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A Case Study for Computer-Aided, Community-Based Water Planning: Gila-San Francisco Decision Support Tool

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ABSTRACT

Natural resource planning spans orders of magnitude across spatial as well as temporal scales. Overlaying the natural processes, economic drivers and human demands further challenge the decision making process. Considerations of different management options that account for sustainable energy and water resources can be effectively tested using modeling and simulation. While models can be biased and oversimplify pertinent physics, the development process and the simulation outcome offer quantitative information, enhance insight, educate a broad audience, and reveal unexpected sensitivities or nonlinearity. A team at Sandia National Laboratories has developed models through stakeholder elicitation that can address a wide range of regional-, national-, and international- challenges dealing with integrated resource planning. System dynamics has served as an ideal platform for engaging with cross-disciplinary experts and decision makers, and a case study in Southwestern New Mexico illustrates this approach.

INTRODUCTION

There is a long history of struggle over access to water in the arid southwest, and water allocation conflicts in the southwestern region of New Mexico are no exception. The legislation surrounding water management of the Gila River (pronounced “Hee-la”) lasted almost fifty years. Figure 1 shows the map of the southwestern region of New Mexico surrounding the Gila River.

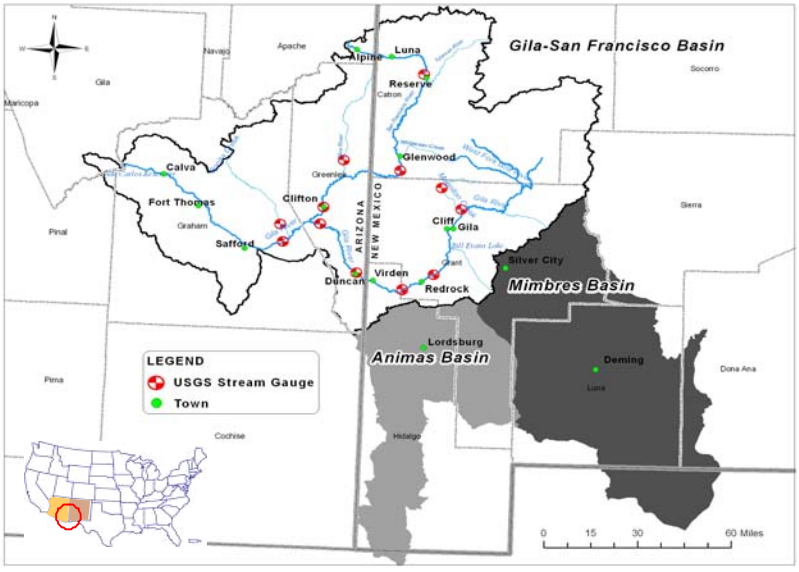

Figure 1 – Upper Gila region spanning New Mexico and Arizona states. The three outlined basins are study regions of the GSF Decision Support Tool. Red circles indicate USGS gauges.

The Gila river and its tributary San Francisco river begin in New Mexico, pass through the State of Arizona before merging into the Colorado River. The Gila-San Francisco Basin covers around 9,000 square mile region of Southwestern New Mexoco. The Gila Wilderness Area, the first designated Wilderness area in the United States, resides in the basin and houses several federally listed endangered species: Southwestern willow flycatcher; Loach minnow, and Spikedace [1]. The agricultural communities that utilize the surface water for irrigation along Gila riparian region also date back to 1800s before New Mexico Statehood [2].

Section 212 (d) of the Arizona Water Settlements Act of 2004 (henceforth 2004 AWSA) modified Section 304(f) to allow the Secretary of Interior to contract with water users in the State of New Mexico, with the approval of its Interstate Stream Commission (NMISC), or with the State, for water from the Gila River, its tributaries, and underground water sources in amounts that will permit consumptive use of water in New Mexico not to exceed an annual average in any period of 10 consecutive years of 14,000 acre-feet, over and above the current legal maximal consumptive uses granted by article IV of the decree of the Supreme Court of the United States in Arizona v. California [3]. Such increased consumptive use can occur only as long as delivery of water does not diminish water supply for users in downstream Arizona. The stipulations within the 2004 AWSA for which additional consumptive use can occur for New Mexico are known as the Consumptive Use Forbearance Agreement (CUFA) [4].

CUFA places several constraints under which the water can be diverted from the Gila river, none of which can be violated before water can be diverted. Table 1 summarizes the CUFA constraints. A cumulative constraint is defined as a constraint that does not limit a daily diversion quantity until it accumulates to its maximum legal limit. A daily constraint is a legal requirement that must be met on a daily basis. Understanding the current water supply scenario with added CUFA potential diversion is a major concern for the region.

More importantly, the 2004 AWSA provides between $66 and $128 million in non-reimbursable funds for New Mexico to develop water supply alternatives, including a New Mexico Unit of the Central Arizona Project [2]. The NMISC has committed to a continuing process of public information and comment to help arrive at such determinations.

In considering any proposal for water utilization, NMISC will consider "*the best available science to assess and mitigate the ecological impacts on Southwest New Mexico, the Gila River, its tributaries and associated riparian corridors, while also considering the historic uses of and future demands for water in the basin and the traditions, cultures and customs affecting those uses.*" [5]

Table 1 - Summary of CUFA conditions required for additional diversion of Gila-San Francisco rivers.

Test	Type	Description
Annual Total < 64,000 AF	Cumulative	Sum of Gila and San Francisco total consumptive use cannot exceed 64,000 AF per year.
Annual San Francisco Total < 4,000 AF	Cumulative	San Francisco annual consumptive use cannot exceed 4,000 AF annually.
10-yr running total < 140,000 AF	Cumulative	Running 10-yr total of Gila and San Francisco consumptive use cannot exceed 140,000 AF.
New Mexico CAP Water Bank < 70,000 AF	Cumulative	The CAP Water Bank, as maintained by the federal agency, must never exceed 70,000 AF
Gauged flow > Daily Diversion Basis (DDB)	Daily	DDB is the amount of water that the downstream users in Arizona are entitled to and must be satisfied before withdrawal is allowed.
Daily San Carlos Reservoir > 30,000 AF	Daily	San Carlos Reservoir provides water use to its downstream users. Minimum storage amount in the San Carlos reservoir is required before any consideration for withdrawal.
Sum of withdrawal < 350 cfs	Daily	Combined withdrawal of rivers cannot exceed 350 cfs.
Gila Virden gauge > 120% of Duncan-Virden Valley call	Daily	Duncan-Virden valley straddles both New Mexico and Arizona and its daily irrigation requirement must be met. The USGS flow gauge near the town of Virden best indicates Gila River flow near the valley.
San Francisco gauges > Required flow for Phelps Dodge	Daily	This section of the CUFA focuses on the water available for the mining company Phelps Dodge throughout the year.
Gauged flow > Potential flow	Daily	This is a New Mexico mandate which requires a specified minimum flow imposed on the Gila and San Francisco rivers.

COMMUNITY-DRIVEN MODELING

Prompted by the 2004 AWSA and an awareness for collaborative solutions, local, state, federal governmental entities teamed with NGOs to form a collaborative modeling team that focuses on building a decision support software for understanding water demand and supply in the Upper Gila region of New Mexico. The process of collaborative modeling has implications that extend beyond southwestern New Mexico, beyond the borders of the United States, and beyond North America.

The team was formed in 2005 and has continued despite various political and funding shortfalls. The Team met bi-weekly between September 2005 and July 2007 via Web conferencing and conducted face-to-face meetings/workshops every quarter-year during that period. Due to a funding shortfall, the team only met four times between the fall of 2007 and the spring of 2008. Since the summer of 2008, the team resumed its virtual WebEx teleconferences and face-to-face meetings without a facilitator. Because of the lapsed time, the team make-up has decreased from fifteen representations to nine, as shown in Table 2. While it is difficult to pinpoint the cause of loss of memberships, the purpose of the meetings

also transitioned from "model-construction" to "model-sensitivities" during those two periods.

One of the advantages of using Web conferencing is its ability to engage geographically diverse Team members across this vast rural region. Participation in these meetings is central to understanding user needs, enhancing communication among users, and receiving feedback from team members.

In addition to modeling collaboratively, the team's feedback on the process is captured in anonymous surveys. Three has been conducted, one in 2006, one in 2007, and one in 2008. The results from these surveys indicate consistent satisfaction with the collaborative process over these years; nevertheless, the impression on the tool varies widely, and there is a general consensus that new membership is required to fully represent the interests in the region [6].

GILA-SAN FRANCISCO DECISION SUPPORT TOOL

The Gila-San Francisco Basin is comprised of complex, highly interactive physical and social processes. These systems are continually evolving in response to changing climatic, ecological, and human conditions that span across multiple spatial and temporal scales. A modeling approach based on the principles of system dynamics has been applied to produce the GSF Decision Support Tool. System dynamics provides a unique framework for integrating the disparate physical and social systems important to water resources management, while providing an interactive environment for engaging the public [7].

Building models using system dynamics is based on a collaboration of ideas and inputs, as well as the feedback loops within each element of the system. "Model building should be a circular process of creating a model structure, testing behavior of the model, comparing that behavior with knowledge about the real world being represented, and reconsidering structure" [8]. The feedback loops for the GSF Decision Support Tool consider supply-side hydrologic units of surface water supply, and both shallow and deep aquifer supply. The demand side includes industry, agriculture (crop irrigation), cattle, population, and riparian growth [9].

The GSF Decision Support tool has been designed with the CUFA constraints, with the following goals in mind:

- Given various constraints, how much water is available from where, when, and to what purpose?
- Given various constraints, how much water is in demand from where, when, and to what purpose?
- What are the tradeoffs among various approaches to managing this water?

In May, 2006, at the face-to-face Team Meeting, the team then developed a list of five variables that they felt would be most influenced by change, or that most reflected uncertainty:

- Demand by category (residential, agricultural, municipal Industrial)
- Instream flow targets
- Population change
- Weather/climate (temperature, precipitation, climate change
- Vegetation composition (density, type land use change)

The team then selected five key metrics for output:

- River discharge by reach, as influenced by diversion and legal constraints
- Water appropriated versus actual use
- Water in storage
- Management effects on water supply/demand
- Effects on aquatic/riparian species and river ecology

The model requirements and historical use data are painstakingly captured using the PowerSim software [10]. There are several hydrologic components: groundwater, surface water, agricultural and riparian consumptive use, industrial and population demands, and terms of diversion based on New Mexico CUFA terms. Along with the model, the team created a desired list of schema that the stakeholders can evaluate using a user-friendly interface overlaying the model itself. The model homepage is the starting point from which users can select scenarios for Climate, CUFA, Population, Agriculture, Minimum River Flows, and Mine Leased Water Rights. Figure 2 shows the homepage of GSF Decision Support Tool.

Figure 2 Homepage of GSF Decision Support Tool.

ILLUSTRATIVE RESULT: CUFA DIVERSION SENSITIVITY TO MINIMUM FLOW

Model calibration and quantification of water availability under the 2004 AWSA are currently being assessed by the team. As an illustration using historical hydrographs between 1979 and 2001, annual potential diversion from the Gila river is shown in Figure 3. The key insight from the dynamic simulation shows that large year-to-year fluctuations exist. More importantly, there are years where the potential water for diversion is larger even with larger minimum flow requirement. This is counterintuitive to what most stakeholders had envisioned. This is due to the constraints placed on the other CUFA constraints listed in Table 1. The interactions of all of the CUFA requirements restrained diversion potential beyond what the stakeholders had anticipated. Addressing the minimum flow requirement may not necessarily reduce the overall diversion potential for surface water diversion.

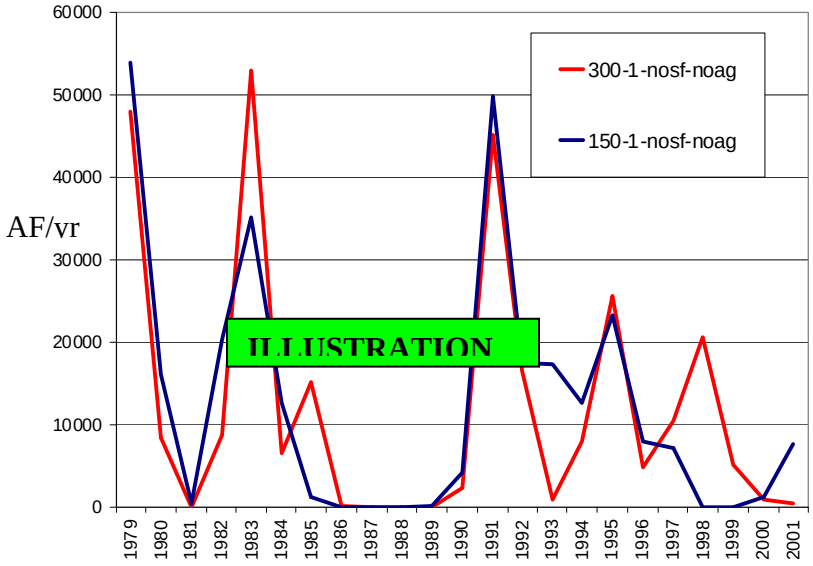

Figure 3 - Gila River water availability using1979-2001 historical hydrograph of USGS Gila gauge. The RED indicates annual allowable CUFA diversion with 300 cfs minimum flow requirement, while the BLUE indicates annual allowable CUFA diversion with 150 cfs. (This figure is only illustrative and cannot be reproduced without the permission of GSF Modeling Team.)

SUMMARY

Collaborative, consensus-driven community modeling process enhances the ethical quality while balancing human interests, ecological demand, and natural resources. Use of a computer-aided tool like the GSF Decision Support Tool provides a platform for productive and engaging dialogues. Sandia National Laboratories' technical expertise in providing decision support tools is well suited for creating neutral, open, and inclusive environment.

The advantages of a collaborative modeling process tolerate the Gila-San Francisco Decision Support Tool indicate an overall sense of ownership, integrated planning and enhanced insight. Nevertheless, the modeling process requires longer, iterative cycles that may not

coincide with long-term funding. More importantly, the values associated with community learning and decision making are difficult to quantify.

Note:* Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

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