

# Introduction to the Savannah and Salkehatchie Surface Water Quantity Models

# What is a Model?

A *numerical model* is a representation of a real-world system that can be solved with computation methods

Numerical models allow us to explore and consider **possible futures**

Models should be as **simple** as possible and as **complex** as needed.

**“All models are wrong, some are useful”**

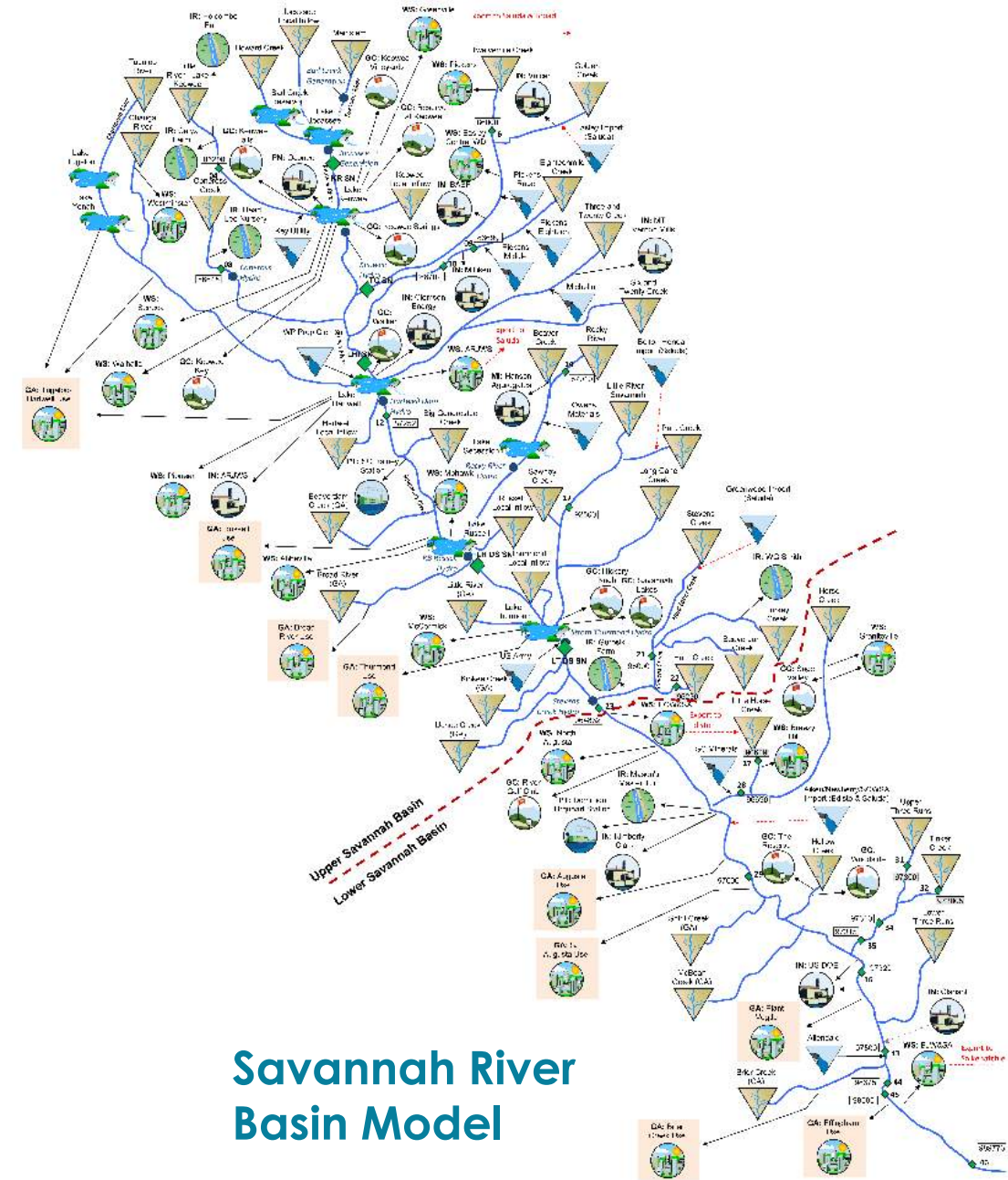
**George Box, 1976  
British Statistician**

Box’s point was that we should focus more on whether something can be applied in a useful manner rather than debating endlessly if an answer is correct in all cases

# Surface Water Model Overview

Water Allocation Modeling *is*:

- Water balance calculations of physical flow
- Water rights calculations of legally available flow
- Accounting of water demands, withdrawals, and return flows
- Accounting of reservoir storage and loss to evaporation
- A representation of stream networks, multiple “nodes”
- Data intensive

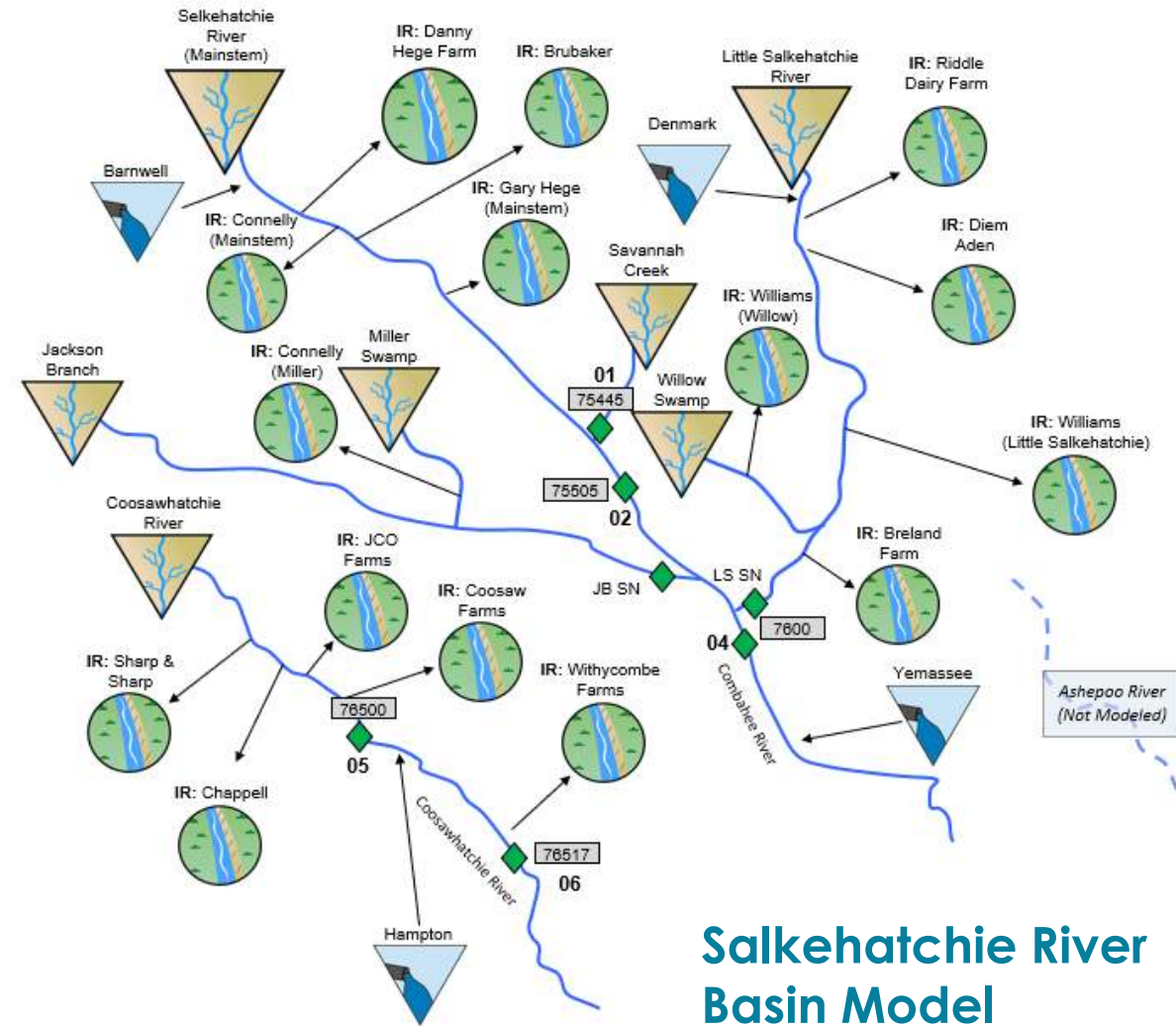


Savannah River Basin Model

# Surface Water Model Overview

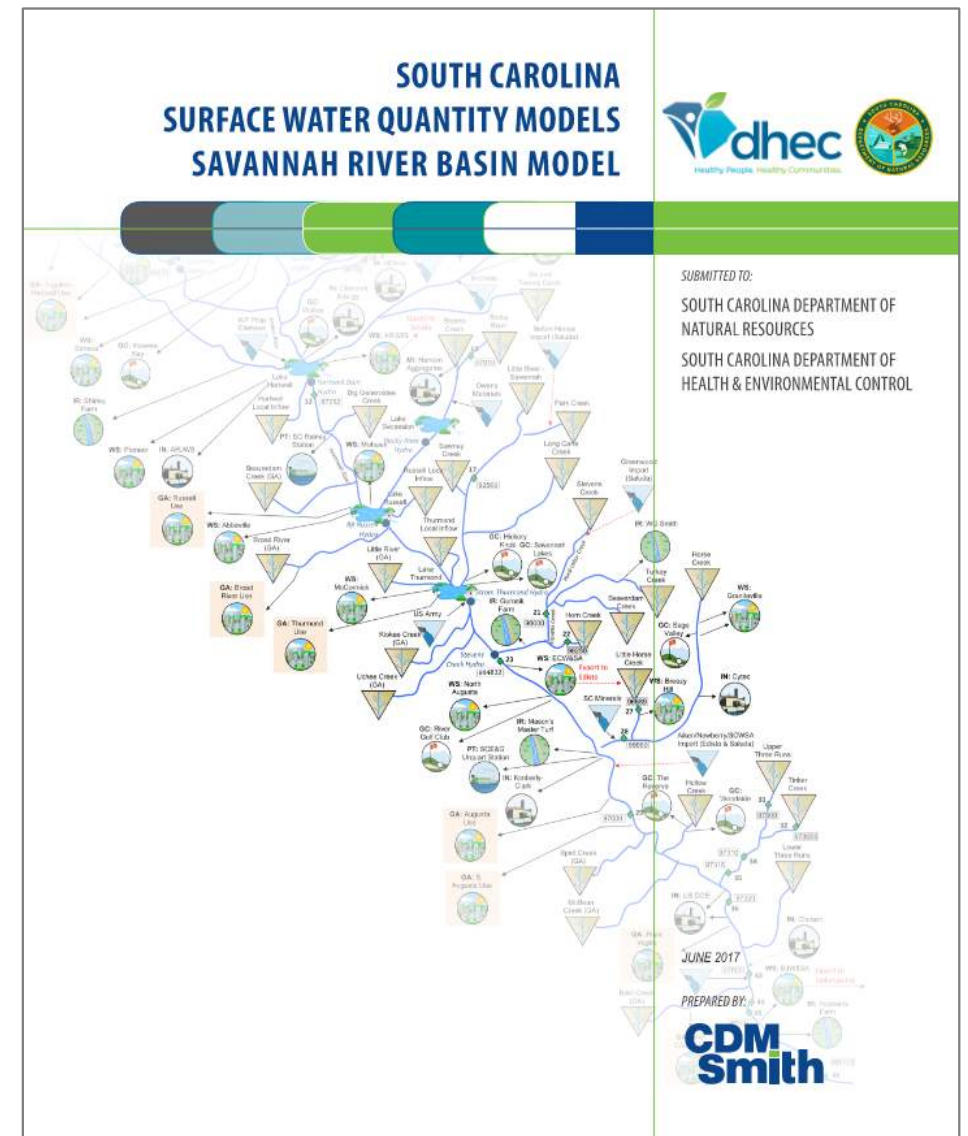
Water Allocation Modeling *is not*:

- Rainfall-runoff calculations
- Hydrologic routing calculations
- Groundwater hydrology modeling
- Water quality modeling



# Simplified Water Allocation Model (SWAM)

- Developed as a desktop tool to facilitate regional and statewide water planning and allocation
- SWAM calculates physically and legally available water, diversions, storage, consumption and return flows at user-defined nodes
- From 2014 to 2017, all eight South Carolina surface water quantity models were built in the SWAM platform
- Model updates were completed in 2023



# In Support of River Basin Planning, the Model Will be Used to:

- Assess current supply availability and shortages across a range of hydrologic conditions
  - **Savannah:** 1939 through 2021 – **82 years**
  - **Salkehatchie:** 1951 through 2021 – **71 years**
- Assess a range of future potential scenarios with respect to changes in water demand
- Assess potential impacts of a “full allocation” scenario
- Compare managed flows to natural flows
- Evaluate drought management plans
- Test, evaluate and help prioritize water management strategies

# Model Inputs and Supporting Information

## Model Inputs

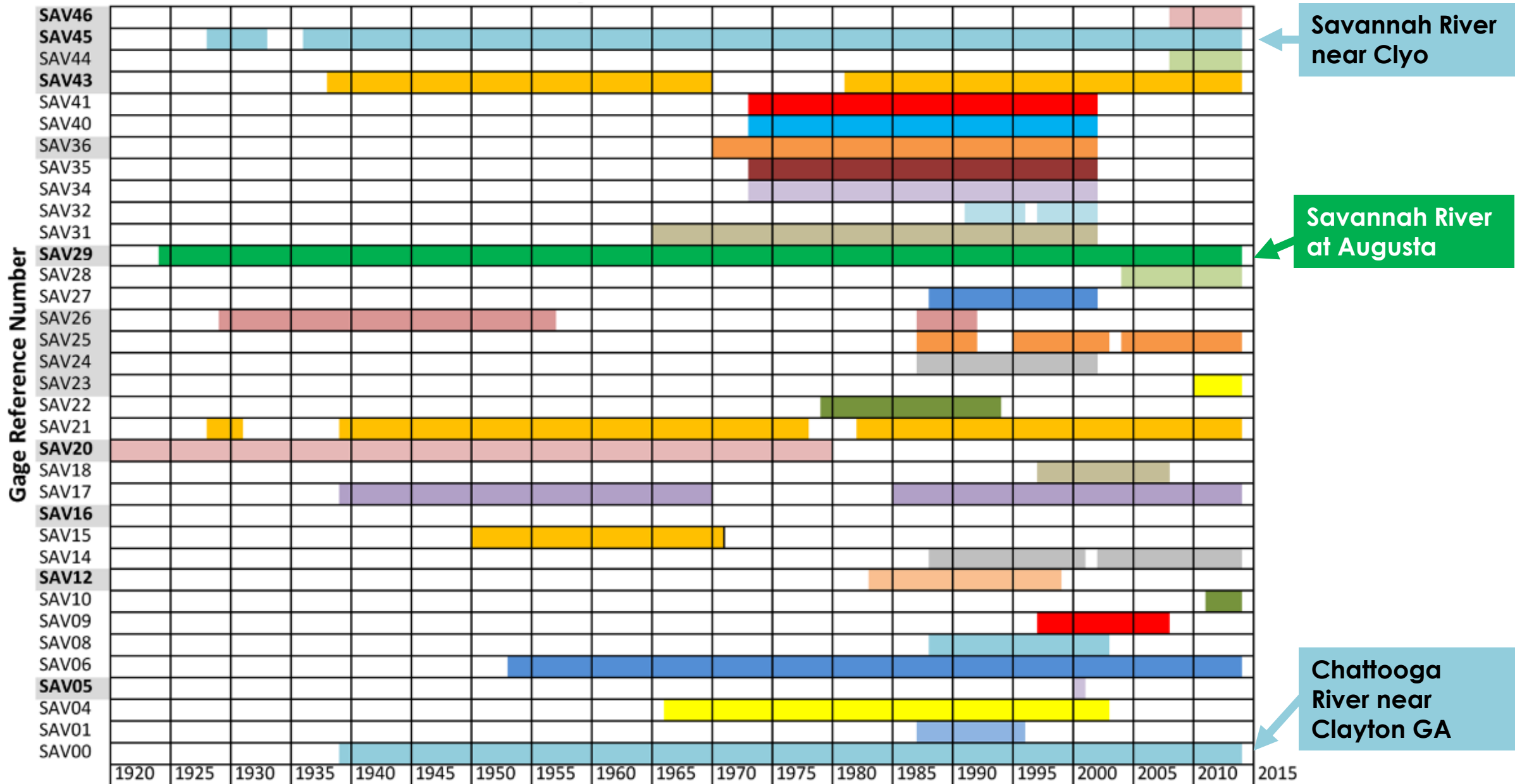
- USGS daily flow records
- Historical operational data
  - Withdrawals (municipal, industrial, thermoelectric, agricultural, golf courses, hatcheries)
  - Wastewater discharges and return flows
  - Transfers in and out of the basin
- Reservoir characteristics and operating rules

## Supporting Information

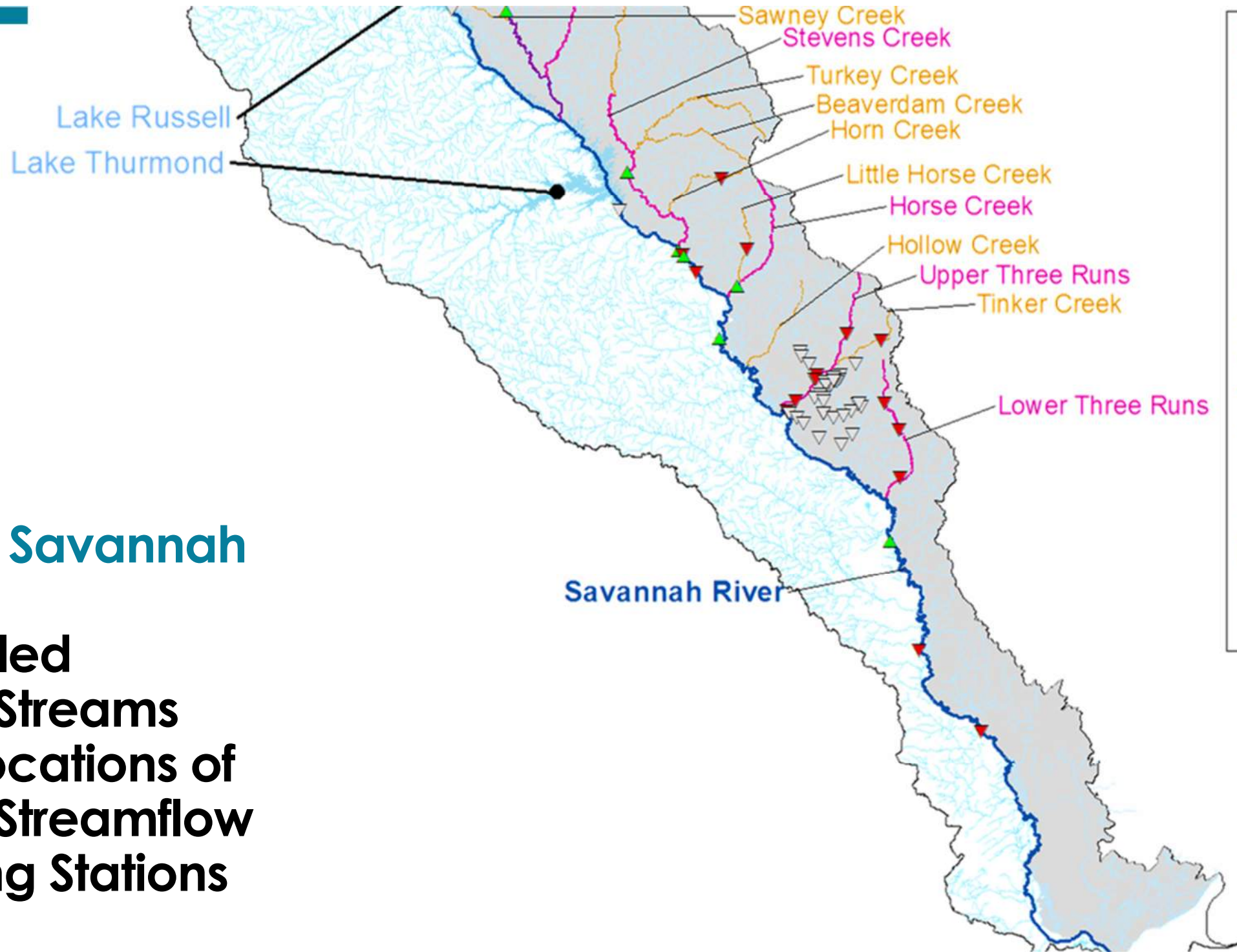
- Subbasin characteristics
  - Drainage area, land use, and slope



# USGS Gage Timeline –Savannah River Basin







**Legend**

**USGS Gages**

**Activity, Framework**

- ▲ Active, Yes
- ▼ Inactive, Yes
- ▽ Inactive, No

**Model Tributaries**

- Mainstem
- Major Branch
- Primary
- Secondary
- Higher Order
- GA Tributaries

■ Reservoirs

■ Savannah (SC Only)

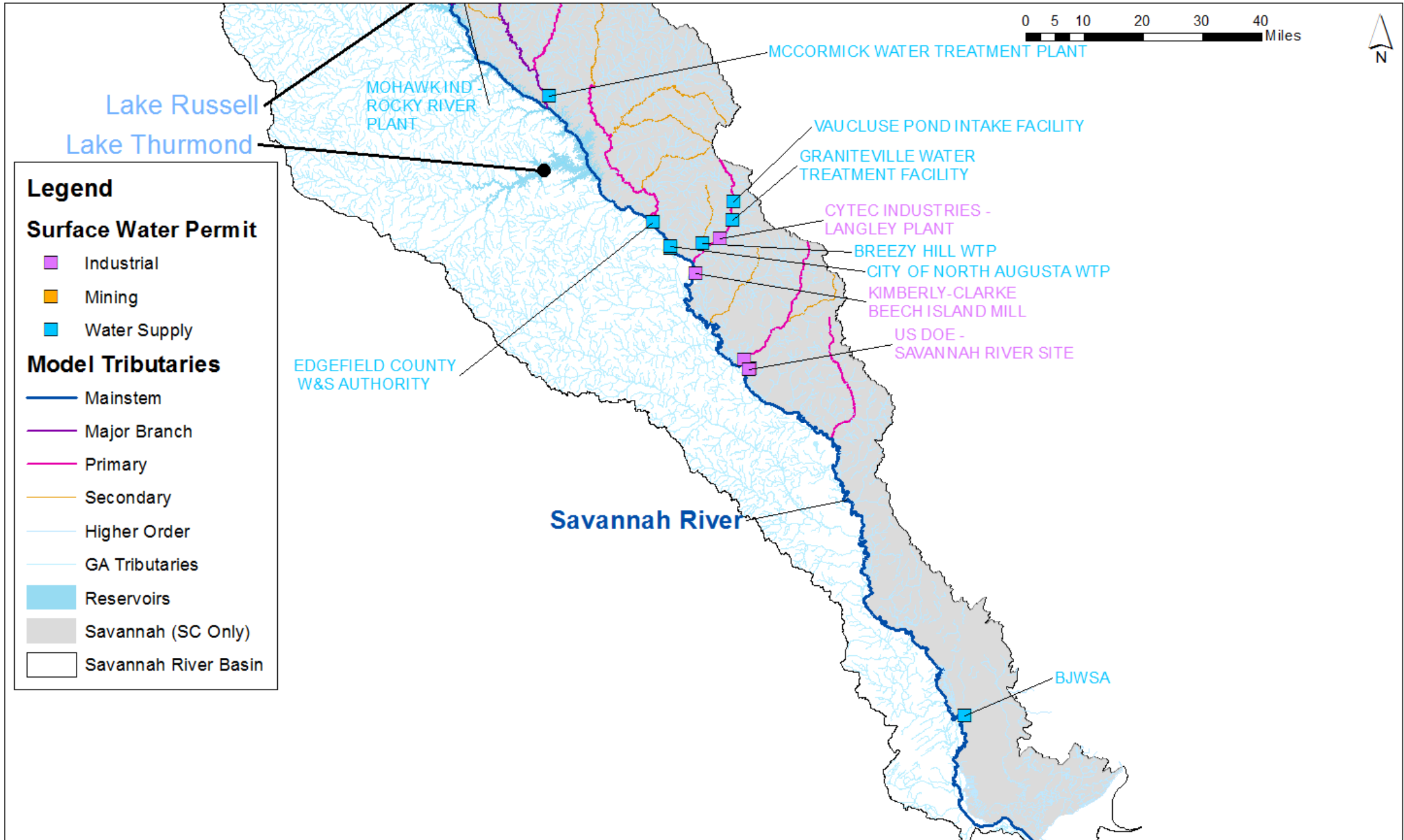
□ Savannah River Basin

## Lower Savannah

# Modeled River/Streams and locations of USGS Streamflow Gaging Stations

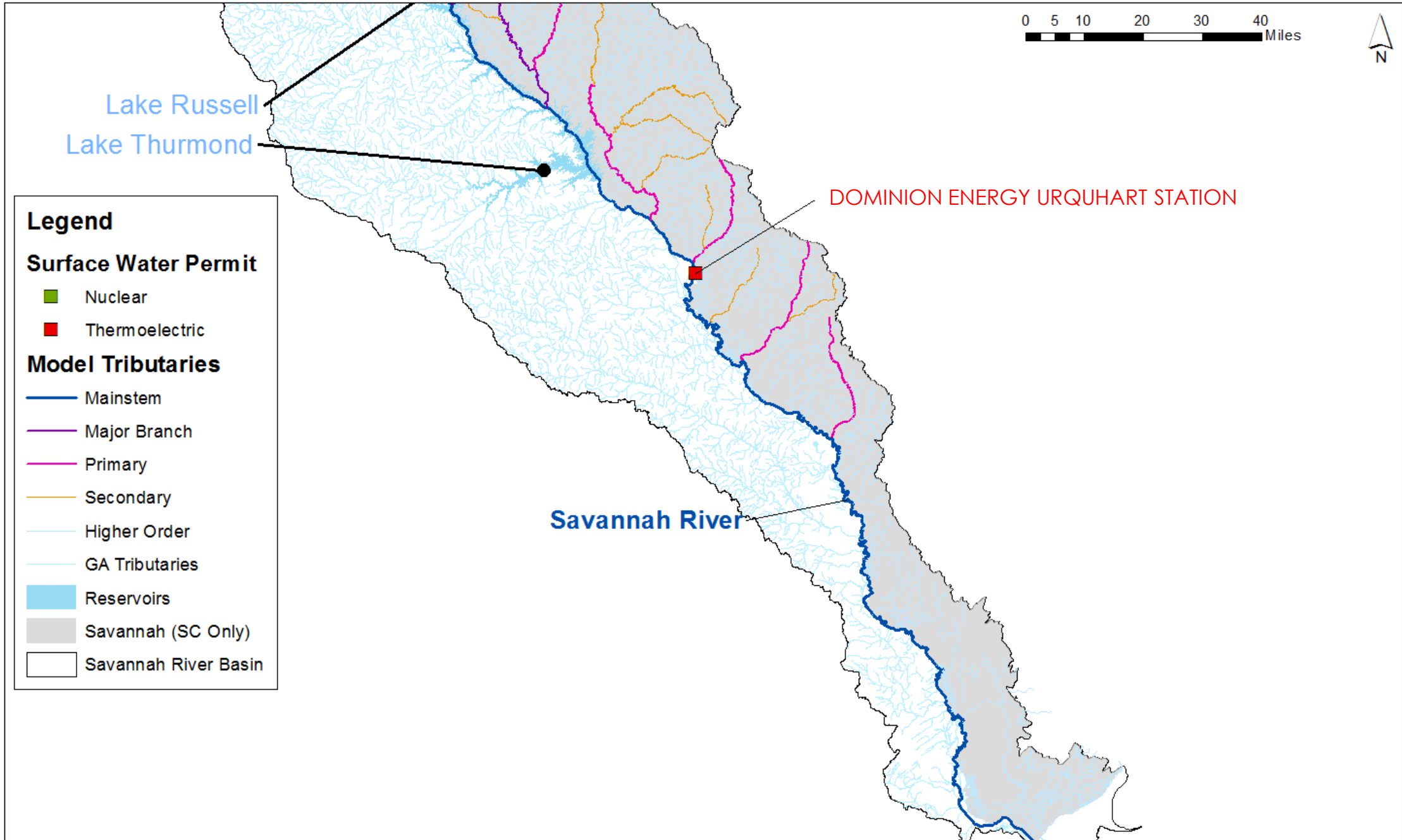
# Lower Savannah

## Municipal and Industrial Surface Water Users



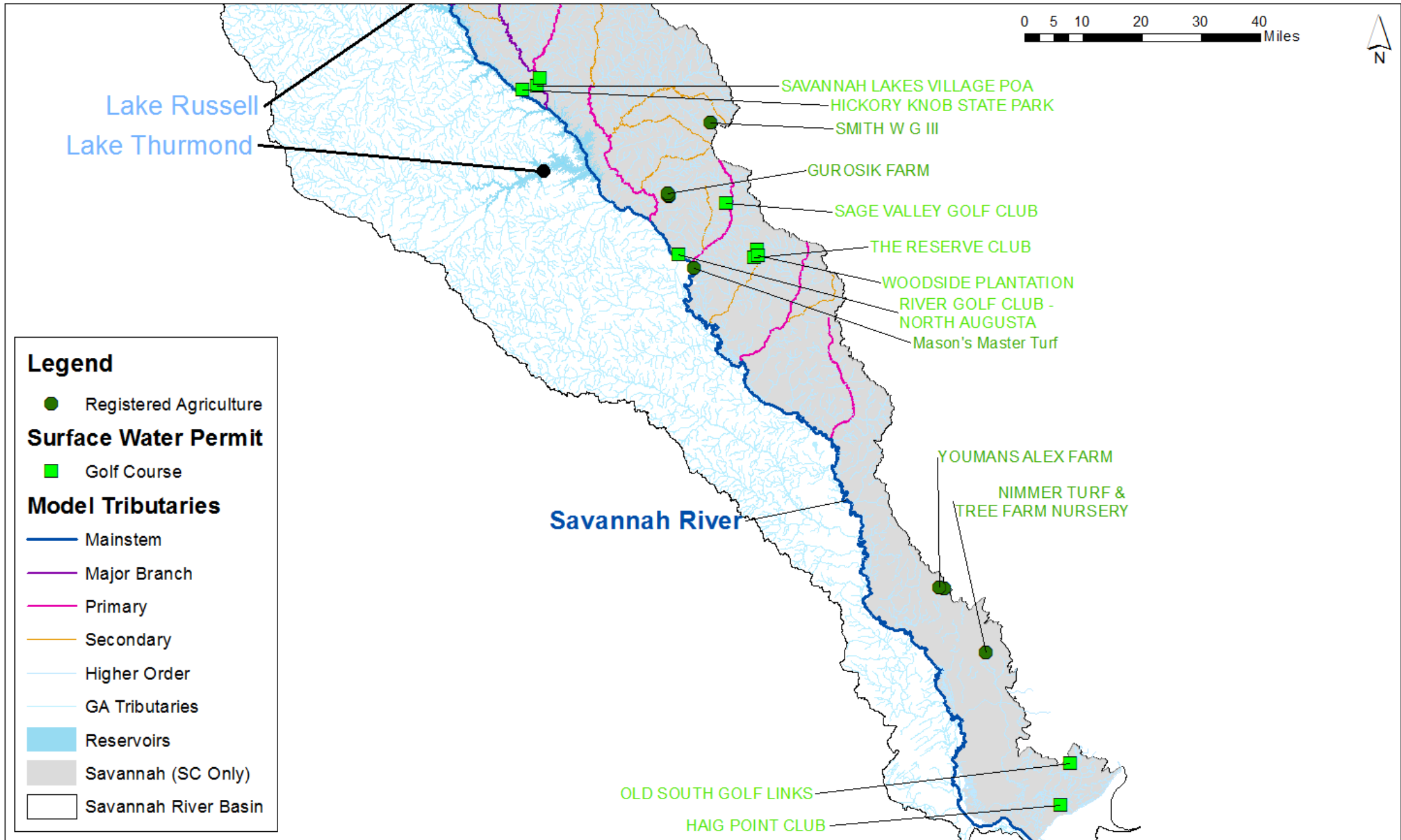
# Lower Savannah

## Energy Surface Water Users



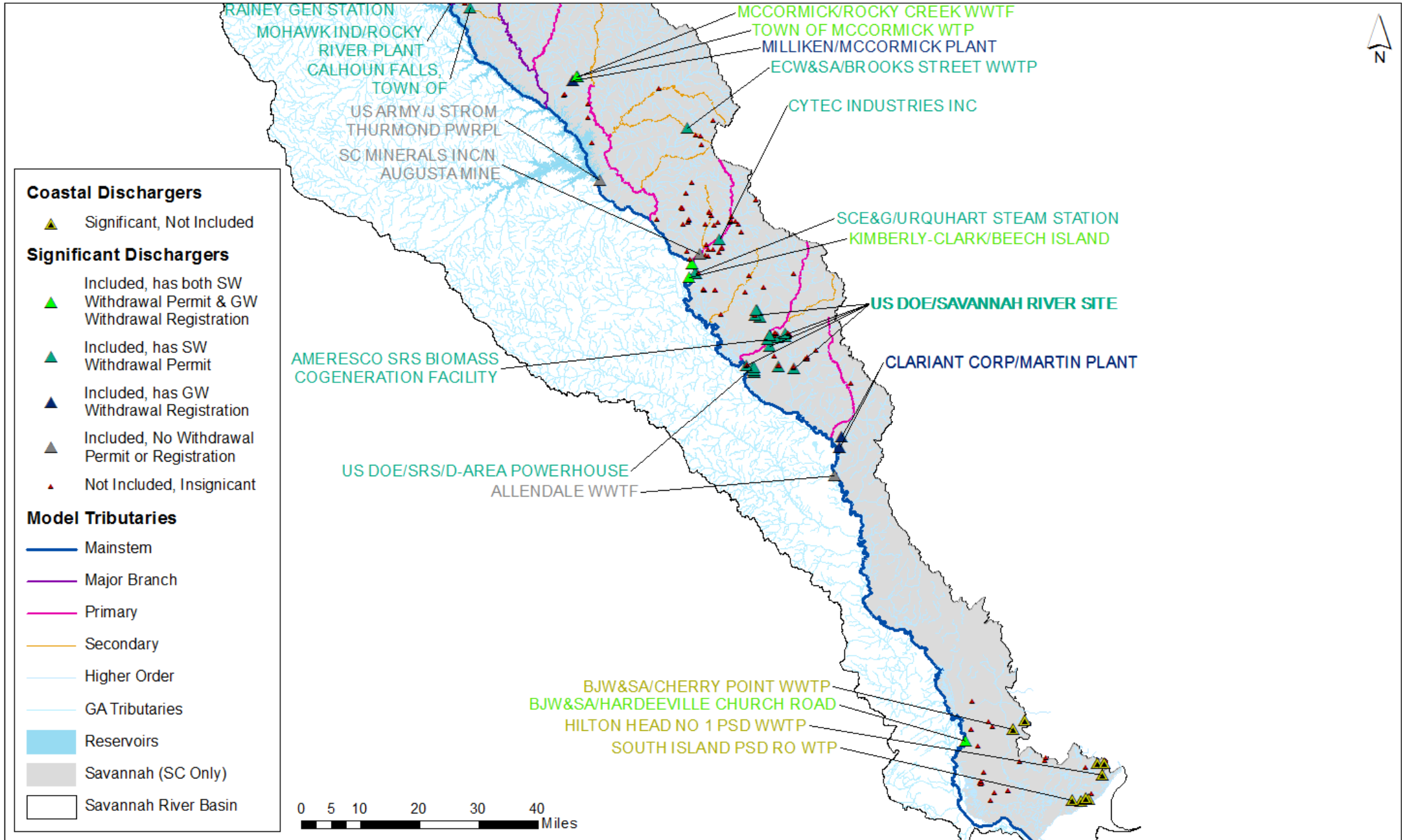
# Lower Savannah

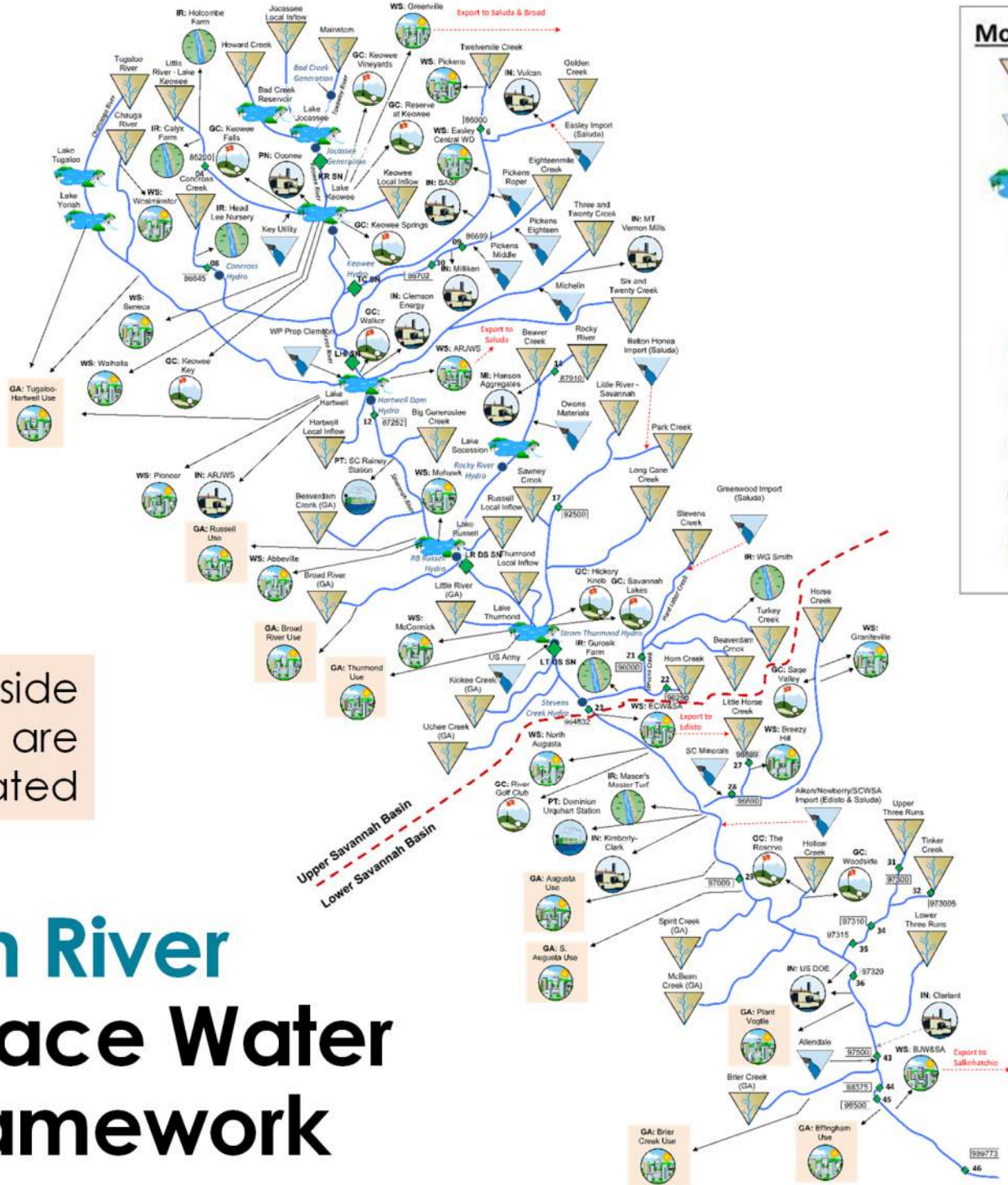
## Surface Water Use for Irrigation














# Lower Savannah

## Wastewater Discharges to Surface Water



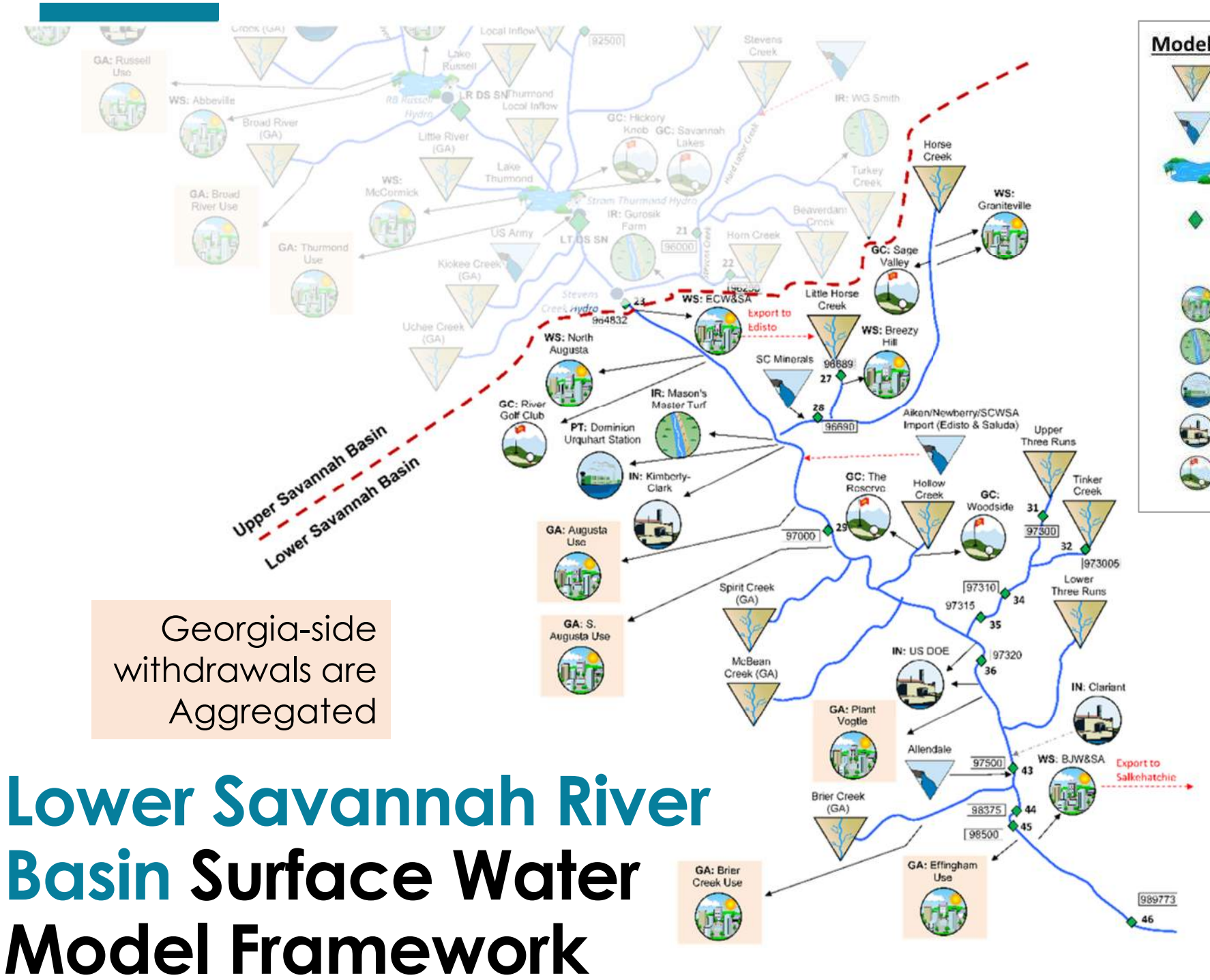


**Model Objects**

-  Tributary
  -  Discharge
  -  Reservoir
  -  Current or Former USGS Stream Gage (with last 5 to 6 digits of Gage ID)
  - Water User Objects**
  -  Municipal
  -  Agriculture (Irrigation)
  -  Thermoelectric or Nuclear
  -  Industrial or Mining
  -  Golf Course (Irrigation)
-  Import or Export (Interbasin Transfer)  
 Discharge from a Groundwater User\*
- \* The associated Water User Object does not have a Surface Water Withdrawal.

Georgia-side withdrawals are Aggregated

# Savannah River Basin Surface Water Model Framework



**Model Objects**

- Tributary
- Discharge
- Reservoir
- Current or Former USGS Stream Gage (with last 5 to 6 digits of Gage ID)

**Water User Objects**

- Municipal
- Agriculture (Irrigation)
- Thermoelectric or Nuclear
- Industrial or Mining
- Golf Course (Irrigation)

**Transfer Types**

- Import or Export (Interbasin Transfer)
- Discharge from a Groundwater User\*

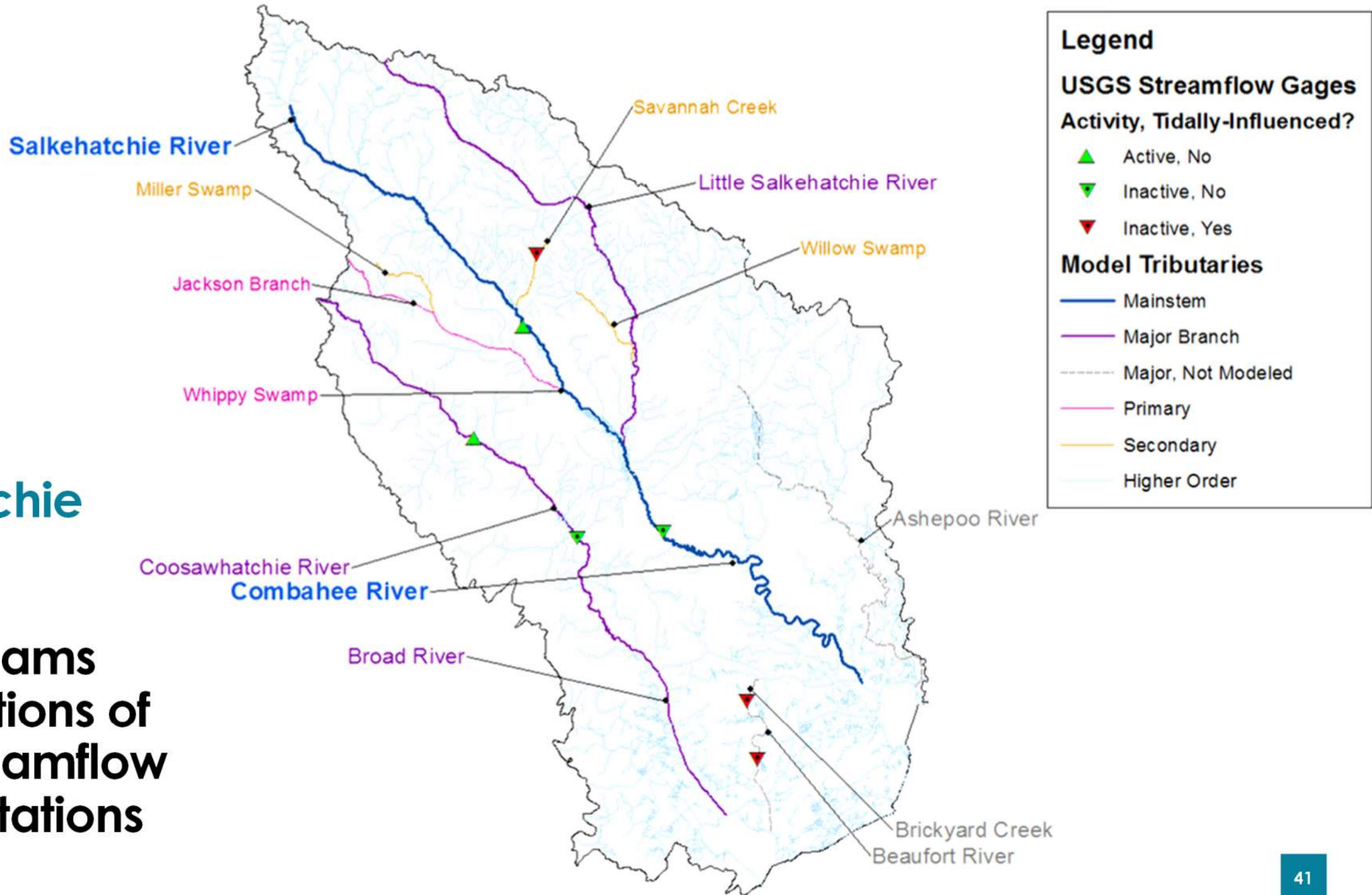
\* The associated Water User Object does not have a Surface Water Withdrawal.

Georgia-side withdrawals are Aggregated

# Lower Savannah River Basin Surface Water Model Framework

# Salkehatchie

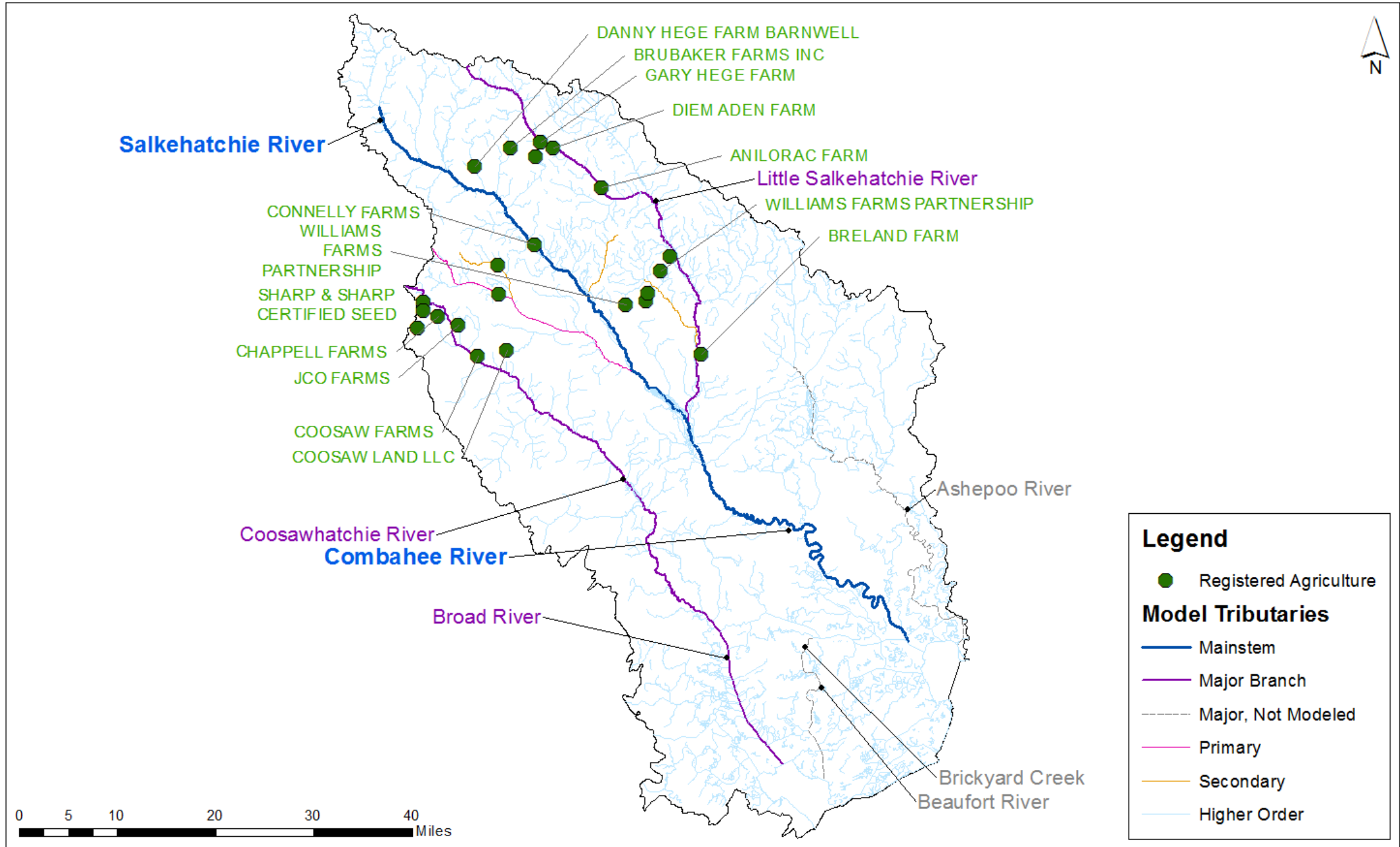
## Modeled River/Streams and locations of USGS Streamflow Gaging Stations





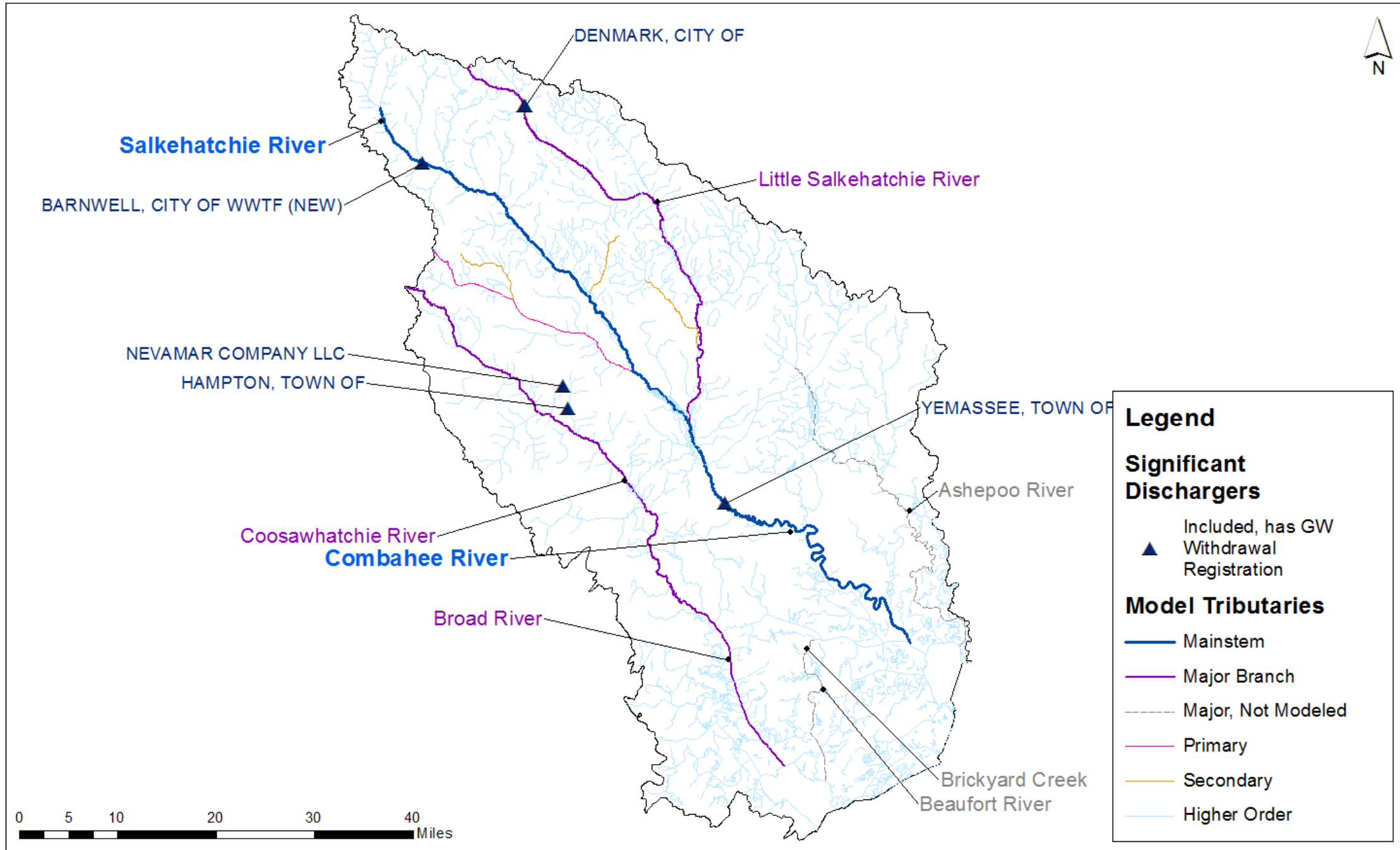
# Salkehatchie

## Surface Water Use for Irrigation

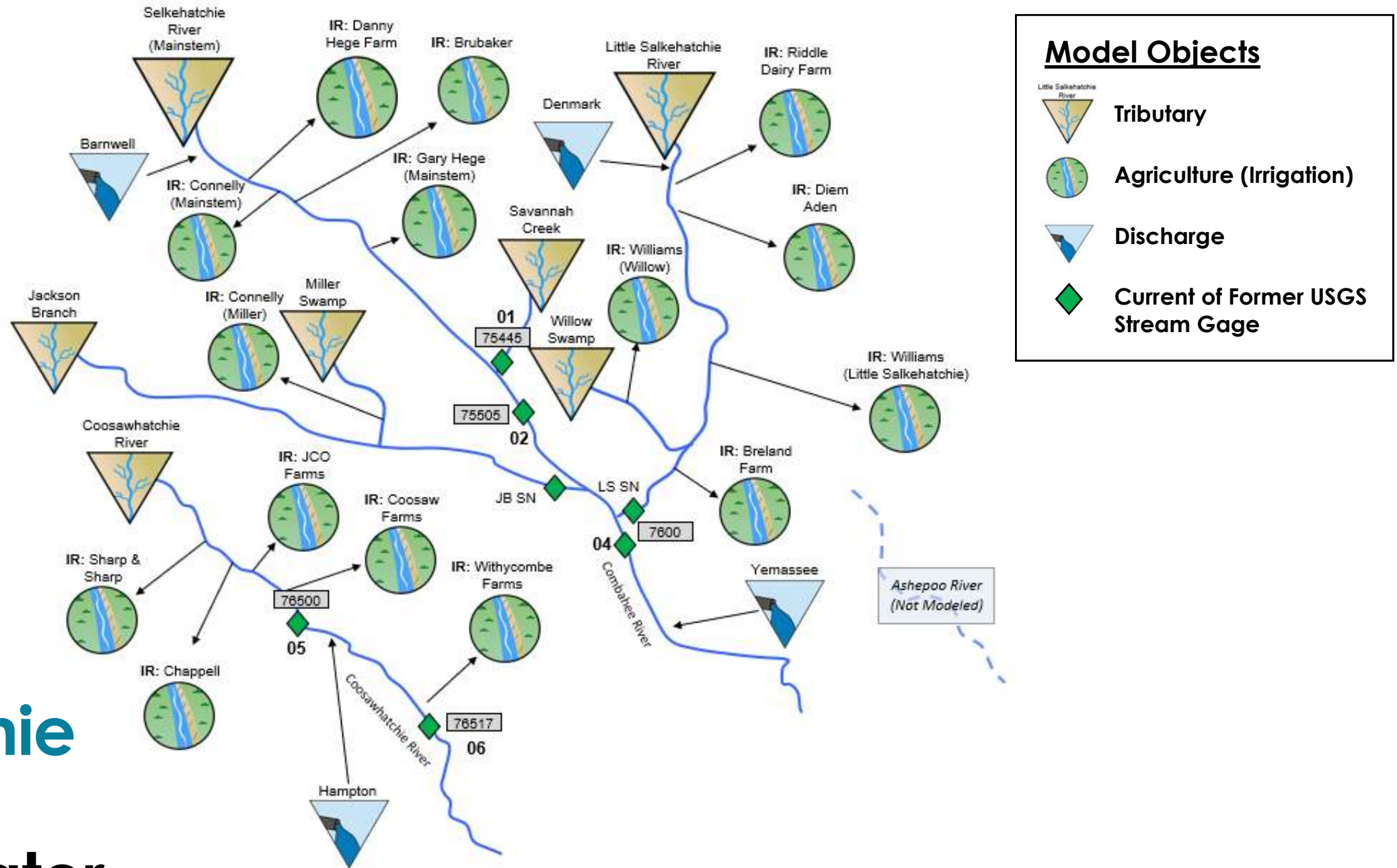


# Salkehatchie

## Wastewater Discharges to Surface Water



# Salkehatchie River Basin Surface Water Model Framework



# SWAM Calculations: Supply

- Physically available flow is a function of:
  - upstream tributary inflows,
  - reach gains and losses,
  - upstream diversions, withdrawals, returns, and storage

**Twelvemile Creek Headwater Flows**

Year (YYYY)	Month (MMM)	Monthly Flow (CFS)
1939	Oct	9.36
1939	Nov	9.13
1939	Dec	9.02
1940	Jan	12.00
1940	Feb	24.87
1940	Mar	22.81
1940	Apr	33.00
1940	May	20.26
1940	Jun	15.31
1940	Jul	13.21
1940	Aug	70.99
1940	Sep	34.11
1940	Oct	14.51
1940	Nov	18.51
1940	Dec	23.02

**Tributary** ×

**Tributary Name:** Twelvemile Creek Delete Tributary Headwater Flows

**Confluence Stream:** Mainstem **Confluence Location:** 35.5 (mi)

Spatial Flow Changes

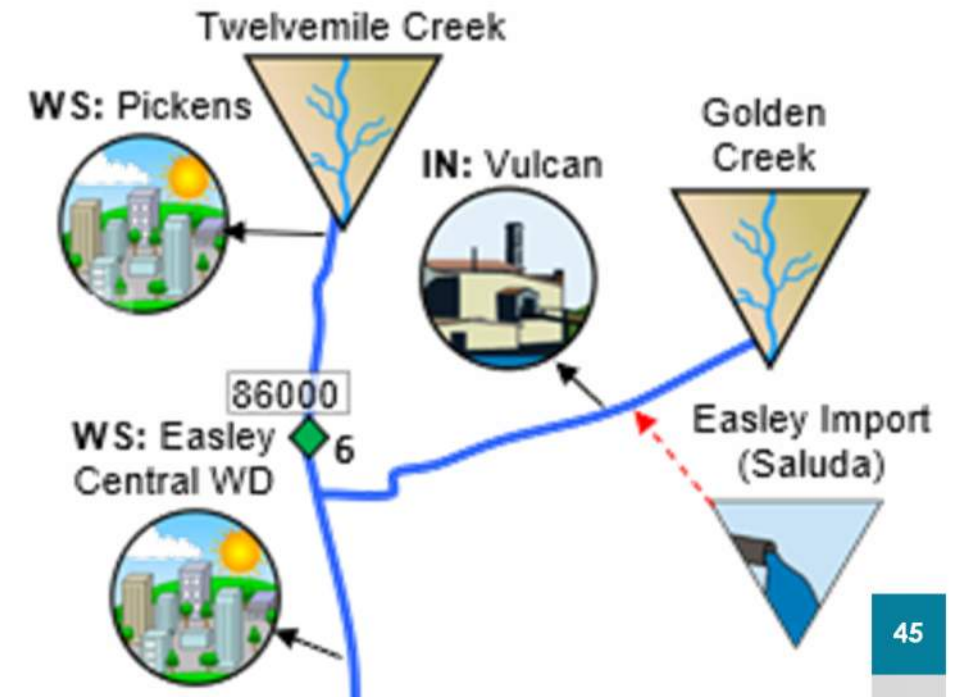
**Subbasin Flow Factors (unitless)**

end mile:	11.5	32.9	0	0	0				
factor:	5.6	7.4	0	0	0				

Temporally Variable Factors

UIF ID SAV206

Save Close



# SWAM Calculations: Supply

- **Legally available** flow is a function of:
  - Permit limits / water rights
  - Minimum Instream flow requirements

## WS: Pickens

Water User

Main | Water Usage | **Source Water** | Return Flows

**Source Stream:** Twelvemile Creek

Source Water Type:  
 Direct River  
 Reservoir  
 Groundwater

Diversion Location: 0.1 (mi)

Priority Date: 1/16/1900

Diversion Capacity: 10000 (CFS)

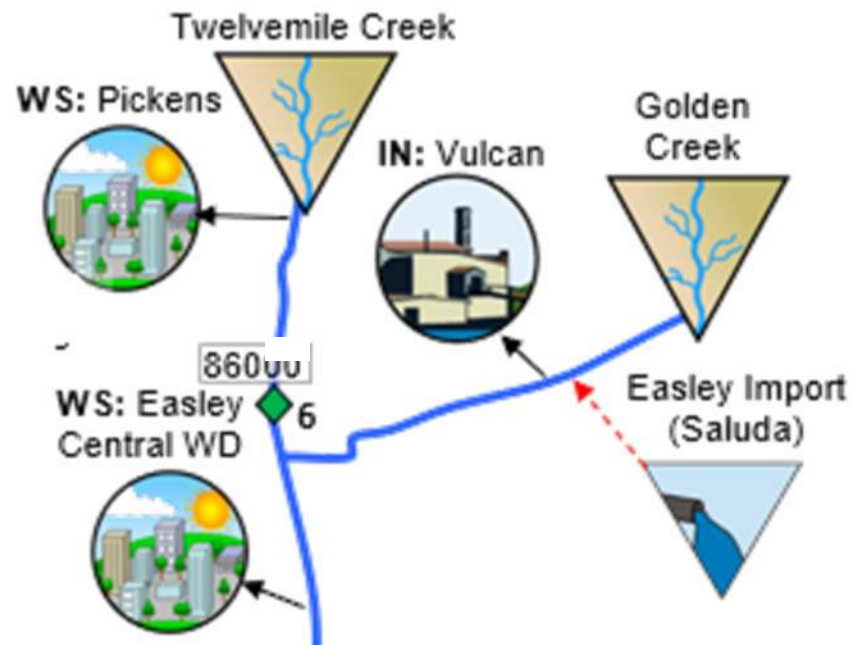
Permit Limit: 219 (MGM)

Seasonal Permit  
 Minimum Flow Requirements

Save

Close

Identifying Notes: permit limits of 159 & 60 MGM for S01 & S02



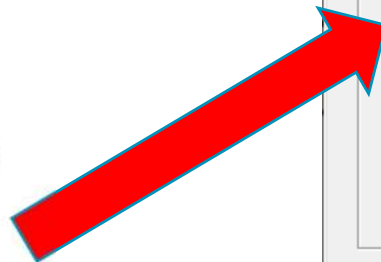
# SWAM Calculations: Demand

WS: Pickens

- WS: User Object:

- Node based withdrawals and returns
- Municipal water demands (prescribed monthly mean)

WS: Pickens



Water User

Main | **Water Usage** | Source Water | Return Flows

Monthly User Distribution

- Manual
- M&I
- Agriculture

Annual Baseline Usage

Total Use  (MGY)

Input Format

- monthly means
- timeseries

Monthly Baseline Usage

Month	Monthly Usage	% Indoor Use	% CU Indoor	% CU Outdoor
Jan	1.39	100	75.3	100
Feb	1.34	100	74.54	100
Mar	1.33	100	75.3	100
Apr	1.31	100	74.68	100
May	1.36	100	77.46	100
Jun	1.43	100	79.85	100
Jul	1.44	100	80.39	100
Aug	1.42	100	79.36	100
Sep	1.45	100	81.93	100
Oct	1.38	100	80.04	100
Nov	1.32	100	79.34	100
Dec	1.32	100	76.17	100

(MGD)

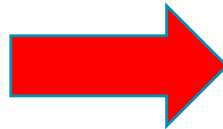
# SWAM Calculations: Reservoirs

## ■ Reservoir Object:

- Dynamic water balance, water supply pool, customized operating rules



Lake Thurmond



Reservoir

Main | Rule Set 1 | Rule Set 2 | Rule Set 3 | Rule Set 4 | Rule Set 5

**Reservoir Name:** Lake Thurmond **Delete Node**

**Storage Capacity:** 1343920 (MG) **Initial Storage:** 640000 (MG) **Dead Pool:** 477372 (MG)

Offline  Online

**Evaporation:**  Monthly Mean  % Volume  Input Timeseries **Edit Timeseries**

**Reservoir Operations:** **Receiving Stream:** Mainstem  Simple  Advanced **Release Location:** 131.5 (mi) **Release Accounts:**  All Users  Specified User

**Flood Control Outflow:**

% Vol	Outflow
0	0
100	0

(CFS)

**Area-Capacity Table:**  Simple  Detailed

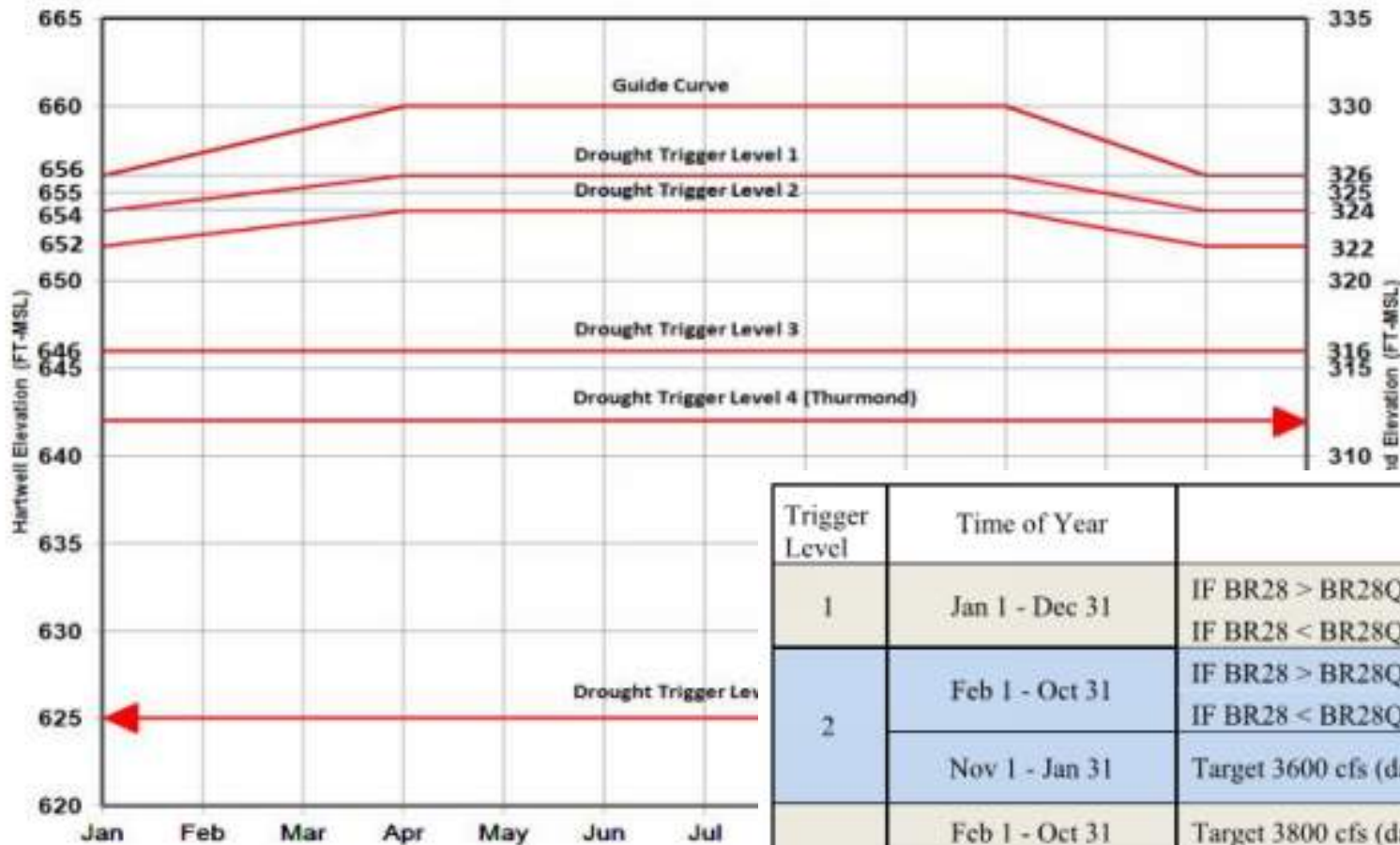
Volume	Area
0	0
146633	15000
356004	36200
381246	39000
462709	43750
521362	49500
606084	57000
703839	64250
817887	70250
944969	78500
1007533	85570
1343920	111065

(MG) (Ac)

Comments:

**Save** **Close**

# USACE Reservoir Operations and Drought Plan



Trigger Level	Time of Year	Drought Response
1	Jan 1 - Dec 31	IF BR28 > BR28Q10, Target 4200 cfs (weekly average) release at Thurmond Dam IF BR28 < BR28Q10, Target 4000 cfs (weekly average) release at Thurmond Dam
2	Feb 1 - Oct 31	IF BR28 > BR28Q10, Target 4000 cfs (weekly average) release at Thurmond Dam IF BR28 < BR28Q10, Target 3800 cfs (daily average) release at Thurmond Dam
	Nov 1 - Jan 31	Target 3600 cfs (daily average) release at Thurmond Dam
3	Feb 1 - Oct 31	Target 3800 cfs (daily average) release at Thurmond Dam
	Nov 1 - Jan 31 (Feb 1 - Feb 28 w/NMFS approval)	Target 3100 cfs (daily average) release at Thurmond Dam
4	Feb 1 - Oct 31	Target 3600 cfs (daily average) release at Thurmond Dam
	Nov 1 - Jan 31 (Feb 1 - Feb 28 w/NMFS approval)	Target 3100 cfs (daily average) release at Thurmond Dam



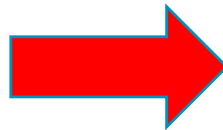
# SWAM Calculations: Reservoirs

- Reservoir Object:

- Example operating rule: Lake Thurmond Drought Level 1 Release Rules



Lake Thurmond



Reservoir

Main | Rule Set 1 | Rule Set 2 | **Rule Set 3** | Rule Set 4 | Rule Set 5

Priority #3

Include Rule  Moving Target?

Level 1 release rules. Rules apply if water level is above Level 2 triggers.

Rule Details

**Moving Averages** Composite Metrics **Ramping Periods** Moving Triggers  Start of Timestep Storage Conditions

Start Date	End Date	Target	Condition Type	Conditional Object 1:	Criteria1:	Cond. 1:	Conditional Object 2:	Criteria2:	Cond. 2:
04/02	10/15	4200	Res Storage AND Flow Ga	Lake Thurmond	>	684288	BR28Q10 Gage	=	0
10/16	12/15	4200	Res Storage AND Flow Ga	Lake Thurmond	>	645186	BR28Q10 Gage	=	0
12/16	12/31	4200	Res Storage AND Flow Ga	Lake Thurmond	>	645186	BR28Q10 Gage	=	0
01/01	04/01	4200	Res Storage AND Flow Ga	Lake Thurmond	>	684288	BR28Q10 Gage	=	0
04/02	10/15	4000	Res Storage AND Flow Ga	Lake Thurmond	>	684288	BR28Q10 Gage	=	1
10/16	12/15	4000	Res Storage AND Flow Ga	Lake Thurmond	>	645186	BR28Q10 Gage	=	1
12/16	12/31	4000	Res Storage AND Flow Ga	Lake Thurmond	>	645186	BR28Q10 Gage	=	1
01/01	04/01	4000	Res Storage AND Flow Ga	Lake Thurmond	>	684288	BR28Q10 Gage	=	1

(CFS or MG) (CFS or MG) (CFS or MG)

Save Close

# Duke Energy Low Inflow Protocol

LIP Stage	Duke Energy Storage Index <sup>1</sup>	Minimum Reservoir Elevation ft AMSL		Maximum Weekly Keowee Water Flow Release ac-ft (cfs)	Public Water Supplier Withdrawal Reductions
		Jocassee	Keowee		
0	85% <= Storage Index < 90%	1096	796	25,000 (1800)	na
	80% <= Storage Index < 85%			20,000 (1440)	
1	na	1092	795	18,750 (1350)	3-5% (goal)
2	na	1087	793	15,000 (1080)	5-10% (goal)
3	na	1083	792	10,000 (720)	10-20% (goal)
4	12% < Storage Index < 25%	1080	791.5	7,500 (540) <sup>2</sup>	20-30%
	Storage Index < 12%		790	Leakage	

Notes:

<sup>1</sup> Storage Index includes remaining usable storage in Keowee, Jocassee, and Bad Creek

<sup>2</sup> No releases that would cause Keowee to fall below 791.5 ft AMSL

## LIP Stage Triggers

Stage	Trigger		US Drought Monitor <sup>2</sup> (12-wk avg)	Streamflow (LTA versus previous 4 months) <sup>3</sup>
0	Duke Energy Storage Index <sup>1</sup> < 90% & USACE Storage Index <sup>4</sup> < 90%	and one of the following	>=0	< 85%
1	USACE in DP 1		1	< 75%
2	USACE in DP 2		2	< 65%
3	USACE in DP 3		3	< 55%
4	Duke Energy Storage Index < 25%		4	< 40%

Notes:

LTA - long-term average; DP - Drought Plan

<sup>1</sup> The Duke Energy Storage Index is based on the usable storage for Keowee, Jocassee, and Bad Creek as specified in the LIP

<sup>2</sup> The US Drought Monitor uses an area-weighted average

<sup>3</sup> Streamflow gages are composite averages of Twelvemile Creek near Liberty, SC; Chattooga River near Clayton, GA; French Broad River near Rosman, NC

<sup>4</sup> USACE Storage Index includes usable storage for Hartwell, Russell, and Thurmond

# Model Time Steps

- Model simulations may use a **daily** or **monthly** timestep
- A **monthly timestep** will be used to look for shortages, test and compare management strategies, and compare flows at strategic nodes.
- A **daily timestep** will be used for comparison to minimum instream flows and for determining changes in risk in ecological-flow relationships.

# Model Calibration

- Calibration performed for multiple sites across a wide range of hydrologic conditions
- **Calibration Targets:** USGS streamflow gage records
- **Key calibration parameters:** reach gain/loss factors
- **Performance metrics:**
  - Annual avg flows (overall water balance)
  - Monthly avg flows (seasonality)
  - Flow percentile distributions (variability, extreme events)
  - Flow timeseries (specific timings, operations)
  - Cumulative flows over entire calibration period
  - Reservoir storage timeseries

# Calibration (Savannah Model)

## 1 Predictive Calibration

- 1983 – 2013 for mainstem and tributaries
- Static reservoir operations used (but historical operations varied)
- Most useful for tributaries and overall mass balance

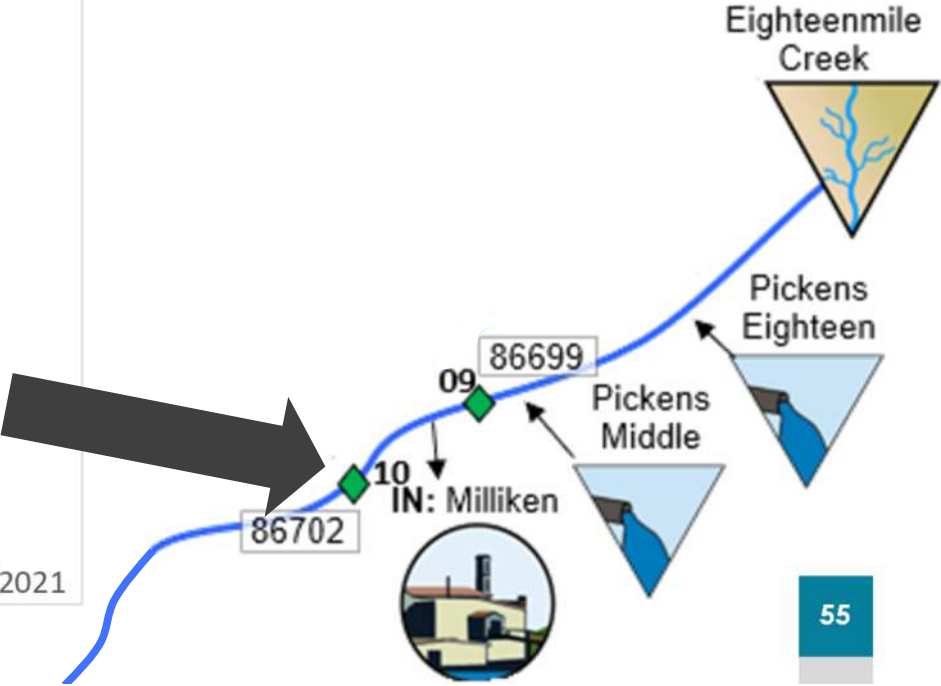
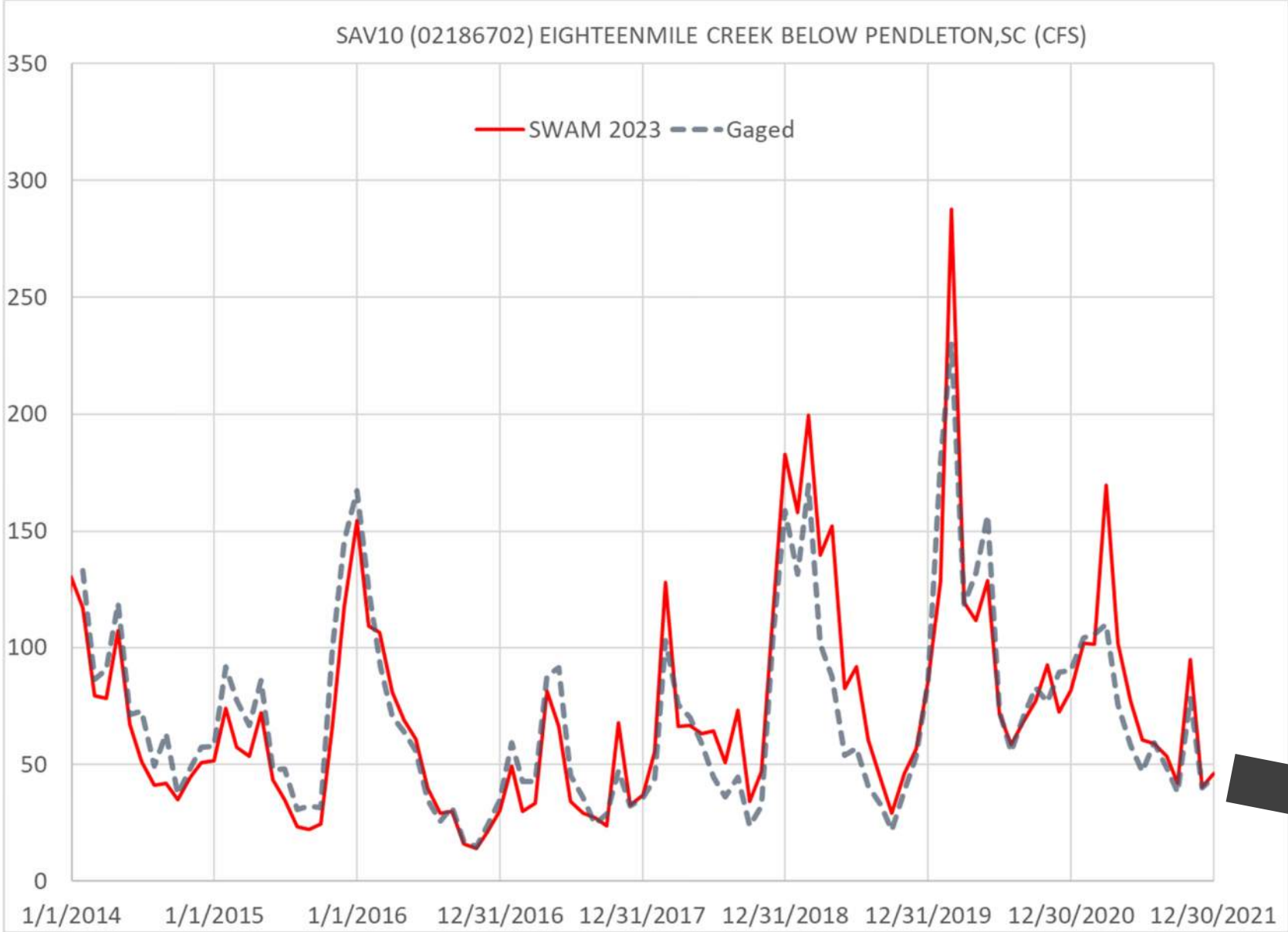
## 2 Prescriptive Downstream Hydrology Validation

- 1983 – 2013 for mainstem
- Use published discharges at Hartwell and Thurmond
- Removes upstream operation uncertainty
- Validate model reach gains/losses below USACE reservoirs

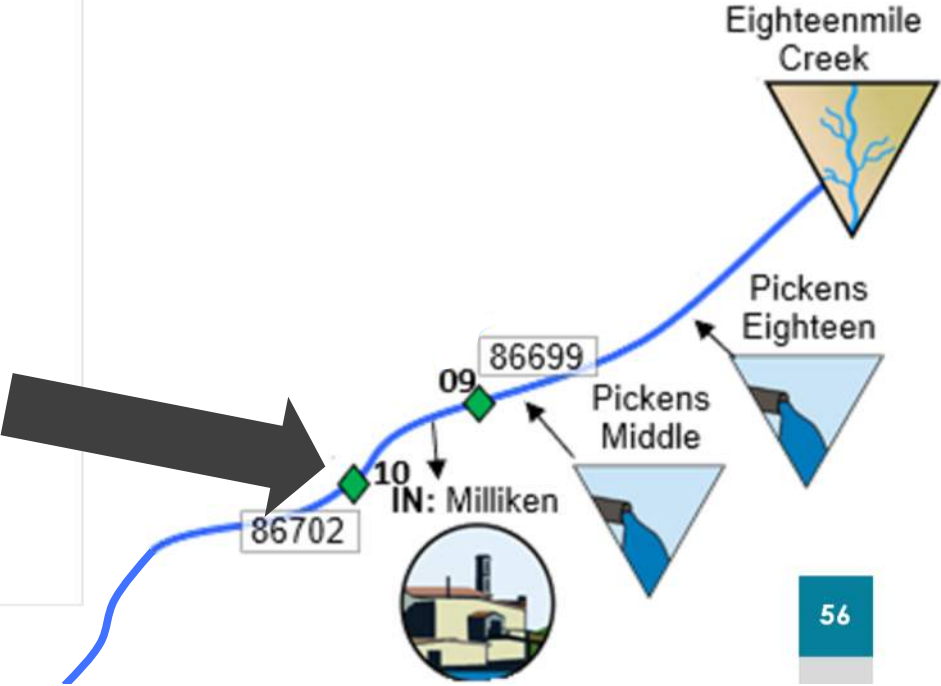
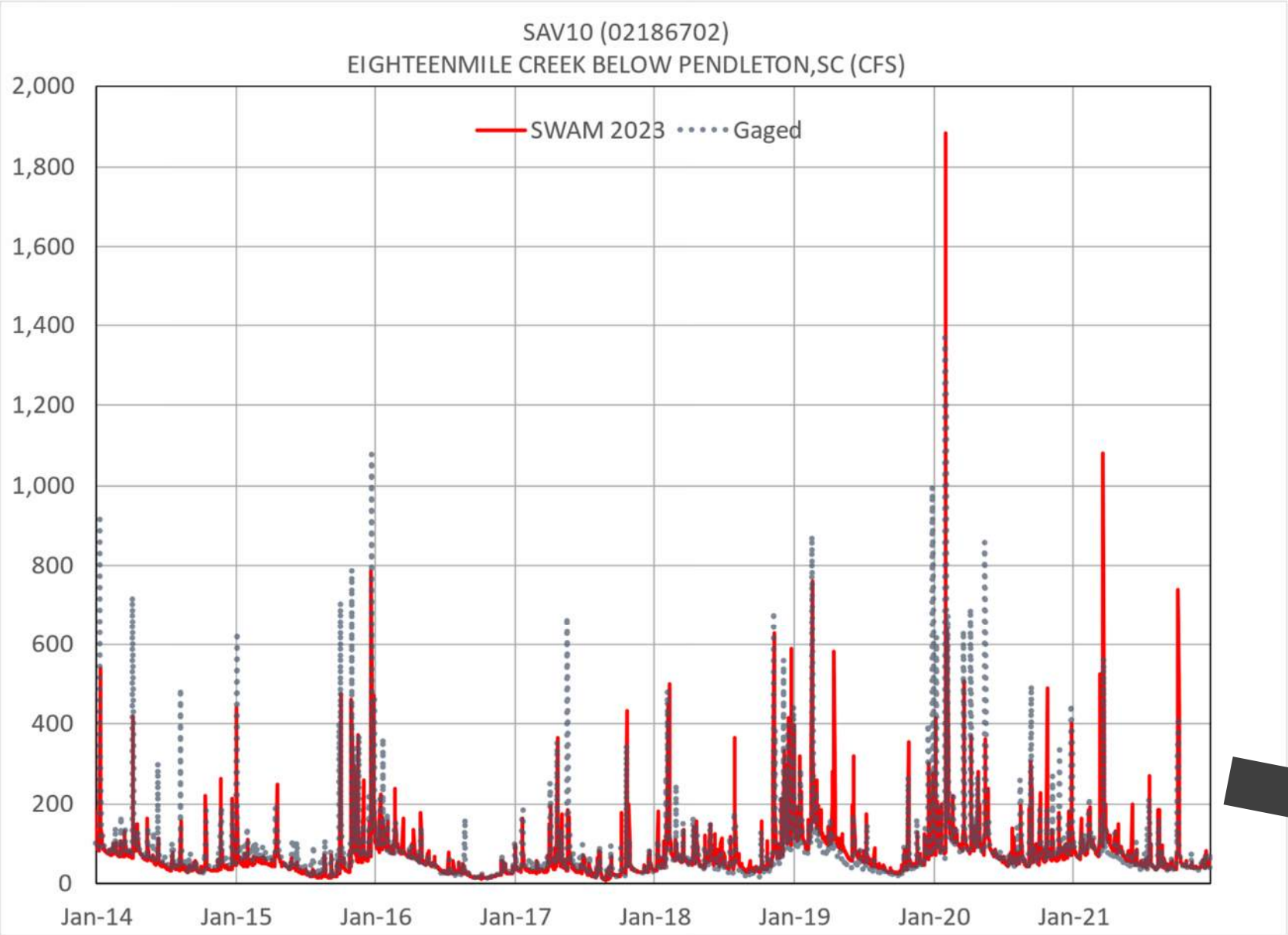
## 3 Predictive Baseline Model Verification

- 2012 and 2013 using current USACE reservoir operations

# Comparison of Monthly Gaged and Modeled Flows



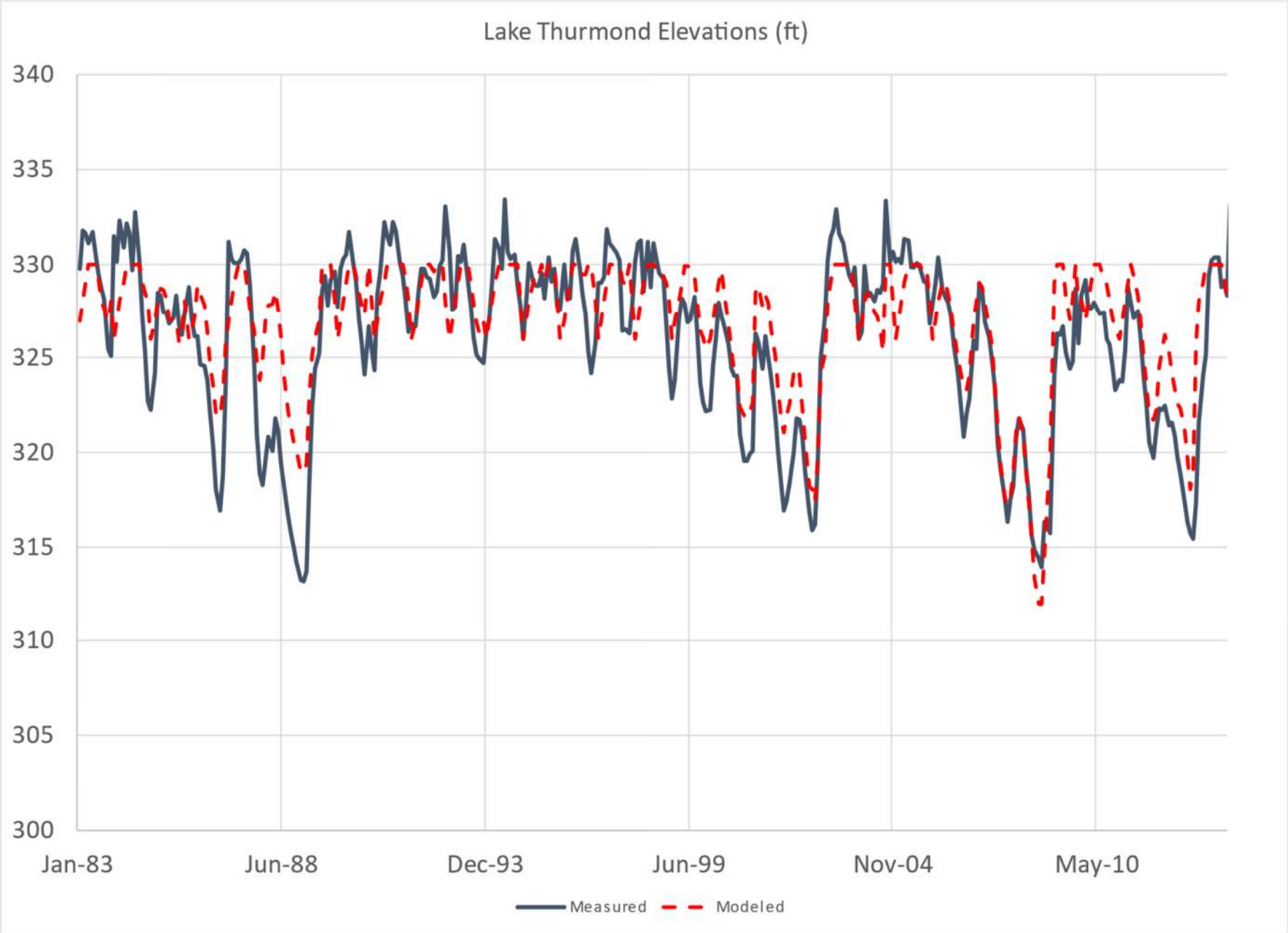
# Comparison of Daily Gaged and Modeled Flows



# Comparison of Measured and Modeled Lake Levels



Lake Thurmond





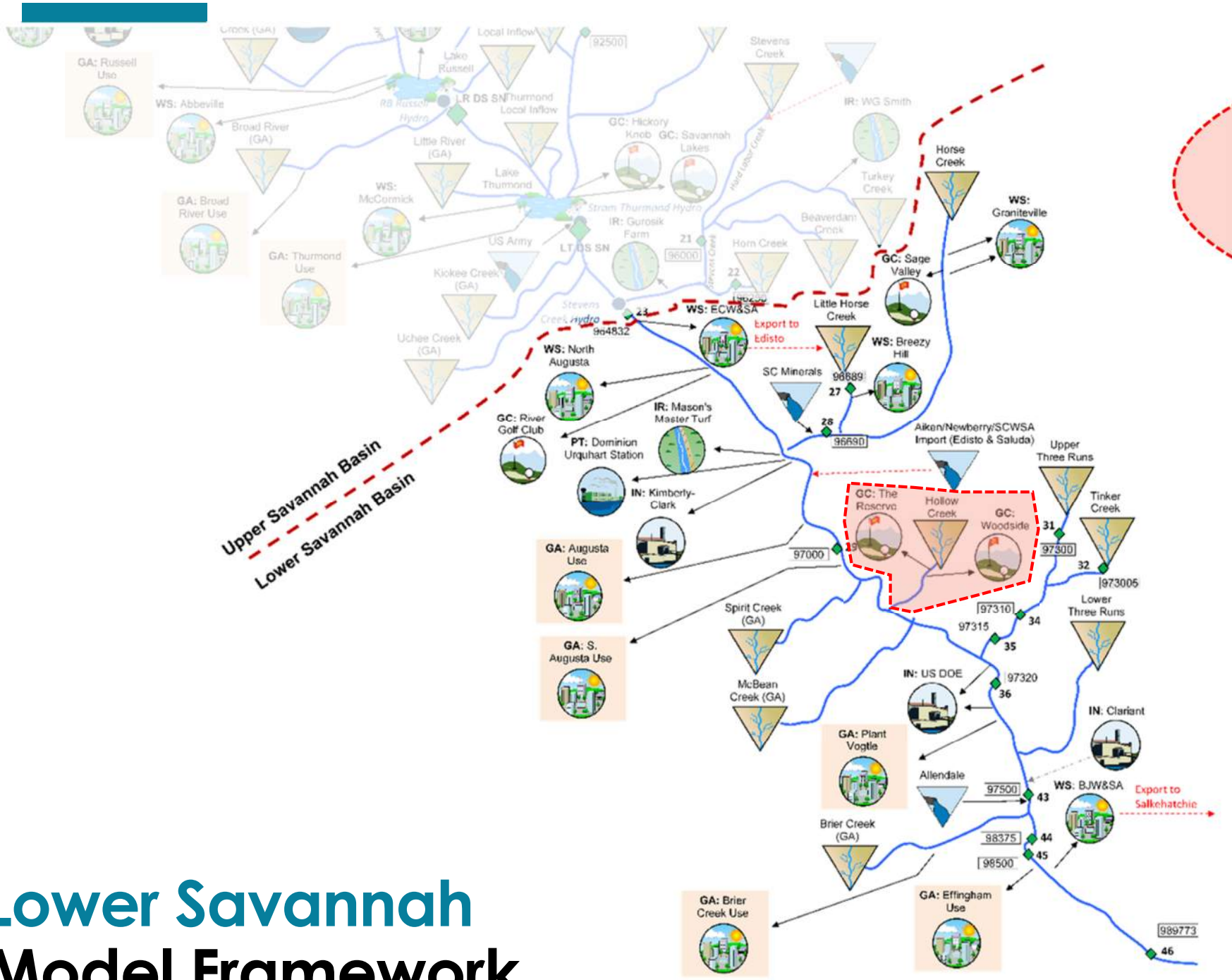


# 2021 Surface Water Model Updates

- Extended baseline hydrology through 2021 (added 7 years)
- Updated monthly mean water demands based on recent water use data
- Updated permit and intake location information
- Removed inactive permittees
- Added new registrations
- Software updates

# Model Limitations

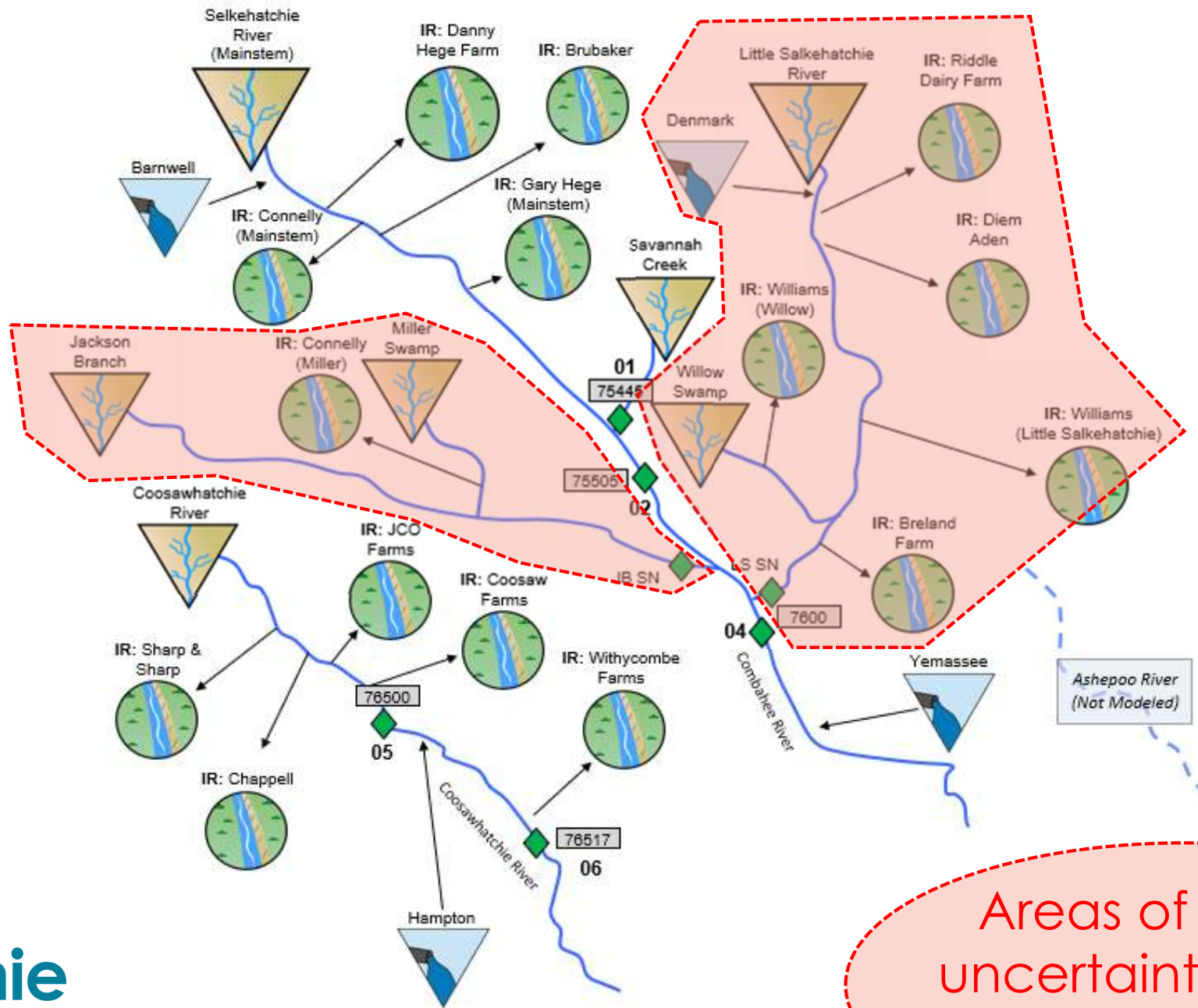
- Greater uncertainty in predictions for ungaged reaches compared to gaged
- Model not designed for reach routing of flow changes at a sub-daily timestep
- Greater uncertainty in supply availability (and “shortage”) predictions associated with small stream withdrawals compared to larger river and reservoir withdrawals
  - e.g. irrigation ponds
- Baseline model assumes past hydrologic variability is representative of future hydrologic variability (stationary climate)



Areas of greater uncertainty (due to lack of gage data)

# Lower Savannah Model Framework

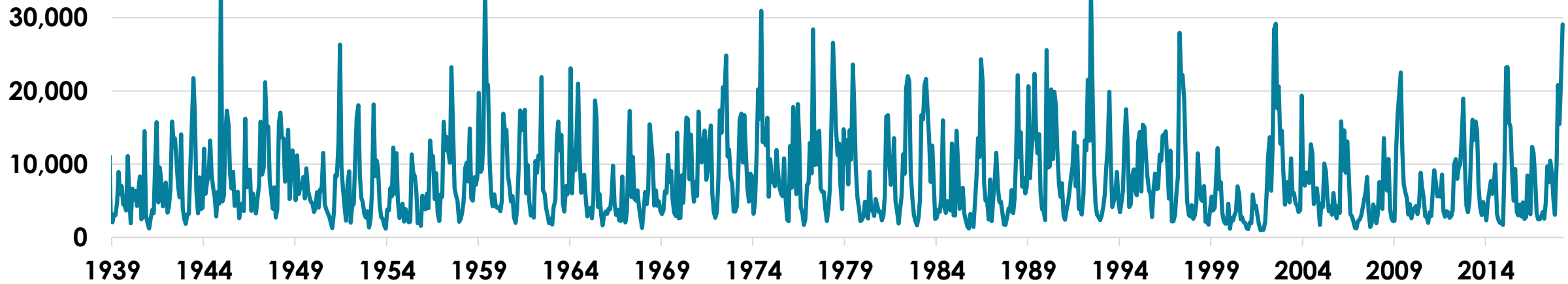
# Salkehatchie Model Framework



Areas of greater uncertainty (due to lack of gage data)

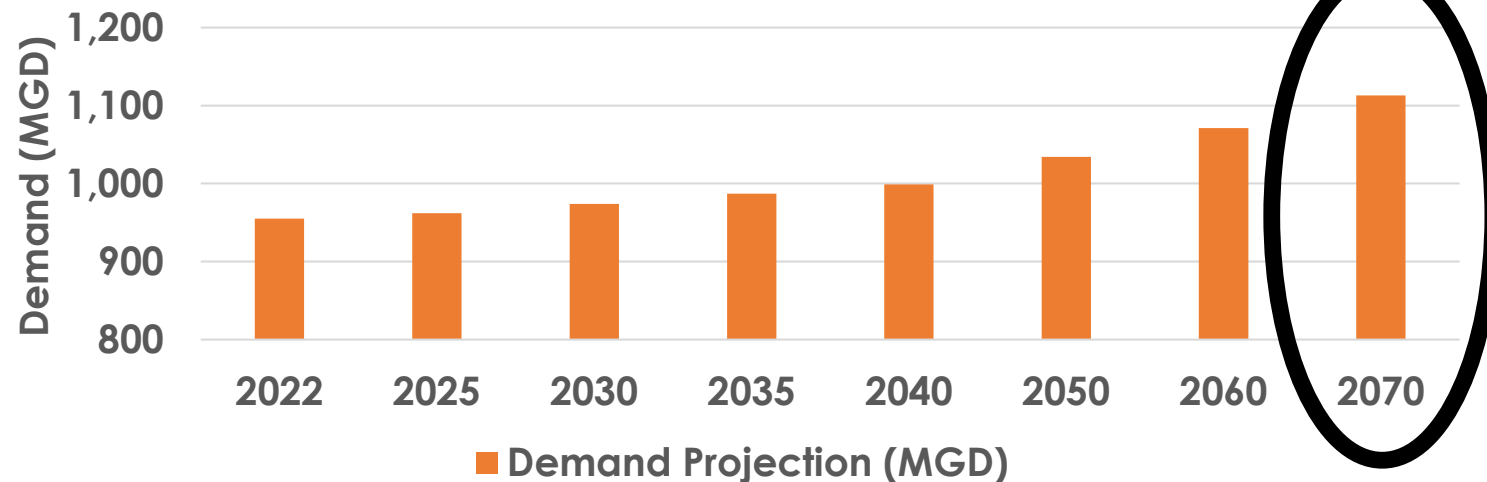
# Evaluating Projected Demands (Example)

Streamflow



← 83 Years of Hydrologic Record →

Demand Projections



**2070 demand projections are applied to the entire period of hydrologic record**

# Performance Measures

Assessment of simulation results will focus on quantifying key performance measures for strategic nodes and reaches of interest across the basin.

## Example / Suggestions:

- Percent change in a monthly minimum flow, 5th percentile flow, mean, and/or median flow
- Percent change in seasonal or monthly flows
- Percent change in surface water supply
- Percent change in mean annual shortage or mean percent shortage
- Change in the number and magnitude of excursions below 20, 30 and 40 percent mean annual daily flows and/or 7Q10 flow
- Change in number of water users that experience a shortage
- Change in the average frequency of shortage
- Percent of time recreational facilities were unavailable on a stream reach

# Strategic Nodes

Nodes in red text were suggested by RBC members during the April 4<sup>th</sup> meeting

Upper Savannah Basin  
Lower Savannah Basin

# Lower Savannah Model

**SAV28**  
Horse Creek at Clearwater

**SAV29**  
Savannah River at Augusta

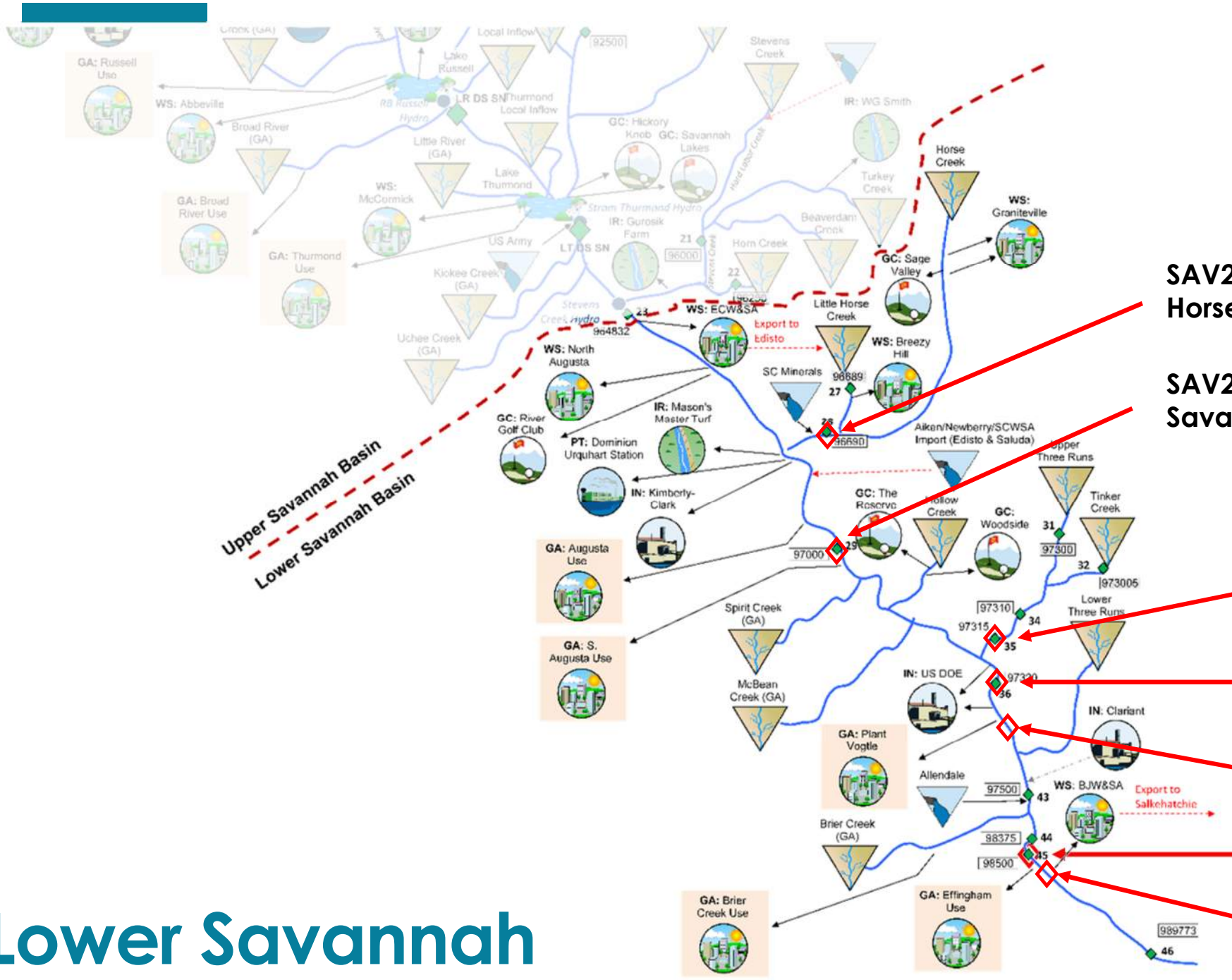
**SAV35**  
Upper Three Runs at Road A (SRS)

**SAV36**  
Savannah River near Jackson

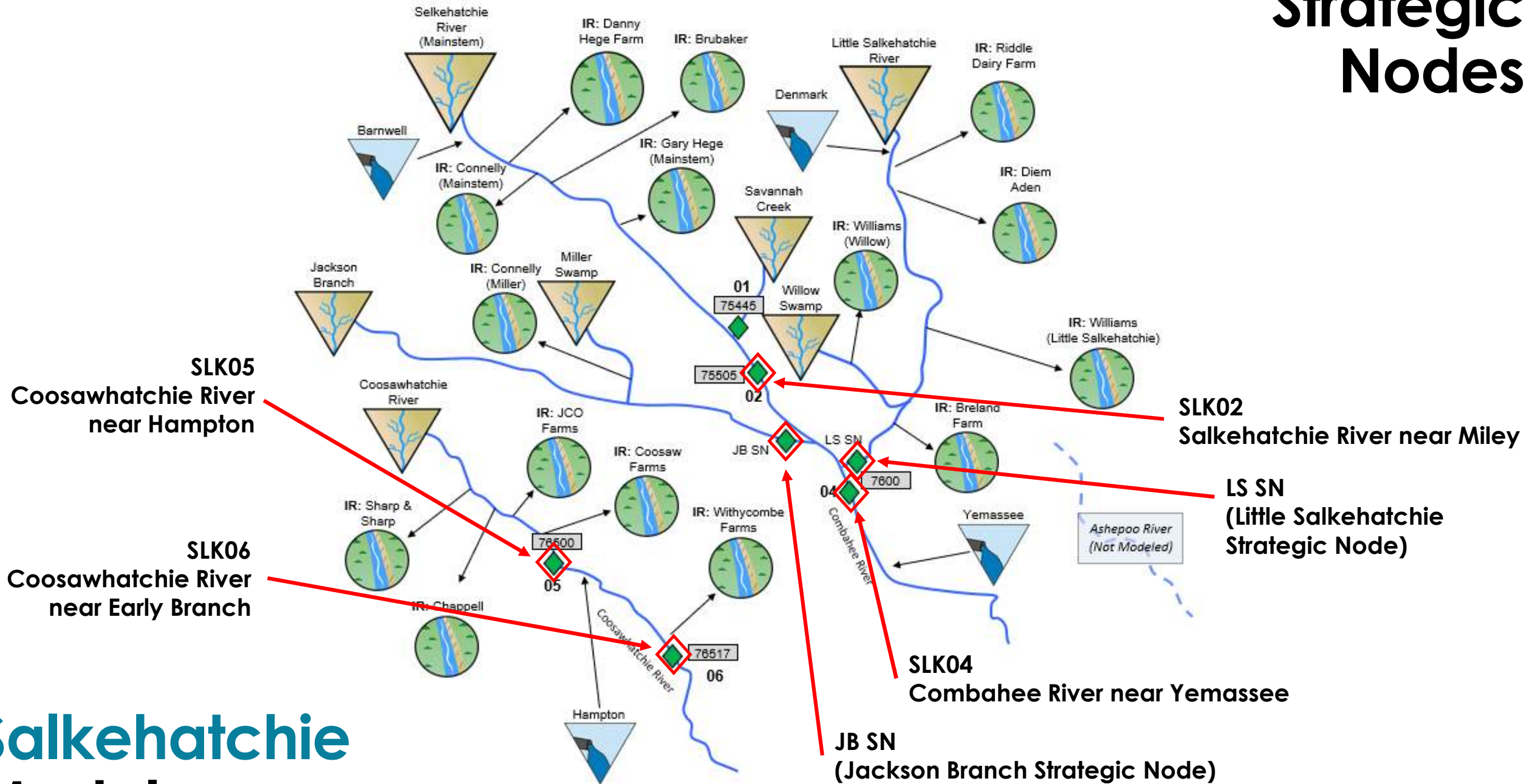
**BV SN**  
Savannah River (RM 199.2)

**SAV45**  
Savannah River near Clyon

**BEU SN**  
Savannah River (RM 304.5)



# Strategic Nodes

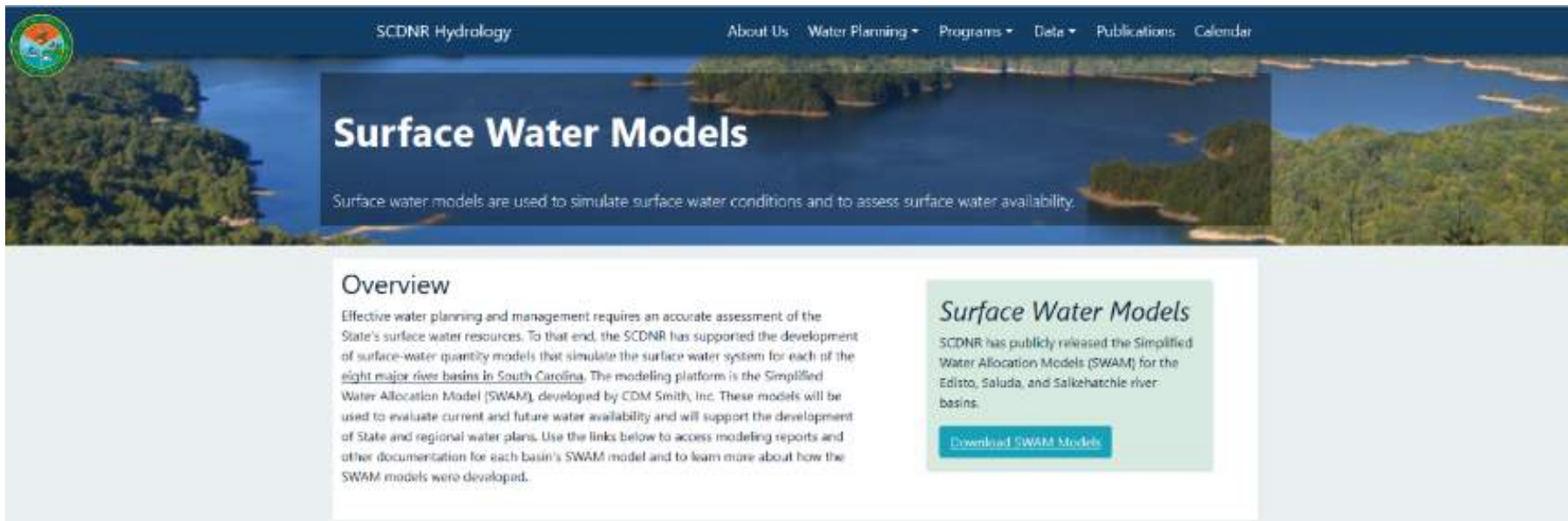


## Salkehatchie Model



# Surface Water Model Access

- Available for download at: <http://hydrology.dnr.sc.gov/surface-water-models.html>
- Also available for download:
  - SWAM User's Manual
  - Model reports for each basin
  - Supplementary technical memoranda



The screenshot shows the SCDNR Hydrology website. The header includes the SCDNR logo and navigation links: About Us, Water Planning, Programs, Data, Publications, and Calendar. The main heading is "Surface Water Models" with a subtext: "Surface water models are used to simulate surface water conditions and to assess surface water availability." Below this, there are two columns of text. The left column is titled "Overview" and describes the development of surface-water quantity models for eight major river basins in South Carolina. The right column is titled "Surface Water Models" and states that SCDNR has publicly released the Simplified Water Allocation Models (SWAM) for the Edisto, Saluda, and Salkehatchie river basins, with a "Download SWAM Models" button.

SCDNR Hydrology

About Us | Water Planning | Programs | Data | Publications | Calendar

## Surface Water Models

Surface water models are used to simulate surface water conditions and to assess surface water availability.

### Overview

Effective water planning and management requires an accurate assessment of the State's surface water resources. To that end, the SCDNR has supported the development of surface-water quantity models that simulate the surface water system for each of the eight major river basins in South Carolina. The modeling platform is the Simplified Water Allocation Model (SWAM), developed by CDM Smith, Inc. These models will be used to evaluate current and future water availability and will support the development of State and regional water plans. Use the links below to access modeling reports and other documentation for each basin's SWAM model and to learn more about how the SWAM models were developed.

### Surface Water Models

SCDNR has publicly released the Simplified Water Allocation Models (SWAM) for the Edisto, Saluda, and Salkehatchie river basins.

[Download SWAM Models](#)