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

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Geohydrology

Sandia National Laboratories

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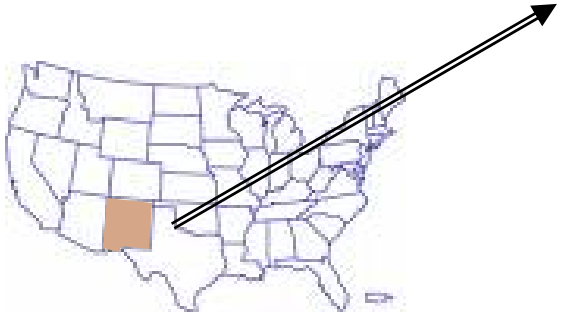
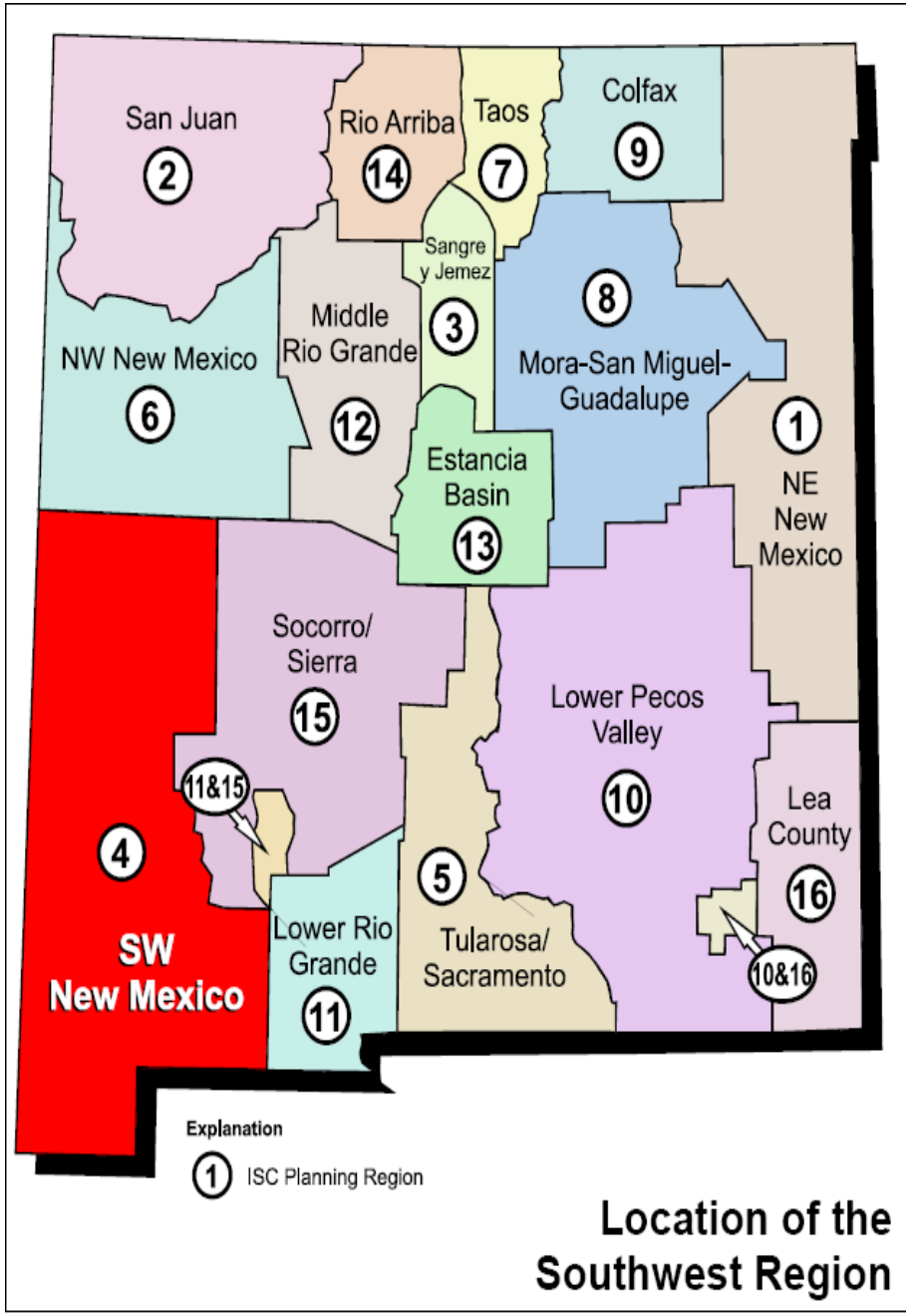
Water Planning in New Mexico





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.

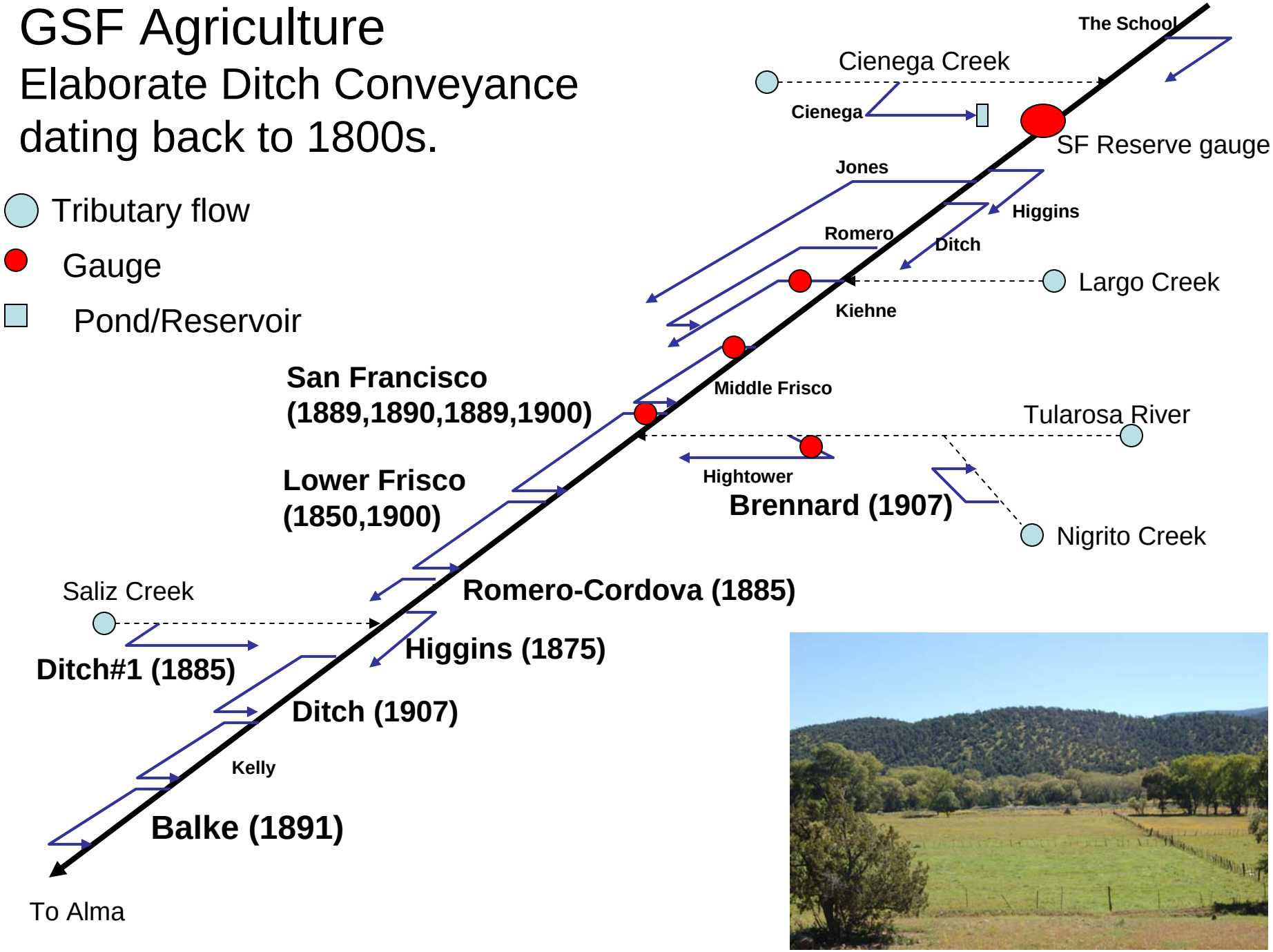
  Consumptive Use and Forbearance Agreement (CUFA) spells out the terms of NM diversion without objections of downstream users.

Other Context

- 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.



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

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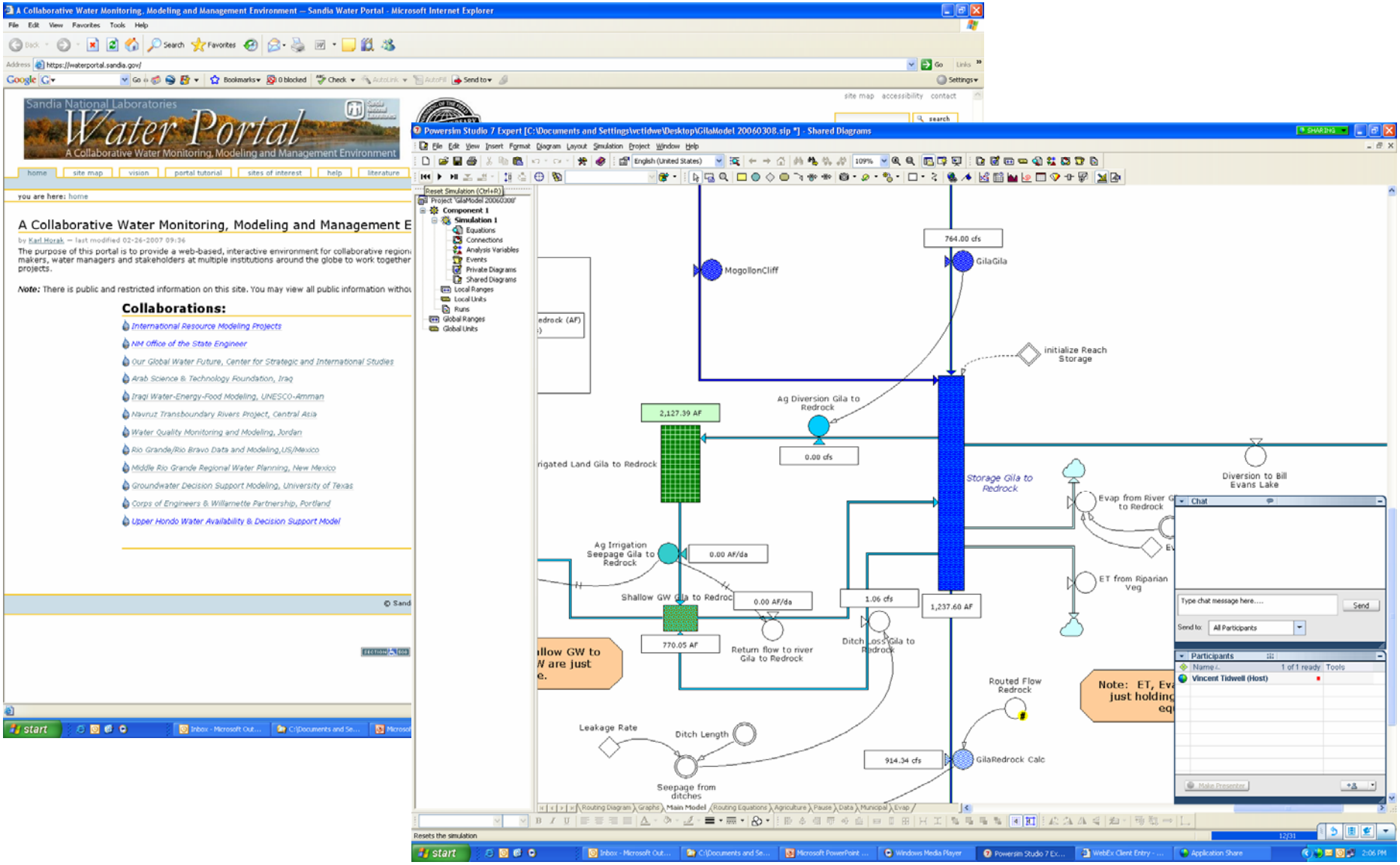
Team Composition

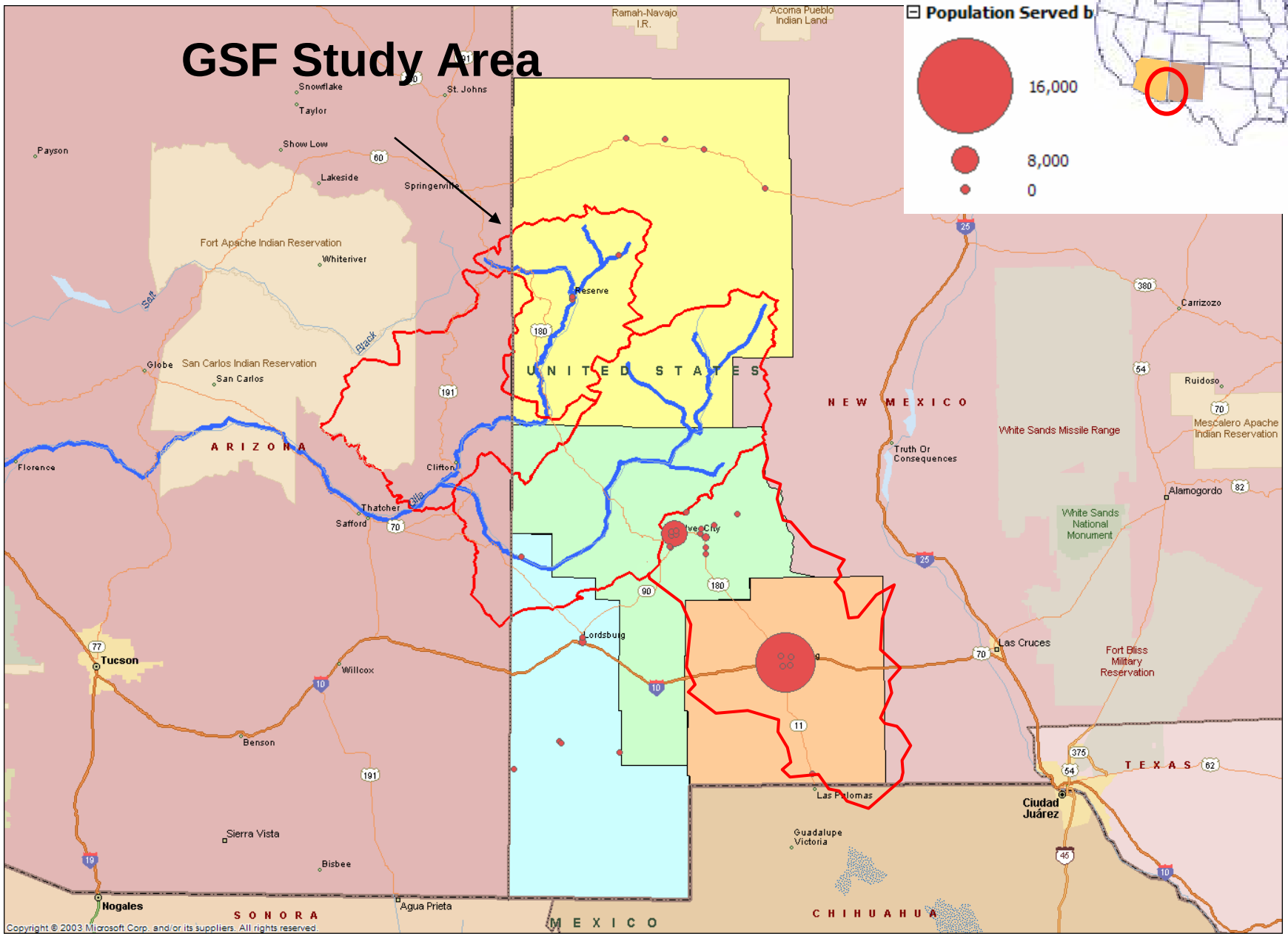
- Bureau of Reclamation
- New Mexico Interstate Stream Commission
- US Fish and Wildlife Service
- Municipalities of Silver City and Deming
- Soil and Water Commission representatives from Grant, Catron, and Luna Counties
- The Nature Conservancy
- Gila Conservation Coalition
- Concerned citizens
- Sandia National Laboratories

Meeting Venue

http://waterportal.sandia.gov

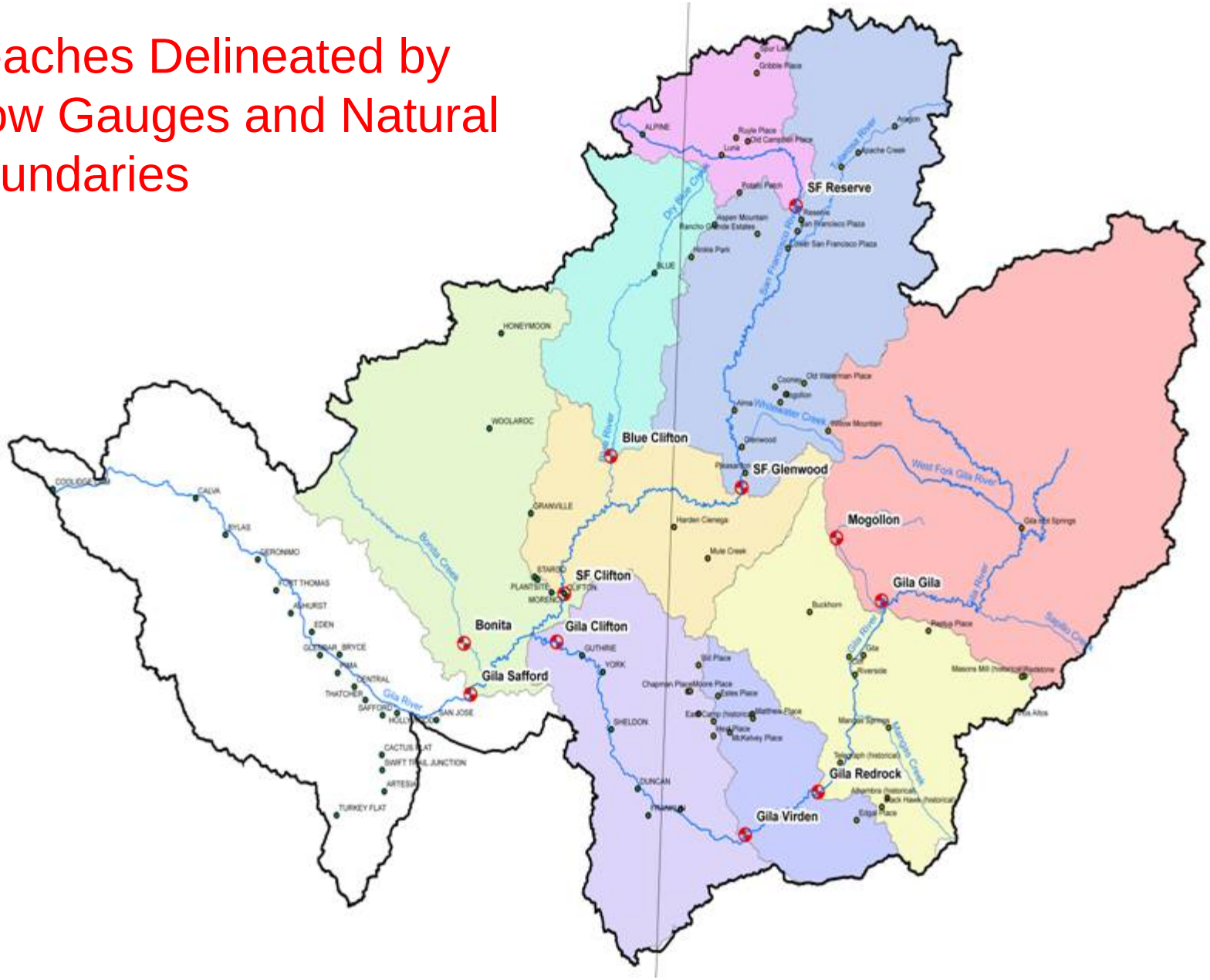


GSF Study Area

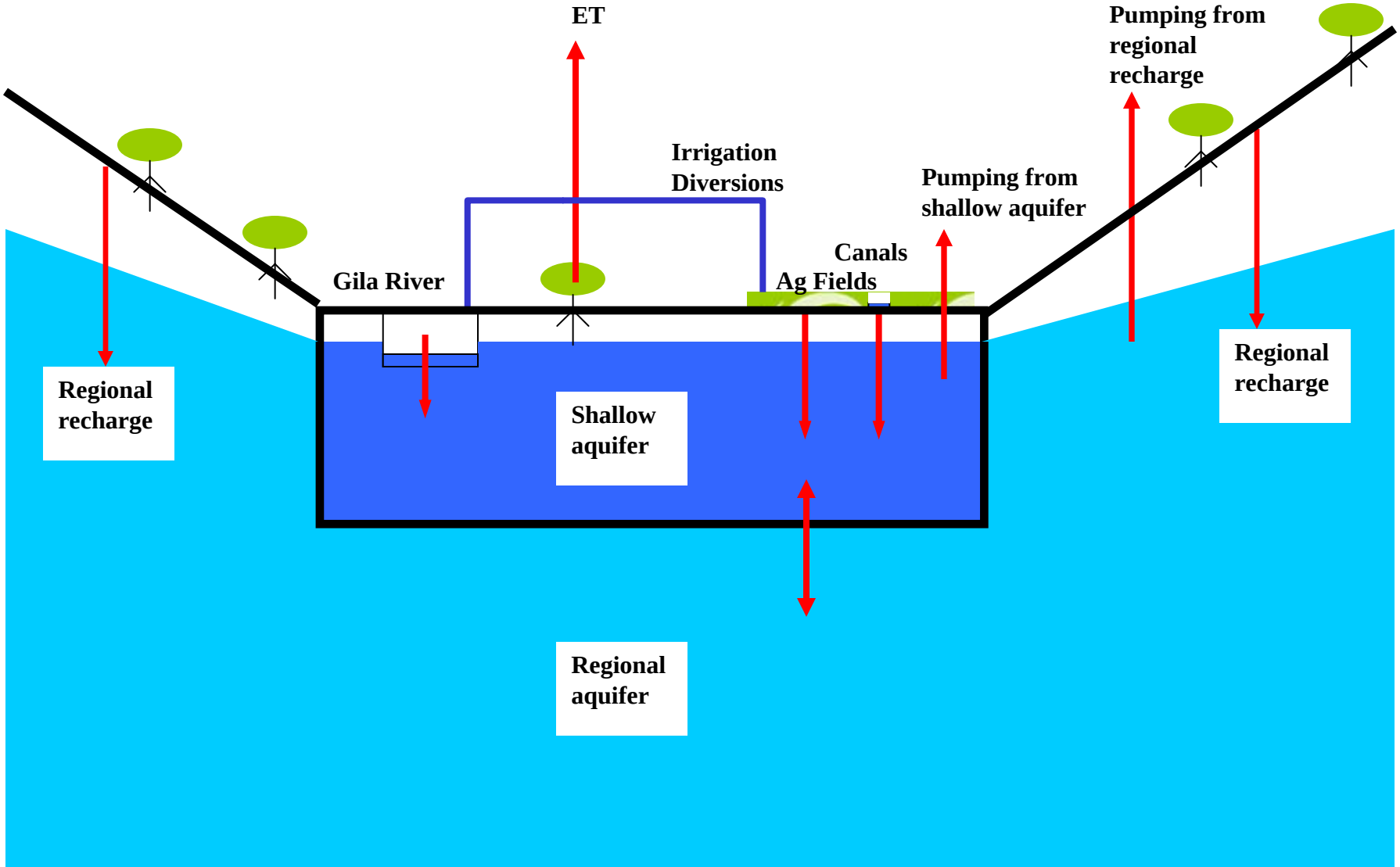


SW Structure Follows A Coarse-Grained Physical Description

Reaches Delineated by Flow Gauges and Natural Boundaries

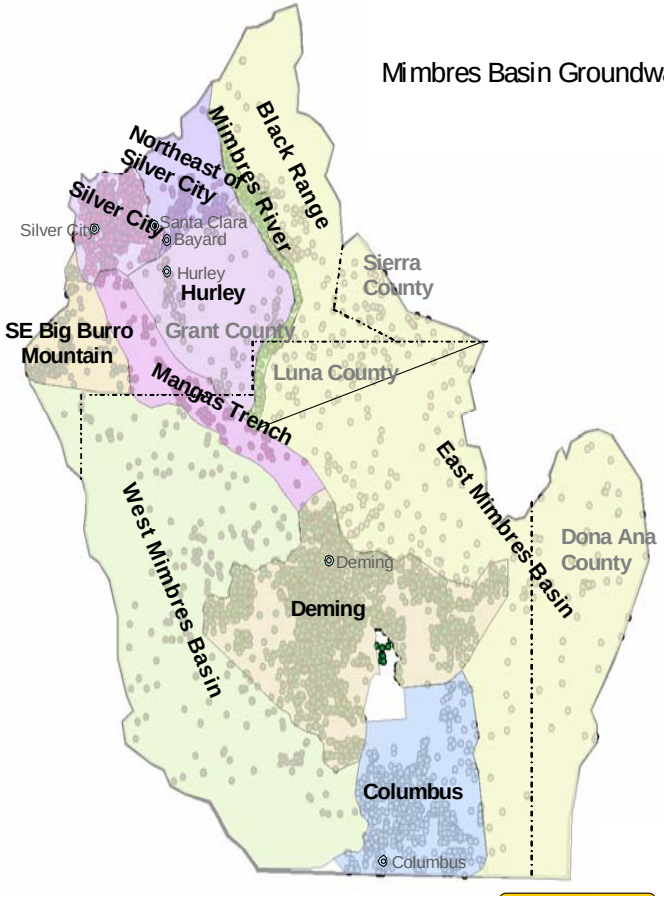


SW/GW Interaction Within Each Reach

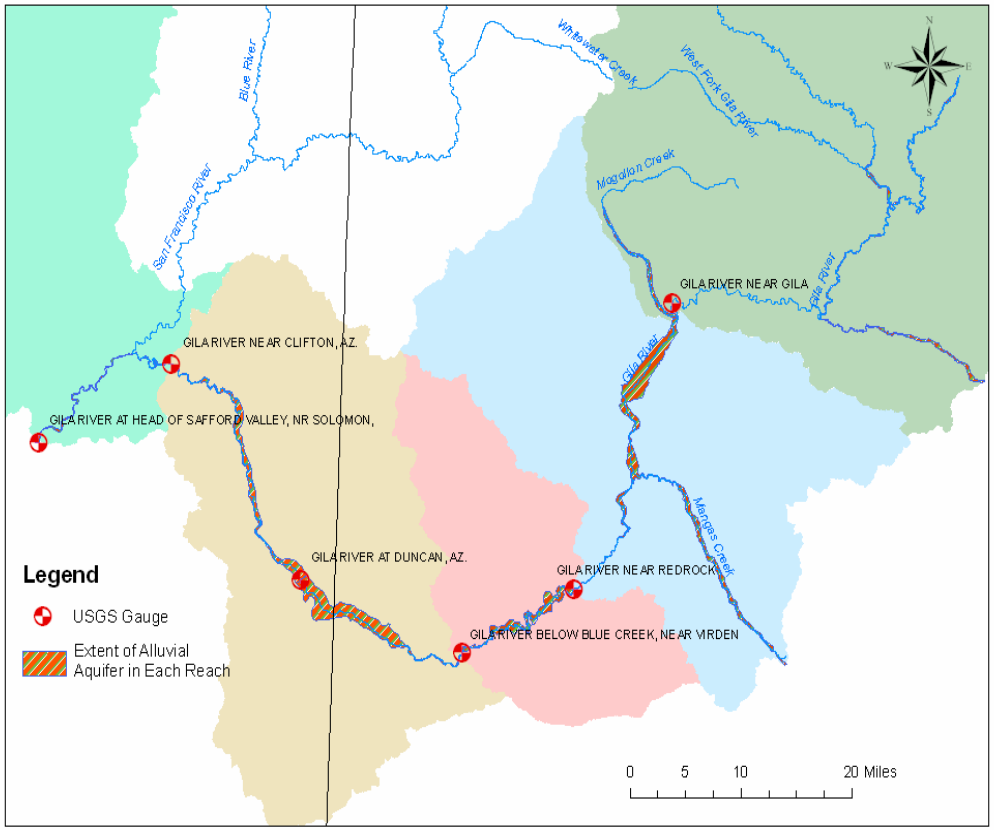


GW Aquifers using GIS, OSE Database

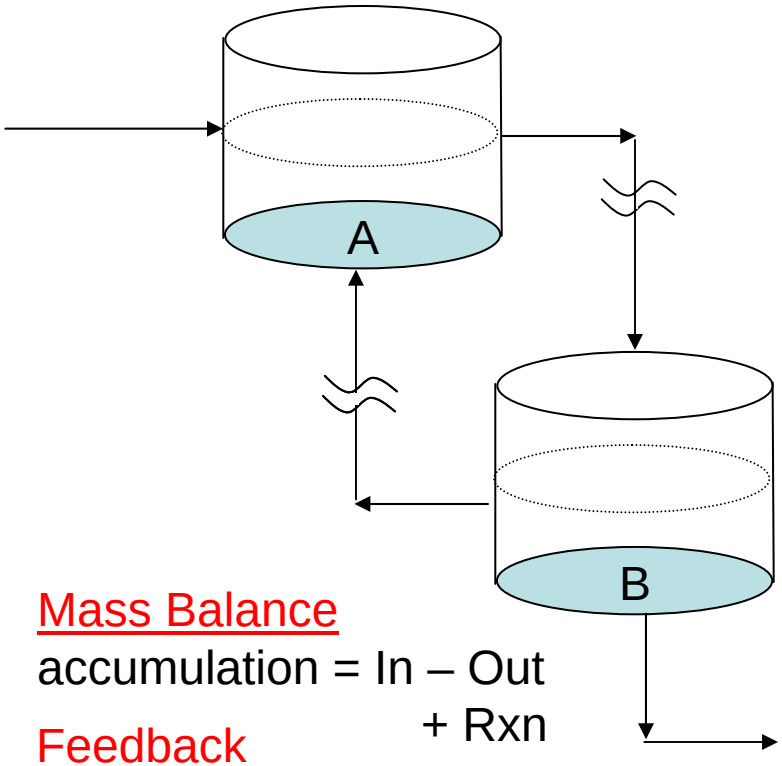
Mimbres Basin Groundwater Sub-basins



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 $In_B = Out_A(t+\Delta t)$

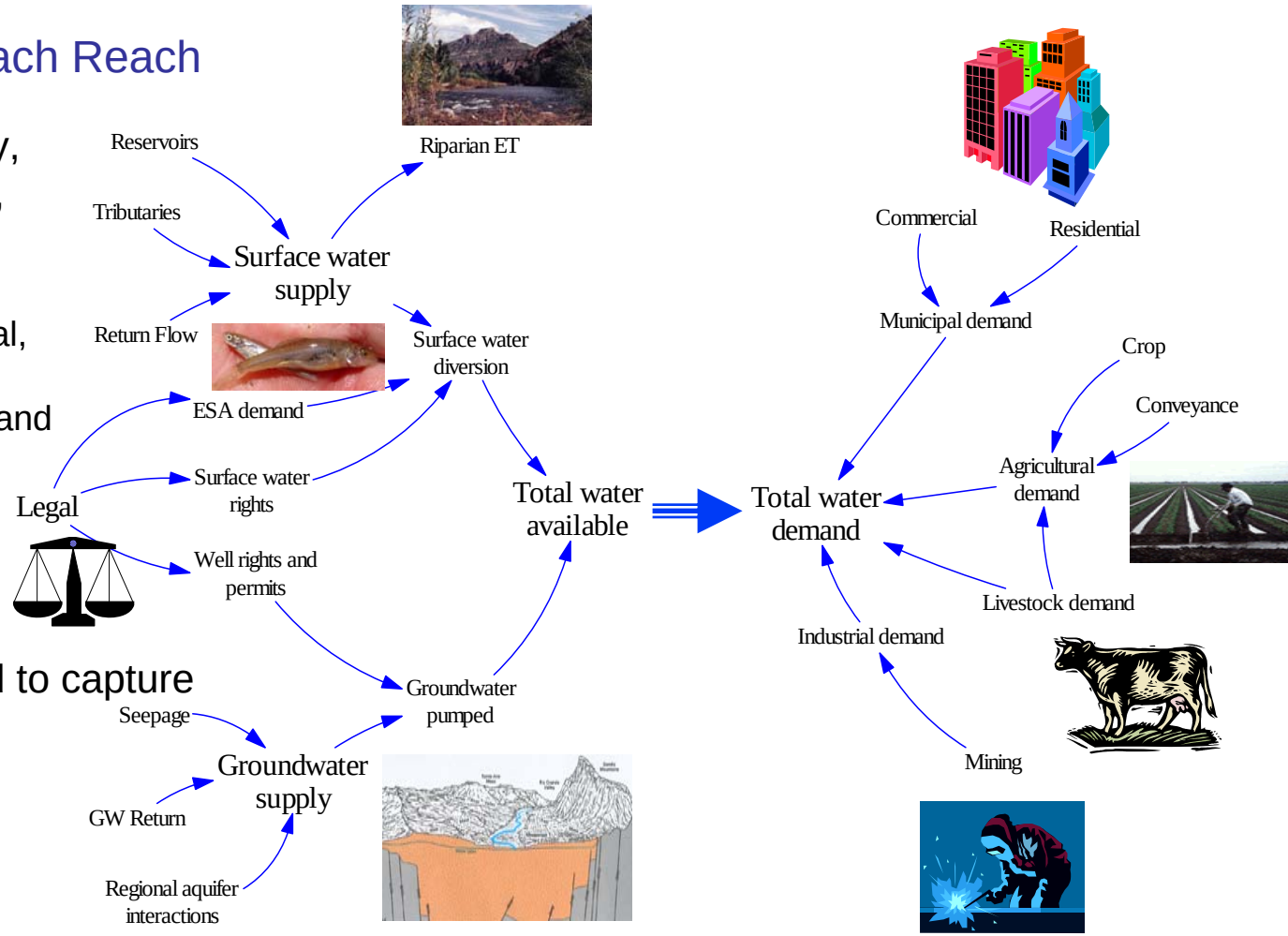
$Recycle_A = Recycle_B\ (t+Dt)$

	Engineering Models	Hydrology
Transient Dynamics	**Continuity, Mass Balance, Thermodynamics, Fluid Mechanics, Feedback**	**Continuity, Darcy Flow, Diffusion, Feedback, Delay**
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**

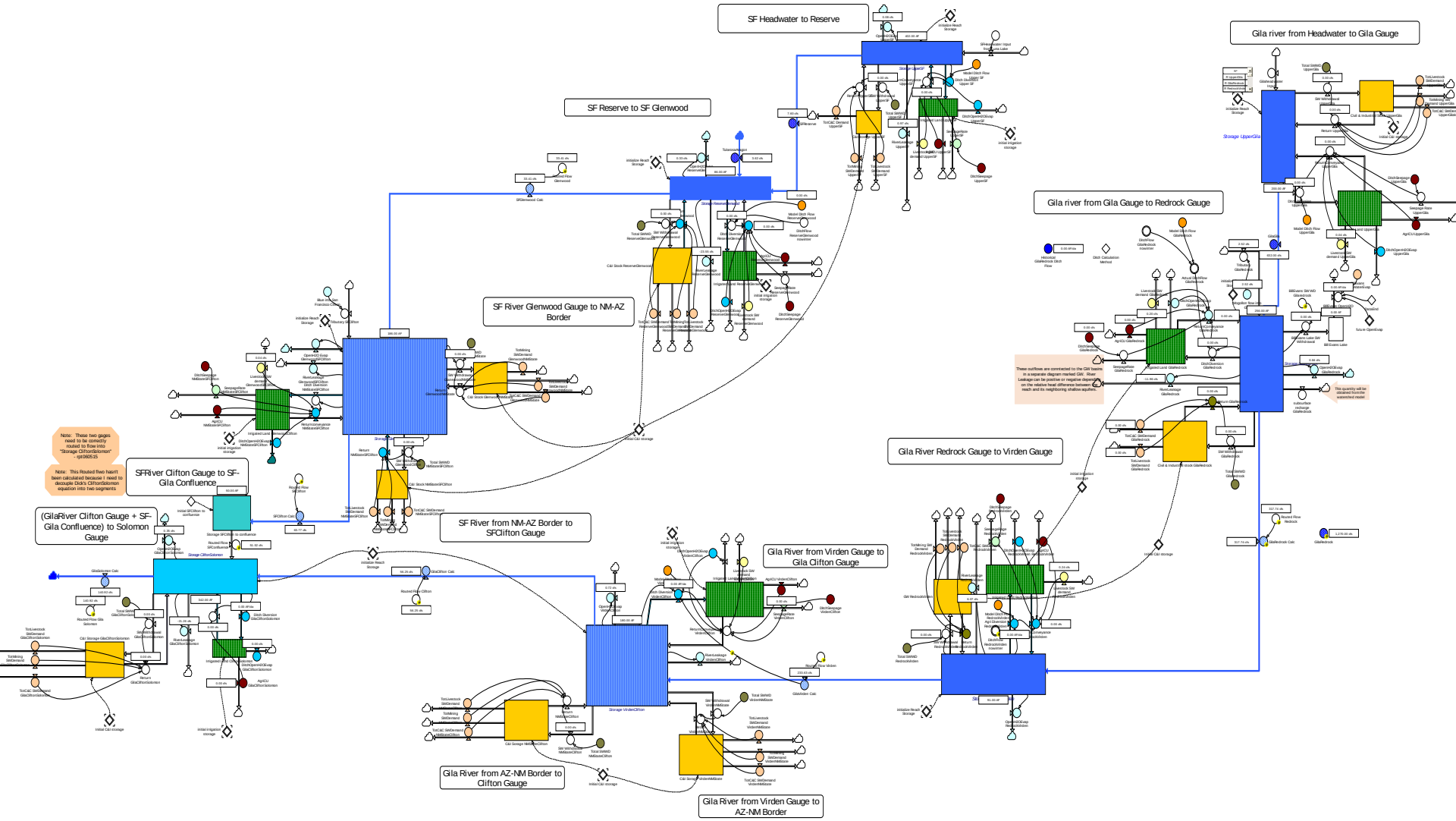
System dynamics sets the framework for modeling intricate coupling between physical and social systems

Water Balance within Each Reach

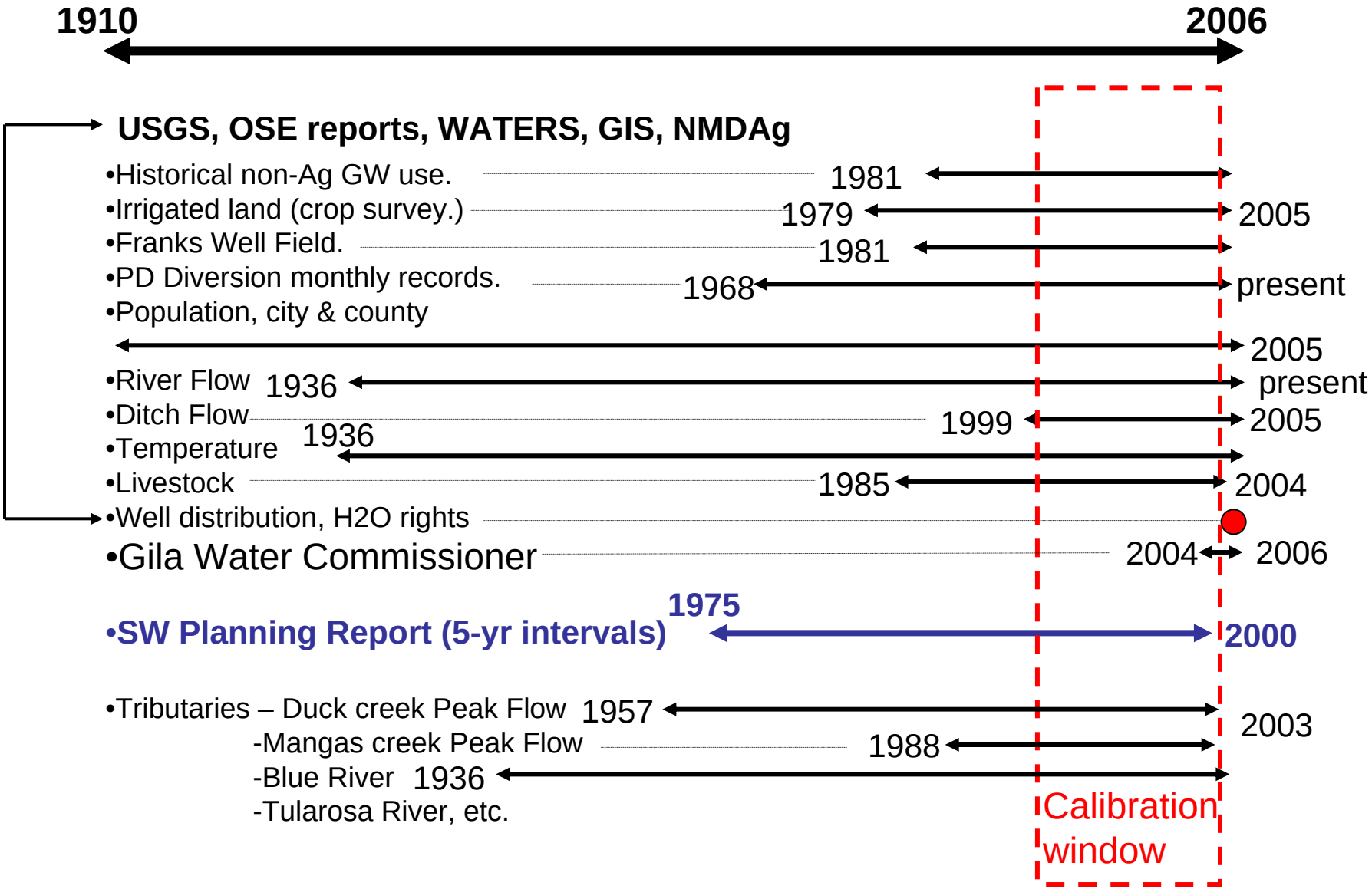
- Surface water hydrology,
- Groundwater hydrology,
- Watershed hydrology,
- Water demand, and
  - Residential/commercial,
  - Industrial/mining,
  - Agricultural/livestock, and
  - Evaporative/riparian
- Institutional constraints.
  - Compact,
  - CUFA, and
  - Minimum Flow.
- Subreaches are created to capture "critical" sections.



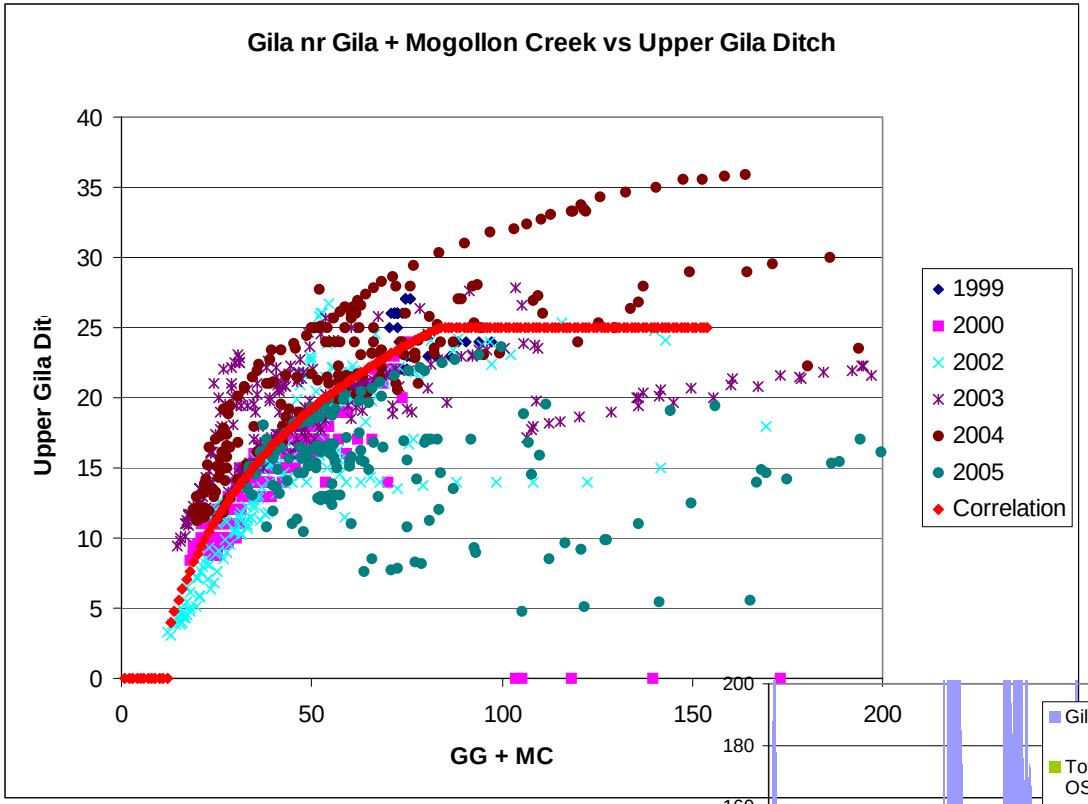
SD using PowerSim

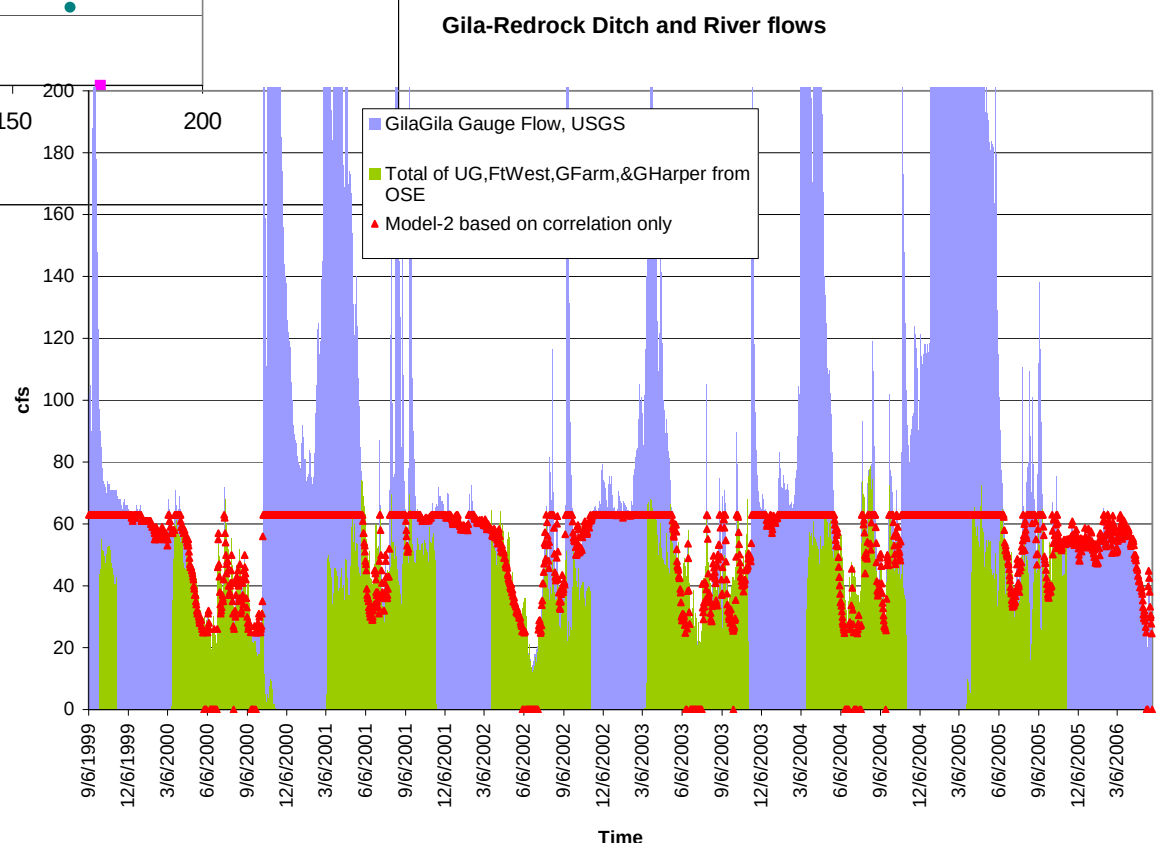


Available Historical Data



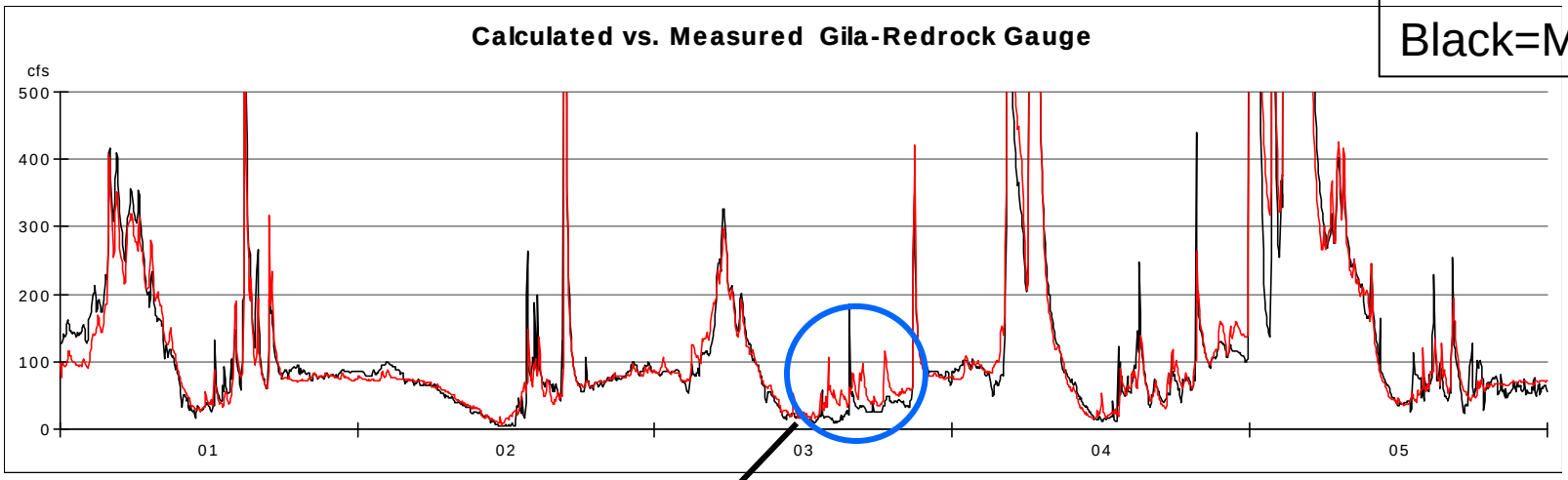
Ditch-River correlation





Model Calibration

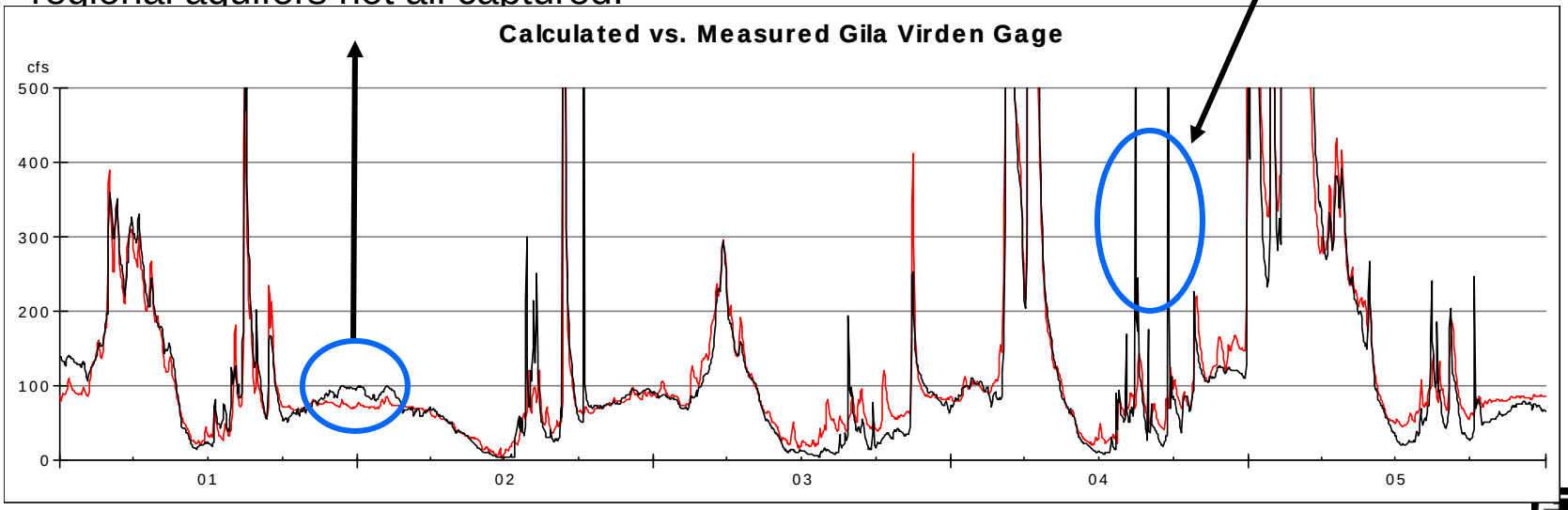
RED=Calculated
Black=Measured



- Upstream peaks may be attentuated downstream.

- Tributary contributions from summer monsoon events and snowmelt are missed

- Dynamics between fluvial and regional aquifers not all captured.



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User Control

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Climate Options and Controls

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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 bewteen 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.

Future River Flow Data

- Repeat Historical Hydrograph Data
- Use Average Annual Hydrograph
- Use 40 Year URGWOPS Sequence

Future Temperature Data

- Repeat Historical Temperature Data
- Use Average Temperature
- Use 40 Year URGWOPS sequence

Increase / Decrease Hydrograph by Percent

-100 -80 -60 -40 -20 0 20 40 60 80 100
%

0 %

Add or Subtract CFS on Hydrograph

-50 -40 -30 -20 -10 0 10 20 30 40 50
cfs

0 cfs

Percent Temp Perturbation

-15 -13 -11 -9 -7 -5 -3 -1 1 3 5 7 9 11 13 15
%

0 %

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Minimum River Flows

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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.

Ag Demand is Currently

- OFF
- ON

Choose Type of Minimum Flows

- Use Season Variable Flows
- Use Constant Flows

San Francisco Constant Potential Flow — 10 cfs

5 10 15 20 25 30 35 40 45 50
cfs

Gila Constant Potential Flow — 150 cfs

10 30 50 70 90 110 130 150 170 190
cfs

San Francisco River Basin

Upper San Francisco Minimum	
150 cfs	Fall
150 cfs	Winter
150 cfs	Spring
150 cfs	Summer

Reserve-Glenwood Minimum	
150 cfs	Fall
150 cfs	Winter
150 cfs	Spring
150 cfs	Summer

Glenwood-Clifton Minimum	
150 cfs	Fall
150 cfs	Winter
150 cfs	Spring
150 cfs	Summer

Modify Upper San Franciscso | Modify Reserve-Glenwood | Modify Glenwood-Clifton

Gila River Basin

Upper Gila Minimum	
150 cfs	Fall
150 cfs	Winter
150 cfs	Spring
150 cfs	Summer

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

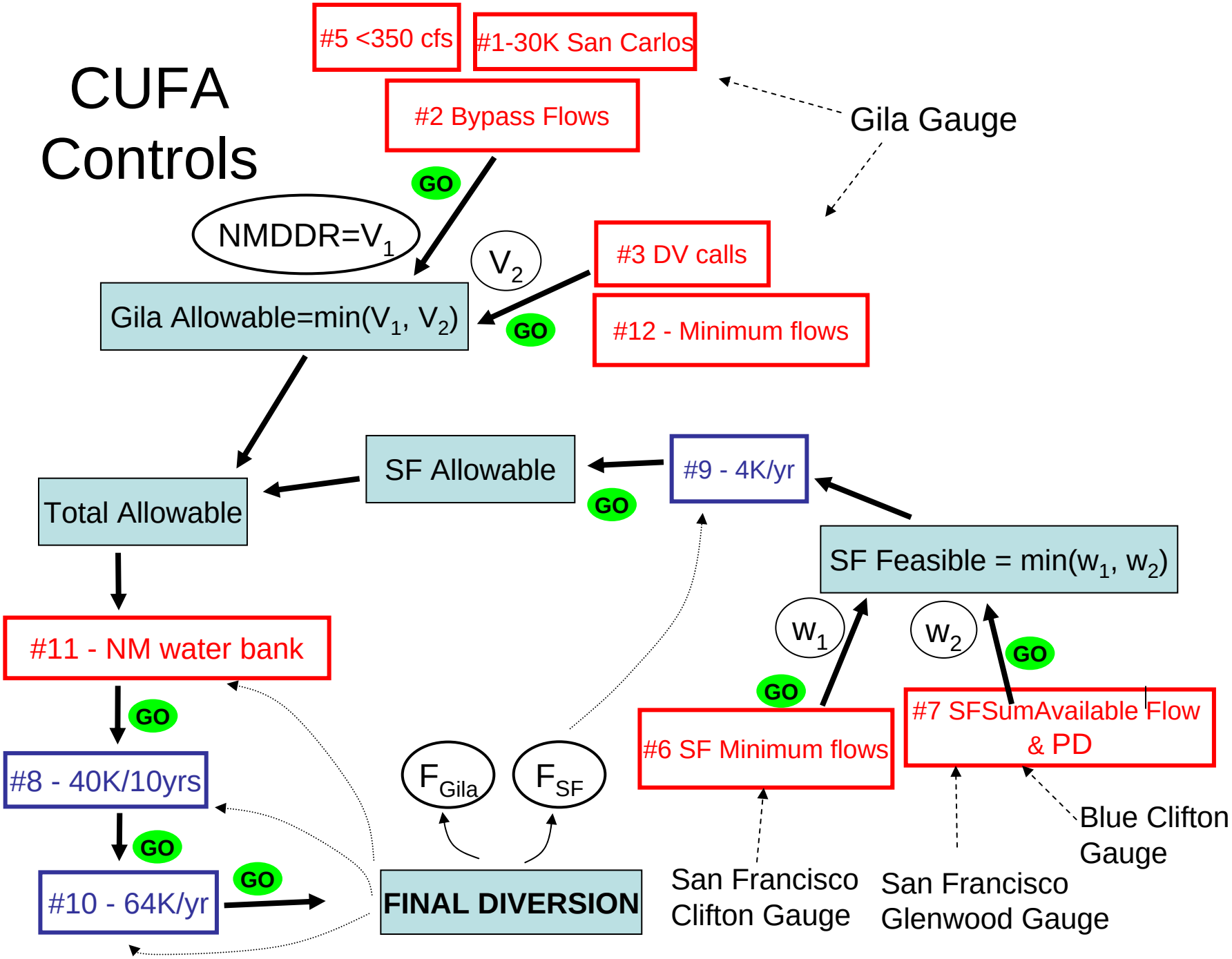
Redrock-Virden Minimum	
150 cfs	Fall
150 cfs	Winter
150 cfs	Spring
150 cfs	Summer

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

Modify Upper Gila | Modify Gila-Redrock | Modify Redrock-Virden | Modify Virden-Clifton

Return to Top | Return to CUFA

CUFA Controls



20-year Summary – SF Diversion OFF

GSF Decision Support Tool

GSF Basin SW Hydrology

GSF SW Irrigation Summary

GSF GW Summary

Mimbres GW Summary

CUFA Summary

Projections of Water Supply & Demand

baseline run

current run

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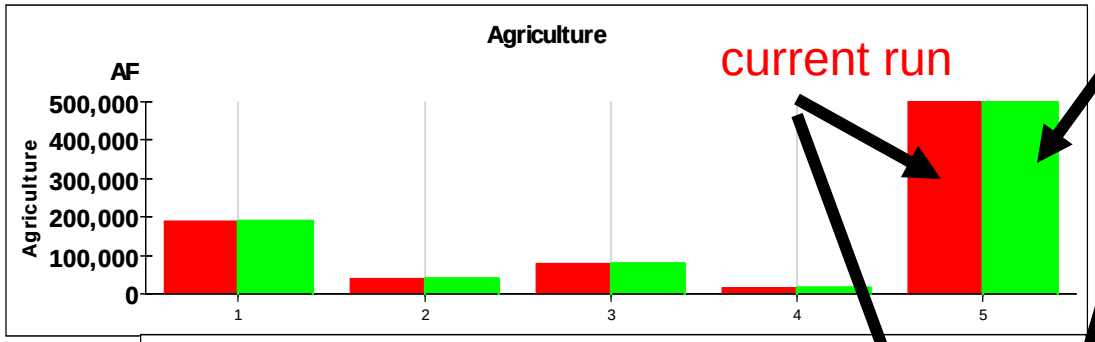
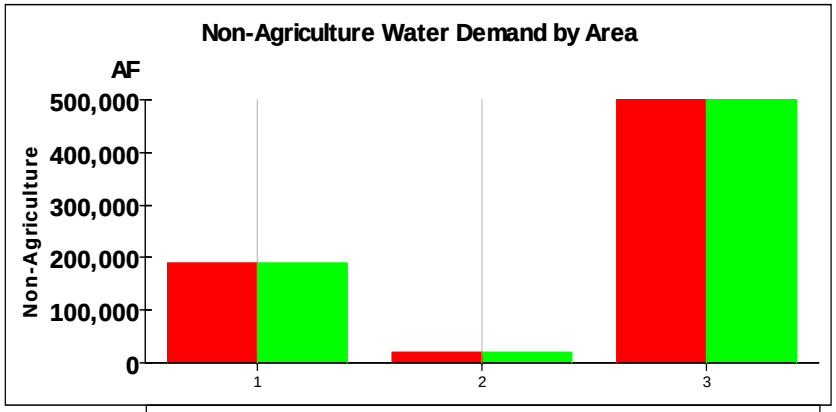
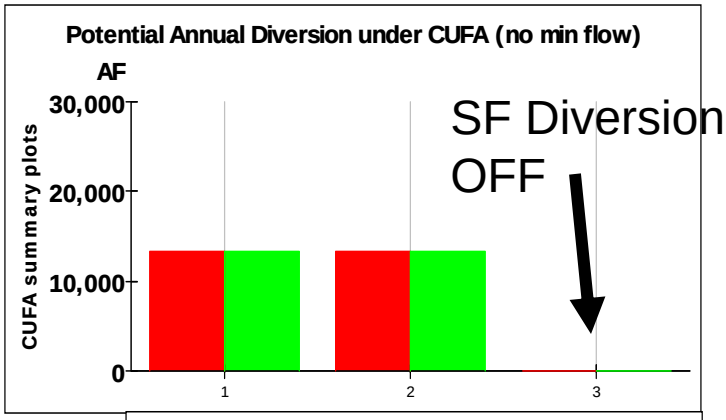


BASELINE SUMMARY

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

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





BASELINE SUMMARY

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

Baseline Summary

Total	Potential Gila	Potential SF
13,333 AF	13,333 AF	0 AF
13,333 AF	13,333 AF	0 AF

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20-year Summary – SF Diversion ON

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Projections of Water Supply & Demand

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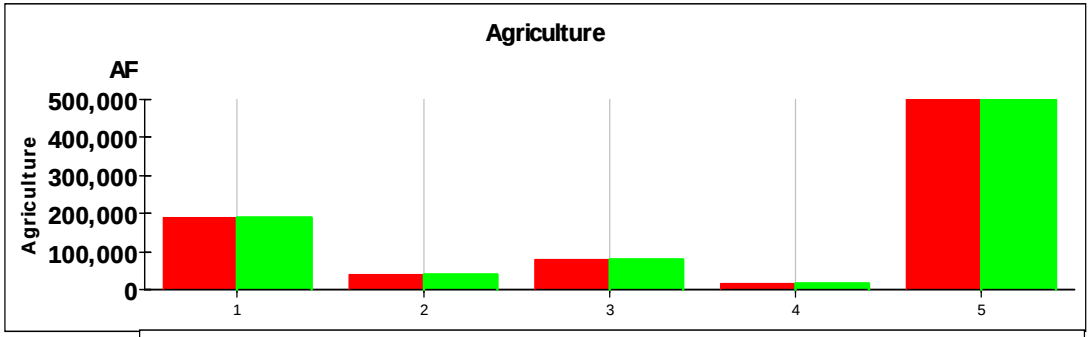
GSF Basin SW Hydrology

GSF SW Irrigation Summary

GSF GW Summary

Mimbres GW Summary

CUFA Summary



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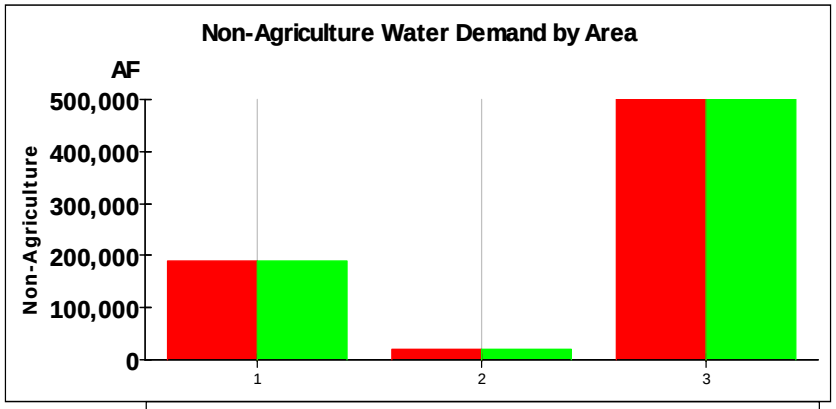

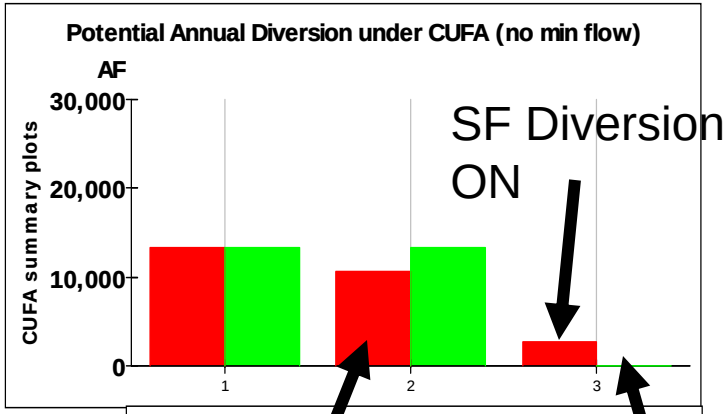

BASELINE SUMMARY

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

Baseline Summary

Total	Potential Gila	Potential SF
13,333 AF	10,558 AF	2,773 AF
13,333 AF	13,333 AF	0 AF

current run

baseline run

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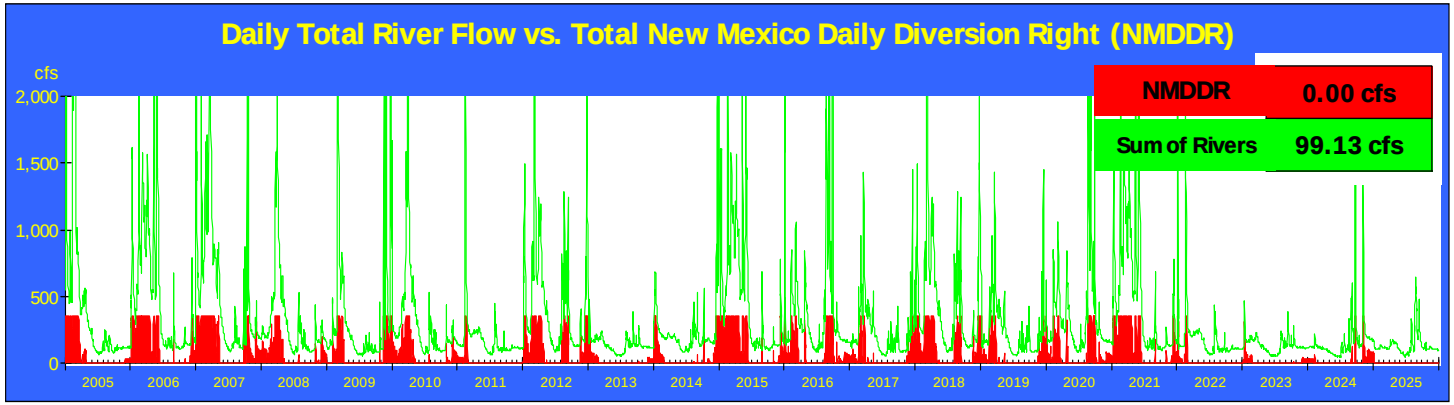
20-year Summary – SF Diversion OFF



CUFA Model
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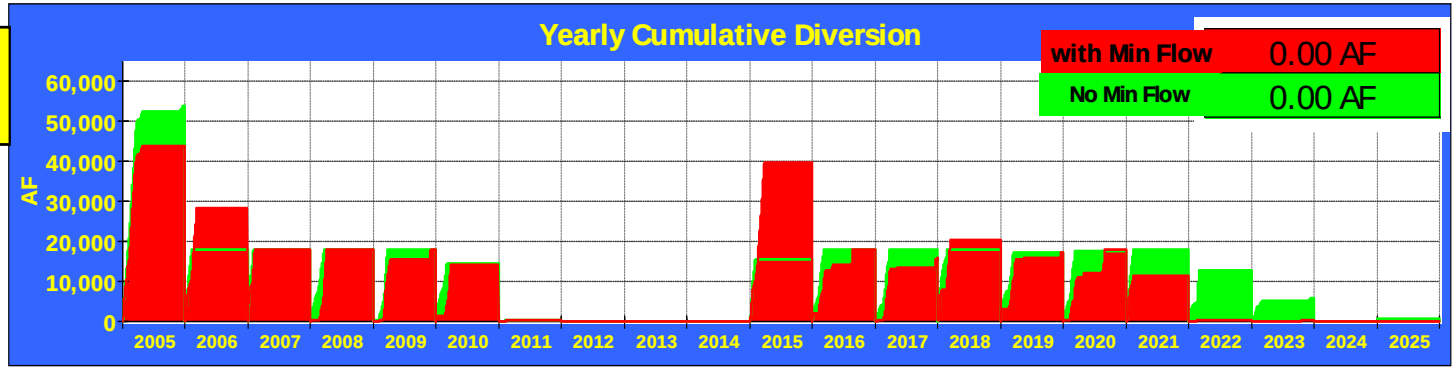
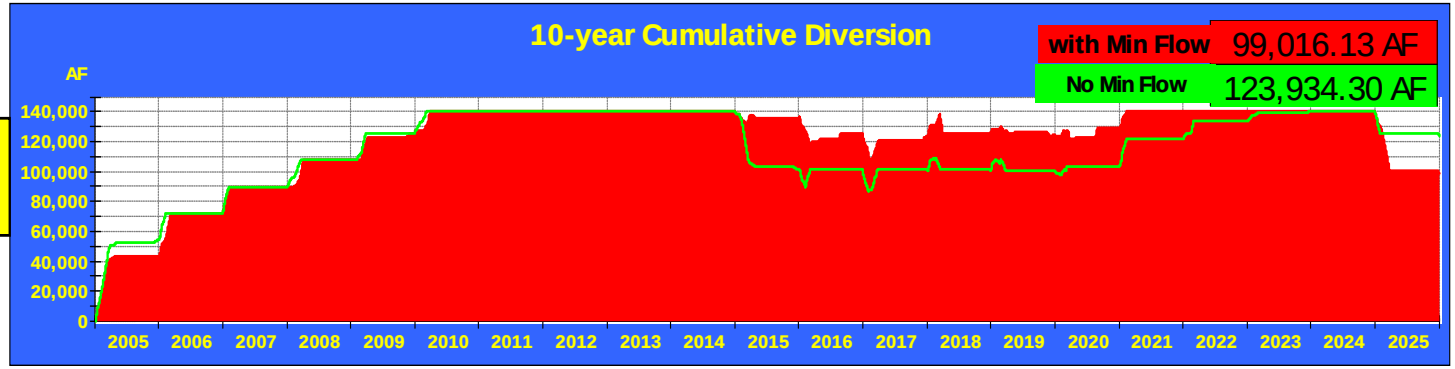
Location with Min Flow
Gila-Redrock
Plotted in Red

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



Location with Min Flow
Gila-Redrock
Plotted in Red



Return

Tables

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

	Avg Annual Rate	Total Volume
SF Acreage	857 acre	
SF Ag CU	1,471 AF/year	31,165 AF
SF Ag Seepage	454 AF/year	9,620 AF
SF Ag Open Evap	30 AF/year	643 AF
SF Diversion Rights	2,315 AF/year	48,614 AF

Mimbres GW	Avg	
Mimbres Irrigation	24,	
Mimbres Population	13,929 AF/year	258,596 AF
Mimbres Industrial	15,254 AF/year	320,316 AF
Mimbres Livestock	1,416 AF/year	29,752 AF

Tests

1	1	2026

Days: 7,671

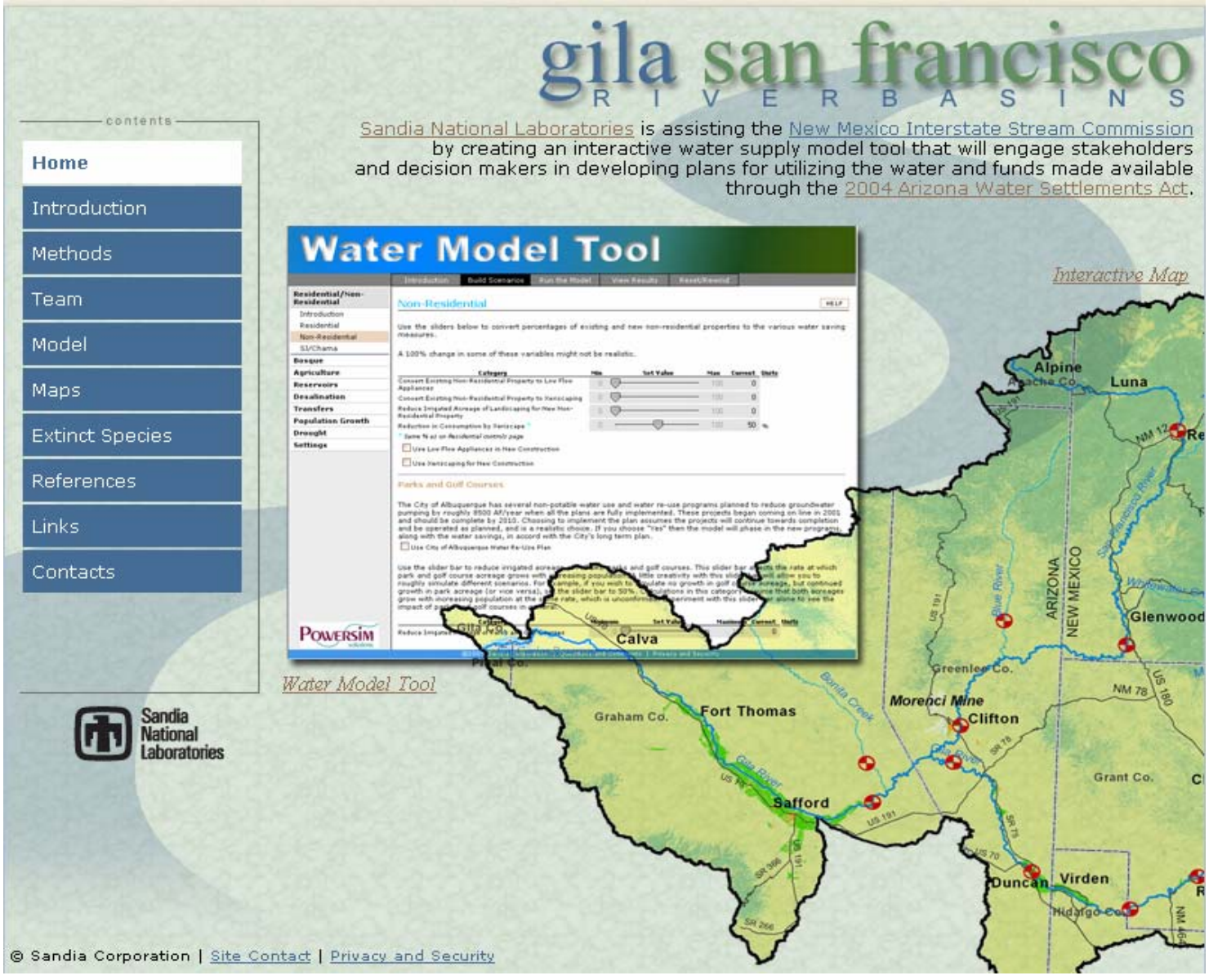
Tests - ON or OFF

1 2 3 4 5 6 7 8 9 10 11 12

Test	Test	# False	% True
Test 1	San Carlos >= 30K AF	766	90 %
Test 2	Sum of Flows > DDB	4,410	43 %
Test 3	GilaVirden > 120% Call for DV	335	96 %
Test 4	Sum of Diversions < DD Right	0	100 %
Test 5	Allowable Diversion < 350 cfs	860	89 %
Test 6	SF Clifton >= SF Minimum Flow	5,100	34 %
		491	94 %
		0	100 %
		0	100 %
		0	100 %
		2,645	66 %
		5,242	32 %

Information Sharing

http://www.sandia.gov/gilasanfrancisco/index.html



Questions?

Model Homepage

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Gila-San Francisco Decision Support Tool

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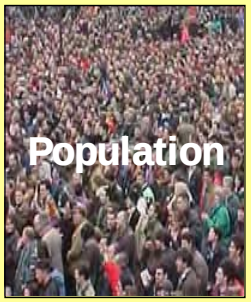
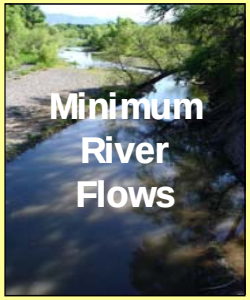
About this Model

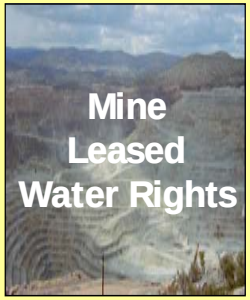
Background

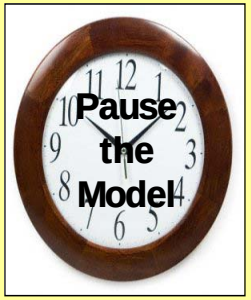
Maps

Executive Summary









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

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Phelps Dodge Mining

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Water to Agriculture

Specify the annual amount of water leased back from PD to irrigators in Gila-Redrock reach. Water transferred to exisiting acreage is a ground water right.

Water Rights Leased to Irrigators

0 AF/year

0 | 1,000 | 2,000 | 3,000 | 4,000 | 5,000 | 6,000 | 7,000 | 8,000 | 9,000 | 10,000 | 11,000 | 12,000 | 13,000 | 14,000

AF/year

Water Usage Choice

- Increase Acreage
- Apply to Existing Acreage

Water to Municipal

Specify the annual amount of water leased to Silver City from PD.

Water Rights Leased to the Municipality of Silver City

0 AF/year

0 | 1,000 | 2,000 | 3,000 | 4,000 | 5,000 | 6,000 | 7,000 | 8,000 | 9,000 | 10,000 | 11,000 | 12,000 | 13,000 | 14,000 | 15,000 | 16,000 | 17,000 | 18,000 | 19,000 | 20,000 | 21,000 | 22,000 | 23,000 | 24,000 | 25,000 | 26,000 | 27,000 | 28,000 | 29,000 | 30,000 | 31,000

AF/year

Silver City Water Rights

4,566.64 AF

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.

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GSF Decision Support Tool

Controls

Set Minimum Flows

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Multipliers for Calculating NMExcess under CUFA terms. Summer refers to periods between May and September.

multiplier-winter

0.5 0.6 0.7 0.8 0.9 1.0

0.80

multiplier-summer

0.5 0.6 0.7 0.8 0.9 1.0

0.75

When Ag demand switch is ON, the minimum flow accounts for the compounding effects of agricultural diversions that in the GSF region. This is added to the model automatically when accounting for minimum flow.

Ag Demand is Currently

- OFF
- ON

CUFA Model

Version:

20071016

Sandia National Laboratories

The NM CAP Water Bank starts with 54, 000 AF as a default. This value can be adjusted.

Initial value for NM CAP Bank

54,000 AF

0 10,000 20,000 30,000 40,000 50,000 60,000 70,000

AF

Choose a river for Diversion

By default, the model will draw a maximum amount of Gila and SF water allowed under CUFA terms and ESA flows

Divert Gila?: Yes / No

Divert SF?: Yes / No

Combined Yearly Max

64,000 AF/year

Choose USGS or Modeled Flows

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 caluculated 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

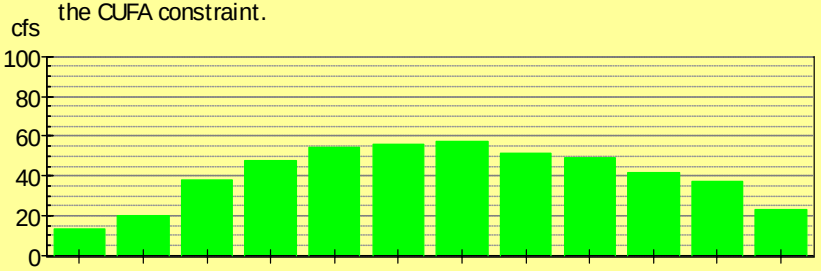
Streamflow Values

to use in CUFA Calculations

- Use Recorded Values
- Use Calculated Values

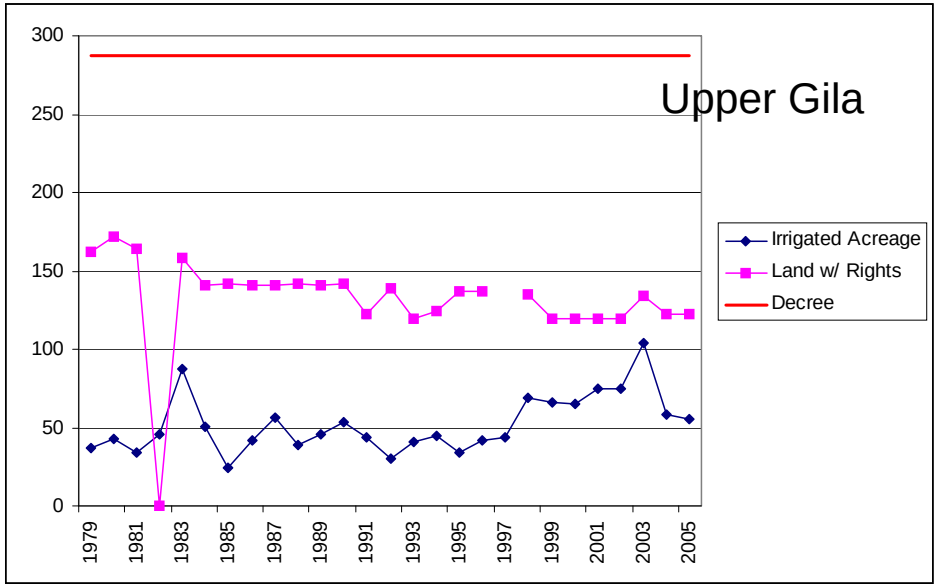
Duncan-Virden Valley Call

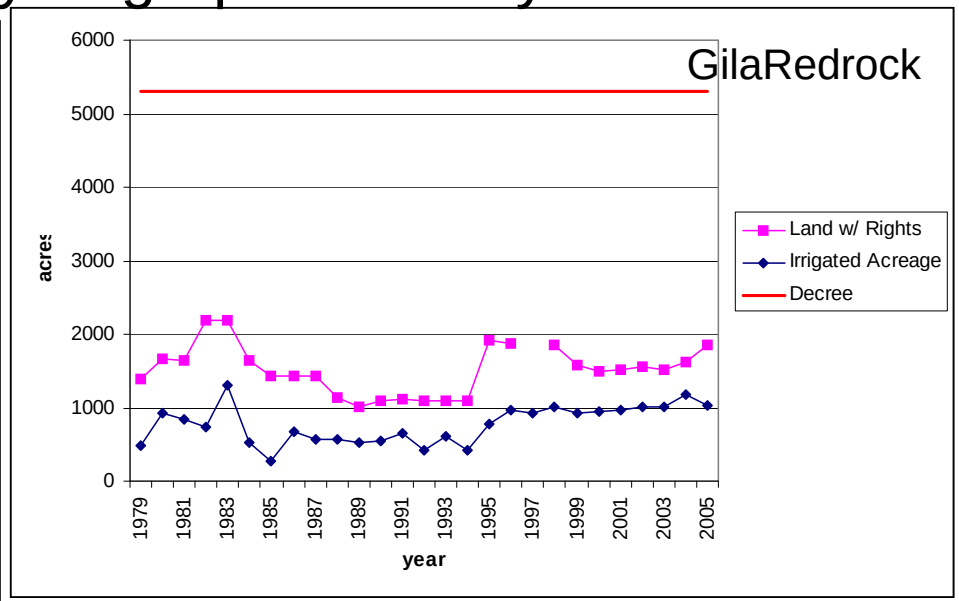
Based on historical data of the Duncan-Virden call from '99 to October '06, an average monthly call volume was computed and used in setting the CUFA constraint.

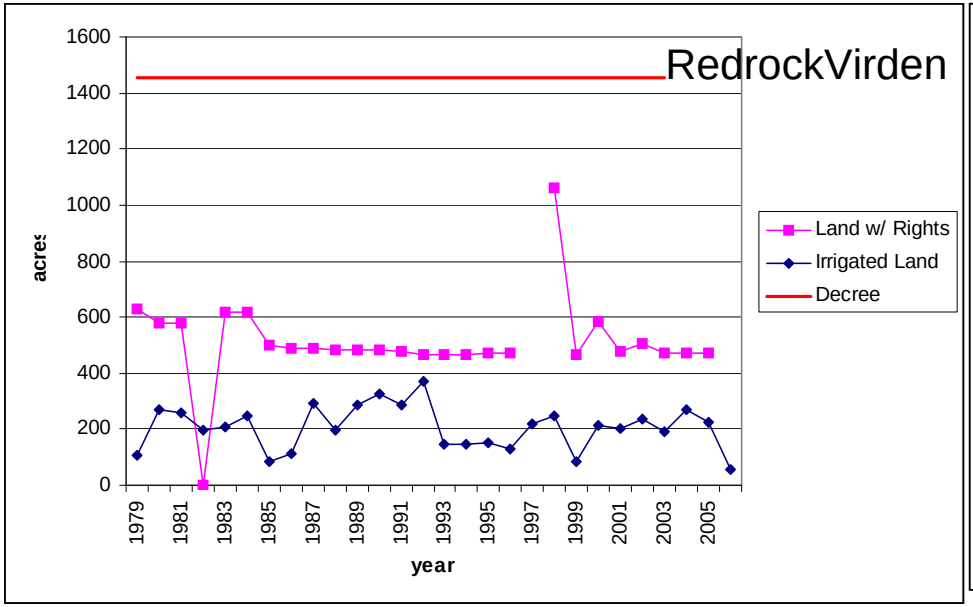


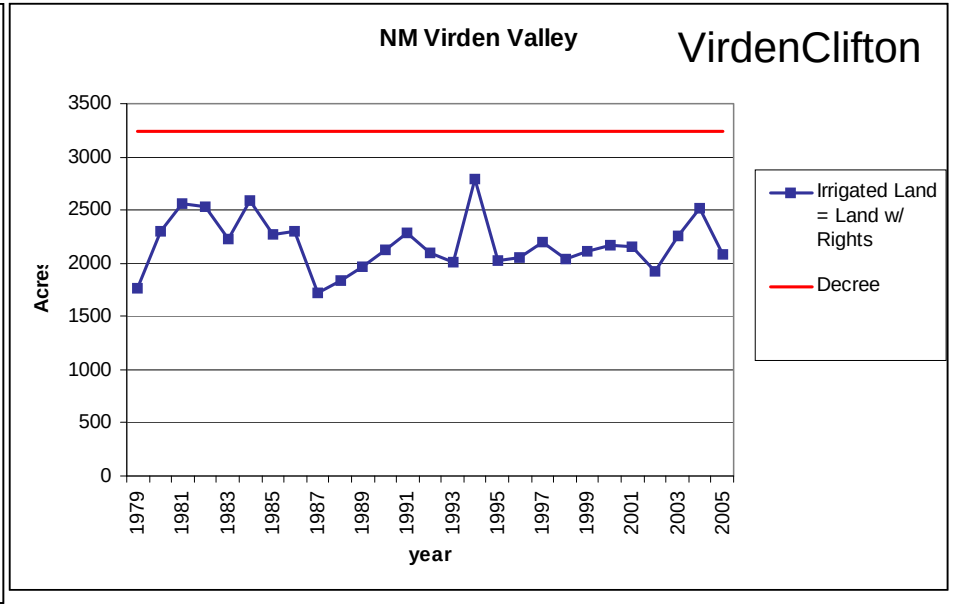
13 cfs	20 cfs	38 cfs	48 cfs	54 cfs	56 cfs	57 cfs	51 cfs	49 cfs	42 cfs	37 cfs	23 cfs
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec

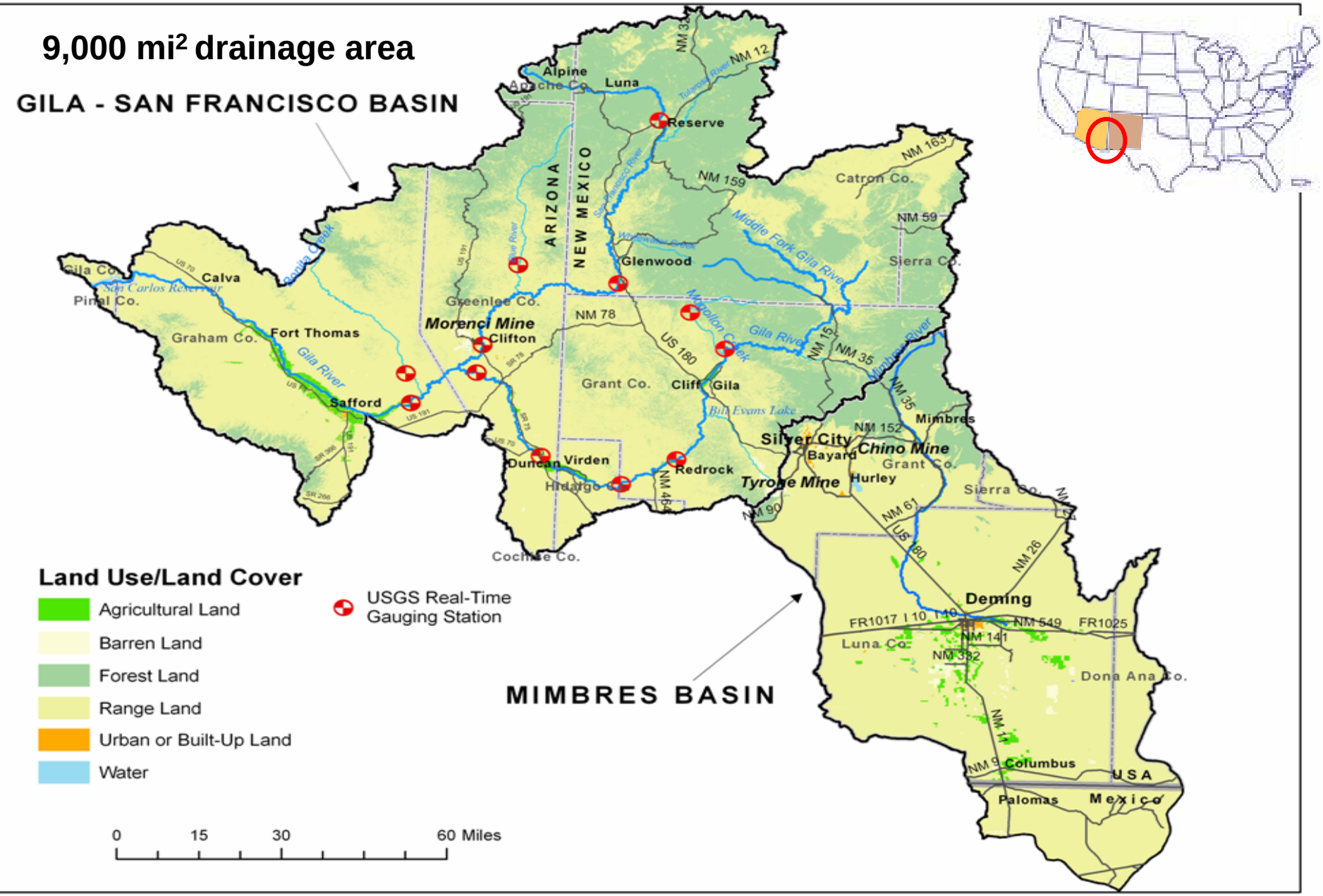
Historical Ag. Use from Hydrographic Survey - Gila










9,000 mi² drainage area
GILA - SAN FRANCISCO BASIN
MIMBRES BASIN
ARIZONA
NEW MEXICO
Alpine
Luna
Reserve
Catron Co.
Sierra Co.
Glenwood
Middle Fork Gila River
Gila Co.
Calva
San Carlos Reservoir
Pinal Co.
Graham Co.
Fort Thomas
Gila River
Safford
Greenlee Co.
Morenci Mine
Clifton
Grant Co.
Cliff
Gila
Bill Evans Lake
Silver City
Bayard
Chino Mine
Hurley
Tyrone Mine
Mimbres
Duncan
Virden
Redrock
Hidalgo Co.
Cochise Co.
Deming
Luna Co.
Dona Ana Co.
Columbus
Palomas
USA
Mexico
Land Use/Land Cover
Agricultural Land
Barren Land
Forest Land
Range Land
Urban or Built-Up Land
Water
USGS Real-Time Gauging Station
0
15
30
60 Miles

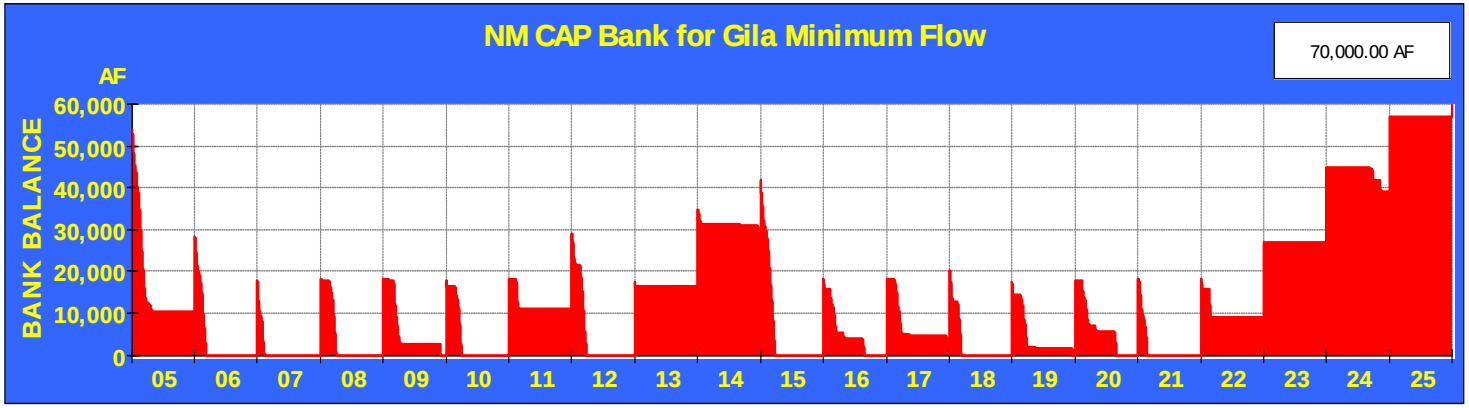
CUFA Model
DRAFT
Version:
20071016

Sandia National Laboratories

Graph Control
Gila-Redrock
Plotted in Red

View 1 Year Detail

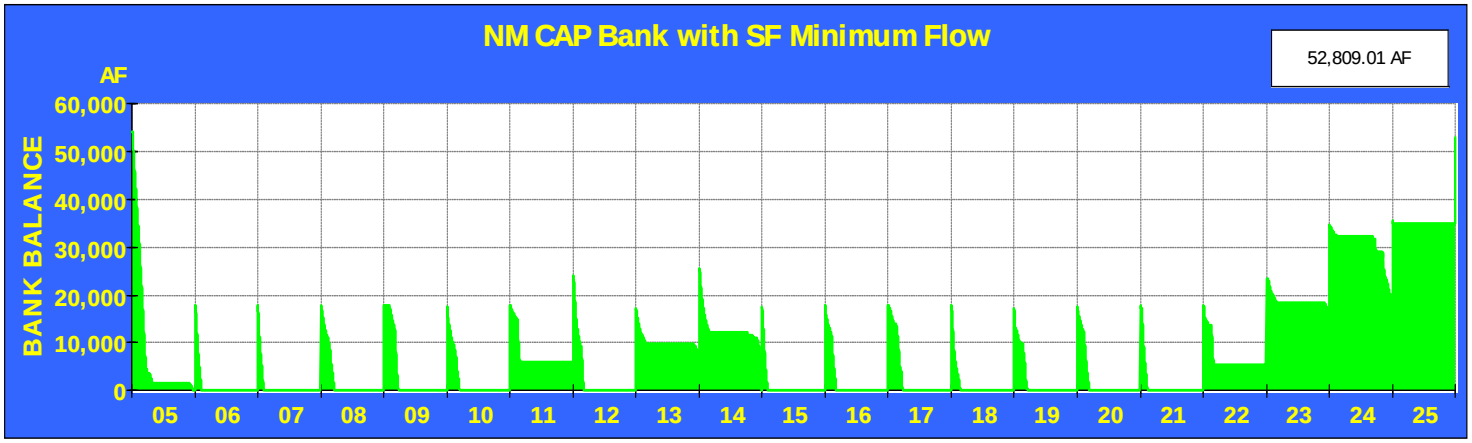
View 5 Year Detail



Graph Control
Upper San Francisco
Plotted in Red

View 1 Year Detail

View 5 Year Detail



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