System Dynamics Modeling for New Mexico’s Upper Gila and San Francisco Rivers

November 14, 2007

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Gila Water Settlements

• 1964 Gila River Apportionment
  US Supreme Court adopted a stipulation to allow equitable apportionment of Gila River between AZ and NM. NM beneficial use of Gila water (totaling 30,000 AF/yr) is declared and enforced by the OSE.

• 1968 Central Arizona Project (CAP)
  NM is allowed an additional 180,000 AF over any running 10-yr period. This provision did not allow funding for NM to divert add’l 18,000 AF/yr, and did not allow diversion over objections of Sr. downstream users.

• 2004 Arizona Water Settlement Act (AWSA)
  180,000 AF is reduced to 140,000 AF.
  Funding is provided to NM to administer its CAP water.
  Consumptive Use and Forbearance Agreement (CUFA) spells out the terms of NM diversion without objections of downstream users.
On June 3, 1924, at Aldo Leopold's insistence, Gila became the world's first designated Wilderness area (and also New Mexico's largest Wilderness). It is comprised of 558,014 acres and now administered by the USFS.
GSF Agriculture
Elaborate Ditch Conveyance
dating back to 1800s.

- Tributary flow
- Gauge
- Pond/Reservoir

**San Francisco (1889, 1890, 1889, 1900)**

**Lower Frisco (1850, 1900)**

**Romero-Cordova (1885)**

**Higgins (1875)**

**Ditch (1907)**

**Balke (1891)**

**To Alma**
Motivation for Modeling

• **Drivers**
  – **NM Consumptive Use and Forbearance Agreement**
    • additional 140,000 AF of Gila Basin water can be diverted in any ten-year period.
    • $66 and $128 million to be used for efforts related to meeting water demand.
  – **Lower Colorado River Compact.**
  – **Unique ecology in the region.**
  – **Co-existence of agricultural, mining, and human demands.**

• **Objectives**
  – **Create decision support tool to address the following questions:**
    • 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?
  – **Provide a medium for communicating with decision-makers and the public.**
Collaborative Modeling Team

• Implemented an open and transparent model development process:

  Membership is voluntary.
  Participation is required.
  Team develops causal structure of model.
  Team identifies data.
  Sandia develops model.
  Team reviews model and output.

• Team met between October 2005 and July 2007.
• Team met every other week for roughly two hours via WebEx. https://waterportal.sandia.gov
• Face-to-face every quarterly.
• May, June, July 2007 workshops.

GOAL => Public software
Team Composition

- Bureau of Reclamation
- New Mexico Interstate Stream Commission
- US Fish and Wildlife Service
- Municipalities of Silver City and Deming
- Soil and Water Commission representatives from Grant, Catron, and Luna Counties
- The Nature Conservancy
- Gila Conservation Coalition
- Concerned citizens
- Sandia National Laboratories
Meeting Venue
http://waterportal.sandia.gov
SW Structure Follows A Coarse-Grained Physical Description

Reaches Delineated by Flow Gauges and Natural Boundaries
SW/GW Interaction Within Each Reach

- Regional recharge
- Gila River
- Irrigation Diversions
- Canals
- Ag Fields
- ET
- Regional recharge
- Shallow aquifer
- Pumping from regional recharge
- Pumping from shallow aquifer
- Regional recharge
GW Aquifers using GIS, OSE Database

Mimbres Basin Groundwater Sub-basins

Gila Basin GW Alluvial Aquifer Boundary

Legend
- USGS Gauge
- Extent of Alluvial Aquifer in Each Reach

Map of Mimbres Basin Groundwater Sub-basins and Gila Basin GW Alluvial Aquifer Boundary.
What do we mean by System Analysis?

**Mass Balance**

accumulation = In – Out + Rxn

**Feedback**

accum. = In–Out+Rxn+Recycle

**Delay**

In\(_B\) = Out\(_A\)\(t+\Delta t\)

Recycle\(_A\) = Recycle\(_B\) \(t+Dt\)

<table>
<thead>
<tr>
<th>Transient Dynamics</th>
<th>Engineering Models</th>
<th>Hydrology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuity, Mass Balance, Thermodynamics, Fluid Mechanics, Feedback</td>
<td>Continuity, Darcy Flow, Diffusion, Feedback, Delay</td>
<td></td>
</tr>
</tbody>
</table>

| Disturbance, Forcing functions, Exogenous variables | Rxn Kinetics, Start-up/Shut-down, Raw Material | Climate change, land use change, growth, contamination. |

| Likely Sphere of Influence | Technical | Mixed Technical, Political, & Regulatory bodies |

| Time scale | sec-day | month-years |

| Rate Quantity | kg/hr | acre-ft/year |
System dynamics sets the framework for modeling intricate coupling between physical and social systems.

Water Balance within Each Reach

- Surface water hydrology,
- Groundwater hydrology,
- Watershed hydrology,
- Water demand, and
  - Residential/commercial,
  - Industrial/mining,
  - Agricultural/livestock, and
  - Evaporative/riparian
- Institutional constraints.  
  - Compact,
  - CUFA, and
  - Minimum Flow.
- Subreaches are created to capture “critical” sections.
SD using PowerSim
Available Historical Data

USGS, OSE reports, WATERS, GIS, NMDAg
- Historical non-Ag GW use.
- Irrigated land (crop survey.)
- Franks Well Field.
- PD Diversion monthly records.
- Population, city & county
- River Flow
- Ditch Flow
- Temperature
- Livestock
- Well distribution, H2O rights
- Gila Water Commissioner

• SW Planning Report (5-yr intervals)
- Tributaries – Duck creek Peak Flow
  - Mangas creek Peak Flow
  - Blue River
  - Tularosa River, etc.

Calibration window
Gila nr Gila + Mogollon Creek vs Upper Gila Ditch

Gila-Redrock Ditch and River flows

- Gila Gauge Flow, USGS
- Total of UG, FtWest, GFarm, & GHarper from OSE
- Model-2 based on correlation only
Model Calibration

- Dynamics between fluvial and regional aquifers not all captured.
- Tributary contributions from summer monsoon events and snowmelt are missed.
- Upstream peaks may be attenuated downstream.
Temperature and River Data Categories are related. Choose of the three options in one category will automatically set the option in the other category.

The historical hydrograph and temperature data at each gauge vary between 1979 and 2005.

The average hydrograph is derived from all the data between 1955 and 2005.

URGWOP stands for Upper Rio Grande Water Operations and Planning Study. In that study historical data was re-ordered by year to create a drought sequence, a short wet sequence, and a long wet sequence. Comparison of Rio Grande data with that of the Gila-San Francisco Basins suggests a correlation such that wet years along the Rio Grande tend to be wet in southwest New Mexico too. It is similar with dry years. Here we order the Gila-San Francisco hydrographs to follow the URGWOPS pattern. It may allow for some comparison between models in the future. If the starting year is 2006, then drought happens 2009-2018 and wet years are 2019-2023 and 2026-2037.
When Ag demand switch is ON, the minimum flow accounts for the compounding effects of agricultural diversions that the OSE commits to the farmers in the GSF region. This is added to the model when accounting for minimum flow.

Choose Type of Minimum Flows
- Use Season Variable Flows
- Use Constant Flows

San Francisco River Basin
- Upper San Francisco Minimum
  - 150 cfs Fall
  - 150 cfs Winter
  - 150 cfs Spring
  - 150 cfs Summer
- Modify Upper San Francisco

Gila River Basin
- Upper Gila Minimum
  - 150 cfs Fall
  - 150 cfs Winter
  - 150 cfs Spring
  - 150 cfs Summer
- Modify Upper Gila

Gila-Redrock
- Gila-Redrock Minimum
  - 150 cfs Fall
  - 150 cfs Winter
  - 150 cfs Spring
  - 150 cfs Summer
- Modify Gila-Redrock

Redrock-Virden
- Redrock-Virden Minimum
  - 150 cfs Fall
  - 150 cfs Winter
  - 150 cfs Spring
  - 150 cfs Summer
- Modify Redrock-Virden

Virden-Clifton
- Virden-Clifton Minimum
  - 150 cfs Fall
  - 150 cfs Winter
  - 150 cfs Spring
  - 150 cfs Summer
- Modify Virden-Clifton

DRAFT
Version: 20071016
20-year Summary – SF Diversion OFF

Baseline Summary is the 20-year summary based on default values of input parameters.

<table>
<thead>
<tr>
<th>Area</th>
<th>Gila SW Ag</th>
<th>SF SW Ag</th>
<th>Gila GW Ag</th>
<th>SF GW Ag</th>
<th>Mimbres GW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>188,475 AF</td>
<td>41,428 AF</td>
<td>81,525 AF</td>
<td>18,193 AF</td>
<td>559,504 AF</td>
</tr>
<tr>
<td>Current</td>
<td>188,475 AF</td>
<td>41,428 AF</td>
<td>81,525 AF</td>
<td>18,193 AF</td>
<td>559,504 AF</td>
</tr>
</tbody>
</table>

Non-Agriculture Water Demand by Area

<table>
<thead>
<tr>
<th>Area</th>
<th>Gila Non-Ag</th>
<th>SF Non-Ag</th>
<th>Mimbres Non-Ag</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>189,532 AF</td>
<td>20,169 AF</td>
<td>608,663 AF</td>
</tr>
<tr>
<td>Current</td>
<td>189,532 AF</td>
<td>20,169 AF</td>
<td>608,663 AF</td>
</tr>
</tbody>
</table>

Potential Annual Diversion under CUFA (no min flow)

<table>
<thead>
<tr>
<th></th>
<th>Total</th>
<th>Potential Gila</th>
<th>Potential SF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>13,333 AF</td>
<td>13,333 AF</td>
<td>0 AF</td>
</tr>
<tr>
<td>Current</td>
<td>13,333 AF</td>
<td>13,333 AF</td>
<td>0 AF</td>
</tr>
</tbody>
</table>

Baseline Summary is the 20-year summary based on default values of input parameters.
20-year Summary – SF Diversion ON

Baseline Summary is the 20-year summary based on default values of input parameters.

Projections of Water Supply & Demand

Baseline Summary

Gila SW Ag: 188,475 AF
SF SW Ag: 41,428 AF
Gila GW Ag: 81,525 AF
SF GW Ag: 18,193 AF
Mimbres GW: 559,504 AF

Potential Annual Diversion under CUFA (no min flow)

Total: 13,333 AF
Potential Gila: 10,558 AF
Potential SF: 2,773 AF

Non-Agriculture Water Demand by Area

Baseline Summary

Gila Non-Ag: 189,532 AF
SF Non-Ag: 20,169 AF
Mimbres Non-Ag: 608,663 AF

SF Diversion ON

current run

baseline run
20-year Summary – SF Diversion OFF

Daily Total River Flow vs. Total New Mexico Daily Diversion Right (NMDDR)

Yearly Cumulative Diversion

10-year Cumulative Diversion

- If the minimum flow control is set at CONSTANT, there is no differentiation amongst diversion locations.

CUFA Model Draft Version: 20071016

Location with Min Flow
Gila-Redrock
Plotted in Red

Return
### Tables

#### Gila GW

<table>
<thead>
<tr>
<th>Category</th>
<th>Avg Annual Rate</th>
<th>Total Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domestic Wells</td>
<td>20 AF/year</td>
<td>413 AF</td>
</tr>
<tr>
<td>DNC Wells</td>
<td>1,818 AF/year</td>
<td>35,483 AF</td>
</tr>
<tr>
<td>Municipality</td>
<td>657 AF/year</td>
<td>14,241 AF</td>
</tr>
<tr>
<td>GW to Mimbres</td>
<td>951 AF/year</td>
<td>17,865 AF</td>
</tr>
<tr>
<td>Commercial</td>
<td>2,183 AF/year</td>
<td></td>
</tr>
<tr>
<td>Livestock</td>
<td>3,206 AF/year</td>
<td></td>
</tr>
<tr>
<td>Mining</td>
<td>392 AF/year</td>
<td></td>
</tr>
<tr>
<td>Supplemental Ag</td>
<td>4,692 AF/year</td>
<td></td>
</tr>
</tbody>
</table>

#### Mimbres GW

<table>
<thead>
<tr>
<th>Category</th>
<th>Avg Annual Rate</th>
<th>Total Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mimbres Irrigation</td>
<td>24,048 AF/year</td>
<td>559,504 AF</td>
</tr>
<tr>
<td>Mimbres Population</td>
<td>13,929 AF/year</td>
<td>258,596 AF</td>
</tr>
<tr>
<td>Mimbres Industrial</td>
<td>15,254 AF/year</td>
<td>320,316 AF</td>
</tr>
<tr>
<td>Mimbres Livestock</td>
<td>1,416 AF/year</td>
<td>29,752 AF</td>
</tr>
</tbody>
</table>

#### Tests

<table>
<thead>
<tr>
<th>Test</th>
<th>Test Description</th>
<th># False</th>
<th>% True</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test 1</td>
<td>San Carlos &gt;= 30K AF</td>
<td>766</td>
<td>90 %</td>
</tr>
<tr>
<td>Test 2</td>
<td>Sum of Flows &gt; DDB</td>
<td>4,410</td>
<td>43 %</td>
</tr>
<tr>
<td>Test 3</td>
<td>GilaVirden &gt; 120% Call for DV</td>
<td>335</td>
<td>96 %</td>
</tr>
<tr>
<td>Test 4</td>
<td>Sum of Diversions &lt; DD Right</td>
<td>0</td>
<td>100 %</td>
</tr>
<tr>
<td>Test 5</td>
<td>Allowable Diversion &lt; 350 cfs</td>
<td>860</td>
<td>89 %</td>
</tr>
<tr>
<td>Test 6</td>
<td>SF Clifton &gt;= SF Minimum Flow</td>
<td>5,100</td>
<td>34 %</td>
</tr>
</tbody>
</table>

#### SF Diversion Rights

<table>
<thead>
<tr>
<th>Category</th>
<th>Avg Annual Rate</th>
<th>Total Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>SF Acreage</td>
<td>857 acre</td>
<td></td>
</tr>
<tr>
<td>SF Ag CU</td>
<td>1,471 AF/year</td>
<td>31,165 AF</td>
</tr>
<tr>
<td>SF Ag Seepage</td>
<td>454 AF/year</td>
<td>9,620 AF</td>
</tr>
<tr>
<td>SF Ag Open Evap</td>
<td>30 AF/year</td>
<td>643 AF</td>
</tr>
<tr>
<td>SF Diversion Rights</td>
<td>2,315 AF/year</td>
<td>48,614 AF</td>
</tr>
</tbody>
</table>
Information Sharing

Questions?
The Gila San Francisco Decision Support Tool is a draft model that can not be used, disseminated, and applied without the consent of the Gila San Francisco Collaborative Modeling Team. It is a research tool that is intended for educating stakeholders, the interested public, and the modeling team. If you have any questions regarding the use of this tool, please contact Vince Tidwell, vctidwe@sandia.gov
The volume of water in the combined Gila-Mimbres River Basins owned by mining is 42,539 AF (maximum 44,572 AF) per year. The table in the information provides the exact split between Gila and Mimbres basin. Changes in the leased values take effect on October 1 of any given year.
The CUFA model will calculate the allowable diversion using either the streamflow values recorded by the USGS for the historical period in question or values calculated by the River Routing portion of this model for some of the streamflow sites. The sites that are calculated are:

- 09432000 Gila River below Blue Creek, near Virden
- 09444500 San Francisco River at Clifton
- 09448500 Gila River at head of Safford Valley

Based on historical data of the Duncan-Virden call from '99 to October '06, an average monthly call volume was computed and used in setting the CUFA constraint.
9,000 mi² drainage area

GILA - SAN FRANCISCO BASIN
NM CAP Bank for Gila Minimum Flow

Graph Control
- Gila-Redrock
  - Plotted in Red

View 1 Year Detail
View 5 Year Detail

NM CAP Bank with SF Minimum Flow

Graph Control
- Upper San Francisco
  - Plotted in Red

View 1 Year Detail
View 5 Year Detail