

Presentation Outline

- Project Background and Status
- Model Calibration/Verification
 - Calibration/Verification Philosophy and Approach
 - Calibration Results and Discussion
- Overview and Demonstration of Broad Basin Model

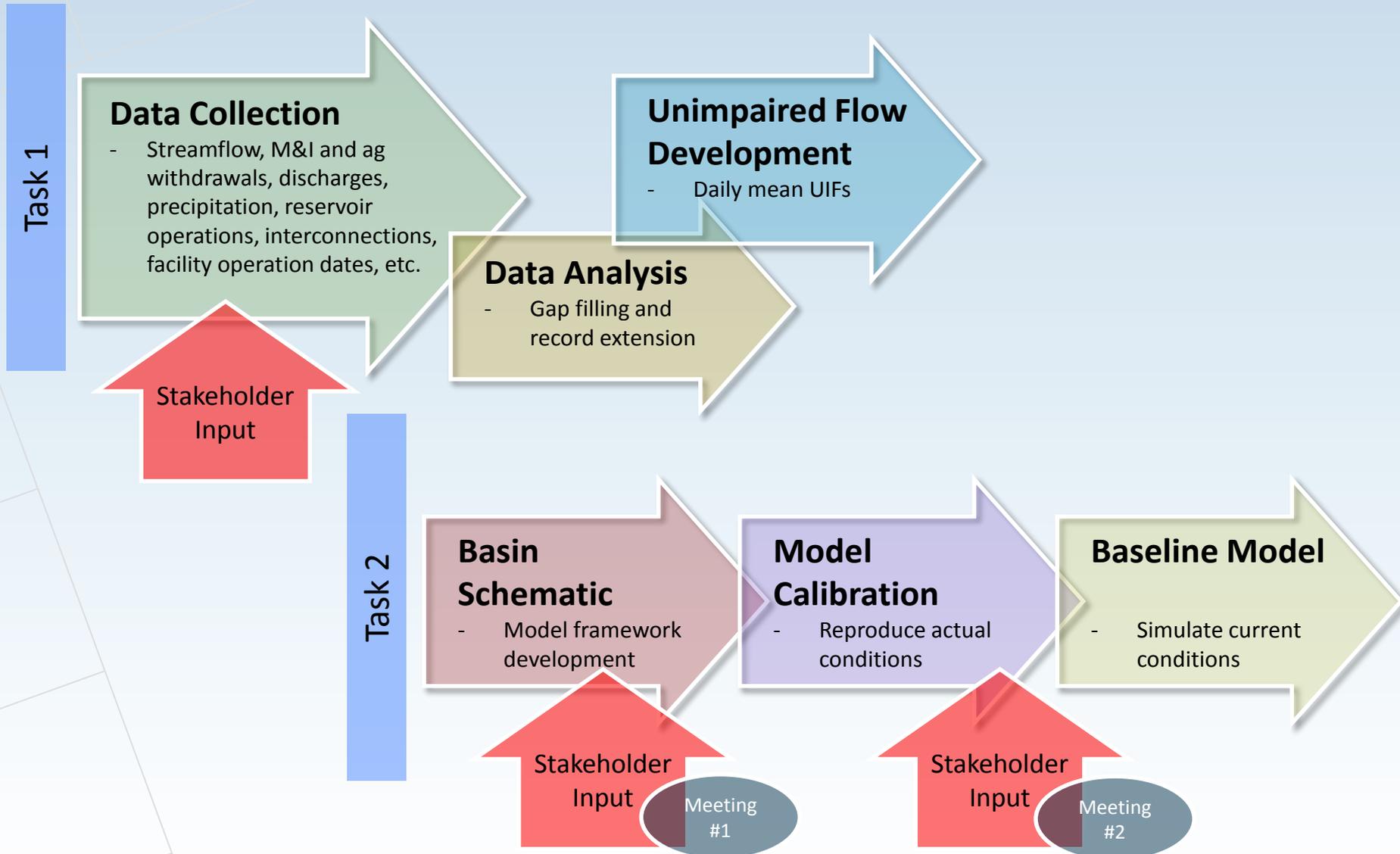
Project Purpose

- Build surface water quantity models capable of:
 - Accounting for inflows and outflows from a basin
 - Accurately simulating streamflows and reservoir levels over the historical inflow record
 - Conducting “What if” scenarios to evaluate future water demands, management strategies and system performance.

The Simplified Water Allocation Model is...

- A water accounting tool
 - *Calculates physically and legally available water*
 - *Traces water through a natural stream network, simulating withdrawals, discharges, storage, and hydroelectric operations*
- Not a precipitation-runoff model (e.g., HEC-HMS)
- Not a hydraulic model (e.g. HEC-RAS)
- Not a water quality model (e.g., QUAL2K)
- Not an optimization model
- Not a groundwater flow model (e.g., MODFLOW)

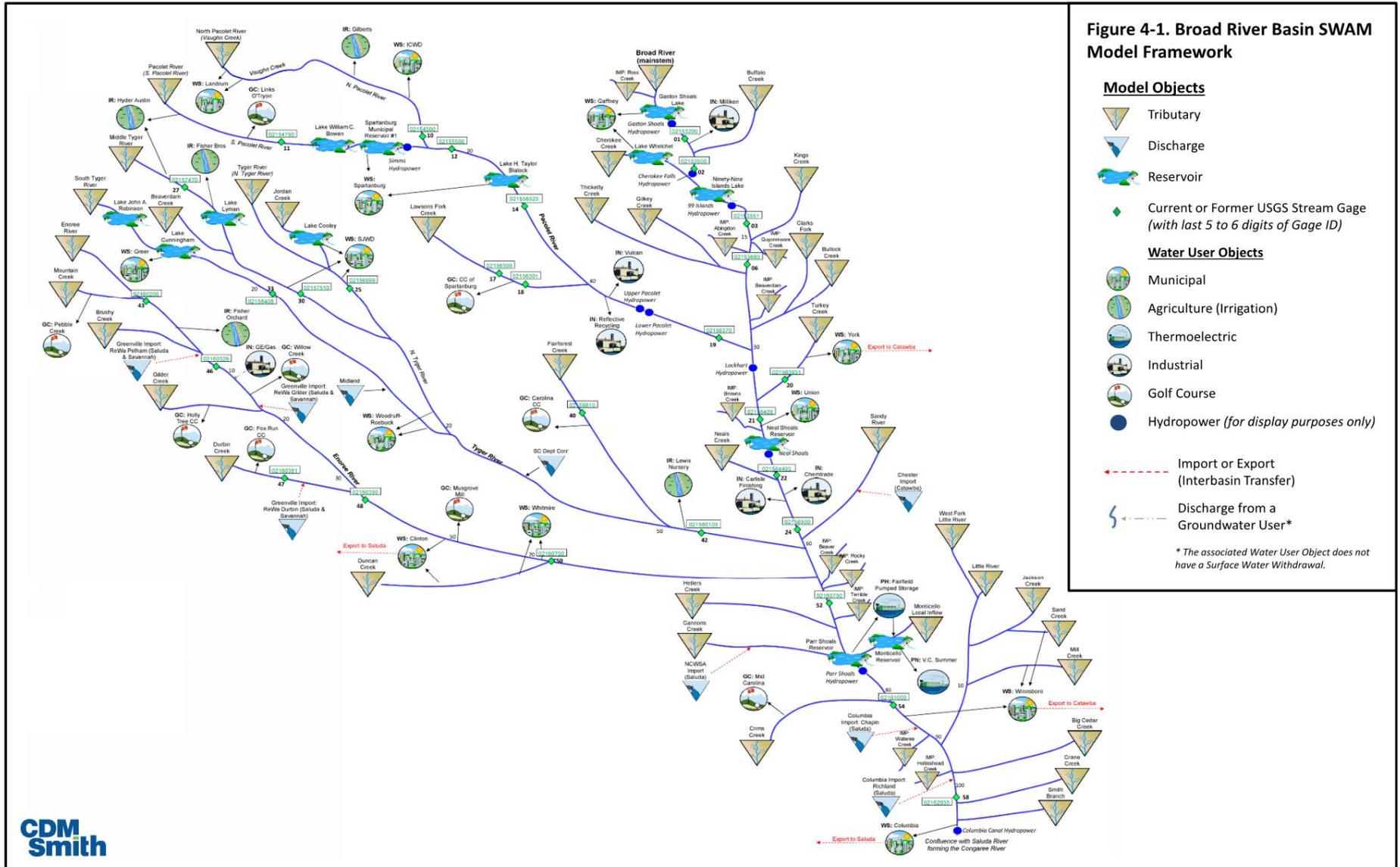
Project Status – Broad Basin



Calibration vs. Baseline Model

- **Calibration Model**
 - Purpose: Confirm models ability to accurately simulate river basin flows and storage amounts
 - Uses recent withdrawal, discharge and flow records
- **Baseline Model**
 - Purpose: Evaluate water availability under future conditions
 - Uses entire record of flow and most current withdrawals and discharges

Broad Basin – SWAM Framework



Modeling Report and Other Documents

- <http://www.dnr.sc.gov/water/waterplan/surfacewater.html>

The screenshot shows the website for the South Carolina Department of Natural Resources (DNR). The header includes the DNR logo and the slogan "Life's Better Outdoors". A navigation menu lists various topics: Buy, Boating, Education, Fishing, Hunting, Land, Maps, Regulations, Water, and Wildlife. The main content area is titled "Surface Water Modeling and Assessments" and contains several paragraphs of text, a "Project Documents" section with a list of links (Monthly Progress Reports, Legislative Quarterly Reports, Technical Reports, Technical Memorandums, Meeting Notes, Presentations, Videos, River Basins), and a footer with social media icons and contact information.

The image shows the cover of a report titled "SOUTH CAROLINA SURFACE WATER QUANTITY MODELS BROAD RIVER BASIN MODEL". The cover features a large, detailed map of the Broad River Basin with various water bodies and infrastructure. The report is submitted to the South Carolina Department of Natural Resources and the South Carolina Department of Health & Environmental Control. It is dated May 2016 and prepared by CDM Smith. The word "DRAFT" is prominently displayed at the bottom left.

Broad River Basin

MODEL CALIBRATION/VERIFICATION

Calibration Objectives

1. Extend hydrologic inputs (headwater UIFs) spatially to adequately represent entire basin hydrology by parameterizing reach hydrologic inputs
2. Refine initial parameter estimates, as appropriate
 - E.g. reservoir operating rules, %Consumptive Use assumptions, return flow locations
3. Gain confidence in the model as a predictive tool by demonstrating its ability to adequately replicate past hydrologic conditions, operations, and water use
 - **without being overly prescriptive**

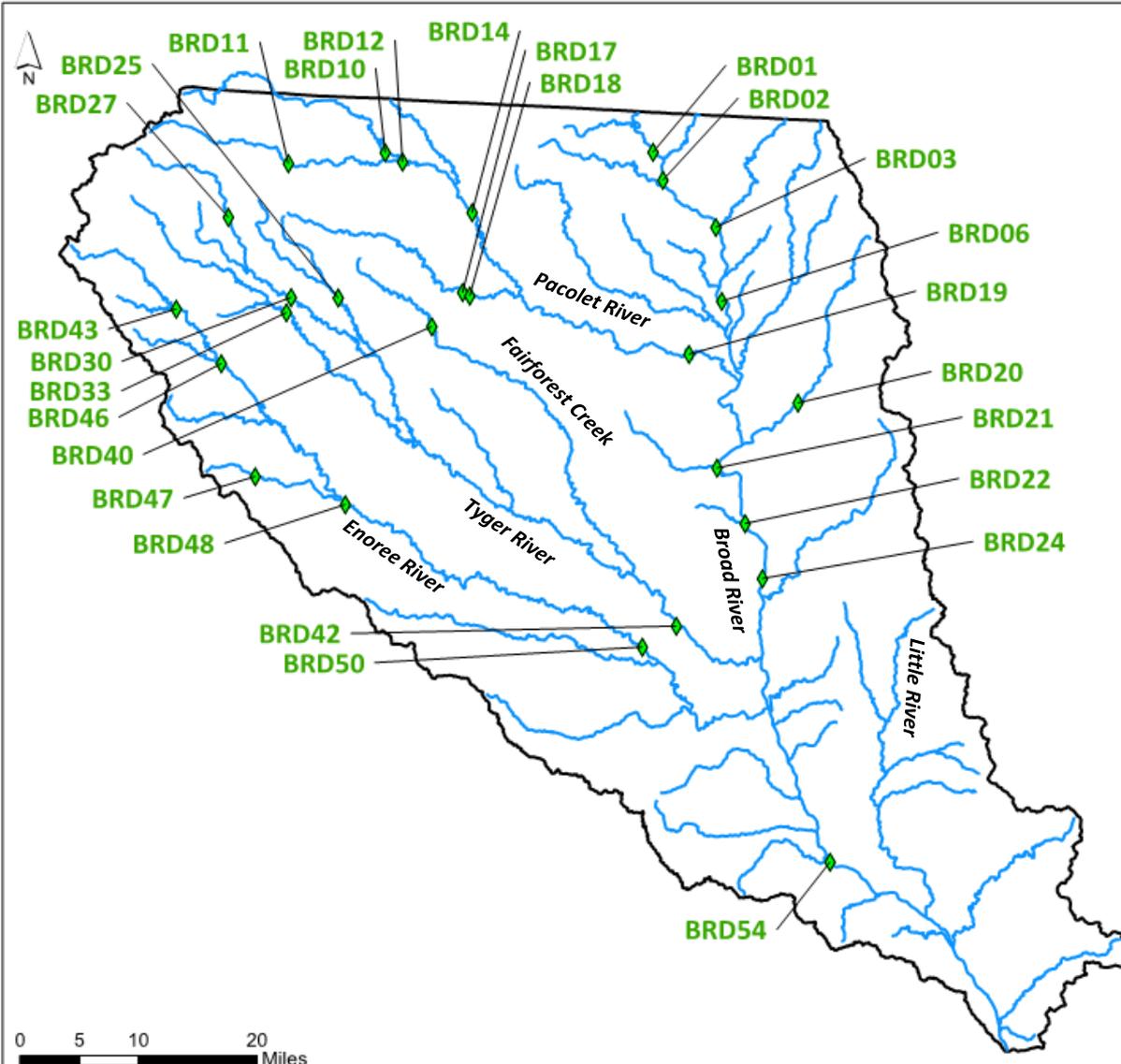
Potential Sources of Model Error and Uncertainty

- Gaged flow data ($\pm 20\%$)
- Gaged reservoir levels ($\pm ?\%$)
- Basin climate and hydrologic variability
- Reported withdrawal data
- Consumptive use percentages
- Return flow locations (outdoor use)
- Return flow lag times (if applicable, e.g. outdoor use)
- *Reservoir operations (operator decision making)*
- *Reach hydrology: gains, losses, local runoff and inflow*

Calibration/Validation General Approach

- 1983 – 2013 hindcast period; monthly timestep
 - Includes droughts in both early and late 2000's
- Comparison to gaged (measured) flow data only
 - operations and impairments are implicit in that data
- Assess performance at (subject to gage data availability):
 - multiple mainstem locations
 - all tributary confluence locations
 - major reservoirs (where levels/storage are available)
- Multiple model performance metrics, including:
 - timeseries plots (monthly and daily variability)
 - annual and monthly means (water balance and seasonality)
 - percentile plots (extremes and frequency)

Calibration/Validation Locations



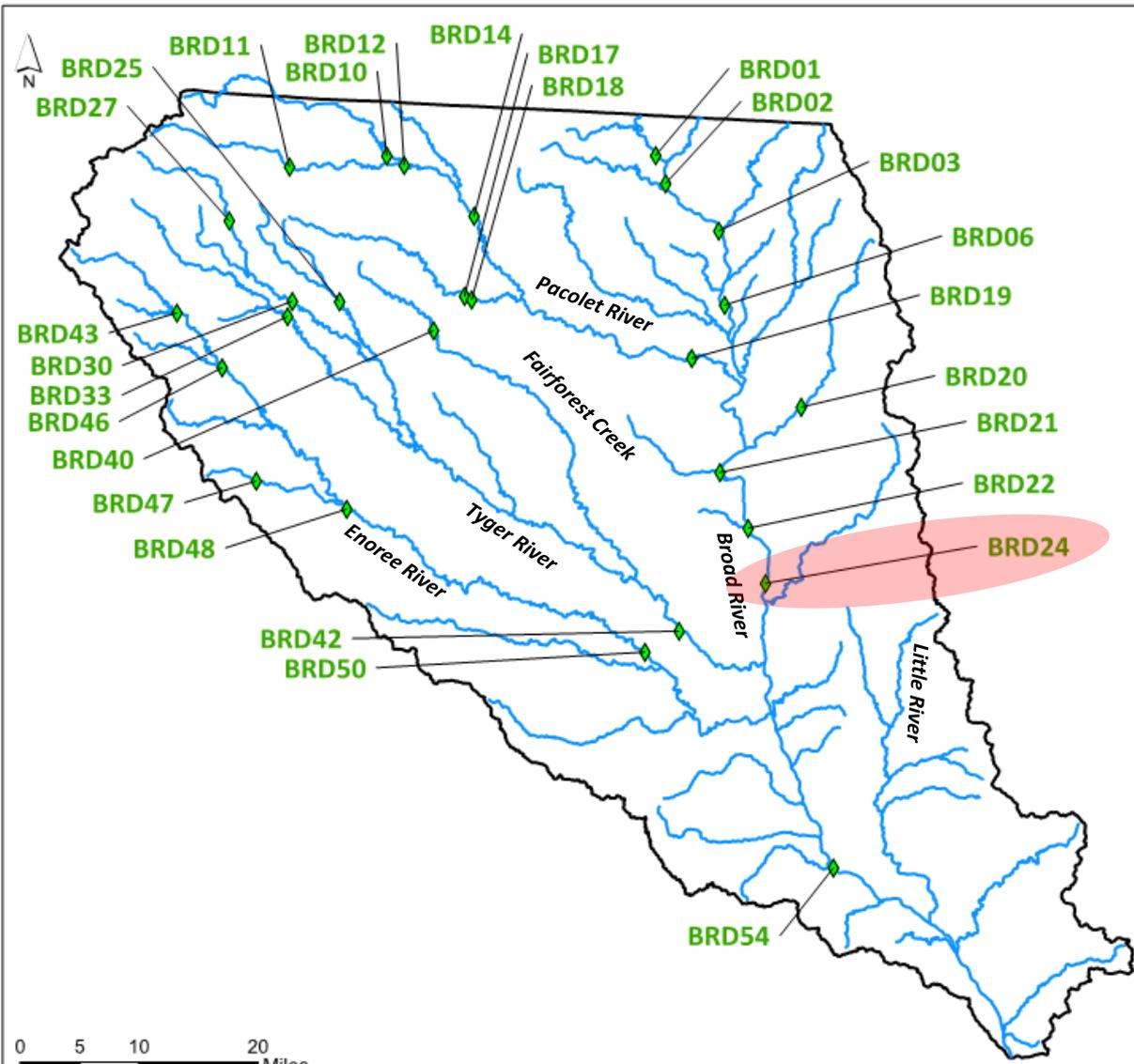
Project Gage ID	USGS Number	Tributary Object	Periods of Record	Basin Area (sq. mi.)	River Mile
BRD01	02153200	Mainstem	9/1997 - current	1,317	5
BRD02	02153500	Mainstem	12/1938 - 9/1971 4/1986 - 9/1990 2/2010 - current	1,501	8
BRD03	02153551	Mainstem	10/1998 - current	1,559	15
BRD06	02153680	Mainstem	6/2001 - 9/2003	1,666	22
BRD10	02154500	North Pacolet	4/1930 - current	114	25
BRD11	02154790	Pacolet River	1/1989 - current	55	6
BRD12	02155500	Pacolet River	12/1929 - 9/1996 10/1997 - 9/2006 6/2007 - 12/2013	209	19
BRD14	021556525	Pacolet River	11/1993 - current	271	28
BRD17	02156300	Lawsons Fork	6/2012 - current	74	21
BRD18	02156301	Lawson Fork	5/1989 - 9/1997	76	21
BRD19	02156370	Pacolet River	8/2012 - current	502	61
BRD20	021563931	Turkey Creek	12/2000 - 8/2003	82	18
BRD21	02156409	Mainstem	10/1996 - 9/1999 4/2011 - 11/2012	2,658	41
BRD22	021564493	Mainstem	3/2012 - current	2,730	48
BRD24	02156500	Mainstem	10/1938 - current	2,781	53
BRD25	02156999	Tyger River	5/2007 - 11/2013	34	2
BRD27	02157470	Middle Tyger River	2/2002 - current	33	10
BRD30	02157510	Middle Tyger River	2/2000 - current	69	22
BRD33	02158408	South Tyger River	2/2001 - current	95	22
BRD40	02159810	Fairforest Creek	5/1988 - 4/1998	23	10
BRD42	02160105	Tyger River	10/1973 - current	756	58
BRD43	02160200	Enoree River	3/1998 - 10/2007	50	1
BRD46	02160326	Enoree River	3/1993 - current	85	9
BRD47	02160381	Durbin Creek	7/1994 - 10/2007 10/2009 - current	13	3
BRD48	02160390	Enoree River	2/1993 - current	249	33
BRD50	02160700	Enoree River	10/1973 - current	443	73
BRD54	02161000	Mainstem	10/1896 - 12/1907 10/1980 - current	4,774	80

Legend

- ◆ USGS Flow Gages
- Streams and Rivers
- Broad River Basin

Broad River near Carlisle

USGS Gage 02156500



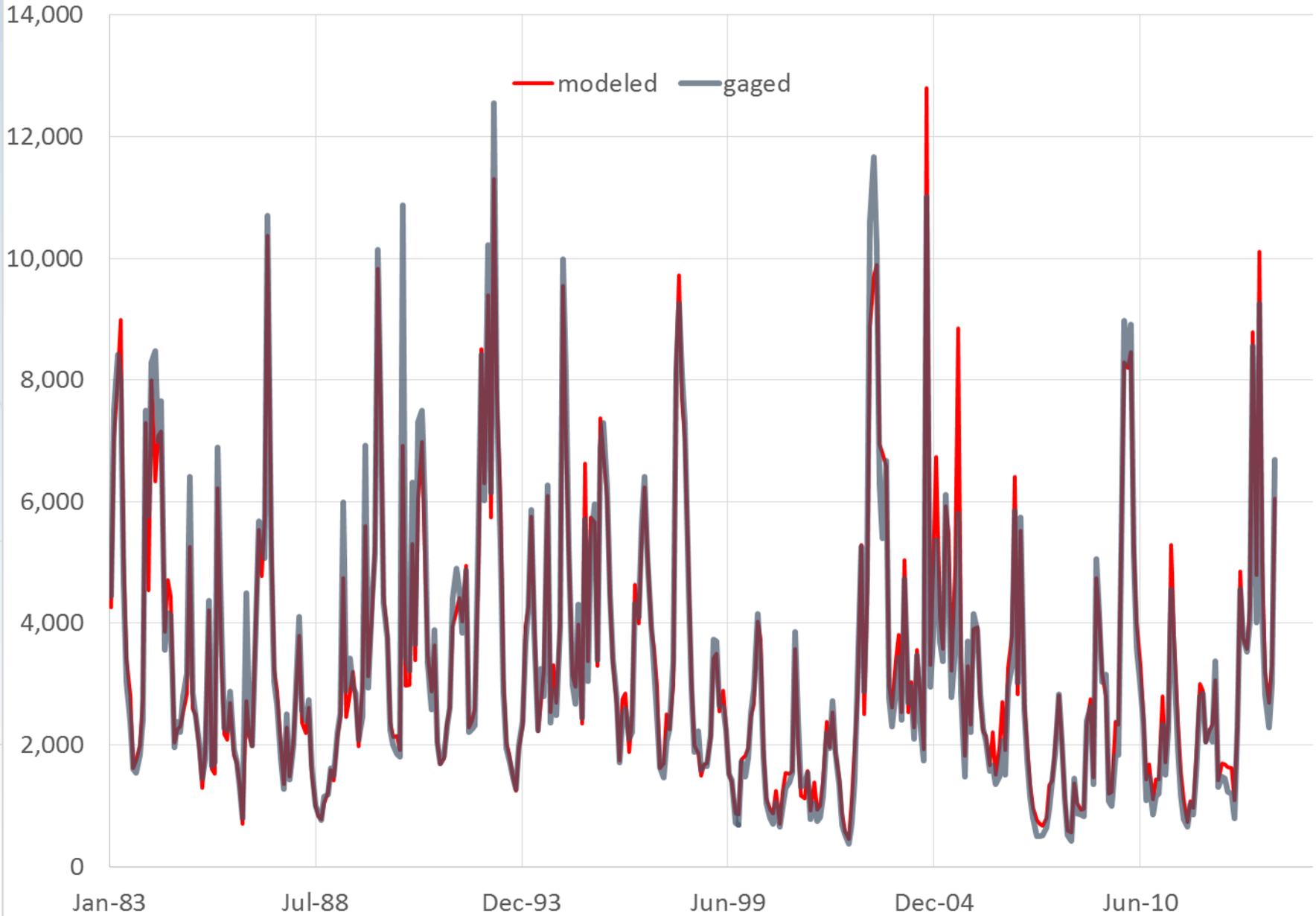
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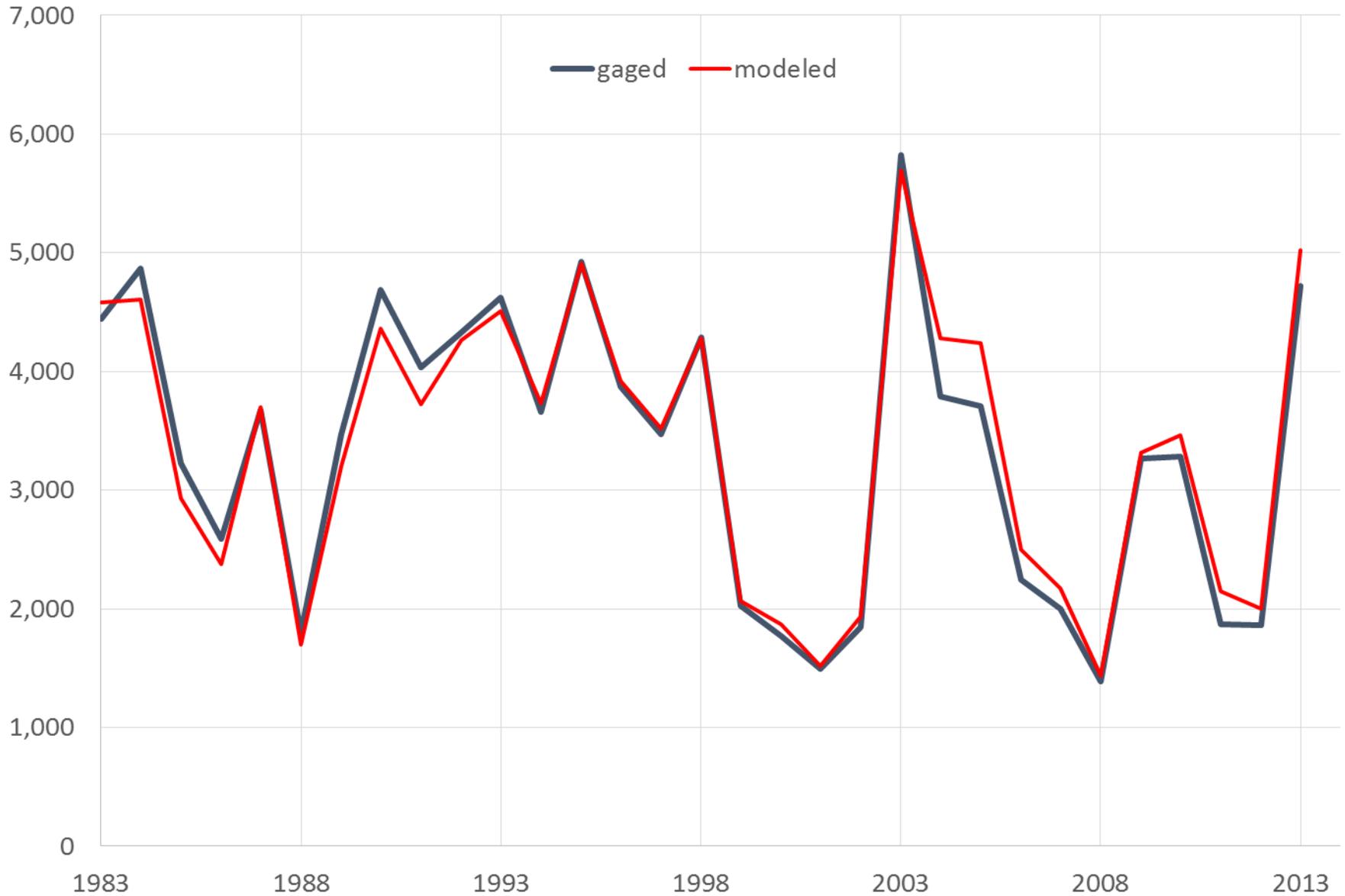
Monthly Flow Comparison

BRD24 (02156500) BROAD RIVER NEAR CARLISLE, SC (CFS)



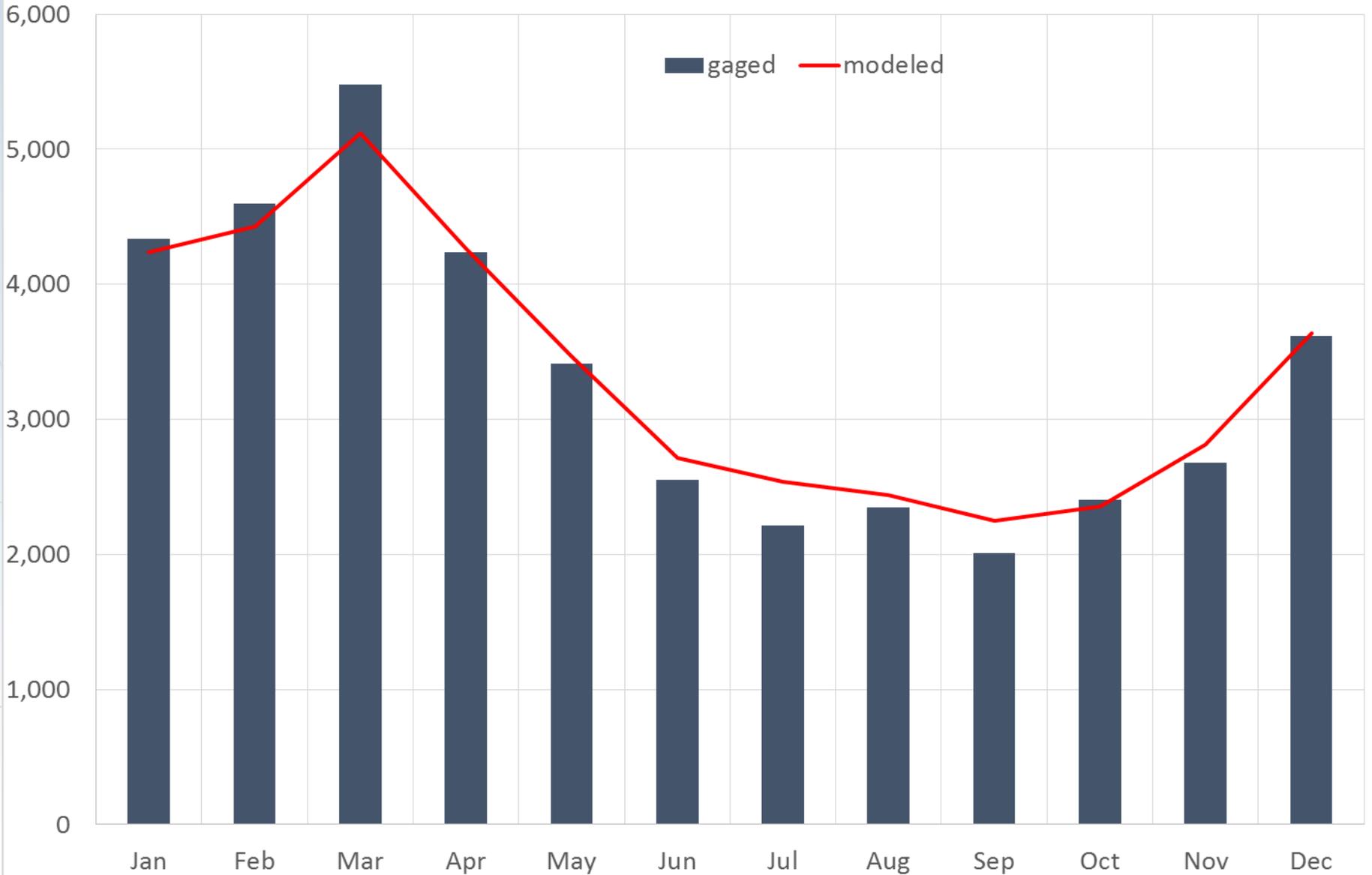
Annual Average Flow Comparison

BRD24 (02156500) BROAD RIVER NEAR CARLISLE, SC (CFS)
Annual Average Flow



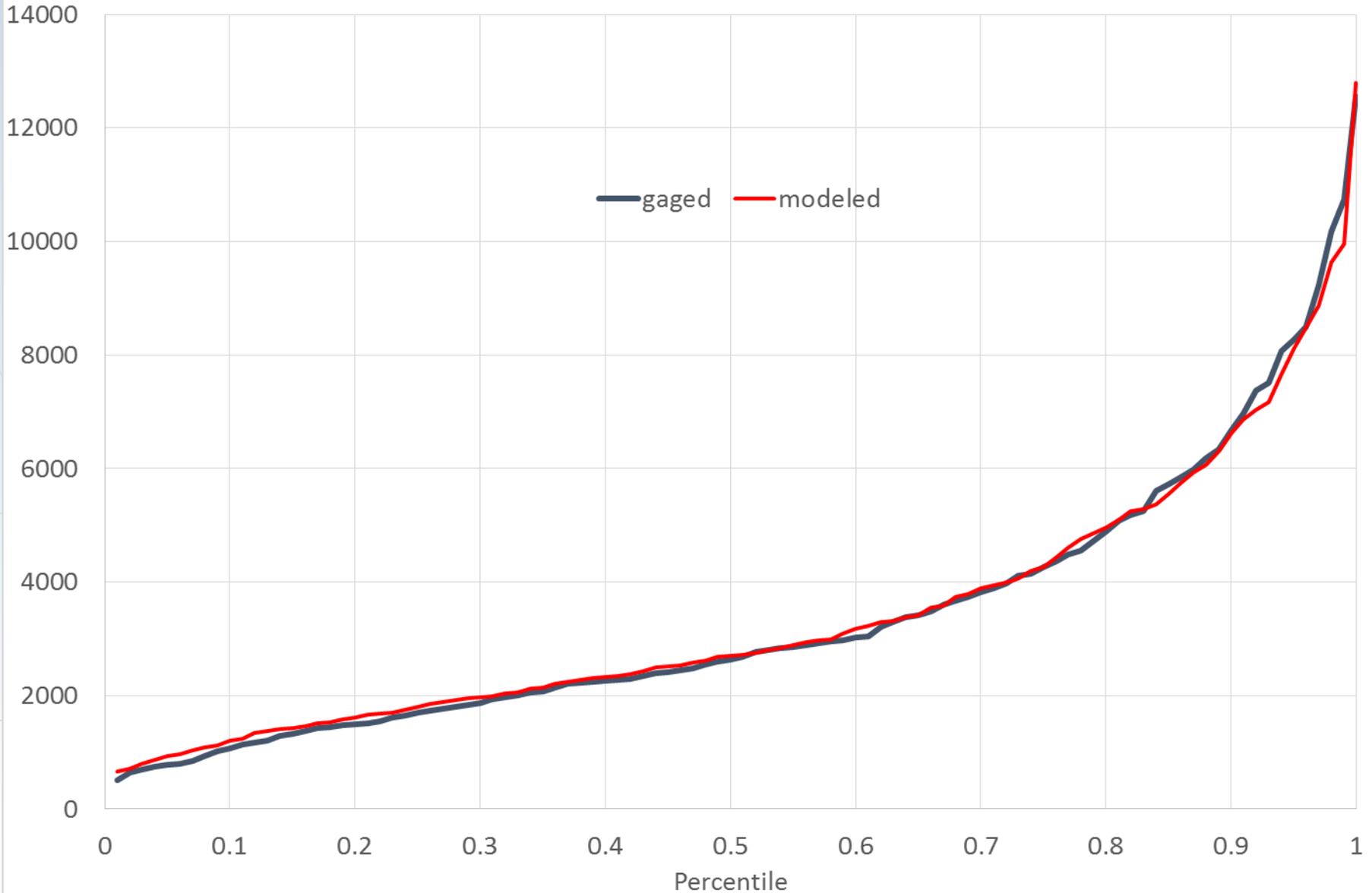
Monthly Mean Flow Comparison

BRD24 (02156500) BROAD RIVER NEAR CARLISLE, SC
Monthly Mean Flow (CFS)



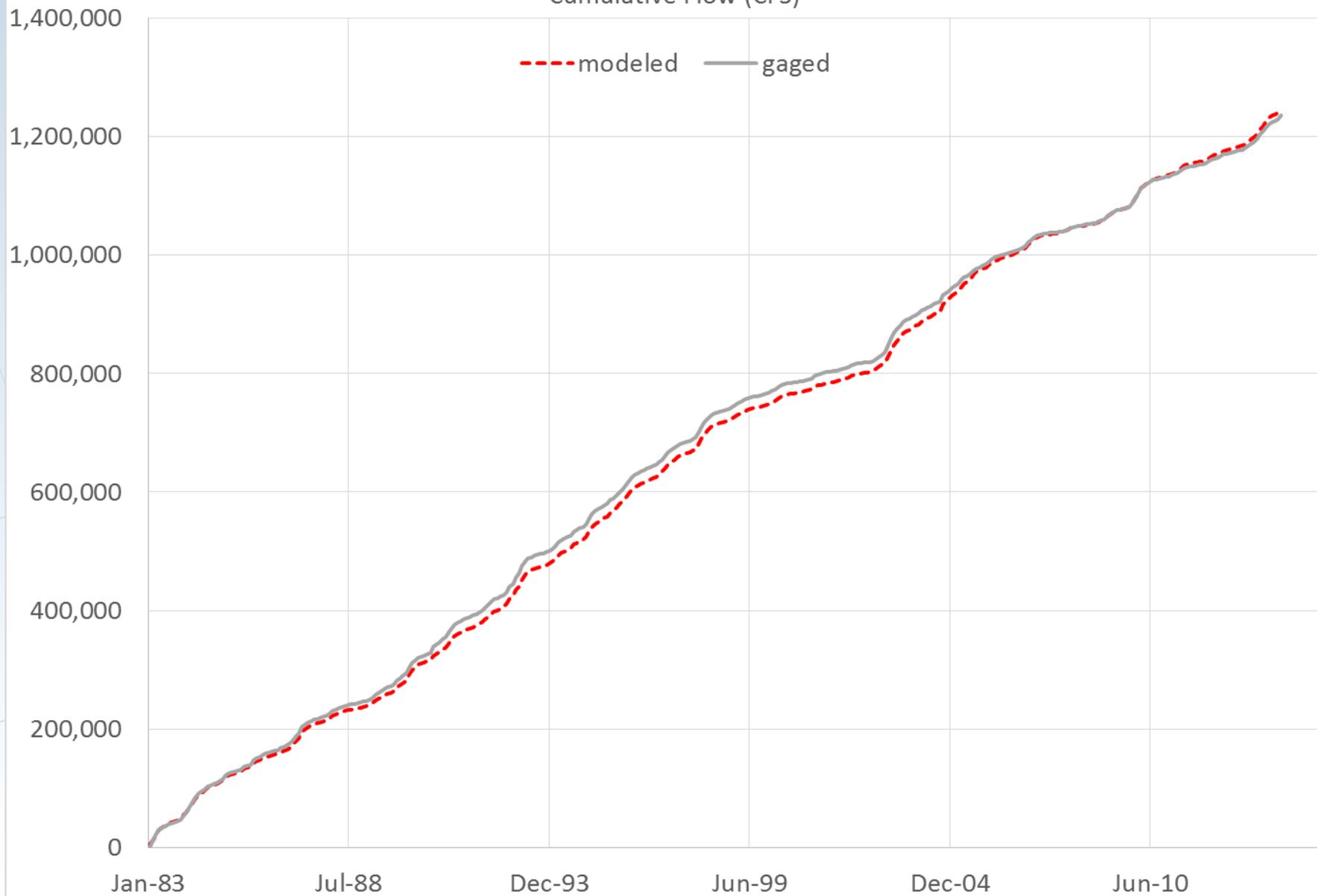
Monthly Flow Percentiles Comparison

BRD24 (02156500) BROAD RIVER NEAR CARLISLE, SC
Monthly Flow Percentiles (CFS)



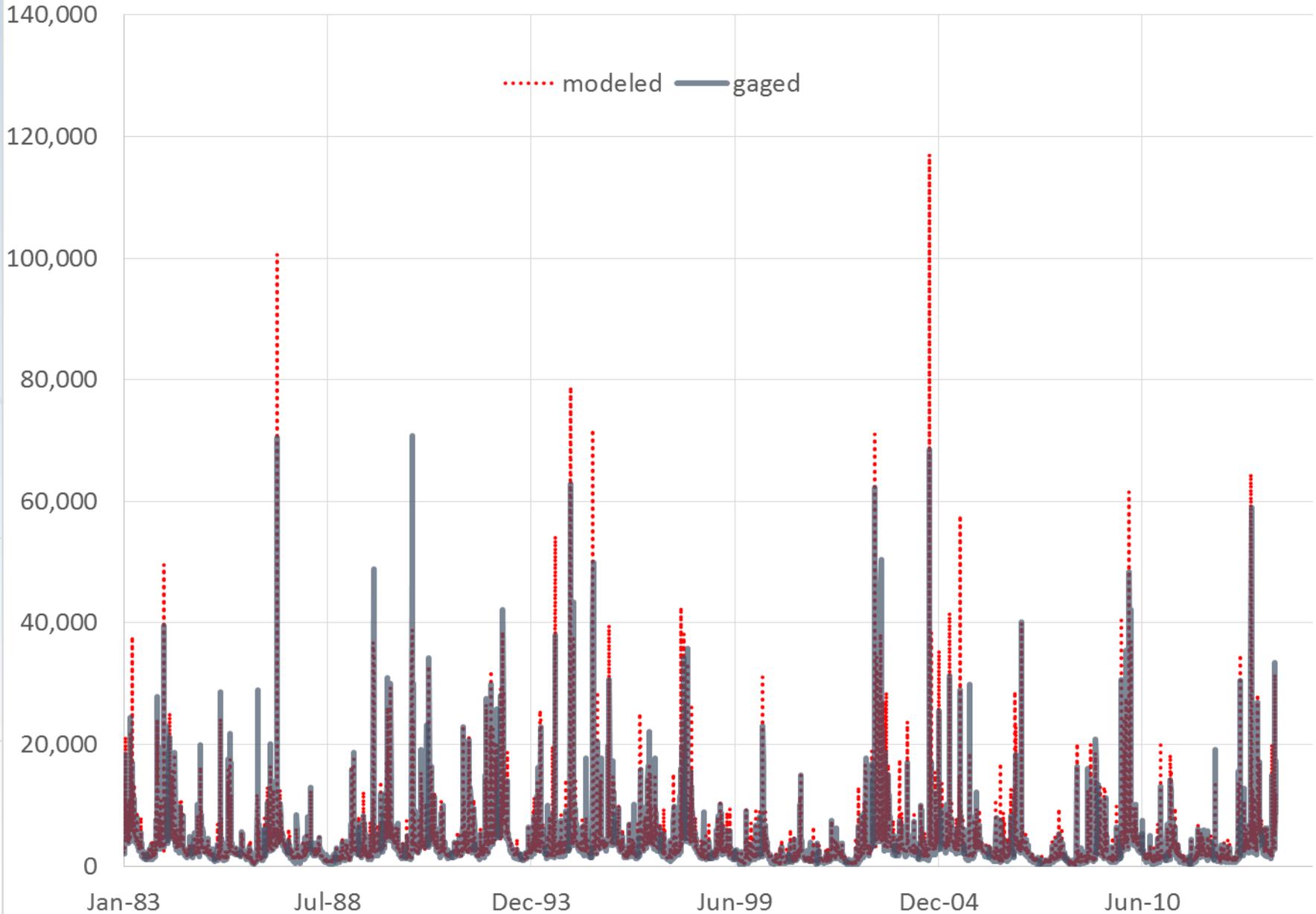
Cumulative Flow Comparison

BRD24 (02156500) BROAD RIVER NEAR CARLISLE, SC
Cumulative Flow (CFS)



Daily Flow Comparison

BRD24 (02156500) BROAD RIVER NEAR CARLISLE, SC (CFS)

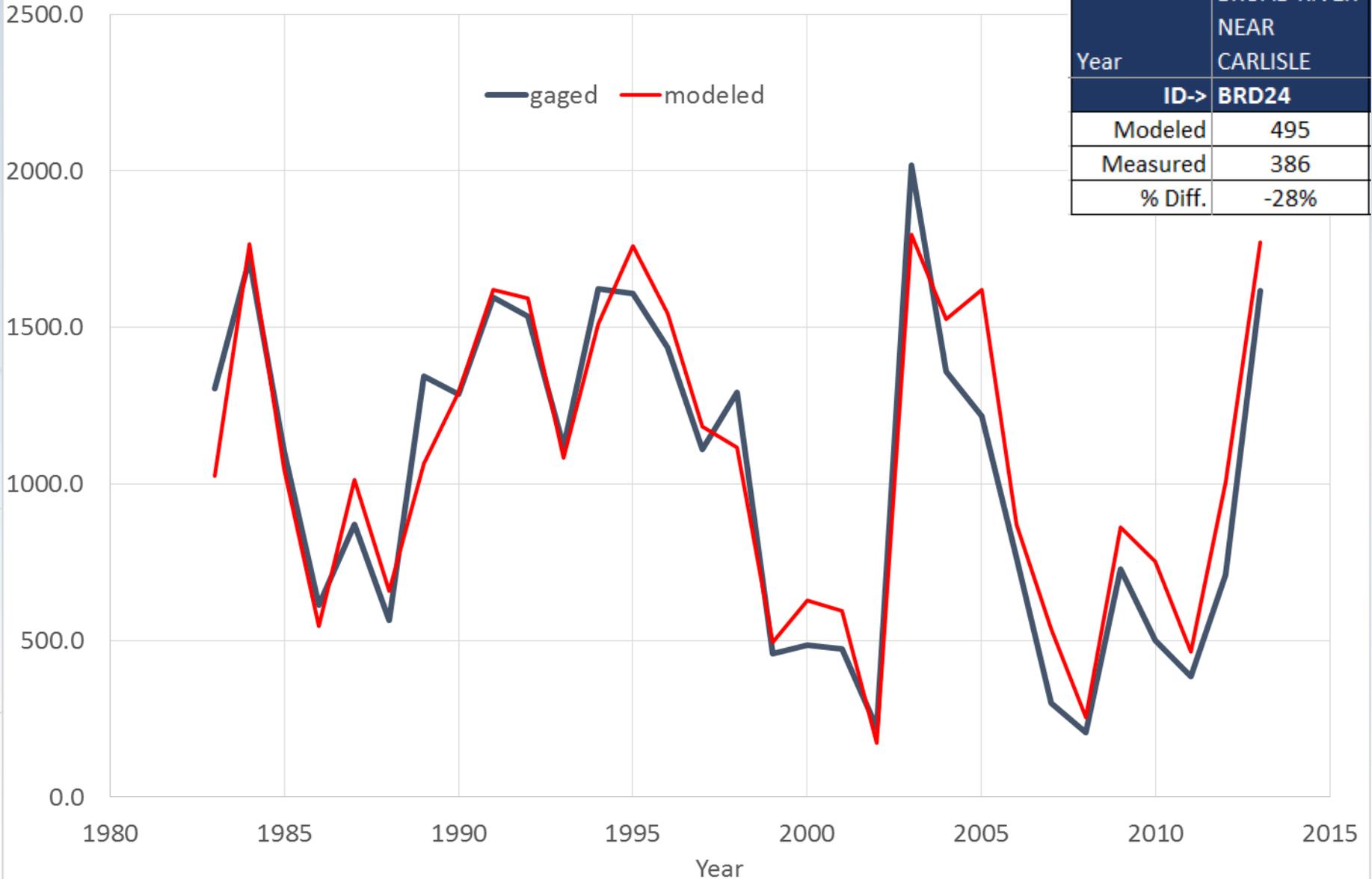


Annual 7 Day Low Flows

BRD24 (02156500) BROAD RIVER NEAR CARLISLE, SC
Annual 7-day Low Flow (CFS)

7Q10 Comparison

BROAD RIVER NEAR CARLISLE	
Year	ID-> BRD24
Modeled	495
Measured	386
% Diff.	-28%



SWAM Calibration/Validation Summary

- For most sites, modeled mean flow values, averaged over the full period of record, are within 5% of measured mean flows

ID	Station	Modeled (cfs)	Measured (cfs)	% Difference	Years to compare
BRD18	LAWSON FORK CREEK @ TREATMENT PLANT @ SPARTANBU	37	134	-72.4%	9
BRD20	TURKEY CREEK NEAR LOWRYS, SC	39	77	-48.4%	4
BRD42	TYGER RIVER NEAR DELTA, SC	771	828	-6.9%	31
BRD46	ENOREE RIVER AT PELHAM, SC	144	146	-1.3%	21
BRD12	PACOLET RIVER NEAR FINGERVILLE, SC	278	281	-1.1%	31
BRD17	LAWSONS FORK CREEK AT SPARTANBURG SC	99	100	-0.6%	2
BRD10	NORTH PACOLET RIVER AT FINGERVILLE, SC	179	180	-0.2%	31
BRD47	DURBIN CREEK ABOVE FOUNTAIN INN, SC	16	16	-0.1%	19
BRD27	MIDDLE TYGER RIVER NEAR GRAMLING, SC	46	46	-0.1%	12
BRD25	N. TYGER RIVER BELOW WELLFORD, SC	27	27	-0.1%	7
BRD33	SOUTH TYGER RIVER BELOW DUNCAN, SC	121	121	0.0%	13
BRD48	ENOREE RIVER NEAR WOODRUFF, SC	343	343	0.0%	21
BRD11	SOUTH PACOLET RIVER NR CAMPOBELLO, SC	89	89	0.2%	25
BRD40	FAIRFOREST CREEK BELOW SPARTANBURG, S.C.	40	40	0.7%	11
BRD24	BROAD RIVER NEAR CARLISLE, SC	3355	3325	0.9%	31
BRD19	PACOLET RIVER NEAR SARATT, SC	629	622	1.1%	2
BRD14	PACOLET RIVER BELOW LAKE BLALOCK NEAR COWPENS, SC	324	320	1.1%	21
BRD06	BROAD R NR HICKORY GROVE, SC	2116	2091	1.2%	3
BRD30	MIDDLE TYGER RIVER NEAR LYMAN, SC	76	74	1.8%	14
BRD02	BROAD RIVER NEAR GAFFNEY, SC	2087	2050	1.8%	9
BRD50	ENOREE RIVER AT WHITMIRE, SC	508	498	2.1%	31
BRD43	ENOREE RIVER AT TAYLORS, SC	74	72	2.3%	10
BRD01	BROAD RIVER NEAR BLACKSBURG, SC	1734	1681	3.1%	17
BRD21	BROAD RIVER NEAR LOCKHART, SC	2647	2551	3.8%	6
BRD03	BROAD RIVER BELOW NINETYNINE ISLAND RESERVOIR, SC	1874	1776	5.5%	16
BRD22	BROAD RIVER BELOW NEAL SHOALS RES. NR CARLISLE, SC	3301	3103	6.4%	2
BRD54	BROAD RIVER AT ALSTON, SC	5611	5226	7.4%	31

} >5% difference

} 2% or less difference

} 5% or less diff.

} >5% difference

SWAM Calibration/Validation Summary

- Monthly mean flows percentile deviations are all generally within 10-20% with no clear bias
- Modeled low flow values (as represented by 7Q10 flows) are within:
 - 4% and 35% on the Broad River
 - 0% to 54% on Pacolet River
 - 0% to 150% on the Tyger River
 - 0% to 36% on the Enoree River
- The model adequately hindcasts delivered water supply for each water user in the model (no significant shortfalls).

Broad River Basin

BASELINE MODEL AND USES

Baseline Model

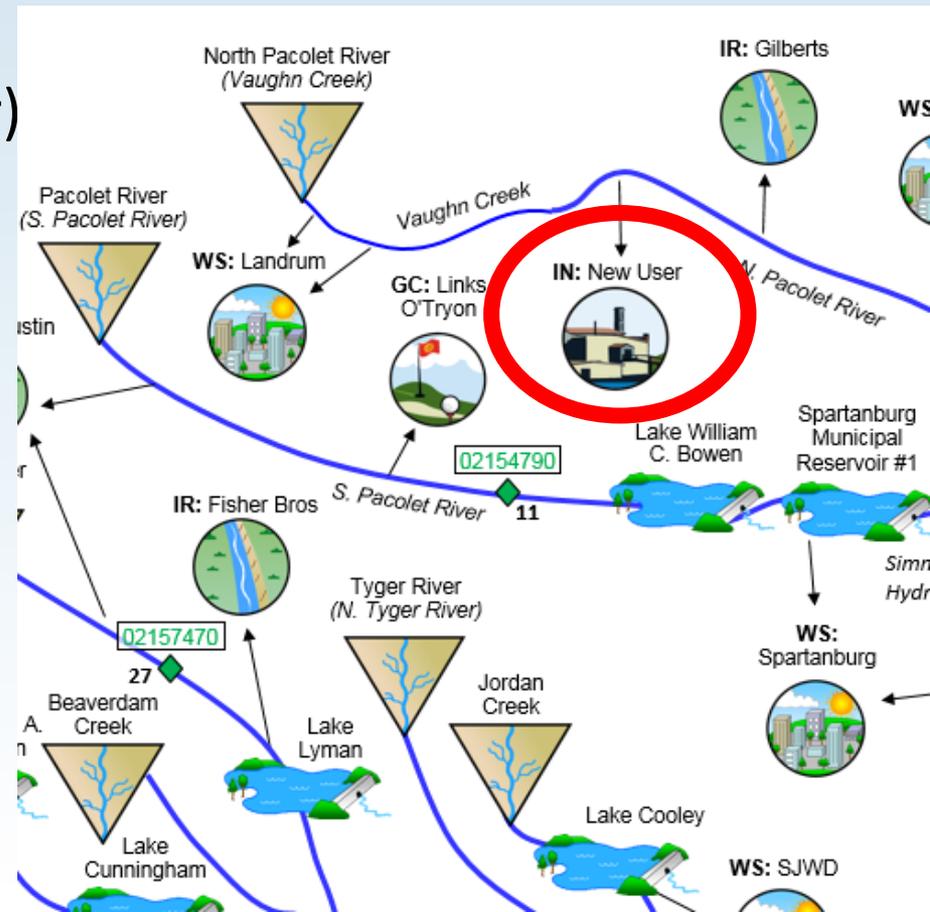
- Will represent current demands and operations combined with an extended period of estimated hydrology
 - Most demands reflect 2004-2013 averages
 - Estimated hydrology from 1929 to 2013
 - Inactive users are not included
- The baseline model serves as the starting point for future predictive simulations

Example Use

Adding a New User

- Add a new M&I permittee on the North Pacolet River
 - Demand = 15 mgd
 - Consumptive Use = 50%
(return to N. Pacolet River)

- *Is there enough water to support the new user?*
- *Does the new withdrawal cause shortages for downstream users?*



Add an Industrial Water User Object from the Palette

Object Palette



Simplified Water Allocation Model (SWAM)

Simulation Period

Start Date (MM/DD/YYYY): 01/01/1983

End Date (MM/DD/YYYY): 12/31/2013

Simulation Type

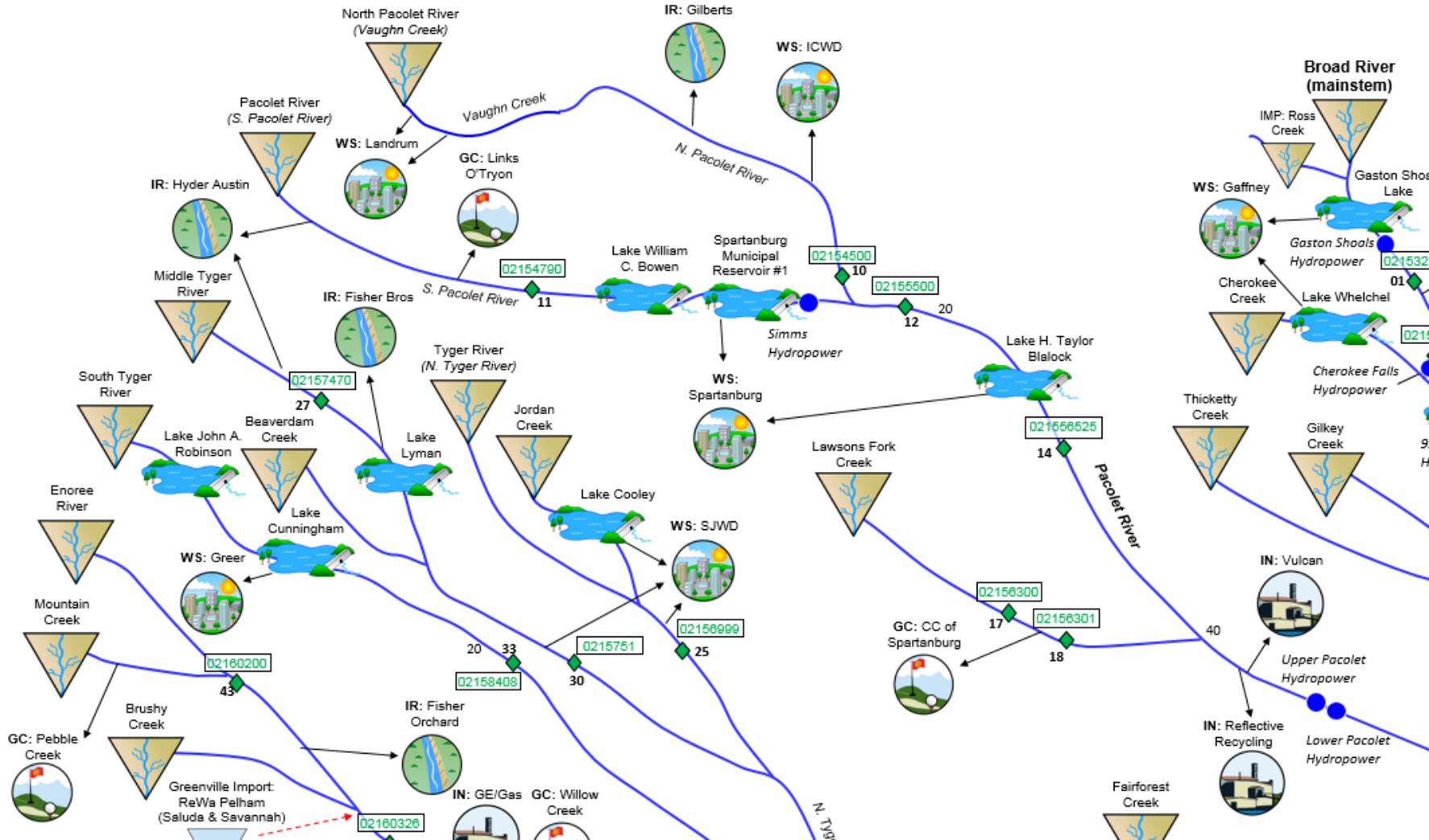
Monthly Planning Prior Appropriations
 Daily Planning Riparian Water Rights
 Short-Term Forecasting
 Firm Yield Calculator

Run (ctrl R)

Input Summaries and Outputting

Input & Output Units

AF, AFM, AFD MG, MGD, CFS m3, m3/d, m3/s



Add an Industrial Water User Object from the Palette

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Run (ctrl R)

Input Summaries and Outputting

Node Priorities Node Locations Reservoir Accounts Output Specs

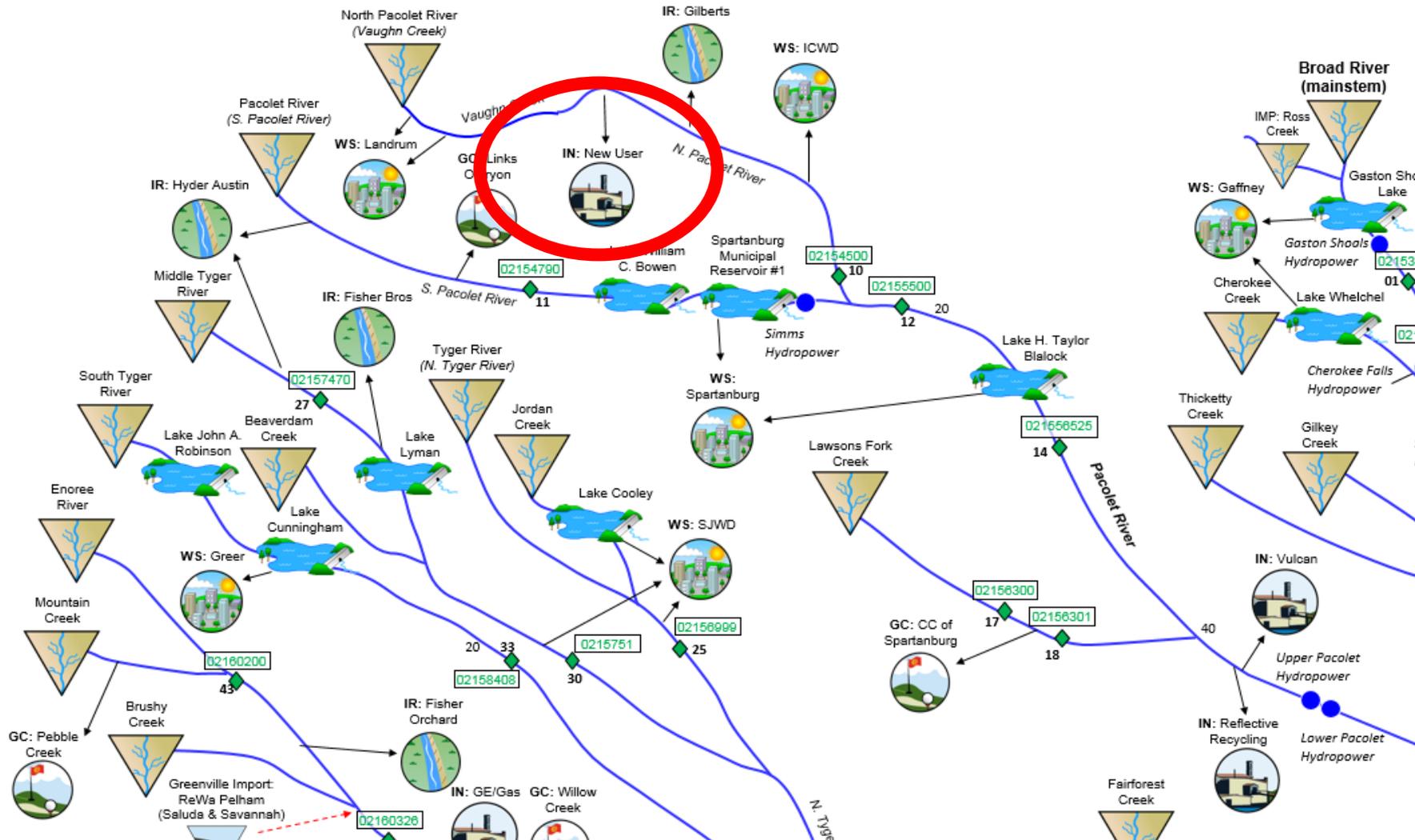
Input & Output Units

AF, AFM, AFD MG, MGD, CFS m3, m3/d, m3/s

Object Palette

The Object Palette contains icons for:

- Water bodies (rivers, lakes, reservoirs)
- Industrial water users (factory icons)
- Hydropower plants (dam icons)
- Reservoirs (lake icons)
- Links and canals (line icons)
- Other infrastructure (dike, dam, etc.)



Add the New User in the Water User Dialogue

Simplified Water Allocation Model (SWAM)

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Input Summaries and Outputting

Node Priorities **Node Locations** **Reservoir Accounts** **Output Specs**

Input & Output Units

AF, AFM, AFD MG, MGD, CFS m3, m3/d, m3/s

Water User

Main | Source Water | Return Flows

Water User Name: IN: New User

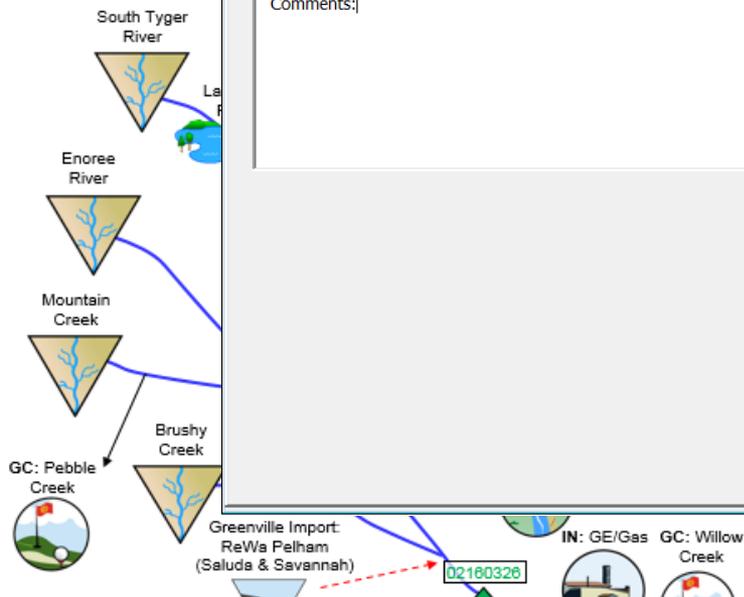
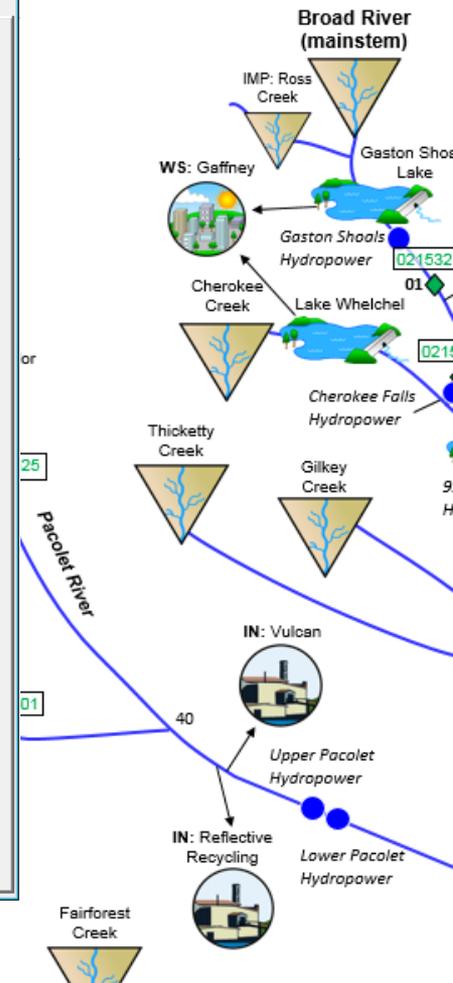
Delete Node Multiple Sources of Water?

Supplemental Supply/Demand Alternatives

Conservation Transbasin Import
 Recapture Reuse Water Exchange
 Ag Transfer

Comments:

Save **Close**



Object Palette

- Water User (highlighted)
- Reservoir
- Hydropower
- Import
- Export
- Transfer
- Conservation
- Recapture Reuse
- Ag Transfer
- Transbasin Import
- Water Exchange
- Other symbols

Specify Water Use

Simplified Water Allocation Model (SWAM)

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Water User

Main | Water Usage | Source Water | Return Flows

Monthly User Distribution
 M&I
 Agriculture

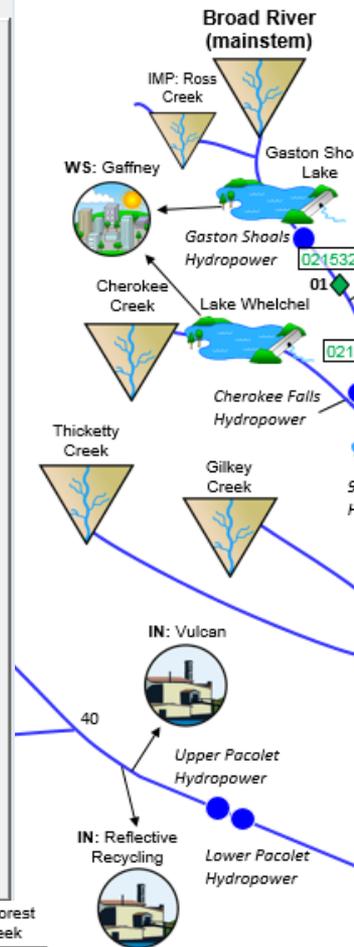
Annual Baseline Usage
 Input Format: monthly means, timeseries

Total Use (MGY) [] **Distribute**

Monthly Baseline Usage (MGD)

Month	Monthly Usage	% Indoor Use	% CU Indoor	% CU Outdoor
Jan	15	100	50	0
Feb	15	100	50	0
Mar	15	100	50	0
Apr	15	100	50	0
May	15	100	50	0
Jun	15	100	50	0
Jul	15	100	50	0
Aug	15	100	50	0
Sep	15	100	50	0
Oct	15	100	50	0
Nov	15	100	50	0
Dec	15	100	50	0

Save **Close**



Object Palette

- Water User (triangle)
- Water Source (triangle)
- Water Reservoir (circle)
- Water Conduit (line)
- Water Pump (circle)
- Water Inlet (circle)
- Water Outlet (circle)
- Water Treatment (circle)
- Water Storage (circle)
- Water Distribution (circle)
- Water Use (circle)
- Water Loss (circle)
- Water Return (circle)
- Water Control (circle)
- Water Barrier (circle)
- Water Structure (circle)
- Water Facility (circle)
- Water Infrastructure (circle)
- Water Asset (circle)
- Water Resource (circle)
- Water Element (circle)
- Water Component (circle)
- Water Part (circle)
- Water Piece (circle)
- Water Bit (circle)
- Water Drop (circle)
- Water Molecule (circle)
- Water Atom (circle)
- Water Ion (circle)
- Water Electron (circle)
- Water Proton (circle)
- Water Neutron (circle)
- Water Quark (circle)
- Water Lepton (circle)
- Water Boson (circle)
- Water Fermion (circle)
- Water Hadron (circle)
- Water Baryon (circle)
- Water Meson (circle)
- Water Photon (circle)
- Water Gluon (circle)
- Water Neutrino (circle)
- Water Antineutrino (circle)
- Water Positron (circle)
- Water Neutronium (circle)
- Water Quarkonium (circle)
- Water Glueball (circle)
- Water Hybrid (circle)
- Water Exotic (circle)
- Water Strange (circle)
- Water Charm (circle)
- Water Bottom (circle)
- Water Top (circle)
- Water Up (circle)
- Water Down (circle)
- Water Strange (circle)
- Water Charm (circle)
- Water Bottom (circle)
- Water Top (circle)
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- Water Down (circle)

Specify Source and Withdrawal Location

Simplified Water Allocation Model (SWAM)

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Simulation Type

- Monthly Planning
- Daily Planning
- Short Term Forecasting
- Firm Yield Calculator
- Prior Appropriations
- Riparian Water Rights

Run (ctrl R)

Input Summaries and Outputting

Node Priorities | Node Locations | Reservoir Accounts | Output Specs

Input & Output Units

- AF, AFM, AFD
- MG, MGD, CFS
- m3, m3/d, m3/s

Water User

Main | Water Usage | Source Water | Return Flows

Source Stream: North Pacolet River

Source Water Type: Direct River

Diversion Location (mi): 10

Priority Date: 1/20/1900

Diversion Capacity (CFS): 10000

Permit Limit (MGM): 10000

Seasonal Permit

Minimum Flow

Save

Close

Identifying Notes:

Run Model Scenario

Simplified Water Allocation Model (SWAM)

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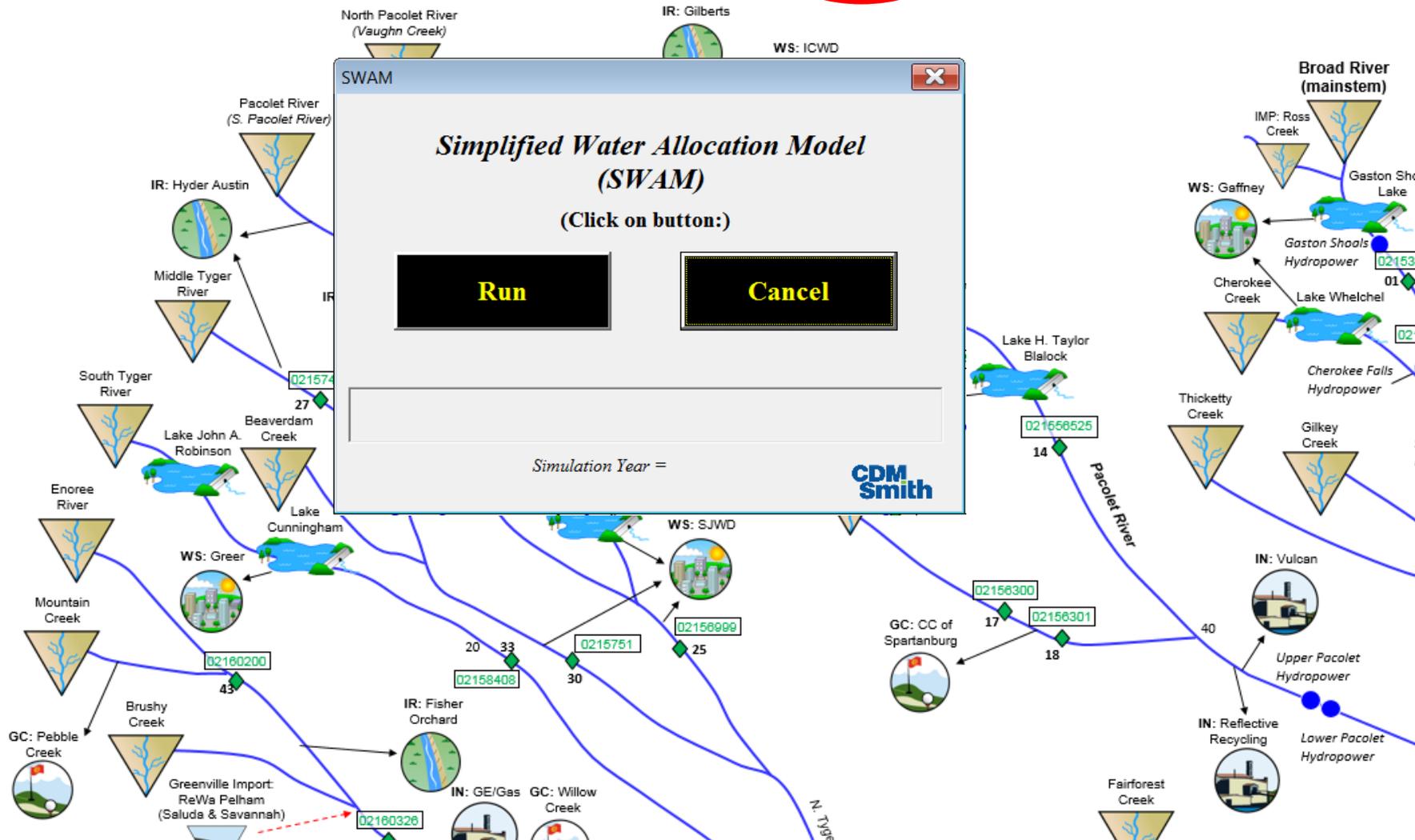
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Input & Output Units

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- MG, MGD, CFS
- m8, m8/d, m3/s

Object Palette



Build a Shortage Plot for the New User

Simplified Water Allocation Model (SWAM)

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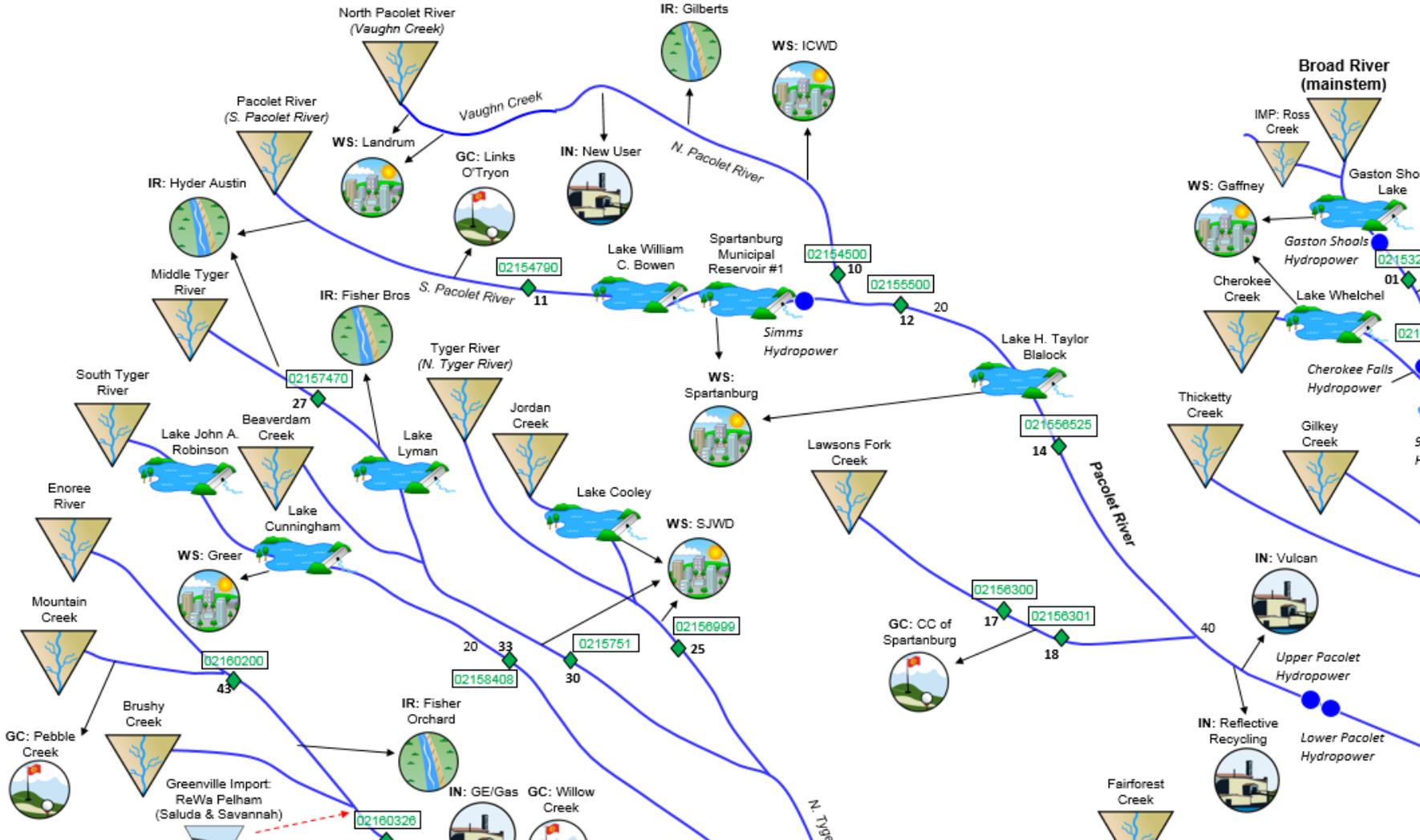
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Reservoir Accounts
Output Specs

Input & Output Units

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Object Palette

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Build a Shortage Plot for the New User

Simplified Water Allocation Model (SWAM)

Simulation Period

Start Date (MM/DD/YYYY): 01/01/1983
End Date (MM/DD/YYYY): 12/31/2013

Simulation Type

- Monthly Planning
- Daily Planning
- Short Term Forecasting
- Firm Yield Calculator
- Prior Appropriations
- Riparian Water Rights

Run (ctrl R)

Input Summaries and Outputting

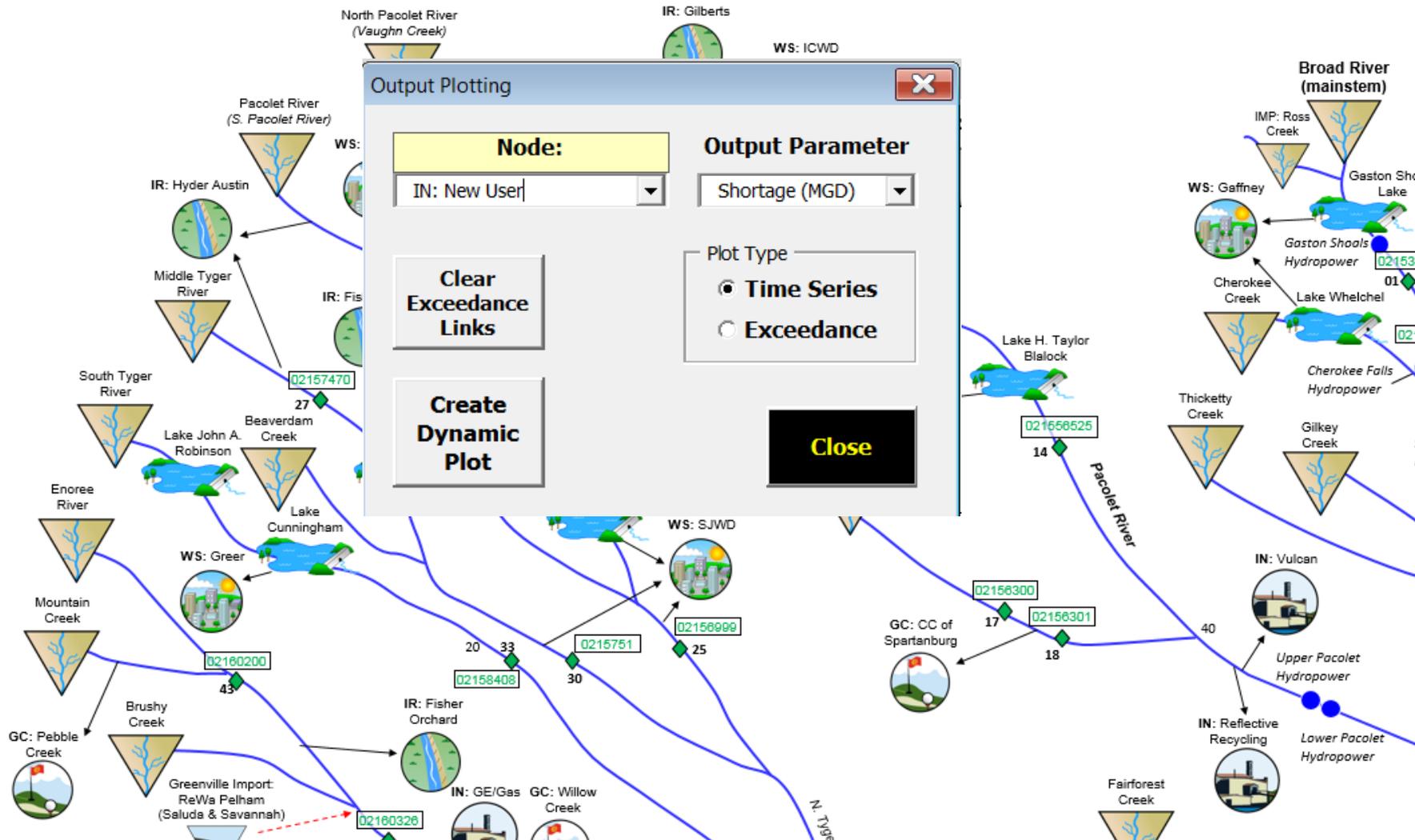
Node Priorities | Node Locations | Reservoir Accounts | Output Specs

Input & Output Units

- AF, AFM, AFD
- MG, MGD, CFS
- m8, m8/d, m3/s



Object Palette



Build a Shortage Plot for the New User

Object Palette



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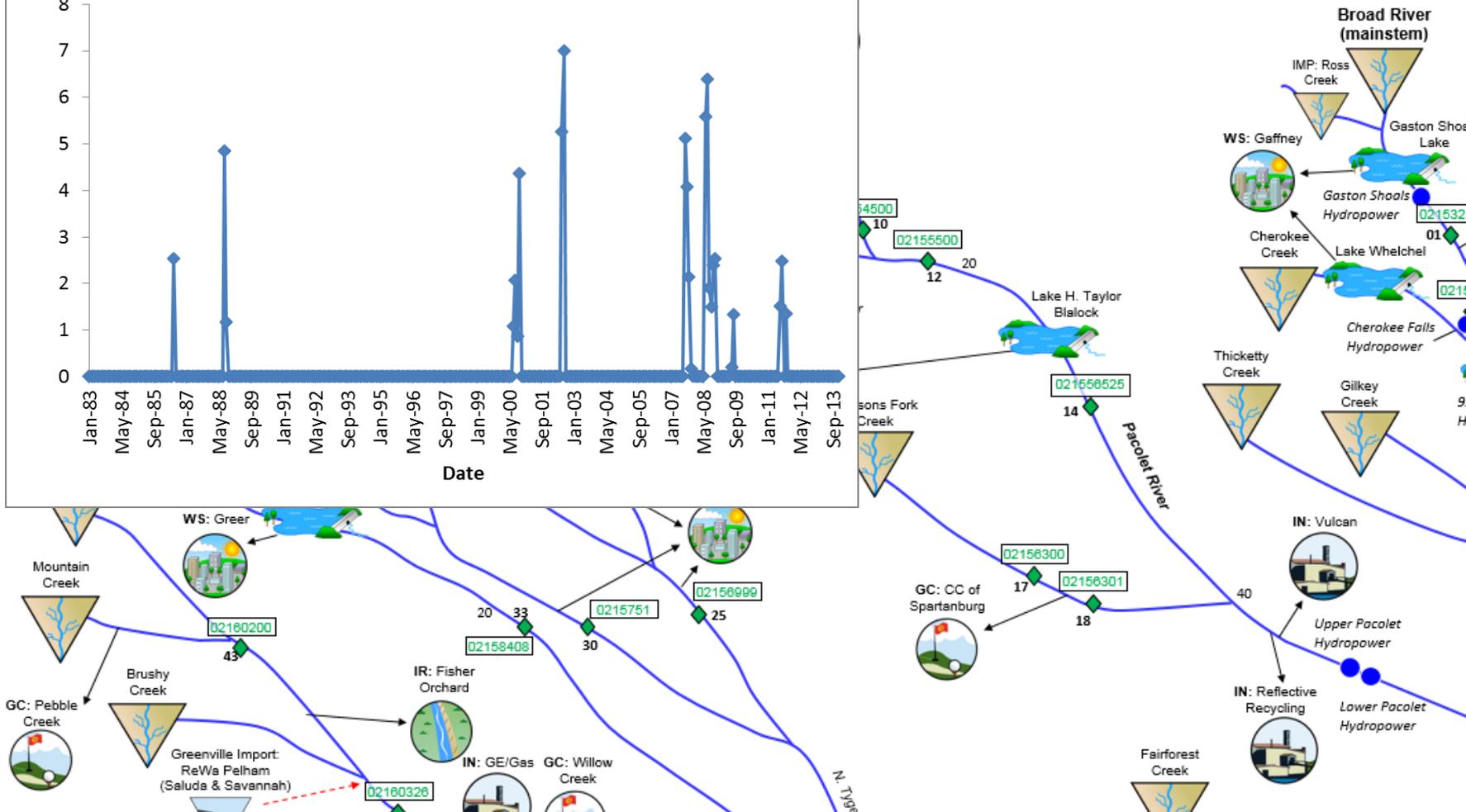
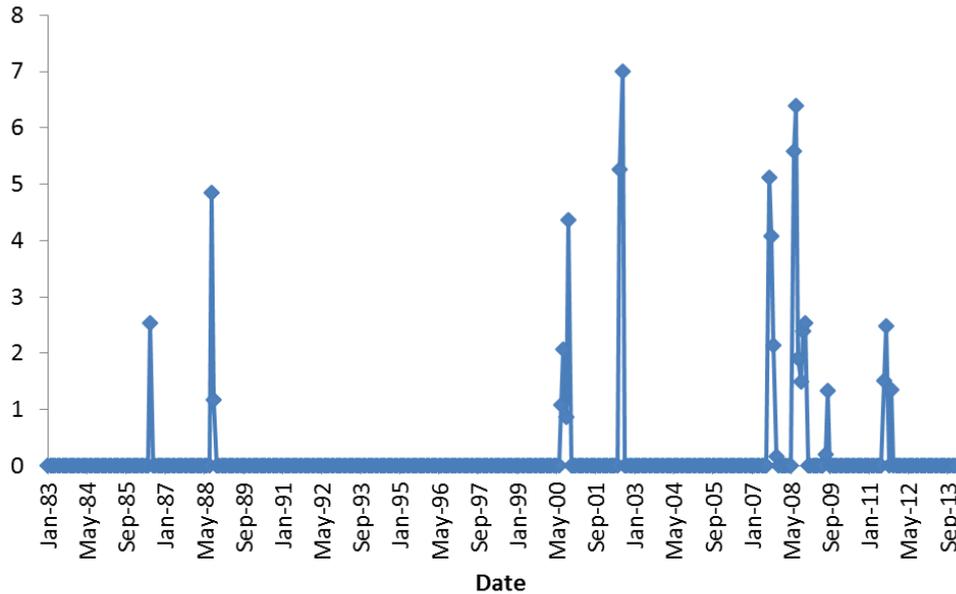
Input Summaries and Outputting

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IN: New User Shortage (MGD)



Shortages are Also Listed in the Node Output Table

Output			<u>Priority Rank</u>	<u>Reach</u>	<u>Location</u>	<u>Permit Limit (MGM)</u>	<u>Diversion Capacity (CFS)</u>	<u>Storage Capacity (MG)</u>	<u>Reservoir Withdrawal Permit (MGM)</u>
	<i>IN: New User</i>		<i>21</i>	<i>North Pacolet River</i>	<i>10</i>	<i>10000</i>	<i>10000</i>	<i>0</i>	
	<u>Date</u>	<u>Physically Avail. (MGD)</u>	<u>Legally Avail. (MGD)</u>	<u>Demand (MGD)</u>	<u>River Withdrawal (MGD)</u>	<u>Storage (MG)</u>	<u>Groundwater Withdrawal (MGD)</u>	<u>Shortage (MGD)</u>	<u>Return Flow (MGD)</u>
	Min	8	8	15	8	0	0	0	4
	Max	166	166	15	15	0	0	7	8
	Avg	47	47	15	15	0	0	0	7
	2/28/08	32	32	15	15	0	0	0	8
	3/31/08	44	44	15	15	0	0	0	8
	4/30/08	32	32	15	15	0	0	0	8
	5/31/08	19	19	15	15	0	0	0	8
	6/30/08	9	9	15	9	0	0	6	5
	7/31/08	9	9	15	9	0	0	6	4
	8/31/08	13	13	15	13	0	0	2	7
	9/30/08	14	14	15	14	0	0	1	7
	10/31/08	13	13	15	13	0	0	2	6
	11/30/08	12	12	15	12	0	0	3	6
	12/31/08	27	27	15	15	0	0	0	8
	1/31/09	35	35	15	15	0	0	0	8
	2/28/09	20	20	15	15	0	0	0	8
	3/31/09	56	56	15	15	0	0	0	8
	4/30/09	56	56	15	15	0	0	0	8
	5/31/09	33	33	15	15	0	0	0	8
	6/30/09	33	33	15	15	0	0	0	8
	7/31/09	15	15	15	15	0	0	0	7
	8/31/09	14	14	15	14	0	0	1	7
	9/30/09	31	31	15	15	0	0	0	8
	10/31/09	31	31	15	15	0	0	0	8
	11/30/09	70	70	15	15	0	0	0	8
	12/31/09	113	113	15	15	0	0	0	8
	1/31/10	107	107	15	15	0	0	0	8

Reduce the New User's Total Water User to 5 mgd

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Monthly Planning Prior Appropriations
 Daily Planning Riparian Water Rights
 Short-Term Forecasting
 Firm Yield Calculator

Run (ctrl R)

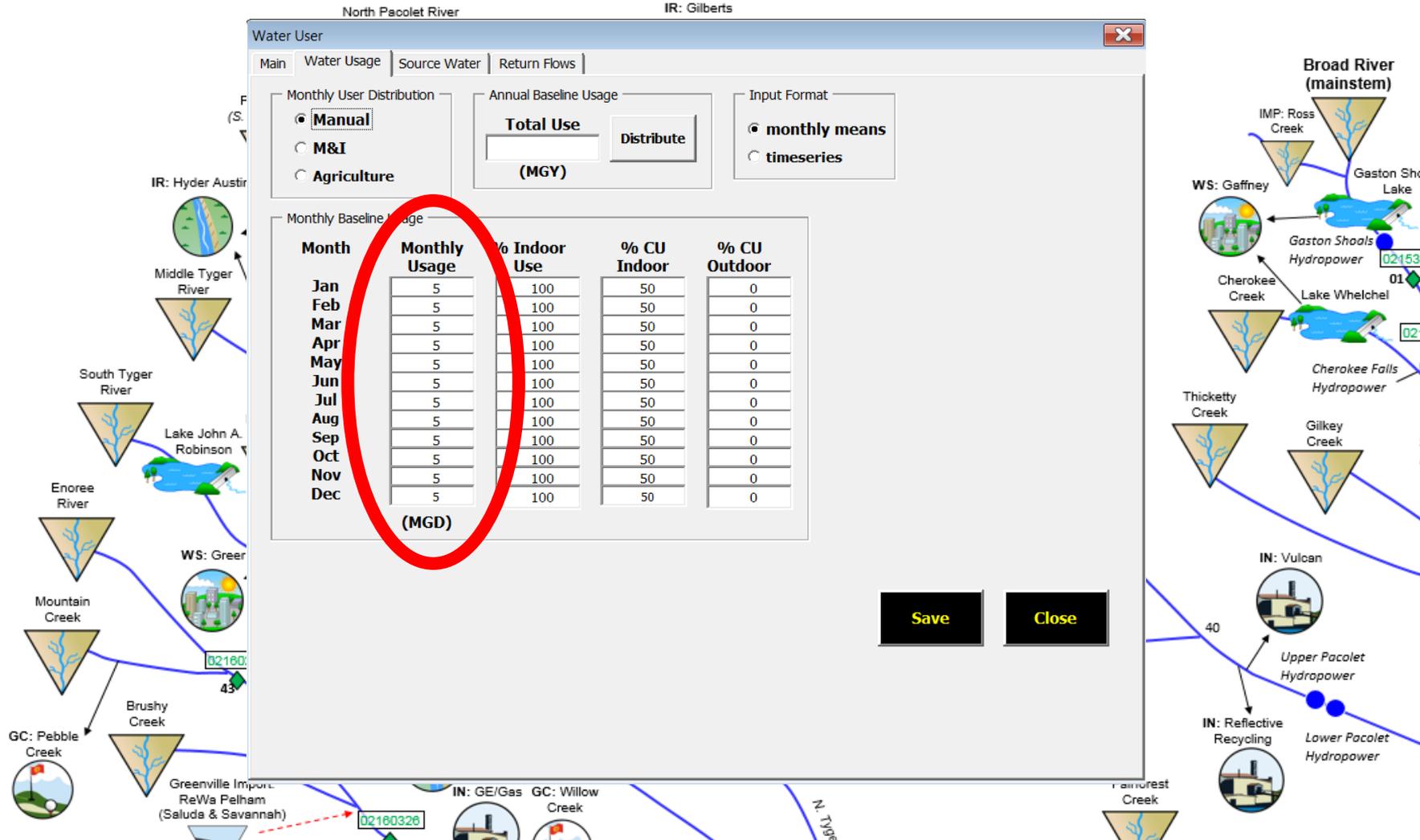
Input Summaries and Outputting

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Input & Output Units

AF, AFM, AFD MG, MGD, CFS m3, m3/d, m3/s

Object Palette



Water User

Main | Water Usage | Source Water | Return Flows

Manual
 M&I
 Agriculture

Annual Baseline Usage

Total Use (MGY) **Distribute**

Input Format: monthly means timeseries

Monthly Baseline Usage

Month	Monthly Usage (MGD)	% Indoor Use	% CU Indoor	% CU Outdoor
Jan	5	100	50	0
Feb	5	100	50	0
Mar	5	100	50	0
Apr	5	100	50	0
May	5	100	50	0
Jun	5	100	50	0
Jul	5	100	50	0
Aug	5	100	50	0
Sep	5	100	50	0
Oct	5	100	50	0
Nov	5	100	50	0
Dec	5	100	50	0

Save **Close**

Rerun Model Scenario

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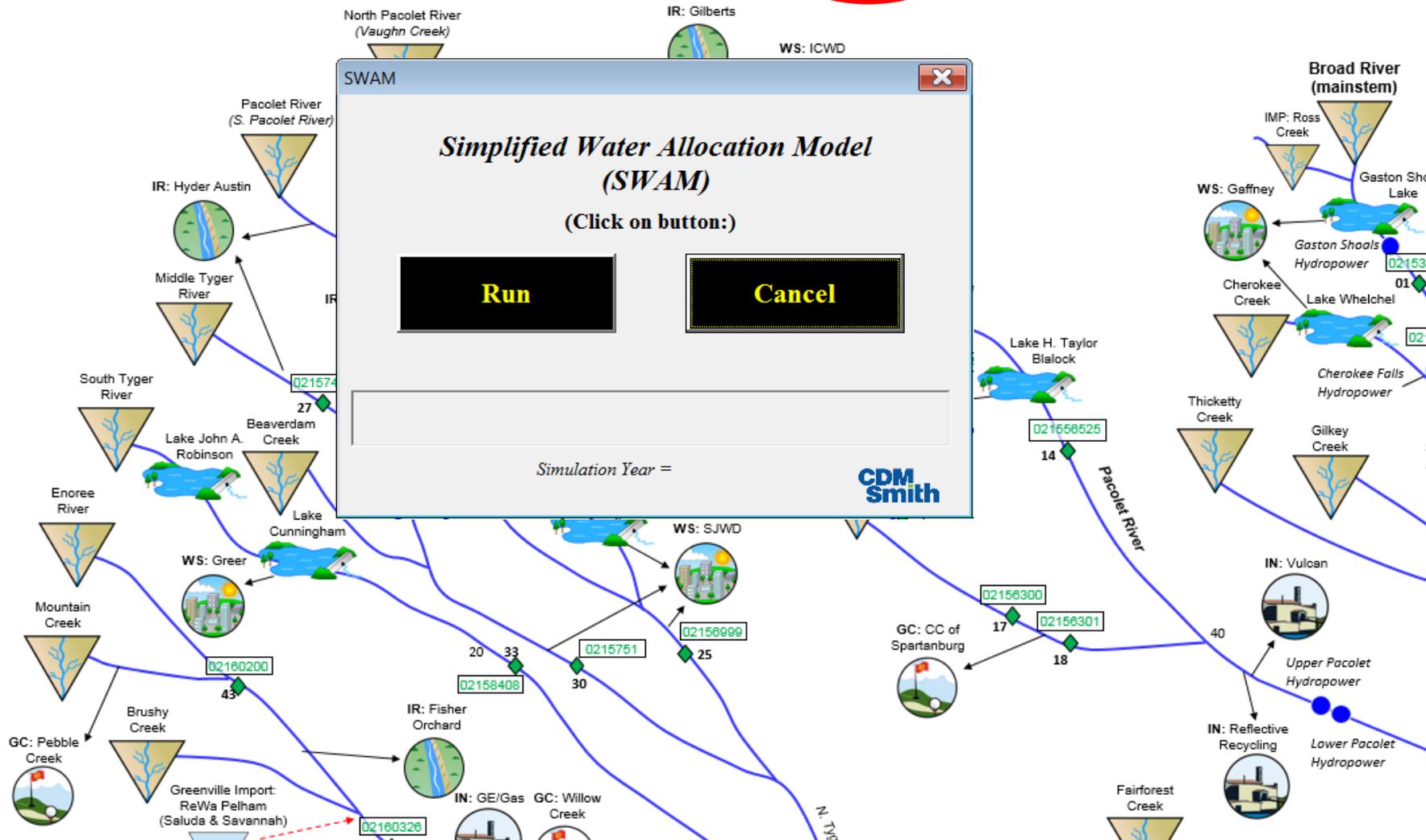
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Object Palette



SWAM

Simplified Water Allocation Model (SWAM)

(Click on button:)

Run **Cancel**

Simulation Year =

CDM Smith

Dynamic Shortage Plots Update Automatically

Object Palette



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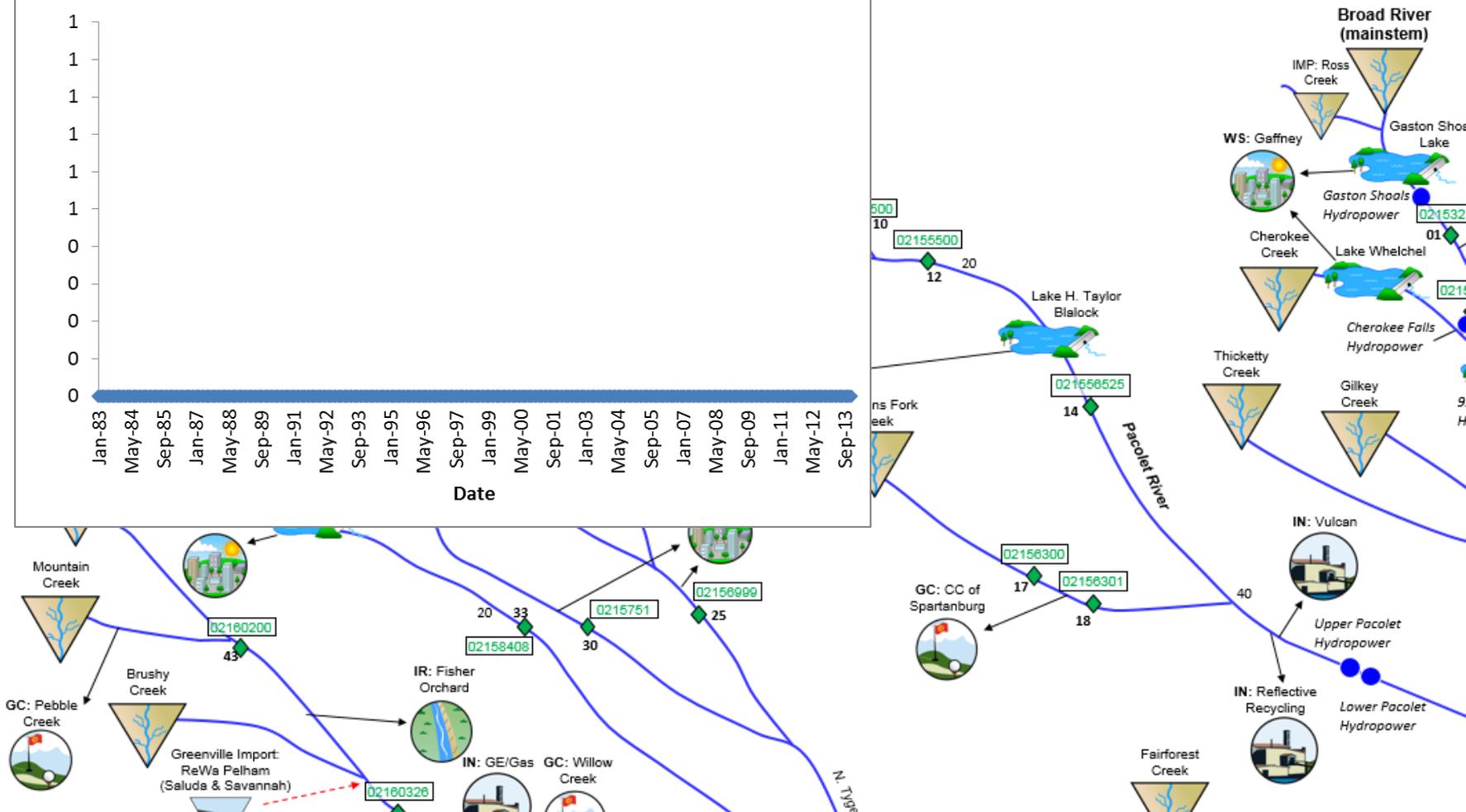
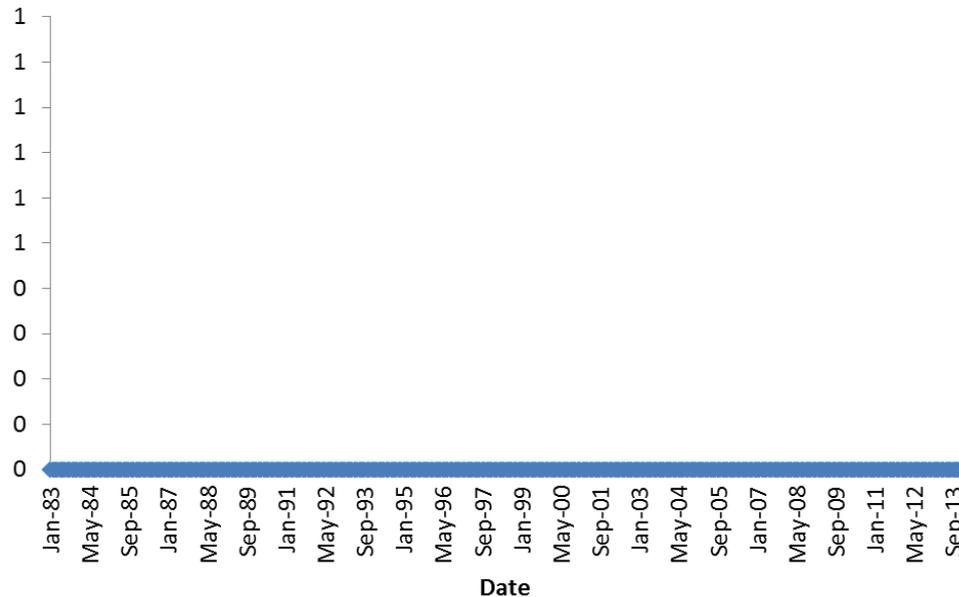
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IN: New User Shortage (MGD)



Check for Shortages for Downstream Users

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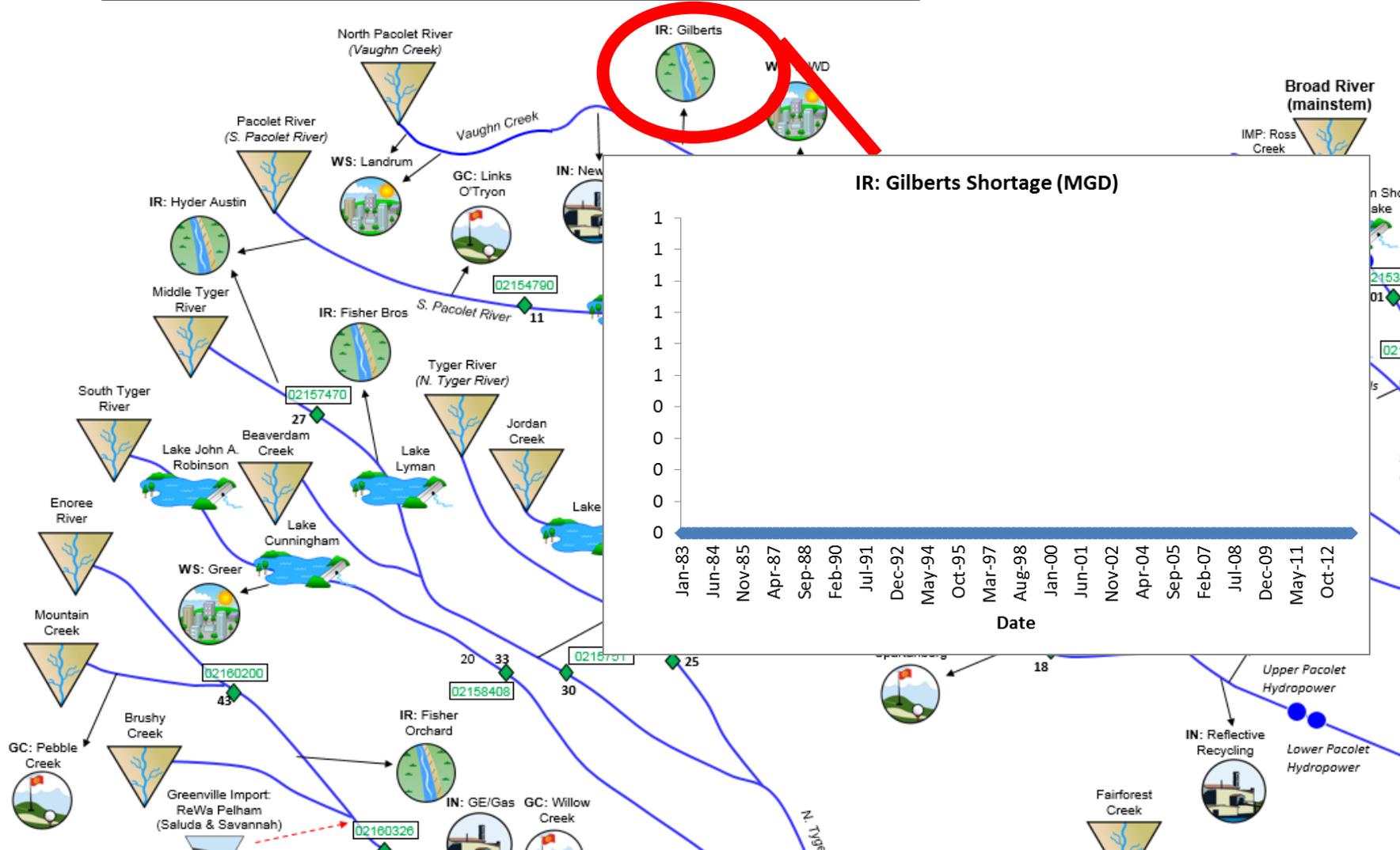
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Object Palette

- Reservoir
- Diversion
- Conduit
- Wetland
- Water Right
- Water Use
- Water Treatment
- Water Storage
- Water Distribution
- Water Quality
- Water Infrastructure
- Water Management
- Water Modeling
- Water Simulation
- Water Analysis
- Water Reporting
- Water Visualization
- Water Integration
- Water Interfacing
- Water Interoperability
- Water Interconnectivity
- Water Interactivity
:



Demonstrations and Q&A

- Station 1 (Nina)

Evaluate increased withdrawals from a reservoir

- Station 2 (John)

Evaluate a proposed new municipal water supply withdrawal

- Station 3 (Kirk)

Evaluate a proposed new industrial user and compare against instream flow requirements

Broad River Basin

THANK YOU