of the water flowing into the delta comes from agricultural drainage and periodic flood flow from the United States and Mexico, with little perennial flow in the lower Colorado River. This has significantly altered the delta's once extensive estuaries and salt flats. Figure 3 shows the Colorado River/Sea of Cortez Basins and their most important characteristics.

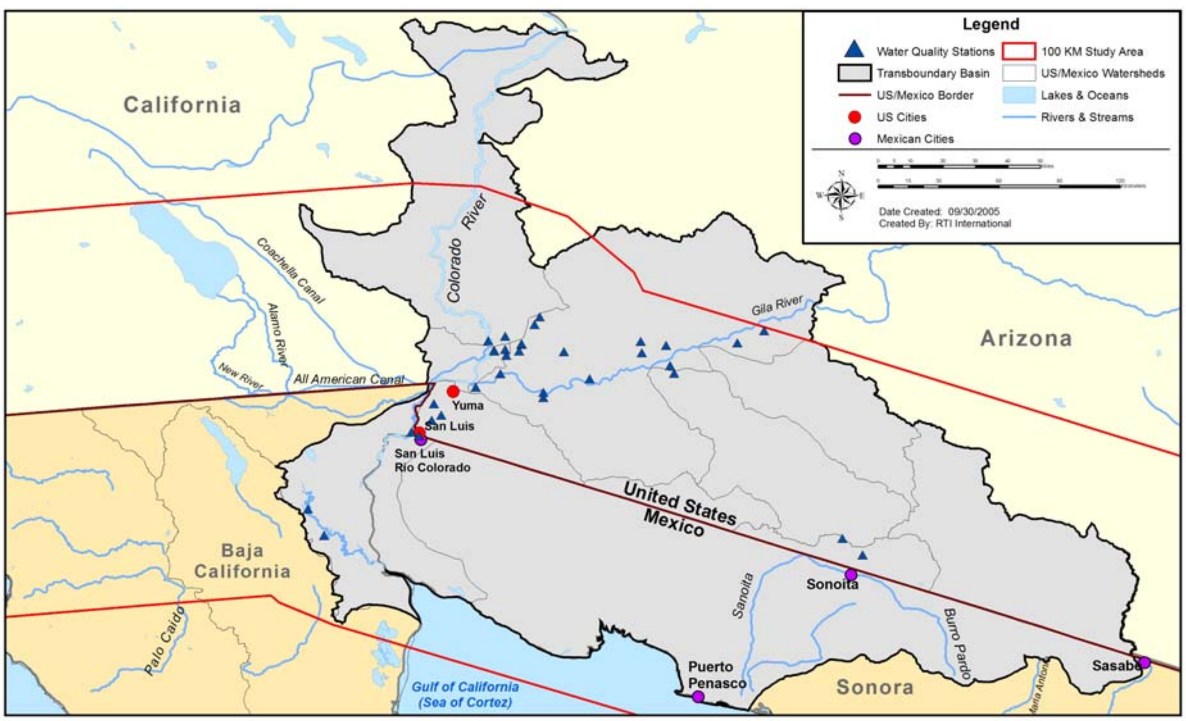

Figure 3. Colorado River/Sea of Cortez Basins.

2.3 Central Desert/Closed Transboundary Basins

The Central Desert/Closed Basins include the Mexican Highlands basins and the Mimbres and Animas basins. Figure 4 shows the Central Desert/Closed Basins and their most important characteristics. The Mexican Highlands Basin contains watersheds that drain to rivers in southern Arizona (e.g., the San Pedro and Santa Cruz Rivers), southwestern New Mexico, northern Sonora (e.g., Aqua Prieta), or the extreme northwestern tip of Chihuahua. The Mimbres/Animas Basin contains watersheds that drain internally in southern New Mexico and northern Chihuahua. Together, these watersheds drain 34,290 square miles (89,000 km^2) (Woodward and Durall, 1996). Water resources are scarce and competition for this limited resource is a major water resource management theme in the region.

Photo by John Hoffman

Santa Cruz River between Nogales and Tumacácori.

The Mexican Highland basins are broad valleys separated by steep mountain ranges, with each basin a mostly closed, independent hydrologic system. Although classified as a desert, the region is renowned for relatively lush vegetation and diverse aquatic habitats. All streams are ephemeral, except in the valleys of Animas Creek. The Central Closed Basin (which includes the Mimbres, Playa, and Marmel watersheds) ranges from sub-humid in the north to arid in the south (Papoulias et al., 1997).

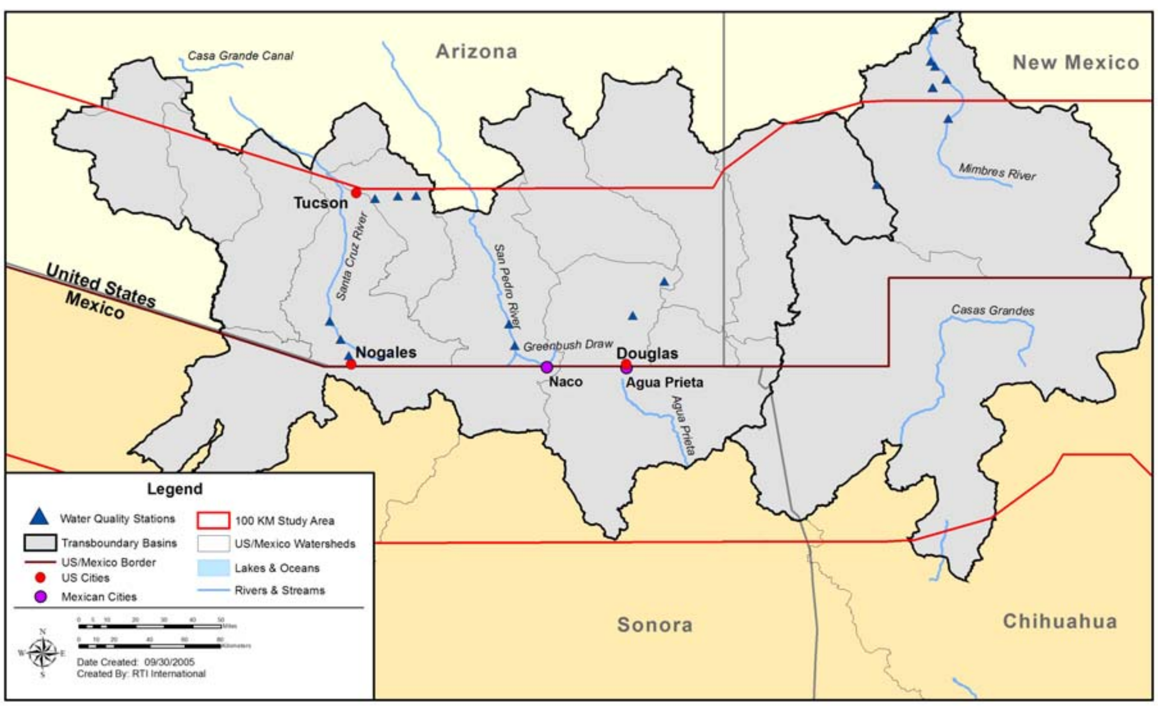

Figure 4. Central Desert/Closed Basins.

2.4 Upper Rio Grande Transboundary Basins

NASA, Earth Observatory

International Amistad Reservoir.

The Upper Rio Grande/Rio Bravo Basin is defined as the area from the Elephant Butte Reservoir in New Mexico to the Falcon Reservoir on the U.S.-Mexico Border. The Rio Grande Basin drains 76,480 square miles (200,000 km^2) (Woodward and Durall, 1996). Figure 5 shows the Upper Rio Grande Basins and their most important characteristics. The basins are divided into three segments: (1) from Elephant Butte Reservoir to Rio Conchos, (2) from Rio Conchos to the Amistad Reservoir, and (3) below the Amistad Reservoir to the Falcon Reservoir. For most of this length the river defines the U.S.-Mexico border and is the major source of surface water for the area (Blackstun et al., 1996)

The climate of the Upper Rio Grande basins is semi-arid to arid, and the availability of water in the river greatly affects water quality in the river. Flows are controlled largely by the series of reservoirs along the river, and the availability of water determines almost all land use within the basin. Land use is varied, including rangeland, agriculture, light industrial uses, mining, and urban areas (five pairs of sister cities on either side of the border). Where reservoirs and other water storage devices are available, urban population and industries can be sustained. Where canals are available to transport water, rangeland, ranches, and agriculture can be supported. Colonias, communities on the U.S. side of the border without basic infrastructure, have a significant impact of water quality and other water issues, and upgrading their infrastructure is one focus for managing water quality in the region.

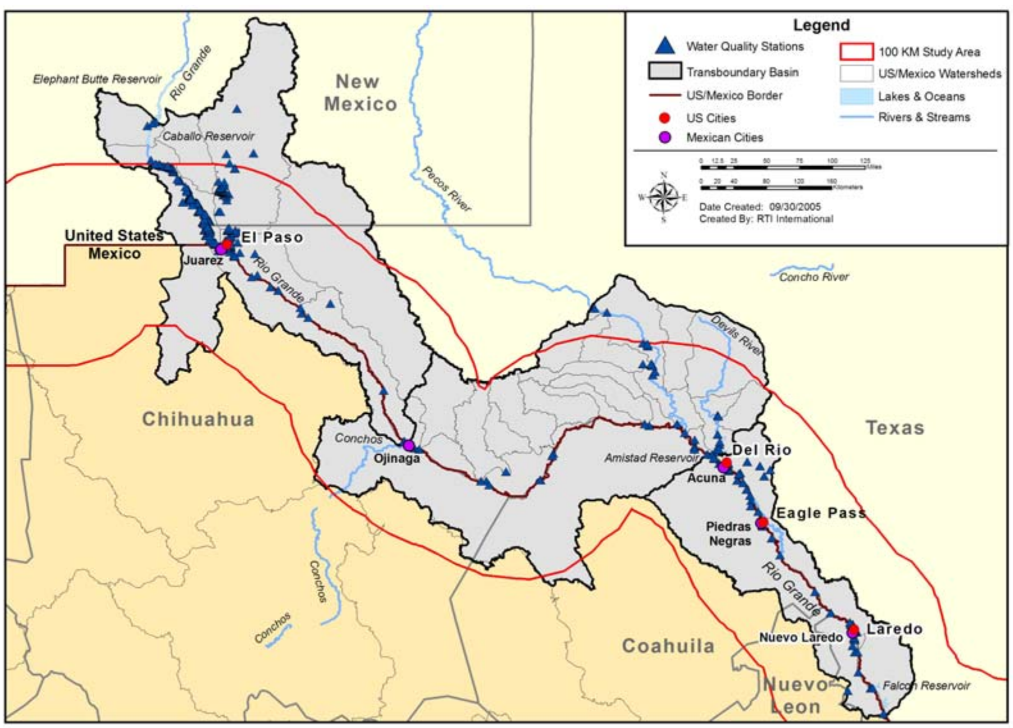

Figure 5. Upper Rio Grande Basins.

2.5 Lower Rio Grande Transboundary Basin

The Lower Rio Grande Valley—below Falcon Reservoir to the Gulf of Mexico—contains watersheds that drain either to the Rio Grande, to the lower reach of the Rio San Juan below the gaging station at Santa Rosalia, or to Arroyo Colorado in southern Texas. It drains an area of 10,240 square miles (27,000 km^2) of the Gulf Coastal Plain. Figure 6 shows the Lower Rio Grande Basin and its most important features.

Courtesy of Texas Commission on Environmental Quality

Collecting water quality and flow data at Arrovo Colorado.

The climate for lower Rio Grande basin becomes more humid downstream, with vegetation ranging from semiarid scrub land near the Falcon Reservoir, to oak forests, and then to marshes and wetlands near the gulf. Urban areas represent a significant proportion of land use within the basin, along with irrigated cropland for vegetables, sorghum, and cotton. Water supplies in the lower Rio Grande are limited and largely controlled by releases from the Falcon Resevoir. Increasing demands from both sides of the border create a water management challenge. Surface water has been and will continue to be the major source of water supply in the basin, and increasing municipal and agricultural demands have significantly decreased the amount of water available for refuge wetlands in the delta region near the Gulf, with negative impacts on plants and wildlife in the estuaries and marshes near the mouth of the river (Buckler et al., 1997).

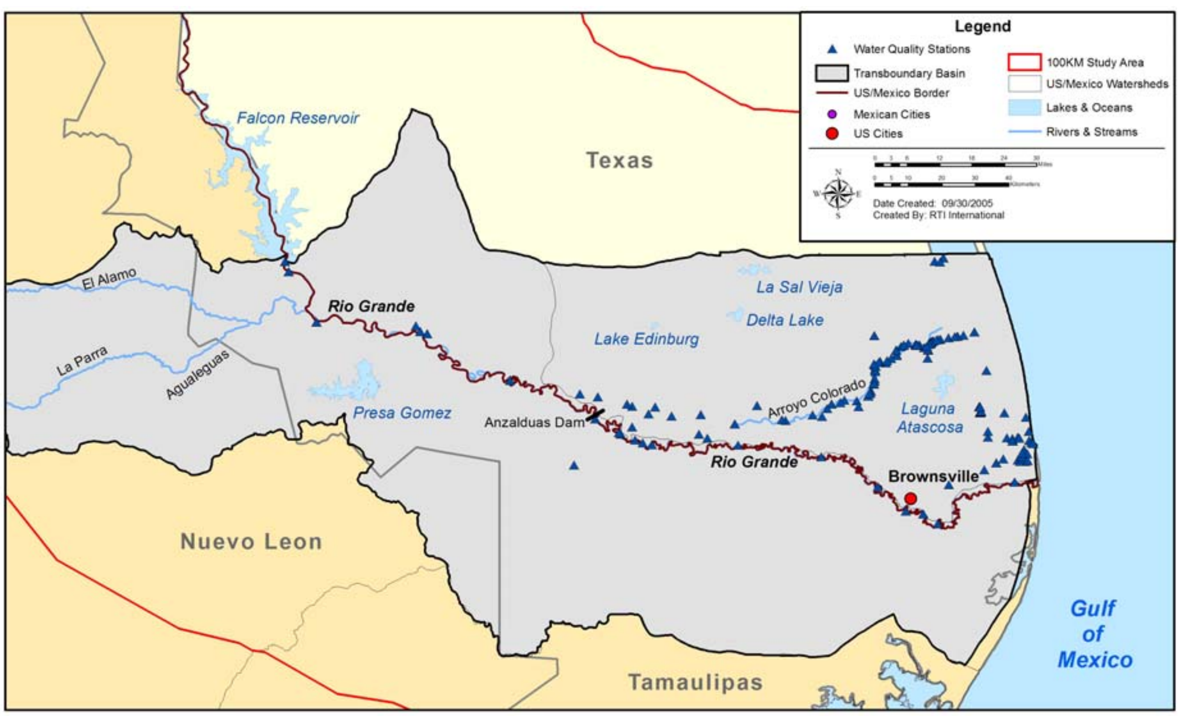

Figure 6. Lower Rio Grande Basin.

3.0 U.S.-Mexico Border Waters Data Repository

The U.S.-Mexico Border Waters Data Repository was developed to compile water quality data from both sides of the U.S.-Mexico border. It was designed to be compatible with and receive data from both U.S. and Mexican water quality data sources and to allow retrieval of comparable data to compare and assess water quality conditions in the border region over time. By establishing baseline water quality conditions on both sides of the border and tracking changes over time, the Repository will help measure progress towards the effective management of the border region's shared water resources.

The Repository contains secondary data of known quality, and it is not intended to replace or supplant the water quality data systems that U.S. and Mexican agencies have established to assess and manage their surface water resources. Instead, it is designed to hold data migrated from these sources to enable easy access to the combined data on the shared water resources of the border region. Data quality procedures were followed to ensure the accurate transfer and processing of the data from the original data sources, but the Repository depends on the primary data systems for ensuring adequate data quality.

This section discusses the Border Waters Data Repository that was built and populated during this project. Section 3.1 describes the methodology used to build the Repository and to collect and process the initial data set from U.S. and Mexican data sources. Section 3.2 describes significant findings from this initial data set, including data content and data gaps.

3.1 Methodology

The main objective of the U.S.-Mexico Border Waters Repository is to provide a means to store and retrieve water quality information for the U.S.-Mexico border areas. Important aspects of the methodology used to build the Repository include its design, data sources, parameters collected, data processing steps, and quality assurance and quality control (QA/QC) measures used to populate the Repository. These aspects are described in the following sections.

3.1.1 Repository Design

The U.S.-Mexico Border Waters Repository is comprehensive but also simple: a repository that can store and maintain data but that is also compatible with other existing systems. The Repository was designed to be easily enhanced, because many data standards are still under development and water quality collection activities seem to be increasing along the Border.

The Repository is a flexible tool designed to allow the easy importation of water quality data from a variety of sources from both sides of the border. In this initial effort, the Repository was populated with data from both U.S. and Mexican sources. For the U.S. side, both recent and historic (legacy) data were included to enable analysis of current and past water quality conditions.

We designed the U.S.-Mexico Border Waters Repository to be

- Easy to maintain, update, and expand

- Easily integrated with EPA's STORET
- Easy to use
- Compliant with EPA Environmental Sampling and Results (ESAR) standards and Latitude/Longitude standards
- Flexible enough to accommodate future changes that may be caused by data standard protocols currently under development by EPA.
- Robust enough to allow for storage of non–water-quality information, such as water flow data
- Able to store maps, text files, diagrams, and other information files.

To achieve those goals, we used

- A simple database structure based largely on STORET
- Best practices in database design to ensure integrity of the links between tables
- Numerous lookup tables, which make aid in navigation and querying and are easy to add or modify as needed
- Binary object storage techniques (to store maps, etc).

In addition, we incorporated many data elements from the EPA ESAR and Latitude/Longitude data standards. The Repository complies with EPA's Latitude and Longitude data standards in that every monitoring station for which data are stored is referenced with geographic coordinates and additional geographic information. This is an important condition for linking water quality data to a georeferenced system that holds hydrological and physiographic information about a region.

The Repository structure is compatible with existing systems (most importantly the U.S. STORET system) but has been simplified to facilitate data entry, maintenance, and access. Appendix B explains in detail the technical design objectives considered when building the data structure for the Repository. Appendix B also shows the data dictionary and entity relational diagrams for the Repository.

The Repository is currently stored as a Microsoft Access database. Microsoft Access 2000 or later is required to use the Repository. However, the Repository was designed so that it could be migrated to another relational database software system, such as open-source MySQL, Oracle, SQL Server, or open-source PostGRESQL.

The Repository does not yet have a user interface; therefore, a basic knowledge of relational databases and structured query language (SQL) is needed to review Appendix B and write queries to extract data summaries from the Repository. In the next phase of the project, we can develop standard queries and include them in the Repository to produce reports and output tables that can be viewed as text files or in standard spreadsheet software, such as Microsoft Excel.

3.1.2 Water Quality Data Sources

We identified and accessed water quality data sources for the project through collaboration with the U.S.-Mexico stakeholder work group. The current Repository includes water quality data extracted from the following sources:

- U.S. EPA (modernized and legacy STORET)
- USGS (NWIS)
- Texas Commission on Environmental Quality (TCEQ)
- International Border Waters Commission (IBWC)
- Southwest Consortium for Environmental Research and Policy (SCERP)
- Comisión Nacional del Agua (CNA)
- Comisión Internacional de Límites y Aguas (CILA).

Some of the water quality data collected during this project were not included in the current Repository because the data sources did not have location coordinates for water quality sampling points:

- Certain CILA data in PDF, jpg and Excel formats (example: data from the wastewater treatment plant in Ciudad Acuña, Coahuila)
- Data from the Beach and Bay Status Report from the Department of Environmental Health, County of San Diego.

Finally, data from several other sources were received near the end of the project. These sources were not included in the current Repository, but may contain useful water quality data:

- *City of San Diego.* Dry weather bio-assessment and chemical monitoring of creeks and rivers.
- *City of San Diego Metropolitan Wastewater Department*. Sampling and analysis of Tijuana wastewater.
- *San Diego County Water Authority.* Regional Colorado River Conveyance Feasibility Study Final Report, which compares Colorado River quality to recommended water quality standards.
- *State of California.* Data report on discontinued water quality stations. Southern Great Basin from Mexican Border to Mono Lake Basin, and Pacific Slope Basins from Tijuana River to Maria River.
- *San Diego State University.* Monitoring and Modeling of Water Quality in the Tijuana River Watershed.
- *San Diego State University.* An overview of the existing literature of the water quality and quantity of the Tijuana River Watershed.
- *City of San Diego Water Department.* Water quality monitoring at Barrett and Morena Reservoirs.

- *Tijuana State Commission of Public Services.* Drinking Water and Wastewater Master Plan for Tijuana and Playas de Rosarito. Water quality data.
- *Tijuana State Commission of Public Services.* Information about Flow, Water Quality, and Efficiency at the wastewater treatment plants.

Data from these sources can be explored during the next phase of this project.

3.1.3 Water Quality Parameters Collected

The stakeholder group selected 12 water quality parameters for data collection and entry in the U.S-Mexico Border Waters Repository. This selection was based on the importance of these parameters in evaluating how water resources are impaired in the border region and their availability in data sources for both sides of the border. The 12 water quality parameters are

- Dissolved Oxygen (DO)
- Nutrients (nitrogen compounds, phosphorus compounds)
- Chlorophyll/biomass
- Conductivity/total dissolved solids/salinity
- Chlorides
- Sulfates
- Acidity/pH/alkalinity
- Chemical oxygen demand (COD)
- Biochemical oxygen demand (BOD)
- Total suspended solids, total solids
- Fecal bacteria (fecal coliform, fecal streptococci)
- Temperature.

These water quality parameters are consistent with the water quality parameters listed on EPA's Border 2012 Web site (http://www.epa.gov/usmexicoborder/indicators.htm) as part of the effort to define water quality environmental indicators. EPA plans to refine these indicators and use them as base-forming measures that should contribute to the development of more complex, integral integrators. (Section 4.0 of this report provides suggestions and recommendations for this further development.)

3.1.4 Flow Data

Flow data are an important component of the Repository both because water supply is a critical issue in the border region and because flow data are needed to accurately calculate and assess water quality status and trends, especially in arid and semiarid areas where seasonal flow can vary greatly. The Repository was designed to hold flow data, and some flow data were collected for the current Repository. Because stations that collect water quality data do not always collect flow information and flow gaging stations do not necessarily collect water quality data, adding flow data to the Repository often requires adding additional station information and locations. Potential sources of water flow data for the border region include:

- IBWC Web site
- STORET
- USGS NWIS gage stations
- San Diego Water Department.

3.1.5 Data Processing

The original sources of water quality data vary both in the methods used to measure the parameters of interest and in how these parameters are named in the databases. For all data sources, data are stored in the Repository in the same format as the original data source, preserving the original water quality indicator name and units, as well as the original water quality indicator ID. However, the Repository needed to have a consistent set of names to enable comparable queries from different data sources, so we created lookup tables in the Repository to link the source-specific indicator names to a standardized name (e.g., chlorophyll a) so that the data can be extracted and analyzed for a particular indicator regardless of the different source-specific names. As we import additional data sources into the Repository, we can easily modify these lookup tables to match new source-specific names to the standardized names. These standardized (or “generic”) names can then be used to query the Repository database. Thirty-six generic water quality parameters are included in the Repository database to represent the 12 selected water quality parameters listed in Section 3.1.3:

1. Fecal coliform
2. Fecal streptococci
3. Chlorophyll a
4. Biomass, periphyton
5. Chlorophyll c
6. Chlorphyll (a+b+c)
7. Chlorophyll b
8. Sulfate
9. Total dissolved solids (TDS)
10. Chloride
11. Dissolved oxygen (DO)
12. Flow rate
13. Conductivity, specific conductance
14. Alkalinity
15. Acidity
16. Hardness
17. Salinity
18. Sodium Adsorption Ratio
19. Turbidity
20. Chemical Oxygen Demand (COD)

21. Total Oxygen Demand
22. Inorganic nitrogen
23. Total phosphorus
24. Organic nitrogen
25. Nitrogen ion
26. Total nitrogen (TN)
27. Nitrite
28. Phosphate
29. Nitrate
30. Ammonia
31. Nitrite plus nitrate
32. Biological oxygen demand (BOD)
33. pH
34. Temperature
35. Total Suspended Solids (TSS)
36. Dissolved solids.

Appendix C of this report lists each standard variable name that has multiple designations in the source data and describes how the variable was assigned in the Repository in terms of its description and units. The Repository data table TL_CHARACTERISTIC, described in Appendix B, is a lookup table that contains information about all water quality indicators for which data were collected in the Repository, and relates the name and indicator ID in the original data source to the generic water quality parameters listed above.

Data were extracted from the original data sources by a specific methodology for each source, as described in Appendix C. In summary, we downloaded the data from the data source Web site (or obtained the data files from the responsible organization). Most of the data files were in text format. We imported each text file into a temporary database with the same structure as the Repository. The text file was also placed in a separate Access data table with the same structure as the original data source. Data were checked for completeness and cleaned and converted as needed to bring it into the Repository format. These steps are described in Appendix C for each data source.

3.1.5 Quality Assurance/Quality Control

Several QA/QC measures were used to ensure accurate transfer of data from the original data sources into the Repository. The first QA/QC step was to count the number of records transferred from the downloaded file into the temporary Access database to ensure that all records from the downloaded file were properly transferred.

The next QA/QC step was to compare the two Access databases (one with the data in the original file structure and one with the data in the Repository structure). A portion of the records stored in these databases were checked to ensure that all information was carried from the original downloaded file to the temporary Access database. This check was done by querying the original data against the restructured data and by visual comparison. We checked 3 to 10 percent of all records for the tables containing results, sample data, location data, and station data. We checked 100 percent of records for the tables containing organization data, analytical methods data, and characteristic data. The rest of the tables are lookup tables that were reviewed for accuracy as they were created or obtained from another data source (i.e., STORET).

3.2 Findings and Recommendations

Different analyses were performed on the collected data to provide examples of the type of analyses that could be done with the data stored in the Repository. These analyses are presented in Appendices D and E. Section 3.2.1 summarizes the data collected and Section 3.2.2 describes the gaps identified in these data. Sections 3.2.3 to 3.2.6 describe the major findings from the Repository and the recommendations that follow from those findings.

Appendix F is a summary of water quality status for a limited number of U.S. watersheds along the border. These summaries are taken from the National Assessment Database (NAD) and represent state assessments of water quality conditions (impaired or not) with respect to specific designated uses (e.g., swimming, drinking water, fish consumption). Because they represent regulatory assessment, data from the NAD can provide a solid baseline for water quality conditions on the U.S. side of the border.

3.2.1 Data Summary

The U.S.-Mexico Waters Repository holds close to 200,000 data points for many different water quality indicators at stations along the border. For each water quality indicator, data frequency is defined as the number of stations with measured values of that indicator. Data frequency of data collected on the U.S.-Mexico Repository was summarized by generic water quality indicator for each basin.

Tables 2 through 5 summarize the number of stations sampling, generating, or reporting data by geographic location (country, state, or transboundary region) in summary (Tables 2 and 3) and by water quality parameter (Tables 4 and 5). Table 2 shows the number of stations by country and state. Table 3 shows the number of stations by transboundary region. Table 4 shows the number of stations by country and water quality indicator. Table 5 shows the number of stations by transboundary region and water quality indicator.

Table 2. Number of Stations Sampling, Generating, or Reporting Data, by State[a]

State	Total Number of Stations	Number of Stations with Flow Data
United States		
California	114	7
Arizona	12	0
New Mexico	30	0
Texas	276	146
U.S. Total	*432*	*16*
Mexico		
Baja California	7	0
Sonora	1	0
Chihuahua	2	0
Coahuila	2	0
Nuevo León	1	1
Tamaulipas	4	0
Mexico Total	*17*	*1*

[a] Some monitoring stations were not assigned to a country or state because of inconsistencies between the station description and the reported latitude and longitude (e.g., coordinates that were not in the state in the description or in the study area at all).

Table 3. Number of Stations Sampling, Generating, or Reporting Data, by Transboundary Region[a]

Transboundary Region	Total Number of Stations
Pacific/Salton Sea	119
Colorado River/Sea of Cortez	5
Central Desert/Closed	18
Rio Grande	147
Lower Rio Grande	160
Total	449

[a] Some monitoring stations were not assigned to a region because of inconsistencies between the station description and the reported latitude and longitude.

Table 4. Number of Stations Sampling, Generating, or Reporting Data on a Water Quality Parameter, by Country[a]

Water Quality Parameter	U.S	Mexico
Fecal coliform	203	16
Fecal streptococci	5	5
Chlorophyll a	214	3
Sulfate	270	9
TDS	27	11
Chloride	279	10
DO	305	12
Conductivity	280	13
COD	51	12
Inorganic Nitrogen	21	0
Phosphorus	276	2
Organic Nitrogen	37	7
Nitrogen	269	5
Nitrite	224	7
Orthophosphate	268	11
Nitrate	150	5
Ammonia	321	9
Nitrite and Nitrate	286	2
BOD	108	13
pH	376	14
Temperature	399	13
TSS	22	13
Total Solids	10	9

[a] Totals do not add to stations totals in Table 3 because each station may sample multiple parameters.

Table 5. Number of Stations Sampling, Generating, or Reporting Data on a Water Quality Parameter, by Transboundary Region

Water Quality Indicator	Transboundary Region				
	Pacific/Salton Sea	Colorado River/Sea of Cortez	Central Desert/Closed	Rio Grande	Lower Rio Grande
Fecal coliform	10	4	7	122	103
Fecal streptococci	1	4	0	6	1
Chlorophyll a	12	1	4	115	112
Sulfate	53	6	15	134	106
TDS	12	4	1	17	6
Chloride	51	6	18	139	110
DO	57	6	16	132	139

(continued)

Table 5. (continued)

Water Quality Indicator	Transboundary Region				
	Pacific/Salton Sea	Colorado River/Sea of Cortez	Central Desert/Closed	Rio Grande	Lower Rio Grande
Conductivity	78	6	10	107	119
COD	1	4	0	17	43
Inorganic Nitrogen	0	0	7	14	0
Phosphorus	43	0	18	133	113
Organic Nitrogen	12	4	7	21	2
Nitrogen	37	1	18	134	112
Nitrite	80	4	8	84	76
Orthophosphate	51	4	9	129	117
Nitrate	21	3	0	79	72
Ammonia	82	4	18	142	115
Nitrite and Nitrate	61	2	18	128	106
BOD	7	4	1	43	73
pH	109	6	18	150	141
Temperature	108	6	17	154	164
TSS	13	4	2	14	4
Total Solids	2	4	1	10	4

3.2.2 Data Gaps

Although some water quality indicators have been measured consistently at many stations for years, important data gaps occur in all regions. For the purposes of this project, a data gap may be defined as the lack of values for some parameter at a given monitoring station at a given point in time, provided that the monitoring station was supposed to collect data for that parameter at that time. A data gap can be of three types:

- **Temporal:** data for a given parameter were expected at a monitoring station or location at a specific point in time. The station might have collected data at other times for that same parameter.
- **Spatial:** data for a given parameter were expected at different times at a location or locations. These locations may or may not have monitoring stations. Other nearby monitoring locations might have collected data for that same parameter at the same period of time.
- **Combination of spatial and temporal:** a data set with a parameter that is monitored on a given segment of a river does not have any data records for different points of the river at different points in time.

Temporal gaps affect trends analyses. In general, the fewer temporal gaps we have for a given parameter at a given monitoring station, the better the trends analyses. Appendix G documents the temporal data gaps found for the water quality parameters of interest.

Spatial gaps can be important when determining water quality status for a particular river segment. Recent data are preferable for establishing water quality status based on water quality standards, water designated use, and stream flow level; therefore, it is important to address spatial and temporal data gaps within five years of a water quality status study.

Spatial gaps can be determined for each transboundary region based on simple observation of water quality monitoring station locations on the maps of each region presented in Section 2:

- In the ***Pacific/Salton Sea Transboundary Basins***, a few water quality stations are located in the Tijuana Watershed, on the Tijuana River on the U.S. side, but there are no stations on the Mexico side. Water quality monitoring stations could be added to the Repository for rivers such as Arroyo Florido, Rio de Las Palmas, or Arroyo Seco to fill in spatial gaps. Many monitors are located near the Sweetwater River, Sweetwater Reservoir, and the San Diego Bay. Some stations are located near other important rivers and waterbodies such as the Mission Bay, San Diego River, and San Dieguito River. To the east, many stations are located at the Salton Sea and its tributaries, the Alamo River, and the New River. In Mexico, no stations are found in the Repository for Laguna Salada.
- For the ***Colorado River/Sea of Cortez Basin***, the Repository does not include many stations for the Colorado River and just a few for the Gila River. The Repository has no stations from the Mexico side mainly because these are desert areas. Spatial data gaps also exist along the Lower Colorado River and Lower Gila River.
- For the ***Central Desert/Closed Basins***, the repository includes data from many stations for the most important rivers: the Santa Cruz River and the San Pedro River. Data are sparse for the Mimbres River and there are no stations on the Mexico side stored on the Repository.
- The ***Upper Rio Grande Basin*** has plenty of monitoring stations on the Rio Grande from the Elephant Butte Reservoir to El Paso/Juarez, but just a few on the segment of Rio Grande from El Paso/Juarez to Amistad Reservoir. There are also a few stations at the Pecos River and a few stations downstream of Amistad Reservoir. More data from stations on the Rio Conchos and other Rio Grande Mexican tributaries could be added to the Repository if they exist. Additionally, more sampling points could be used along the Rio Grande above International Falcon Reservoir.
- The ***Lower Rio Grande Basin*** has just a few stations below International Falcon Reservoir and above Anzalduas Dam. On the Mexico side, there are a couple of stations on the Rio San Juan and Rio El Alamo, both tributaries of Rio Grande. There are plenty of stations on the Arroyo Colorado, Laguna Madre, and South Bay. More data from stations on the Rio Grande from Anzalduas Dam to the South Bay estuary are needed if they exist.

One additional kind of spatial gap is the case when a river or segment of a river has a number of monitoring stations, but those stations do not all collect data for the same water quality parameters. If an analysis requires evenly located data on a river segment for a given parameter, this can pose a data gap for that particular analysis. For example, stations TCEQ-15561, TCEQ-15562, TCEQ-15563 and TCEQ-15561 are located on the Arroyo Colorado at the Lower Rio Grande Basin with a maximum distance of 4 km between the stations. Dissolved oxygen, pH, and turbidity are monitored at all four stations, but chlorophyll a, chloride, and sulfate are monitored only at stations TCEQ-15561 and TCEQ-15562.

Data gaps can also be caused by missing data elements in the source data. These records cannot be entered into the Repository because necessary data fields, such as locational information (latitude and longitude), are missing from the data set.

3.2.3 Finding 1: The Variability of the Study Area Makes It Difficult to Draw General Conclusions

The border region reflects great diversity in geography, physiography, and hydrology. This diversity affects how monitoring stations collect information and what kind of information monitoring stations collect. For example, a station on the Salton Sea will be very different from a station on the Rio Grande, and there are differences between the upper Rio Grande, which has been dramatically altered by reservoirs and irrigation infrastructure, and the lower Rio Grande, which is a delta/estuary. As a result, it is difficult to draw general conclusions about water quality status along the border. However, conclusions can be drawn about individual border segments of similar character.

Water quality comparisons can be done for specific data points, but standards vary by state, and variability is so great that it can be difficult to draw general conclusions about water quality even for a single watershed. We can select specific monitoring stations located along a given river segment or lake/reservoir and use recorded water quality data to reach some conclusions about that river segment status. As shown in the examples included in Appendix D, the analyst first selects a benchmark value from existing water quality standards assigned to that river segment for a particular use category. Next, the analyst compares each water quality reading from the monitoring stations with the benchmark. The analyst will then determine the percentage of data points exceeding the benchmark. For example, the analyst can find out that 50 percent of the data points recorded on a station for a particular parameter (e.g., nitrates) are exceeding the established water quality standard for that segment.

Recommendations: Because of the diversity of the study area, water quality conditions should be analyzed and assessed in smaller segments or watersheds along the border. The development of indicators (see Section 4) should also consider the complex framework of water management and use that impacts water quality in the border region.

3.2.4 Finding 2: The Lack of Unified Water Quality Standards Leads to Ambiguity in Assessing the Status of Waterbodies that Cross the Border

Water quality standards in the four U.S. border states have been established for different waterbodies and rivers, for many pollutants, and for different use categories. As in the United States, Mexico has also adopted surface water quality standards for some pollutants based on use categories. In most cases, water quality standards differ between the two countries. Even within the United States, water quality standards vary from state to state, and in some cases, water quality standards may vary from one river segment to another, depending on use and other waterbody characteristics. The lack of unified water quality standards leads to ambiguity in determining the status of a stream or waterbody that crosses a national or state border.

Recommendation: While acknowledging the many difficulties inherent in reaching a binational consensus on border water quality issues, the stakeholders have expressed their desire to work towards the creation of a unified body of water quality benchmarks. A unified set of benchmarks would help with the implementation of equivalent sampling and analytical methods on both sides of the border, which would improve the comparability of the data in the Repository and enable the use of these data to assess water quality for the shared waters in the border area. A unified set of benchmarks is therefore an important first step in developing and implementing a measurement program for effective indicators of water quality in the border region. (Section 4 provides suggestions for developing and applying such indicators.)

3.2.5 Finding 3: The Repository Contains Far Less Data for Mexico than the United States, Making Balanced, Binational Analysis Difficult

The Repository contains surface water quality data for a number of monitoring stations on the U.S. side of the border, located on rivers and streams, springs, lakes and reservoirs, and canals, as well as at facilities. However, there are far less data in the Repository from the Mexico side of the border, with data points from a very limited number of locations. These locations identified latitude and longitude; the date when the reading was made; and the parameter name, value, and units, but do not include metadata about sampling or analytical methods used to obtain the value. This disparity in quantity and completeness of data makes it difficult to conduct balanced, binational analysis.

Recommendations: We identified additional sources of Mexico water quality data late in this study. These sources should be explored and considered for inclusion in the next phase of the project. In addition, the Mexico stakeholders have expressed a desire to continue efforts to identify additional data sources that may contain metadata for existing stations, but have requested a Web-based system to facilitate review of the data they have contributed and input of new data to the Repository as available. The next steps on the project should include implementation of a simple Web site to allow secure data uploads and downloads to facilitate this data exchange. Finally, Phase 2 of the project could support field work in Mexico to position new monitoring points to fill spatial data. Global positioning system (GPS) technology can be used to accurately position such points and locate important sources of water pollution, such as discharges from industrial facilities and wastewater treatment plants.

3.2.6 Finding 4: The Lack of Flow Data in the Repository Hinders Analysis

The Repository currently includes only a small amount of flow data from STORET and NWIS. Flow data are needed for the following kinds of analyses:

- Water quality status analyses where standards are established based on flow levels
- Water supply/demand studies, water budget analyses, and general watershed hydrology studies that can complement water quality analyses
- Detailed pollutant modeling on a given watershed.

Recommendation: To enable such analyses, additional flow data can be added to the Repository for targeted waterbodies or (as available) for the entire border area. We are aware of the availability of large records of flow data collected by IBWC (and available on their Web site) for the Rio Grande/Rio Bravo. In addition, data from the USGS NWIS system should be fully accessed and included in the repository.

4.0 Developing Water Quality Indicators for the U.S.-Mexico Border

The Border 2012 program mandates that water quality indicators be developed and used to demonstrate real, meaningful, and measurable results in meeting the goals of Border 2012. To ensure that these goals are met and to increase overall capacity to respond to environmental and health problems at the border, the Border Indicators Task Force (BITF) was established in December 2003. The role of BITF is to coordinate with all Border 2012 groups and stakeholders to define a set of indicators and develop protocols for the collection, analysis, and quality control of the data necessary for the calculation and interpretation of those indicators.

Indicators are useful, informative tools when they are related to a conceptual framework that holistically describes the interactions within a system. The Pressure-State-Response (PSR) conceptual framework has been used as a starting point to help define needed border area indicators. This model follows a linear logic where a pressure causes a change in state, which then evokes a response. More recently, the Driving Forces-Pressure-State-Impact-Response (DPSIR) conceptual framework, an extension of the PSR model, has been applied in developing a conceptual framework more suitable for Border 2012 needs. DPSIR seems well suited to the Border 2012 program because it allows for the identification and analysis of relationships between border-specific development actions and the effects produced on the environment and human health. The enhanced understanding of these relationships would allow policy makers to develop the region in a sustainable manner, aware of potential environmental and human health consequences. Additional information on the emerging Border 2012 Program's *Strategy for Indicator Development* is available at http://www.epa.gov/usmexicoborder/pdf/indicator_strat.pdf.

Indicators can be used on either an ongoing basis or for a finite period of time. Regardless of the length of data collection or indicator usage, a review process is necessary to evaluate the performance of the indicator. What may be a useful indicator now may change with time, given the development of technology, further improvements along the border, changing needs of the public, or increased insights in policy or science. The BITF proposes that a review occur two years after an indicator is first implemented and then every five years thereafter. At a minimum, the review should answer the following questions:

- **Purpose—**Why was the indicator developed?
- **Data collection and management—**What protocol was followed?
- **Data reliability—**Is the source reliable?
- **Quality assurance—**How accurate and precise are the data?

- **Information—**What does the indicator convey? Is it true to its purpose? How does the information compare to the standard?
- **Limitations—**What are the outstanding gaps or limitations of the indicator?
- **Conclusion**—Are the data useful and should the indicator continue to be used?

Parameters that could be applied in the development of water quality indicators are included in recommendations for a *Binational Set of Indicators for the Border 2012 Program* (available at http://www.epa.gov/usmexicoborder/pdf/indicators_set.pdf). These materials cover several types of proposed environmental indicators, with the aim of stimulating discussion and consideration among the various workgroups regarding the appropriateness of the indicators for measuring program progress and assessing environmental and health changes in the region's conditions.

This list of potential indicators, given further refinement, will eventually become the official *Binational Set of Indicators for the Border 2012 Program*. Environmental indicators to support Goal 1 (Reduce Water Contamination) include the set of 12 physical, chemical, and biological parameters related to surface water quality conditions that were selected for data collection and entry in the U.S-Mexico Border Waters Repository (see Section 3.1.3). The Repository has assembled all readily available ambient monitoring data related to this set of parameters. As described in Section 3, the Repository provides a good platform to investigate different alternatives for developing the needed 2012 water quality state indicators. As illustrated in Figure 7, this development process would lead to indicators that are consistent with the overall Border 2012 conceptual framework.

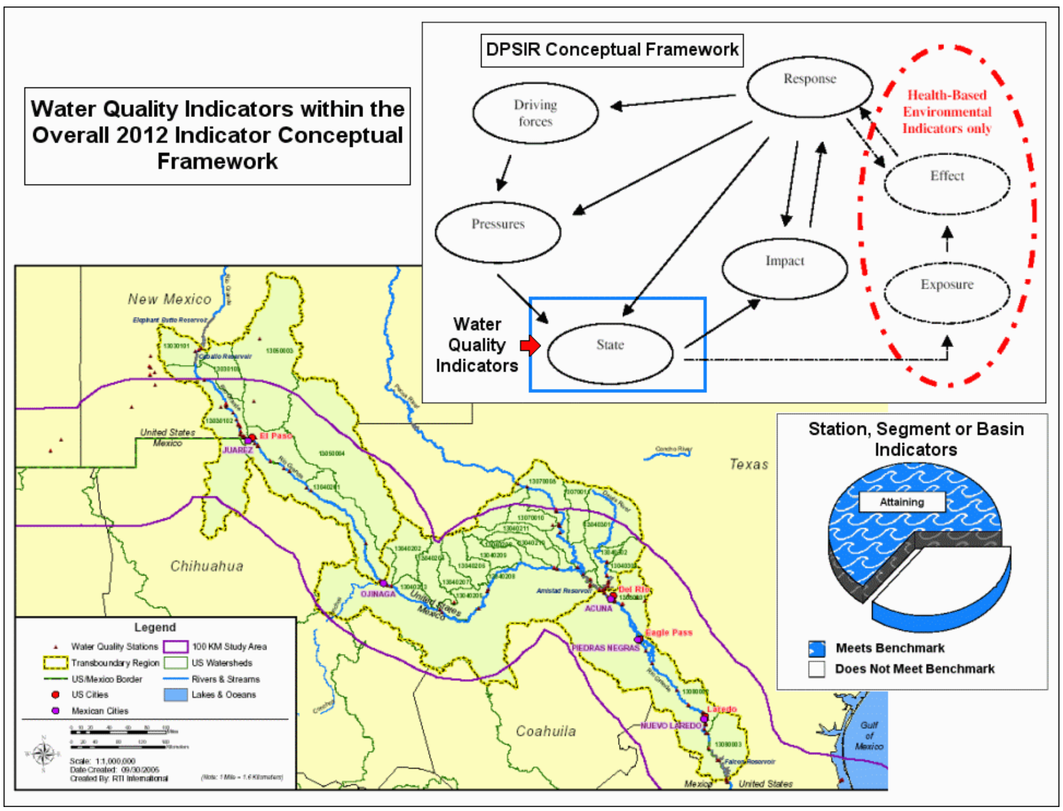

Figure 7. Process for developing water quality indicators within the Border 2012 conceptual framework.

The parameters in the Repository include measures commonly applied directly in water quality standards criteria and measures, such as COD and BOD, commonly used in permits to achieve pollutant discharge reductions needed to safeguard the standards for receiving waters. The proposed indicators include parameters related to the protection of aquatic-life designated uses and other parameters (e.g., fecal coliform) related to human-health–oriented body contact recreation uses. Microbial parameters are also used as indicators to safeguard drinking water uses, as are parameters such as chlorides and sulfates as applied to inland fresh waters (river and lakes). Table 6 summarizes these considerations for the different Border 2012 parameters collected in the Repository.

Table 6. Repository Parameters Related to Aquatic Life or Public Health Uses and Typical Applicability as Ambient Water Standards or for Use in Permitting

Water Quality Indicator	Aquatic Life Support Uses	Public Health Uses	Ambient Water	Permitting
Fecal coliform		●	●	●
Chlorophyll a	●		●	
Sulfate[a]		●	●	●
TDS[a]		●	●	●
Chloride[a]		●	●	●
DO	●		●	
Conductivity[a]		●	●	●
COD	●			●
Orthophosphate	●		●	
Nitrate	●		●	
Ammonia	●		●	●
BOD	●			●
pH	●		●	●
Temperature	●		●	●
TSS	●		●	●

[a] Applied mainly to inland fresh waters.

Water quality indicators for major uses of water resources can be related to the water quality standards developed under both U.S. and Mexican water quality management programs. The parameter criteria from these water quality standards can be combined with appropriate benchmarks (or norms) to define indicators of the environmental state or condition of individual monitoring standards or associated assessment segments. The site-specific indicator information can then be aggregated over larger geographical units such as basins. The Interagency Task Force on Monitoring (ITFM), a joint EPA and USGS initiative, helped establish a framework for applying available water quality monitoring information to establish water quality indicators for the status and trends tracking of environmental conditions. The ITFM work showed how broad categories of environmental indicators—for instance, ecological health or human health concerns—can be related to major types of water uses that can represent specific management objectives. These management objectives are analogous to the designated uses that U.S. states set in their water-quality standards and report to the U.S. EPA as part of the Clean Water Act's Section 305(b) Integrated Reporting process.

The work of ITFM continues through the USGS-sponsored interagency Water Information Coordination Program and the Advisory Committee on Water Information (http://water.usgs .gov/wicp/). These interagency initiatives are based on directives in the Office of Management and Budget (OMB) Memorandum No. 92-01, which designates DOI, through USGS, as the lead agency. Other U.S. federal organizations (including the EPA) that fund, collect, or use water resources information work with USGS to implement program recommendations. Documents stemming from the work of ITFM can be found at http://water.usgs.gov/wicp/itfm.html. The work of ITFM has been very influential for EPA in the design and ongoing enhancement of the performance measures used in EPA programs as part of the Government Performance and Results Act or the related OMB Program Assessment Rating Tool systems.

Outcome indicators similar to the water quality indicators recommended for development by the Border 2012 initiative are found in performance measures EPA is developing (http://www.epa.gov/ water/waterplan/) for programs operating within the United States and for special measures under development dealing with water quality standards attainment for waters in the U.S.-Mexico border area. These proposed outcome measures related to the evaluation of programs in the United States under the Clean Water Act can be developed in ways that compliment the Border 2012 indicator initiatives, thus achieving significant efficiencies in creating and maintaining the data infrastructures needed for operational status and trends outcome measures. Further information on EPA reporting measures relevant to the development of Border 2012 water quality indicators can be found in the *National Water Program Guidance: FY 05 Midyear Reporting on Final Measures and Commitments* (available at http://www.epa.gov/water/waterplan/documents/ FY05measuremidyeardata.pdf).

The major actions needed to apply information in the Repository are to select appropriate benchmarks (or norms) to help interpret the parameter information relative to concepts of designated use attainment or non-attainment. Benchmark information can be taken for either implemented water quality standards criteria or from the national criteria guidelines developed by EPA or corresponding Mexican government agencies that guide management programs delegated to states and other water resource agencies. These benchmarks are typically applied according to major waterbody types (e.g., rivers, lakes, and estuaries/near coastal waters). The benchmarks can also be organized according to major designated use categories (e.g., aquatic life support and public health uses).

To facilitate checks on data adequacy and help pinpoint areas where there may be apparent data gaps, the indicators would be developed parameter by parameter for assessment segments in the vicinity of the primary ambient monitoring sites. This site-specific information could then be analyzed for its suitability in creating indicators for larger geographic units, such as border area basins (e.g., the Rio Grande Basin). Such basin-level indicators could be organized by waterbody type, major designated use category (aquatic life or public health), and parameter. Because data gaps are likely to exist for some parameters within a basin, the organization in terms of designated use categories will be helpful in taking available parameter information to develop indicators of use attainment. This development approach would be consistent with practices followed in Clean Water Act assessment programs in the United States and would help provide indicators of immediate value to ongoing management activities in the border area.

5.0 Mexico Border Reach File

The MBRF is a prototype product created using a method similar to the one used to create the U.S. National Hydrography Dataset (NHD), which is a comprehensive set of digital spatial data that contains information about such surface water features as lakes, ponds, streams, rivers, springs, and wells. Within the NHD, surface water features are combined to form "reaches," which provide the framework for linking water-related data to the NHD surface water drainage network.

5.1 Methodology

The MBRF prototype was created to showcase the potential of an NHD-like hydrographic network in Mexico in which all waterbody and river reaches are uniquely identified and linked in a network. RTI then reach indexed the water quality monitoring stations to the MBRF so that each station was uniquely identified by a river or lake reach in the network. The reach indexing, or pinpointing, of stations onto the MBRF was possible because of the MBRF's unique networking features and the existence of latitude/longitude information for a given station. The reach indexing itself was made possible by the existence of tools such as EPA's Reach Indexing Tool (RIT). Because each station was indexed to the MBRF network, all the water quality data related to the stations can be also related to a unique point in the MBRF network. This prototype shows the potential of what a future official Mexican reach file can do to perform water quality modeling and assessments in the entire Mexican territory.

The MBRF was derived from several initial shapefiles[2] received from CNA. CNA had already appended the linework into a large national-scale file comprising the northern portion of Mexico. There were no cataloging unit (CU) boundaries, and no NHD data existed that could be conflated (transferred) onto the Mexican linework. Despite these differences, it was possible to alter the attribute information stored on the nodes, lines, and polygons of the Mexican linework so that the NHD Create software could operate on it. To create an NHD-style data set, RTI used NHD Create to append the linework and conflated existing reach codes from the NHD data onto the linework.

CNA also provided point name data, which could be converted to something that emulates the U.S. Geographic Names Information System (GNIS). This was not done because the linework from CNA did not include name data and the level of effort to manually assign point names to linear features (and thereby name) a relatively small number of reaches using tools in NHD Create was deemed excessive.

Appendix H explains the process of creating the MBRF in detail.

The prototype MBRF can be used to showcase the functionality of reach indexing water-quality–related information to a hydrography network. The monitoring stations on the Mexico side, and therefore all the water quality data contained within the stations, were reach indexed using

[2] A shapefile is an editable spatial database format generated in the desktop software application ArcView that stores the location, shape, and attribute information of geographic features.

EPA's RIT to illustrate how different tools can be combined to provide more valuable information for water quality analyses and modeling.

5.2 Findings and Recommendations

The MBRF represents an initial step to creating a NHD-like geographic information system (GIS) hydrography layer for the Mexican side of the border. Another attempt to create a binational hydrography was made by the University of Texas at Austin (UTA). UTA has created a hydrologic geodatabase for the Rio Grande/Rio Bravo Basin using ArcHydro and available data from either side of the border. Some important findings relating these efforts include the following:

- The raw linework obtained from CNA to create the MBRF was acceptable, although some connectivity and arc direction issues surfaced that will need to be corrected in the next version. The final MBRF network is functional, but it requires further editing to ensure proper connectivity and flow direction.
- Additional editing is required to include reach names.
- The Rio Grande is depicted as it was in the original linework. Considerable effort will be required to integrate the U.S. side into the Mexican data set. Because of scale and CU delineation issues, a complete integration of the U.S. and Mexican systems many not be feasible.
- UTA's Rio Grande basin geodatabase has some advantages over the MBRF: it is built in a modern, flexible geodatabase format called ArcHydro, and the hydrography linework has been edited to obtain good flow characteristics. UTA's geodatabase also contains higher quality linework for the Rio Grande/Rio Bravo basin than does the MBRF.

Based on a review of these two efforts, the U.S.-Mexico Border Waters stakeholders group has come to the conclusion that the ArcHydro model developed by UTA provides the best option for developing a GIS hydrography layer for the Mexico side of the border because the ArcHydro data model is more flexible and does not require strict definition of hydrologic units as part of the feature-naming conventions. The NHD-based hydrography developed for this project can be easily imported into ArcHydro. Future enhancements should include completing the ArcHydro hydrographic dataset for the entire border, using the available NHD creation tools as appropriate and importing the resulting coverages into ArcHydro. This development could include development of metadata standards similar to those established for the NHD. Additional study and collaboration between U.S. and Mexico stakeholders is needed to develop a detailed approach for developing the Mexican GIS ArcHydro hydrography coverage for the border area and developing options for linking that network to the NHD coverage on the U.S. side.

6.0 Future Work

The U.S.-Mexico Border Waters project represents a very important first step towards the creation of a multidisciplinary and multiorganizational team that will identify needs on water resources management along the border. It is important to identify funding sources and obtain resources to build on this effort by performing studies and improving these tools to help reach the goals set forth by EPA's Border 2012 program and other programs pursuing the improvement of the quality of the shared waters in the border area.

Future phases of this project need to build on the extensive expertise of organizations that have worked on environmentally related issues in the border area, such as SCERP, UTA, University of Texas at El Paso, San Diego State University, New Mexico State University, Arizona State University, University of Utah, Universidad Autónoma de Baja California, Universidad Autónoma de Sonora, and other universities in Mexico and the United States. CNA, CILA, and IBWC have also built on their own expertise working on border water resources issues. SCERP is currently developing a Transborder Watershed Research Program that focuses on land use practices in the San Pedro and Tijuana watersheds. Other organizations are currently working on a variety of projects with the goal of improving the human condition on the U.S.-Mexico Border.

Many different future activities have been identified during the development of this project, to be proposed and prioritized for completion on subsequent phases. The completion of this report in particular has shed light on how the U.S-Mexico Border Waters Repository can be enhanced and improved as new benchmarks are developed and information become available, and on how robust indicators can be developed to measure improvements in water quality conditions for the shared waters along the border.

The implementation of more sophisticated analytical methodologies will become possible as more water quality data are stored and maintained in the Repository and benchmarks and indicators are further developed. The addition of GIS-based tools and the georeferencing of water-quality related data will also provide us with the opportunity to perform more statistically sound and realistic analyses to support the border water assessment efforts. The creation of the MBRF prototype and the georeferencing of stations show the potential of combining water quality data with GIS-based tools.

6.1 Maintaining and Enhancing the Repository

The U.S.-Mexico Border Waters Repository can be enhanced by adding new data standards as they become available. These standards, such as EPA's ESAR standards, try to create uniformity among the different existing repositories such as STORET and other surrogate systems. CNA may consider the benefits of including some of these data standards into its own water quality system (Sistema Nacional de Información de la Calidad del Agua [SNICA]) and by transferring the water data already collected and stored in the Repository.

The Repository should be migrated to a more robust relational database management system, such as the commercial ORACLE or SQL Server systems or open source systems such as MySQL or PostGRESQL. This migration would ensure referential integrity of data and provide enhanced security and user management tools. A graphical user interface can be built on top of the Repository to facilitate data entry and maintenance. The Repository could also be enhanced with additional lookup tables to provide more thematic information related to water resources and to allow for simpler and more powerful querying of the stored data.

An important next step is a Web-based system to provide tools to enable the Mexico data providers to review and verify Repository data, edit data already in the Repository, and upload additional water quality data into the system.[3] Such a data verification and input tool would help automate the review and update processes for a distributed client network making use of modern Internet-based techniques, and is especially critical as a way to fill the data gaps on the Mexico side of the border. This data verification tool would query the underlying relational database tables to produce data formats that would be convenient for end users to examine and verify their water quality information. Similarly the tool could provide table formats to enable data providers to conveniently upload data to the Repository.

Future Repository enhancements could include

- Mechanisms to allow uploads of additional water quality (or flow) data for established stations
- Tools to provide basic locational information for both established and new stations (a streamlined locational tool to help in verifying lat/long station locations)
- Analytical programs to provide basic summary statistics on data availability for individual stations, and for groups of station over defined watershed basins, to help identify where sufficient data are available to move forward to develop Border 2012 indicators and where there are still data gaps.

As end users provide additions or corrections to the Repository, the Web-enabled system could be periodically refreshed with updates to these basic summary statistics.

6.2 Water Quality Analysis

Water quality analyses and modeling can be scaled up to accommodate more variables and scenarios as more data and tools are incorporated into the Repository. The Repository can become a key component within a decision support system that includes GIS-based analysis tools, mapping tools, and Web interfaces for downloading additional information. Water quality analysis and modeling would then be able to better simulate the complex universe behind water resources and uses on the U.S.-Mexico border.

One of the key ideas stemming from this project is to create a decision support tool for Mexico that incorporates some components of SNICA, the Repository, the MBRF prototype, and analysis tools from EPA’s BASINS (Better Assessment Science Integrating Point and Nonpoint Sources). This decision support tool should be tested for a watershed on the border, most likely on the Rio Grande/Rio Bravo watershed because an important project has already been developed there by UTA. This effort would require, among other activities, the collection of flow data for the most important rivers on the border watersheds, the georeferencing of industrial discharge points in Mexico, and the acquisition and storage of industrial discharge data from Mexico. CNA has expressed its interest in pursuing this effort to enhance SNICA and to build upon its current system by incorporating publicly available tools such as BASINS.

[3] Because Repository data for the U.S. side of the border is extracted directly from existing EPA and USGS systems (STORET and NWIS) that have extensive data quality measures in place, a data upload and verification system is not needed for the U.S. data.

6.3 Mexico Border Reach File

The completion, demonstration, and use of an MBRF is needed at the next stage of this project to relate water quality information to an ArcHydro-based network of the Mexican hydrographic system and to convey the advantages of having reach-indexed water quality data for future water quality analyses and modeling. This could also be a first step towards creating an official national Mexico hydrography network. Training of officials from CNA, CILA, and other Mexican agencies on the MBRF and BASINS are also proposed activities for subsequent phases.

During the stakeholders meeting in Juarez in November 2004, two resource intensive activities were identified as future needs for subsequent phases. One of these activities is the geopositioning of all wastewater and industrial discharges on both sides of the border using global positioning system (GPS) equipment. It was proposed that SCERP could help with students from the different universities in their Consortium to assist in getting this information.

The other identified activity was the use of remote sensing techniques to identify water quality indicators, with emphasis on the Rio Grande. Mexican and U.S. agencies are very much interested in implementing this technology because it can identify pollution sources and measure indicators via satellite imagery, reducing considerably the costs of sampling and monitoring necessary to measure progress towards improving water quality conditions for the shared waters of U.S. and Mexico.

7.0 References

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