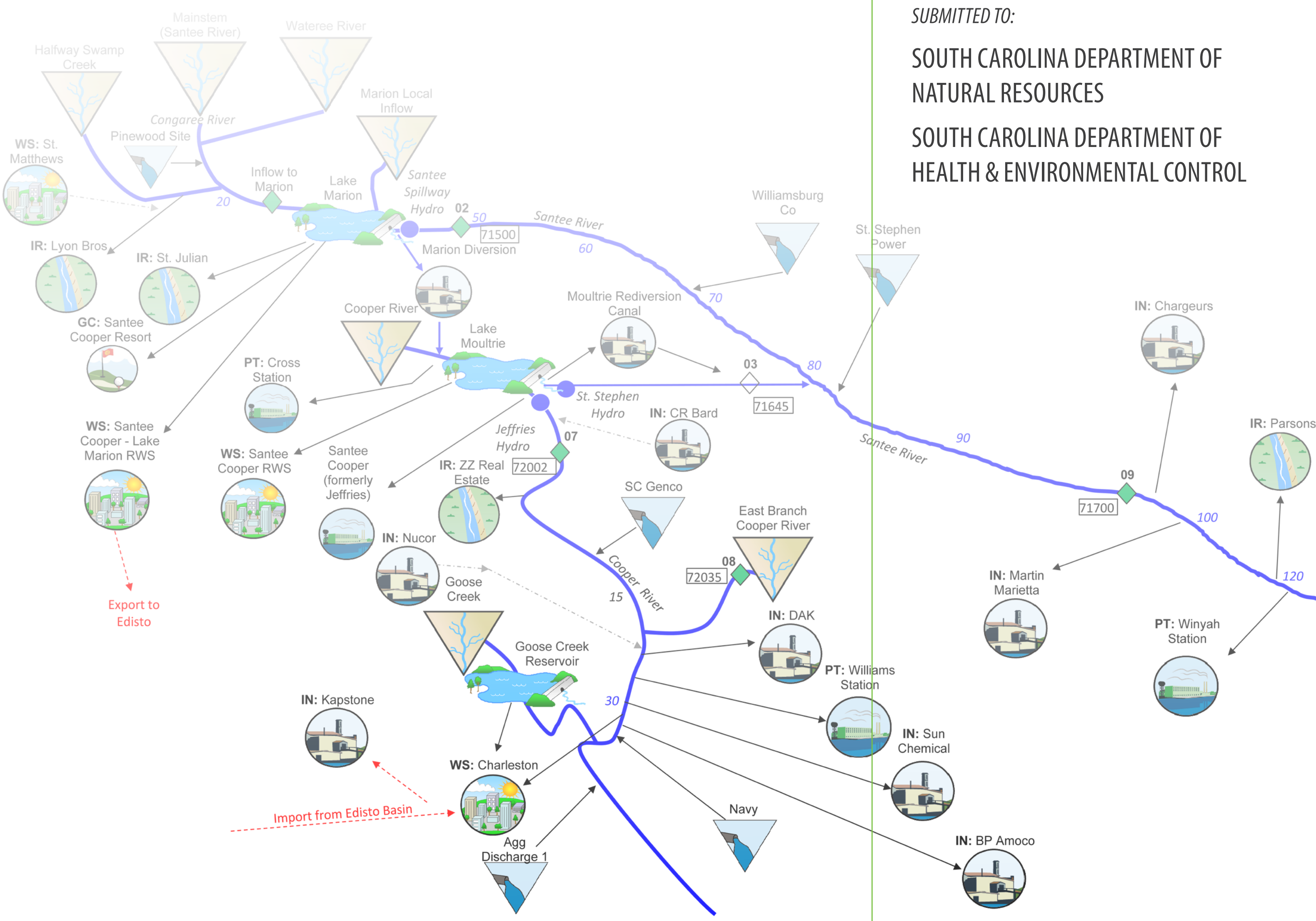
SOUTH CAROLINA
SURFACE WATER QUANTITY MODELS
SANTEE RIVER BASIN MODEL



SUBMITTED TO:

SOUTH CAROLINA DEPARTMENT OF NATURAL RESOURCES

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Section 1
Purpose

This document, the Santee River Basin Modeling Report, is provided in support of the Surface Water Availability Assessment for the South Carolina Department of Natural Resources (DNR) and the South Carolina Department of Health and Environmental Control (DHEC). The Surface Water Availability Assessment is part of a broader strategy to augment statewide water planning tools and policies, culminating in the development of regional water plans and the update of the State Water Plan.

The Surface Water Availability Assessment focuses on the development of surface water quantity models. The models are primarily intended to represent the impacts of water withdrawals, return flows, and storage on the usable and reliably available water quantity throughout each major river basin in the state. With this ability, they will be used for regional water planning and management, policy evaluation and permit assessments.

This Santee River Basin Modeling Report presents the model objectives; identifies revisions made to the initial model framework; summarizes model inputs and assumptions; presents the calibration approach and results; and provides guidelines for model use. Further guidance on use of the Santee River Basin Model is provided in the *Simplified Water Allocation Model (SWAM) User's Manual Version 4.0* (CDM Smith, 2016).

Additionally, this document is intended to help disseminate the information about how the model represents the South Carolina portion of the Santee River Basin to parties with a vested interest in water management (stakeholders). To this end, the language is intended to be accessible and explanatory, describing the model development process in clear English without undue reliance on mathematical formulations, programming nuances, or modeling vernacular.

Section 2

Modeling Objectives

The Santee River Basin Model in SWAM has been developed for multiple purposes, but it is primarily intended to support future permitting, policy, and planning efforts throughout the basin. Fundamentally, the model will simulate the natural hydrology through the network of the combined Wateree and Congaree rivers at Lake Marion and through the complex exchange of flows between the Santee River, Lake Moultrie, and the Cooper River, including their major tributaries, and the impacts to the river flows from human intervention: withdrawals, discharges, impoundment, and interbasin transfers.

The model will simulate historic hydrologic conditions from 1951 through 2010. Defining and developing this hydrologic period of record required numerous assumptions and estimations of past flow and water use patterns, which were vetted during the calibration process. The purpose of the models is not to reproduce with high accuracy the flow on any given day in history. Rather, the purpose is to reproduce with confidence the frequency at which natural and managed flows have reached any given threshold, and by extension, how they might reach these thresholds under future use conditions. To this end, one important objective of model formulation was to reproduce hydrologic peaks and low flows on a monthly and daily basis, recession patterns on a monthly and daily basis, and average flows over months and years.

The end goals of the model are derived specifically from the project scope. The intended uses include:

1. Evaluate surface-water availability in support of the Surface Water Withdrawal, Permitting, Use, and Reporting Act;
2. Predict future surface-water availability using projected demands;
3. Develop regional water-supply plans;
4. Test the effectiveness of new water-management strategies or new operating rules; and
5. Evaluate the impacts of future withdrawals on instream flow needs and minimum instream flows as defined by regulation and to test alternative flow recommendations.

Lastly, the model is intended to support a large user base, including staff at DNR and DHEC along with stakeholders throughout the South Carolina portion of the Santee River Basin. To this end, the master file will be maintained on a cloud-based server, and will be made accessible to trained users through agreement with DNR and/or DHEC. To support its accessibility, the SWAM model interface is designed to be visual and intuitive, but using the model and extracting results properly will require training for any future user.

Section 3

Review of the Modeling Plan

The modeling approach, data requirements, software, and resolution are described in the *South Carolina Surface Water Quantity Models - Modeling Plan*, (CDM Smith, November 2014).

The Modeling Plan is an overarching approach, intended to guide the development of all eight river basin models for South Carolina by describing consistent procedures, guidelines, and assumptions that will apply to each basin and model. It is not an exhaustive step-by-step procedure for developing a model in SWAM, nor does this address all of the specific issues that may be unique to particular basins. Rather, the Modeling Plan offers strategic guidelines aimed at helping model development staff make consistent judgments and decisions regarding model resolution, data input, and representation of operational variables and priorities.

The Modeling Plan was followed during development of the Santee River Basin Model. Where appropriate, additional discussion has been included in this report, to elaborate on specific aspects covered in the Modeling Plan. In certain instances, the procedures and guidelines detailed in the plan were modified and/or enhanced during development of the pilot model developed for the Saluda River Basin and the subsequent models developed for the Broad, Edisto, Pee Dee, Catawba-Wateree, and Salkehatchie river basins. The enhanced procedures and guidelines, and the “lessons learned” were applied to the Santee River Basin – especially, with regard to model calibration and validation.

Section 4

Santee Model Framework

The initial Santee River Basin SWAM Model Framework was developed in collaboration with South Carolina DNR and DHEC, and was presented in the memorandum *Santee Basin SWAM Model Framework* (CDM Smith, February 2016). The proposed framework was developed as a starting point for representing the South Carolina portion of the Santee Basin river network and its significant water withdrawals and discharges. The guiding principles in determining what elements of the Santee River Basin to simulate explicitly were:

1. Begin with a simple representation, with the understanding that it is easier to add additional details in the future than to remove unnecessary detail to make the model more efficient.

2. Incorporate all significant withdrawals and discharges. Significant withdrawals include those that have a permit or registration – which indicated that they may withdrawal over 3 million gallons in any month. Significant discharges are those that average over 3 million gallons per month (mg/month). In some instances, discharges that average less than 3 mg/month were included, such as discharges directly associated with a permitted or registered withdrawal.

3. Any tributary with current uses (permitted or registered withdrawals or significant discharge) will be represented explicitly. These include most primary tributaries to the Santee and its major branches, and some secondary tributaries.

4. Generally, tributaries that are unused are not included explicitly, but the hydrologic contributions from these tributaries are embedded in the unimpaired flows (or reach gains) in downstream locations. As unimpaired flows (UIFs) are developed throughout the Santee, some additional tributaries may be added explicitly if warranted as candidates to support future use (or these can be easily added at any time in the future as permit applications are received).

During model development, simplifications were made in some areas, while more detail was added in others. **Figure 4-1** visually depicts the SWAM model framework, including tributaries, water users, and dischargers. As the framework is presented in the following paragraphs, changes made to the original model framework are noted. The most significant change occurred with the representation of the interaction between Lake Marion, Lake Moultrie, Santee River, Cooper River, the Rediversion and Diversion Canals, and what qualifies as the model "mainstem." The previous framework had the mainstem defined by the Diversion Canal to Lake Moultrie, then the Rediversion Canal from Lake Moultrie back to the Santee River. Then, the releases from Lake Marion and Lake Moultrie were represented by Water User objects and also involved having a separate Santee Headwater tributary object that connected to the mainstem. This arose from uncertainties from no records having been kept for the flows passing through St. Stephen hydropower on the Rediversion Canal. However, the current framework has rearranged this system into a more intuitive schematic where the Santee River is the mainstem at all times, Lake Moultrie is on the Cooper River, and the Diversion/Rediversion Canals are represented by Water User objects.

4.1 Representation of Water Withdrawals

As noted above, significant withdrawals include those that have a permit or registration – which indicated that they may withdraw over 3 million gallons in any month. Withdraws may include both water used directly by that water user and water sold to other water users who may or may not be included as separate objects in the model. Since water withdrawals are associated with the permit holder rather than the ultimate water user, the Water User objects reflect the withdrawals associated with their permit.

4.2 Representation of Discharges

Water and wastewater discharges can be simulated two ways in SWAM. First, they can be associated with a Water User object, each of which may specify five points of discharge anywhere in the river network. These discharges are not represented with visual model objects, but are identified within the dialogue box for the associated Water User object. Alternatively, discharges can be specified within a Discharge object. There are advantages and disadvantages with both methods. Associating discharges with withdrawals helps to automatically maintain a reasonable water balance because discharges are specified as seasonally-variable percentage of the withdrawal. However, it may be more difficult to test a maximum discharge permit level using this approach. Alternatively, using a tributary object to specify outflows allows for more precise representation of discharge variability, but does not automatically preserve the water balance (the user will need to adjust withdrawals to match simulated discharge). This second approach is also appropriate for interbasin transfers, in which source water resides in another basin but is discharged in the basin represented by the model.

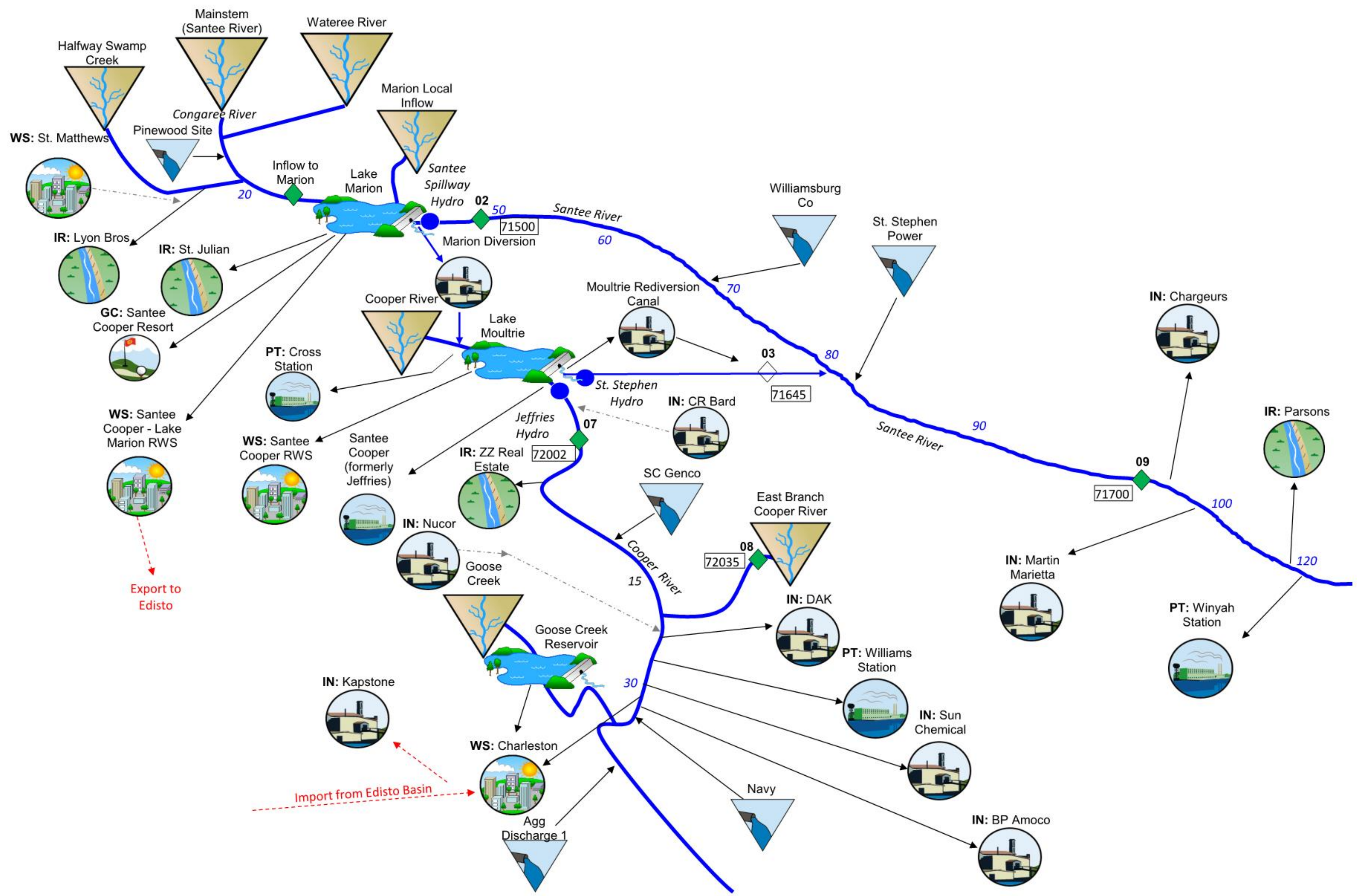
In the Santee River Basin Model, discharges are most often represented within the Water User object. The several exceptions, where a Discharge object was used, include the following:

- Several industrial discharges – Williamsburg Co, Pinewood Site, St. Stephen Power, Navy, SC Genco, and Agg Discharge 1 (combination of Kinder Morgan, Hess/Charleston, Delfin, Petroliance, and Detyens), were deemed significant enough to include in the model; however, the industry either purchases water from another permit holder or withdraws (or supplements) using groundwater. They do not have their own surface water withdrawal permit.

4.3 Representation of Hydropower Facilities

The Santee River Basin has three hydropower facilities: Santee Spillway Hydro from Lake Marion to the Santee River; Jeffries Hydro from Lake Moultrie to the Cooper River; and St. Stephen Hydro from Lake Moultrie to the Rediversion Canal back to the Santee River. The storage target and minimum flows for the Santee Spillway Hydro and Jeffries Hydro are specified within the Reservoir objects associated with the hydropower facility. St. Stephen Hydro is represented by a User object. Rules for these facilities are discussed further in Section 6.

Figure 4-1. Santee River Basin SWAM 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
- Industrial
- Golf Course
- Hydropower *(for display purposes only)*
- Import or Export (Interbasin Transfer)
- Discharge from a Groundwater User*

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

4.4 Groundwater Users and Associated Discharge

Although the Santee Model focuses on surface water, representation of groundwater withdrawal (demand) within the model can be useful when the return flows, which are greater than 3 mg/month, are to surface water. In these cases, representation of the groundwater withdrawal by a Water User object, especially for municipalities, is useful because the (monthly) discharge percentage is specified with the Water User object. Since model scenarios typically focus on changes to water demand/use, the user can simply update the demand (in the Water User object, “Water Usage” tab), and the return flows will automatically be re-calculated. For water users who withdraw groundwater, the “Groundwater” option is selected in the Source Water Type section of the “Source Water” tab.

In the Santee River Basin, two significant industrial and one municipal groundwater withdrawals were identified – **CR Bard, Nucor**, and **St. Matthews**, which had a corresponding, significant discharge to surface water. These are represented by Water User objects. Other dischargers with associated groundwater intakes, **Pinewood Site** and **St. Stephen Power**, have inactive intakes and have no available records and thus have been included as Discharge Objects.

4.5 Implicit Tributaries

Typically, these models have implicit tributaries, which capture ungaged drainage areas at certain locations along the mainstem. However, this basin has a relatively small drainage area and a short mainstem, which in conjunction with the tidally-influenced areas, does not appear to have significant ungaged areas. Therefore, no implicit tributaries were created for this model.

Section 5

Model Versions

For each river basin, two model versions were developed: a calibration model and a baseline model. The two models have different objectives and purposes, and, consequently, employ different parameter assignments, as described below.

The calibration model was developed to determine the “best fit” value of key model hydrologic parameters, as described in Section 7. Its utility beyond the calibration exercise is limited as the calibration model has been developed to recreate historical conditions which are not necessarily representative of current or planned future conditions. This model was parameterized using historical water use and reservoir operations data to best reflect past conditions in the basin. These data include time-varying river and reservoir withdrawals and consumptive use estimates and historical reservoir release and operational rules. Also included in the calibration version of the model are water users that may be no longer active but were active during the selected calibration period. As discussed in Section 7, the simulation period for this version of the model focuses on the recent past (1986 – 2010) rather than the full record of estimated hydrology.

In contrast, the baseline model is intended to represent current demands and operations in the basin combined with an extended period of estimated hydrology. This model will serve as the starting point for any future predictive simulations with the model (e.g., planning or permitting support) and should be maintained as a useful “baseline” point of reference. Though the hydrologic record for the Santee Basin extends back to 1942, for this model, the simulation period is limited back to 1951, the start of the hydrologic record for the upstream Catawba-Wateree Basin. Each element in the baseline model is assigned water use rates that reflect current demands only and are not time variable (except seasonal). Current demands were estimated by averaging water use data over the past ten years (2004 – 2013) for most users, on a monthly basis. These monthly demands are repeated in the baseline model for each simulation year. Similarly, reservoir operations defined in the baseline model are based on current rules, guidelines, and minimum release requirements. In certain instances, future rules that are not yet in effect, can be included (and can be toggled on or off in the model). A final difference between the two models is that only active water users are included in the baseline model. Inactive user objects included in the calibration model have been removed from the baseline model.

Section 6
Model Inputs

SWAM inputs include unimpaired flows (UIFs); reservoir characteristics such as operating rule curves, storage-area-relationships, and evaporation rates; and water user information, including withdrawals, consumptive use, and return flows. This section primarily presents the inputs used in the baseline Santee River Basin model, but also summarizes the major differences between the baseline and calibration models. As explained in Section 5, the calibration model incorporates historical water withdrawal and return data so that UIF flows and reach gains and losses can be calibrated to USGS gage flows. In contrast, the baseline model represents current demands and operations in the basin combined with an extended period of estimated hydrology. For future uses of the model, users can adjust the inputs, including demands, permit limits, and operational strategies, to perform "what if" simulations of basin water availability.

The following subsections describe the specific inputs to the Santee River Basin baseline model. Unless specifically noted, the inputs discussed below are the same in both the calibration model and baseline model.

6.1 Model Tributaries

The primary hydrologic inputs to the model are unimpaired flows for each tributary object. These flows, entered as a continuous timeseries of monthly and daily average data, represent either the flow at the top of each tributary object reach (headwater flows; explicit tributary objects) or at the bottom of the reach (confluence flows; implicit tributary objects). Additionally, mid-stream UIFs, though not used directly in the SWAM model construction, can serve as useful references in the model calibration process, particularly with respect to quantified reach gains and losses (discussed in Section 7).

6.1.1 Explicit Tributary Objects: Headwater Flows

Explicit tributary objects in SWAM are tributaries that include any number of Water User objects and/or reservoir objects with operations and water use explicitly simulated in the model. Conversely, implicit tributary objects (discussed below) are treated as simple point inflows to receiving streams in the model, without any simulated water use or operations. For further discussion on explicit versus implicit tributary objects in SWAM, please refer to the SWAM User's Manual.

Explicit tributary objects are parameterized in SWAM with headwater flows, representing unimpaired flows at the top of the given modeled reach. These flows may be raw gage flow, area-prorated from calculated UIFs elsewhere in the basin, or output flows from existing models. The beginning of the Santee River Basin is formed by the full drainage of the Saluda, Congaree, Broad and Catawba-Wateree River Basins. For the calibration model, mainstem flows are determined from the Saluda Basin by scaling gage flows on the Congaree River (SLD27, USGS gage ID 02169500) to the full drainage of the basin. Then headwater flows for the Wateree River tributary object are formed by a combination of gage data at CAT21 (USGS gage ID 02148315) and filled-in modeled flows from the Catawba-Wateree SWAM calibration model during record gaps, which occurred at high flows. For the Santee baseline model, these two flows series will be populated with output from each upstream basin's respective baseline flows such that predictive exercises across multiple basins can be carried throughout.

Table 6-1 summarizes the gages, or in most instances, the reference gages used to develop headwater flows. **Figure 6-1** highlights the upstream drainage areas associated with the explicit tributary headwater flows. Green polygons correspond to unimpaired USGS gaged flow and purple polygons correspond to estimated ungaged flows. The gray areas represent the drainage associated with the output for the upstream Saluda and Catawba-Wateree River Basin models. The inset table designates the project ID for each flow point, whether it was gaged or ungaged, the name of the tributary, and the corresponding drainage area in acres.

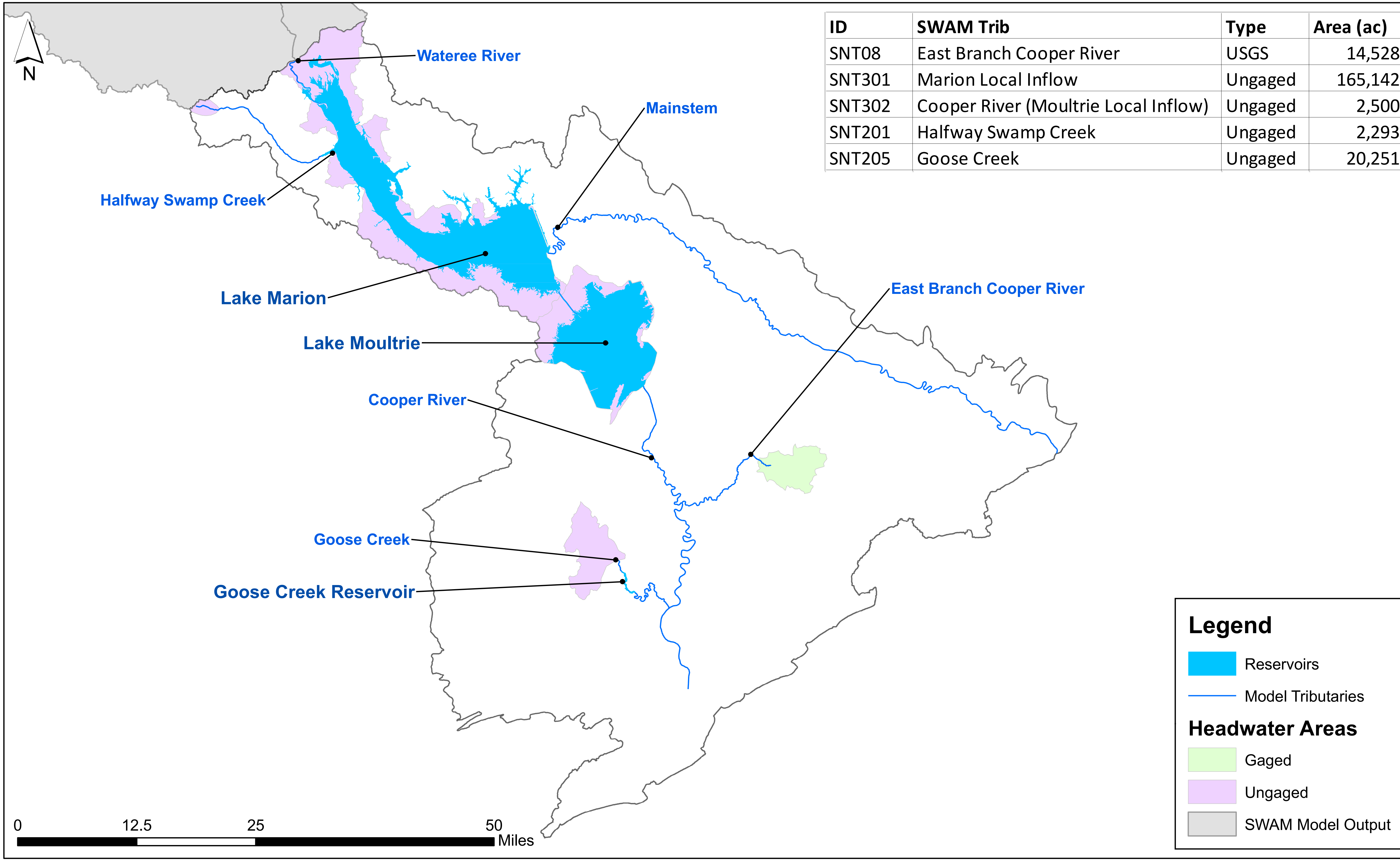
6.1.2 Implicit Tributary Objects: Confluence Flows

No implicit tributaries were created for this model, as discussed in Section 4.5.

6.1.3 Reach Gains and Losses

In SWAM, mainstem gain/loss factors and tributary subbasin flow factors capture ungaged flow gains and losses associated with increasing drainage area with distance downstream and/or interaction with subsurface flow (leakage, seepage). These reach-specific factors are the primary parameters adjusted during model calibration, as further explained in Section 7. The gain/loss and subbasin flow factors are applied to the input headwater flows and represent a steady and uniform gain/loss percentage relevant to the designated reach. Actual flow volume changes are calculated for a specific location based on these reach-specific factors and in proportion to stream length and the object headwater flow for the given timestep.

There are subtle differences in the way in which these gains and losses are characterized in the model inputs for non-mainstem tributary objects versus the mainstem tributary object, although they effectively achieve the same thing in the model calculations. For the mainstem, gain/loss factors are specified on a per unit mile basis. For example, if the mainstem headwater flow is 10 cfs in a given timestep with a gain factor of 0.1 per mile specified for the entire mainstem reach, then the model applies a rate of gain of 1 cfs/mile throughout the length of the mainstem. At the end of a 5-mile reach with no other inflows or outflow, the flow would be 15 cfs. For all other tributary objects, subbasin flow factors are specified as a total subbasin flow gain factor, used to calculate total natural (unimpaired) flow at the end of the designated reach. For example, if a tributary flow is 10 cfs in a given timestep, with a subbasin flow factor of 5, then the end-of-reach flow (with no other inflows or outflows) is 50 cfs. The model linearly interpolates when calculating the unimpaired flow at intermediary points in the reach. The differences between mainstem vs. non-mainstem factors reflect physical differences between the two types of tributary objects as represented in SWAM. For non-mainstem tributaries, flow gains are usually dominated by easily-quantifiable increases in drainage area with distance downstream and therefore easily parameterized with drainage area-based subbasin flow factors. For the mainstem, however, the bulk of the drainage area changes are already captured by the tributary objects and any additional changes in flow are more likely to be attributable to subsurface hydrologic interactions or highly localized surface runoff. Such flow changes are more easily represented with per mile gain/loss factors. Both mainstem and tributary flow factors can be spatially variable in the model for up to five different sub-reaches. For further discussion on SWAM reach gain/loss factors, please refer to the SWAM User's Manual. Tributary object gain/loss and subbasin flow factors are the primary calibration parameters in the model, as discussed in Section 7. Recognizing the uncertainty in these parameters, factors are adjusted, as appropriate, to achieve a better match of modeled vs. measured downstream flows. As a starting point in the model, however, overall non-mainstem tributary subbasin flow factors were prescribed in the model based only on drainage area ratios (headwater vs. confluence). Drainage areas are shown in **Figure 6-1** and corresponding tributary and mainstem flow factors are summarized in **Table 6-2**.



ID	SWAM Trib	Type	Area (ac)
SNT08	East Branch Cooper River	USGS	14,528
SNT301	Marion Local Inflow	Ungaged	165,142
SNT302	Cooper River (Moultrie Local Inflow)	Ungaged	2,500
SNT201	Halfway Swamp Creek	Ungaged	2,293
SNT205	Goose Creek	Ungaged	20,251

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Figure 6-1
Headwater Areas for Model Tributaries in the Santee River Basin

Table 6-1. Gages and Reference Gages Used for Headwater Flows on Explicit Tributaries

	Headwater Input			USGS Reference Gage (Unimpaired)		
Project ID	**Type**	**USGS Number**	**SWAM Tributary**	**Project Gage ID**	**USGS Number**	**Stream**
None	SWAM Model Output	-	Mainstem (Santee River)	-	-	-
None	SWAM Model Output	-	Wateree River	-	-	-
SNT08	Gaged	02172035	East Branch Cooper River	-	-	-
SNT301	Ungaged	-	Marion Local Inflow	SNT05	02171680	Wedboo Creek
SNT302	Ungaged	-	Cooper River (Moultrie Local Inflow)	SNT05	02171680	Wedboo Creek
SNT201	Ungaged	-	Halfway Swamp Creek	SNT05	02171680	Wedboo Creek
SNT205	Ungaged	-	Goose Creek	SNT05	02171680	Wedboo Creek

Table 6-2. Model Tributary Inputs

SWAM Tributary Object	Tributary Type	Confluence Stream	Confluence Location (mile)	Area (ac)	Headwater ID	End Mile	Original Drainage Ratio	Subbasin Flow Factor (unitless)
Santee River (Mainstem)	Explicit	None	None	-	None	44.3	-	0*
						52.7	-	0*
						65.9	-	0*
						75.1	-	0*
						127	-	0*
Wateree River	Explicit	Mainstem	0.1	3,600,000	None	0.1	1.0	1.0
Halfway Swamp Creek	Explicit	Mainstem	18.9	2,293	SNT201	18.4	21.5	21.5
Cooper River	Explicit	Mainstem	999	2,500	SNT302	1.0	1.0	0.5
						18.0	51.1	51.1
						38.0	82.2	82.2
						48.0	109.8	109.8
East Branch Cooper River	Explicit	Cooper River	19.2	14,528	SNT08	13.3	8.2	8.2
Goose Creek	Explicit	Cooper River	37.7	20,251	SNT205	15.0	1.9	1.9
Marion Local Inflow	Explicit	Mainstem	44	165,142	SNT301	0.1	1.0	1.0

**On the Mainstem, these are referred to as "gain/loss factors", not "subbasin flow factors".*

6.2 Reservoirs

Three reservoirs are represented in the Santee River Basin Model: Lake Marion, Lake Moultrie, and Goose Creek Reservoir. Though multiple users have intakes on Bushy Park Reservoir, this reservoir receives flow from the Back River, which is fed by the Cooper River, and releases back to the Cooper River. Therefore, usage on Bushy Park Reservoir is modeled as from the Cooper River. **Table 6-3** provides a summary of model inputs and other information used to characterize each reservoir. Additional details and explanation for certain reservoir inputs are summarized below in **Tables 6-4** and **6-5**, which consist mostly of information adapted from a bathymetric report (USGS, 1988) and an environmental impact statement for hydroelectric facilities (SCPSA, 2007).

6.2.1 Evaporation

In SWAM, evaporative losses can be specified using monthly-varying seasonal rates (inches per day or percent volume) or with a user-specified timeseries of monthly or daily evaporative losses (inches per month or inches per day). In both the calibration and baseline models, evaporative losses are specified using a timeseries developed during the UIF process. Evaporation was computed using the Hargreaves method from daily temperature data and latitude, and further adjusted by pan evaporation data compiled by Purvis (undated). Temperature stations for were chosen based on proximity to pan evaporation sites. Temperature and evaporation stations used in developing evaporative loss estimated are listed in **Table 6-3.**

Table 6-3. Reservoir Inputs

Reservoir	Lake Marion	Lake Moultrie	Goose Creek Reservoir
Purpose	Power, recreation, and water supply	Power, recreation, and water supply	Water supply and recreation
Receiving Stream	Mainstem (Santee River)	Cooper River	Goose Creek
Temperature Station for Evaporation	Charleston USW00013880	Charleston USW00013881	Charleston USW00013882
Evaporation Station	Summerville USC00388426	Summerville USC00388427	Summerville USC00388428
Precipitation Station	Santee Cooper USC00387712/ Rimini USC00387313	Pinopolis Dam USC00386893/ Moncks Corner USC00385946/ Pinopolis USC00386890	Summerville USC00388426
Release Location (mi)	44.6	1	4.6
Storage Capacity (MG)	464,338	362,000	1,564
Dead Pool (MG)	142,703	128,879	0
Operating Rules	Advanced	Advanced	Simple

6.2.2 Direct Precipitation

Typically, large reservoirs in SWAM release to an explicit tributary object and have an additional tributary representing local inflow and direct precipitation. Both Lake Marion and Lake Moultrie are large enough to merit respective local inflow objects, where such objects are estimated via area proration of an appropriate unimpaired flow. Since Lake Moultrie is essentially the headwaters of the Cooper River, the local inflow plus direct precipitation also serves as the headwater flows for the Cooper River tributary object.

Direct precipitation to Goose Creek Reservoir was considered negligible, and not explicitly included in the model. However, precipitation rates were factored into the calculation of non-negative net evaporation rates for these smaller reservoirs. In other words, when evaporation was equal to or exceeded precipitation, precipitation was subtracted from the gross evaporation rate to calculate net rates. For timesteps where precipitation exceeded evaporation, net evaporation rates were set to zero.

6.2.3 Area-Capacity Relationships and Flood Control Outflow

Area-capacity relationships for the three reservoirs are summarized in **Table 6-4**. The area-capacity relationships are represented in SWAM with 12 points or less, which in some cases is a simplified representation of the full tabular relationship. SWAM treats flood flows (when reservoirs are at capacity) simply as bypass flow. Generally, flood control outflow relationships are not needed, and not assigned. For all three reservoirs, no specific volume to flood control outflow relationships were assigned.

6.2.4 Releases and Operating Rules

Reservoir release locations are assigned in the model based on best available information for dam and outflow locations. Actual modeled releases are calculated in the model based on prescribed operating rules and release targets (see SWAM User's Manual). Enhancements to SWAM reservoir rules now include three types of advanced operations: minimum releases, storage curves, and instream flow targets. Both Lake Marion and Lake Moultrie have these advanced rules. **Table 6-5** summarizes which of these three types of rules apply to each reservoir, the rule set priority, and the corresponding dates and conditions. While SWAM performs reservoir calculations in terms of volume, elevations are also displayed for ease of comparison to existing rules. Unless otherwise noted, these elevations are in the NGVD29 datum. These two reservoirs also follow stricter minimum releases than listed in Table 6-5, which are enforced by rules in **Table 6-9** (see Section 6.3.2).

The South Carolina Public Service Authority (Santee Cooper) manages both Lake Marion and Lake Moultrie, and the City of Charleston owns Goose Creek Reservoir. All three reservoirs serve as municipal water supply; Goose Creek Reservoir supplies **WS: Charleston**, **WS: Santee Cooper RWS** from Lake Moultrie, and **WS: Santee Cooper – Lake Marion RWS** from Lake Marion, as well as a couple irrigators, **GC: Santee Cooper Resort** and **IR: St. Julian**. Both Lake Marion and Lake Moultrie have seasonal storage targets, following an annual pattern of between 75 and 76 feet in the spring through fall, to near 72 feet for winter drawdown. These targets have the ramping feature enabled, which mimics the actual operation, whereby an operator will gradually release or retain water throughout a period, with the goal of meeting the target at the end of the period. Lake Marion and Lake Moultrie each have year-round minimum releases to support instream flows and demands for the two canal user objects **Marion Diversion Canal** and **Moultrie Rediversion Canal** (see Section 6.3.2). Lake Marion's minimum release is conditioned on the ratio of its storage relative to Lake Moultrie's, releasing more when Lake Moultrie is at a lower volume.

Table 6-4. Reservoir Area-Capacity Relationship

Reservoir	Volume (MG)	Area (Acres)
Lake Marion	2,281	10
	2,933	1,500
	7,820	6,000
	13,686	10,000
	32,585	19,000
	71,687	29,000
	136,858	40,000
	211,803	51,000
	276,974	60,000
	342,144	71,000
	391,022	80,000
	464,338	106,700
Lake Moultrie	1629	1500
	4,888	3,000
	9,776	4,500
	22,810	7,000
	55,395	13,500
	89,609	20,000
	149,892	30,000
	182,477	35,000
	218,320	40,000
	247,647	44,000
	316,076	55,000
	345,403	59,874
Goose Creek Reservoir	0	0
	1,564	600

6.3 Water Users

6.3.1 Sources of Supply

Table 6-6 summarizes the sources of supply for all Water User objects included in the model. This information includes withdrawal tributaries (or reservoirs), diversion locations, and permit limits. As noted in the table, one minor difference between the calibration and baseline model is **PT: Jeffries Station** in the calibration model is called **Santee Cooper (formerly Jeffries)** in the baseline. This user ceased coal-fired operations in 2012, and oil-fired operations in 2015, but Santee Cooper is maintaining the surface water withdrawal permit for future reuse of the plant site. Multiple users have their intakes represented as the Cooper River as a simplification given Bushy Park Reservoir and the Back River are not represented explicitly in the model. These are **IN: DAK**, **IN: BP Amoco**, **IN: Sun Chemical**, **PT: Williams Station**, and one of the intakes for **WS: Charleston**. Three users are sourced entirely from groundwater: **IN: CR Bard, IN: Nucor**, and **WS: St. Matthews**.

Table 6-5. Advanced Reservoir Rules

Reservoir	Priority	Type	Target	Months	Conditioned On:
Lake Marion	1	Minimum Release (cfs)	4,500	Jan - Dec	Lake Moultrie Storage Ratio > 0.95
			5,200	Jan - Dec	Lake Moultrie Storage Ratio < 0.95
	2	Storage Curve (MG)	398,877 (74.3')	Jan 16 - Feb 8	
			418,254 (75')	Feb 9 - Mar 10	
			432,917 (75.6')	Mar 11 - May 31	
			432,917 (75.6')	Jun 1 - Jul 31	
			418,254 (75')	Aug 1 - Oct 11	
			381,246 (73.6')	Oct 12 - Dec 15	
			347,032 (72.2')	Dec 16 - Jan 15	
Lake Moultrie	1	Minimum Release (cfs)	4,500	Jan - Dec	
	2	Storage Curve (MG)	335,138 (74.3')	Jan 16 - Feb 8	
			346,494 (75')	Feb 9 - Mar 10	
			361,782 (75.6')	Mar 11 - May 31	
			361,782 (75.6')	Jun 1 - Jul 31	
			346,494 (75')	Aug 1 - Oct 11	
			324,874 (73.6')	Oct 12 - Dec 15	
			302,390 (72.2')	Dec 16 - Jan 15	

Table 6-6. Water User Objects and Sources of Supply Included in the Santee River Basin Model

Model Object ID	Facility Name	Source of Supply	Intake ID	Diversion Location (mi)	Permit Limit (MGM)	Note
IN: Chargeurs	Chargeurs Wool USA Inc	Mainstem	08IN001S01	96.7	15.6	1
IN: DAK	DAK Americas Cooper River Facility	Cooper River (Durham Creek*)	08IN003S01	18.3	134.0	1
IN: BP Amoco	BP Amoco - Cooper River Plant	Cooper River (Bushy Park Reservoir/Back River*)	08IN006S01	32.5	2325.0	1
IN: Sun Chemical	Bushy Park Site (CRP LLC)	Cooper River (Back River*)	08IN008S01	29.9	401.8	1
IR: ZZ Real Estate	ZZ Real Estate LLC	Cooper River (West Branch Cooper River)	08IR001S01	7.8	181.9	1,3
Marion Diversion Canal	Diversion Canal	Mainstem	None	45	-	1
Moultrie Rediversion Canal	Rediversion Canal	Cooper River	None	1.1	-	1
PT: Williams Station	SCE&G Williams Station	Cooper River (Bushy Park Reservoir/Back River*)	08PT001S01	25.9	17142.0	1
			08PT001S02		982.0	
Santee Cooper (formerly Jeffries)	Santee Cooper Jefferies Generating Station	Cooper River (Tailrace Canal)	08PT002S01	1.2	4693.0	2
			08PT002S02		707.0	
PT: Cross Station	Santee Cooper Cross Generating Station	Cooper River (Diversion Canal)	08PT003S01	0.3	1436.3	1
			08PT003S02		1436.3	
WS: Santee Cooper RWS	Santee Cooper Lake Moultrie RWS	Cooper River/Lake Moultrie	08WS007S01	1	2325.0	1
			08WS007S02		2325.0	
IR: Lyons Bros	Lyons Brothers Farm	Halfway Swamp Creek	09IR032S01	12.1	-	1
IN: Kapstone	Kapstone Charleston Kraft LLC	Mainstem (Edisto River Tunnel)	10IN003S02	1006.1	3042.0	1,5
WS: Charleston	Charleston CPW - Hanahan WTP	Cooper River (Bushy Park Reservoir/Back River*)	10WS004S01	29.8	4562.5	1
		Goose Creek Reservoir/Goose Creek	10WS004S02	4.6	304.2	
		Mainstem (Edisto River Tunnel)	10WS004S05	1006	8729.0	1,4
IR: Parsons	Parsons Nursery	Mainstem (North Santee River)	22IR034S01	118	0.8	1,3
			22IR034S02		18.0	
			22IR034S04		5.6	
IN: Martin Marietta	Martin Marietta Materials - Georgetown Quarry	Mainstem	22MI001S01	99.1	67.0	1
PT: Winyah Station	Santee Cooper Winyah Generating Station	Mainstem	22PT001S01	120	3348.0	1
			22PT001S03		558.0	
GC: Santee Cooper Resort	Santee-Cooper Resort Inc	Mainstem/Lake Marion	38GC006S01	44.6	26.8	1
IR: St Julian	St Julian Plantation	Mainstem/Lake Marion	38IR024S01	44.6	20.4	1,3
			38IR024S02		7.0	
WS: Santee Cooper - Lake Marion RWS	Santee Cooper - Lake Marion RWS	Mainstem/Lake Marion	38WS052S01	44.6	775.0	1

Note 1 indicates the withdrawal is currently active, and was included in both the baseline and calibration model.

Note 2 indicates the withdrawal was previously active for another purpose and permit is being kept active.

Note 3 indicates registered limit for irrigation.

Note 4 indicates interbasin transfer

Note 5 pertains specifically to Kapstone, which draws from the Edisto tunnel but technically permitted for Goose Creek Reservoir.

6.3.2 Demands

Table 6-7 presents the monthly demand for Municipal (WS), Industrial/Mining (IN), and Thermoelectric (PT) Water User objects in the baseline model. Monthly irrigation demands for Golf Course (GC) and Agricultural (IR) Water User objects are presented in **Table 6-8**. The baseline model monthly demand assigned to each Water User object was calculated by averaging monthly demands (as reported to DHEC) over the ten-year period from 2004 through 2013 for most users, with some exceptions. **IN: Chargeurs**, **IN: DAK**, **PT: Cross Station** had changes in the pattern of overall demand, leading to a baselines being defined by varying years (2011-2013, 2011-2013, and 2010-2013). Because of data gaps, **IN: Sun Chemical** has a baseline from 2007-2013 averages. Several users did not start withdrawing water until recent years: **IN: Martin Marietta** did not start until 2013 and **WS: Santee Cooper – Lake Marion RWS** did not start until 2009. **Santee Cooper (formerly Jeffries)** has a baseline demand of zero as its current usage is negligible miscellaneous activities while the surface water permit is being kept active.

For all permitted users, demands for the calibration period (1983 through 2010) were input as a timeseries of monthly values based on monthly withdrawals reported to DHEC and supplemented by data collected from each water user by CDM Smith. Two user objects do not directly correspond to a surface water permit holder, but instead represent transfers on canals. **Marion Diversion Canal** represents the transfer of flows from Lake Marion to Lake Moultrie and **Moultrie Rediversion Canal** represents the rediversion canal from Lake Moultrie back to the Santee River. Although in reality, both of these transfers directly withdraw from the reservoirs, in the model the withdrawals occur immediately downstream of their respective dams. This ensures whatever is left after meeting reservoir storage targets can be diverted/rediverted. These demands are subject to maintaining minimum instream flows for the Santee and Cooper Rivers, which are summarized in **Table 6-9**. These minimum instream flows ensure minimum release requirements for Lake Marion and Lake Moultrie can be satisfied. Additionally, the **Marion Diversion Canal** has a conservation feature enabled such that it reduces its transfer when Lake Moultrie's storage is high relative to Lake Marion.

6.3.3 Transbasin Imports

In South Carolina, there are many examples of water users who access source waters in multiple river basins and/or discharge return flows to multiple basins. In order to consistently represent transbasin imports and exports in the SWAM models, a set of guidelines were developed, which are summarized in **Appendix C – Guidelines for Representing Multi-Basin Water Users in SWAM**. In the Santee River Basin Model, **WS: Charleston** imports water from the Edisto River Basin via the Edisto River Tunnel. In both the calibration and baseline models, this import is treated as a transbasin import in SWAM and is represented as Source Water Account #1. **IN: Kapstone**, while technically permitted for Goose Creek Reservoir, in actuality pulls water from the Edisto River Tunnel as well. Therefore, in the baseline model this is treated as tranbasin import. Flows for these two users are summarized in **Table 6-10**.

6.3.4 Consumptive Use and Return Flows

As discussed in Section 4.2, return flows (discharges) can be simulated two ways in SWAM. They can be associated with a Water User object (calculated return flows) or specified within a Discharge object (prescribed discharges). **Table 6-11** summarizes the calibration and baseline model objects representing return flows, their location, and the percent of return flow assigned to each location. In this table, the "*% of Return Flow*" represents the allocation to one or more discharge locations, not the consumptive use percentage. In many instances, multiple NPDES discharge locations associated with a unique Water User object were lumped together, based on their close proximity to one another (e.g., all pipes for **PT: Williams Station** returns were combined). One outfall is shared by both **IN: DAK** and **WS: Santee Cooper RWS**, which required splitting returns between the two objects. Multiple significant dischargers exist in coastal areas. For those associated with a Water User object, they are treated similarly to that of an export discharge—that is their portion of the return flow is assigned to an arbitrarily distant downstream location on the mainstem. Significant coastal dischargers not associated with a Water User object were not included in the model. No returns are assumed for golf course and agricultural irrigation (i.e., 100% consumptive use).

Table 6-12 presents the monthly percent consumptive use for water users with known return flows. For most municipal and industrial water users, consumptive use was calculated from DHEC-reported withdrawals and discharges over the baseline period (2004 through 2013). **IN: Chargeurs** ceased reporting discharges in 2010 and **IN: Martin Marietta** have no reported discharges, therefore their baseline consumption is assumed as 100%. Several users had their consumptive use defined by the estimated percent of return flow indicated in its surface water withdrawal permit. **IN: DAK** used this estimate as a means to split the return flow between it and **WS: Santee Cooper RWS**. **PT: Williams Station** and **PT: Winyah Station** used the permit estimate as their reported discharge data had high uncertainty when compared to reported withdrawals. Both **Marion Diversion Canal** and **Moultrie Rediversion Canal** have no consumptive use as their purpose is simply to transfer water.

Table 6-13 presents the baseline model monthly average returns represented by a Discharge object. The returns were calculated by averaging the DHEC-reported discharges for the baseline period (2004 through 2013).

6.4 Summary

This section has presented the form and numerical values of data that are input into the Santee River Basin Model, in the context of the model framework discussed in Section 4. Data descriptions are organized according to the model objects which house the data. For more details on SWAM model input requirements and mechanics, readers are referred to the SWAM User's Manual. Note that, as discussed in Section 7, a small portion of these input data may be adjusted as part of the calibration process. For the Santee River Basin model, these calibration inputs only included reach hydrologic gain/loss factors, demands for the two canal water user objects, and to a very limited extent, reservoir operating rule targets.

Table 6-7. Baseline Model Average Monthly Demand for IN, PT, and WS Water Users

Baseline Model Average Monthly Demand (MGD)									
Month	**IN: Chargeurs**	**IN: DAK**	**IN: BP Amoco**	**IN: Sun Chemical**	**PT: Williams Station**	**PT: Cross Station**	**WS: Santee Cooper RWS**	**IN: Kapstone**	**WS: Charleston**
Permit Limit (MGD)	**0.5**	**4.4**	**76.5**	**13.2**	**596.2**	**47.2**	**76.5**	**100.0**	**447.2**
Jan	0.1	0.5	6.7	2.1	431.9	27.5	14.5	26.1	55.0
Feb	0.1	0.7	7.3	2.1	451.9	27.7	14.2	26.2	55.1
Mar	0.1	0.7	6.7	2.1	405.5	26.4	14.8	25.4	69.2
Apr	0.1	0.7	6.8	2.2	423.3	25.3	16.3	25.5	66.9
May	0.1	0.7	6.3	2.2	467.1	28.0	17.8	25.9	73.9
Jun	0.1	0.8	6.7	2.3	512.5	29.7	18.4	26.6	74.8
Jul	0.1	0.9	7.1	2.3	479.6	31.2	18.1	26.7	72.4
Aug	0.1	0.8	7.0	2.4	535.1	29.7	17.3	27.1	69.5
Sep	0.1	0.8	7.0	2.4	401.0	29.2	17.2	27.0	68.4
Oct	0.1	0.8	6.5	2.2	341.4	25.4	16.2	26.4	65.3
Nov	0.1	1.0	6.4	2.0	438.7	29.3	15.6	25.6	61.1
Dec	0.1	0.9	6.0	1.9	464.3	28.2	15.1	24.9	55.8
Month	**IN: Martin Marietta**	**PT: Winyah Station**	**WS: Lake Marion RWS**	**WS: St. Matthews**	**IN: Nucor**	**IN: CR Bard**	**Marion Diversion Canal**	**Moultrie Rediversion Canal**	**Santee Cooper (formerly Jeffries)**
Permit Limit (MGD)	**2.2**	**128.5**	**25.5**	**-**	**-**	**-**	**-**	**-**	**177.6**
Jan	0.4	4.6	0.5	0.3	3.0	0.2	18,000	15,500	0
Feb	0.4	4.2	0.5	0.3	3.1	0.3	18,000	15,500	0
Mar	0.4	4.9	0.6	0.3	2.8	0.2	18,000	15,500	0
Apr	0.4	5.7	0.6	0.3	2.8	0.2	18,000	15,500	0
May	0.4	5.5	0.6	0.3	2.8	0.2	18,000	15,500	0
Jun	0.4	7.4	0.7	0.3	3.0	0.2	18,000	15,500	0
Jul	0.4	7.2	0.8	0.3	2.6	0.2	18,000	15,500	0
Aug	0.4	4.3	0.8	0.3	2.9	0.3	18,000	15,500	0
Sep	0.4	3.3	0.7	0.3	2.8	0.2	18,000	15,500	0
Oct	0.4	3.6	0.7	0.3	2.6	0.3	18,000	15,500	0
Nov	0.4	4.3	0.6	0.3	2.7	0.2	18,000	15,500	0
Dec	0.3	4.0	0.5	0.3	2.7	0.2	18,000	15,500	0

Permit limits shown in MGD rather than MGM for comparative purposes. Actual permit limits are in MGM.

Table 6-8. Baseline Model Average Monthly Demand for GC and IR Water Users

Baseline Model Average Monthly Demand (MGD)					
Month	GC: Santee Cooper Resort	IR: Lyon Bros	IR: ZZ Real Estate	IR: Parsons	IR: St. Julian
Jan	0.07	0.00	1.15	0.07	0.00
Feb	0.08	0.00	1.21	0.08	0.00
Mar	0.07	0.00	1.46	0.14	0.00
Apr	0.08	0.00	2.28	0.28	0.00
May	0.07	0.04	2.68	0.33	0.00
Jun	0.08	0.10	3.25	0.44	0.09
Jul	0.07	0.15	2.83	0.46	0.05
Aug	0.07	0.07	2.86	0.43	0.03
Sep	0.08	0.02	2.55	0.31	0.08
Oct	0.07	0.00	1.88	0.18	0.01
Nov	0.08	0.00	1.59	0.13	0.00
Dec	0.07	0.00	1.21	0.08	0.00

Table 6-9. Baseline Model Instream Minimum Flow Requirements

Baseline Model Monthly Min Flows (cfs)		
Month	Marion Diversion Canal	Moultrie Rediversion Canal
Jan	600	7000
Feb	600	4500
Mar	600	4000
Apr	600	3000
May	600	4000
Jun	600	5000
Jul	600	5000
Aug	600	5000
Sep	600	5000
Oct	600	5000
Nov	600	5000
Dec	600	5000

Table 6-10. Baseline Model Average Monthly Transbasin Imports

	Baseline Model Avg Monthly Transbasin Import (cfs)	
Month	WS: Charleston	IN: Kapstone
Jan	14	40
Feb	15	40
Mar	16	39
Apr	25	39
May	31	40
Jun	23	42
Jul	18	42
Aug	16	42
Sep	19	42
Oct	21	41
Nov	17	40
Dec	12	39

Table 6-11. Returns and Associated Model Objects

Model Object ID	Facility Name	NPDES Pipe ID	Associated Water Permit	Discharge Tributary	Model River Mile	% of Return Flow
Returns Represented Within Water User Objects						
IN: Chargeurs	CHARGEURS WOOL (USA) INC	SC0000990-001	08IN001	Mainstem	96.8	100
IN: BP Amoco	BP AMOCO CHEMICALS COOPER RIVER	SC0028584-001	08IN006	Cooper River	33.3	100
IN: Sun Chemical	SUN CHEMICAL CORP/BUSHY PARK	SC0003441	08IN008	Cooper River	30.2	100
PT: Williams Station	SCGENCO/A M WILLIAMS STATION	SC0003883	08PT001	Cooper River	26.0	100
Santee Cooper (formerly Jeffries)	SCPSA/JEFFERIES GEN STATION	SC0001091	08PT002	Cooper River	1.3	100
PT: Cross Station	SCPSA/CROSS GENERATING STATION	SC0037401	08PT003	Cooper River (Diversion Canal)	0.3	100
IN: DAK/ WS: Santee Cooper RWS	DAK AMERICAS LLC/COOPER RIVER PLANT	SC0026506-001	08IN003/ 08WS007	Cooper River	21.5	100/8
WS: Santee Cooper RWS	SCPSA/MONCKS CORNER WTP	SCG641011-001	08WS007	Cooper River	1.9	11
	MONCKS CORNER WWTF	SC0021598-001		Cooper River	6.5	15
	BCW&SA/CENTRAL BERKELEY WWTP	SC0039764-001				15
	BCW&SA/ST STEPHEN WWTP	SC0025259-001		Mainstem	81.1	4
	SUMMERVILLE WWTF	SC0037541-001		**Coastal**	**1003.0**	62
IN: Kapstone	KAPSTONE CHARLESTON KRAFT LLC	SC0001759	10IN003	Cooper River	40.1	100
PT: Winyah Station	SCPSA/WINYAH STEAM STATION	SC0022471-002	22PT001	Mainstem (North Santee River)	121	100
WS: Santee Cooper - Lake Marion RWS	LAKE MARION REGIONAL WTP	SCG646061-001	38WS052	Mainstem	28.1	53
	TOWN OF BOWMAN	SC0040037-001		**Out of basin (Edisto)**	**1011.0**	47
WS: Charleston	BCW&SA/LOWER BERKELEY WWTF	SC0046060-001	10WS004	Cooper River	34.4	17
	NCSD/FELIX C DAVIS WWTP	SC0024783-001		Cooper River	45.8	27
	CHARLESTON CPW/PLUM ISLAND	SC0021229-001		**Coastal**	**1010.0**	56
	MT PLEASANT/CENTER ST & RR RD.	SC0040771				
IN: CR Bard	C R BARD INC	SC0035190-001	08IN007G	Cooper River	2.2	100
IN: Nucor	NUCOR STEEL/BERKELEY PLANT	SC0047392	08IN011G/ 08WS058G	Cooper River	27.6	100
WS: St. Matthews	ST MATTHEWS/SOUTH PLANT	SC0028801-001	09WS001G	Halfway Swamp Creek	5.0	100
In-basin Returns Represented by Individual or Aggregated Discharge Objects						
Williamsburg Co	WILLIAMSBURG CO/SANTEE RV WWTF	SC0048097-001	None	Mainstem	69.2	-
Pinewood Site	PINEWOOD SITE CUSTODIAL TRUST	SC0042170	None	Mainstem	7.8	-
St. Stephen Power	US ARMY/ST STEPHEN POWER PLANT	SC0047937	None	Mainstem (Rediversion Canal)	81.2	-
Agg Discharge 1	KINDER MORGAN-SHIPYARD RIVER TERMINAL	SC0001350	None	Cooper River	42.1	-
	HESS/CHARLESTON NORTH TERMINAL	SC0002852-001				
	DELFIN GROUP USA LLC	SC0003026-004				
	PETROLIANCE LLC/CHARLESTON	SC0047261-001				
	DETYENS SHIPYARD/MAIN YARD	SC0047562				
Navy	NAVAL NUCLEAR POWER TRAINING UNIT	SC0043206-003	None	Cooper River	34.7	-
SC Genco	SCGENCO/WILLIAMS ASH DISP HW52	SC0046175-001	None	Cooper River	11.6	-

Note: Returns outside of the Santee River Basin or are in coastal areas are indicated in ***bold***.

Table 6-12. Baseline Model Monthly Consumptive Use Percentage

Baseline Model Average Consumptive Use (%)									
Month	**IN: Chargeurs**	**IN: DAK**	**IN: BP Amoco**	**IN: Sun Chemical**	**PT: Williams Station**	**PT: Cross Station**	**WS: Santee Cooper RWS**	**IN: Kapstone**	**WS: Charleston**
Jan	100.0	22.0	38.4	1.3	21.0	75.3	39.7	0.6	52.8
Feb	100.0	22.0	40.4	5.5	21.0	74.5	31.1	1.3	43.7
Mar	100.0	22.0	36.4	5.1	21.0	75.7	36.6	0.5	49.6
Apr	100.0	22.0	37.4	5.3	21.0	73.5	45.0	1.4	54.2
May	100.0	22.0	32.9	2.9	21.0	75.6	52.5	2.1	64.1
Jun	100.0	22.0	36.5	2.7	21.0	73.9	50.4	1.7	58.7
Jul	100.0	22.0	34.4	2.7	21.0	74.3	48.9	1.6	60.8
Aug	100.0	22.0	32.2	3.6	21.0	71.3	47.6	1.9	53.1
Sep	100.0	22.0	36.3	5.5	21.0	71.9	49.7	1.8	54.2
Oct	100.0	22.0	36.1	3.0	21.0	70.7	49.0	1.5	54.4
Nov	100.0	22.0	34.9	3.2	21.0	74.1	48.9	1.5	58.6
Dec	100.0	22.0	31.8	4.1	21.0	70.6	43.9	1.0	52.8
Month	**IN: Martin Marietta**	**PT: Winyah Station**	**WS: Lake Marion RWS**	**WS: St. Matthews**	**IN: Nucor**	**IN: CR Bard**	**Marion Diversion Canal**	**Moultrie Rediversion Canal**	**Santee Cooper (formerly Jeffries)**
Jan	100.0	85.0	69.2	32.0	81.8	7.4	0	0	100
Feb	100.0	85.0	62.4	25.4	71.2	4.9	0	0	100
Mar	100.0	85.0	66.0	28.9	76.5	3.7	0	0	100
Apr	100.0	85.0	65.7	34.5	73.4	2.2	0	0	100
May	100.0	85.0	71.5	32.3	68.5	4.0	0	0	100
Jun	100.0	85.0	67.1	34.4	67.1	8.0	0	0	100
Jul	100.0	85.0	74.8	44.0	60.9	2.0	0	0	100
Aug	100.0	76.5	73.5	37.9	50.1	2.4	0	0	100
Sep	100.0	76.5	62.6	36.2	64.3	4.7	0	0	100
Oct	100.0	76.5	69.6	38.0	62.1	3.6	0	0	100
Nov	100.0	68.0	74.3	34.0	79.0	3.6	0	0	100
Dec	100.0	76.5	71.3	28.9	73.3	7.0	0	0	100

Table 6-13. Baseline Model Monthly Return Flows for Discharge Objects

Monthly Return Flow (MGD)						
Month	Williamsburg Co	Pinewood Site	St. Stephen Power	Navy	SC Genco	Agg Discharge 1
Jan	0.3	1.2	0.1	28.7	0.4	0.8
Feb	0.4	2.4	0.1	24.6	1.0	0.7
Mar	0.4	1.3	0.2	21.8	0.6	1.2
Apr	0.3	2.0	0.2	19.3	0.5	1.0
May	0.3	0.6	0.2	18.0	0.4	1.3
Jun	0.4	1.1	0.2	20.4	0.7	1.2
Jul	0.4	2.0	0.2	28.2	0.9	1.4
Aug	0.4	1.1	0.2	24.9	1.1	1.3
Sep	0.4	1.1	0.1	28.2	0.9	1.1
Oct	0.4	0.8	0.1	22.6	0.5	1.4
Nov	0.3	0.9	0.1	23.9	0.4	1.1
Dec	0.4	1.0	0.1	22.9	0.4	1.1

Section 7

Model Calibration/Verification

7.1 Philosophy and Objectives

SWAM is a water allocation model that moves simulated water from upstream to downstream, combines flows at confluence points, routes water through reservoirs, and allocates water to a series of water user nodes. It is designed for applications at a river basin scale. In common with all water allocation models, neither rainfall-runoff, nor reach routing, are performed in SWAM. As such, the "calibration" process should be viewed differently compared to catchment or river hydrologic modeling.

The primary objective in the SWAM calibration process is to verify that the model accurately represents water availability throughout the basin by testing (individually and collectively) the ungaged flow estimates, the combination of flows, and the simulated water uses and management strategies. More specifically, the objectives include:

- extending the hydrologic input drivers of the model (headwater unimpaired flows) spatially downstream to adequately represent the unimpaired hydrology of the entire basin by incorporating hydrologic gains and losses below the headwaters;
- refining, as necessary and appropriate, a small number of other model parameter estimates within appropriate ranges of uncertainty, potentially including: reservoir operational rules, consumptive use percentages, and nonpoint (outdoor use) return flow locations; and
- gaining confidence in the model as a predictive tool by demonstrating its ability to adequately replicate past hydrologic conditions, operations, and water use.

In many ways, the exercise described here is more about model verification than true model calibration. The model parameterization is supported by a large set of known information and data – including tributary flows, drainage areas, water use and return data, and reservoir operating rules. These primary inputs are not changed during model calibration. In fact, only a small number of parameters are modified as part of this process. This is a key difference compared to hydrologic model calibration exercises, where a large number of parameters can be adjusted to achieve a desired modeled vs. measured fit. Because SWAM is a data-driven model and not a parametric reproduction of the physics that govern streamflow dynamics, care is taken so that observed data used to create model inputs are not altered. In calibrating SWAM, generally the primary parameters adjusted are reach gain/loss factors for select tributary objects. These factors capture ungaged flow gains associated with increasing drainage area with distance downstream. Flow gains through a subbasin are initially assumed to be linearly proportional to drainage area, in line with common ungaged flow estimation techniques. However, there is significant uncertainty in this assumption and it is therefore appropriate to adjust these factors, within a small range, as part of the model calibration process. These are often the only parameters changed in the model during calibration, though adjustments can also be made if needed to reservoir operating rules, consumptive use rates, and flow estimates in ungaged headwater basins. It is important to note that reservoir operating rules are simulated in the verification of the model in lieu of actual historic data on reservoir usage (which is built into the UIF datasets). This is to help ensure that the model has predictive strength for simulating the continuation of prescribed rules into the future, by demonstrating that the rules adequately reproduce historic reservoir dynamics.

Consideration also needs to be given to the accuracy of the measured or reported data that serve as key inputs to the model and are not adjusted as part of the calibration exercise. For example, historical water withdrawals are reported to DHEC by individual water users based on imperfect measurement or estimation techniques. Even larger errors may exist in the USGS flow gage data used to characterize headwater flows in the model. These errors are known to be upwards of 20% at some gages and under some conditions (USGS, http://wdr.water.usgs.gov/current/documentation.html). The uncertainty of model inputs merits consideration in the evaluation of model output accuracy.

Lastly, in considering the model calibration and verification, it is also important to keep in mind the ultimate objectives of the models. The final models are intended to support planning and permitting decision making. Planners will use the models to quantify impacts of future demand increases on water availability. For example, if basin municipal demands increase by 50%, how will that generally impact river flows and is there enough water to sustain that growth? Planners might also use the models to analyze alternative solutions to meeting projected growth, such as conservation, reservoir enlargement projects, and transbasin imports. With respect to permitting, regulators will look to the model to identify any potential water availability problems with new permit requests and to quantify the impacts of new or modified permits on downstream river flows. In other words, they will look to the model to answer the question of: if a new permit is granted, how will it impact downstream critical river flows and downstream existing users?

Given the methods and objectives described above, there is no expectation that downstream gaged flows, on a monthly or daily basis, will be replicated exactly. The lack of reach routing, in particular, limits the accuracy of the models at a daily timestep. Rather, the questions are only whether the representation of downstream flows is adequate for the model's intended purposes, key dynamics and operations of the river basin are generally captured (as measured by the frequency of various flow thresholds and reasonable representation of the timing and magnitude of the rise and fall of hydrographs), and whether the models will ultimately be useful as supporting tools for the State.

7.2 Methods

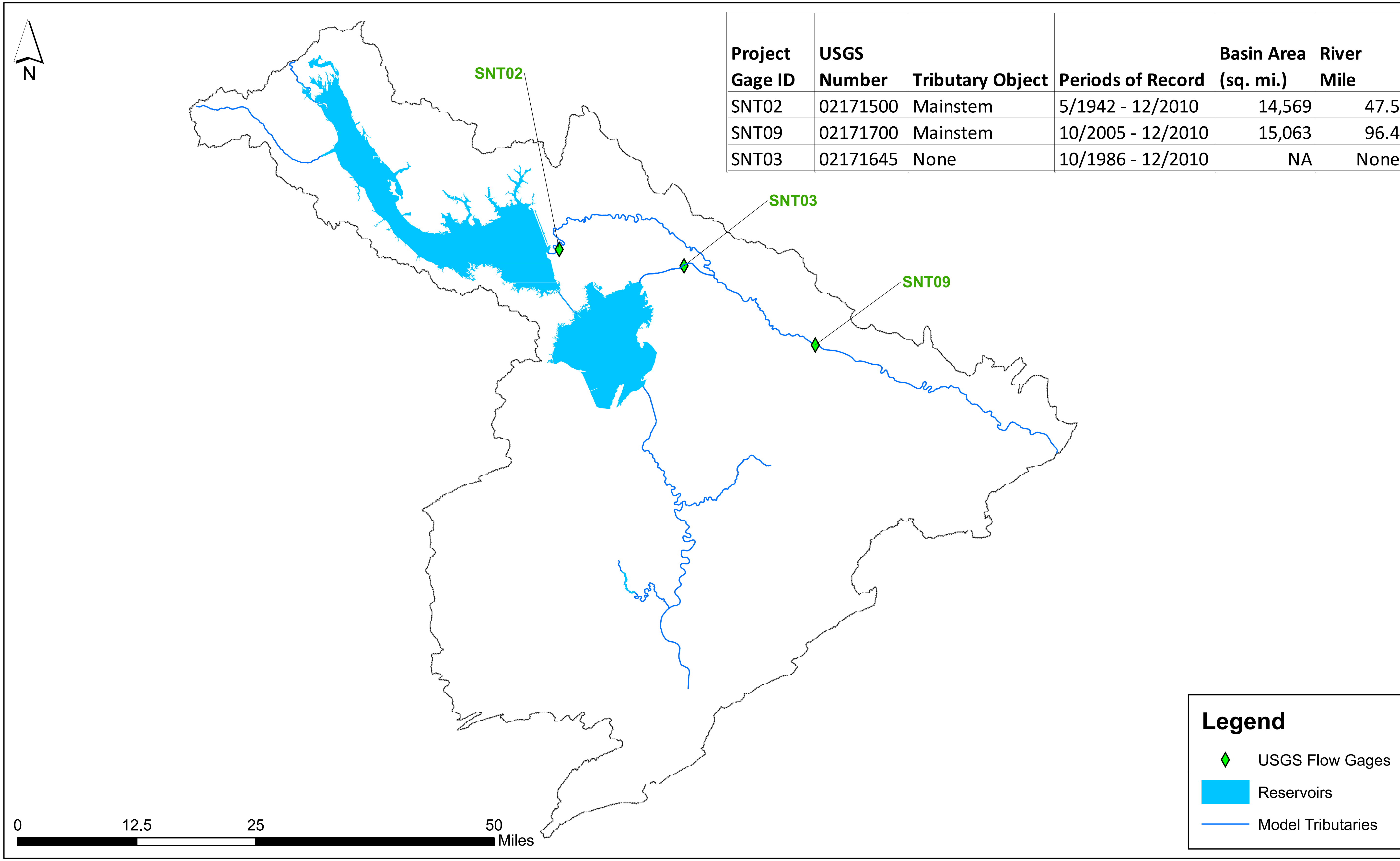
Model calibration in the Santee River Basin was performed over a period of historical hydrology from 1986 through 2010. Calibration was limited to 2010 because of its reliance on (high) flows from the Catawba-Wateree model. As noted in Section 6, headwater inputs to the Santee model, representing flow in the Wateree River, used gage data at low and medium flows. The most downstream gage on the Wateree does not record at high flows. Therefore, to fill in the gaps, the Catawba-Wateree model flows were used, which is limited to 2010 due to limitations of the Catawba-Wateree inflow dataset. Unlike other basin calibrations which extend back to 1983, the Santee was capped to 1986. This is due to the creation of the Rediversion Canal in 1985, which by enabling the transfer of flows from Lake Moultrie back to the Santee River, completely changed the dynamic of this basin's complex system of canals, reservoirs, and mainstem flows. This 24-year record provides a good range of hydrologic and climate variability in the basin, particular the drought years of 2007 and 2008. For the few available gages and Lakes Marion and Moultrie, modeled flows and reservoir storage/elevations were compared to measured flows and reservoir storage/elevations. Reservoir releases and targets reflect the recommendations from Santee Cooper's Final Environmental Impact Statement (FEIS).

7.2.1 Calibration Steps

The Santee River Basin's calibration was somewhat unique compared to previous basins. Other basins fundamentally are driven by natural hydrology, and as a result calibration is primarily focused on gains/losses and headwater flows. The Santee River Basin instead is governed by an artificial transfer of flows via canals that naturally would not have existed. For instance, the Cooper River used to be an independent and completely tidally-influenced river. With the creation of Lake Moultrie in its headwaters and connection to Lake Marion via the Diversion Canal, this system no longer was isolated and the nature of the Cooper River changed entirely. Guided by the principles described in Section 7.1, the following specific steps were followed, often iteratively, as part of this specific calibration/verification process:

1. Tributary headwater flows were extended to the tributary confluence points using drainage area ratios to calculate tributary object subbasin flow factors (see Section 6).
2. Reservoir storage targets and minimum releases for hydropower created the boundary conditions from which remaining available water can be transferred via canals (represented by Water User objects).
3. Demands for the Diversion and Rediversion Canal Water User objects were adjusted within the context of: A) preserving the historic fluctuations in the reservoirs set from Step (2), B) matching within reason the observed variability in gages affected by these transfers, and C) maintaining minimum instream flows required for fish in the Santee and Cooper Rivers.
4. Simulated reservoir operating rules were finalized based on monthly reservoir level modeled vs. measured comparisons and Step (3).
5. Intermediary subbasin flow factors were adjusted for tributary objects to achieve adequate modeled vs. measured comparisons at selected tributary gage targets, based on monthly timestep modeling.
6. Mainstem reach gain/loss factors (per unit length) were assessed to determine if adjustments were warranted to better achieve calibration at mainstem gage locations, based on monthly timestep modeling. For this model, no adjustments were justified, in part due to the limited number of gage locations.
7. The adequacy of the daily timestep model was verified by reviewing daily output once the monthly model was calibrated.
8. Lastly, all remaining water users in the model were checked to ensure that historical demands were being fully met in the model or, alternatively, if demands were not being met during certain periods, that there was a sensible explanation for the modeled shortfalls.

All USGS flow gages at downstream locations in the basin with reasonable records, not tidally-influenced, and within the targeted calibration period were used to assess model performance and guide the model calibration steps described above. The gages used for calibration are shown in **Figure 7-1**. Note that in order to minimize the uncertainty in the calibration targets, only gaged (i.e. measured) flow records were used to assess model performance as part of this exercise. No ungaged flow estimates or record filling techniques were used to supplement this data set (although many of



Project Gage ID	USGS Number	Tributary Object	Periods of Record	Basin Area (sq. mi.)	River Mile
SNT02	02171500	Mainstem	5/1942 - 12/2010	14,569	47.5
SNT09	02171700	Mainstem	10/2005 - 12/2010	15,063	96.4
SNT03	02171645	None	10/1986 - 12/2010	NA	None

CDM Smith

Figure 7-1
USGS Streamflow Gages Used in Calibration

the input flows were developed through various record extensions techniques). Note also that all upstream basin water use and operations are implicitly represented in these gaged data, thereby providing an ideal target to which the combination of estimated UIFs and historic water uses could be compared. Overall, only three streamflow gages were usable for the calibration. Though SNT09 is tidally-influenced, its reported data appears to have been filtered such that only non-influenced flows are reported, and is therefore applicable for calibration purposes. SNT07 (not depicted) on the Cooper River downstream of Lake Moultrie was tested as a possible calibration gage, as it is also only partially influenced by tides. However, this data still included tidally-influenced flows and the threshold at which releases from Moultrie overcame the influence were unclear. SNT03 is not technically on a model tributary object. Calibrating to this gage involves not comparing to modeled flows, but instead to modeled withdrawals for the **Moultrie Rediversion Canal** object, which are limited by releases from Lake Moultrie and minimum instream flows.

7.2.2 Reservoir Levels and Storage

In addition to the flow gages, reported historical reservoir levels and storage (where available) were also used as calibration/verification targets to a certain extent. In the Santee River Basin, several factors complicate the use of reservoir levels and storage as calibration targets, as described below:

- The model uses a static set of reservoir operating rules throughout the calibration period. In reality, reservoir level and storage fluctuations outside of predefined ranges often occur due to operator decisions that are not consistent with normal operating rules.
- The model also uses a static set of (current) reservoir characteristics throughout the calibration period (e.g., dam height). Modifications to dams, hydropower plants, bypass reaches, and spillways during the calibration period are not accounted for.

7.2.3 Calibration Parameters and Performance Metrics

As indicated above, options for model calibration parameters (i.e. those that are adjusted to achieve better modeled vs. measured matches) are limited to a small group of inputs with relatively high associated uncertainty. In general, these might include any of the following: mainstem hydrologic gain/loss factors, tributary subbasin flow factors, reservoir operational rules, assumed consumptive use percentages, and return flow locations and/or lag times associated with outdoor use. Normally, the primary calibration parameters in SWAM are the reach gain/loss factors and adjustments to other parameters are secondary and often not required. For the Santee Basin model calibration, subbasin flow factors were adjusted only to a limited extent as part of the calibration process and no gain/loss factor adjustments were made. The final model subbasin flow factors and gain/loss factors are presented in Section 6, **Table 6-3**.

A number of performance metrics were used to assess the model's ability to reproduce past basin hydrology and operations. These include: monthly and daily water user supply delivery and/or shortfalls; monthly and daily timeseries plots of both river flow and reservoir levels; annual and monthly mean flow values; monthly and daily percentile plots of river flow values; and mean flow values averaged over the entire period of record. As emphasized in the calibration sequence outlined in Section 7.2.1, the focus of calibration was on reproducing historic patterns of reservoir storage/elevation and achieving representative demands for the canal Water User objects such that historic variability is preserved while still maintaining predictive potential. The other calibration metrics can offer important context, but as this is no longer a strictly hydrologic calibration, cannot be construed with as much weight as in previous basins.

The reliability of past water supply to meet specific water user demands is an important consideration in the calibration process to ensure that water user demands and supply portfolios are properly represented in the model, as well as providing checks on supply availability at specific points of withdrawal. Timeseries plots, both monthly and daily, are used to assess the model's ability to simulate observed temporal variation and patterns in flow and storage data and to capture an appropriate range of high and low flow values. Percentile plots are useful for assessing the model's ability to reproduce the range of flows, including extreme events, observed in the past (and are particularly important when considering that the value of a long-term planning model like this is its ability to predict the frequency at which future flow thresholds might be exceeded, or the frequency that various amounts of water will be available). Monthly statistics provide valuable information on the model's ability to generally reproduce seasonal patterns, while annual totals and period of record mean flows help confirm the overall water balance represented in the model.

Assessment of performance and adequacy of calibration was primarily based on graphical comparisons (modeled vs. measured) of the metrics described above. It is our opinion that graphical results, in combination with sound engineering judgement, provide the most comprehensive view of model performance for this type of model. Reliance on specific statistical metrics can result in a skewed and/or shortsighted assessments of model performance. Ultimately, keeping in mind the philosophies and objectives described in Section 7.1, consideration was given as to whether the model calibration could be significantly improved with further parameter adjustments, given the limited calibration "knobs" available in the process. In actuality, a clear point of "diminishing returns" was reached whereby no significant improvements in performance could be achieved without either: a) adjusting parameters outside of their range of uncertainty or, b) constructing an overly prescriptive historical model that then becomes less useful for future predictive simulations. At this point, the calibration exercise was considered completed.

7.3 Results

Detailed monthly and daily model calibration results are provided in **Appendix A** and **B**, respectively. In general, a reasonable agreement between modeled and measured data is observed for all targeted sites, especially given the high uncertainty for this system. Discrepancies between modeled and measured flow data are generally within the reported range of uncertainty associated with the USGS flow data used to drive the models (5 – 20%) (USGS http://wdr.water.usgs.gov/current/documentation.html). Record quality of specific streamflow gages are discussed below.[1] Seasonal and annual patterns in both flow and reservoir storage data are reproduced well by the model. Monthly fluctuations (timeseries) and extreme conditions (percentiles) are also well reproduced by the model for most sites. Modeled vs. measured cumulative flow over the entire calibration period was compared at select sites to confirm that there was not an overall bias toward too high or too low of flows. Though there is a slight over-prediction at SNT03 and under-prediction at SNT02, two things must be kept in consideration: 1) these accumulations reflect static reservoir storage rules and Water User demands, which would have varied historically, and 2) are over the years 1986 – 2010 and this metric demonstrates notable sensitivity to selection of years. The spatial and temporal availability of gage records is more limited compared to other basins (such as the Broad River Basin) however. Of the three gages used in calibration, only SNT02 and SNT03 had more than 10 years of data.

[1] Gage quality reports from 2006 to 2013 can be found at http://wdr.water.usgs.gov/allsearch.php and 1999 to 2004 can be found at http://pubs.usgs.gov/wdr/wdr_sc/scAARindex.html.

Table 7-1 contains modeled and measured averages over the full period of record, along with the available number of years for comparison. For two of the three gages, modeled mean flow values were within 2% of measured mean flows, and the remaining gage (which includes tidally filtered flows) was within 10% of measured mean flows. This indicates that the overall water balance is well represented and there are no obvious missing or excess sources of flow in the model. Monthly flow percentiles should be interpreted cautiously as modeled results at these gages heavily reflect static reservoir rules and Water User demands, and not natural hydrology. Because of this, middle-range percentiles are well-reproduced but there is high uncertainty on the extreme ends. SNT02 in particular is difficult to capture as it has two flow regimes—either a base release of around 600 cfs or an extremely high and infrequent release to pass large flows.

Table 7-1. Annual Flow Statistics

Project ID	Station	Modeled Average	Measured Average	% Diff Average	Years of Record
SNT03	REDIV CANAL AT SANTEE RIVER NR ST STEPHEN, SC	7,779	7,697	1.1%	25
SNT02	SANTEE RIVER NEAR PINEVILLE, SC	1,574	1,605	-1.9%	28
SNT09	SANTEE RIVER NR JAMESTOWN, SC	6,409	5,814	10.2%	6

Monthly reservoir storage and level comparisons, while clearly simplified due to the static assumptions (rules) incorporated into the model, were aimed at achieving the specified targets, and not necessarily reproducing exact dynamic responses to historic withdrawal rates. Given these static rules, Lakes Marion and Moultrie reproduce years in which storage targets were followed and most importantly, capture the drawdowns observed in the drought years of 2007-2008. Some of the differences in observed and simulated reservoir levels are attributed to anomalies in reservoir operations associated with reservoir maintenance, or other non-routine activities. Other differences are attributed to the fact that the simulated reservoirs were governed by rules and targets that, while often achievable in the model, may have been subject to other operational decisions or constraints that are not represented.

Lastly, a key difference between some of the observed and simulated reservoir storage amounts/elevations is the amount of water in the flood pool. SWAM allows water to accumulate in the flood pool, and then releases water in accordance with spillway rating curves. However, in the absence of precise and credible rating curves, it is common practice in water availability modeling to simply assume that all water above a spillway will spill in a timestep. This is a reasonable assumption at a monthly timestep. At a daily timestep, it can cause a slight shift in some of the highest flows, but this generally does not deter from any long-term simulation of water availability. All the model reservoirs simulated in a way that caps the reservoir capacity at the spillway elevation, and any excess water is assumed to spill in one timestep. If downstream flows are found to be overly skewed because of this simplification, it can be adjusted to meter flood water out in accordance with estimated rating curves, but to date, this has not appeared to be necessary.

In terms of daily timestep simulations, daily flow fluctuations are generally well captured by the model. As mentioned above, SNT02 has two flow regimes of either approximately 600 cfs or extremely high flows. In many cases, the model tends to over-represent these high flows. This can be attributed to the fixed demands of the **Marion Diversion Canal** object, which essentially caps how much can be transferred to Lake Moultrie, leaving the remaining high flows to continue down the Santee River. For SNT03, without doing a prescriptive exercise, the best that can be achieved via the **Moultrie Rediversion Canal** object is representing range and general pattern for the transfer of flows through the Rediversion Canal. Despite these uncertainties, the downstream hydrograph at SNT09 depicting all these transfers still maintains a reasonable representation of observed gage flows. The discussion from monthly percentiles plots also applies for the daily percentile plots—certain flow regimes will be over- or -under-represented with static reservoir rules and demands.

Additionally, the model adequately hindcasts delivered water supply for each of the permitted/registered water users in the model. Simulated supply roughly equals simulated demand for most users, with no significant shortfalls. Except of course, the two canal objects **Marion Diversion Canal** and **Moultrie Rediversion Canal**, which are designed to have shortages; otherwise, always meeting their full demands would result in not replicating observed variability in Lake Moultrie and downstream gages. One user is impacted by this exchange—**Santee Cooper (formerly Jeffries)**. As it is downstream of the modeled effects of the Rediversion Canal, when **Moultrie Rediversion Canal** draws too much water and/or has a shortage, so will this user.

Section 8

User Guidelines for the Baseline Model

The baseline Santee River Basin Model will be located on a cloud-based server which can be accessed using a virtual desktop approach. Interested stakeholders will be provided access to the model by DNR and/or DHEC upon completion of a model training course. Current plans are for training to be offered to stakeholders once the models for all eight river basins are completed.

This model will be useful for the following types of scenarios:

- Comparison of water availability resulting from managed flow (future or current) to unimpaired flow throughout the basin.
- Comparison of current use patterns to fully permitted use of the allocated water (or any potential future demand level), and resulting flow throughout the river network.
- Evaluation of new withdrawal and discharge permits, and associated minimum streamflow requirements.
- Alternative management strategies for basin planning activities.

Given the lack of flow gages on the Cooper River for which to calibrate the model, the model user must understand that a higher level of uncertainty exists with regard to modeled flows on the Cooper, compared to other reaches of the model. Similarly, on the Santee River, from the SNT09 gage to the coast (which is tidally influenced), there is no historical flow information to support adjustment of subbasin flow factors, and no calibration targets. In these two reaches, known and significant withdrawals and discharges are included, but no effort was made to validate the model, other than confirming that no significant shortfalls were present in historical withdrawals.

Users will also be able to change the duration of a model run in order to focus on specific years or hydrologic conditions. For example, the default model will run on a daily or monthly time step from 1951 through 2010 in order to test scenarios over the full historic period of recorded hydrologic conditions. In some cases, though, it may be useful to compile output over just the period corresponding to the drought of record, or an unusually wet period.

Since the model begins at the confluence of the Congaree and Wateree Rivers, any predictive exercise requires model output from the respective Saluda and Catawba-Wateree SWAM models. The user may have the option to run these models in conjunction and be responsible for carrying over the output, or different scenarios may already be made available for common scenarios (e.g., incorporating projected 50-year demands).

Flow conditions can also be changed by the user, though it will be important for the user to understand implications when unimpaired flows (naturalized flows) are replaced with other time series.

Regardless of the type of scenario to be run, it is important to understand how to interpret the output. Whether running long-duration or short-duration runs, the output of the model will represent time series of flows, reservoir levels, and water uses. As such, the results can be interpreted by how frequently flow or reservoir levels are above or below certain thresholds, or how often demands are satisfied. This frequency, when extrapolated into future use, can then be translated into probabilities of occurrence in the future. It will be the user's responsibility to manipulate the output to present appropriate interpretations for the questions being asked, as illustrated in the following example:

> *Example: For a 10-year model run over a dry historic decade, a user is interested in knowing the frequency that a reservoir drops below a certain pool elevation. Results indicate that under current demand patterns, the reservoir will drop below this threshold in one month out of the ten years. Under future demand projections (modified by the user), the results indicate that the reservoir will drop below this threshold in six months during the driest of the ten years. If the results are presented annually, both scenarios would be the same: a 10% probability of dropping below that level in any given year. If they are presented monthly, they will, of course, be different. Depending on the nature of the question, it will be important for users to be aware of how output can be used, interpreted, and misinterpreted.*

Further guidance on use of the Model is provided in the *Simplified Water Allocation Model (SWAM) User's Manual Version 4.0* (CDM Smith, 2016). The User's Guide provides a description of the model objects, inputs, and outputs and provides guidelines for their use. A technical documentation section is included which provides detailed descriptions of the fundamental equations and algorithms used in SWAM.

Section 9

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Appendix A

Santee River Basin Model Monthly Calibration Results

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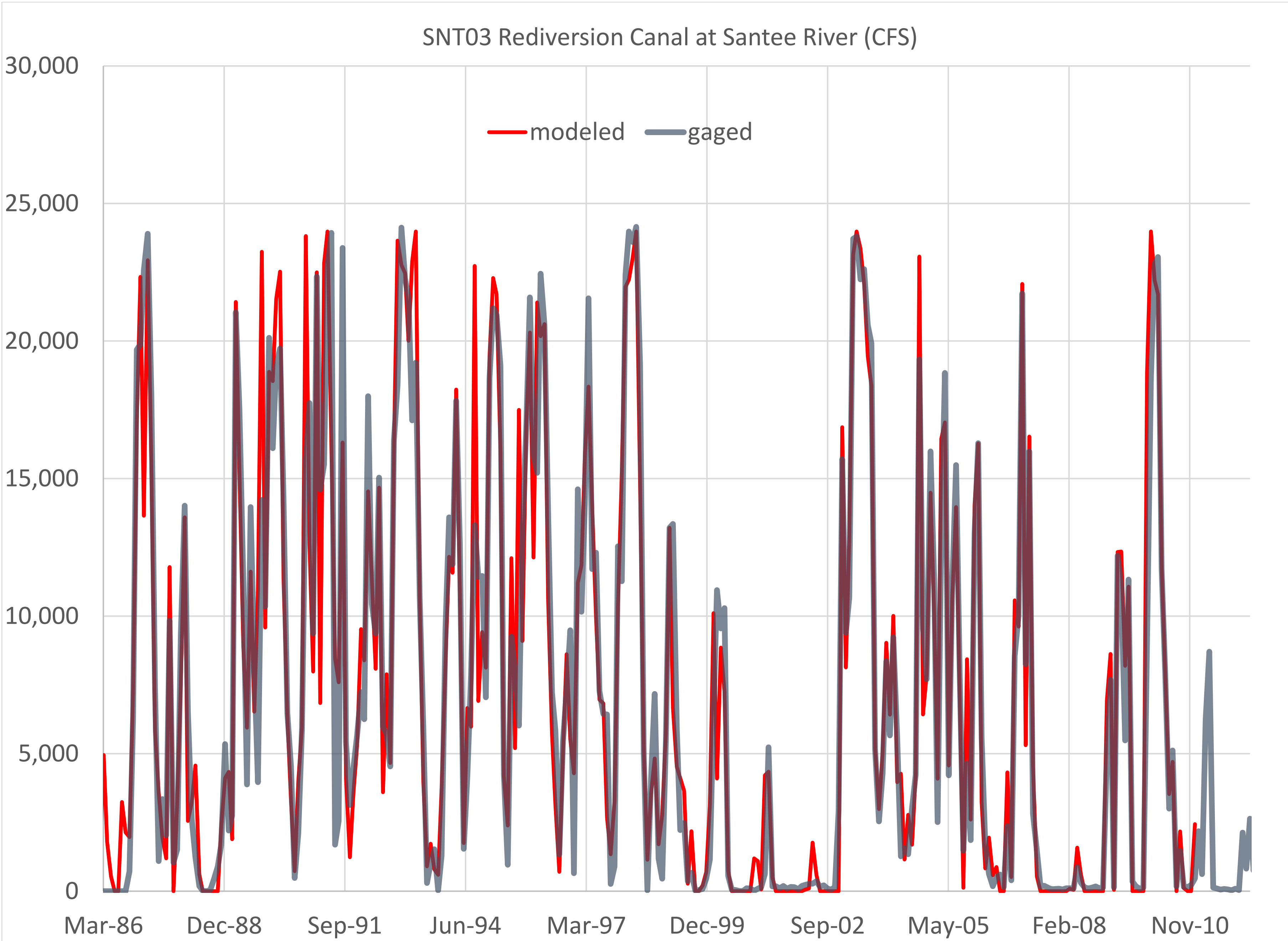
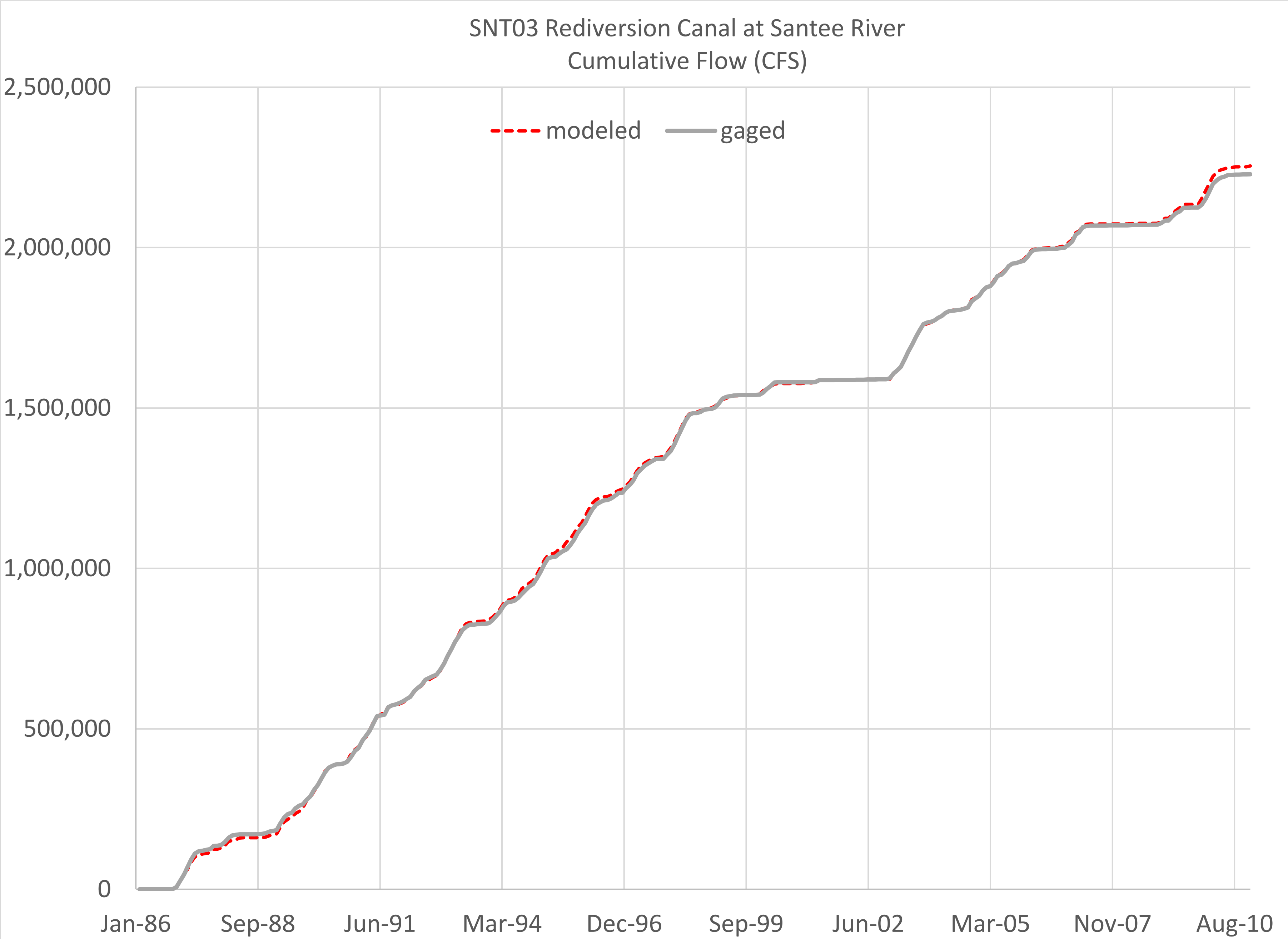
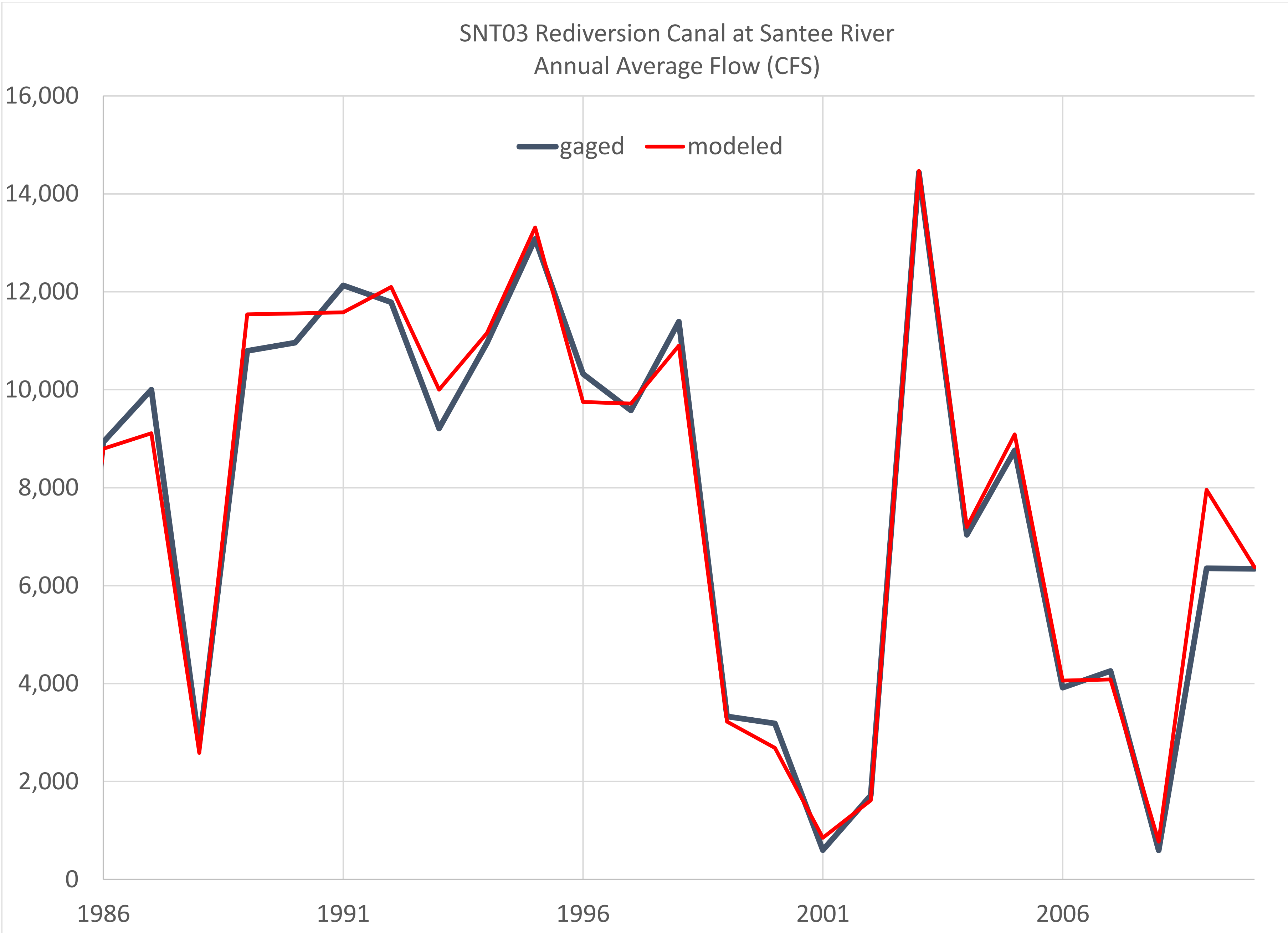
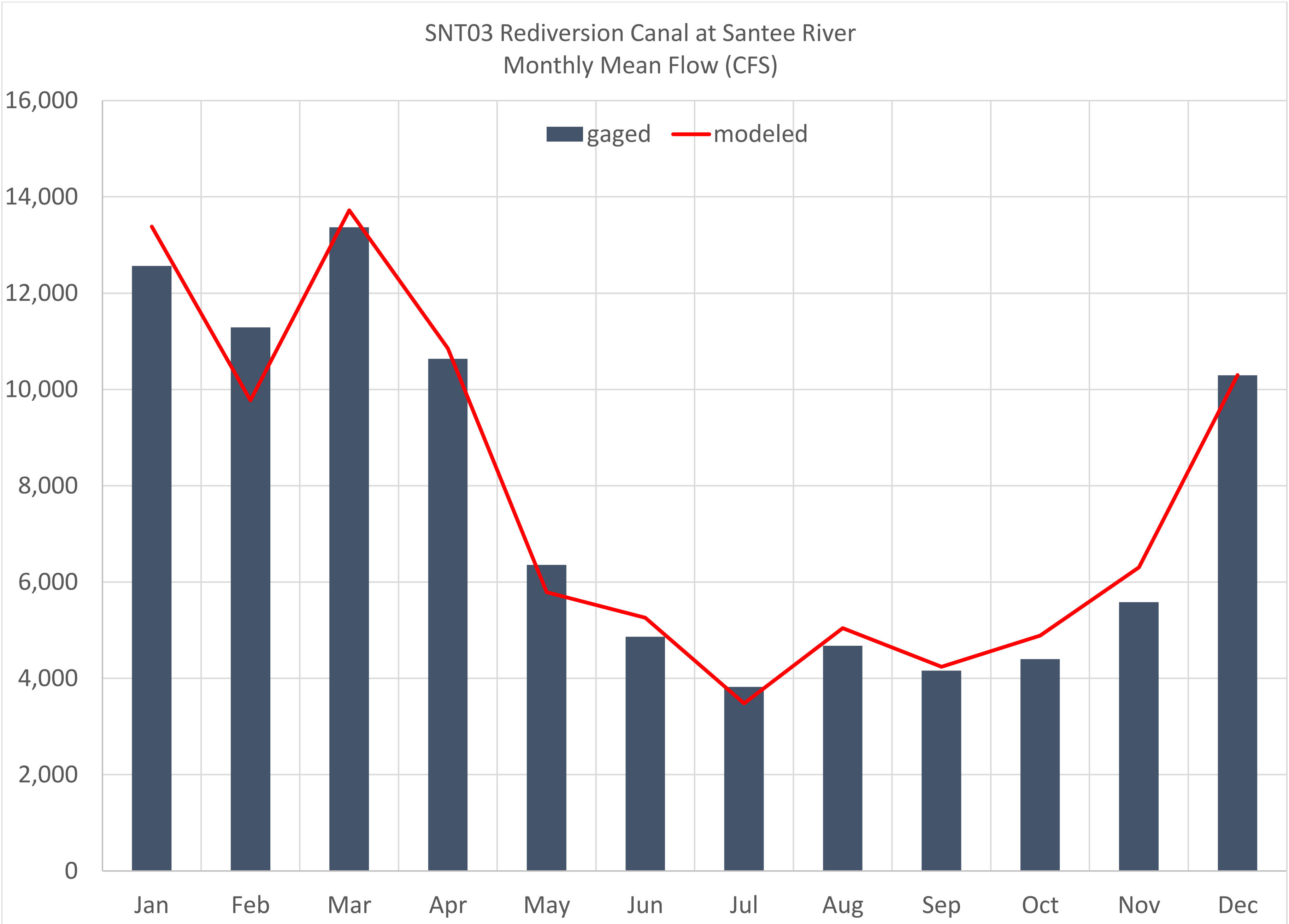
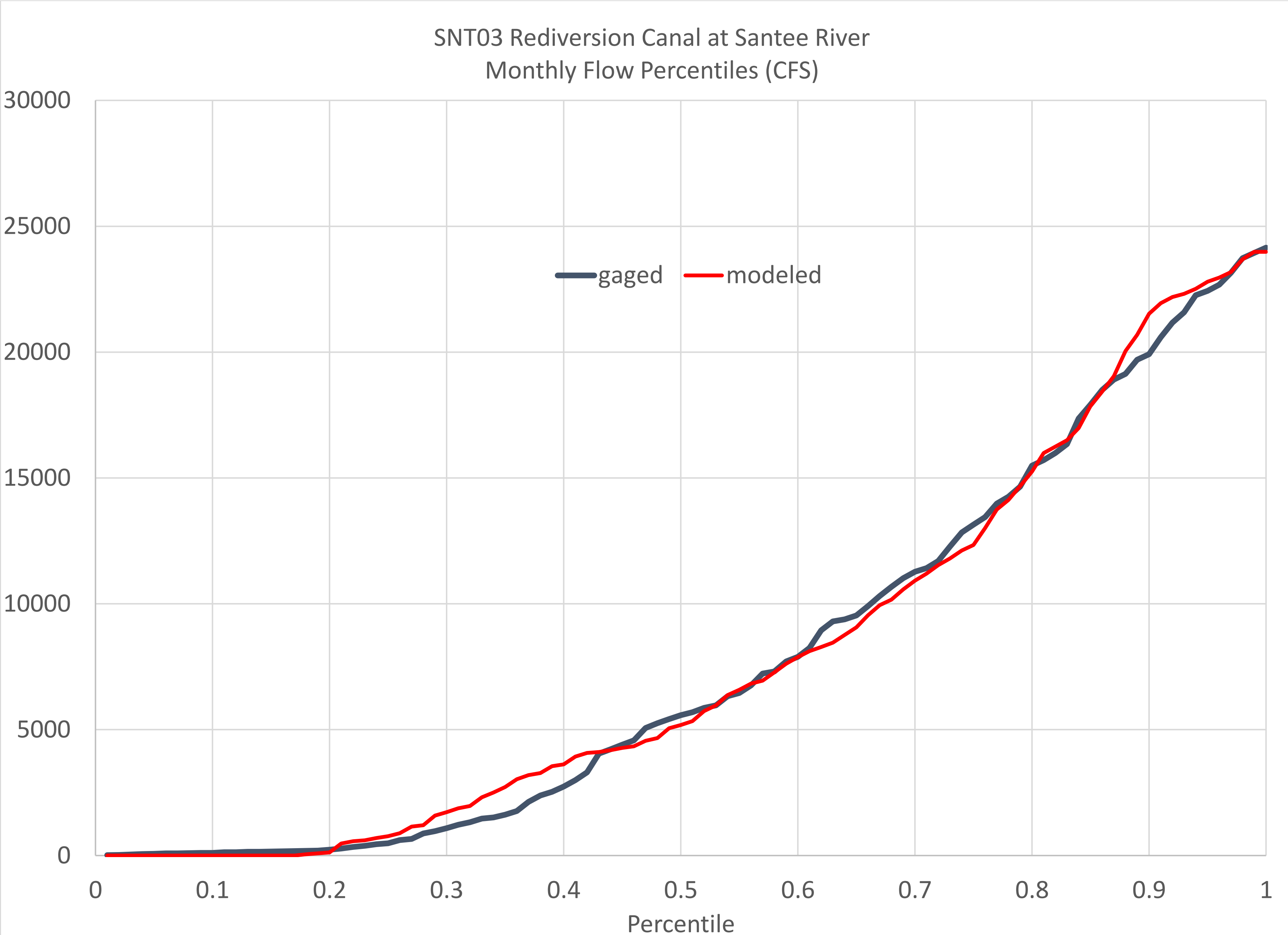

SNT03 Rediversion Canal at Santee River (CFS)
modeled
gaged
30,000
25,000
20,000
15,000
10,000
5,000
0
Mar-86
Dec-88
Sep-91
Jun-94
Mar-97
Dec-99
Sep-02
May-05
Feb-08
Nov-10

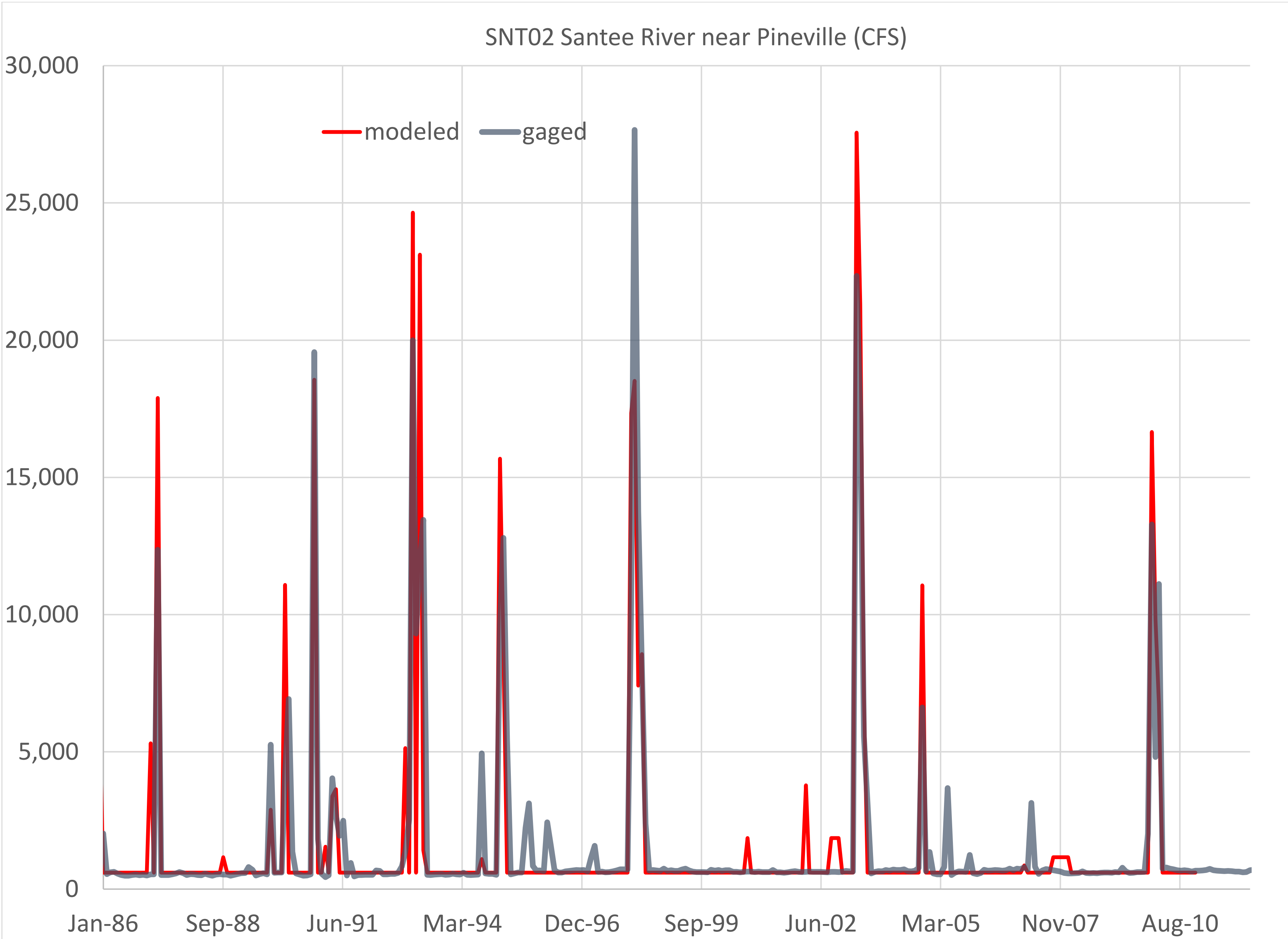

SNT03 Rediversion Canal at Santee River
Cumulative Flow (CFS)
modeled
gaged
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
Jan-86
Sep-88
Jun-91
Mar-94
Dec-96
Sep-99
Jun-02
Mar-05
Nov-07
Aug-10

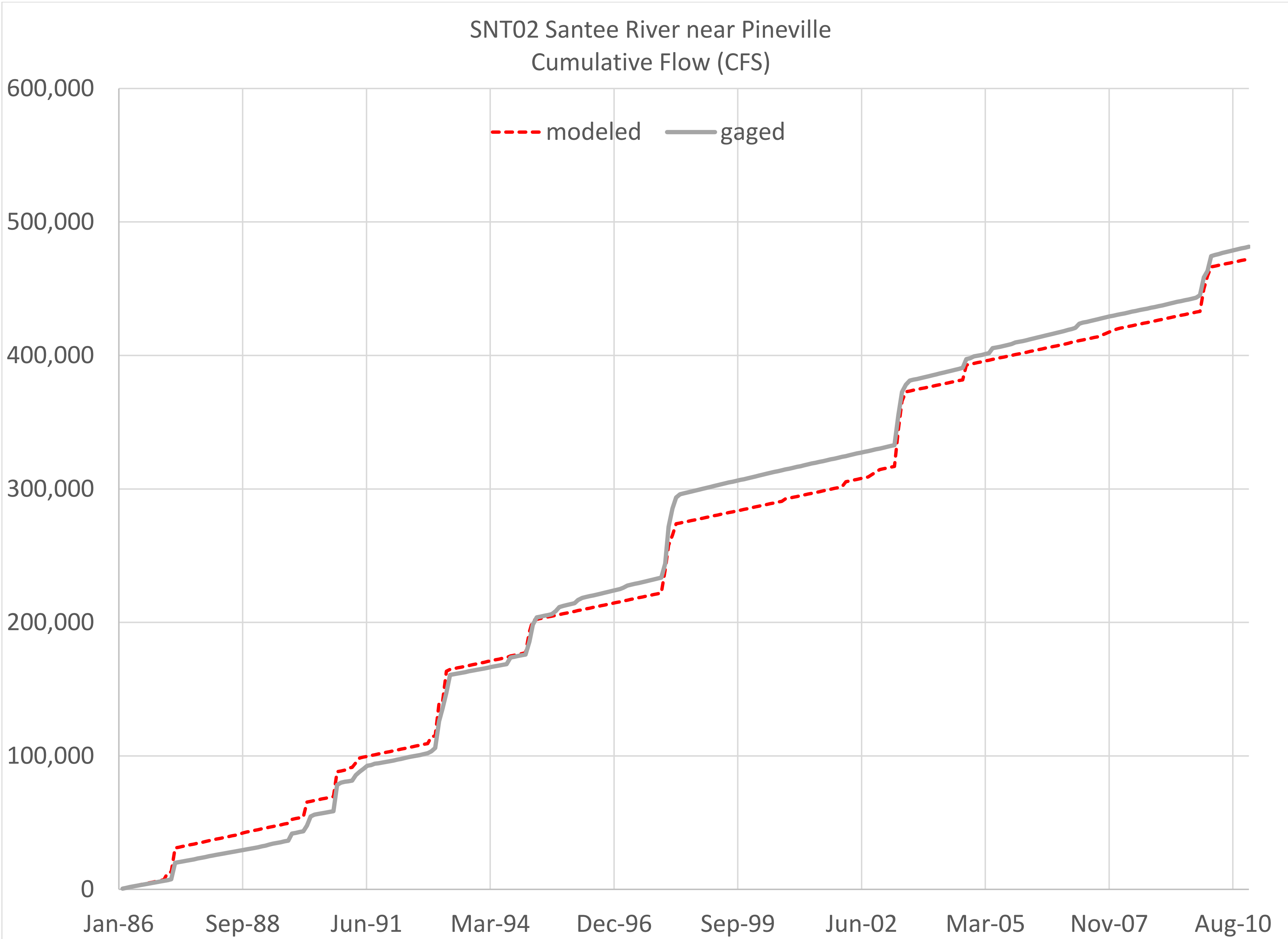


SNT03 Rediversion Canal at Santee River
Annual Average Flow (CFS)
gaged
modeled
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1986
1991
1996
2001
2006

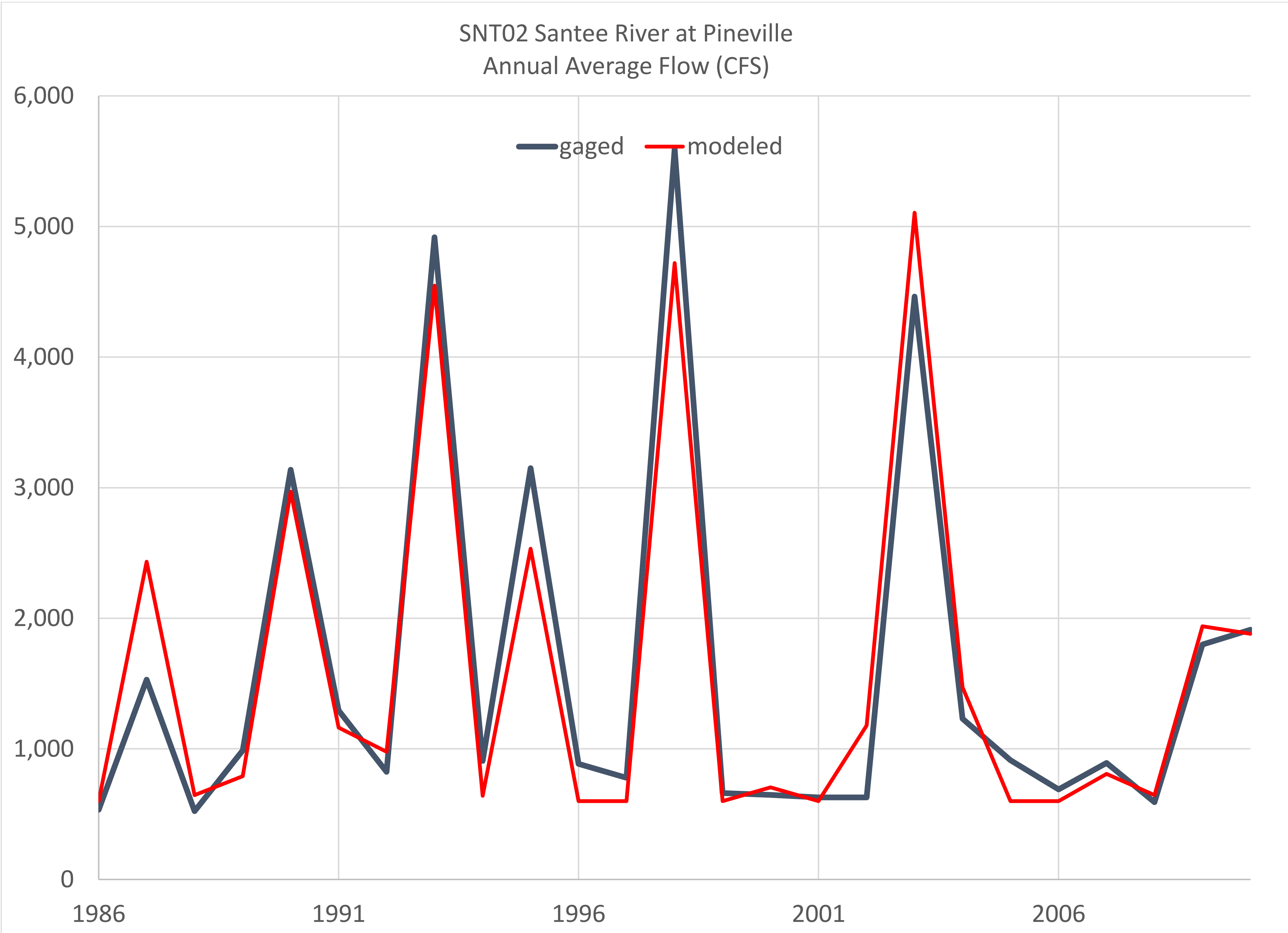

SNT03 Rediversion Canal at Santee River
Monthly Mean Flow (CFS)
gaged
modeled
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

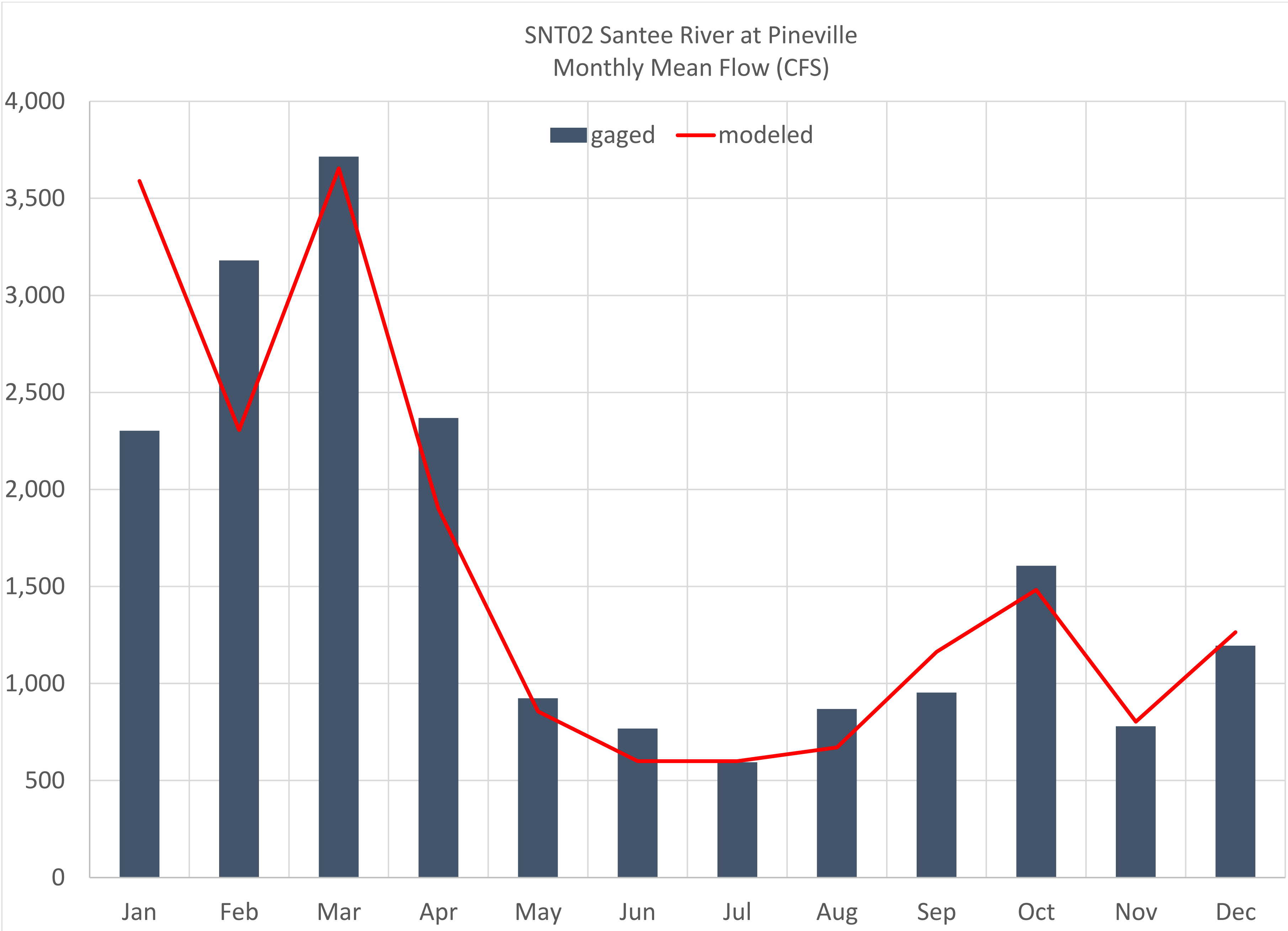

SNT03 Rediversion Canal at Santee River
Monthly Flow Percentiles (CFS)
30000
25000
20000
15000
10000
5000
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile
gaged
modeled

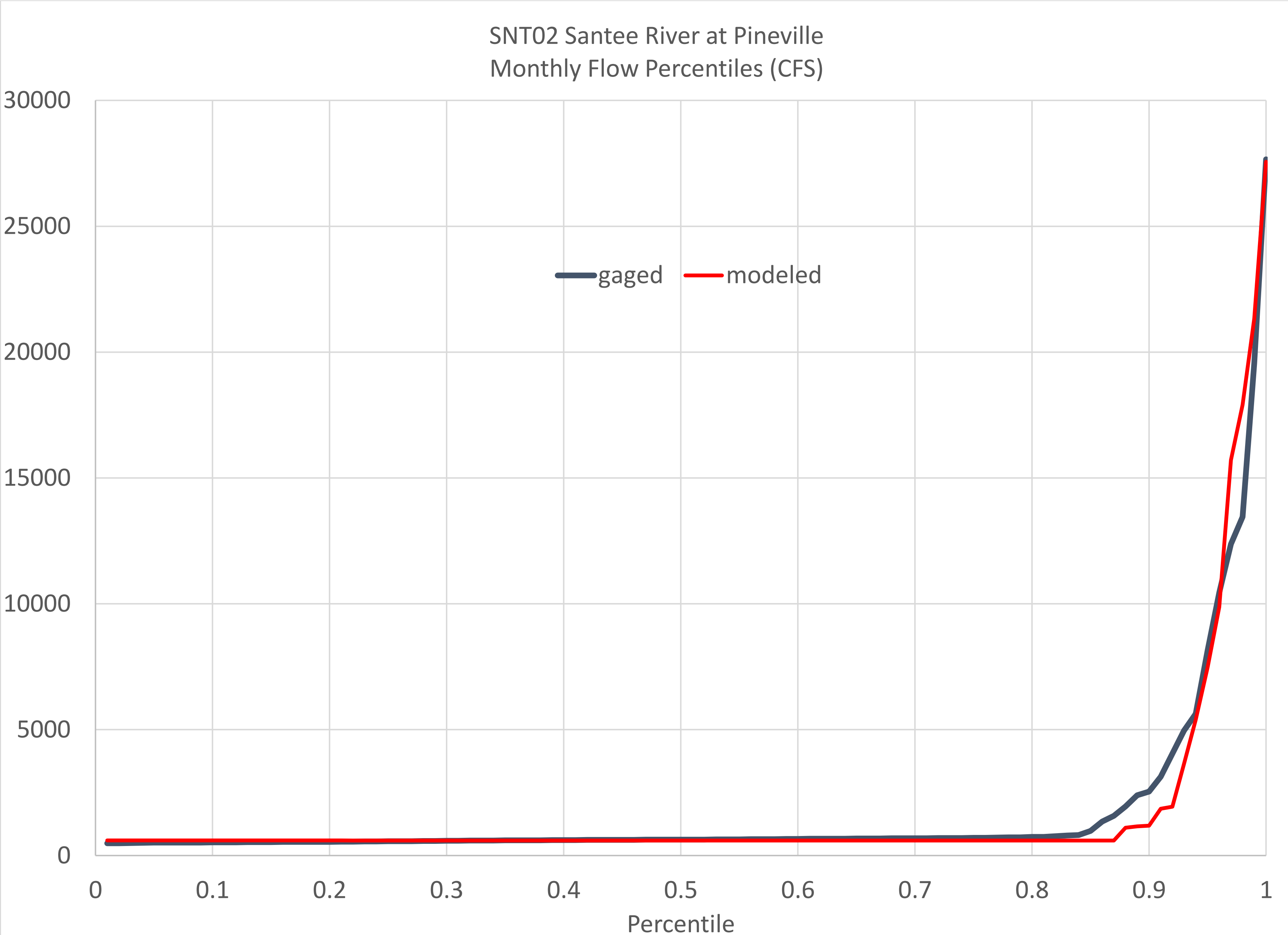

SNT02 Santee River near Pineville (CFS)
modeled
gaged
30,000
25,000
20,000
15,000
10,000
5,000
0
Jan-86
Sep-88
Jun-91
Mar-94
Dec-96
Sep-99
Jun-02
Mar-05
Nov-07
Aug-10



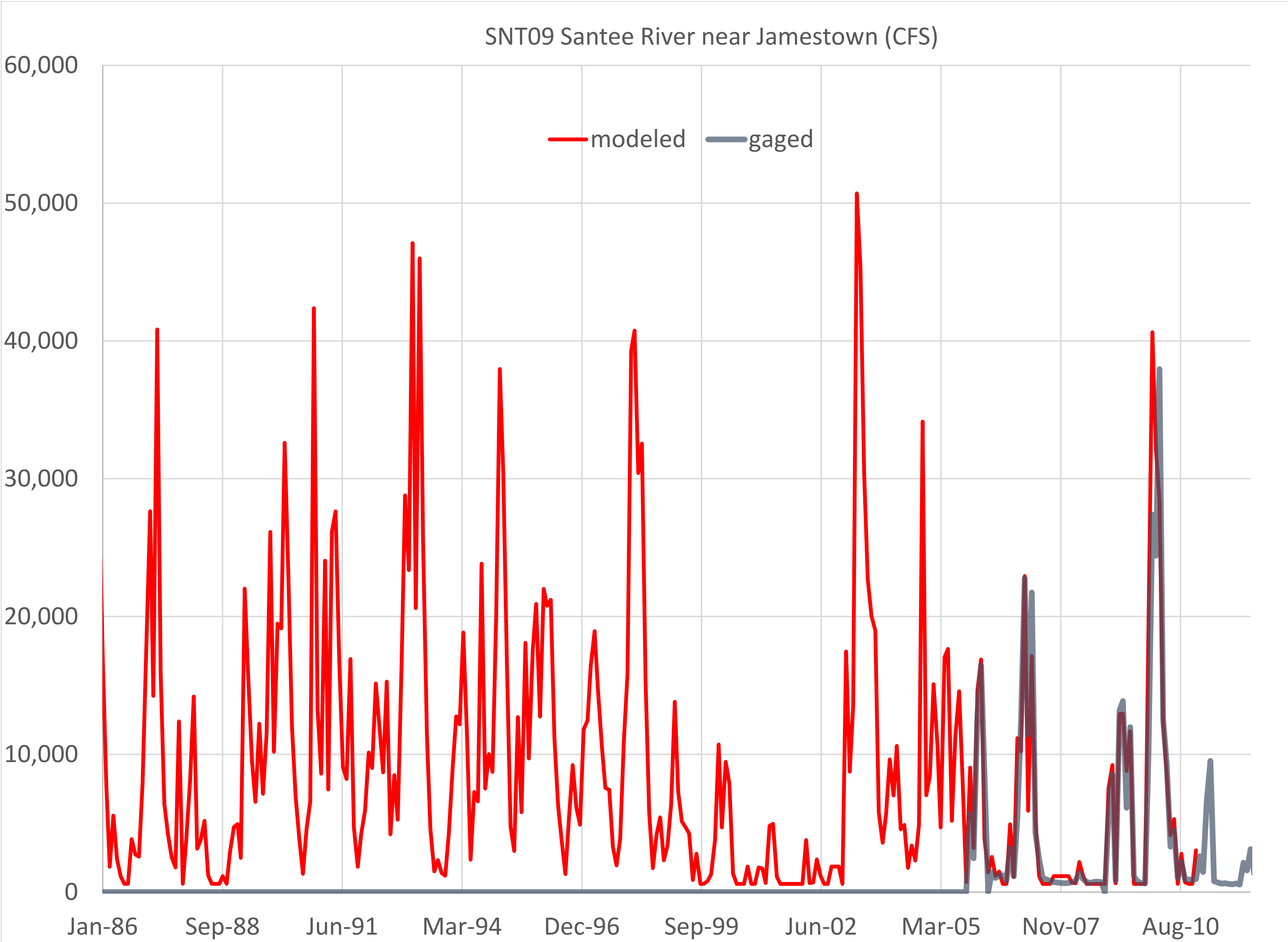
SNT02 Santee River near Pineville
Cumulative Flow (CFS)
modeled
gaged
600,000
500,000
400,000
300,000
200,000
100,000
0
Jan-86
Sep-88
Jun-91
Mar-94
Dec-96
Sep-99
Jun-02
Mar-05
Nov-07
Aug-10


SNT02 Santee River at Pineville
Annual Average Flow (CFS)
gaged
modeled
6,000
5,000
4,000
3,000
2,000
1,000
0
1986
1991
1996
2001
2006

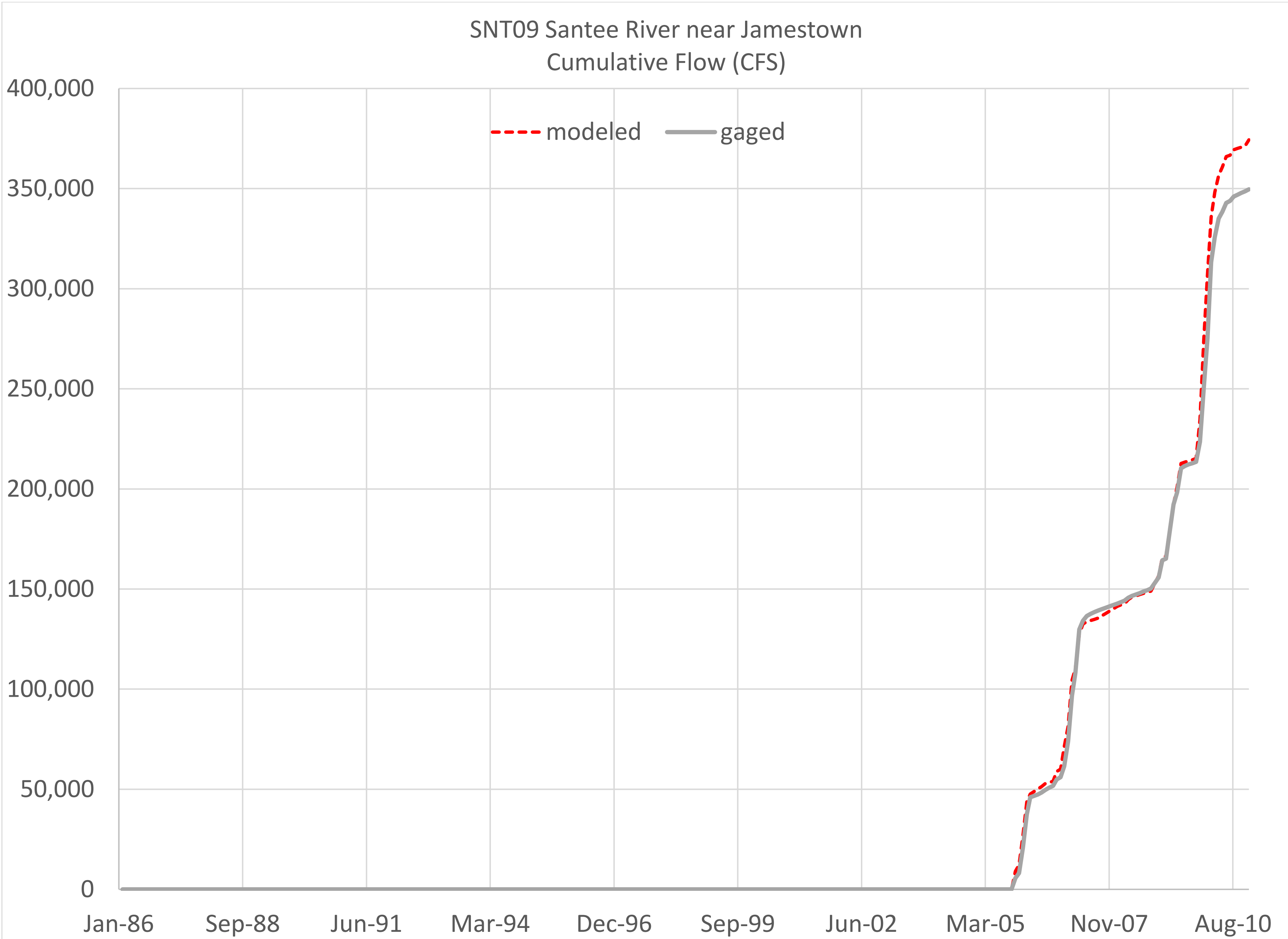

SNT02 Santee River at Pineville
Monthly Mean Flow (CFS)
gaged
modeled
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec



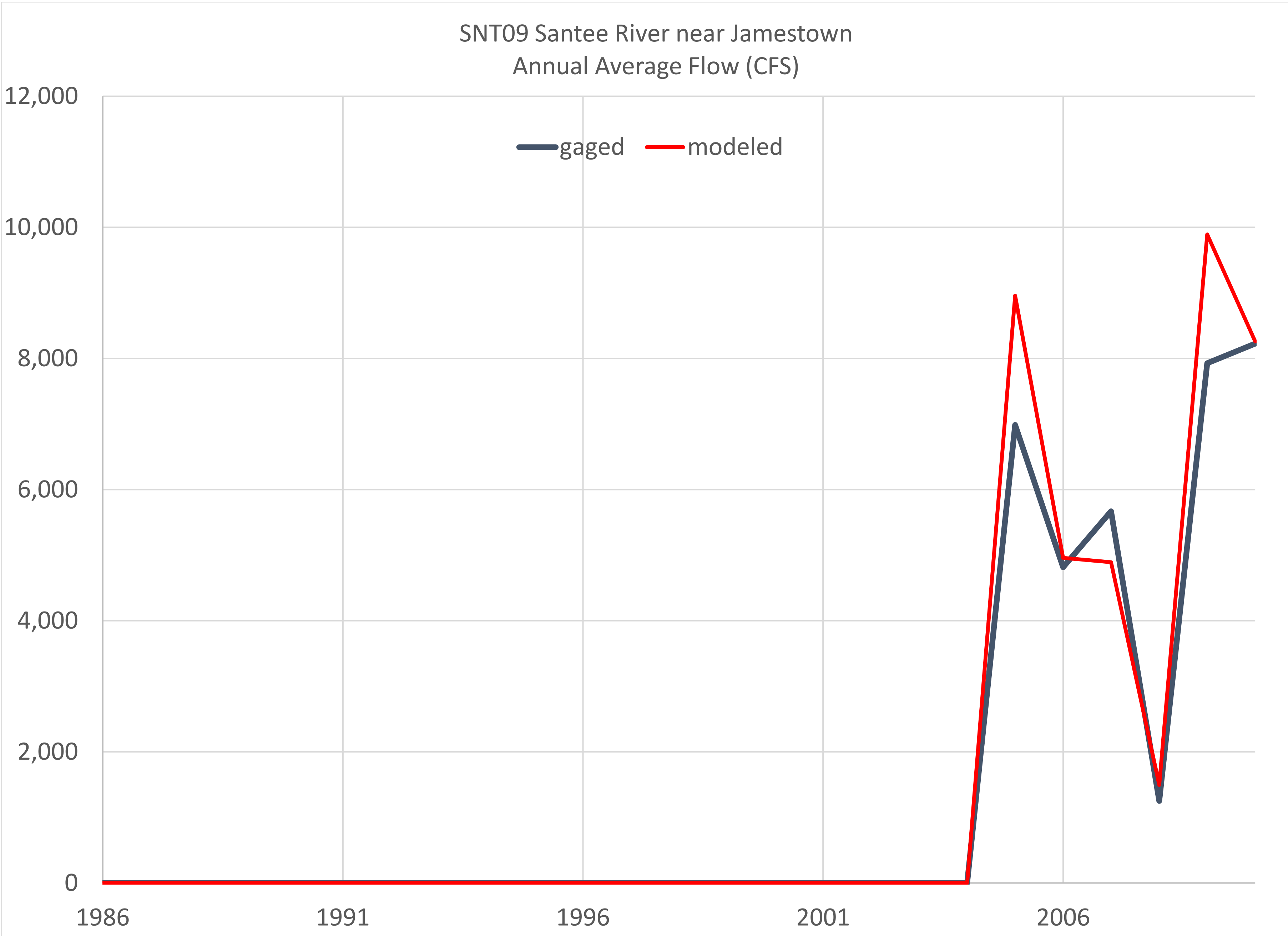
SNT02 Santee River at Pineville
Monthly Flow Percentiles (CFS)
30000
25000
20000
15000
10000
5000
0
gaged
modeled
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile



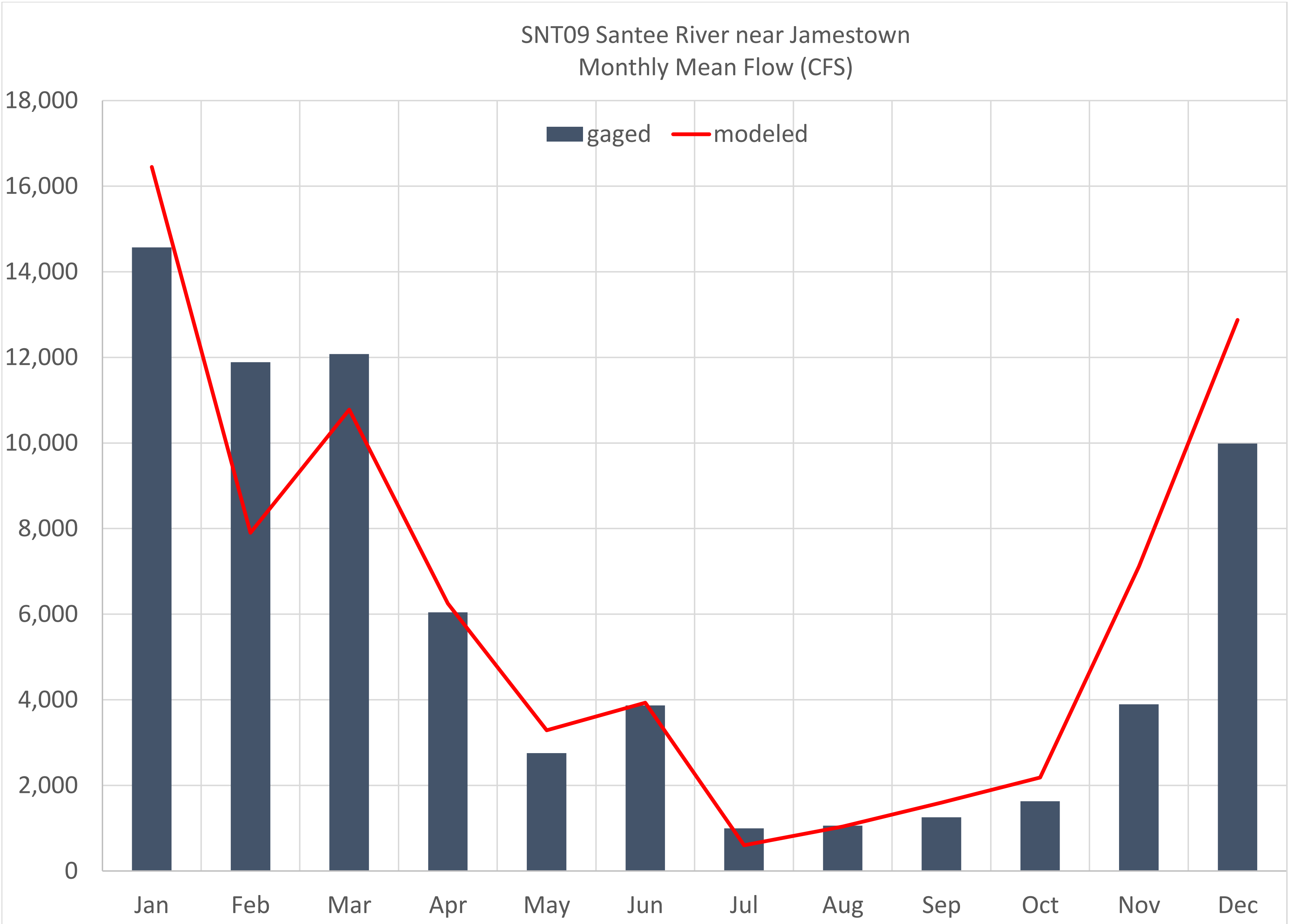
SNT09 Santee River near Jamestown (CFS)
modeled
gaged
60,000
50,000
40,000
30,000
20,000
10,000
0
Jan-86
Sep-88
Jun-91
Mar-94
Dec-96
Sep-99
Jun-02
Mar-05
Nov-07
Aug-10

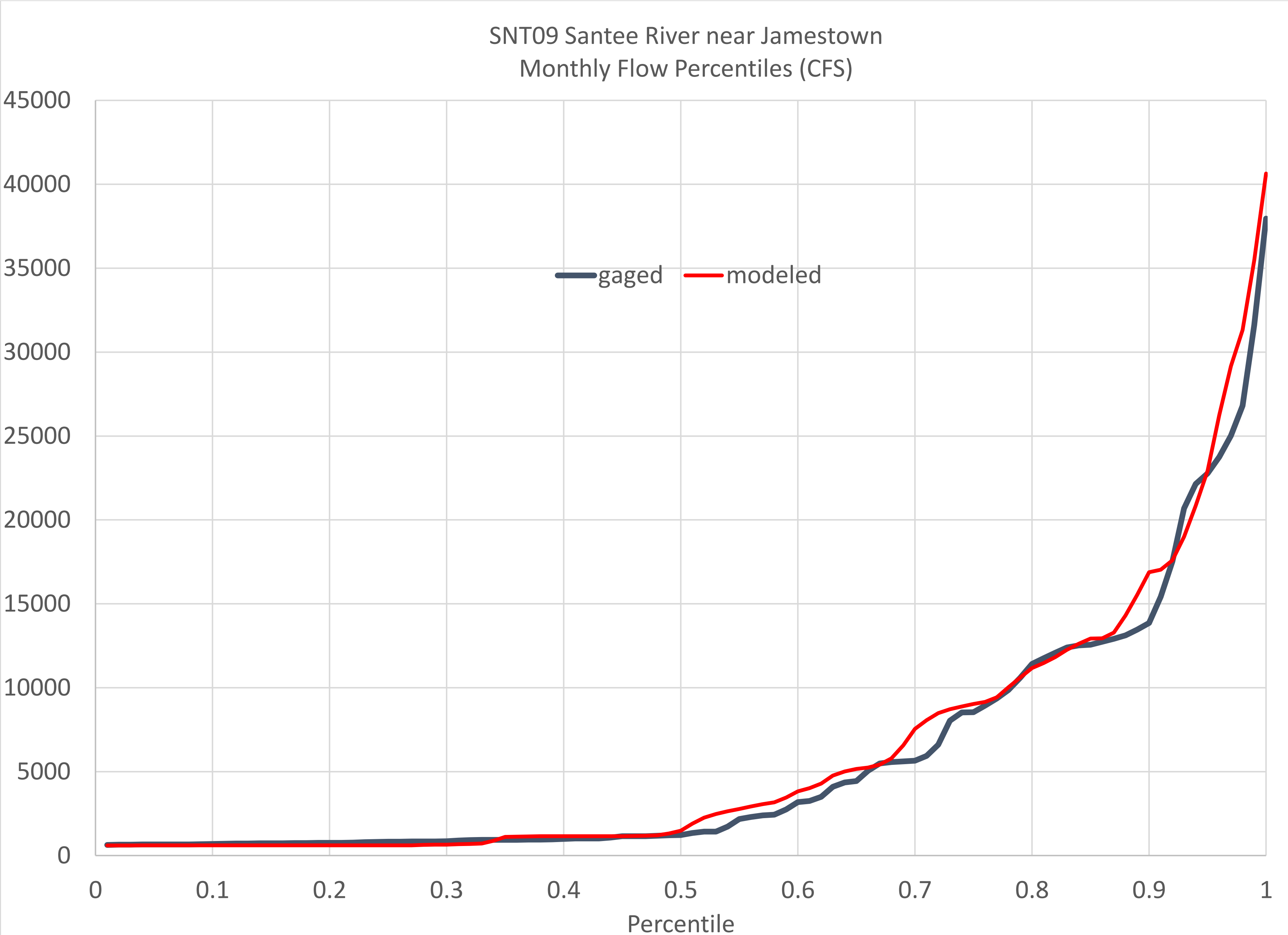


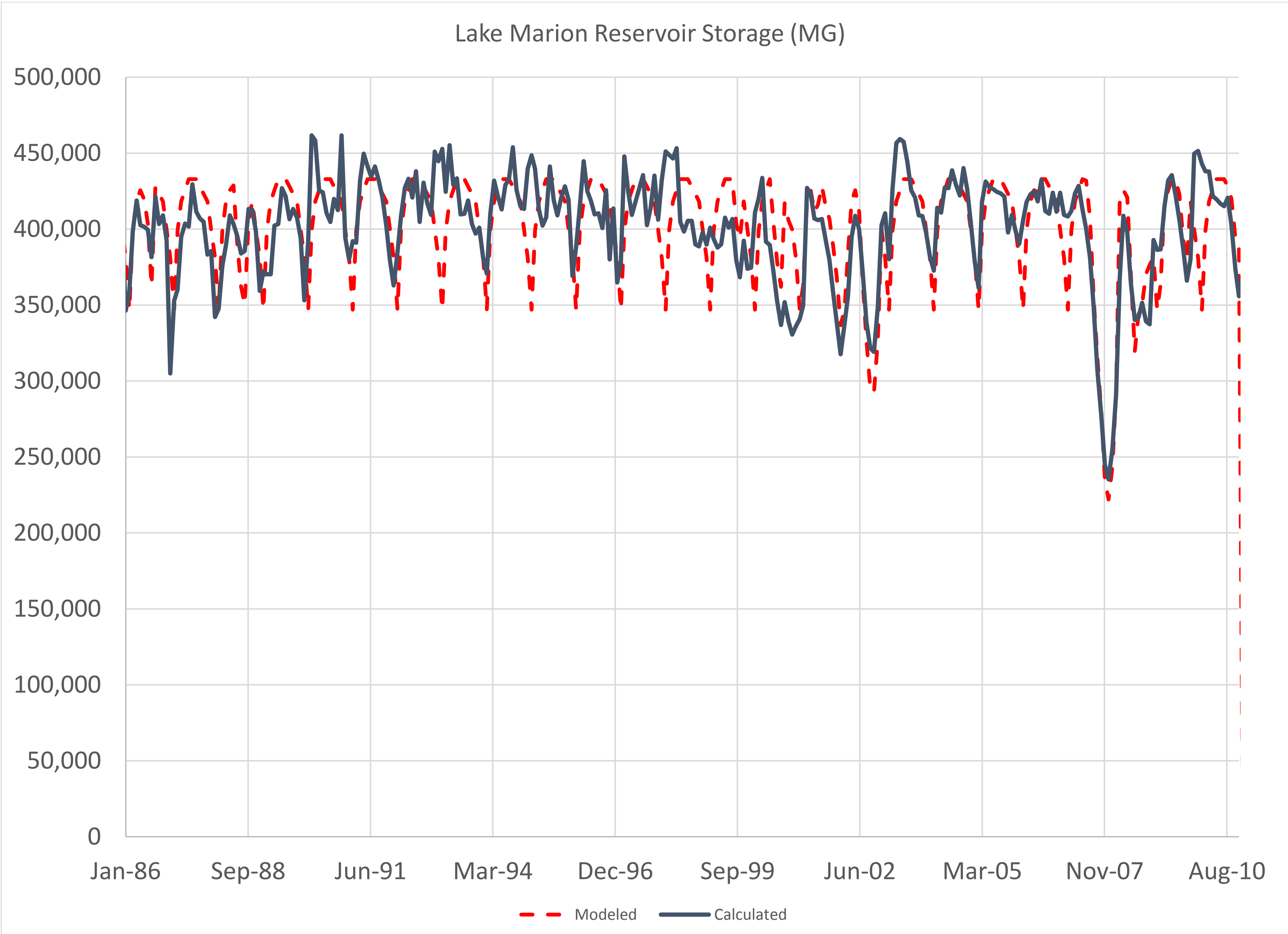
SNT09 Santee River near Jamestown
Cumulative Flow (CFS)
modeled
gaged
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
Jan-86
Sep-88
Jun-91
Mar-94
Dec-96
Sep-99
Jun-02
Mar-05
Nov-07
Aug-10



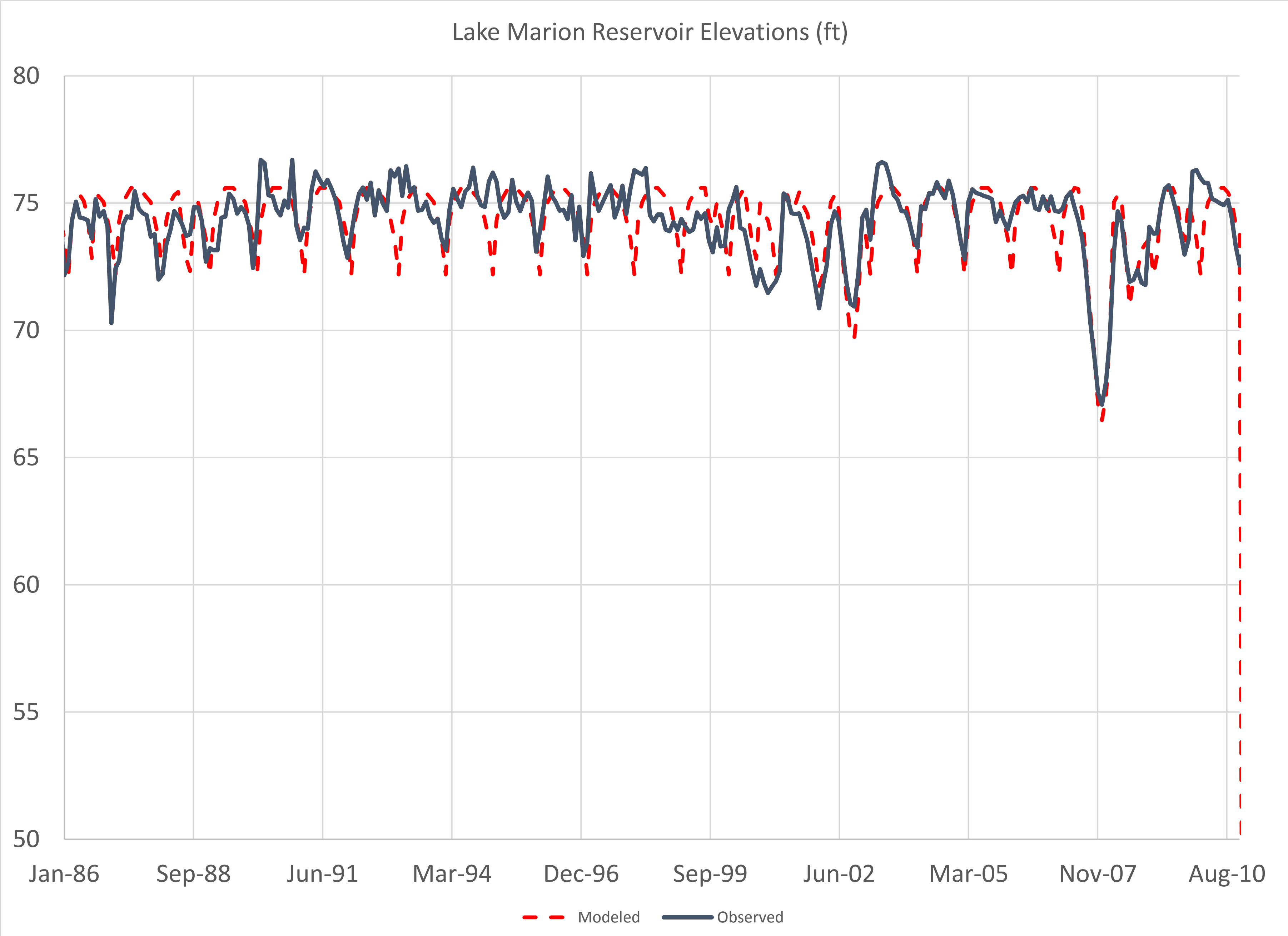
SNT09 Santee River near Jamestown
Annual Average Flow (CFS)
gaged
modeled
12,000
10,000
8,000
6,000
4,000
2,000
0
1986
1991
1996
2001
2006


SNT09 Santee River near Jamestown
Monthly Mean Flow (CFS)
gaged
modeled
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

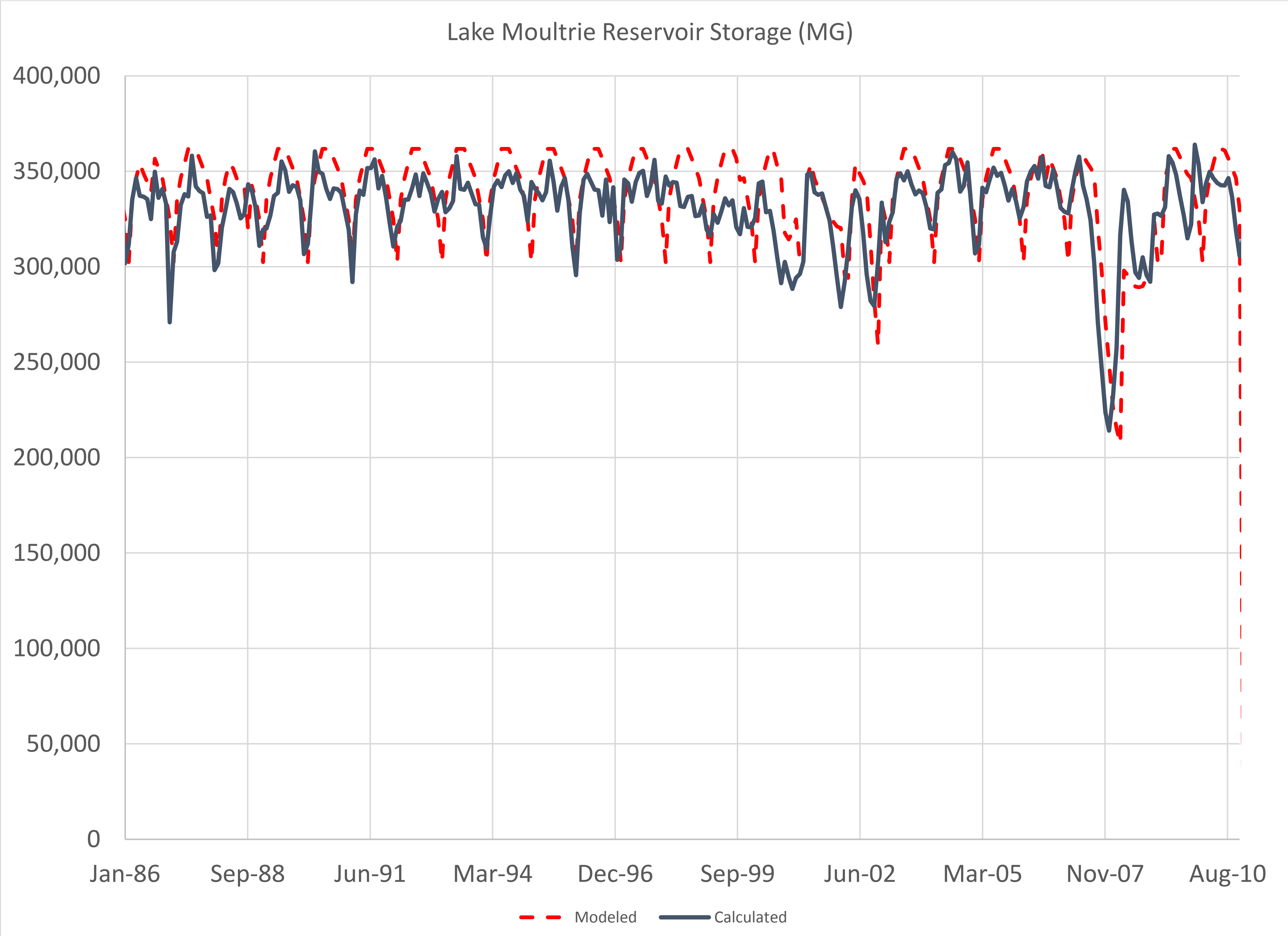

SNT09 Santee River near Jamestown
Monthly Flow Percentiles (CFS)
gaged
modeled
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile



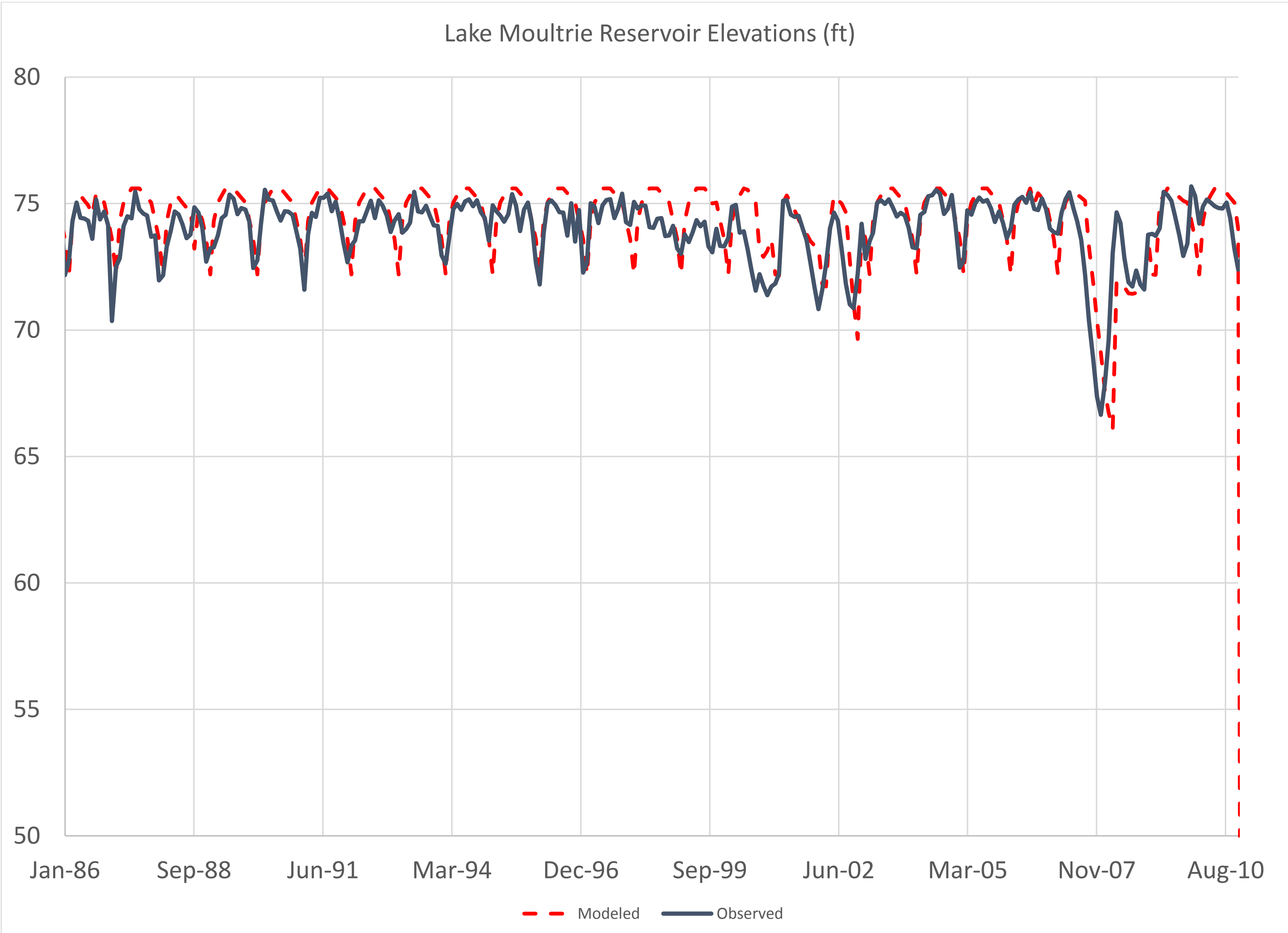
Lake Marion Reservoir Storage (MG)
500,000
450,000
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
Jan-86
Sep-88
Jun-91
Mar-94
Dec-96
Sep-99
Jun-02
Mar-05
Nov-07
Aug-10
Modeled
Calculated



Lake Marion Reservoir Elevations (ft)
80
75
70
65
60
55
50
Jan-86
Sep-88
Jun-91
Mar-94
Dec-96
Sep-99
Jun-02
Mar-05
Nov-07
Aug-10
Modeled
Observed



Lake Moultrie Reservoir Storage (MG)
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
Jan-86
Sep-88
Jun-91
Mar-94
Dec-96
Sep-99
Jun-02
Mar-05
Nov-07
Aug-10
Modeled
Calculated



Lake Moultrie Reservoir Elevations (ft)
80
75
70
65
60
55
50
Jan-86
Sep-88
Jun-91
Mar-94
Dec-96
Sep-99
Jun-02
Mar-05
Nov-07
Aug-10
Modeled
Observed

Appendix B

Santee River Basin Model Daily Calibration Results

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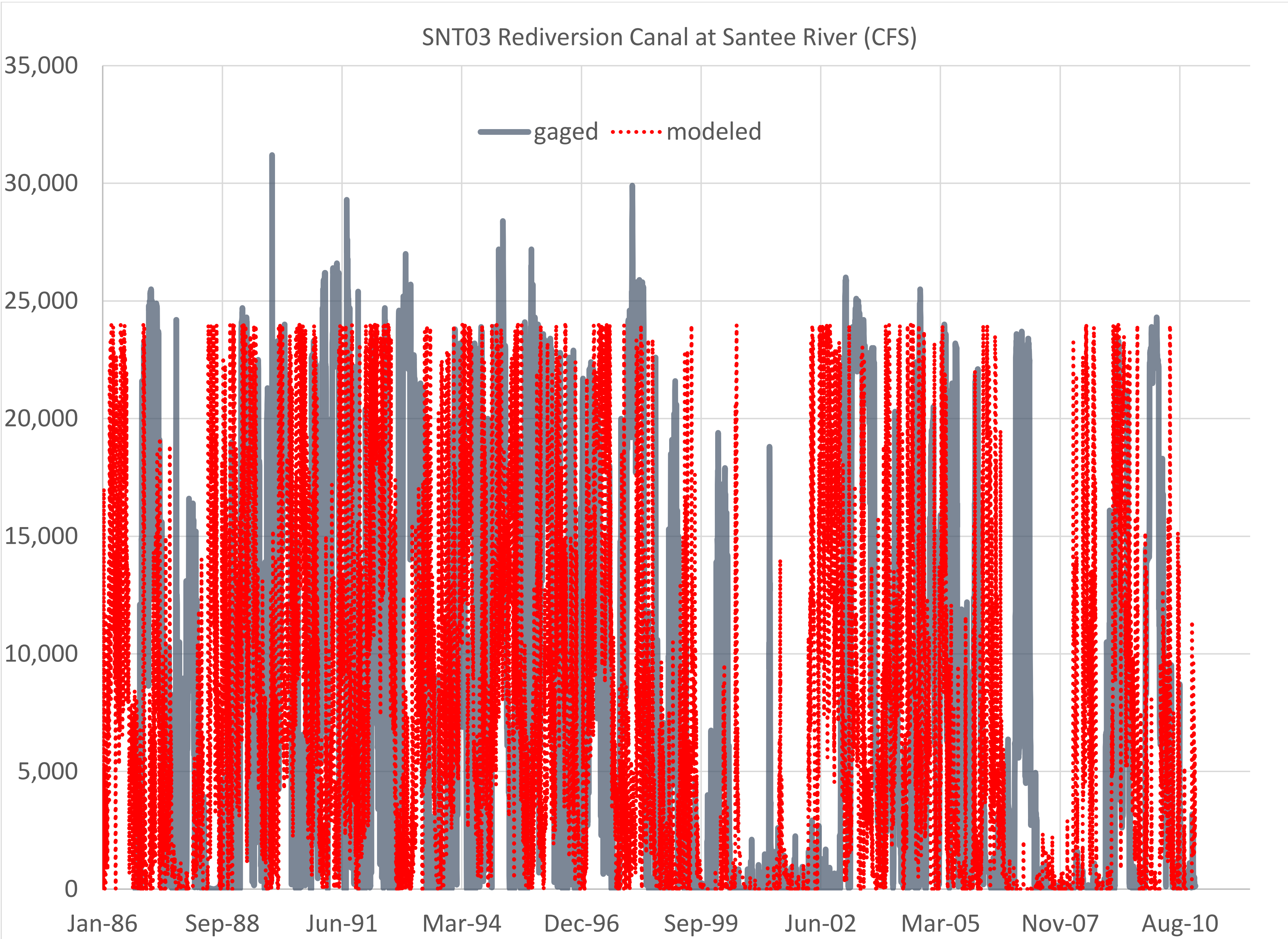
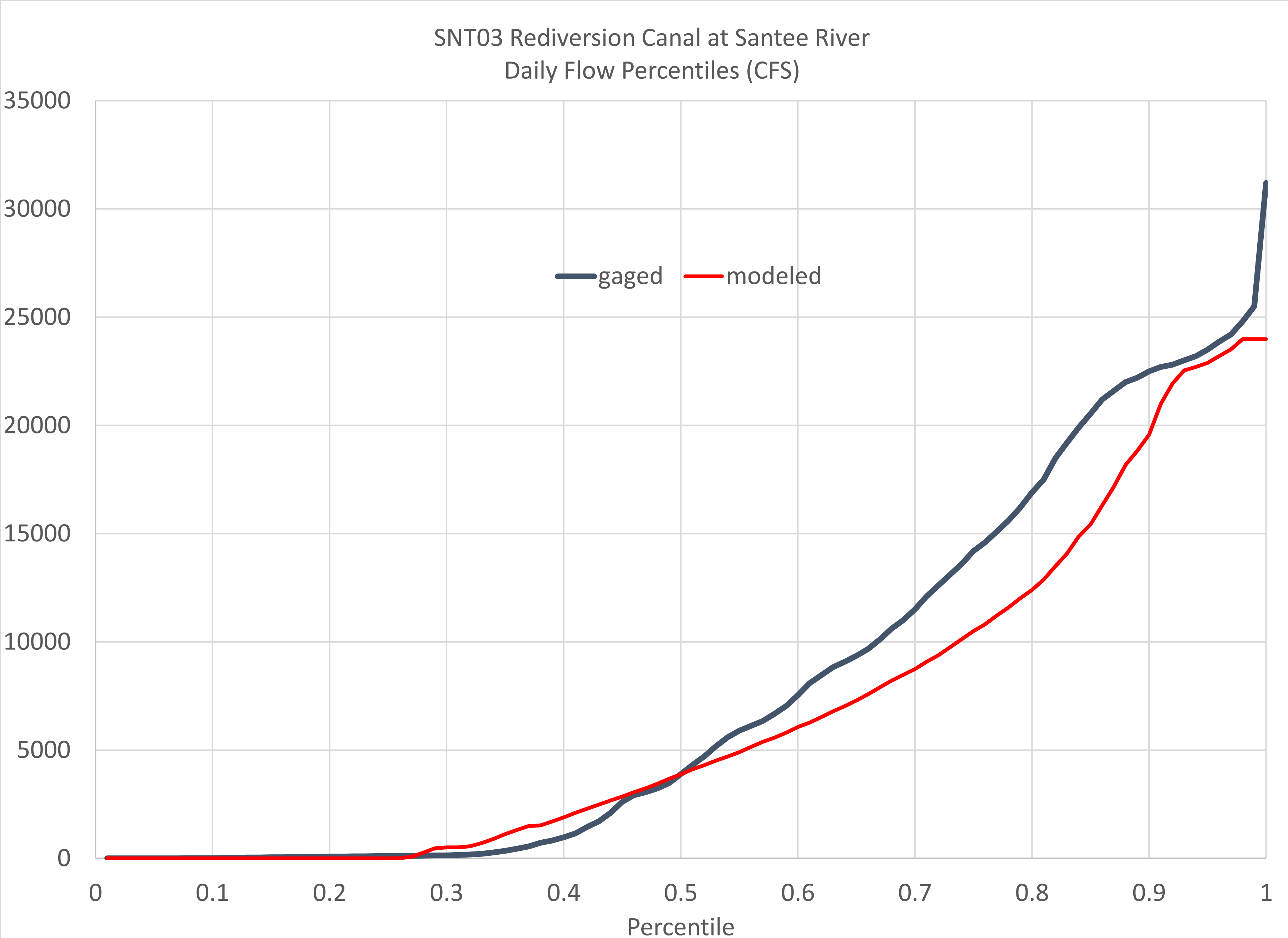
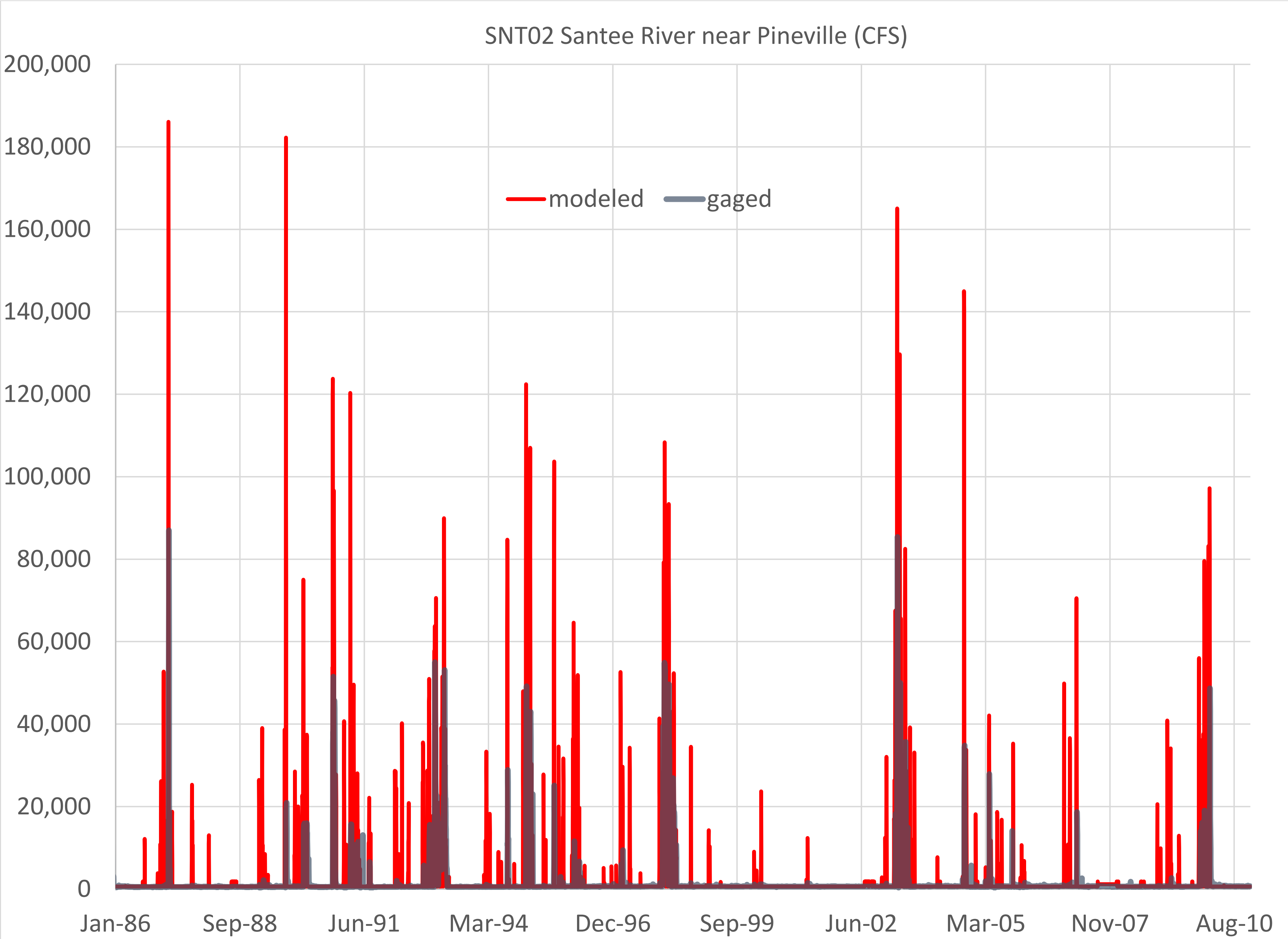
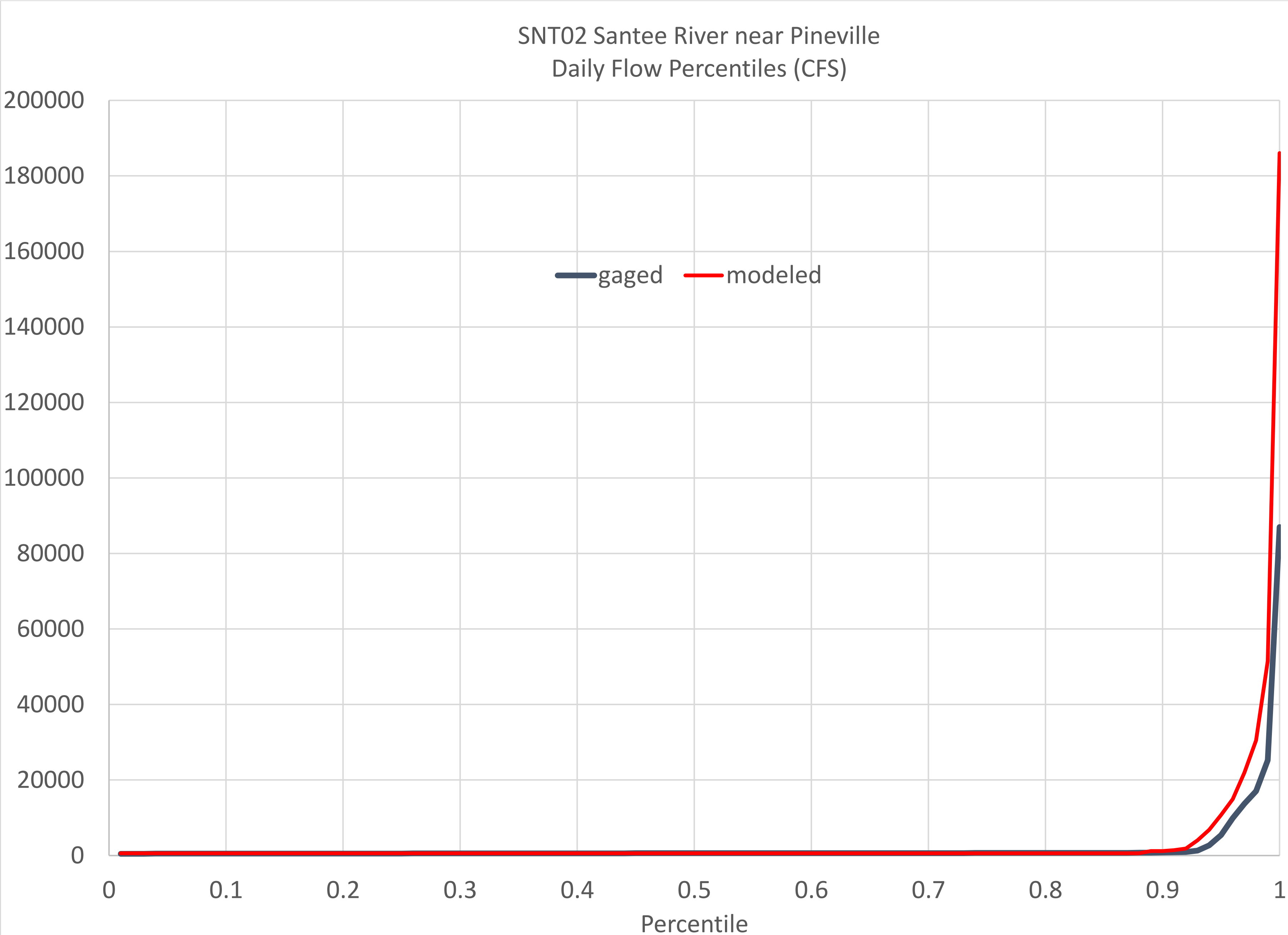
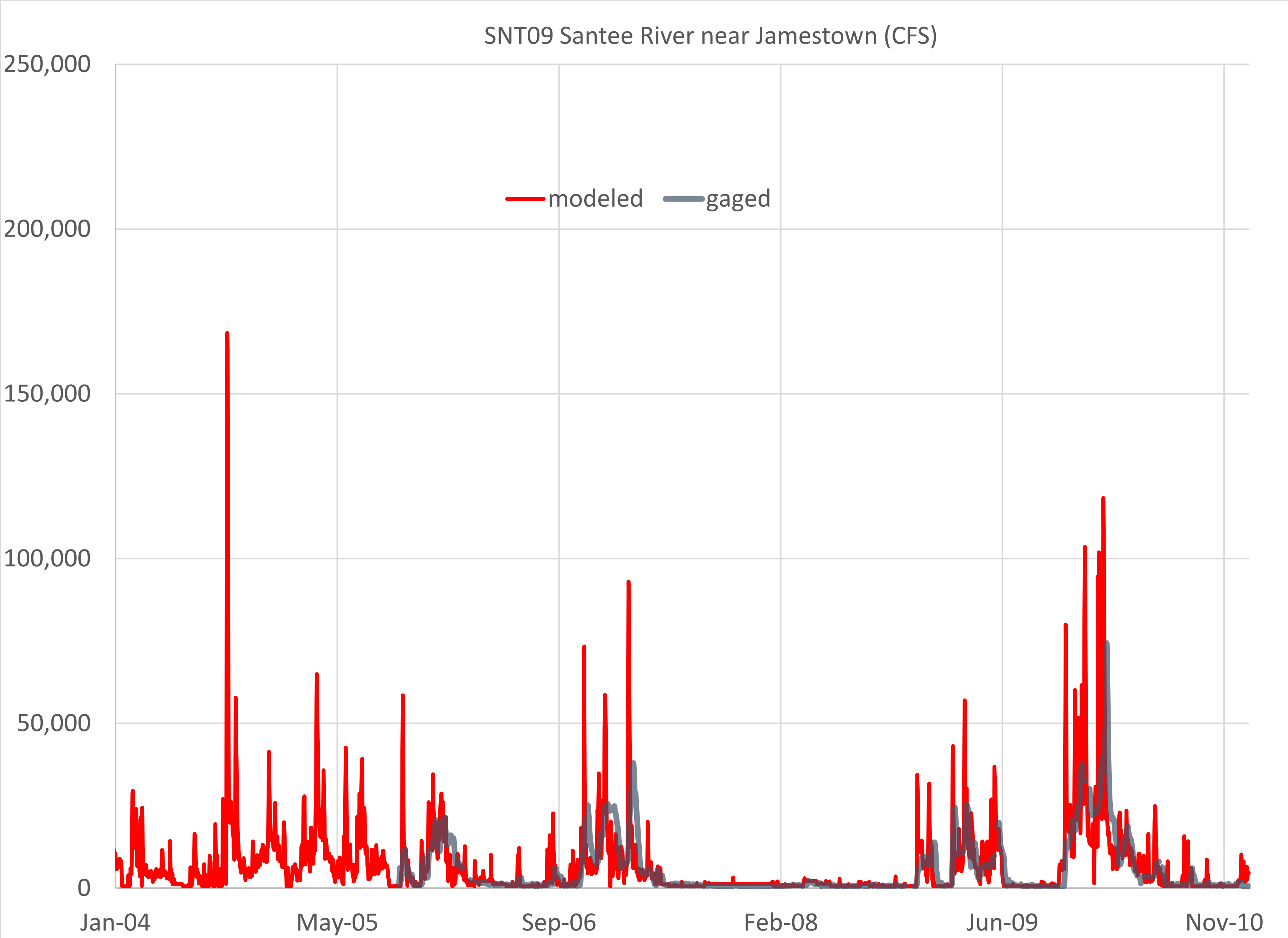


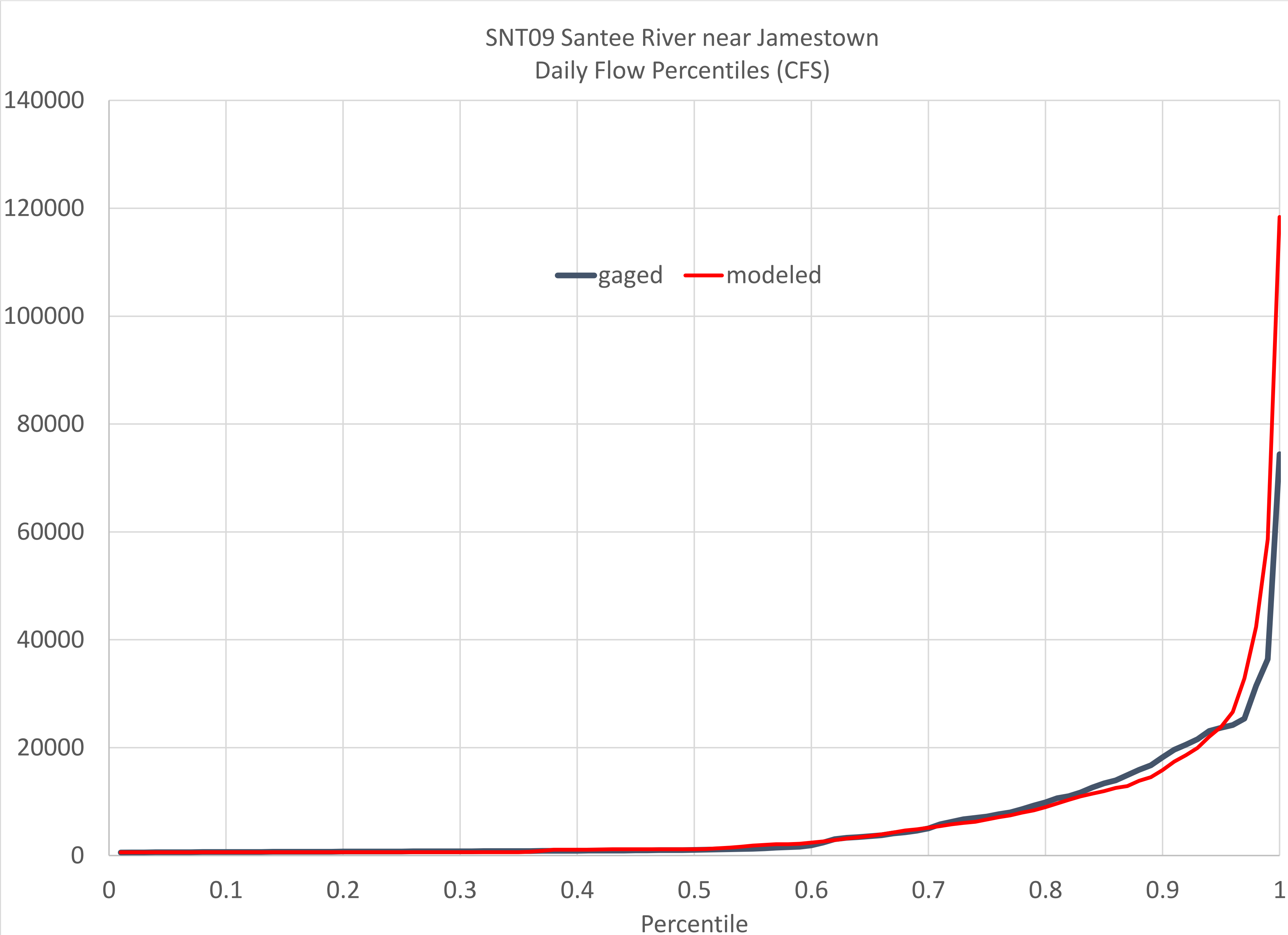
SNT03 Rediversion Canal at Santee River (CFS)
gaged
modeled
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
Jan-86
Sep-88
Jun-91
Mar-94
Dec-96
Sep-99
Jun-02
Mar-05
Nov-07
Aug-10

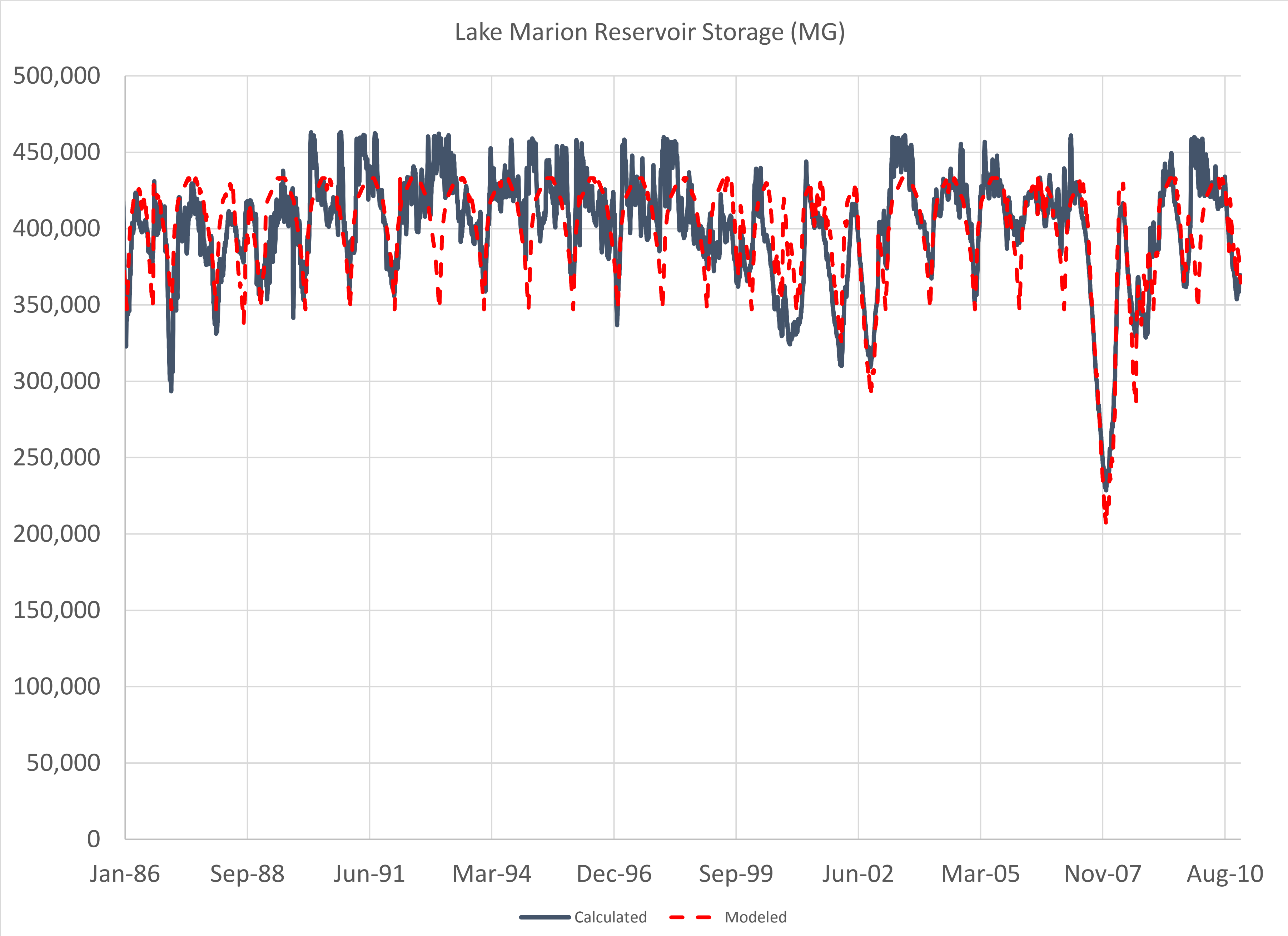

SNT03 Rediversion Canal at Santee River
Daily Flow Percentiles (CFS)
35000
30000
25000
20000
15000
10000
5000
0
gaged
modeled
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile


SNT02 Santee River near Pineville (CFS)
modeled
gaged
200,000
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
Jan-86
Sep-88
Jun-91
Mar-94
Dec-96
Sep-99
Jun-02
Mar-05
Nov-07
Aug-10

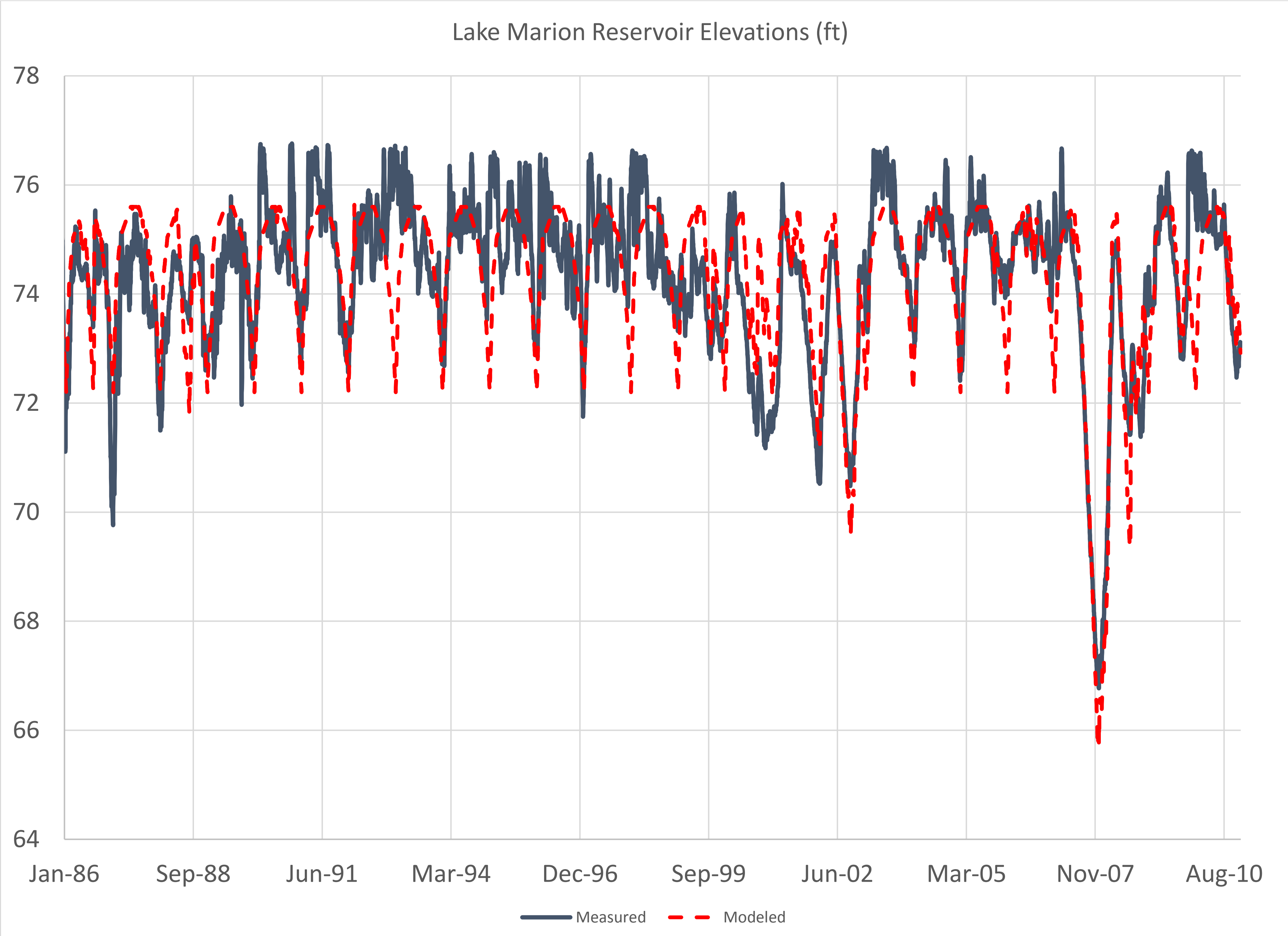

SNT02 Santee River near Pineville
Daily Flow Percentiles (CFS)
gaged
modeled
200000
180000
160000
140000
120000
100000
80000
60000
40000
20000
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

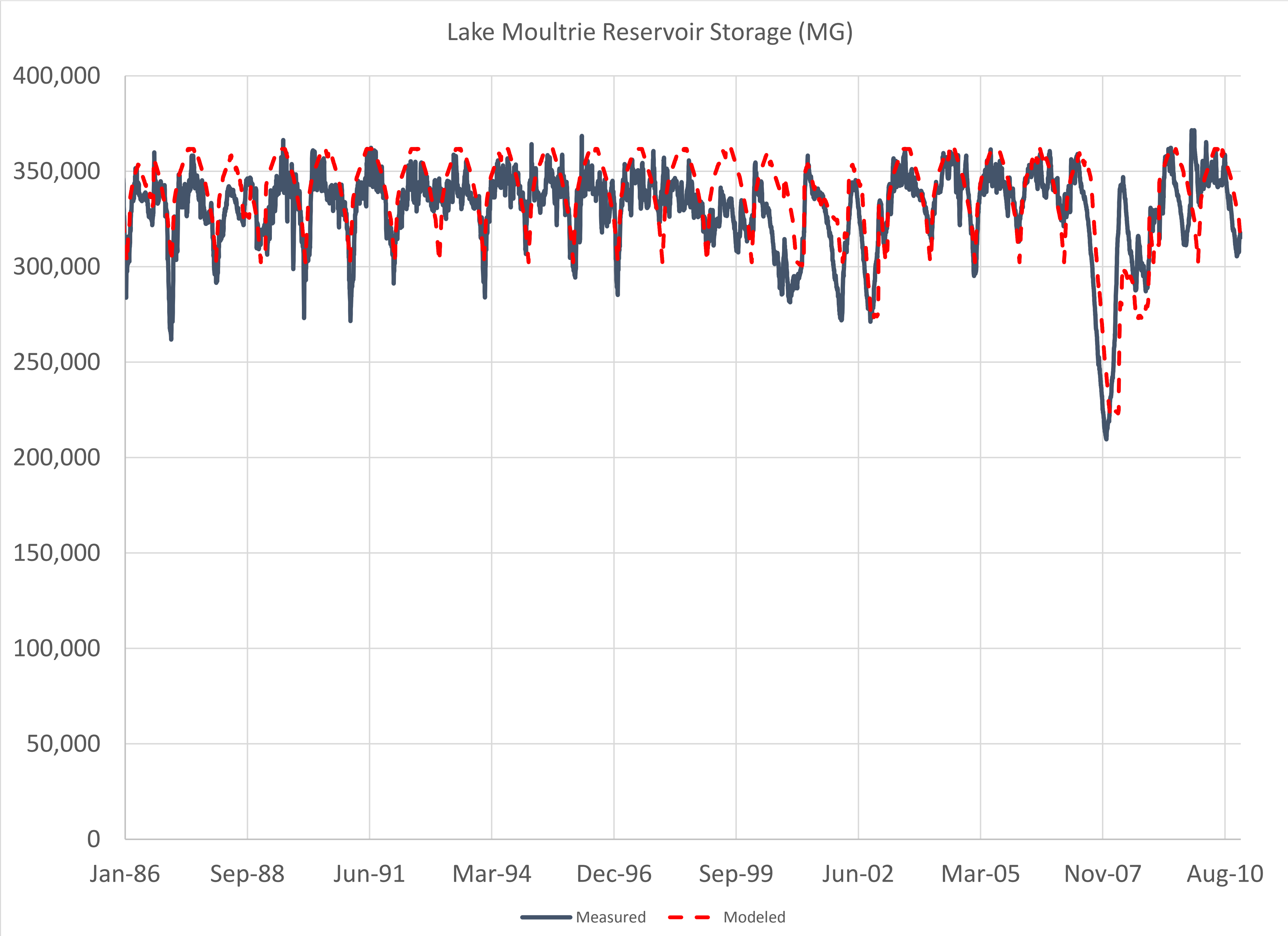

SNT09 Santee River near Jamestown (CFS)
modeled
gaged
250,000
200,000
150,000
100,000
50,000
0
Jan-04
May-05
Sep-06
Feb-08
Jun-09
Nov-10


SNT09 Santee River near Jamestown
Daily Flow Percentiles (CFS)
140000
120000
100000
80000
60000
40000
20000
0
gaged
modeled
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

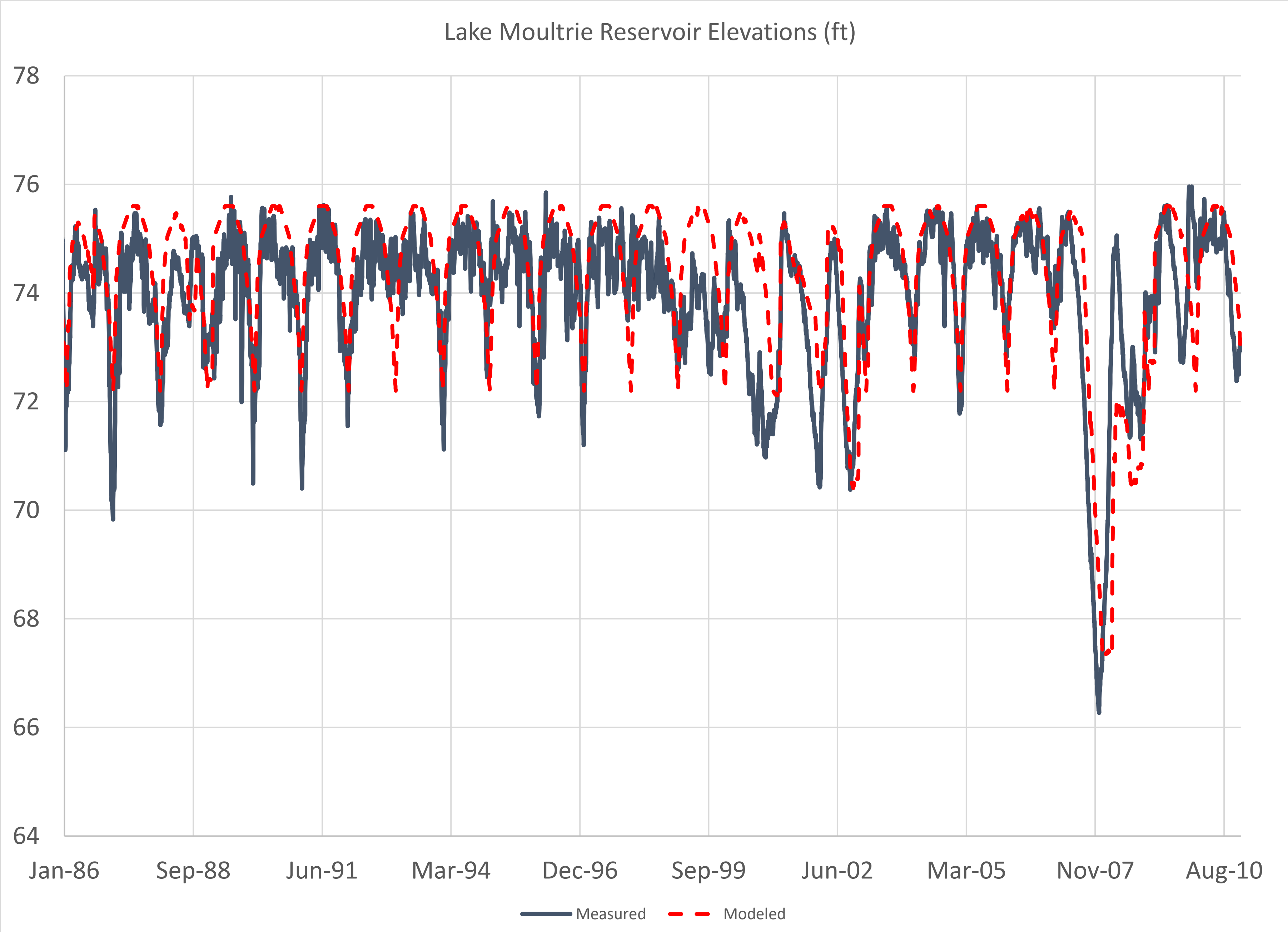


Lake Marion Reservoir Storage (MG)
500,000
450,000
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
Jan-86
Sep-88
Jun-91
Mar-94
Dec-96
Sep-99
Jun-02
Mar-05
Nov-07
Aug-10
Calculated
Modeled


Lake Marion Reservoir Elevations (ft)
78
76
74
72
70
68
66
64
Jan-86
Sep-88
Jun-91
Mar-94
Dec-96
Sep-99
Jun-02
Mar-05
Nov-07
Aug-10
Measured
Modeled



Lake Moultrie Reservoir Storage (MG)
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
Jan-86
Sep-88
Jun-91
Mar-94
Dec-96
Sep-99
Jun-02
Mar-05
Nov-07
Aug-10
Measured
Modeled


Lake Moultrie Reservoir Elevations (ft)
78
76
74
72
70
68
66
64
Jan-86
Sep-88
Jun-91
Mar-94
Dec-96
Sep-99
Jun-02
Mar-05
Nov-07
Aug-10
Measured
Modeled

Appendix C

Guidelines for Representing Multi-Basin Water Users in SWAM

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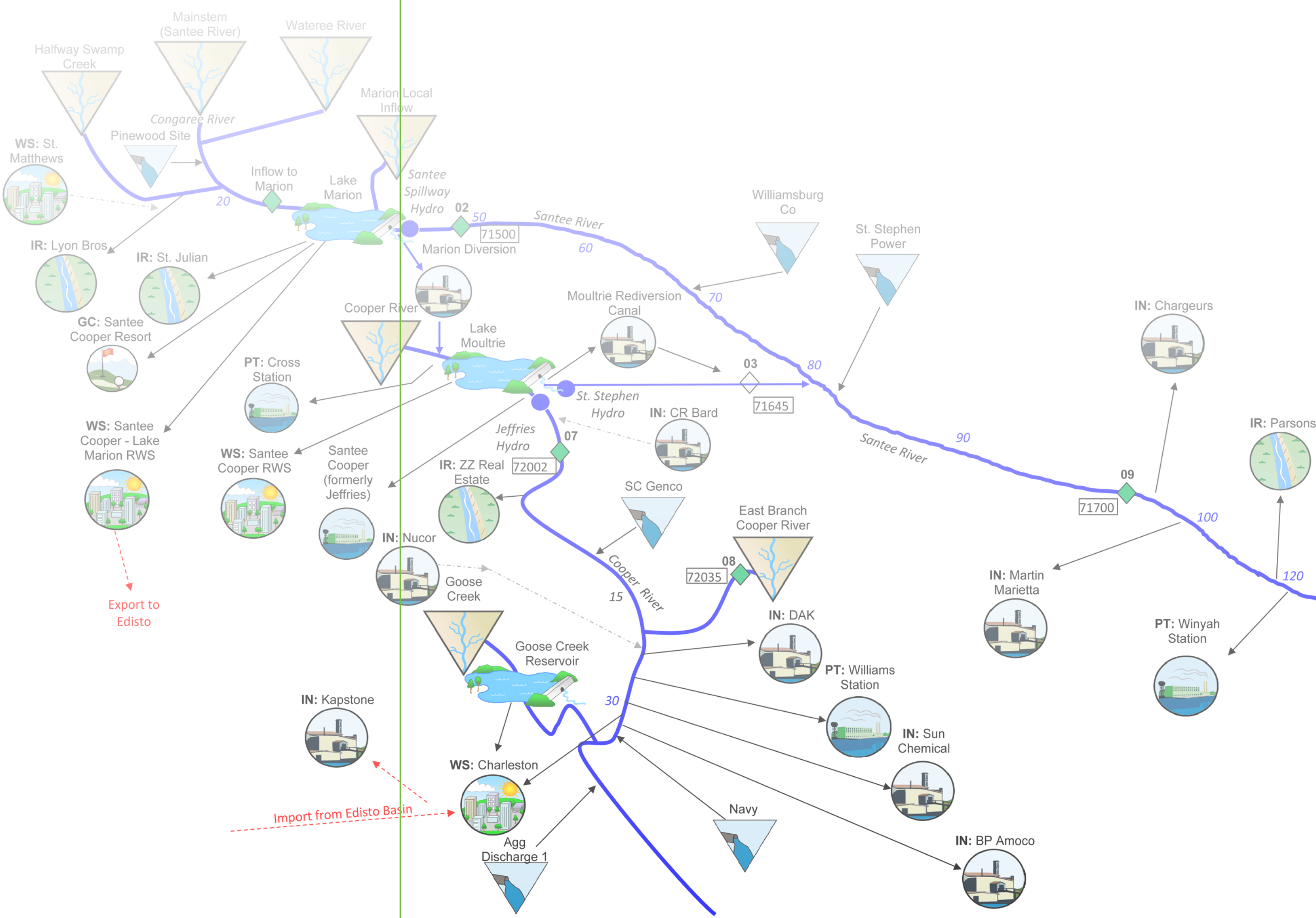
Appendix C
Guidelines for Representing Multi-Basin Water Users in SWAM

There are many examples in South Carolina of water users that access source waters in multiple river basins and/or discharge return flows to multiple basins. Since SWAM models for each major river basin are being developed, it is important to represent the multi-basin users concisely and clearly in the models. The following provides a recommended set of consistent guidelines to follow as each river basin model is developed. **In all cases, the constructs should be documented in the basin reports and described in the model itself using the Comment boxes.**

1. If a water user's primary source of supply and discharge locations are located with the given river basin, then this user should be explicitly included as a Water User object in that basin model.
    a. If secondary sources are from outside of the basin, then these should be included using the "transbasin import" option in SWAM.
    b. If a portion of the return flows are discharged to a different basin, then this should be incorporated by using the multiple return flow location option, with the exported portion represented by a specified location far downstream of the end of the basin mainstem (e.g. mile "999").
2. If only a water user's secondary source of supply (i.e., not the largest portion of overall supply) is located outside the river basin being modeled, then this should be represented as a water user with an "Export" identifier in the name (e.g. "Greenville Export") in the river basin model where the source is located.
    a. For this object, set the usage values based on only the amount sourced from inside the basin (i.e. only that portion of demand met by in-basin water).
    b. Set the return flow location for this use to a location outside of the basin (e.g. mainstem mile "999").
    c. For future demand projection simulations, the in-basin portion of overall demand will need to be disaggregated from the total demand projection, likely by assuming a uniform percent increase.
3. If a portion of a water user's return flow discharges to a different basin than the primary source basin, then this portion of return flow should be represented as a Discharge object (e.g. named "Greenville Import") in the appropriate basin model.
    a. Reported discharge data can be used to easily quantify this discharge for historical calibration simulations.
    b. For future demand projection simulations, this discharge can be easily quantified by analyzing the return flow output for the primary (source water basin). See 1b.

above. However, the user will need to manually make the changes to the prescribed Discharge object flows in the model.



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