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Gila-San Francisco Decision Support Tool to Address the Impact of 2004 Arizona Water Settlement Act

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ABSTRACT
In 2004, the Arizona Water Settlements Act (AWSA) was signed into law, which provides New Mexico an additional 140,000 AF of water from the Gila Basin in any ten year period. In addition, New Mexico will receive $66M for "paying costs of water utilization alternatives to meet water supply demands in the Southwest Water Planning Region." Since 2005, Sandia National Laboratories, concerned citizens, local water stakeholders, and key federal and state agencies have collaboratively developed a system-dynamics model to simulate regional water availability and use. Overlaying the regional water balance, terms of the Consumptive Use and Forbearance Agreement (CUFA) are incorporated in the model. The tool aims to provide the public a platform to capture sensitivities due to different demand and supply scenarios, to uncover the intricate coupling between water resources and demands, and to enhance overall understanding of the human and ecological impact on the river health.

INTRODUCTION
Water resource management requires collaborative solutions that reach across institutional and political boundaries. In southwestern New Mexico, the water managers are faced with an important legal decision that will potentially challenge its existing management practice and impact citizens, businesses, as well as the ecology surrounding the upper Gila river. Geographically, the Southwestern Water Planning region spans four legislative state counties: Catron, Luna, Hidalgo, and Grant county, as shown in Figure 1. Hydrologically, this region covers the Gila-San Francisco basin, the Mimbres basin, the Animas basin and several other small closed groundwater basins. The total areal coverage are approximately 9,000 mi^2 for Gila-San Francisco basin, 4,600 mi^2 for Mimbres basin, and 2,400 mi^2 for Animas basin. The Gila Wilderness Area, the first designated Wilderness area in the United States, resides in the Gila-San Francisco basin and is home to 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].

Litigation over water rights with neighboring Arizona have been numerous. In the U.S. Supreme Court litigation *Arizona v California*, 376 U.S. 340 (1964), the State of New Mexico presented evidence of present and past uses of water from its tributaries in the Lower Colorado River Basin including the Gila River and its tributaries. In addition, New Mexico presented a water supply study showing how the state could apply and use the water it claimed as its equitable share of the Gila River. In the resulting report of the Special Master, it was found that New Mexico should be allowed present uses as an equitable apportionment of the waters of the Gila Basin, but did not make an apportionment of water to New Mexico to provide for future uses.

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

Subsequently, the 1968 Colorado River Basin Project Act, P.L. 90-537, which authorized the building of the Central Arizona Project (CAP) included allocation of 18,000 acre-feet of water to New Mexico. This water is in addition to the water awarded in the 1964 court decree (30,000 acre-feet of consumptive use per year). The allocation was effected through an exchange by the Secretary of the Interior of 18,000 acre feet of CAP water for an equal amount of diversions of Gila Basin water. However, the 1968 Act did not provide a means for New Mexico to divert the Gila Basin water without objection by senior downstream users. The 2004 Arizona Water Settlements Act (henceforth 2004 AWSA) amends the 1968 Act and together with the Consumptive Use and Forbearance Agreement (CUFA), provides both the ability to divert without objection by downstream parties and the funding to help. [3,4]

CONSUMPTIVE USE AND FORBEARANCE AGREEMENT

Specifically, the 2004 Arizona Water Settlements Act provides New Mexico 140,000 acre-feet of additional depletions from the Gila Basin in New Mexico in any ten year period. In addition, the State of New Mexico will receive $66M for "paying costs of water utilization alternatives to meet water supply demands in the Southwest Water Planning Region of New Mexico, as determined by the New Mexico Interstate Stream Commission (NMISC). Funds may be used to cover costs of an actual water supply project, environmental mitigation, or restoration activities associated with or necessary for the project. Further, if New Mexico decides to build a project to divert Gila Basin water in exchange for CAP water, the state will have access to an additional $34-$62 million. According to the settlement, New Mexico has until 2014 to notify the Secretary of the Interior about plans to divert water from the Gila River that include a diversion. The legislation designates the U.S. Bureau of Reclamation as the lead federal action agency and provides that the State of New Mexico through the Interstate Stream Commission may elect to serve as joint lead. As such the Bureau (and NMISC) will plan the formal environmental compliance activities (e.g., NEPA). The 2004 AWSA Act requires that the NEPA process must be completed with a record of decision by 2019.

There are environmental concerns relating to possible environmental costs if New Mexico were to develop its entitlement to the Gila River. As the last main stem river in New Mexico without a major water development project, increased water diversion may reduce water available for wildlife, vegetation, nutrient cycling and other vital river functions. In response, the NMISC, the Office of the Governor of the state of New Mexico have both adopted policies that "recognize the unique and valuable ecology of the Gila Basin" and committed to a continuing process of information gathering and public meetings with local water managers and community groups. In considering any proposal for water utilization under Section 212 of the 2004 AWSA, full consideration will be given to "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." [5-7]

The Consumptive Use and Forbearance Agreement sets forth the rights and responsibilities of all involved parties between New Mexico and Arizona. The CUFA also describes the terms and parameters under which diversions by New Mexico may occur without objection by the downstream parties, because additional diversions in New Mexico will be junior to all Gila Basin rights existing as of September 30, 1968. It also describes how the Secretary of Interior will exchange CAP water for Gila Basin water and how disputes may be resolved. 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 daily constraint is a legal requirement that must be met on a daily basis. A cumulative constraint is defined as a constraint that does not impose a limit until it accumulates to its prescribed legal limit. For example, an annual total diversion of 64,000 AF is a cumulative constraint that is not "active" on a day-to-day basis until the maximum limit is reached.

Table 1 - Summary of CUFA conditions required for additional diversion from 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 preserved before withdrawal is allowed.
Gauges flow > Daily Diversion Right (DDR)	Daily	DDR is a prescribed fraction of the difference between available gauged flow and DDB.
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.
Gila Gauged flow > Gila Minimum flow	Daily	This is a New Mexico mandate which requires a specified minimum flow imposed on the Gila river.
San Francisco Gauged flow > San Francisco Minimum flow	Daily	This is a New Mexico mandate which requires a specified minimum flow imposed on the San Francisco river.

COMMUNITY-DRIVEN MODELING

Understanding the current water supply scenario with added CUFA potential diversion is a major concern for the region. Since 2005, Sandia has led the development of a decision support tool with a collaborative modeling team comprised of local, state, and federal entities. The team focuses on building a model for understanding water demand and supply in the impacted four-county region of New Mexico. Specifically, the collaborative team helped define the scope and purpose of the model, conceptualize cause and effect relations, review/suggest data to be used in the model, and performed model review. Other than a shared common interest founded on the 2004 AWSA, the process of collaborative modeling has implications that extend beyond southwestern New Mexico. Table 2 lists the past and present membership of the modeling team.

The team was formed in 2005 and has continued despite various political and funding shortfalls. The group 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. The resulting tool for evaluating implications of CUFA terms is known as the Gila-San Francisco Decision Support Tool. The team has scaled back since fall of 2007. During 2008, the team met mostly through WebEx teleconferences and had only one face-to-face workshop. Because of the intermittent lapsed time, the active participation has decreased over the years. In addition to developing a model and evaluating its results collectively, the team's feedback on the process is captured in anonymous surveys. Three surveys have been conducted annually between 2006 and 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 [8].

Table 2 – Gila-San Francisco Model Team Contributors (as of 2008).

Description
Municipality of Deming
Municipality of Silver City
Cliff/Gila Farm Bureau
Gila Conservation Coalition
The Nature Conservancy
Black Range Resource Conservation & Development
Bureau of Reclamation
New Mexico Interstate Stream Commission
Sandia National Laboratories
Gila San Francisco Water Commission
Office of State Engineers, Deming
Soil and Water Commission representatives from Grant, Catron, and Luna Counties
US Fish and Wildlife Service

GILA-SAN FRANCISCO DECISION SUPPORT TOOL

The hydrologic cycle 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 create the Gila-San Francisco Decision Support Tool. System dynamics provides an unique framework for integrating the disparate physical and social systems important to water resources management, while providing an interactive environment for engaging the public with varying degrees of technical knowledge [9, 10]. Figure 2 represents an Influence Diagram outlining the important inter-relations amongst different sectors and feedback loops. Elements in Figure 2 represent the volumes and rate processes controlling the hydrologic sub-components relevant to the study region. Intuitively, the major hydrologic units are surface water supply and groundwater supply. The groundwater supply is further broken down into two groups, shallow aquifer storage and deep aquifer storage. The other volumes to be considered are the amount of water demanded by human consumption, crop irrigation, riparian growth, industrial consumptive use, livestock use, and finally, CUFA diversion. The various rates of change from natural or man-made processes reveal a complex diagram of interactions and feedback loops. For example, the major consumptive use in agriculture relies on river diversion, but a fraction of the total volume is returned to groundwater supply via seepage. More refined diagrams can be constructed for each major sector and are described elsewhere [11].

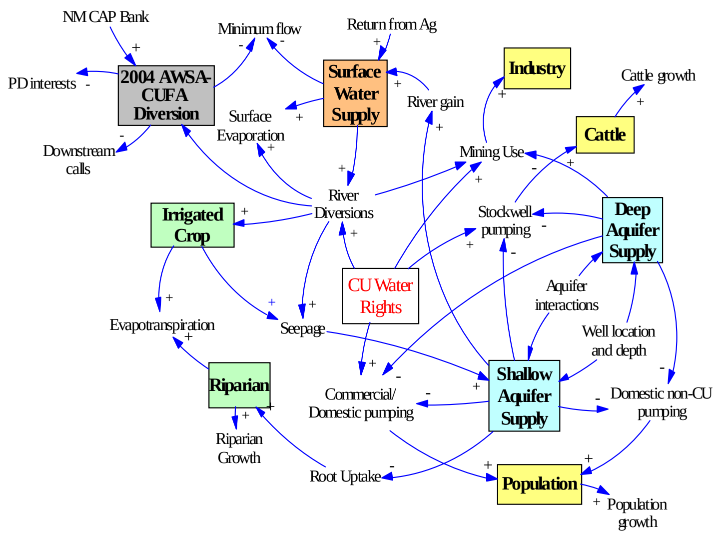


Figure 2 – Conceptual Influence Diagram of the overall water balance. The boxes represent volumetric units of water for different supply and use. The arrows represent influencing rate processes that either increase of decrease water supplies. The sign designation reflects either reinforcing rate processes or depleting rate processes.

The model requirements and historical use data are painstakingly captured using the commercial software package PowerSim™ Studio [12]. There are several key hydrologic components in the system dynamics model: groundwater, surface water, agricultural and riparian consumptive use, industrial and population demands, and terms of diversion based on New Mexico CUFA terms. The Consumptive Use (CU) water rights adjudicated in the 1964 Supreme Court decision represent the maximum allowable use of existing water. It consists primarily of mining rights, local farming and ranching, and domestic use. Also noted in Figure 2, the water rights holders have the ability to supplement surface water diversion with groundwater pumping. Nevertheless, the water rights that are exercised vary year-to-year and have been recorded on a yearly basis. An average consumptive use quantity is based on historic hydrographic surveys and non-agriculture consumptive use summary reports from New Mexico's Office of the State Engineer between 1979 and 2005 [13].

Along with the model, the modeling team created a prioritized list of external perturbations that the decision makers can evaluate via a user interface built by Sandia. The user interface is shown in Figure 3. The users can manually adjust baseline parameters related to Temperature, CUFA, Population, Agriculture, Minimum River Flows, and Mine Leased Water Rights.

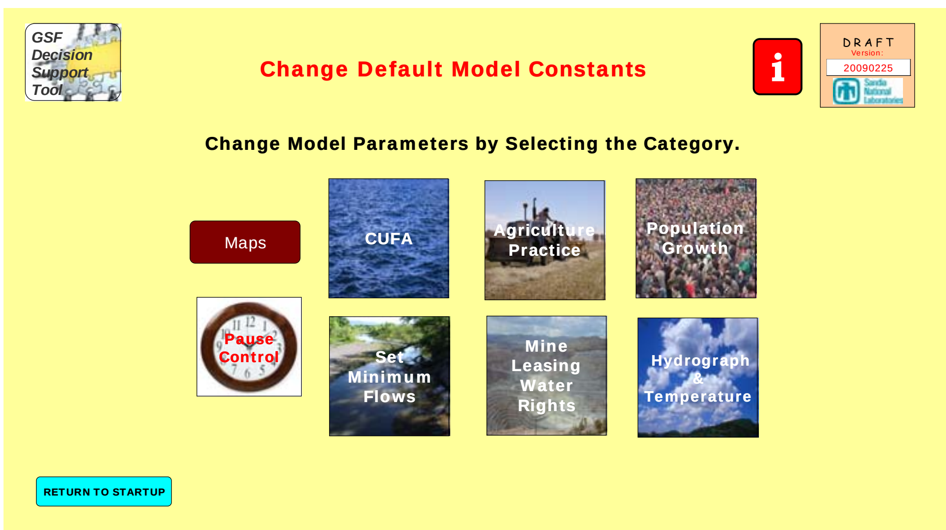


Figure 3 – Scenario building user-interface for assessing impact of model input parameters to water demand.

ILLUSTRATIVE ANALYSIS: CUFA DIVERSION

At the onset of model development, three important questions were posed as the objectives for the model.

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

To address the first question, an analysis is carried out to illustrate water availability by implementing the CUFA provisions using historic river flow data in the Gila-San Francisco Decision Support Tool. Using historical hydrographs between 1979 and 2001, annual potential diversion from the Gila river based on CUFA constraints using two different minimum flow settings for Gila river is shown in Figure 4. The minimum flow settings have no physical basis and are chosen at 300 cfs and 150 cfs solely for illustrative purpose. Other than the minimum flow settings, these two dynamic simulations begin from the same baseline conditions in 1979 and continue on to 2001. The key insight from the dynamic simulation shows that there are large year-to-year fluctuations. While the average annual diversion is greater with lower minimum flow requirement, there are years where the potential CUFA diversion is larger with higher imposed minimum flow. This is counterintuitive to what the modeling team had envisioned. Of all the days between 1979 and 2001 when no diversion were allowed, the statistics of how each constraint contributed towards no-diversion decision is shown in Figure 5. Figure 5 shows the percent share of each constraint being active normalized across all the zero-diversion days. Out of twelve provisions, four constraints controlled over 60% of no-diversion decisions, three of which are cumulative constraints that prohibit diversion beyond limits of 64,000 AF/year for the combined Gila and San Francisco rivers, or 4,000 AF/year for the San Francisco river, or 140,000 AF over any running 10-year period. Hence, the sensitivity of diversion quantity with respect to the minimum flow requirements is diminished if the constraining components are unrelated to minimum flows. In this analysis, raising the minimum flow requirement may not necessarily reduce the overall CUFA diversion potential.

Another important statistics that is readily extractable from the tool is the period of CUFA diversion. Figure 6 shows the average flow in each month that the CUFA diversion is allowed. It is apparent that the available diversion occurs during winter months.

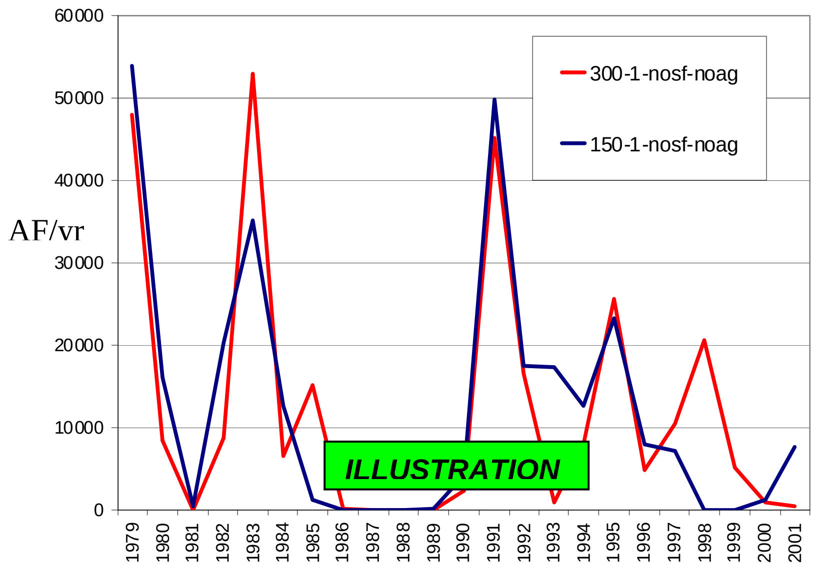


Figure 4 - Available annual CUFA diversion based on 1979-2001 historical hydrograph of USGS Gila gauge. The RED indicates annual allowable CUFA diversion with 300 cfs minimum flow requirement, while the BLUE indicates annual allowable CUFA diversion with 150 cfs. (This figure is only illustrative and cannot be reproduced without the permission of GSF Modeling Team.)

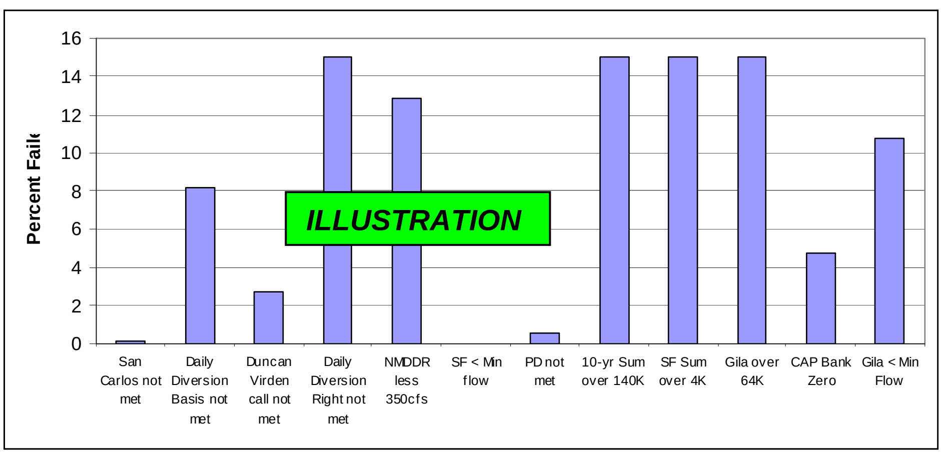


Figure 5 – Of all the days that no-diversion occurs during historical period between 1979 and 2001, the statistics of active constraints in normalized percentage. The sum of all the bars is 100%. CUFA rules are given in Table 1. (This figure is only illustrative and cannot be reproduced without the permission of GSF Modeling Team.)

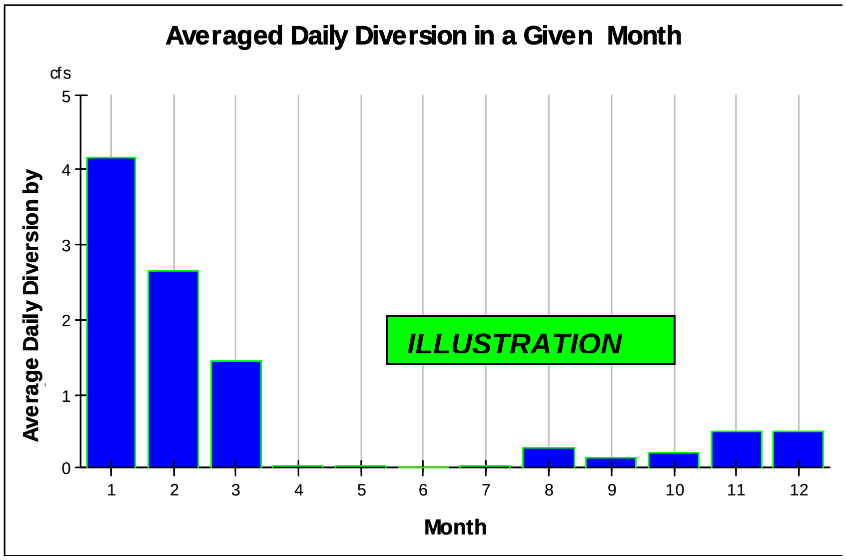
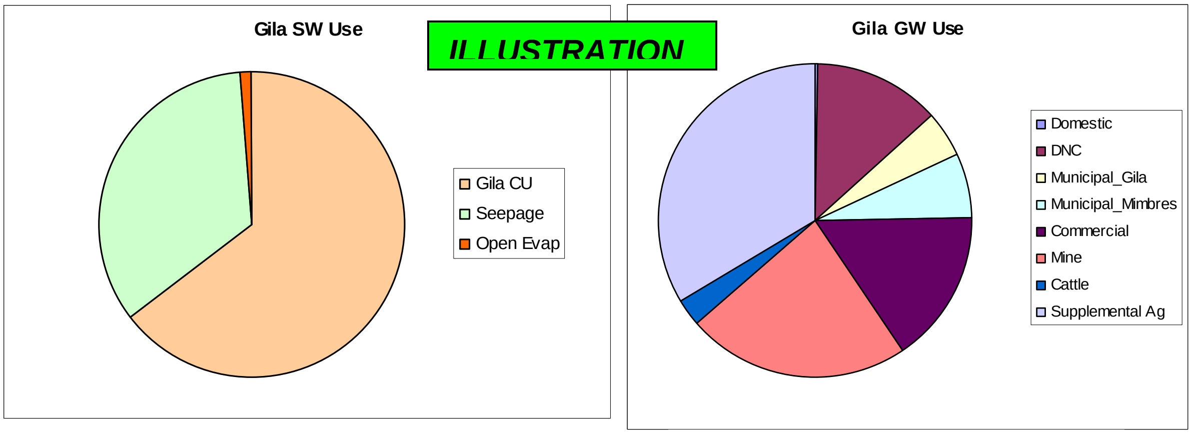


Figure 6 – Average daily CUFA diversion by month over 1979-2001 period. (This figure is only illustrative and cannot be reproduced without the permission of GSF Modeling Team.)

ILLUSTRATIVE ANALYSIS: WATER DEMAND

To address the second concern, the tool evaluates the water demand in the different basins across different sectors from 2005 to 2025. Beyond the historical time horizon, the Gila-San Francisco Decision Support Tool projects the water demand that is consistent with historical rates as well as those projected by published trends and reports [14-16]. Likewise these use rates can be modified by manipulations of the slidebars and radio buttons in the user interface to explore a broader range of future water use scenarios. Figure 7 shows the breakdown of average annual surface water and groundwater demand in Gila-San Francisco basin while Figure 8 shows the average annual water demand in the Mimbres basin.

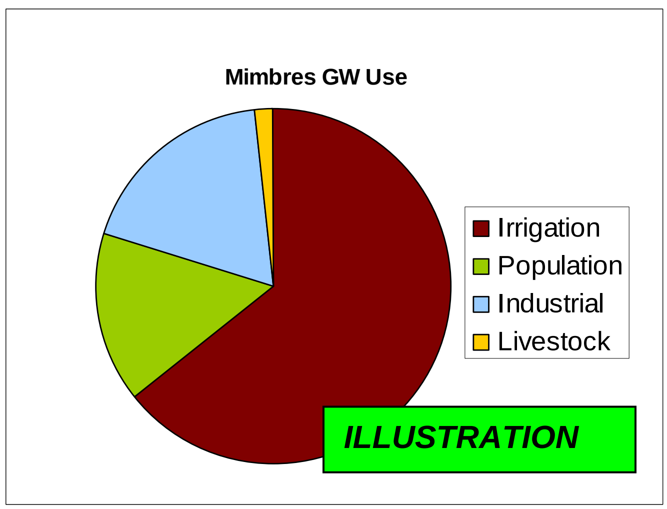
Based on Figure 7, the water use in the Gila-San Francisco region is predominantly surface water as two-third of the total water needs are supplied by the river and its tributaries. The groundwater component supports human activities with supplemental agriculture, mining, commercial, and domestic non-consumptive use being the largest shares of total groundwater demand. Nevertheless, the water demand in the Gila-San Francisco basin is small compared to the annual usage in Mimbres basin. Based on Figure 8, it is apparent that the irrigation water demand from Mimbres groundwater supply will be dominant over the four-county region. The basin also support water usage for the majority of population in the southwestern New Mexico region. Maintaining balanced and sustainable water resources across the Gila-San Francisco, Mimbres, and Animas basins can be evaluated through dynamic simulation of the Gila-San Francisco Decision Support Tool.



GSF Surface water Demand
13,924 AF/yr

GSF Groundwater Demand
7,788 AF/yr

Figure 7 Illustration of average annual water demand (2005-2025) in the Gila-San Francisco basin by water sources and by sector. (This figure is only illustrative and cannot be reproduced without the permission of GSF Modeling Team.)



Irrigation – 52,713 AF/yr
Population – 12,697 AF/yr
Industrial - 15,254 AF/yr
Livestock – 1,416 AF/yr

Figure 8 – Illustration of average annual groundwater demand (2005-2025) by sector in the Mimbres basin. (This figure is only illustrative and cannot be reproduced without the permission of GSF Modeling Team.)

ILLUSTRATIVE ANALYSIS: TRADE-OFFS

The last and the most important analysis question for many stakeholder involves the various tradeoff scenarios of managing water supply and demand. As an illustration, the impact of mining water rights leased back to irrigators in the Gila-San Francisco basin is evaluated. The users can adjust a slider-bar that changes the default setting of zero acre-feet of leased water to values up to 31,000 AF/yr, which is the total water rights that the mining companies hold [17]. While some of water rights owned by the mining companies are in use for the purpose of mineral extraction through surface water diversion to Bill Evans lake and groundwater pumping, a portion of currently underutilized water rights can be leased back to farming. The current model evaluates the implication to this measure. As shown in Table 3, going from zero leased water rights to 3,000 AF/yr and to 10,000 AF/yr will burden surface water consumptive use by a factor of 1.2 and 2.1 as well as groundwater pumping by a factor of 1.6 and 2.3 respectively. The model demonstrates a useful tool to evaluate the sensitivities and effectiveness of various water budgeting scenarios.

Table 3 – Gila-San Francisco average annual groundwater pumping impact due to increased leased water rights from Mining companies to irrigators spanning over 2005-2025. (These numbers are only illustrative and cannot be reproduced without the permission of GSF Modeling Team.)

Leased Water Rights from Mining companies to Irrigators	**GSF surface water consumptive use**	**GSF groundwater pumping for irrigation**
0 AF/year (baseline)	5,010 AF/yr	2,948 AF/yr
3,000 AF/yr	6,056 AF/yr	4,902 AF/yr
10,000 AF/yr	10,277 AF/yr	7,681 AF/yr

SUMMARY

A decision support tool for assessing the impact of additional water allocation for New Mexico in response to the 2004 Gila Water Settlements Act is described in this work. In order to understand the implications of additional water withdrawal from the Gila and San Francisco Rivers, a decision support tool has been built to represent the current water demand and supply. Based on principles of system dynamics, the tool is founded on a hydrologic balance of surface water/groundwater supplies with demand. The tool is fitted with a user interface to facilitate evaluation of various water supply and demand scenarios. In efforts to build broad consensus in the tool a collaborative modeling process utilized to engage stakeholders and the public in model development. The model currently summarizes the consumptive use of water in the region as well as the potential CUFA diversion over a 20-year horizon. More scenario runs are needed to quantify the sensitivities of potential CUFA diversions relative to exogenous perturbations as well as various trade-off options to manage projected human or ecological demands in a sustainable fashion.

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.

REFERENCES

[1] Endangered Species List of New Mexico
[2] Soles, E. S., "Where the River Meets the Ditch: Human and Natural Impacts on the Gila River, New Mexico, 1880-2000," Master of Art Thesis, Rural Geography, Northern Arizona University, August, 2003.
[3] Public Law 108-451, December 2004, Arizona Water Settlements Act.
[4] New Mexico Consumptive Use and Forbearance Agreement Among The Gila River Indian Community, San Carlos Irrigation and Drainage District, The United State, Franklin Irrigation District, Gila Valley Irrigation District, Phelps Dodge Corporation, The Secretary of the Interior, and Other Parties Located in the Upper Valley of the Gila River.
[5] Fact sheet, Arizona Water Settlement Act Planning Workshops, 2008.
[6] Press Release, Office of Governor of the state of New Mexico. April & June, 2008.
[7] Excerpt from the New Mexico Interstate Stream Commission Policy on Gila-San Francisco River Basin Planning and Decision Process.
[8] Franky, C.E., "Determining Model Robustness within a Collaborative User Framework: The Gila-San Francisco Decision Support Tool," Master of Science Thesis, Water Resource Management, University of Nevada, Las Vegas, December 2008.
[9] Forrester, J. W. 1990. Principles of Systems. Productivity Press. Portland, Oregon.
[10] Forrester, J. W. 1986. Lessons from System Dynamics Modeling. System Dynamics Review 3(2): 136-149.
[11] Sun, A., V. Tidwell, G. Klise, L. Malczynski, W. Peplinski, and J. Brainard. 2008. System Dynamics Model of Southwestern New Mexico Hydrology to Assess Impact of the 2004 Arizona Water Settlements Act., pp 1-13. In: Proceedings of the International Conference on System Dynamics, Athens, Greece. 2008.
[12] Powersim Software: www.powersim.com
[13] New Mexico Office of State Engineers Annual Irrigated Acreage and Consumptive Use Report, 1979 to 2005.
[14] University of New Mexico Bureau of Business and Economic Research, http://www.unm.edu/~bber/.
[15] Daniel B. Stephens & Associates, Inc. (2005), Southwest New Mexico Regional Water Plan.
[16] Balleau Groundwater, Inc. (2006), Supplement on Water Use and Wellfield Service – Town of Silver City Water Plan.
[17] Private communication, Office of State Engineers.