Collaborative Modeling to Evaluate Water Management Scenarios in the Rio Grande Basin

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Abstract:

This paper describes the collaborative modeling process and the resulting water resources planning model developed to evaluate water management scenarios in the transboundary Rio Grande basin. The Rio Grande located in North America is a severely water stressed basin and faces numerous management challenges as it crosses numerous jurisdictional boundaries. A collaborative process was undertaken to identify and model water management scenarios to improve water supply for stakeholders, the environment and international obligations of water delivery from Mexico to the U.S. A transparent and open process of data collection, model building and scenario development through stakeholder input was completed by a project committee was comprised of university, non-governmental and governmental experts in both countries. The governmental agencies involved provided technical guidance and had no capacity to make legal water decisions in either country. The outcome of the process was a planning model described in this paper, with data and operations that were agreed on by water planning

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officials in each country. Water management scenarios were created from stakeholder input and were modeled and evaluated for effectiveness with the planning model.

Keywords: Collaborative Modeling, Sustainability, Rio Grande, Scenarios

Introduction

Efficient water management requires collaboration among authorities and stakeholders to achieve common goals with regards to often limited water resources. Usually, the existing water management in a basin is tested against alternative management scenarios to evaluate if the current management meets the goals specified or if are alternative policies that might improve the water availability for stakeholders, environmental and system requirements. A clear and transparent water planning process for creating and testing these management scenarios is necessary to ensure the participation of stakeholders and policy makers. The *Shared Vision* technique provides a framework for the water planning process through the incorporation of traditional methodologies, organized public participation, and the use of collaborative modeling in the creation of an integrated decision support tool (Cardwell et al. 2008). *Collaborative modeling* involves the participation of stakeholders in all parts of the modeling process; this approach is useful to ensure cooperation, transparency, credibility and understanding of the basin and the problems to be addressed (Cardwell and Langsdale 2011).

Collaborative modeling in a large-scale transboundary basin can be more difficult due to the size of the basin and the numerous jurisdictional boundaries that the river crosses. The Rio Grande, located in North America, is considered one of the most water stressed basin in the world (WWF 2007), increasing population and prolonged droughts are placing additional strain on an already stressed basin. The Rio Grande basin comprises an area of 557,722 km^2 and forms 2,034 km of the border between the United States (US) and Mexico (Figure 1) (Patino-Gomez et al. 2007). Each country has further jurisdictional divisions into states; in the US, the river flows through Colorado, New Mexico and Texas, while in Mexico, the basin extends through the states of Chihuahua, Durango, Coahuila, Nuevo Leon and Tamaulipas. The objective of this paper is to describe the collaborative modeling process used to (1) construct a water resources planning model that considers the Rio Grande Basin as a whole entity from El Paso, Texas to the Gulf of Mexico and (2) evaluate scenarios that may help to improve the water management in the basin.

A water planning model for the Rio Grande was created as part of a multidisciplinary, bi-national effort to evaluate alternative scenarios for improving water management in the basin. The collaborative project, named the *Physical Assessment Project* (PAP), was carried out by scientists, academics and professionals from both countries; a steering committee was formed in 2002 comprised of governmental research institutions, non-governmental agencies, and universities from the US and Mexico (PAP 2005a). The first part of this document describes the background of the PAP and the collaborative process used in this project.

A brief introduction to the collaborative modeling process is presented here and then described in more detail in the remainder of the paper. An initial set of 33 scenarios were defined through an extensive interview process with stakeholders, authorities and project partners; these are strategies that interviewees were willing to implement themselves. Twelve scenarios were tested in the Rio Grande planning model to quantify the benefits and drawbacks that each scenario provides to stakeholders, environmental and system requirements; each scenario was compared to a baseline scenario that is a no-action or business as usual scenario. Results from this first round of scenario modeling were presented again to stakeholders for their feedback. Based on these interactions and results, seven winning scenarios, called meta-scenarios, were defined and evaluated. The meta-scenarios are combinations of individual scenarios aimed at providing benefits to the whole system without diminishing the current benefits of any user. A second round of stakeholder consultations took place to report the results of the meta-scenarios. Furthermore, a methodology was developed to systematically evaluate the performance of each scenario for individual water users, groups of water users, regions, and for the whole Rio Grande Basin. This paper describes the construction of the Rio Grande planning model, the scenarios evaluated and the methodology developed for the analysis of results.

Background

The Rio Grande is the fifth longest river in North America flowing 2,892 km from its headwaters in the San Juan Mountains of southern Colorado to the Gulf of Mexico. In 2010, the estimated population is 10.5 million people, 17% in the US and 83% in Mexico. Currently, municipal demands account for only 14% of the total water demands in the basin, while irrigation accounts for 86%. Mexico irrigates approximately 366,000 hectare (ha) (CONAGUA 2010), while the US irrigates about 402,000 ha of which about 40,000 ha lie upstream from Texas in New Mexico and Colorado. The drought of the 1990's (1994-2007) made evident the water management problems in the basin: (a) over allocation of water rights, more water is withdrawn than the water naturally produced in the basin (CONAGUA 2008a, Sandoval-Solis and McKinney 2011), (b) low water use efficiencies (IBWC 2003), (c) uncoordinated water management between agencies and countries (IBWC 2001 and 2002), and (d) nonexistent policies to supply water to the environment; i.e., in February 2001 the river mouth was blocked by a sand bar caused by low flow conditions, it remained closed until September 2001 when the IBWC (International Boundary and Water Commission) dredged it open (Blankinship 2005).

In 2002, the *Physical Assessment Project* (PAP) was launched as an umbrella project to provide answers to the problems described above, three main tasks were undertaken: (1) constructing an integrated geo-referenced database, (2) building a water resources planning model to test water management scenarios, and (3) defining these scenarios through consultation with stakeholders and authorities (PAP 2002). The first years of the PAP (2002-2006) were focused in the construction of a bi-national Hydrologic Information System (HIS) (Patiño-Gomez and McKinney 2005, Patiño-Gomez et al. 2007). In 2005 the framework of the planning model was defined for the purpose of analyzing scenarios to improve the water management of the basin (PAP 2005b). Subsequently, the PAP was devoted to examining alternative strategies to improve the water management in the basin, within the existing laws and treaties (PAP 2005a). The PAP adopted a whole-basin planning approach for the project, i.e., a holistic bottom-up approach to propose solutions and include stakeholders in the process.

The PAP was implemented by scientists, academics and professionals from both the U.S. and Mexico; the steering committee was comprised of eight institutions, four from each country: two non-governmental organizations (NGOs), the National Heritage Institute (US) and World Wildlife Foundation (Mexico); 2 government research agencies, the US Geological Survey (US) and the Instituto Mexicano de Tecnología del Agua (Mexico); and 4 universities, the University of Texas at Austin (US), University of Arizona (US), Instituto Tecnológico de Estudios Superiores de Monterrey (Mexico) and Universidad Autónoma de Ciudad Juarez (Mexico). The government agencies involved in the PAP do not have the ability to make decisions related to water allocation, laws or treaties; however, they provide technical expertise and support during the planning process. Sadoff and Grey (2005) suggest that cooperation on international rivers must be completed without any agencies that have the authority or mandate to impose water management solutions.

Collaborative Modeling Process

A water resources planning model for the Rio Grande Basin was created through a collaborative modeling process; this approach considered the active participation of stakeholders and government officials of both countries. The participatory process was aimed at providing confidence and transparency to stakeholders and decision makers regarding the planning model; it also helped to integrate ideas and concerns during the decision making process by including the best available science and technology. The collaborative process began with data collection and continued through the model selection and building, scenario development and outreach phases. Each step in this process is described in this section.

Bi-national Hydrologic Information System for the Rio Grande

As part of the collaborative process, it was important that the people involved in the decision-making process had access to and were aware of the data available. Because of this, a Hydrologic Information System (HIS) was built for the Rio Grande to compile all the data available regarding hydrology, climatology, water quality and infrastructure in the basin (Patiño-Gomez and McKinney 2005, Patiño-Gomez et al. 2007). The geo-referenced database was used as the main source of information during the model construction and post-processing of results. The database uses a standard Arc Hydro data model to organize data according to the “basin” principle (Maidment 2002). The geodatabase was the first step in establishing the necessary understanding of the basin as a whole, spatial and temporal information was provided by water authorities, government organizations, NGO’s and project partners from the U.S. and Mexico.

Basin Scale Planning Model

A water resources planning model was built to evaluate water management scenarios; the *Rio Grande WEAP model* simulates the water allocation system, division of water between the US and Mexico, infrastructure, surface water and groundwater resources of both countries (Figure 2). For the Rio Grande, several planning models have been built for different purposes including: dispute resolution (Tate 2002), water availability (Brandes Co. 2004) and drought management (Vigestol 2002). For the Rio Conchos sub-basin, main tributary of the Rio Grande, planning models have been built for water management (Stewart et al. 2004, Gastelum et al. 2009), drought management (Gastelum 2006), rainfall-runoff response (Gomez-Martinez et al. 2005) and to assess the impact of climate change in the water management (Ingol-Blanco 2011). The Rio Grande WEAP model was used to aid in dispute resolution, policy and decision making, as were the OASIS (Tate 2002) and Stella (Vigerstol 2002) models, for the whole Rio Grande Basin and not just the Rio Conchos, e.g., Gastelum (2006), with two main differences: (1) the modeling involved the participation of stakeholders during model construction, and (2) it was based on extensive calibration and validation.

In 2005, during a bi-national Rio Grande water summit, the Water Evaluation and Planning model (WEAP) software platform was chosen to simulate the water allocation system for the whole basin (McKinney and Purkey 2005); it was selected from among other platforms such as OASIS (Tate 2002), Stella (Vigerstol 2002), because it is user-friendly, has flexible modeling capabilities to characterize the Rio Grande basin and is free to developing countries. The scripting language in WEAP allows the representation of important institutional characteristics such as the division of water according to the Treaty of 1944, the water allocation system in Texas and in

Mexico according to their respective regulations, among other important features. Yates et al. (2005a and b) provide detailed descriptions of the WEAP platform.

A series of training sessions were carried out for PAP partners and interested stakeholders to introduce the functioning and operation of the model. These training sessions were carried out along the basin: (1) at Ciudad Juarez in 2005 with materials including a tutorial for model construction in English and Spanish for the Rio Conchos Basin (Nicolau del Roure and McKinney 2005); (2) at Cuernavaca in 2009 with a reservoir operation tutorial; and (3) at Mexico City in 2009 with a tutorial for water quality modeling below Falcon reservoir was incorporated (Ingol-Blanco and McKinney 2009). These tutorials were aimed at promoting the acceptance and use of the planning model.

Several workshops presenting the model were held for two main reasons; first, to explain the operation and algorithms used to represent the water allocation system of the basin; and second, to receive feedback from stakeholders and authorities regarding the basin representation, input data, system operation and undocumented empirical rules used to allocate water. Workshops represented an important public venue to learn and incorporate into the model the operation of the system, to show transparency regarding input data and the assumptions embedded in the model, and to prove the adequacy of the model. A total of six workshops were held: (1) at Cd. Juarez and Cuernavaca in 2006; (2) at Cuernavaca, Mexico City, Monterrey and El Paso Texas in 2009; and (3) at Riverside California in 2010.

Since 2006, the Rio Grande WEAP model has been subject to extensive calibration, validation, sensitivity analysis and testing. Usually, these examinations were carried out in the workshops mentioned above or during meetings with key system operators, academics or stakeholders that know how the system operates so they can ask penetrating questions and challenge assumptions and data. For instance, in one meeting, every Mexican water right was verified, one by one, to be adequately uploaded and discretized into the model. A total of 4,405 Mexican water rights were verified this meeting; this shows the level of scrutiny that the model has been subjected to. Computed reservoir storage and streamflows were compared against historical records to demonstrate that the model adequately represents the system. Goodness-of-fit coefficients, such as the Nash-Sutcliffe Coefficient of Efficiency and Index of Agreement (Legates and McCabe 1999), were used to quantify how well the model represents the historic basic operation. These meetings have helped the project gain credibility with stakeholders, government institutions and the scientific community.

One important tool used in the PAP process was the establishment of an FTP website. This website was used as the main mechanism to share information and documents among project partners and stakeholders, the tool ensured the transparency and accessibility to data and information by over 50 participants. Tutorials, reports, related project documents, the Rio Grande HIS and updates of the Rio Grande WEAP model were made available through this portal hosted by the University of Texas at Austin.

Scenarios and Outreach

In 2002, during a workshop to design the HIS for the Rio Grande, ideas for scenarios were discussed by the project partners and the workshop participants (PAP 2002). After this workshop, several meetings and field trips were held to identify the challenges and possible solutions for Rio Grande water management problems. In addition, the development of the HIS provided knowledge regarding the available knowledge upon which to build the planning model. In 2006, 33 scenarios were defined based on consultations with project partners, authorities, stakeholders and NGOs in the basin. Based n this, 12 scenarios were analyzed using the planning model (Sandoval-Solis et al. 2008). In 2009 seven “winning” scenarios, called meta-scenarios, were defined based on the results of the first round of scenario modeling (PAP 2009). These meta-scenarios represent short and long term policies that might help to improve the water management for stakeholders, environmental requirements and treaty obligations.

The results of the scenario modeling were presented to several stakeholder groups and water authorities are described. In June 2009, results were presented to the International Boundary and Water Commission (IBWC) in Ciudad Juarez, Mexico; the US and Mexican IBWC commissioners attended this meeting where the planning model and the results of scenarios were discussed. In August 2009, results were presented to the Rio Bravo Basin Council in Monterrey, Mexico. This organization defines the water management policies for the Rio Grande on the Mexican side. In October 2009, results were presented to the Texas Commission on Environmental Quality (TCEQ); the Commission Chair and staff were briefed regarding the results of the scenarios analyzed. Also, results of scenarios that improve the delivery of environmental flows were presented to several NGOs, including the World Wildlife Fund, Profauna, The Nature Conservancy, Environmental Defense, among other institutions. Several meetings were organized to present the model and results to stakeholders from both countries.

Rio Grande Planning Model

One of the outcomes of the collaborative model process was the basin-wide water resources planning model. The *Rio Grande WEAP model* is a water planning model that calculates the balance between inflows, change of reservoir and aquifer storage and evaporation losses in reservoirs, delivery to water demands, return flows, and flows to the Rio Grande all the way from

Elephant Butte reservoir in New Mexico to the Gulf of Mexico; it is a monthly time-step model that replicates a 60-year period of hydrologic conditions from October 1940 to September 2000 (Figure 2). The model considers the main tributaries of the Rio Grande in both the U.S. and Mexico. Table 1 shows a summary of the water demands considered in the model. Stakeholders, government agencies and NGOs provided the input data for calculating the naturalized (undeveloped) flows; capacities, storage-elevation curves and evaporation losses in reservoirs; and streamflow data through the HIS built for the Rio Grande (Patiño-Gomez et al. 2007, CONAGUA 2008a, Brandes Co. 2004). Extensive details of the model are contained in Danner et al. (2006).

The Rio Grande WEAP model simulates the complex water allocation system of the basin; stakeholders and water authorities provided their knowledge, experience, documentation and empirical rules to set the operational *logic* that governs the water allocation in the model. Several sets of rules were programed in the model in order to define the allocation system, priorities and constraints associated with each particular regulation. Four main rule sets were included in the model: (1) Texas Watermaster Rules to allocate water in the US; (2) Mexican CONAGUA rules to allocate water in Mexico; (3) the 1944 U.S.-Mexico Treaty rules for dividing the water between the U.S. and Mexico; and (3) the rules to account for the water stored for each country in the international Amistad and Falcon reservoirs.

A hydrologic break in the Rio Grande occurs between El Paso and Fort Quitman, Texas where there is often little or no water in that reach (Teasley and McKinney, 2005). This hydrologic break creates a disconnect where water management decisions made upstream from Elephant Butte to El Paso/Ciudad Juarez have little effect on the river downstream of the confluence with the Rio Conchos. The convention of 1906 and the Rio Grande Compact regulate the water allocation upstream of Fort Quitman (IBWC 1906, TCEQ 1938). Below Fort Quitman, in Texas water is allocated using the prior appropriation rule from Fort Quitman to Amistad and based on the water use and the type of water right from Amistad to the Gulf (TCEQ 2006). In Mexico, water is allocated according to its permitted water users (CONAGUA 2008b CONAGUA 2008b). All the water that reaches the Rio Grande and the gains along the mainstream are allocated to each country according to the Treaty of 1944 (IBWC 1944). All these allocation rules were programmed in the model, as more conversations and interaction with stakeholders took place, the model was improved to better represent water allocation logic in the basin.

Naturalized flows (also called unimpaired or undeveloped flows) are the main input to the Rio Grande planning model, they represent the streamflows that hypothetically would have occurred in the river in the absence of human activities. Before 2008, naturalized flow data were available only from US derived data sources (Brandes Co. 2004), results presented to Mexican authorities using US data were not always fully acknowledged. In 2008 Mexican water authorities published a set of naturalized flows for rivers in Mexican territory and along the Rio Grande (CONAGUA 2008a). These data were annual flows, while the Rio Grande model needs monthly flows. Two actions were taken to prove the credibility of the Rio Grande planning model and its results. First, both sets of naturalized flows were analyzed to determine if they are statistically similar or different using a Wilcoxon rank sum statistical test. The results showed that in 21 out 27 (78%) control points along the river the time series are similar; this analysis was documented, a memorandum was sent to stakeholders and authorities showing the comparison of both data sets (Sandoval-Solis et al. 2010); however, the results from the model were still not fully acknowledged. Second, the annual time series of the Mexican naturalized flows were disaggregated using the monthly distribution from the U.S. naturalized flows, and this hybrid monthly time series was used in the model for rivers originating in Mexico. Results from the model did not change significantly, verifying that both series are similar; nevertheless, Mexican authorities were more comfortable knowing that their information was being used in the model. This provided a lot of credibility to the collaborative modeling process, showing the willingness of the parties to collaborate and overcome technical obstacles, as well as demonstrating the robustness of the model.

During this collaborative modeling process, one of the breakthroughs happened when the model was calibrated. In the US, historic data for water supplies and diversions from reservoirs is public (IBWC 2012); however, in Mexico these data were not public until 2008, when the water availability study was published by Mexican water authorities (CONAGUA 2008a). A *Historic* scenario was built using these historic data in order to compare the model results with the historical records of streamflow, water deliveries and reservoir storages. The US and Mexican storage accounts in the international reservoirs (Amistad and Falcon) are good indicators of model performance (Figure 3); due to their location in the middle of the basin, inaccurate representation of the water management upstream or downstream is immediately evident in a mismatch between model results and historic records. In fact, the good performance of the model, demonstrated in the Historic scenario, is the result of a close engagement with stakeholders and authorities since the beginning of the project to understand the details of water management in the basin. To ensure that the modeling process remained transparent, documentation was created for the model and the testing process (Danner *et al*., 2006).

Scenarios for the Rio Grande

The scenarios analyzed in the PAP are the result of a series of consultations regarding challenges and opportunities to improve the water management in the Rio Grande. In 2002, the

PAP outlined the idea to build a planning model and explore scenarios (PAP 2002). The scenarios' purpose was to freely explore alternative strategies to improve the water management within the context of the existing legal arrangements, e.g., the 1944 Treaty and the Texas Water Master Rules, and to determine which of them were physically feasible. After this, an economic, legal and institutional analysis would be carried out for those scenarios that were deemed to be physically feasible. In 2006, a list of 33 scenarios was defined based on consultations with stakeholders, authorities, stakeholders and NGOs in the basin.

Before starting to evaluate alternative scenarios, the no-action scenario, called the *Baseline* scenario, was defined. The Baseline scenario considers the repetition of the 60-year hydrology available (1940-2000), the current regulations to allocate water in the system, and the water demands fixed at 2004 volumes for Mexico and 70% of the full allocation demand for the US. All these assumptions were derived from consultations with stakeholders; they felt comfortable about the repetition of the historic hydrology because it contains the record drought of the 1950's (1948-1957), the drought of the 1960's (1961-1965) and the beginning of the extended drought of the 1990's (1994-2007). The 2004 water right volumes for Mexican water demands were used for two reasons; first these volumes represent the maximum water diversion legally allowed; and second, after 2004 two new policies to conserve water were implemented and stakeholders wanted to know the impact of these policies. Similarly, the 70% of the full allocation demand for US water users was assumed because this was the maximum water allocation after the 90's drought, this percentage has been reduced to 62% in recent years (Sandoval-Solis 2011).

An initial set of 33 potential water management improvement scenarios for the upper and lower Rio Grande basin on both the U.S. and Mexican sides were identified through extensive stakeholder interviews (PAP 2006). This long list of scenarios underwent further refinement through extensive discussions with engineers from the US (TCEQ), Mexico (CONAGUA-Comisión Nacional del Agua) and the international authority in the basin (IBWC). A short list of 12 scenarios was modeled first based on suggestions from stakeholders and project partners, these were the scenarios that looked more promising based on the expertise of the people consulted (Sandoval-Solis et al. 2008).

The initial round of scenarios modeled were individual or simple combination of the following policies (Table2, Phase 1 and 2 and Figure 4): (I) reduction of water demand through a buyback of water rights; this policy was implemented in two irrigation districts, DR-005 and DR-090, in the Rio Conchos basin through a Mexican Department of Agriculture program (Sandoval-Solis et al. 2011b); (II) conjunctive use of surface water and groundwater sources through an in-lieu groundwater banking technique (Sandoval-Solis et al. 2011c); (III) increased water use efficiency through improvements in infrastructure and irrigation methods, this policy was implemented in three irrigation districts in the Rio Conchos, DR-005, DR-090 and DR-103, through Minute 309 (IBWC 2003, Sandoval-Solis and McKinney 2010); (IV) environmental flows to improve the riparian and aquatic ecosystems in the basin, intentional release of water from La Boquilla and Francisco I. Madero reservoirs to meet environmental requirements in the Rio Conchos Basin (Sandoval-Solis and McKinney 2009); and (V) agricultural water demand reduction enforced in Texas since their water allocation was reduced from 70% to 62% of their full water rights allocation (personal communication, Carlos Rubenstein, Commissioner, TCEQ, October 2009).

The objective of the first round of scenario modeling was to identify the benefits and drawbacks that each scenario provides to the system; these basic scenarios were compared against the Baseline scenario (Table 2 Phase 1 and 2 and Figure 4). Results from these scenarios were documented and discussed with stakeholders in 2009. The outcome from these discussions was a list of seven winning scenarios, called *Meta-scenarios*, that were derived based on the analysis of the initial set of 12 scenarios, these Meta-scenarios were suggested to be compared with the *Current scenario*, which is the scenario that considers the policies already implemented in the basin after 2004 (PAP 2009).

In 2009, a second round of scenarios, Current and Meta-scenarios, were modeled and analyzed (Table 3, Phase 3). Meta-scenarios were integrated from policies already implemented plus a policy that was known to improve the water management or counteract the negative effects of policies already implemented. Through this process *Short-term* and *Long-term* scenarios were designed and proposed in order to improve water management in the basin (Figure 4). Similarly, results from the second round of scenarios were documented and presented to stakeholders in 2010 and 2011. At this point, the economic, legal and institutional analysis of the Short-term and Long-term scenarios was developed and documented (Sandoval-Solis 2011).

One of the most important results of the scenarios that was demonstrated to stakeholders is the feasibility of improving the environment while, at the same time, not affecting other water users. (Sandoval-Solis 2011). The long- and short-term scenarios consider the supply of environmental flows in the Rio Conchos basin while at the same time meeting human requirements and treaty obligations. This is one of the most important findings of the project; water for the environment has always been neglected in the Rio Grande basin due to the over allocation of water rights, and the scarcity of this resource. These results promoting the water management for environmental and human requirements have been presented to stakeholders and authorities along the Rio Grande basin.

During the scenario analysis, each stakeholder was evaluated using *performance criteria* that represented their essential or desired characteristics required for their water supply, these criteria were defined during meetings, workshops and conversation. Water users expressed their interest for a reliable water supply, that recovers fast from deficits and when deficits happen, the average and worst case deficit should be small; thus, the performance criteria selected for water users were reliability, resilience, vulnerability and maximum deficit (Hashimoto et al. 1982, McMahon et al. 2006 and Sandoval-Solis et al. 2011a). The selection of these desired characteristics is based on their empirical experience, in reality their water supply varies a lot from one year to another (not reliable); because of extended droughts, the system does not recover fast (not resilient); and when there is a drought, the average and maximum deficit usually are large (high vulnerability and max. deficit). The performance criteria selected for environmental requirements were the same as for water users. Similarly, authorities expressed that the delivery of water from Mexico to the US according to the treaty of 1944 ("the treaty obligations") is desired to be reliable, does not vary much through time, and when deficits happen, the expected deficit should be small and deficits must be paid as soon as possible; thus the performance criteria selected to evaluate the treaty obligations were reliability, standard deviation, vulnerability and resilience. Historically, the delivery of treaty obligations varies a lot from one year to another because it is supplied from six Mexican rivers of which four are unregulated and have high variability. Besides, the delivery is unreliable, about half of the time the system is in deficit; when deficit happens, they tend to be large (high vulnerability); and the treaty deficit is not always paid in the immediate following cycle (low resilience) (Sandoval-Solis and McKinney 2011). Presenting the performance criteria results to stakeholders and authorities improved the understanding of the benefits or drawbacks that each scenario may provide, given their desired characteristics.

One of the challenges when analyzing scenarios in the Rio Grande is the basin size; there are plenty of water users to evaluate, analyzing scenarios involved the comparison of thousands of performance criteria. While each stakeholder wanted to know the result of their performance criteria for each scenario, decision makers and authorities wanted to know concisely if a scenario improved the water management and by how much. To address this problem, two indices were used to summarize the result: the *Sustainability Index* (SI) and the *Sustainability by Group* (SG) (Sandoval-Solis et al. 2011a). The SI combines the performance criteria of a stakeholder into a single value using a geometric average, making the comparison of scenarios for each stakeholder easier, but still there were plenty of SI's to compare. The SG combines the SI's of a group of stakeholders into one value using a weighted average. The SG summarize results by type of use, region, or for the whole basin; it helps to identify water management improvements at a glance, for the whole basin, region or groups of water users.

These two indices allowed the development of a methodology to systematically evaluate scenarios for individual water users, groups of water users, regions, and for the whole Rio Grande basin (Sandoval-Solis et al. 2011a). Results can be divided in three levels for different purposes and audiences (Table 3). In the first level, performance criteria are calculated for stakeholders, the environment or system requirements; at this level it is possible to analyze in detail the effects of each scenario for individual water users, environmental control points and treaty obligations. At the second level, the SI is used to summarize the performance criteria for each stakeholder; at this level it is easier to compare different scenarios than at the performance criteria level. Results of the previous two levels are intended to inform water users and water operators. At the third level, the SG is used to summarize the results of the SI; results are displayed according to water users groups, regions and for the whole basin. At this level it is easier to compare different scenarios from the perspective of water user's groups, regions or the whole basin. Results from this level make it possible to identify areas of potential improvement and regions at risk. Results from this level are intended to inform water authorities, decision makers and planners (Sandoval-Solis 2011, Sandoval-Solis et al. 2011a).

Successes

Evaluating the success or failure of a project like this is very difficult. According to Loucks et al. (1981), a measure of success of any basin' study resides in the answer to the following three questions:

(1) "*Did the study have a beneficial impact on the planning and decision-making process?*" Yes, it did. For the planning process, the model developed in this project will be used as the foundation for a future institutional water planning model of the basin. For the decision making process, water users, scientists, authorities, and decision makers are aware of the potential benefits that are possible to achieve through implementation of the scenarios analyzed, for whom and where, in the short and long term. This project balanced the interests of different groups (environmentalist, farmers, municipalities and authorities) providing a better understanding of the basin.

(2) "*Did the results of the study make the debate over the proper choice of alternatives more informed?*" Yes, it did. After presenting the scenario analysis results to water users, scientists, NGO's, authorities, and decision makers of both countries know which policies have a

high likelihood of improving or worsening the performance of the system; the decision making process will be more informed because of the collaborative modeling process.

(3) "*Did it introduce competitive alternatives which otherwise could not have been considered?*" Yes, it did. For instance, the short and long term scenarios provide strategies to reconcile environmental and anthropogenic water requirements; this project provided evidence that environmental water requirements can be included as an integral part of the basin water management without harming human water users (Sandoval-Solis 2011). This is an important result since environmental requirements have tended to be neglected in the Rio Grande Basin because: (a) they are thought to harm human water users and/or (b) there is no water left for this purpose. This research proved the contrary. Based on these answers, the collaborative modeling promoted by the PAP was successful in enlightening the water planning and management of the Rio Grande.

Failures

There were several failures that were unintended during the process described here. The biggest failure was the lack of technical support <u>at the right time</u> during the negotiation of water regulation in the Rio Bravo Water Council, the organization in charge of defining rules for water allocation on the Mexican side of the basin for the. Despite the fact that stakeholders, NGOs and most of the government institutions were convinced of the usefulness and accuracy of the Rio Grande WEAP model, the Mexican water authority, CONAGUA, was not completely convinced of the model, and people from this agency have preference for a different modeling platform.

Workshop and training sessions were provided to CONAGUA; however, when the basin council became aware of the existence of the Rio Grande WEAP model, it was too late, and they had already taken the decision to use a different platform. However, given the extensive documentation, calibration and acceptance of the Rio Grande WEAP model, the new CONAGUA *Rio Grande model* is being built using the logic, structure, scenario analysis and algorithms developed in the Rio Grande WEAP model. There are weakness already identified for this new model, the biggest one is that it will only consider the Mexican side of the basin, resulting in yet another Rio Grande model that is not integrated. Authorities and stakeholder have been briefed regarding the mutual dependence of water availability between the two countries. It has been proved that a change in US water management affects Mexico's water availability and vice versa (Sandoval-Solis et al. 2011a), and still the basin council, integrated by stakeholders, decided to build an incomplete planning model, perhaps, this was a more political decision than an technical decision. The new model is planned to be released by the end of 2012.

Next collaborative processes in the Rio Grande

Since 2008, the PAP team has been part of an international scientific committee to estimate environmental flows in the Big Bend reach of the Rio Grande and to design policies that can provide these environmental requirements. The objective of this committee is to determine the amount of water necessary to support the riparian and aquatic ecosystems in this region, and to determine water management policies that can provide this water, most of the water in this region comes from Mexico, the PAP is providing the support to design the water management policies given its expertise in the basin.

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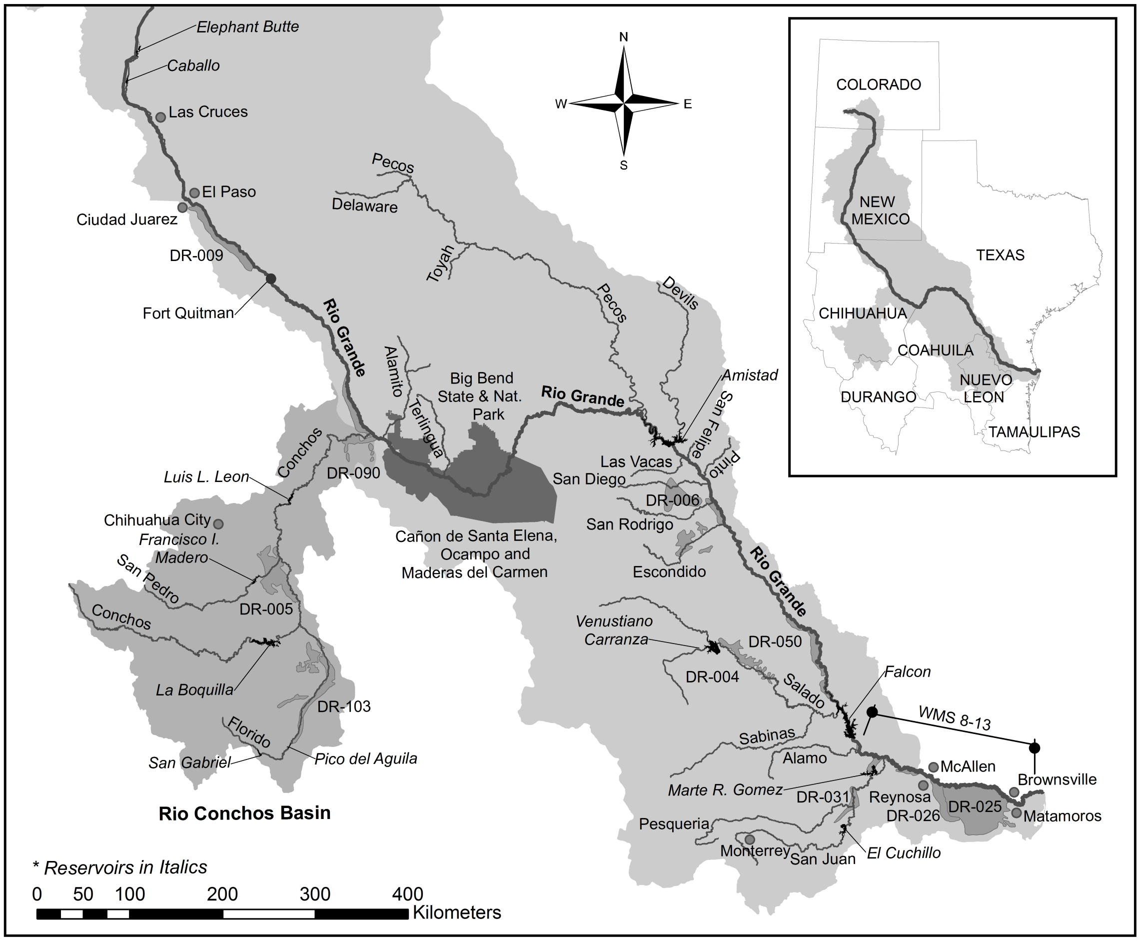


Figure 1. Rio Grande Basin

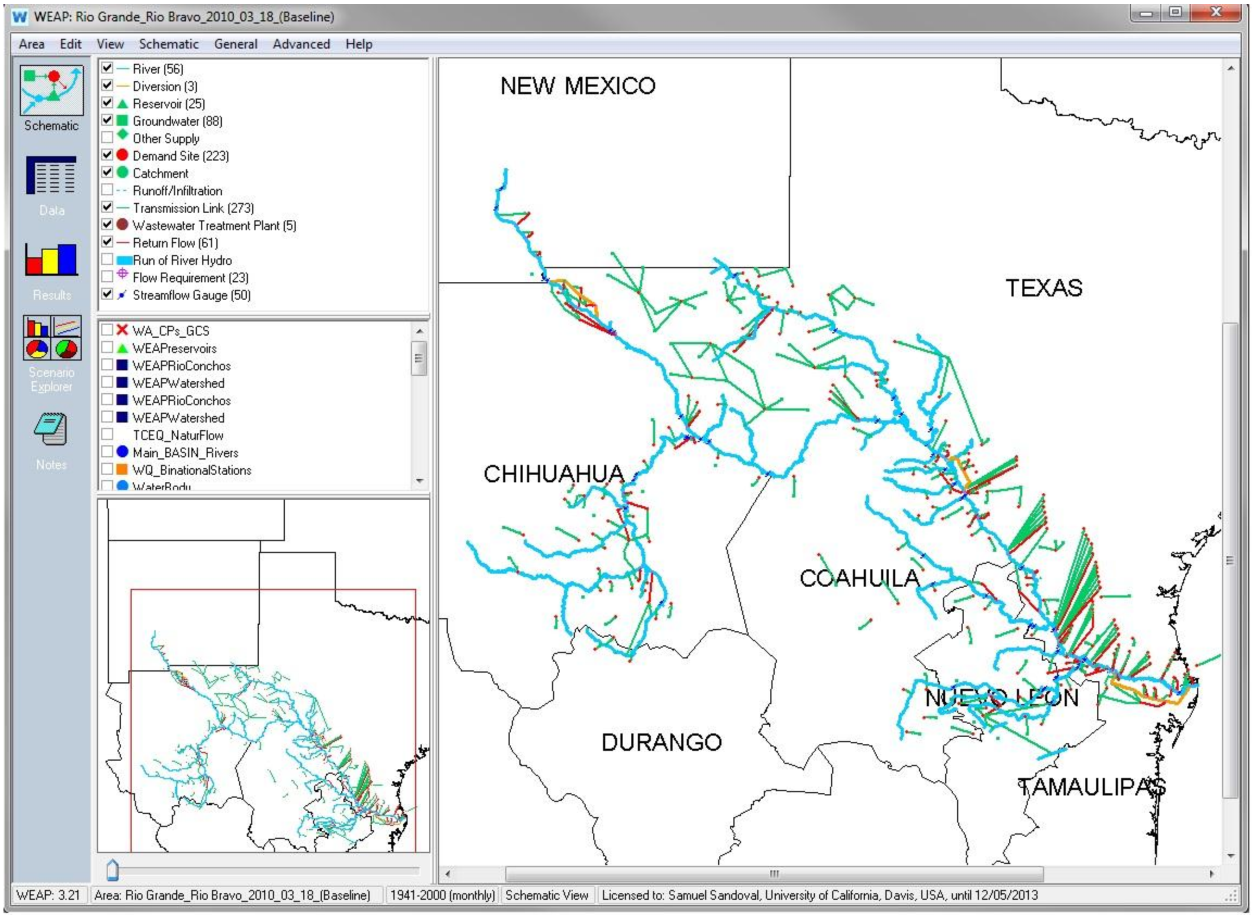
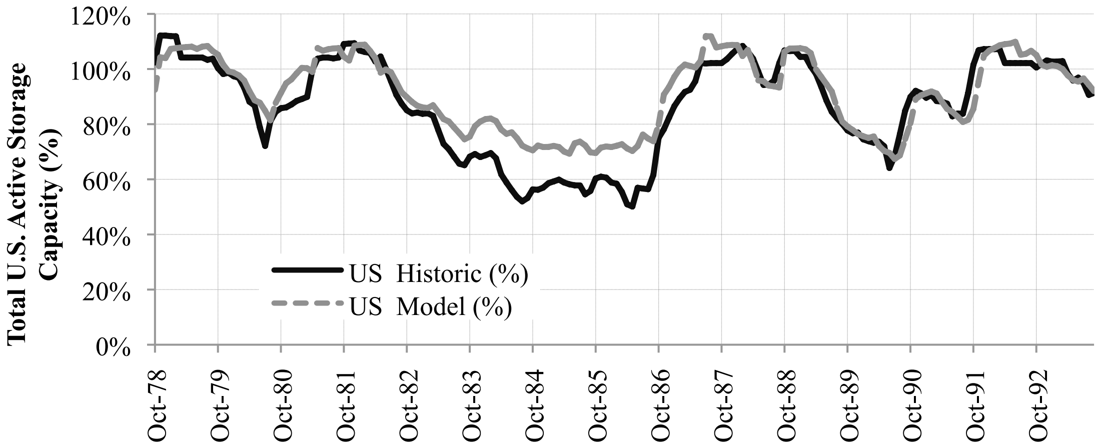
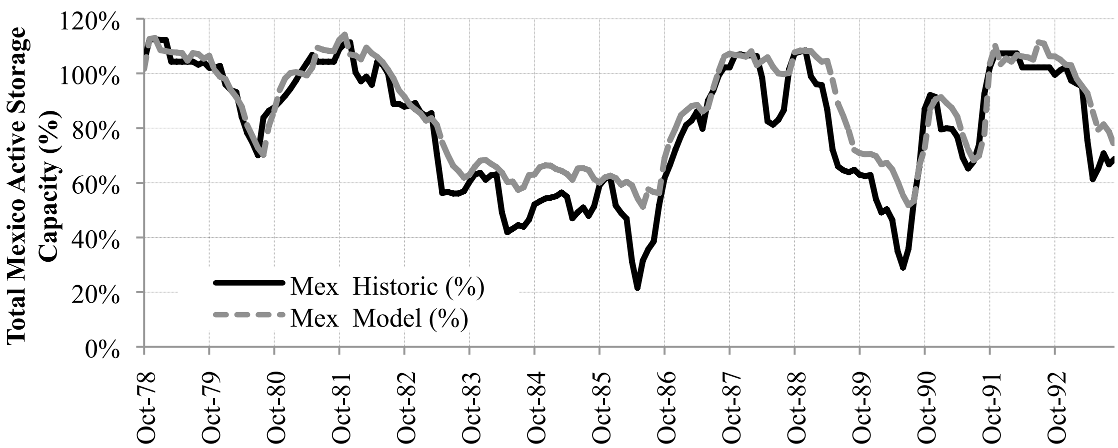


Figure 2. Planning model for the Rio Grande



a) US storage in the international reservoirs Amistad and Falcon



b) Mexican storage in the international reservoirs Amistad and Falcon

Figure 3. Combined storage for each country at the international reservoirs, Model versus *Historic* scenario

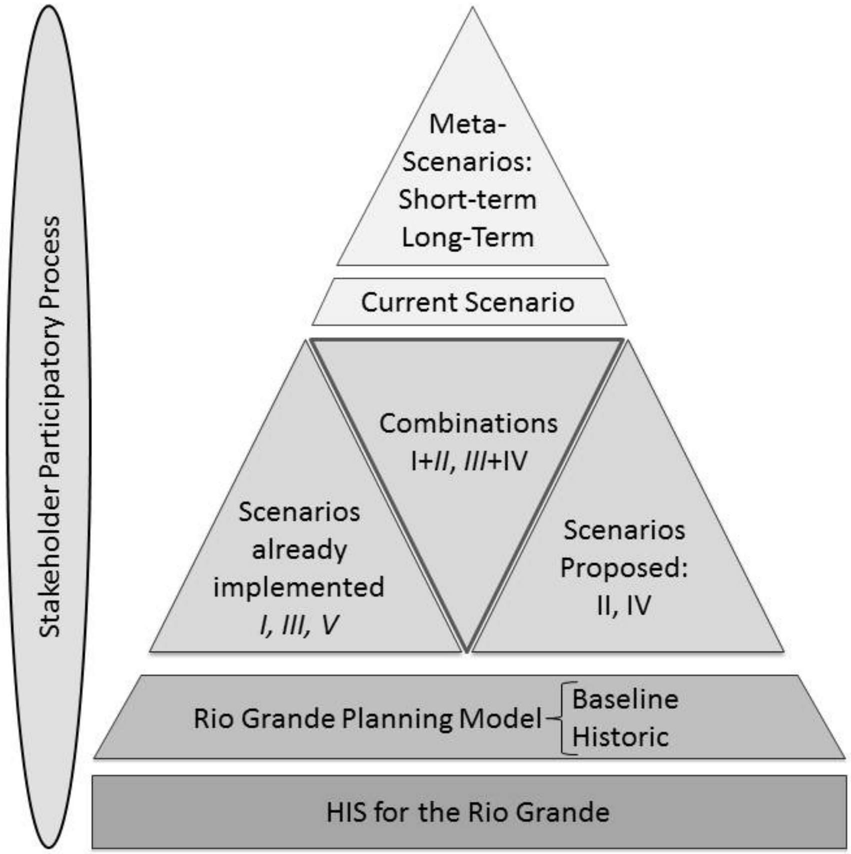


Figure 4. Collaborative Modeling Framework

Table 1. Water demands considered in the Rio Grande model

Water Use	Demands	Mexico	United States
Municipal	Number	21	23
	(Million m^3/year)	731	283*
Irrigation	Number	39	53
	(Million m^3/year)	3,939	2374*
Other	Number	1	20
	(Million m^3/year)	47	11*
Groundwater	Number	35	21
	(Million m^3/year)	1,663	2,840**
Total	Number	96	120
	(Million m^3/year)	6,380	5,509

* 70% of the Full allocation demand. The current allocation is 62% of the Full Allocation

** This value represents an upper bound on aquifer withdrawal by these water demands

Table 2. Phases of the Scenarios Analysis

Phase	Analysis	Policy	Location	
			Upper	Lower
1	Individual	*Baseline*	No-Action	No-Action
		Scenarios	*I*, II, *III*, IV	I, III, *V*
2	Combined	*Baseline*	No-Action	No-Action
		Scenarios	*I*+II, *III*+IV	I+III
3	Meta-Scenarios	*Current*	*I*, *III*	*V*
		Short-term	*I*+II, *III*+IV	I
		Long-term*	I**	III

Scenarios in *Italics* are the scenarios already implemented
* Long-term scenario includes the policies of the Short-term scenario
** This scenario is proposed to be extended of what was already implemented

Table 3. Level of Information obtained and for whom are they oriented

Level	Data Management	Results by	Oriented to
1	Performance Criteria	Criteria: - Reliability - Resilience - Vulnerability - Maximum Deficit - Standard Deviation	- Water Users - Water Operators - Stakeholders
2	Sustainability Index	User: - Water Users -Envrionment - System Requirements	- Decision Makers - Stakeholders
3	Sustainability by Group	Group: - Whole Basin - Regions - Type of Use	- Authorities - Decision Makers - Planners