8-20-2007

Water resources assessment in the greater Rio Casas Grandes Watershed

Bruce Thomson

Abdul-Mehdi Ali

Water Resources Assessment in the Greater Rio Casas Grandes Watershed

WR 573
Summer 2007
University of New Mexico

Preface

WR 573, Field Methods, is a class taught each summer in the Water Resources program at the University of New Mexico (www.unm.edu/~wrp). The purpose of this class is to introduce students in the program to methods used in water resources investigations and includes field measurements of hydrologic parameters, field and laboratory analyses of water quality characteristics, and methods of collecting and interpreting information on water resources policies and management in a particular watershed.

The subject of the WR 573 class during the summer of 2007 was the Rio Casas Grandes watershed in the state of Chihuahua Mexico. The class was taught by Professors Bruce Thomson (Director, Water Resources Program) and Bill Fleming (Community and Regional Planning), assisted by Jeanie Fleming. Special assistance with laboratory analyses was provided by Dr. Mehdi Ali (Earth and Planetary Sciences).

Class participants from the Water Resource Program were: Christian Gunning, Shawn Hardeman, Jessica Johnston, KT LaBadie, Jake Meadows, Alicia Paz-Solis, Lynda Price, and Annelia Tinklenberg. Brad Wylie from the Community and Regional Planning department also participated.

Questions regarding this report should be directed to Bruce Thomson (bthomson@unm.edu).

Table of Contents

Preface 2
Table of Contents 3
List of Figures 5
List of Tables 5
Acknowledgements 6
Introduction 7
Description of watershed 7
  History 7
    Paquimé Water Use (circa 1200 AD) 7
    Spanish Colonia Period (1535-1821) 9
    Mexican Period (1810-1890) 10
    Mormon Settlements (1885-present) 10
    Colonia Juarez 11
  Physical characteristics 11
    General 11
    Geology 13
    Ecology 13
  Social and cultural characteristics 15
    Population 15
    Economy 15
    Political Status 16
    Mexican Water Law 16
Research methods 17
  Physical data 17
    Rapid assessment 17
      Watershed Watch riparian survey 17
      Macro-invertebrate inventory 18
      Stream flow 18
    Water quality 19
      Site selection and sampling protocol 19
      Analytical methods 20
  Social and cultural data 21
Results 22
  Physical data 22
    Rapid assessment 22
      Macro-invertebrate inventory 22
      Stream flow 22
      Watershed Watch riparian survey 23
    Water quality 23
Discussion 27
  Challenges and Constraints 27
    Scarcity of Water 27
    Accounting for Water Supply and Demand 28

Socioeconomic Constraints 28
Compare and Contrast of Management Strategies 29
Regulatory Framework 29
Water Quality Standards 30
Conclusion 31
References 32

List of Figures

Figure 1.Charles Di Peso's publication entitled Casas Grandes and the Gran Chichimeca is a chronological legend of Mexico before Cortez. The image parallels Mexican history with the history in Chihuahua with Casas Grandes at its core........................ 9
Figure 2. Map of the study locations within the Rio Casas Grandes watershed............... 12
Figure 3. Map of physiographic regions, separation of the Chihuahua Desert from the Sierra Madres.. 14
Figure 4. Map of sample locations distinguishing groundwater and surface water sources. 20
Figure 5. Piper diagram depicting cations and anions from surface and groundwater samples taken near Casas Grandes, Mexico. 24
Figure 6. Aqueous Fluoride concentration from sample locations plotted against 1994 standards developed by Mexico's Ministry of Health for certifying the quality of drinking water. 25
Figure 7. Aqueous Aluminum concentrations from sample locations plotted against 1994 standards developed by Mexico's Ministry of Health for certifying the quality of drinking water. 26

List of Tables

Table 1. Taxa Group Organization. 18
Table 2. Macro-invertebrate counts. 22
Table 3. Results of Rapid Riparian Assessment. 23
Table 4. Regulatory framework for water management in Chihuahua and New Mexico. 29
Table 5. Comparing United States' Safe Drinking Water Act Standards (SDWA MCLs) to standards established by the New Mexico Environment Department, and Mexico's Secretary of Health for potable water. 30

Acknowledgements

The students of the WR573 express their heartfelt thanks to everyone who made this project possible. Each of the interviewees mentioned below provided invaluable historical and personal contexts. The generosity and hard work of Bill and Jeanie Flemming, Bruce Thomson, Abdul-Mehdi Ali, John Hatch, and many others allowed the project to proceed smoothly and rapidly.

Introduction

The Rio Casas Grandes watershed is located in northern Chihuahua, Mexico, on the eastern flank of the Sierra Madres. Like all arid desert regions, this watershed faces problems related to a lack of fresh water. Increasing populations, agriculture, and industry create a challenge to water managers and users in the watershed. Water shortages from drought combined with increased use have caused decreases in water tables as well as increases in the number of fallow fields in the lower reaches of the watershed. Poor land management practices combined with water shortages have the potential to threaten the livelihood of communities within this watershed.

Students in the University of New Mexico's (UNM) Water Resources Program (WRP) field course studied the greater Rio Casas Grandes watershed with a focus on the Rio Piedras Verdes sub-watershed. This course was designed for students to apply their knowledge and understanding of water resource issues to the water issues in the greater Rio Casas Grandes watershed. Due to the lack of quantitative data in the area, various types of quantitative field methods were performed to create a baseline of riparian health, water quality, and hydrology data. Interviews were conducted with professionals, academics, and farmers to provide first hand perspectives of the history, land use, and resource management within the Rio Casas Grandes watershed.

The primary objectives for this course were to identify the water resource challenges in the Rio Casas Grandes watershed through both quantitative and qualitative assessments. Historical water use patterns, political and cultural constraints were identified, along with the quantitative information needed to improve water management. Water quality of the region was assessed and water management practices of the Rio Casas Grandes watershed were compared with those of New Mexico.

Description of watershed

History

Paquimé Water Use (circa 1200 AD)

Northwestern Chihuahua has been continually inhabited for centuries. Among some of the most interesting archaeological sites in the region are the ruins of Paquimé (or Casas Grandes), a sizable pre-European settlement which contained complex water systems designed to supply for domestic water, including stone-lined water channels and covered reservoirs. These ruins lie approximately 6 miles south of Nuevos Casas Grandes. To date, the site is approximately 50% excavated. Built over a thousand years ago, the site is composed of ancient plazas, ceremonial mounds and a beautiful adobe maze. Some important water-related features observed in the ruins of Paquimé include the following: Casa del Pozo (House of the Well), Casa del Pozo Segunda (House of the Well), Deposito I (Reservoir I), Deposito II (Reservoir II).

The House of the Well was an important component of the multistory dwelling area. It is believed that approximately 800 people occupied the 339 domestic rooms. The apartment complex had an acequia and sewer system and a subterranean walk-in well under the floor at the center of the House of the Well. This well was designed and located so as to tap the water table. A strategically designed stairway led from the well up to the ground-story room. It is believed that the well served as a supplementary domestic water source in times of scarcity, or that it functioned as a ceremonial feature.

Reservoir I was built either to control the flow of the water in the underground pipe system or as a settling tank to remove silt carried in the water. A stoned-lined swirl basin was built on the north side where water flowed into the reservoir. This slowed the flow of water and allowed sediment to deposit before the water flowed into the reservoir. A small wooden flow-control gate was located on the east side of the basin. This might have been used to regulate flow into the underground stone and clay lined tunnels. Reservoir II, replaced Reservoir I as part of an "urban renewal program." This reflects a possible increase in water demand and the need to store more water for the community. Reservoir II was 40 percent larger in capacity than reservoir I.

Paquimé flourished until approximately 1200 AD. At this time it began to fall into disrepair. Civil construction and public maintenance stopped. Some public ceremonial areas were invaded by residents who made them into living units. In later periods, deceased were buried in the city water and plaza drains which clogged and fouled both systems, thus marking the end of an era for the city and its inhabitants. Nonetheless, lessons of city planning and water systems withstand the test of time and can be read from the archaelogical record (Scurlock, 1992). As a final note, numerous small rock walls are found throughout the region that are thought to date to the Paquimé era. Known as trincheras or check-dams, they are thought to have slowed and broadened the pulse of flood waters in the region, allowing for optimum use of the regions infrequent, intense summer monsoon rains.

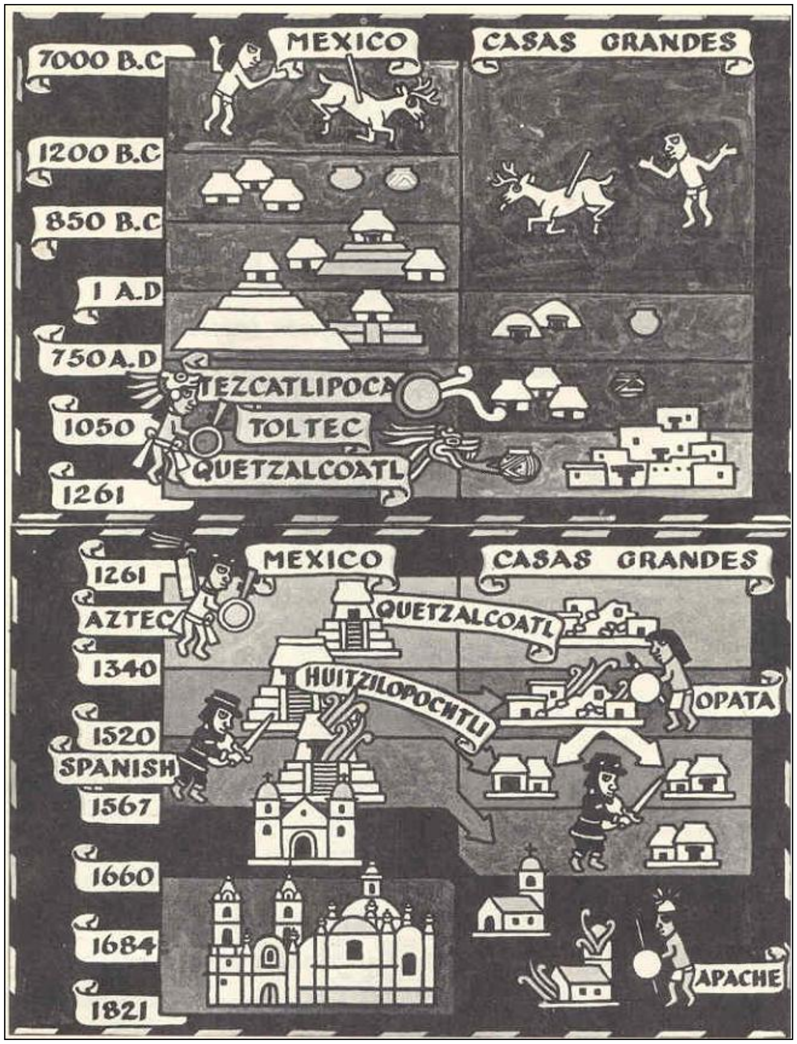

Figure 1.Charles Di Peso's publication entitled Casas Grandes and the Gran Chichimeca is a chronological legend of Mexico before Cortez. The image parallels Mexican history with the history in Chihuahua with Casas Grandes at its core.

Spanish Colonia Period (1535-1821)

The first Spanish explorers in the northern Chihuahua region estimated that there were approximately 80-95 Indian groups living in the area (Scurlock, 1992). Possible descendants of the Paquimé culture of Casas Grande were found dispersed throughout the foothills of the Sierra Madres. Some of these groups were practicing subsistence agriculture. Hunting, gathering and trade with other groups were still extremely important. The Spanish heard stories of large towns to the north that cultivated large crops, produced textile goods, and traded fine embellishments such as turquoise and feathers. These stories lead the Spanish to believe that these cultures may have gold or silver and sent explorers and missionaries on expeditions in search of riches.

A description written by an expeditionary described the Casas Grandes River valley as abundantly vegetated, the most beautiful and beneficial of all the rivers found in the area, and suitable for irrigated agriculture with little effort or cost. Many other expeditions began using the route through Casa Grandes to explore lands further to the north in search of gold and other riches. Approximately one century after Ibarra's first visit to the region, the Franciscan missionaries established the San Antonio de Padua de Casas Grandes mission. Around the same time, Spanish settlers began farming in the valley. The region's second Franciscan mission, the Nuestra Señora de la Soledad de los Janos, was built in 1665. Abuse and insults from Spanish officials and clergyman led to a rebellion of indigenous inhabitants, which led to the destruction of the church in 1684. It was not until 1686 that the Spanish were able to resettle the Casas Grandes area.

Mexican Period (1810-1890)

Northwest Chihuahuan settlements were frequently raided by the fierce Apaches who wanted to protect their lands. Many of the lands in the region were abandoned due to fear of the Apaches or sold at very low prices, which lead to wealthy individuals such as Luis Terrazas owning much of the land. After Northwest Chihuahua fell to Apache raids, another revolution started in 1857 in the northern part of Mexico. By 1870, many Apaches had been killed or captured and placed on reservations by the US government, decreasing the risk to regional settlements. As late as 1920, Apache survivors were living in the Sierra Madres.

The poorest people, who generally did not own their own lands, were led by President Benito Juarez against the upper class Mexicans, who had been in control of the government for years. President Benito Juarez was forced to move to Ciudad Chihuahua in 1864 during the revolutions. Luis Terrazas, a wealthy banker and landowner, was placed in office by Juarez in 1864. He has been attributed with the phrase that expresses the autocratic attitude of the times, and constitutes the reason for the discontentment of the working class: "Yo no soy de Chihuahua, Chihuahua es mio," I am not from Chihuahua, Chihuahua is mine.

Mormon Settlements (1885-present)

In 1885, the Mormon colonists were permitted to enter Mexico by President Porfirio Diaz. Mormon settlements were established near Asencion, Nuevo Casas Grandes, and Casas Grandes. The settlements of Colonia Diaz, Colonia Dublan, and Colonia Juarez built gridded towns and irrigation canals. The Mormon town of Colonia Juarez was officially established in 1885, with the mission of converting the Indians and creating sanctuary for polygamous Mormons seeking refuge from the government of the United States. While the Mormon Church no longer officially sanctioned polygamy, many established plural families chose to leave the U.S. rather than separate. The successful establishment of this faith has made the Mormon religion Mexico's second largest denomination, with 1.5 million members, second only to Catholicism.

An interesting anecdotal event attesting to the Mormon faith and historical perspective was narrated by John Hatch, a resident of Colonia Juarez. He tells of a long standing drought that had plagued the area in 1886 that threatened crops and livelihoods. The

Mormon community held a series of prayers and fasts. Soon after a large earthquake shook the region, creating avalanches that sparked widespread forest fires. Soon after, however, water began to flow from new upland springs, and the Rio Piedras Verdes became a perennial stream. According to Hatch, the river has not run dry since.

Colonia Juarez

The Rio Piedras Verdes flows through the middle of Colonia Juarez. When the first settlers came to the valley, they were informed that they'd purchased tracks of steep, rocky canyon lands rather than, as they'd believed, flat valley lands appropriate for row crops. The settlers accepted the alternative lands and turned their efforts to planting fruit orchards that would be more suitable for the canyon lands. Some cattle ranching also occurs within the watershed. (Hatch, 2007)

The Mormons created a gravity-fed irrigation system using water from the Rio Piedras Verdes to irrigate the orchards. This system was exclusively used until the 1950's, when diesel and electric water pumps and water wells became available, allowing for a significant increase in irrigated acreage. Presently, irrigation wells are required to have flow meters in place that are monitored by the Comision Nacional del Agua (Hatch, 2007). Since their establishment in the area, farmers near Colonia Juarez have conscientiously implemented water conservation mechanisms, such as reuse of dishwater, bathwater and have established the position of a water master who governs the equitable distribution of water (Bennion, 2004). However, Mexican officials passing through town often commented that Colonia Juarez must be using more than their share of the water to create such a paradise (Hatch, 1954)

John Hatch noted that important hydrological features of the area are closely connected to people's livelihoods. Arroyo Tinajas drains the watershed immediately north of the Piedras Verdes, is an ephemeral stream which is frequently dry during the dry season (Hatch, 2007). The Rio Piedras Verdes is often dry south of Colonia Juarez, presumably due to agricultural diversions and ground water infiltration. Hatch commented that during his childhood the grasslands within the valley were open and productive. Within the last fifty years mesquite brush has encroached on these grasslands and the grass cover has declined substantially. He points to over-grazing as a likely culprit.

Physical characteristics

General

The primary study site was on or near the Rio Piedras Verdes, which is a tributary of the Rio Casas Grandes. The Rio Piedras Verdes flows from an extensive watershed deep in the Sierra Madres, with its headwaters in the Sierra Cordones El Aguila. From the headwaters, the Rio Piedras Verdes flows west for approximately 10 kilometers towards the ranchero Pacheco before turning north. It then flows north for approximately 18 kilometers before turning towards the east near the Sierra De Enmedio. The Rio Piedras Verdes then winds through a shallow mesa canyon with steep rock cliffs before reaching the ranchero Los Nogalas, which appears to be the first point of diversion for agricultural use.

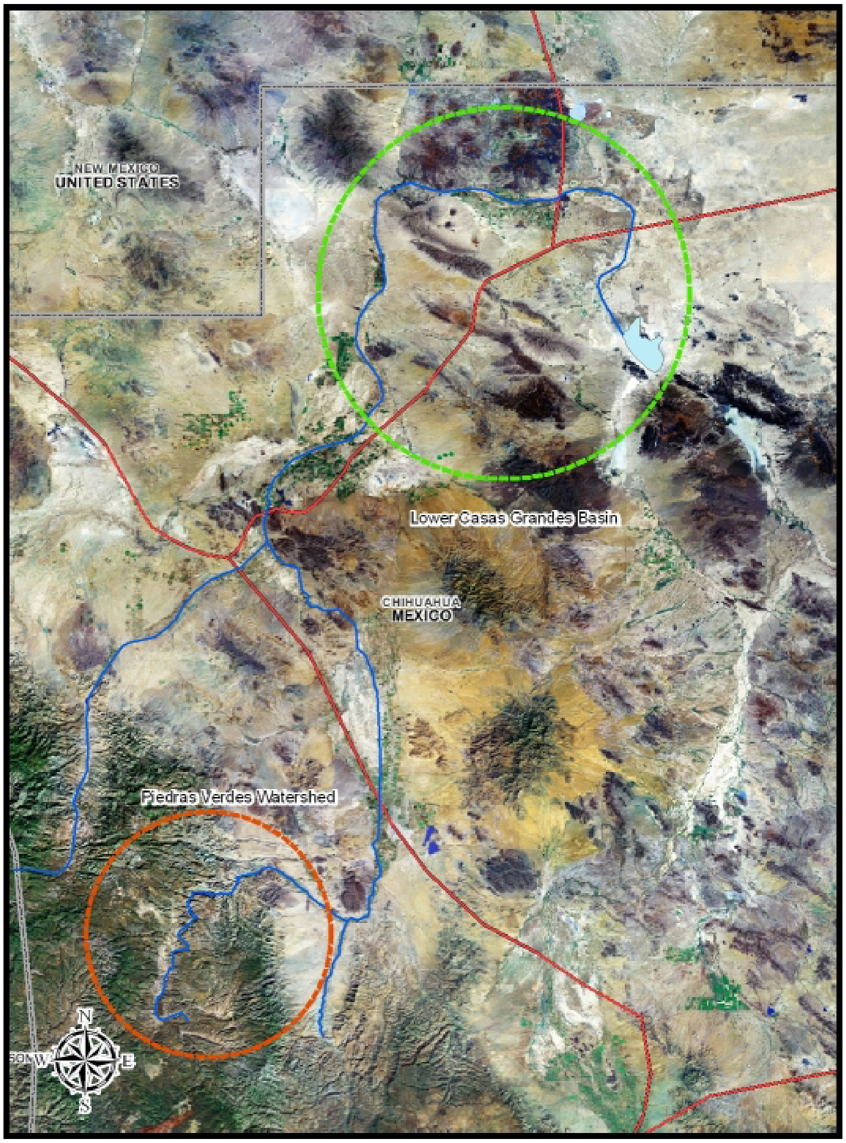

Figure 2. Map of the study locations within the Rio Casas Grandes watershed.

The dimensions of the watershed are quite extensive and complex covering an area of approximately 200 square kilometers. The drainage systems vary on both sides of the river with mountain ranges to the west and flat mesas to the east. Within the watershed there are a number of tributaries that feed the Rio Piedras Verdes. Due to limited access, this study was not able to determine which tributaries are perennial and which are ephemeral. Although there are no stream gages along the Rio Piedras Verdes, reports from local residents indicate that the river flows year-round. The streambed characteristics of the Rio Piedras Verdes in the upper part of the watershed, before Colonia Juarez, appears wide and shallow with predominately rounded boulder and cobble size stones, and intermittent spots of gravel in the streambed. As the Rio Piedras Verdes flows through Colonia Juarez, the river channel is cleared of vegetation and rocks in the streambed by machines in an effort to improve drainage and protect the Colonia from flooding.

Downstream from Colonia Juarez, the Rio Piedras Verdes continues until it meets the Arroyos Tinaja and Tapicitas coming in from the north. The Rio Piedras Verdes then flows in a southeasterly direction towards the confluence where it joins with the Rio Casas Grandes at the Hacienda San Diego, site of one of the residences of Don Luis Terrazas. From the confluence, the Rio Casas Grandes flows north through Nuevo Casas Grandes towards the Guadalupe Victoria Valley in the Lower Casas Grandes Basin, then it empties into the Laguna Guzman, a playa lake.

The Rio Casas Grandes flows into a small section of a much larger river basin called the Casas Grandes – Santa Maria – Carmen. This is a closed basin or cuencas cerradas, and is made up of interior drainage systems that empty into a larger paleolake system called the Laguna Cabeza de Baca in the northern part of Chihuahua, Mexico. The northern part of the basin is the Mimbres Basin, which drains much of south western New Mexico. The physiographic province of the area is commonly referred to as the Sierra y Llanuras del Norte, mountains and plains of the north. However, this province is also split into two distinct geological provinces called Grandes Llanuras De Norteaméri, the Great Plains of North America, and Sierra Madre Del Sur, the Mother Mountain Range of the South.

Geology

The two major geological provinces that make up the Piedras Verdes Watershed and the Lower Casas Grandes Basin are also known as the Mexican Basin and range of eastern Chihuahua and the Sierra Madre Occidental lying along the Chihuahua/Sonora-Sinaloa border (Guidebook of the Border Region; Hawley 1969 and DeFord 1969). The basin and range region, which is in the eastern portion of the state, is predominately made up of basin-fill from lacustrine deposits, plus fluvial, alluvial and Aeolian deposits. The basin also contains evidence of recent volcanism in the form of extensive lava flows and numerous cinder cones. On the edge of this region, with the Sierra Madre Occidental running north-northwest to south-southeast, there are chains of mountains that run parallel to the basin. Here there is evidence of faulting and uplifting of the lacustrine deposits. The Sierra Madre Occidental is referred to as a great plateau of extrusive igneous volcanic rock with ridges, mesas, and minor plateaus segmented by gorges. The Rio Piedras Verdes flows from such a gorge in the Sierra Madre.

Ecology

The ecology of this area is characteristic of the Chihuahuan desert and is split between desert scrub and semi-arid grasslands. Riparian vegetation such as Cottonwood, Sycamore, Hackberry and Juniper are found along or near rivers and springs. At higher elevation, there are coniferous forests with Ponderosa Pine, Douglas Fir, and Arizona

Cypress (CDRI 2007).

Chihuahuan desert scrub dominates the Lower Casas Grandes Basin. This desert environment is primarily the result of the rain shadow effect of the Sierra Madres. Annual precipitation values of this region vary between 18 inches in the mountains above 7,000 feet to an average of 6 inches in the lowlands east of Ascensión. The vegetation includes creosote bush, sotol or desert spoon, yucca, cat claw acacia, mesquite, and ocotillo. The semi-arid grasslands of the Chihuahuan desert include many of the same vegetation types as the desert scrub except for creosote bush. There is a higher occurrence of grasses such as blue grama, as well as other shrubs such as cat claw acacia and Mormon tea bush. Agaves are typically found in the semi-arid grasslands, especially on hill slopes, along with ocotillo, yucca, cane cholla and prickly pear.

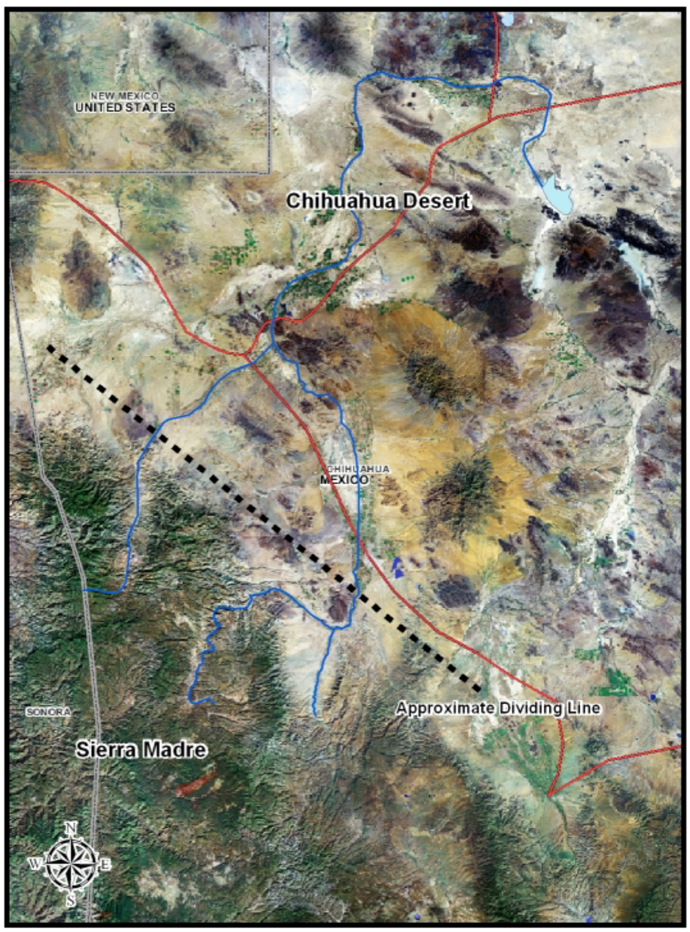

Figure 3. Map of physiographic regions, separation of the Chihuahua Desert from the Sierra Madres.

Social and cultural characteristics

Population

The population of the state of Chihuahua was 3,241,444 according to 2005 census data (INEGI). The municipality of Nuevo Casas Grandes was recorded as having 54,411 residents according to official census data, however, many estimate the population closer to 80,000 (INEGI; Ruiz, 2007 and Hebard, 2007). The population of the Casas Grandes municipality is approximately 8,413, including many smaller settlements such as Colonia Juarez with a population of 1,046 (INEGI). The population within the Piedras Verdes watershed includes the settlements of Colonia Juarez (1,046 pop.), Ojos de Pratt (6 pop.), Ejido Pacheco (35 pop.), Ejido Hernandez (128 pop.), and Piedras Verdes (4 pop.) (INEGI).

Economy

The economy in the Rio Casas Grandes watershed includes irrigated agriculture (chiles, pistachios, apples, peaches, pecans, onions, wheat, sorghum, grasses), ranching, logging, tourism (Mata Ortiz, Casas Grandes), and mining.

Many ranchers and farmers are looking for alternative forms of employment because of low cattle prices and long droughts. Some Chihuahuans are turning their sights on tourism, such as the farmers near Guadalupe Victoria. A group of farmers, for example, recently began building the Boca Grande Dam on the Rio Casas Grandes, hoping to draw tourists (foreign and Mexican) to the recreational opportunities created by the reservoir (Granados, 2007). A lack of funding, uncertain regulatory status, and questions about the geotechnical characteristics of the dam site has left the dam only partially complete.

Most agriculture in Guadalupe Victoria is dependent on ground water pumping as its source of water. Water levels are rapidly falling due to over pumping of this resource. In addition, many rural, agriculture families are moving to the cities of Nuevo Casas Grandes and Ciudad Juarez in search of employment opportunities. Competition between agriculture and other uses in the area has been noted. Some farmers believe the Bismark mine near Ascension, an active copper, lead, and zinc mine, is responsible for regional groundwater depletions as a result of mine dewatering activities.

The economy in the Piedras Verdes subwatershed includes irrigation farming (e.g. apples, peaches, and pecans), cattle grazing, tourism, and logging. The orchards in this watershed were almost 80% apples. However, rising winter temperatures in the valley have greatly decreased apple production. Farmers have replaced most of the apple trees with peaches in the past decade so that the orchards in the Piedras Verdes are currently almost 100% peaches (Hatch, 2007). Yet in 2007, late frosts destroyed the majority of the peach crop (Hatch, 2007). In this region, farmers do not have crop insurance or subsidies to help them through hard times.

Just as in the rest of the Rio Casas Grandes region, fewer locals in the Piedras Verdes watershed are sticking to agriculture. As Pepino, an old rancher in the upper Piedras

Verdes, pointed out, less young people are interested in ranching in the upper watershed (Pepino, 2007). The grazing of cattle in the watershed has been severely impacted by drought and low cattle prices. Logging in the Upper Piedras Verdes has been occurring since the 1930s or 1940s. Logging has decreased and reforestation programs are in place for the watershed (Gonzalez, 2007). Officially, no clear cutting is allowed and all loggers must have permits issued by the government, and must conduct environmental studies to demonstrate there will be no unacceptable impact on the environment. Locals note, however, that violation of such rules does often occur.

Political Status

Chihuahua is Mexico's largest state, and has an area of 94,571 sq mi (244,938 sq km). Chihuahua is bordered on the north by the U.S. states of New Mexico and Texas, on the west by Sonora and Sinaloa, on the south by Durango, and on the east by Coahuila. Mexico's government is very centralized. The federal government controls most public financial activities, including taxation, and tax revenues are allocated to the 31 States by the government in Mexico City. The States in turn funnel money to the municipal governments (municipios). The municipios are responsible for most public services in the city. Municipios are run by the municipal president and council.

Mexican Water Law

Water in Mexico is a national asset. As such, it is protected and controlled by the federal government. Decentralization has taken place recently, giving more responsibility and control of distribution to states and municipalities (Miranda, 2003). The Secretaría de Agricultúra y Recursos Hidráulica (SARH) is the department of the executive branch that handles water allocation in Mexico. The Comisión Nacional del Agua (CNA) works with SARH to administer water rights. The Comisión carries out planning, finance, irrigation works infrastructure, urban and industrial infrastructure, research, and water administration. Water can be used by allocation or concession. Allocation occurs when a state is granted the right to use and exploit the national waters. A concession grants a private entity or individual the right to use national waters. CNA may also penalize for abuses of the national waters through fines or closure of water operations. CNA has authority over all aspects of water use and protection. However, a recent change in the Mexican Constitution requires that municipalities be responsible for potable water services, sewage drainage and treatment, and disposal of waste (Miranda, 2003). "Current water policy in Mexico is based on three general aims: 1) to build the necessary infrastructure to reduce existing gaps and meet increasing demands; 2) to increase water efficiency use; and 3) to reduce water pollution through abatement and control" (Tanski et al, 112).

Research methods

Physical data

Rapid assessment

A rapid riparian assessment is a field monitoring technique for evaluating the health of riparian ecosystems and water quality. The rapid riparian assessment preformed on the Rio Piedras Verdes consisted of three primary components: a stream flow estimate; a macro-invertebrate inventory; and a multiple-parameter physical and vegetation stream channel survey.

Watershed Watch riparian survey

The Rio Piedras Verdes was evaluated using the New Mexico Watershed Watch program rapid assessment survey. Twelve parameters were evaluated and rated on a scale of poor (0 to 1), fair (1 to 2), good (2 to 3) and excellent (3 to 4). Values were assigned based on a cooperative group visual survey. The twelve parameters are listed below with a brief description of the importance of each parameter in relation to water quality.

- Riparian vegetation structural diversity: Evaluation of the structural diversity of the riparian system, or the variety of vegetation height classes. The more height classes present in a system, the healthier the riparian ecosystem.
- Bank stability: This parameter considers erosion present along the stream bank, with stable banks indicating a healthy ecosystem.
- Bank cover: The amount of vegetation providing bank cover, or the amount of bare soil present. Greater bank cover indicates a healthier ecosystem.
- Vegetation buffer width: This parameter looks at the width of vegetation present that buffers the riparian zone. The larger the vegetation width present, the healthier the riparian ecosystem.
- Vegetation diversity: The number of plant species present in the riparian zone. More species indicates a healthier ecosystem.
- Embeddedness: Evaluation of the sand, pebbles and gravel within the riverbed. In particular, the fraction of the substrate that is surrounded by sediment. A lower fraction of substrate embeddedness indicates a healthier ecosystem.
- Flow: Evaluation of stream flow present based on elevation. Higher flows indicate a healthier ecosystem. Since the sites evaluated were below 7,000 feet, excellent flow conditions would be present with a flow of 5 cubic feet per second (cfs) or higher.
- Canopy shading the water: The amount of shade and sunlight on the stream due to vegetation canopy cover. Those systems with a combination of mixed sun and shade are healthiest by providing a variety of water temperature gradients and microhabitats.
- Benthic insects: Inventory of benthic macro-invertebrates present in the system. A system that is dominated by mayflies, stoneflies, and caddis flies is considered healthiest as those species are most sensitive to water quality characteristics.
- Width to depth ratio of frequently flooded channel: This parameter looks at the

ratio of width to depth of the bank-full channel (the frequent floodplain). The lower the ratio, the healthier the ecosystem.

- Pools and riffles: The ratio of pools to riffles, which is an indicator of habitat variety. The lower the ratio, the greater the habitat variety.
- Streambed geology: This parameter looks at the types of riverbed substrate, with a higher percentage of boulders, cobbles, and gravel indicating optimal streambed conditions.

Macro-invertebrate inventory

Stream insects and crustaceans were sampled, categorized and counted in the Rio Piedras Verdes as a way to assess stream health and water quality. Samples were collected using seines and they were evaluated and sorted in trays. Using the Save Our Streams evaluation worksheet, macro-invertebrates were classified into three taxa groups based on their tolerance of water pollution. The chart below provides a breakdown of each of the organisms within the three taxa groups.

Taxa Group	Organisms	Water Quality Indicators
Group one	Stonefly, caddisfly, water penny, riffle beetle, mayfly, gilled snail, dobsonfly	Sensitive to pollution, only found in good quality water
Group two	Crayfish, sowbug, scud, alderfly, fishfly larva, damselfly, watersnipe fly larva, crane fly, beetle larva, dragon fly, clam	Some tolerance to pollution, can be found in both good and fair quality water
Group three	Aquatic worm, midge fly larvae, blackfly larvae, leech, pouch snails, other snails	Tolerant to pollution, can be found in any quality of water

Table 1. Taxa Group Organization.

Stream flow

Steam flow was evaluated in the Rio Piedras Verdes at two locations. The first location (upstream) was at the Romney Ranch, where the Watershed Watch survey and macro-invertebrate assessment also took place. The second location (downstream) was just above the diversion dam for the local acequia. The stream was divided into sections at each site using a measuring tape. An average depth was calculated for each section. Using a neutrally buoyant float (a large orange), the velocity was calculated by measuring the time it took for the float to travel a pre-determined distance. This information was then used to calculate flow in units of cubic feet per second (cfs) for the stream. The use of a smaller float proved necessary where the depth was less than the diameter of the original float.

Water quality

Site selection and sampling protocol

Sample locations were determined primarily by the presence of water. Points of interest included surface water both above and below the irrigation diversion structure, in addition to domestic well water. Samples from various sources were taken to analyze the constituents of the water, evaluate its suitability for human consumption, and compare surface and groundwater properties to look at potential source connectivity and watershed topology.

Water samples were collected using a grab method and were filtered on site to remove suspended particles that could potentially influence aquatic chemistry analysis. All samples were filtered using positive pressure (syringe piston). The samples collected for metals analysis were preserved using a dilute nitric acid solution and the pH was verified to be at or near 2. Samples collected for analysis of anions were stored in a cooler containing ice to ensure a temperature colder than 40^0 F was maintained.

In addition, a digital multimeter was used to measure temperature, pH, and electrical conductivity on site. Multiple measurements at the same site over time allowed for the observation of temporal trends including temperature and pH.

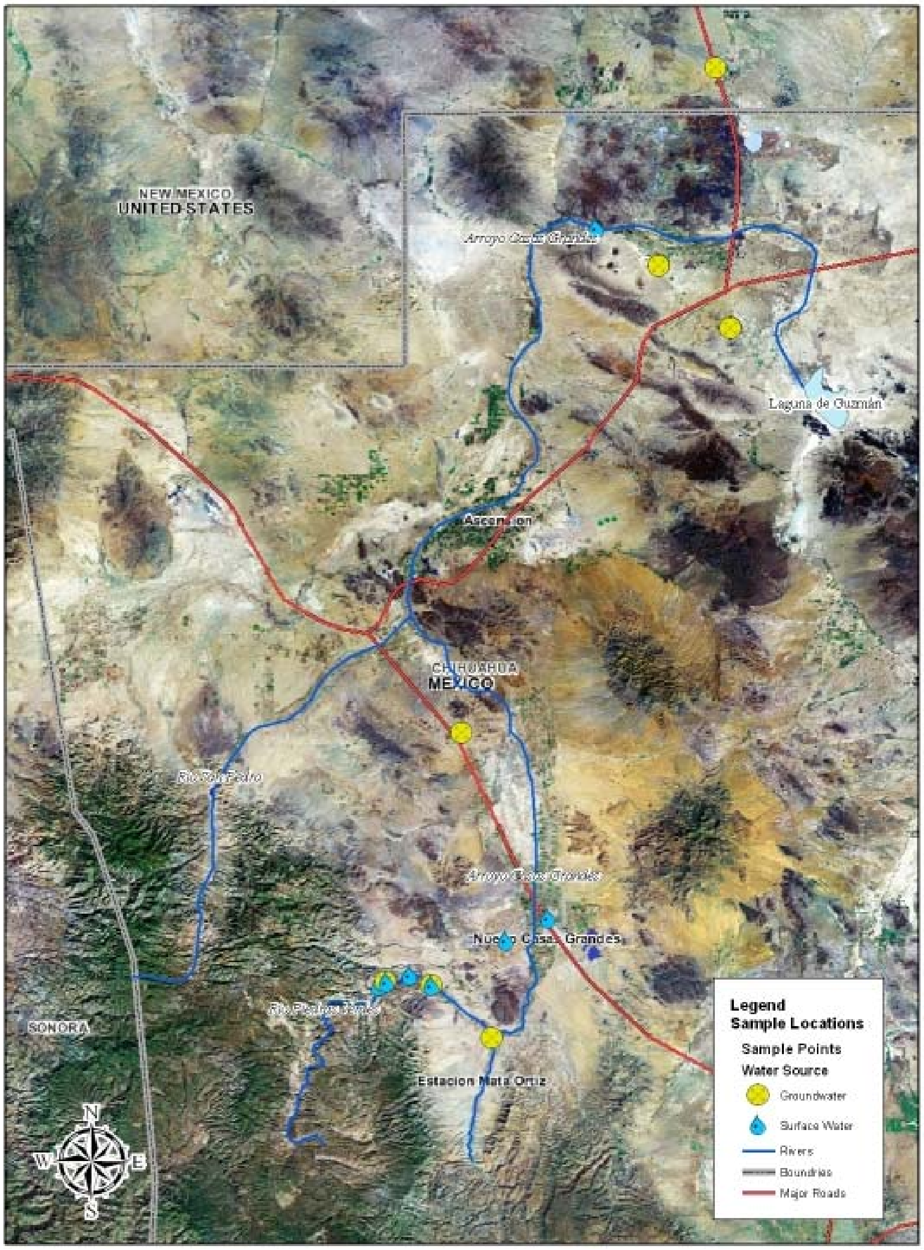

Figure 4. Map of sample locations distinguishing groundwater and surface water sources.

Analytical methods

Water samples were analyzed at the University of New Mexico Water Analytical Laboratory. Samples were analyzed for cation concentration using inductively coupled plasma optical emission spectrometry (ICP-OES). Samples were analyzed for anion concentration using ion chromatography - anion exchange (IC). Alkalinity was evaluated using sulfuric acid titrations with phenolphthalein indicator.

Social and cultural data

Various professionals, academics and farmers from the state of Chihuahua were interviewed. Most meetings were coordinated in advance and were conducted in a casual setting. A list of interviewees, along with a brief background, follows.

Alfredo Granados: Research Professor of Geosciences at the Universidad Autonoma de Ciudad Juarez. He coordinated and led a day of field visits with a number of his graduate students, who discussed regional topics such as groundwater, hydrogeology, and geology in the lower Rio Casas Grandes basin.

John Hatch: Colonia Juarez resident, farmer, and retired teacher. Three generations of his family have lived in Colonia Juarez. He provided a compelling oral history of the area, along with perspectives on contemporary land use trends.

Elmer Hatch: Colonia Juarez resident and restaurant owner; discussed history of the area.

Raul Palacios Perches: President of JMAS (Junta Municipal de Agua y Saneamiento) de Nuevo Casas Grandes; shared information about municipal water management (waste water) and about the goals of JMAS.

Claudia Ruiz: Employee of the Ecology and Urban Development Office; shared information about municipal water use, current conservation education, and how land use planning is integrated with natural resource planning.

Ken Farnsworth: Colonia Juarez resident, farmer and ecology teacher; talked about water quality issues and how to integrate environmental and water resource education and into the school curriculum.

Loretta Farnsworth: Colonia Juarez resident; shared her perspectives on current land use practices.

Pepino: Local rancher; mentioned that youth have lost their interests in ranching.

Mauris Whitten: Local rancher; practices rotational grazing in the upper Rio Casas Grandes watershed and mentions that there has been success with this method. The main challenge he personally sees is the price of cattle have not risen while the price of other commodities have risen.

Don Pedro Gonzales: Employee of the Unidad de Manejo Forestal Babicora; shared information about the forest management practices and regulations in the Rio Casas Grandes watershed.

Mauricio Selgado: Employee of the Paquimé Museum; discussed the Paquimé history, historical uses of water and different methods by which previous civilizations obtained and stored water.

Julia Hernandez: Employee of the Paquimé Museum; described the competing uses of ground water in the region.

Results

Physical data

Rapid assessment

Macro-invertebrate inventory

A macro-invertebrate inventory was performed in the Rio Piedras Verdes. A sample size of 126 specimens was obtained and categorized, representing 11 different organism groups. The majority of the species found were in the group one (pollution sensitive) taxa, indicating that the water in the Rio Peidras Verdes is of high quality and has low levels of pollution. This is due to the fact that organisms in the group one taxa can only survive in good quality waters.

	Total # organisms found	times	Quality points	equals	Total value
Group 1	76	X	3	=	228
Group 2	9	X	2	=	18
Group 3	41	X	1	=	41
Total	126	X		=	287

Table 2. Macro-invertebrate counts.

To calculate a comparison value, the total value for all groups was divided by the total number of organisms found. This assessment shows a value of 2.27 which can then be used as a comparison to future study.

Stream flow

Stream flow was calculated for two sites along the Piedras Verdes river. The upstream site was at the Romney Ranch where a flow of 30.2 cubic feet per second (cfs) was measured. The second site was located just upstream of the diversion dam, and was downstream approximately 4 km from the Romney Ranch. The flow of the second site was determined to be 8.9 cfs.

The reduction of flow between sites 1 and 2 is believed to be due to agricultural diversions along the river and probably ground water infiltration. There are many orchards and other crops between the two sites and most are irrigated with either surface or ground water. Only 30% of the flow found at the upstream site was found at the downstream site, which indicates a reduction of 70% within a 4 km stretch. This is an indicator that water quantity and allocation are both issues in this stretch of river.

Watershed Watch riparian survey

The results from the New Mexico Watershed Watch riparian survey show that the riparian ecosystem is in good condition at the assessment location. The overall score on the survey was 31 value points and the average for all 12 parameters was 2.58 points. The best score possible was 48 points, with the lowest score possible being zero points. This survey therefore rates the Rio Piedras Verdes above average for riparian health. A breakdown of each category can be seen below. Overall, the system had high scores in all parameters except those related to vegetation and riparian bank stability. This is most likely a result of unrestricted grazing along the stream bank.

Parameter	Score	Value
Riparian vegetation structural diversity	Excellent: >3 height classes (grass, shrub, tree) present	3
Bank Stability	Good: some erosion	2.5
Bank cover	Poor: < 40% cover	0.5
Vegetation buffer width	Poor: <20 feet	0.5
Vegetation diversity	Fair: 5 to 14 plant species present	1.5
Embeddedness	Good: 25% to 50% embedded	2
Flow	Excellent: >5 cfs	4
Canopy shading the water	Excellent: mixed sun and shade	4
Benthic insects	Excellent: mayflies, stoneflies, caddisflies dominant	4
Width to depth ratio of bank-full channel	Fair: ratio between 15 and 25, overbank flow	1.5
Pools and riffles	Excellent: ratio <7, high variety of habitats	3.5
Streambed geology	Excellent: >70% boulders, cobbles, gravel	4
Total	**Good**	**31 (average 2.58)**

Table 3. Results of Rapid Riparian Assessment.

In summary, the rapid riparian assessment provides a simple, low-cost method to evaluate the health of the riparian ecosystem. In addition, this evaluation can be repeated at the same location over time to assess changes in the riparian ecosystem. To provide a comparison for future study, calculated scores from Table 3 can be compared from one evaluation to the next.

Water quality

The quantitative portion of this survey assessed regional water quality; preliminary investigations showed that regional water quality is generally high.

Amongst all samples, substantial spatial variation was observed in ion chemistry. Electrical conductivity, which provides a rapid estimate of total dissolved solids concentration, showed an overall decrease with progression upstream in the watershed. Figure 5 demonstrates the variability of anion and cation constituents of the water. The diagram contains both surface and groundwater data.

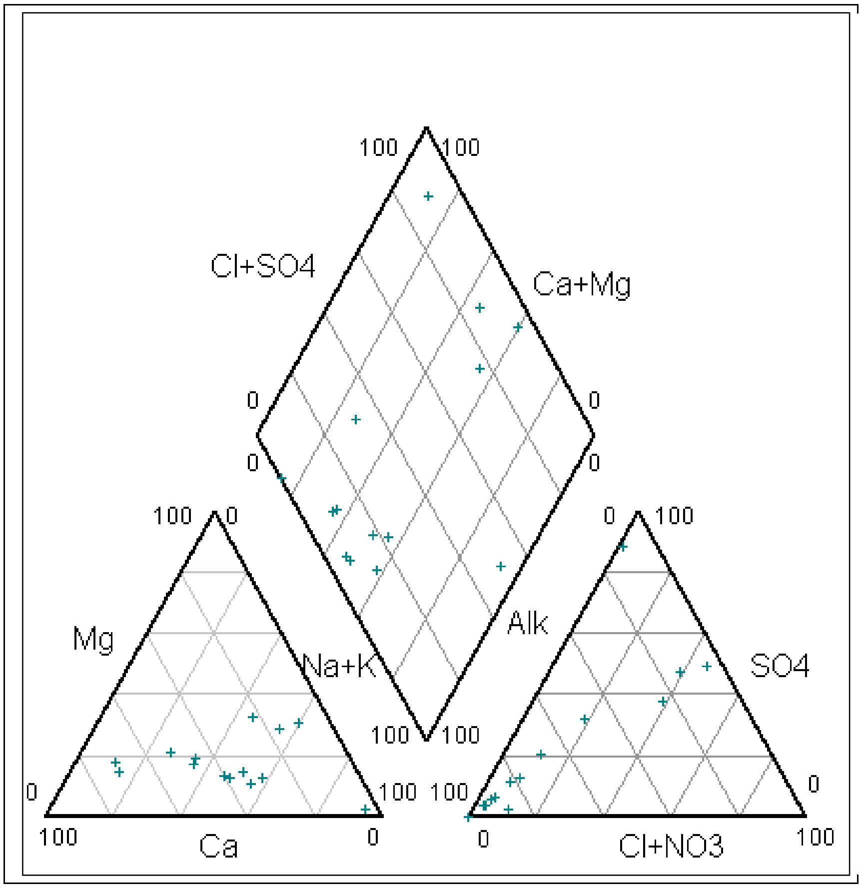

Figure 5. Piper diagram depicting major cations and anions from surface and groundwater samples taken near Casas Grandes, Mexico.

Substantial temporal variation in temperature and pH was observed among the surface water samples collected in this study. Both wind and solar radiation appeared to significantly influence temperature on the upper reaches of the Rio Piedras Verdes, while solar radiation appeared to significantly influence pH. It is believed that the observed increase in pH during the daylight hours followed by a decrease at night was caused by light-dependent, CO_2-consuming photosynthesis during the day followed by $C0_2$-producing respiration at night by photosynthetic organisms including algae and aquatic macrophytes.

Many of the samples did not exceed Mexico's drinking water standards for anions and cations (see Table 5). Notable exceptions were aluminum and fluoride, where many samples exceeded the more stringent Mexican but not U.S. drinking water standards. Figure 6 and Figure 7 demonstrate the high variability of aqueous concentrations of fluoride and aluminum as they relate to Mexico's drinking water standard. It should be noted that surface water along the Rio Casas Grandes is not used for public water supply;

all communities rely upon ground water sources. However, many of the areas from which samples were obtained were rural and lacked access to municipal infrastructure. As such, human consumption of groundwater in these rural areas is likely, therefore comparison of water quality to drinking water standards is relevant.

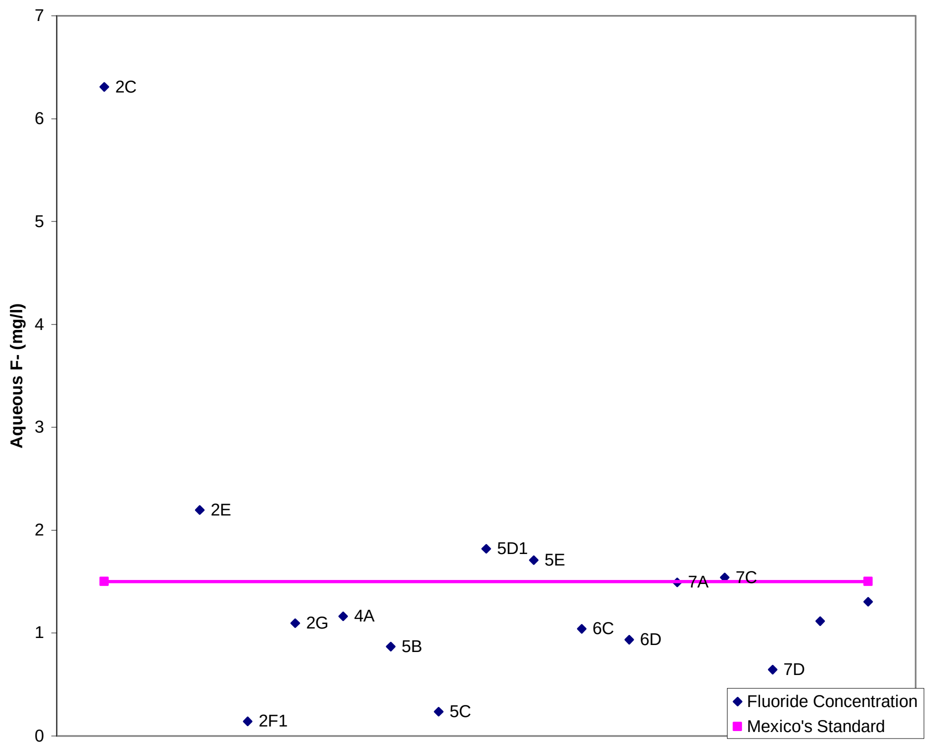

Figure 6. Dissolved fluoride concentration from sample locations plotted against 1994 standards developed by Mexico's Ministry of Health for certifying the quality of drinking water.

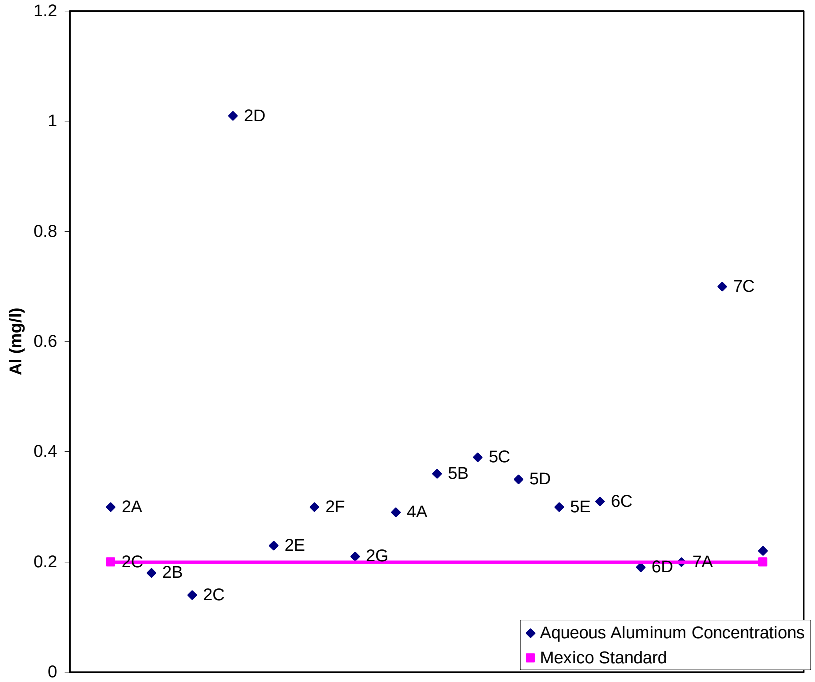

Figure 7. Dissolved aluminum concentrations from sample locations plotted against 1994 standards developed by Mexico's Ministry of Health for certifying the quality of drinking water.

Measurement of organic or microbial constituents in water samples were not conducted due to the inability to process the samples within prescribed holding times. In addition, sampling locations were not representative of the region at large. Thus, the water analysis presented here is superficial both in detail and geographical scope. Nevertheless, these results provide a preliminary assessment of the general water quality characteristics of surface and ground water resources within the watershed.

Discussion

Challenges and Constraints

Scarcity of Water

This assessment of water resources in the Rio Casas Grandes watershed was not sufficient to determine quantitative water uses within the region. However, through discussions with stakeholders and evaluation of water quality in the region, issues of water quantity appear to be the major issue in the watershed.

Decreasing water tables, over use of surface and ground water resources, limited enforcement of management regulations, and a lack of information are all challenges facing water managers in the Rio Casas Grandes watershed. Near Guadalupe Victoria, Chihuahua, the upper unconfined aquifer is nearly exhausted and has a drawdown rate estimated at 1.25 meters per year (Granados, 2007). In many other areas, particularly in heavily-irrigated lowlands, well owners have observed decreasing water levels, although there are no public record of these declines available. In the Nuevo Casas Grandes region, for example, it is estimated that the water level in the aquifer has dropped 15 meters in the last 17 years (Pelacios, 2007), but publicly available data are lacking.

Interviews with regional stakeholders suggest that groundwater in most of the Rio Casas Grandes watershed is heavily over used. Although the groundwater basins in most of the watershed are closed and allow for no new well permits or drilling, interviews indicate that new wells continue to be drilled. In the Guadalupe Victoria region, by some estimates, only one out of every four wells is properly permitted. It is widely acknowledged that non-permitted drilling is occurring in many of the groundwater basins throughout Chihuahua (Granados, 2007; Pelacios, 2007; Hebard, 2007; and Tanski et al, 2003). Measurement of current water use, enforcement of regulations on new well installations and limits on water use is crucial to sound water management, including the maintenance of regional ecosystems and the water-dependant agriculture industry.

Regional stakeholders cite water conservation as a recently emerging awareness by water users in the region. The Ecological and Urban Development Office is working toward conservation education and increased water use efficiency (Ruiz, 2007). Increased efficiency of agricultural water use is particularly critical to effective water resource management in the region. By some estimates, 90% of all water consumption in the region is used for irrigation (Tanski et al, 2003). The Mexican Government has begun to help farmers switch to more efficient irrigation systems. However, many farmers have been unable to switch due to the large capital investment needed, since government programs only provide reimbursements to farmers after they have invested in new infrastructure (Pelacios, 2007).

Accounting for Water Supply and Demand

On the demand side, stakeholders indicate that accounting of groundwater withdrawals has greatly improved in recent years through government metering of groundwater wells. In addition, municipal use appears to be well-characterized. However, information on diversion and consumption of surface water is much more limited.

On the supply side, regional information on ground and surface water resources is largely unknown. Such surveys of existing water resources are expensive and require many years of record to be of much value. Partnerships between government and regional agricultural interests to monitor groundwater wells might provide a cost-effective groundwater record. In addition, partnerships between government and regional schools to monitor low-cost staff gages in key river tributaries might provide a cost-effective surface water record. Finally, partnerships with U.S. schools and government agencies might provide technical assistance and expertise to facilitate the cost-effective organization and distribution of complex regional water resource data sets.

The lack of information of the available water resources also proves to be a big challenge for water managers and farmers alike in the Rio Casas Grandes watershed. More research needs to be carried out on the availability of surface water and groundwater resources of the watershed in order to effectively manage these resources (Granados, 2007; Tanski et al, 2003). "When funds are available, little is devoted to research" (Tanski et al, 108). It is very difficult for water managers and CNA to make decisions concerning the water resources in an area when little is known about the quantity, quality, and surface-subsurface interaction of the waters. Likewise, if information is not shared with the public, water management and conservation becomes more difficult.

Many water managers in Chihuahua expressed the importance of the "cultura de agua" (Ruiz, 2007; Pelacios, 2007). The "cultura de agua" is the holistic approach to water and its value. One way authorities are hoping to implement this concept is through youth education and water festivals. Also, if farmers do not trust the federal agencies because information is not made available to them, the federal agencies will have a more difficult time making changes within the management regime.

Socioeconomic Constraints

Two primary socioeconomic constraints observed in the Rio Casas Grandes watershed were a lack of access to capital and a rapidly increasing population. Taken together, these constraints seem to inhibit strong local watershed management. The lack of access to capital for infrastructure and education, for example, appear to hinder the production and development of effective water management standards. The UACJ group noted that a number of valuable research projects exist, but lack full or timely funding.

The rapid increase in the region's population adds to the challenge of water management by causing commensurate increases in the demand of water for domestic, agriculture, and industrial uses. Whether current water resources will support future economic expansion remains to be seen.

Populations are increasing throughout the world and many regions are facing imminent water shortages. Many of the challenges and constraints faced by the Rio Casas Grandes watershed exist in other regions, including Albuquerque, New Mexico. Collaborations between business, government, and education in both regions could potentially lead to increased knowledge about the water resources and sound management options for all.

Compare and Contrast of Management Strategies

Regulatory Framework

In both Chihuahua and New Mexico there are many more agencies involved in the various aspects of water management than are shown in Table 4. However, this table provides an overview of the management regimes the two regions. Most of the regulatory agencies in Chihuahua are Mexican federal agencies, while in New Mexico there are a number of state agencies in addition to U.S. federal agencies. CNA has been going through a process of decentralization and has created a number of state-based CNAs and Consejos de Cuencas (watershed advisory councils); these agencies still report to the main federal CNA agency.

Description	Chihuahua	New Mexico
Water Ownership	Federal	Private, State & some Federal
Obtain a Right	Allocation or concession from Federal government – *federal*	First to use the water has priority, permitting from State government -*state*
Regulating Agency	CNA (Comisión Nacional del Aguas) –*federal*	OSE (Office of the State Engineer) -*state*
Irrigation Infrastructure	SARH (Secretaría de Agricultúra y Recursos Hidráulica) –*federal*	BoR (Bureau of Reclamation) -*federal*
Environment	SEMARNAT (Secretaría de Medio Ambiente y Recursos Naturales) -*federal*	EPA (Environmental Protection Agency) -*federal*, NMED (New Mexico Environment Department) -*state*
Municipalities	JMAS (Juntas Municipal Agua y Saneamiento) -*federal*, Municipality -*local*	Municipal Water Utility -*local*
Groundwater	COTAS (Comités Técnico de Agua Subterráneas) –*federal*	OSE (Office of the State Engineer) -*state*

Table 4. Comparison of the regulatory framework for water management in

Chihuahua and New Mexico.

Water Quality Standards

Table 5 compares the water quality standards between the U.S., New Mexico and Mexico. While variations exist, the differences are relatively minor. Access to safe drinking water for all residents remains a critical goal for the regions in question. Understanding the standards that are applied to the regions in question is necessary to reaching this goal of drinking water access, in addition to the watershed assessment at large.

Contaminant	SDWA MCL	NMED GW Std	1994 Mexico Standards
Inorganics			
Al	NS	5	0.2
Sb	0.006	NS	NS
As	0.01	0.1	0.5
Ba	2	1	0.07
Be	0.004	NS	NS
Cd	0.005	0.01	0.005
Cr	0.1	0.05	0.05
Cl	250	250	250
Co	NS	0.05	NS
Cu	1.3	1	2
CN	0.2	0.2	0.07
F	4	1.6	1.5
Fe	0.3	1	0.3
Pb	0.015	0.05	0.025
Mn	0.05	0.2	0.15
Mo	NS	1	NS
Hg	0.002	0.002	0.001
Ni	NS	0.2	NS
NO3-	10	10	10
NO2-	1	NS	0.05
Se	0.05	0.05	0.05
Ag	NS	0.005	NS
SO42-	250	600	400
TDS	500	1000	1000
U	0.02	0.03	NS
Zn	5	10	5
Asbestos (fiber < 10 um)	7e6	0	
pH	6.5-8.5	6-9	6.9-8.5

Table 5. Comparing United States' Safe Drinking Water Act Standards (SDWA MCLs) to standards established by the New Mexico Environment Department Ground Water (NMED GW) standards, and potable water standards established by Mexico's Secretary of Health.

Conclusion

The main objectives of this assessment were to:

- identify the water resource challenges facing the in the greater Rio Casas Grandes watershed at large,
- identify historical uses of water,
- identify political and cultural constraints for water managers,
- identify quantitative information needs faced by water management,
- asssess the water quality of the watershed,
- and to compare and contrast the water management practices of the Rio Casas Grandes watershed with those of New Mexico.

A rapid riparian stream assessment and water quality samples were taken to create a baseline assessment of an upstream tributary of the Rio Casas Grandes. The rapid riparian stream assessment determined that the upstream tributary, the Rio Piedras Verdes above Colonia Juarez, hosted a healthy ecosystem. The water quality was generally found to be high throughout the region.

Through interviews and literature research, we identified several challenges and constraints to water management in the Greater Rio Casas Grandes watershed. Some of the challenges and constraints included decreasing water tables, over-allocation of resources, limited oversight of water regulations, lack of water resource information, lack of access to capital, and urban population growth. Consequently, additional watershed assessments are needed in the Greater Rio Casas Grandes watershed to monitor changes over time in order to identify areas of concern and to assist resource managers equitably allocate scarce water resources. Implementing watershed assessment programs in other parts of Chihuahua would prove useful as a starting point to formulate a larger picture of the water resources in the region.

Overall, we discovered that the challenges faced by Chihuahua in managing its water resources are similar to the challenges in New Mexico. Both regions now contend with increasing populations and the consequent struggles to provide adequate water supplies to their residents. Both regions struggle to balance competing land uses and water demands in a water-scarce region. Both states can benefit from increased collaboration between water professionals, stakeholders, and academic water experts from Chihuahua and New Mexico to identify optimal water resource management strategies in the region. Establishing an official partnership between the Water Resources Program at UNM and the Universidad Autonoma de Ciudad Juarez could serve as a starting point for innovative, collaborative water resource studies and management in New Mexico and Chihuahua.

References

Bennion, J. 2004. *Desert Patriarchy, Mormon and Mennonite Communities in the Chihuahua Valley*. University of Arizona Press. Tucson, Arizona.

Chihuahuan Desert Research Institute, The Chihuahuan Desert Region, http://www.cdri.org/Desert/index.html, accessed June 2007.

Diego A. Cordoba, Sherman A. Wengerd, John Shomaker. 1969. Guidebook of the Border region / New Mexico Geological Society, Twentieth Field Conference, October 23, 24, and 25.

Di Peso, Charles. 1972. Casas Grandes and the Grand Chichimeca, Reprinted from El Palacio Vol 75, No. 4. Museum of New Mexico, Albuquerque, New Mexico.

Fleming, J.P., 1987. An Adobe Maze for Modern Explorers, New York Times, February 22, 1987.

Gonzalez, Don Pedro. 2007. Personal Contact/Interview.

Granados Olivas, Alfredo. 2007. Personal Contact/Interview.

Hatch, N. 1954. *Colonia Juarez.* Deseret Book Company. Salt Lake City, Utah.

Hebard, Elaine. 2007. Personal Contact/Interview.

Instituto Nacional de Estadistica Geografia e Informatica (INEGI). 2005. Population Data. *Available at* http://www.inegi.gob.mx/est/contenidos/espanol/sistemas/conteo2005/localidad/iter/. *Accessed on* 13 June 2007.

Liu, Z. Li, Q. Sun, H. Liao, C. Li, H. Wang, J. Wu, K. 2006. Diurnal Variations of Hydrochemistry in a Travertine-depositing Stream at Baishuitai, Yunnan, SW China.

AQUATIC GEOCHEMISTRY, Bibliographic details 2006, VOL 12; NUMBER 2, pages 103-121.

Mexico Ministry of Health. 1996. NORMA Oficial Mexicana NOM-127-SSA1-1994, Salud ambiental, agua para uso y consumo humano-Límites permisibles de calidad y tratamientos a que debe someterse el agua para su potabilización. Available at: http://www.salud.gob.mx/. Accessed on 6/13/07.

Miranda, Carlos Ramos. 2003. "Legal Issues in the Regulation of Water Supply in Mexico." *U.S.-Mexico Law Journal*. Vol.11, pg 75.

Palacios Perches, Raul. 2007. Personal Contact/Interview.

Pepino. 2007. Personal Contact/Interview.

Ruiz Ortiz, Claudia Elena. 2007. Personal Contact/Interview.

Scurlock, Dan, 1992. High Desert Land and its Peoples: A Guidebook to the Eco-Cultural History and Archeology of the Casas Grandes Area, Chihuahua Mexico. UNM Press Albuquerque, Albuquerque, New Mexico.

Tanski, Janet M., Adrian T. Hansen, Alfredo Granados Olivas, Mauricio Mercado Perez, Hebard, Elaine, Samani, Zohrab. Water Quality on the U.S.-Mexico Border: An Assessment of the Mimbres Basin Aquifer and the Region Surrounding Columbus, New Mexico, USA and Puerto Palomas, Chihuahua, Mexico. Southwest Consortium for Environmental Research and Policy, Final Report, SCERP Project No. PP96II-19. *Available at* http://www.scerp.org/projects/Tanski.pdf. *Accessed on* 13 June 2007.

U.S. E.P.A. 2007. Drinking Water Standards. Available at: http://www.epa.gov/safewater/standards.html. Accessed on: 6/13/07.