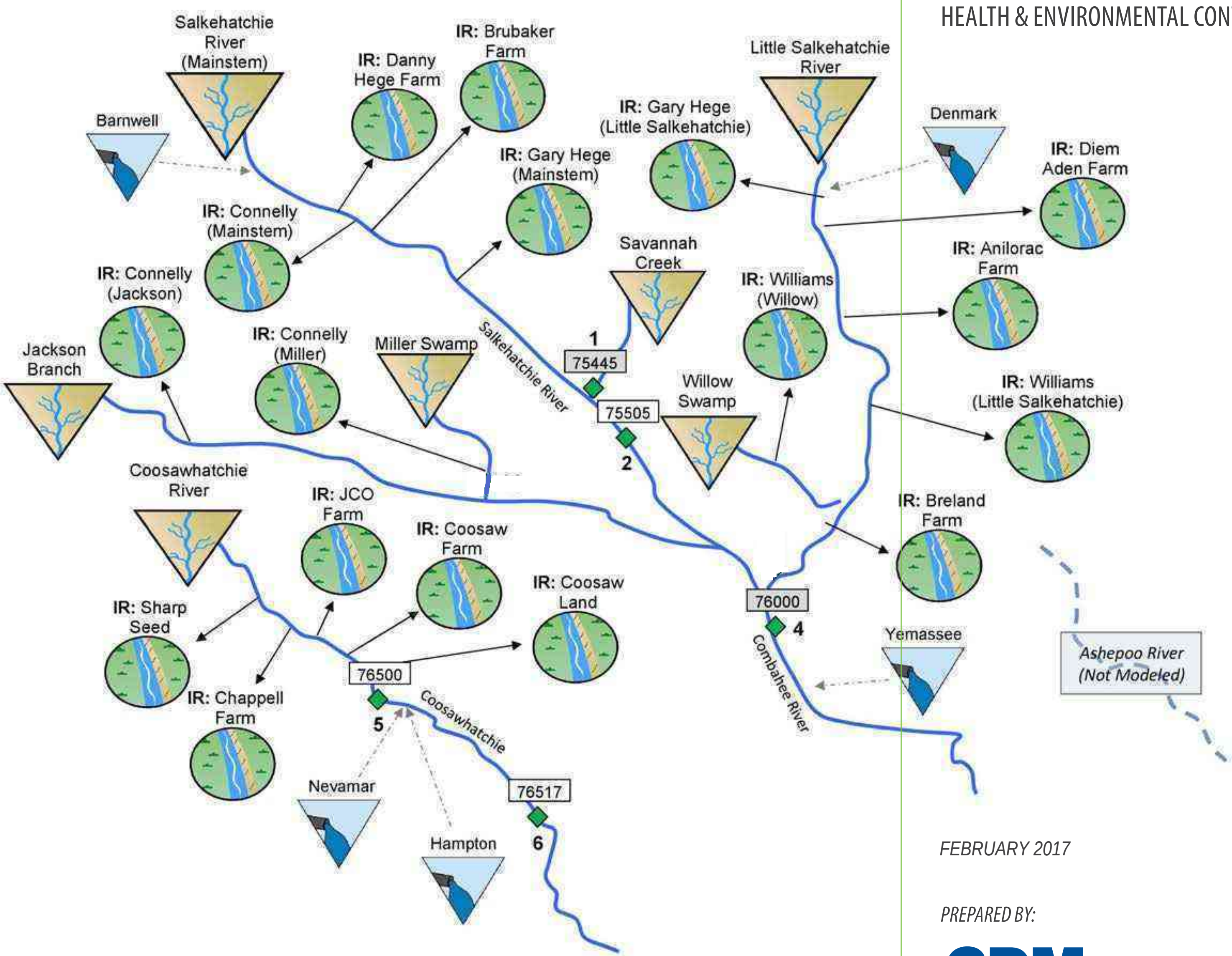
SOUTH CAROLINA
SURFACE WATER QUANTITY MODELS
SALKEHATCHIE RIVER BASIN MODEL

SUBMITTED TO:

SOUTH CAROLINA DEPARTMENT OF NATURAL RESOURCES

SOUTH CAROLINA DEPARTMENT OF HEALTH & ENVIRONMENTAL CONTROL



FEBRUARY 2017

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Section 1

Purpose

This document, the Salkehatchie 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 Salkehatchie 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 Salkehatchie 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 Salkehatchie 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 Salkehatchie 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 Salkehatchie River and its major tributaries, and the impacts to the river flows from human intervention: withdrawals, discharges, and interbasin transfers.

The model will simulate historic hydrologic conditions from 1951 through 2013. 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 Salkehatchie 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 Salkehatchie 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 Edisto, Pee Dee and Broad river basins. The enhanced procedures and guidelines, and the "lessons learned" were applied to the Salkehatchie River Basin – especially, with regard to model calibration and validation.

Section 4

Salkehatchie Model Framework

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

4.1 Representation of Water Withdrawals

As noted above, significant surface 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. In the modeled portion of the Salkehatchie River Basin, the only surface water withdrawals are registered withdrawals for agriculture.

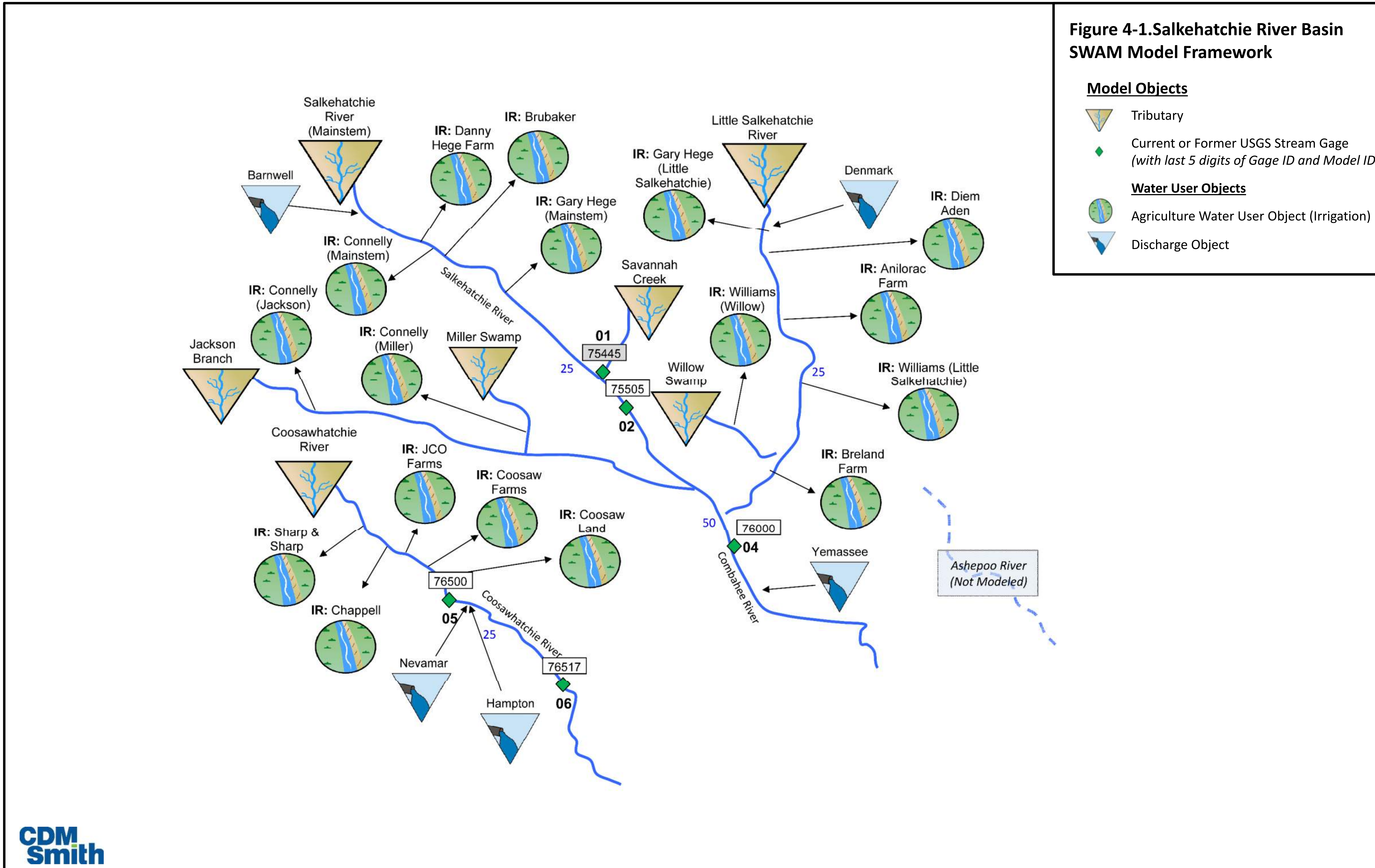


Figure 4-1.Salkehatchie River Basin SWAM Model Framework

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 Discharge 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. The second approach was used in the Salkehatchie River Basin Model, as explained below.

4.3 Groundwater Users and Associated Discharge

Although the Salkehatchie 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 Salkehatchie Basin, there were several groundwater users which are represented by a Discharge Object. The decision to include them as Discharge Objects was a result of poor or inconsistent correlation between their reported groundwater withdrawal and discharge. These include the following:

- Nevamar Company LLC
- Town of Hampton
- Town of Yemassee
- City of Denmark
- City of Barnwell

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 (1983 – 2013) 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. For this model, the simulation period extends back to 1951, the start of the hydrologic record for the Salkehatchie River 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.

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 summarizes the inputs used in both the calibration and baseline Salkehatchie River Basin 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 Salkehatchie models. 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, or area-prorated from calculated UIFs elsewhere in the basin. **Table 6-1** summarizes the gages, or in many 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 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

In the SWAM models developed in other South Carolina river basins, implicit tributaries were used to account for select mainstem tributaries that did not have withdrawals, discharges or significant

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
SLK10	Ungaged	-	Salkehatchie River (Mainstem)	SLK02	02175500	Salkehatchie River
SLK13	Ungaged	-	Little Salkehatchie River			
SLK14	Ungaged	-	Willow Swamp			
SLK11	Ungaged	-	Miller Swamp	SLK05	02176500	Coosawhatchie River
SLK12	Ungaged	-	Jackson Branch			
SLK15	Ungaged	-	Coosawhatchie River			
SLK01	Gaged	02175445	Savannah Creek	-	-	-

reservoirs, but had significant flows. Typically, these tributaries had enough flow to support a future water withdrawal. By including them, two things are accomplished:

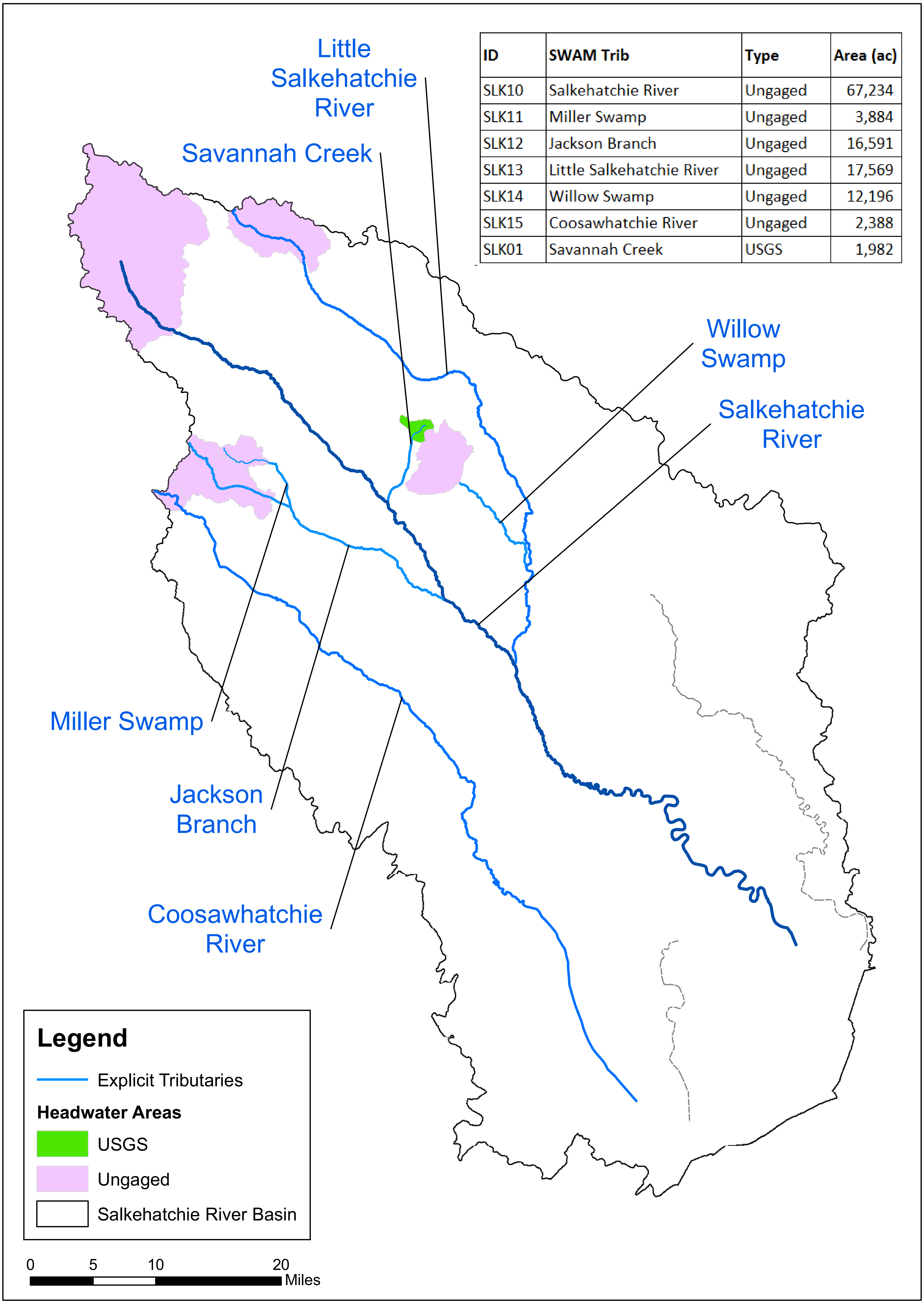
- The implicit tributary flow is added at the actual river mile where the flow enters the mainstem, as opposed to being added as a dispersed flow over a mainstem segment.
- Having the implicit tributary in the model makes it easier to convert them to explicit tributaries in the future, in the event a new withdrawal or discharge is proposed, and needs to be evaluated. This eliminates the need for future adjustments to the mainstem gains (explained below).

Since the Salkehatchie River Basin is relatively small, there were no tributaries identified for inclusion as implicit tributaries in the model.

6.1.3 Reach Gains and Losses

In SWAM, mainstem gain/loss factors and tributary sub-basin 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 sub-basin 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, sub-basin 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 sub-basin 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



ID	SWAM Trib	Type	Area (ac)
SLK10	Salkehatchie River	Ungaged	67,234
SLK11	Miller Swamp	Ungaged	3,884
SLK12	Jackson Branch	Ungaged	16,591
SLK13	Little Salkehatchie River	Ungaged	17,569
SLK14	Willow Swamp	Ungaged	12,196
SLK15	Coosawhatchie River	Ungaged	2,388
SLK01	Savannah Creek	USGS	1,982

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Figure 6-1: Headwater Areas for Explicit Tributaries in the Salkehatchie River Basin

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 sub-basin 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 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 sub-basin 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 sub-basin 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.**

Table 6-2. Model Tributary Inputs

SWAM Tributary Object	Tributary Type	Confluence Stream	Confluence Location (mile)	Confluence Drainage Area (ac)	Headwater ID	End Mile	Drainage Area Ratio	Subbasin Flow Factor (unitless)
Mainstem	Explicit	None	None	695,540	SLK10	29.3	*NA*	0.068*
						56.9		0.04*
						500		0.0*
Coosawhatchie River	Explicit	None (Mainstem)	80	496,000	SLK15	7.4	10.8	10.8
						19.7	52.6	52.6
						34.5	102.4	100.0
Jackson Branch	Explicit	Mainstem	37.5	86,850	SLK12	17.4	4.5	3.0
Little Salkehatchie River	Explicit	Mainstem	46	260,296	SLK13	48.2	12.7	6.0
Miller Swamp	Explicit	Jackson Branch	1.5	12,621	SLK11	4.3	3.2	3.2
Savannah Creek	Explicit	Mainstem	27.1	7,845	SLK01	7.2	4.0	4.0
Willow Swamp	Explicit	Little Salkehatchie	38.4	37,758	SLK14	10	3.1	3.1

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

6.2 Water Users

6.2.1 Sources of Supply

Table 6-3 summarizes the sources of supply for all Water User objects included in the model. This information includes withdrawal tributaries, diversion locations, and permit limits.

6.2.2 Demands

Table 6-4 presents the monthly demand for Agricultural (IR) Water User objects in the baseline model. 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. Demands for the calibration period (1983 through 2013) were input as a timeseries of monthly values based on monthly withdrawals reported to DHEC. **IR: Anilorac** has an active registration, but no historic demands.

Table 6-3. Water User Objects and Sources of Supply Included in the Salkehatchie River Basin Model

Model Object ID	Facility Name	Source of Supply	Intake ID	Diversion Location (mi)	Registration Limit (MGM)	Note
IR: Anilorac	Anilorac Farm	Little Salkehatchie River	05IR011S01	12.7	8	1
IR: Breland	Breland Farm	Little Salkehatchie River	15IR002S01	39.6	3	1
IR: Brubaker	Brubaker Farms Inc	Mainstem	05IR007S01	10.8	30	1
IR: Chappell	Chappell Farms	Coosawhatchie River	03IR002S02	3.3	40.7	1
IR: Connelly (Mainstem)	Connelly Farms	Mainstem	03IR011S01	18.6	90.8	1
IR: Connelly (Miller)	Connelly Farms	Miller Swamp	03IR011S02	0.3	107.0	1
IR: Connelly (Jackson)	Connelly Farms	Jackson Branch	03IR011S03	0.2	27.8	1
IR: Coosaw Farms	Coosaw Farms	Coosawhatchie River	03IR004S01	8.8	27.5	1
IR: Coosaw Land	Coosaw Land LLC	Coosawhatchie River	25IR059S01	12.5	-	1
IR: Danny Hege	Danny Hege Farm Barnwell	Mainstem	06IR007S01	9.1	41.3	1
IR: Diem Aden	Diem Aden Farm	Little Salkehatchie River	05IR042S01	6	16.9	1
IR: Gary Hege (Mainstem)	Gary Hege Farm	Mainstem	05IR023S01	13	68.6	1
IR: Gary Hege (Little Salkehatchie)	Gary Hege Farm	Little Salkehatchie River	05IR023S02	4.5	-	1
IR: JCO Farms	JCO Farms	Coosawhatchie River	03IR010S01	6.7	615.4	1
IR: Sharp & Sharp	Sharp & Sharp Certified Seed	Coosawhatchie River	03IR006S01	6.3	145	1
			03IR006S02	3.2	41	
			03IR006S03	0.3	18	
IR: Williams (Little Salkehatchie)	Williams Farms Partnership	Little Salkehatchie River	15IR012S01	37	30	1
IR: Williams (Willow)	Williams Farms Partnership	Willow Swamp	15IR012S02	2	27	1
			15IR012S03		27	
			15IR012S04		27	
			15IR012S05		27	

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

Table 6-4. Baseline Model Average Water Demand for IR Water Users

	Baseline Model Average Monthly Water Demand (MGD)								
Month	IR: Anilorac	IR: Breland	IR: Brubaker	IR: Chappell	IR: Connelly (Mainstem)	IR: Connelly (Miller)	IR: Connelly (Jackson)	IR: Coosaw Farms	IR: Coosaw Land
Surface Water Registration Limit (MGD)-->	0.3	0.1	1.0	1.3	3.0	3.5	0.9	0.9	-
Jan	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Feb	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
Mar	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.2
Apr	0.0	0.0	0.2	0.0	0.0	0.1	0.0	0.1	0.1
May	0.0	0.0	0.4	0.1	0.1	0.1	0.0	0.3	0.0
Jun	0.0	0.0	0.6	0.1	0.5	0.8	0.2	0.3	0.0
Jul	0.0	0.0	0.6	0.1	0.4	0.4	0.1	0.2	0.0
Aug	0.0	0.0	0.4	0.0	0.6	0.3	0.1	0.2	0.0
Sep	0.0	0.0	0.3	0.0	0.0	0.1	0.0	0.1	0.0
Oct	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Nov	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Dec	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

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

Table 6-4 (cont'd). Baseline Model Average Water Demand for IR Water Users

	Baseline Model Average Monthly Water Demand (MGD)							
Month	IR: Danny Hege	IR: Diem Aden	IR: Gary Hege (Mainstem)	IR: Gary Hege (Little Salkehatchie)	IR: JCO Farms	IR: Sharp & Sharp	IR: Williams (Little Salkehatchie)	IR: Williams (Willow)
Surface Water Registration Limit (MGD)-->	1.4	0.6	2.3	-	20.2	6.7	1.0	3.6
Jan	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Feb	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Mar	0.0	0.0	0.2	0.0	0.1	0.6	0.0	0.1
Apr	0.2	0.1	0.4	0.0	0.1	1.2	0.0	0.1
May	0.5	0.2	0.7	0.1	0.1	2.0	0.4	1.5
Jun	0.7	0.2	1.2	0.2	0.1	2.3	0.4	1.6
Jul	0.8	0.2	1.2	0.3	0.1	1.9	0.4	1.5
Aug	0.6	0.1	0.5	0.1	0.1	2.1	0.4	1.5
Sep	0.4	0.1	0.3	0.0	0.0	1.5	0.4	1.6
Oct	0.1	0.1	0.3	0.0	0.0	0.2	0.3	1.3
Nov	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.1
Dec	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.1

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

6.2.3 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 Salkehatchie River Basin Model, several water users import water from the Savannah River Basin. However, none of these transbasin imports will be included in the model due to their discharge locations being near the coast or on a non-modeled river.

6.2.4 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 or specified within a Discharge object. **Table 6-5** summarizes the calibration and baseline model objects representing return flows, their location, and the percent of return flow assigned to each location. No returns are assumed for golf course and agricultural irrigation (i.e., 100% consumptive use).

Table 6-6 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).

6.3 Summary

This section has presented the form and numerical values of data that are input into the Salkehatchie 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 Salkehatchie River Basin model, these calibration inputs only include reach hydrologic gain/loss factors. UIFs were also adjusted during calibration, when it was determined that a different reference gage was able to provide a better match of downstream gage flows, compared to the originally selected reference gage for a specific tributary.

Table 6-5. Returns and Associated Model Objects

Model Object ID	Facility Name	NPDES Pipe ID	Associated Water Permit	Discharge Tributary	Model River Mile
In-basin Returns Represented by Individual Discharge Objects					
Barnwell	City of Barnwell WWTF	SC0047872-001	06WS003G	Mainstem	0.4
Denmark	City of Denmark	SC0040215-001	05WS002G	Little Salkehatchie River	0.1
Denmark	City of Denmark	SC0040215-002			
Hampton	Town of Hampton	SC0021318-001	25WS001G	Coosawhatchie River	23.3
Nevamar	Nevamar Company LLC	SC0001830-001	25IN001G	Coosawhatchie River	23.4
Yemassee	Town of Yemassee	SC0025950-001	25WS004G	Mainstem	56.8

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

	Monthly Return Flow (MGD)				
Month	Barnwell	Yemassee	Denmark	Hampton	Nevamar
Jan	1.0	0.1	0.4	0.7	0.4
Feb	1.0	0.1	0.4	0.9	0.4
Mar	1.0	0.1	0.6	1.0	0.5
Apr	0.9	0.1	0.6	0.9	0.5
May	0.9	0.1	0.4	0.7	0.6
Jun	0.9	0.1	0.5	0.8	0.7
Jul	0.9	0.1	0.4	0.8	0.7
Aug	0.9	0.1	0.5	0.7	0.8
Sep	0.8	0.1	0.4	0.7	0.7
Oct	0.8	0.1	0.3	0.6	0.6
Nov	0.8	0.1	0.3	0.6	0.4
Dec	0.9	0.1	0.4	0.7	0.5

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 overriding objective of the SWAM calibration process is to verify that the model is generally accurately representing water availability in the basin; i.e. that ungaged flow estimates are roughly accurate, that flows are being combined correctly, and that basin operations and water use are well captured. 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 typically 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 sub-basin flow factors for select tributary objects and reach gain/loss factors for the mainstem. These factors capture ungaged flow gains associated with increasing drainage area with distance downstream. Flow gains through a sub-basin 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.

Consideration also needs to be given to the availability and 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 can be upwards of 20% at some gages and under some conditions (USGS, http://wdr.water.usgs.gov/current/documentation.html). In the Salkehatchie River Basin, flows are only available from five current or former USGS gages, and only two gages characterize flows for more than six years. Of the two gages which have flow records from 1951 through present day, the USGS characterizes the records from the Coosawhatchie River gage near Hampton (02176500) as "poor", meaning that the daily discharges may be greater than 15% of the true value. Records from the Salkehatchie River gage near Miley (02175500) are characterized as "fair", meaning that the daily discharges are within 15% of the true value. Flows below 10 cfs are characterized as "poor" at this gage. The uncertainty of model inputs, such as gaged flows, and the relative lack of gaged flows to serve as inputs (compared to other basins) 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

For the model calibration exercise, the fully constructed and parameterized Salkehatchie Basin model, as described in Sections 5 and 6, was used to simulate the 1983 through 2013 historical period. The calibration also focused on the period 1951 to 1957 since gage data on the Combahee River was only available during that period. As described in these sections, the calibration model includes input data representative of past conditions, rather than current conditions in the basin. The specific simulation time period was selected because of a higher confidence in reported withdrawal and discharge data for this period compared to earlier periods. The 31-year record also provides a good range of hydrologic and climate variability in the basin to adequately test the model, including extended high and low flow periods.

Guided by the principles described in Section 7.1, the following specific steps were followed (in order) as part of the 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. 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.

3. Mainstem reach gain/loss factors (per unit length) were adjusted to better achieve calibration at mainstem gage locations, based on monthly timestep modeling. This factor can be varied in multiple locations along the main stem.

4. The adequacy of the daily timestep model was verified by reviewing daily output once the monthly model was calibrated.

All USGS flow gages at non-tidally influenced downstream locations in the basin with reasonable records 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 our 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 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. Lastly, all 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.

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 very small group of inputs with relatively high associated uncertainty. In general, and for future basin models, these might include any of the following: mainstem hydrologic gain/loss factors, tributary sub-basin flow factors, reservoir operational rules, assumed consumptive use percentages, and return flow locations and/or lag times associated with outdoor use. However, the primary calibration parameters in SWAM are the sub-basin flow factors and mainstem gain/loss factors. The final model sub-basin flow factors and mainstem gains/losses are presented in Section 6, Table 6-2. The use of alternative reference gages to estimate an ungaged headwater tributary flow is also considered during calibration. Similarly, the method used to extend a headwater UIF may also be re-evaluated, and an alternative extension method may be found to produce a better match of modeled vs. measured flows at a downstream gage. Adjustments to most other parameters are secondary and often not required.

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; cumulative flow

Project Gage ID	USGS Number	Tributary Object	Periods of Record	Basin Area (sq. mi.)	River Mile
SLK02	02175500	Salkehatchie River	2/1951 - 9/2014	342	29.3
SLK04	02176000	Combahee River	6/1951 - 6/1957	1087	56.9
SLK05	02176500	Coosawhatchie River	2/1951 - 9/2014	196	19.7
SLK06	02176517	Coosawhatchie River	10/1995 - 9/1998	383	34.5

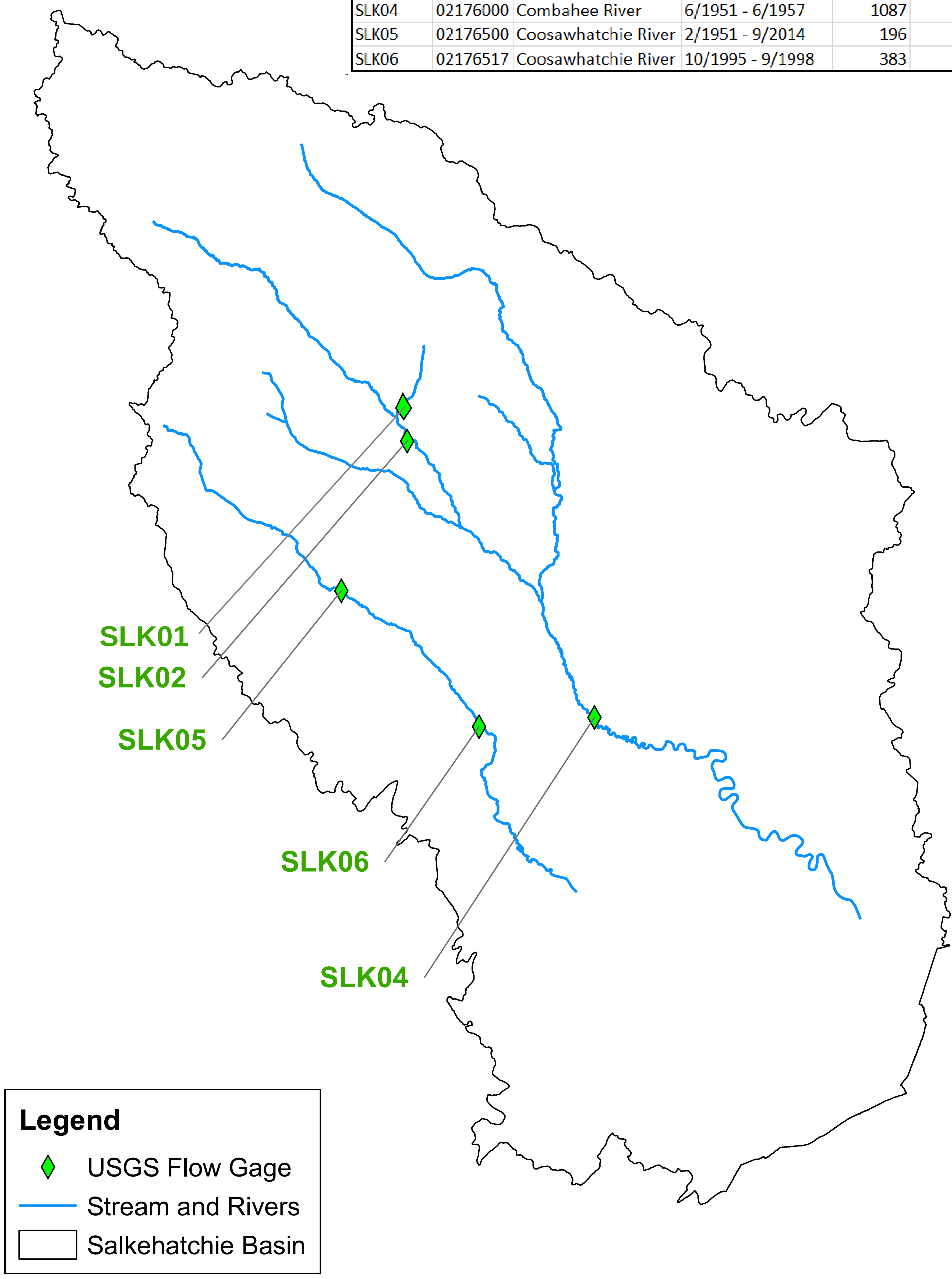


Figure 7-1. USGS Streamflow Gages Used in Calibration

plots; annual and monthly mean flow values; monthly and daily percentile plots of river flow values; annual 7-day low flows with a 10-year recurrence interval (7Q10); and mean flow values averaged over the entire period of record.

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. Cumulative flow plots are useful confirm that there is not an overall bias of too high or too low flows over an extended period. 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. Lastly, regulatory low flows (7Q10) are of specific interest as the model could be used to predict such low flows as a function of future impairment. However, the limitations of the daily model and supporting data should be properly considered in assessing model performance on this particular metric. Note that for the purposes of this exercise a simplified 7Q10 calculation was employed. Our approach used the Excel percentile function to estimate the 10-year recurrence interval (10th percentile) of modeled and measured 7 day low flows. This differs from the more standard methods often using specific fitted probability distributions (e.g. log-Pearson).

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. In addition to the graphical assessments, period of record flow averages and 7Q10 values were assessed based on tabular comparisons and percent differences. 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 strong agreement between modeled and measured data is observed for the four gaged sites with continuous or partial flow records between 1983 and 2013 (SLK01, SLK02, SLK05 and SLK06), and the one gaged site with flow records between 1951 and 1957 (SLK04). Strong agreement between measured and modeled flows at SLK01, SLK02 and SLK05 is to be expected, given that the headwater flows for these gages were established based on the gage flows. Discrepancies between modeled and measured flow data at the other two gages (SLK04 and SLK06) are less than the reported range of uncertainty associated with the USGS flow data used to drive the models (5 to >15%) (USGS http://wdr.water.usgs.gov/current/documentation.html). Seasonal and annual patterns in flow are reproduced well by the model. Monthly fluctuations (timeseries) and extreme conditions (percentiles) are also very well reproduced by the model for all for locations.

Modeled vs. measured cumulative flow over the entire calibration period was compared at all sites to confirm that there was not an overall bias toward too high or too low of flows. Using the monthly timestep, the comparisons indicate that the modeled cumulative flows are within 1.5% of cumulative measured flows at the four primary calibration sites, indicating that the model is not significantly over- or under-predicting flows. At SLK04, which has flow records from 1951-1957, cumulative modeled flow was within 5% of cumulative measured flow. The model tends to over predict low flows at SLK04, while under predicting peak flows. The lack of gage data on the Little Salkehatchie River and Jackson Branch, which flow into the mainstem (Salkehatchie River) just above SLK04, limits the accuracy to which flows in these two tributaries can be modeled. There also is a lack of candidate reference gages for which to establish headwater flows for these tributaries. The best match of flows at SLK04 was achieved using SLK05 as a reference gage for Jackson Branch/Miller Swamp, and SLK02 for the Little Salkehatchie/Willow Swamp. However, as noted, this combination, along with some adjustments to sub-basin flow factors, still resulted in modeled flows that were less “flashy” than measured flows.

Table 7-1 contains modeled and measured averages over the calibration period of record, along with the available number of years for comparison. For all sites, modeled mean flow values, averaged over the full period of record, were all within 5% of measured mean flows. Monthly flow percentiles are also well captured by the model across nearly all sites. Monthly flow percentile deviations at SLK01, SLK02 and SLK05 are all generally between 0% and 3% with no clear bias one way or the other. At SLK04 and SLK06, higher deviations ranging between 20% and 40% occur, primarily in the summer months.

Table 7-1. Annual Flow Statistics (CFS), Salkehatchie River Basin

Project ID	Station	Modeled Average	Measured Average	% Diff Average	Years of Record
SLK02	Salkehatchie River Near Miley	278	287	-3.2%	31
SLK05	Coosawhatchie River near Hamtpon	138	139	-0.5%	31
SLK01	Savannah Creek at Ehrhardt	4	4	-0.1%	3
SLK06	Coosawhatchie River near Early Branch	409	399	2.4%	4
SLK04	Combahee River near Yemassee	493	471	4.5%	7*

** 1951-1957*

In terms of daily timestep simulations, daily flow fluctuations are generally well captured by the model. Modeled daily percentile plots exhibit excellent agreement with measured data for the Coosawhatchie River locations (SLK05 and SLK06) as well as the Savannah Creek (SLK01) and upper Salkehatchie River (SLK02). Similar to the monthly timestep, the model tends to over predict low flows at SLK04, while under predicting peak flows.

Modeled regulatory low flow values (7Q10) compare favorably with 7Q10 flows calculated from the gage data, especially considering they are all less than 20 cfs. At SLK05, modeled and measured 7Q10 flows were 0 cfs. At SLK01 modeled and measured 7Q10 flows were both 0.2 cfs. At SLK02 modeled and measured 7Q10 flows were 9.6 cfs and 15.3 cfs respectively. At SLK06 modeled and measured 7Q10 flows were 4.9 cfs and 2.1 cfs respectively.

The model adequately hindcasts delivered water supply to most water users in the model (which are all agricultural). Limited exceptions to this include the withdrawals associated with several farms on tributaries to the Coosawhatchie River, Miller Swamp, and Willow Swamp. On the Coosawhatchie River, small impoundments, which were not modeled, appear to provide enough storage to prevent shortages when river flows approach, or are at zero. For the few shortages observed, it is also possible that reported or estimated (hindcasted) surface water usage is inaccurate and irrigation was temporarily reduced due to supply limitations.

7.4 Model Uncertainty

Although the comparisons of modeled flow to observed flow suggests that the model accurately predicts both low and high flows at each gage location, the relative lack of gage data increases the uncertainty associated with this basin, compared to the other modeled basins in South Carolina. There exist no gages to validate model results on the Little Salkehatchie River, for example. The uncertainty in flows in the Little Salkehatchie likely contributes to the model over-predicting low flows and under-predicting high flows at SLK04, located on the Salkehatchie River downstream of the confluence with the Little Salkehatchie River. Three of the five gages in the basin had less than seven years of flow data. This also increases the level of uncertainty of the model, as there is less time over which to validate the model results.

With very few gages to provide data and very few tributaries, the modeled variation in high and low flows mimics that of the available data and contributing tributaries. Observed flow on the Salkehatchie River, which begins in the upper and middle Coastal plain, is relative steady, compared to flow in the Coosawhatchie River, which is predominately in the middle and lower Coastal Plain. The Coosawhatchie River exhibits more flashiness, with sporadic periods of very low to no flow in summer months of certain years, as a result of its dependence on rainfall and runoff. Conversely, the Salkehatchie River is likely fed by discharges from groundwater storage and headwater streams. This variation in observed flow dynamics must be considered when using the model. Near the gage locations, more certainty exists with regard to the ability of the model to reasonably represent flow. Away from the gages, these changes in flow dynamics reduce the level of certainty, and modeled flows may not match actual flows as closely.

Section 8

User Guidelines for the Baseline Model

The baseline Salkehatchie 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.

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 2013 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.

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

References

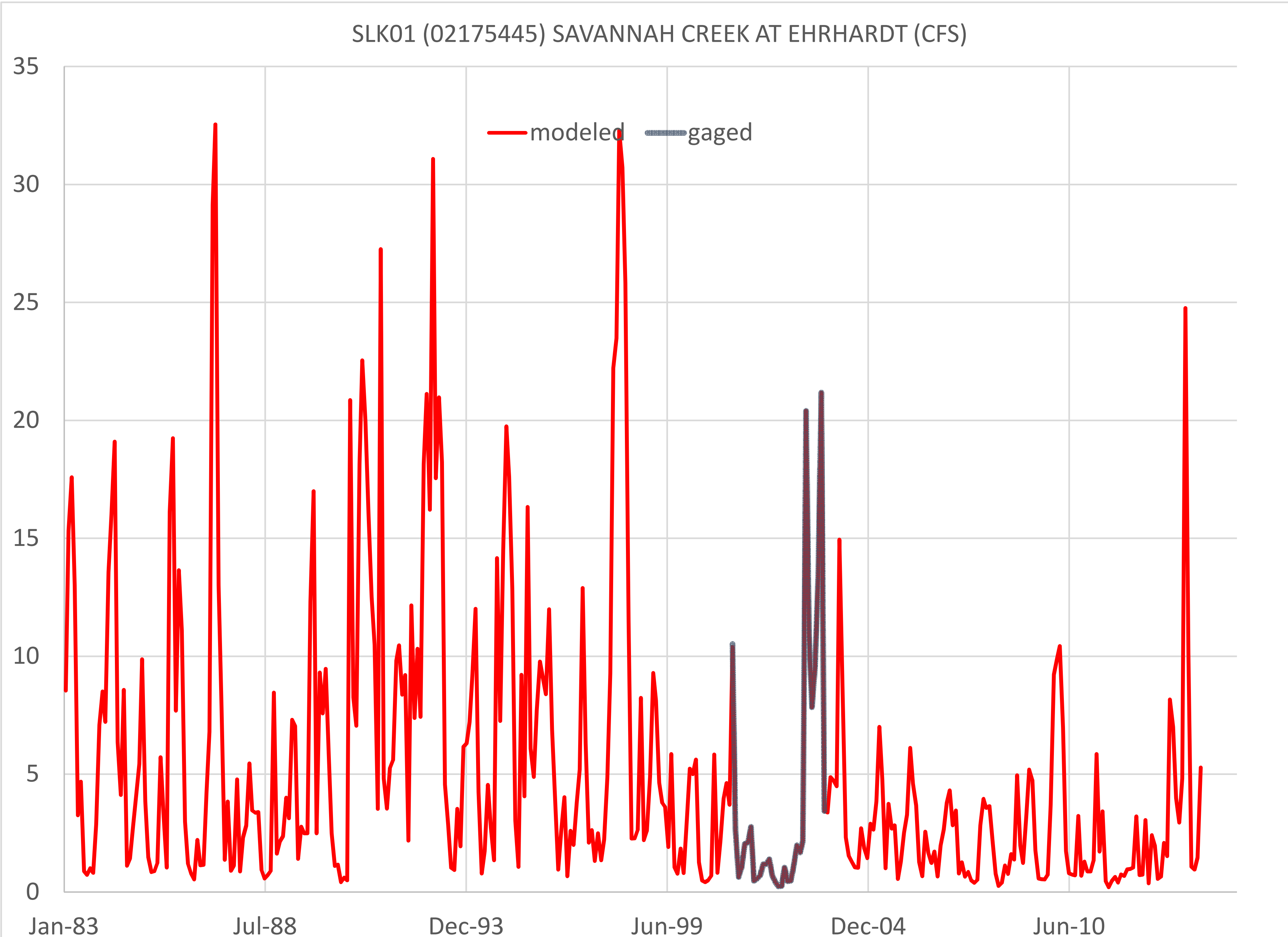
CDM Smith, October 2015. *Salkehatchie Basin SWAM Model Framework*

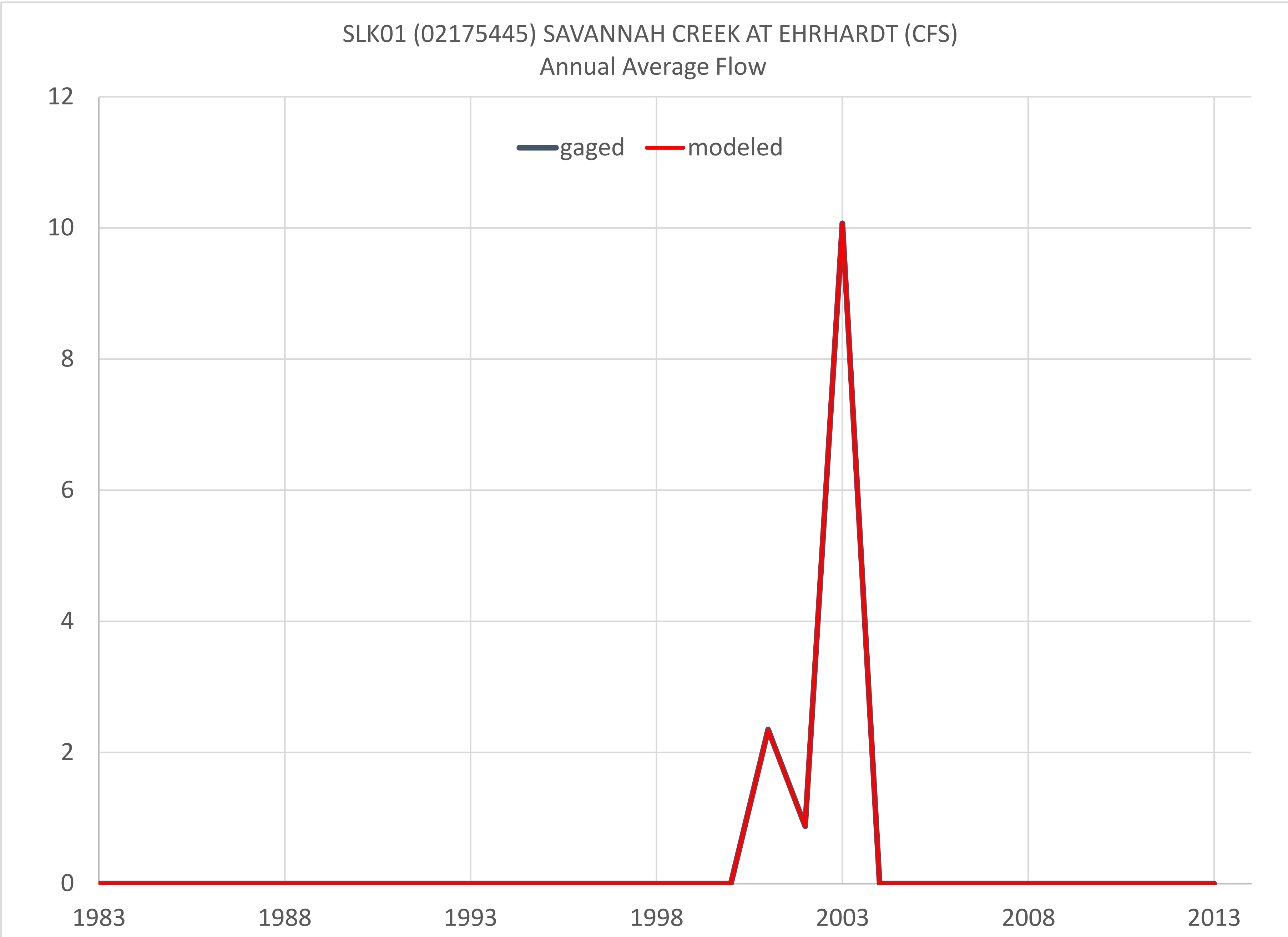
CDM Smith, 2016. *Simplified Water Allocation Model (SWAM) User's Manual, Version 4.0.*

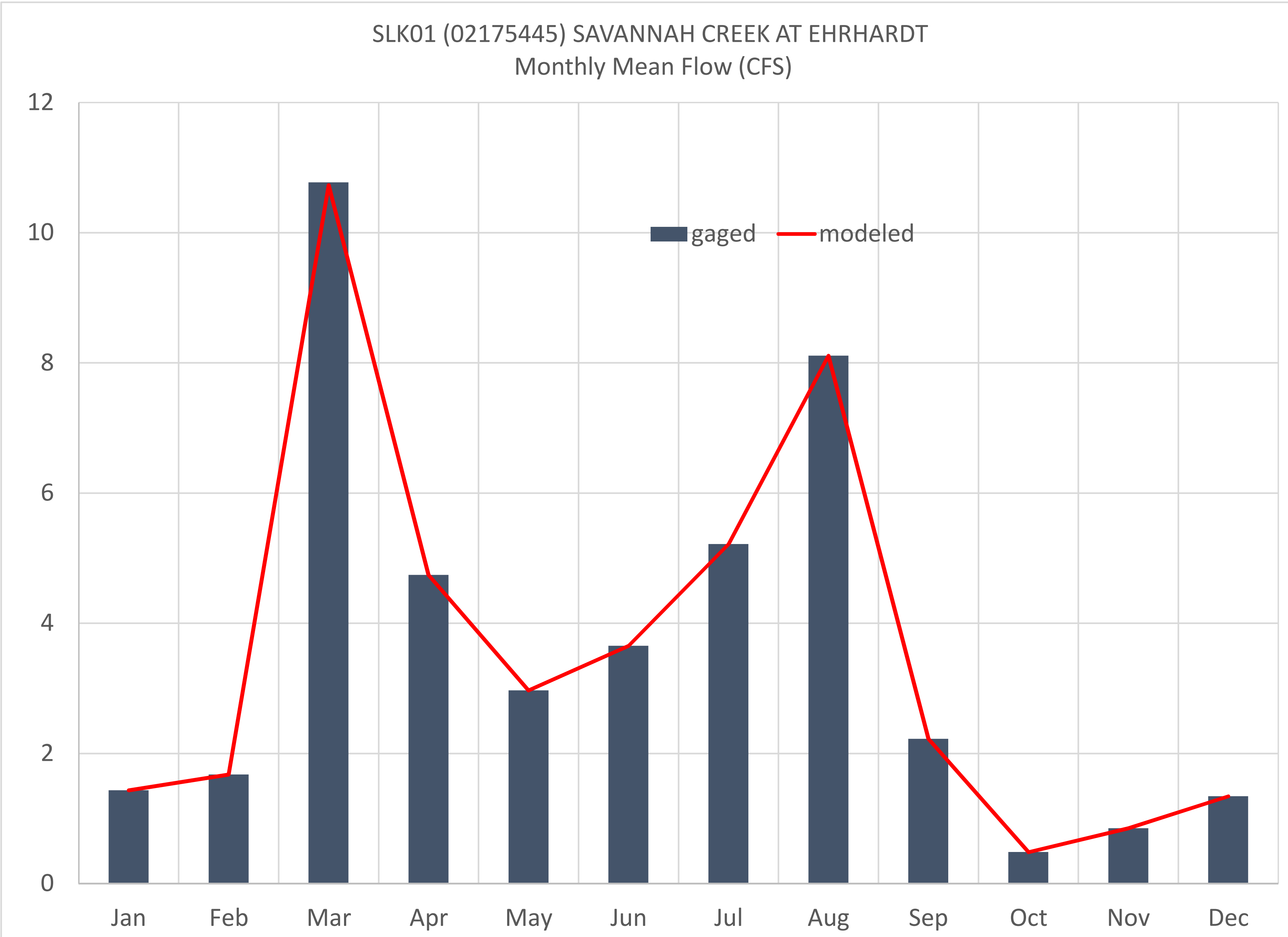
Appendix A

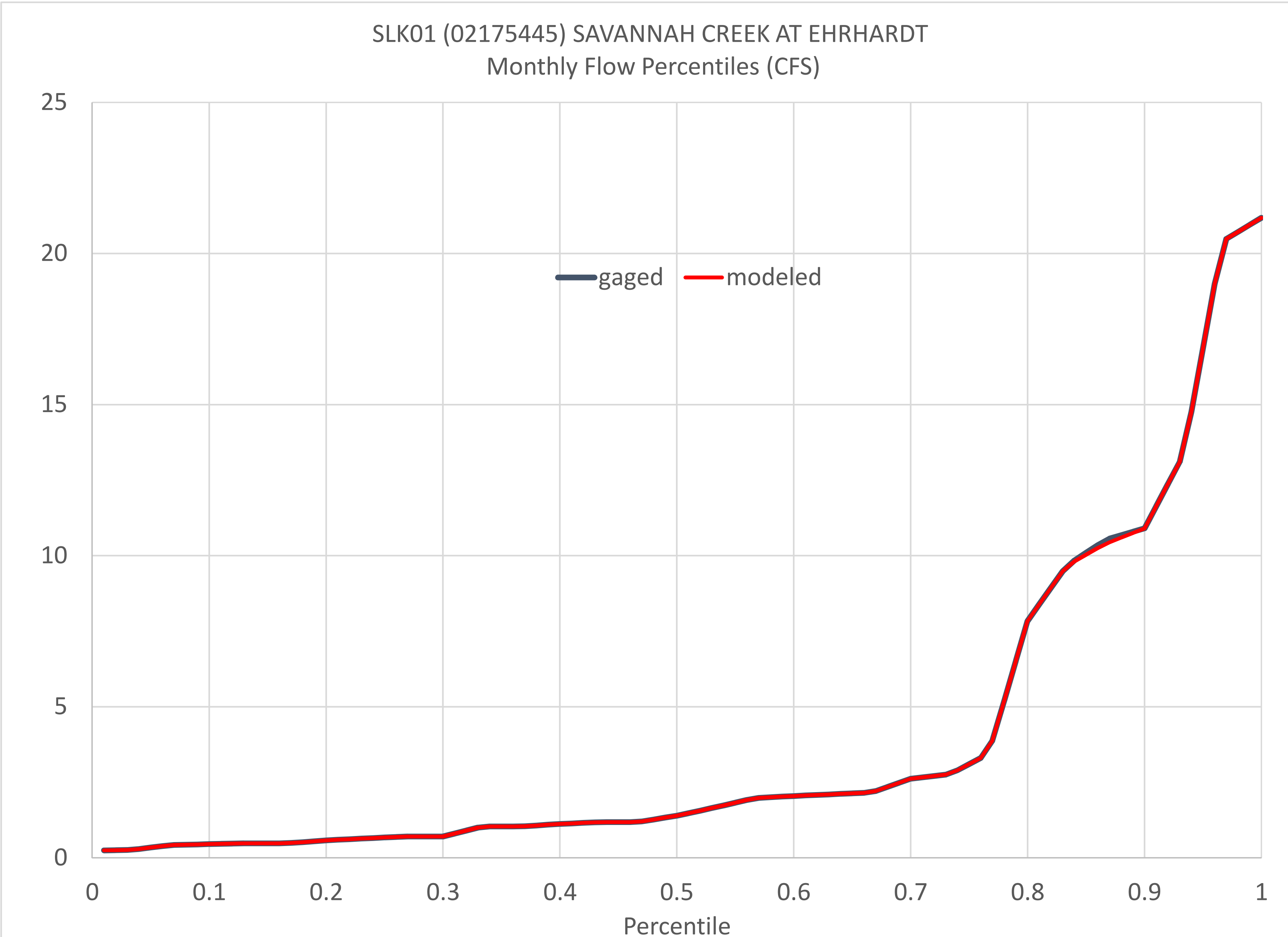
Salkehatchie River Basin Model Monthly Calibration Results

CDM Smith

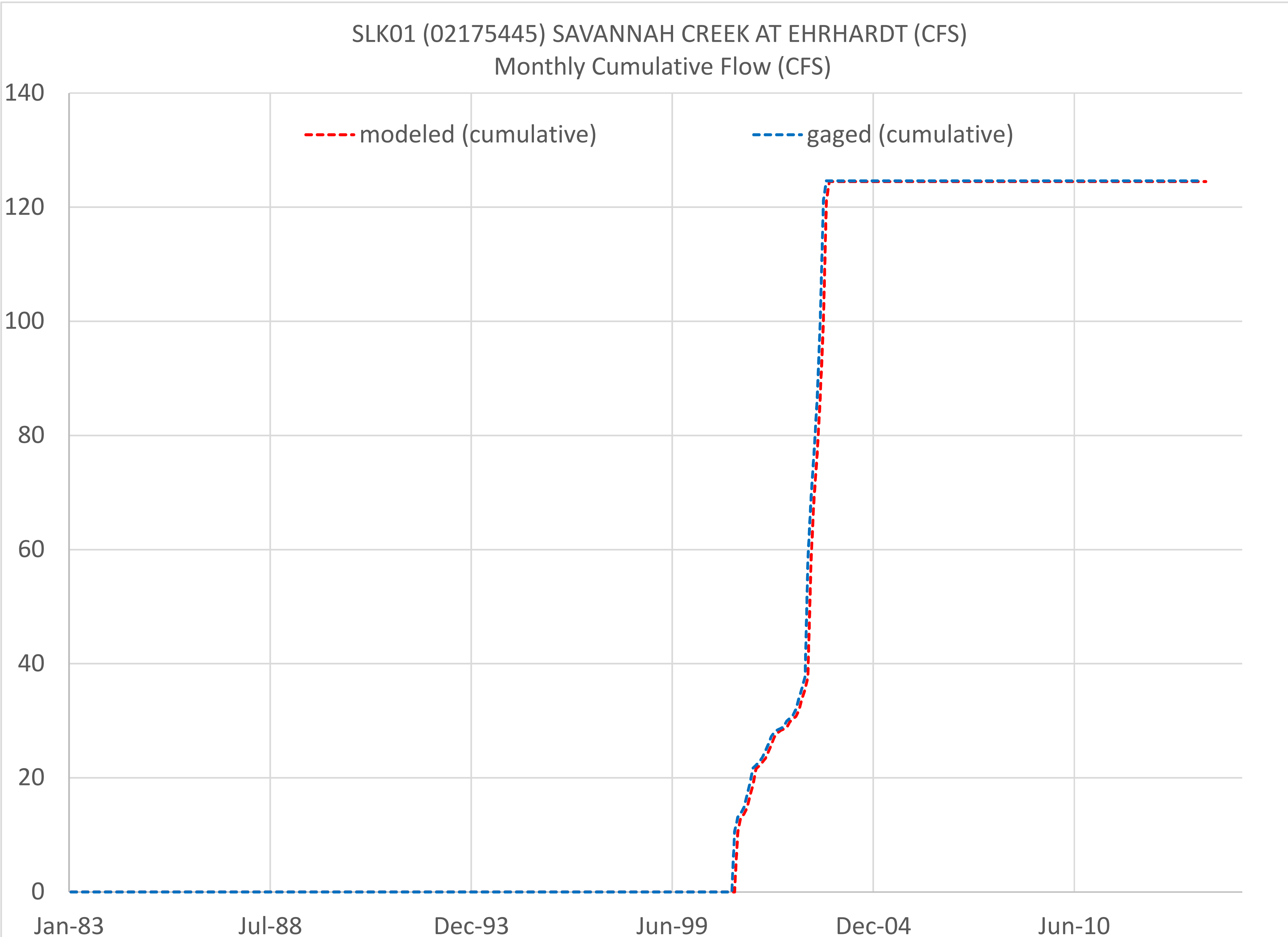

SLK01 (02175445) SAVANNAH CREEK AT EHRHARDT (CFS)
modeled
gaged
35
30
25
20
15
10
5
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

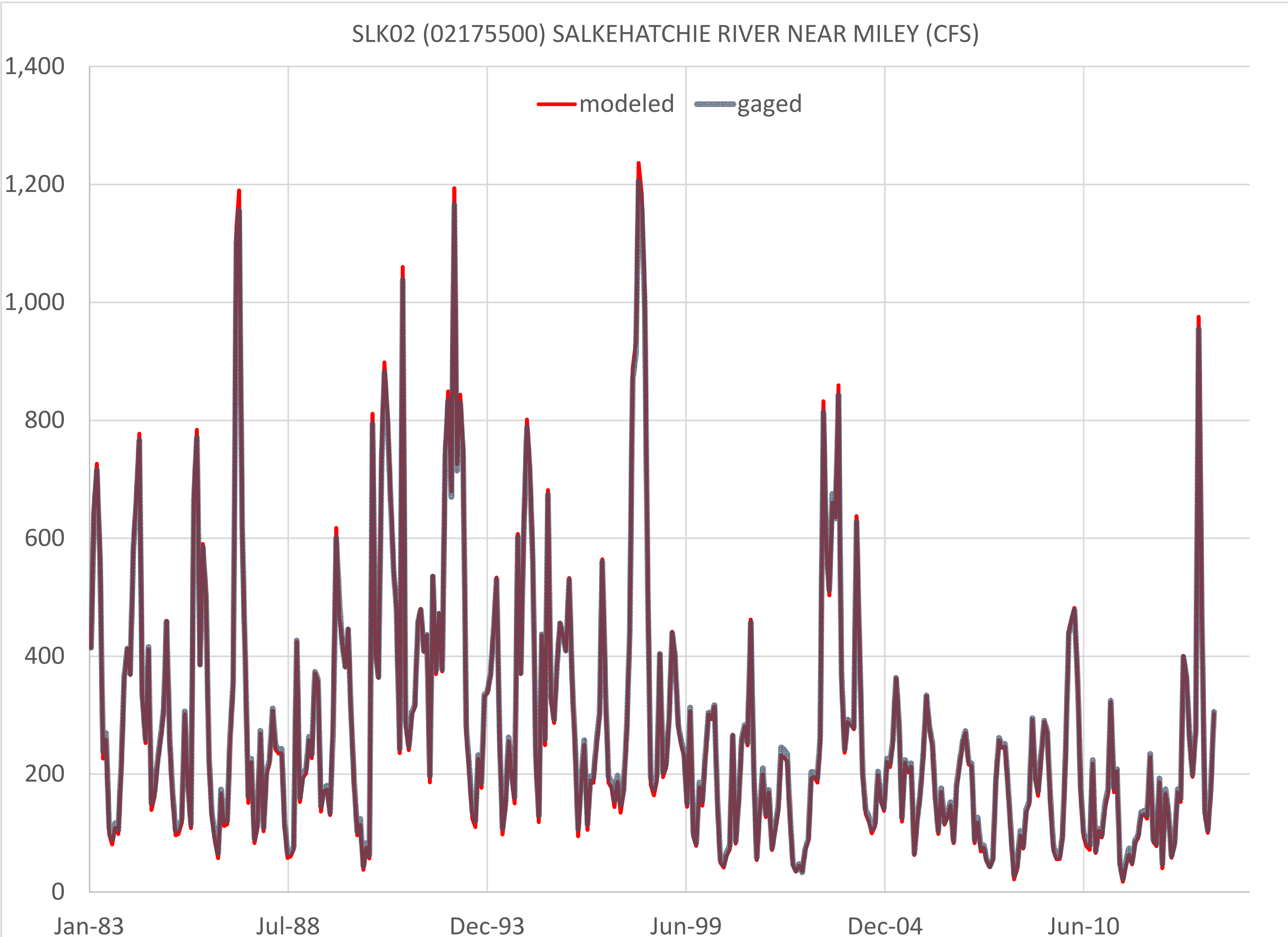

SLK01 (02175445) SAVANNAH CREEK AT EHRHARDT (CFS)
Annual Average Flow
gaged
modeled
12
10
8
6
4
2
0
1983
1988
1993
1998
2003
2008
2013

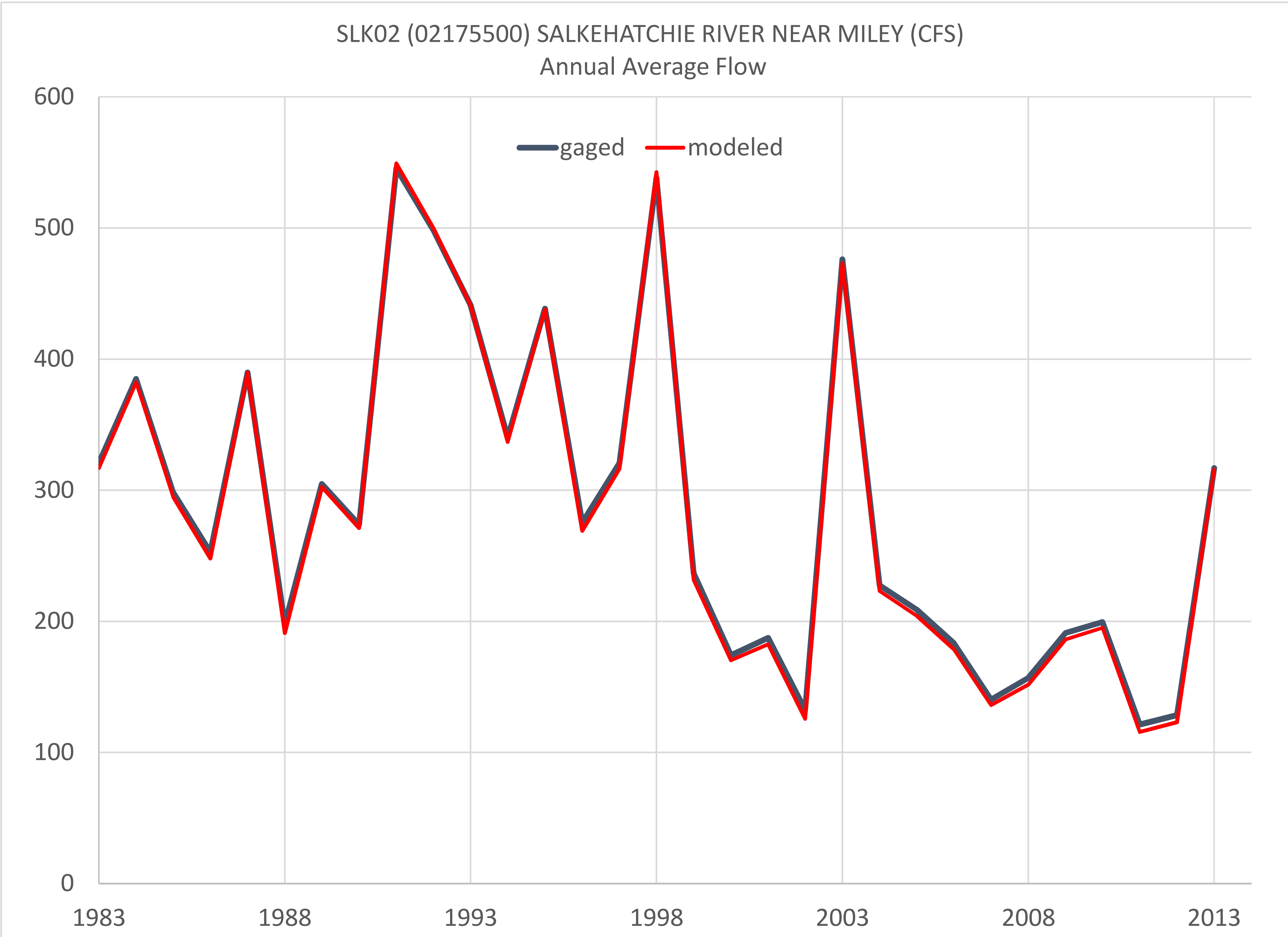

SLK01 (02175445) SAVANNAH CREEK AT EHRHARDT
Monthly Mean Flow (CFS)
gaged
modeled
12
10
8
6
4
2
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

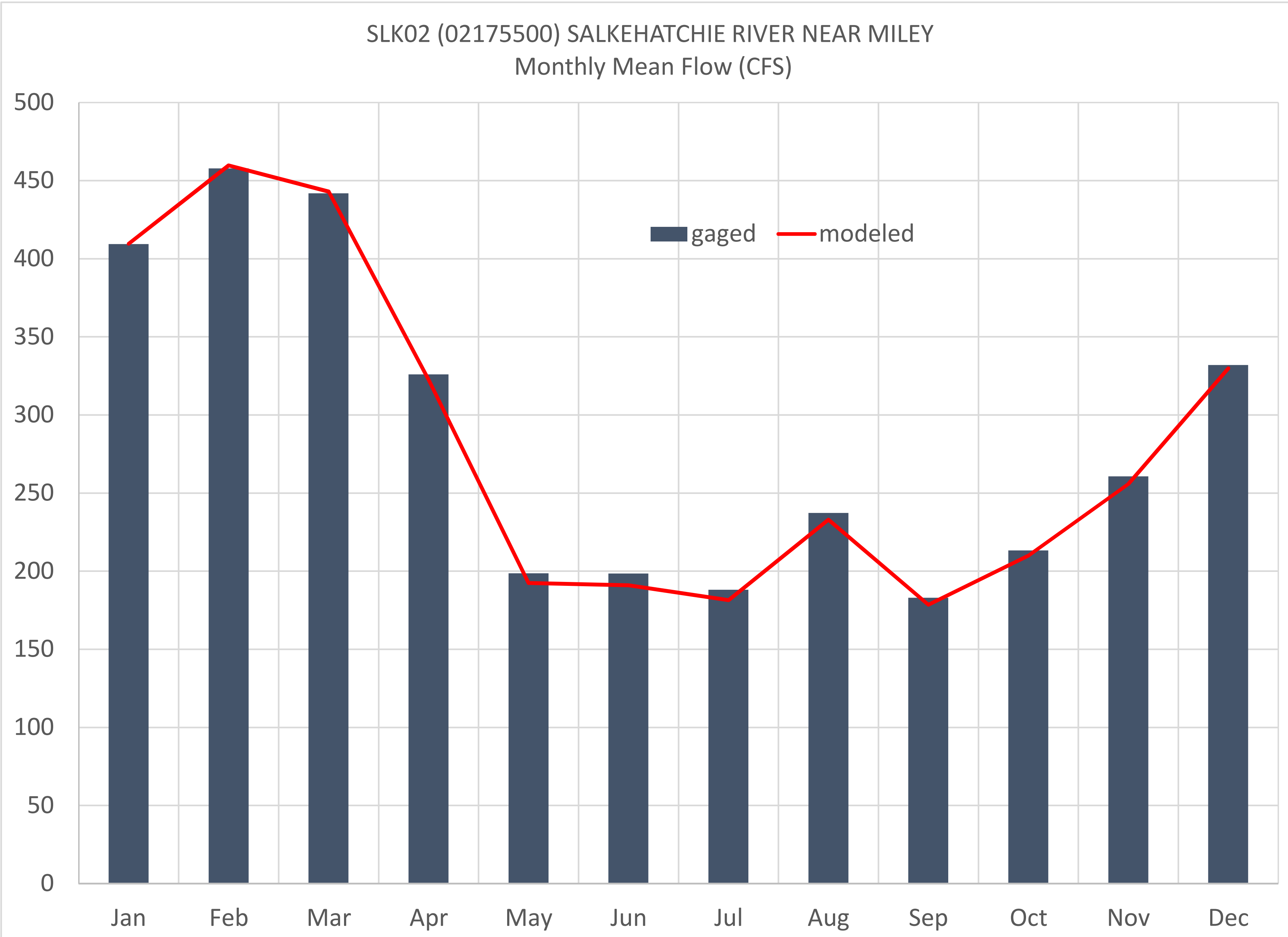


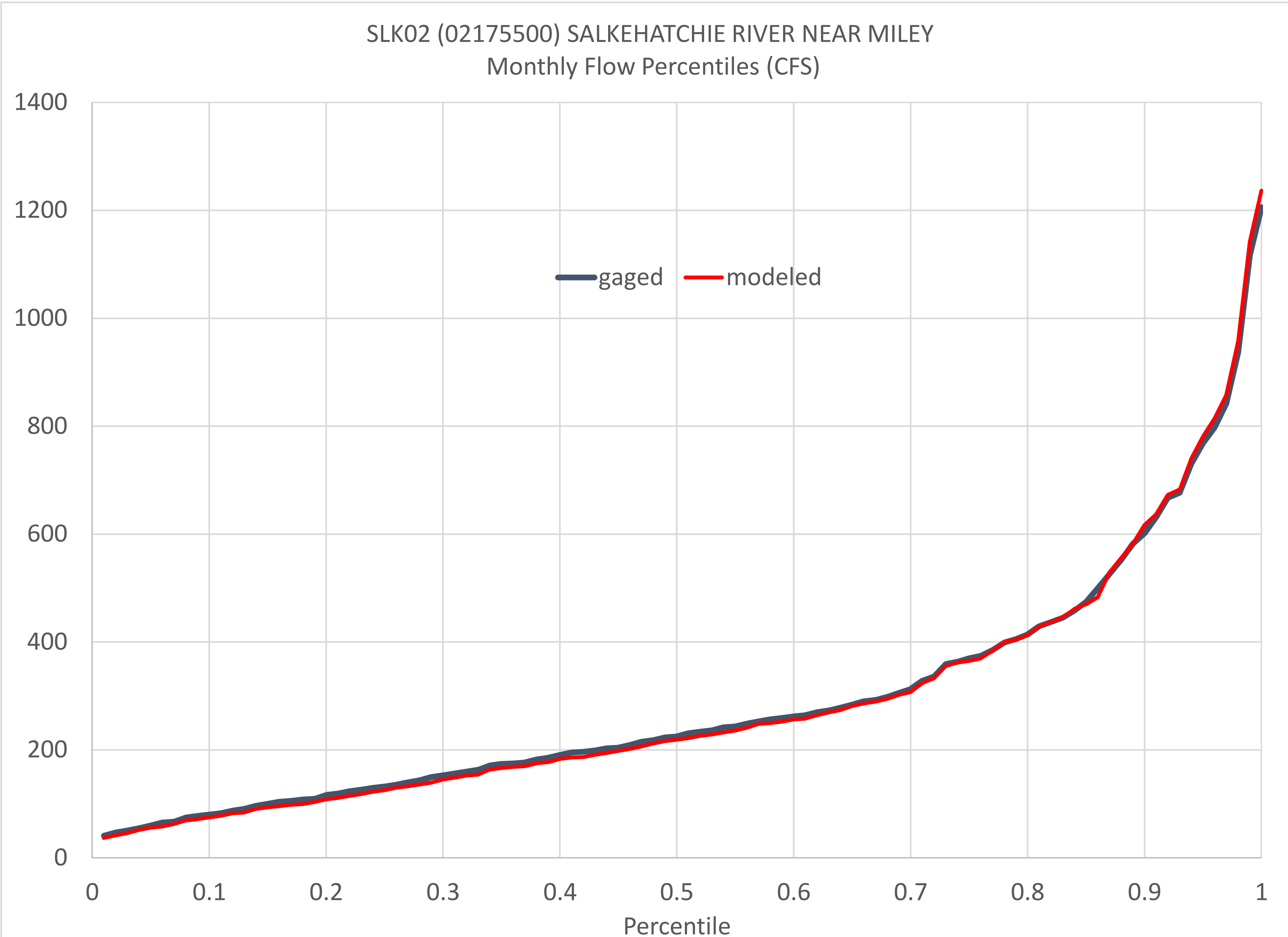
SLK01 (02175445) SAVANNAH CREEK AT EHRHARDT
Monthly Flow Percentiles (CFS)
25
20
15
10
5
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile
gaged
modeled


SLK01 (02175445) SAVANNAH CREEK AT EHRHARDT (CFS)
Monthly Cumulative Flow (CFS)
modeled (cumulative)
gaged (cumulative)
0
20
40
60
80
100
120
140
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

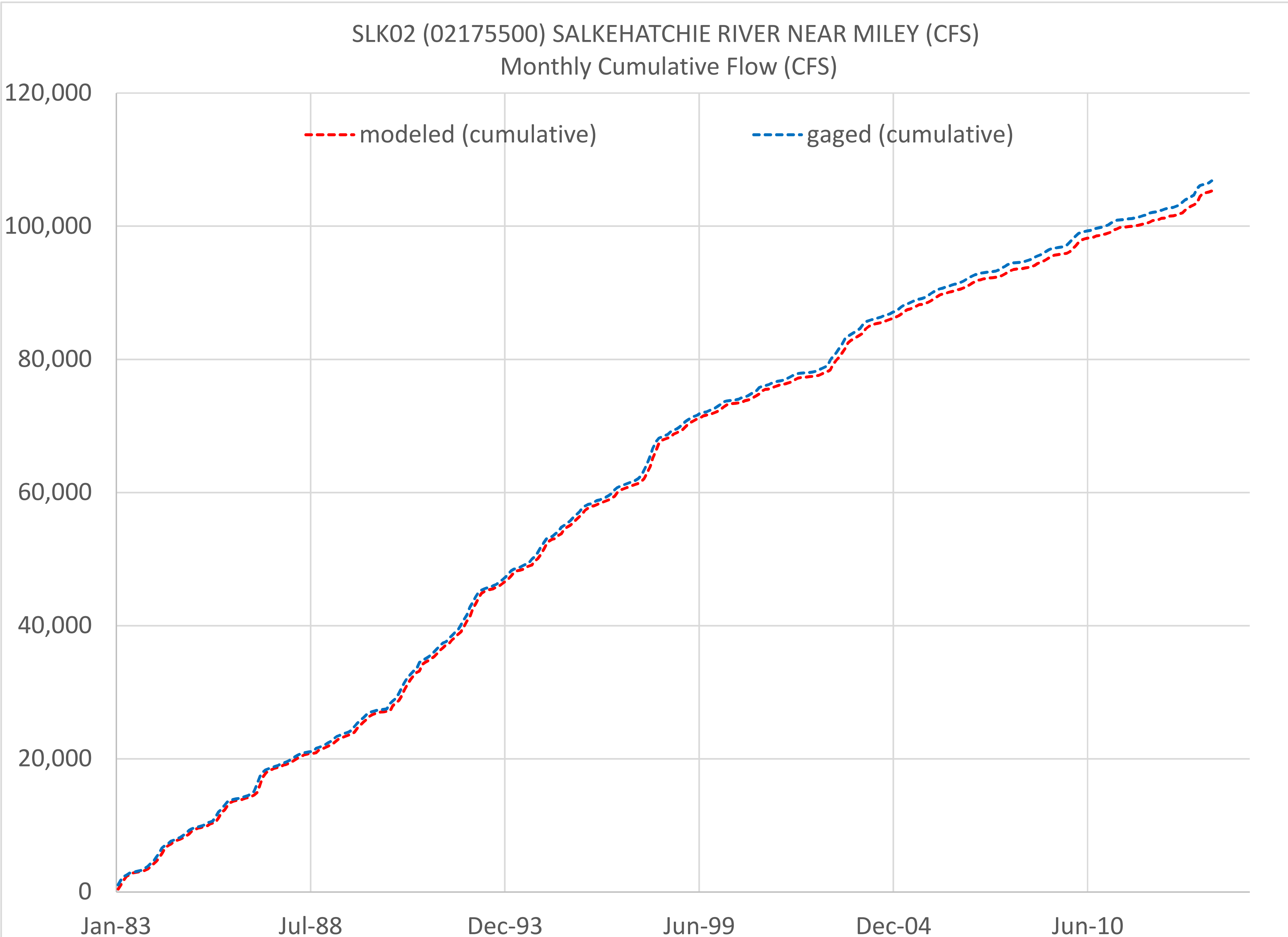

SLK02 (02175500) SALKEHATCHIE RIVER NEAR MILEY (CFS)
modeled
gaged
1,400
1,200
1,000
800
600
400
200
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10


SLK02 (02175500) SALKEHATCHIE RIVER NEAR MILEY (CFS)
Annual Average Flow
gaged
modeled
600
500
400
300
200
100
0
1983
1988
1993
1998
2003
2008
2013

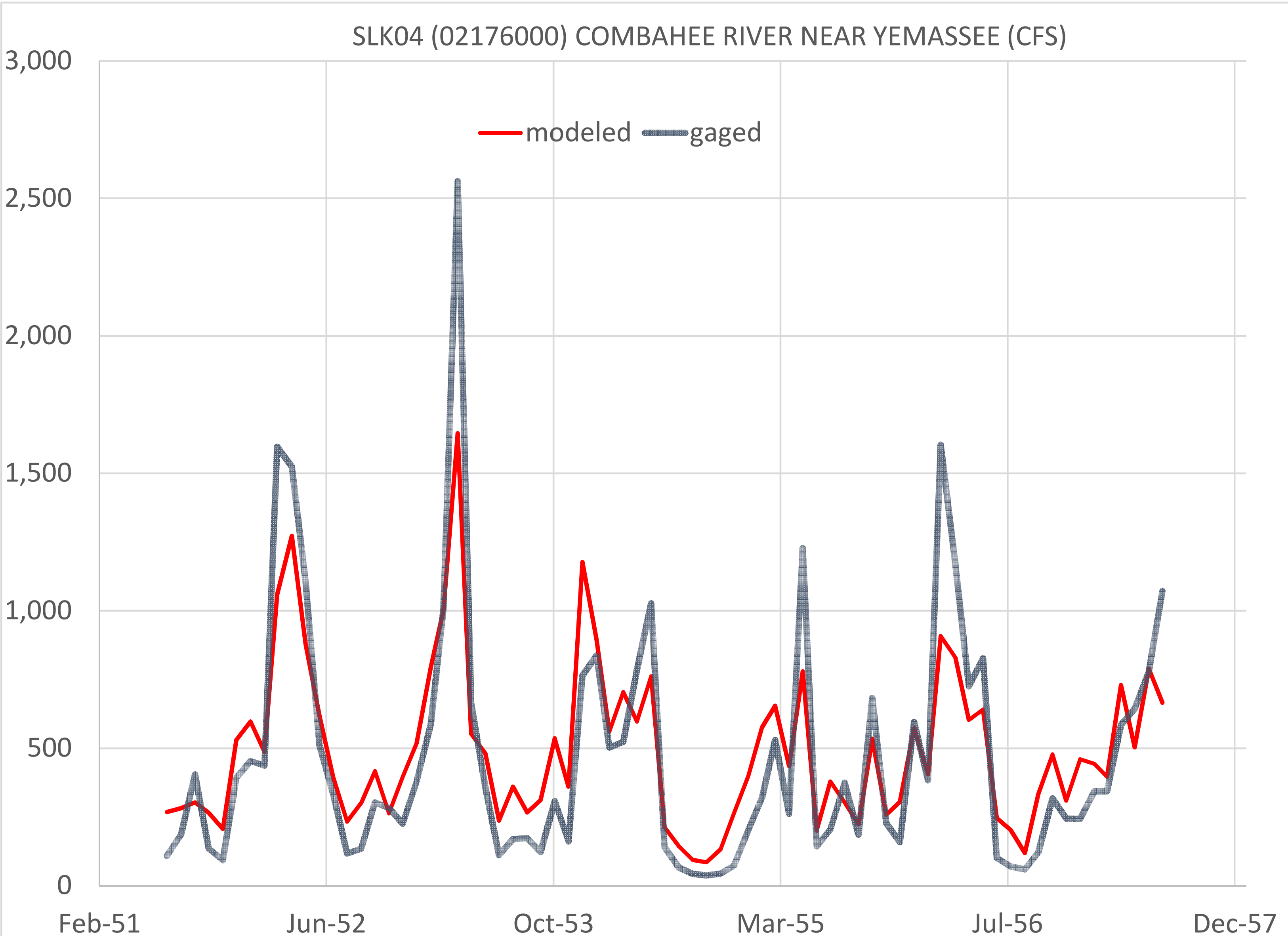

SLK02 (02175500) SALKEHATCHIE RIVER NEAR MILEY
Monthly Mean Flow (CFS)
gaged
modeled
500
450
400
350
300
250
200
150
100
50
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

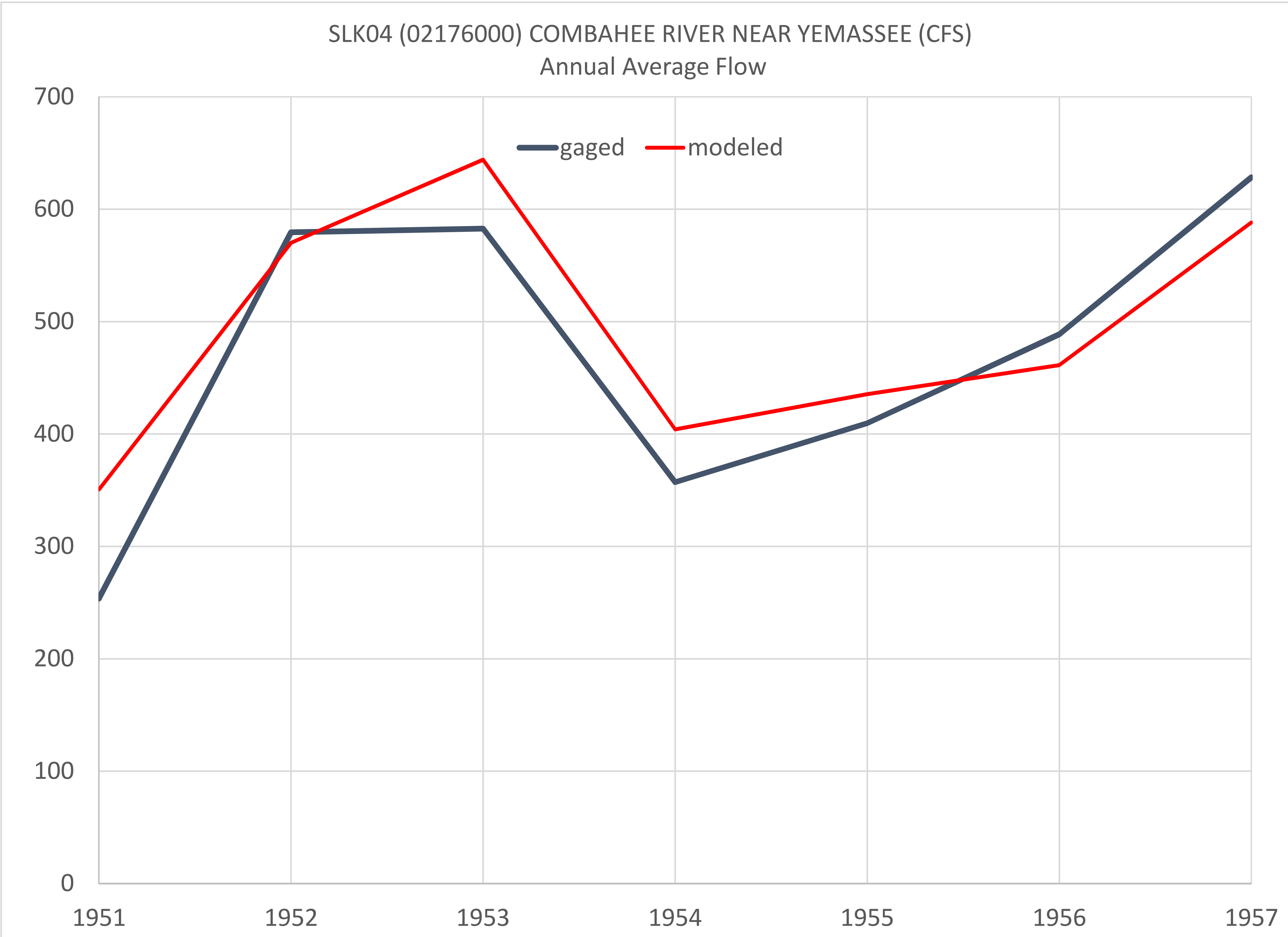


SLK02 (02175500) SALKEHATCHIE RIVER NEAR MILEY
Monthly Flow Percentiles (CFS)
gaged
modeled
1400
1200
1000
800
600
400
200
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

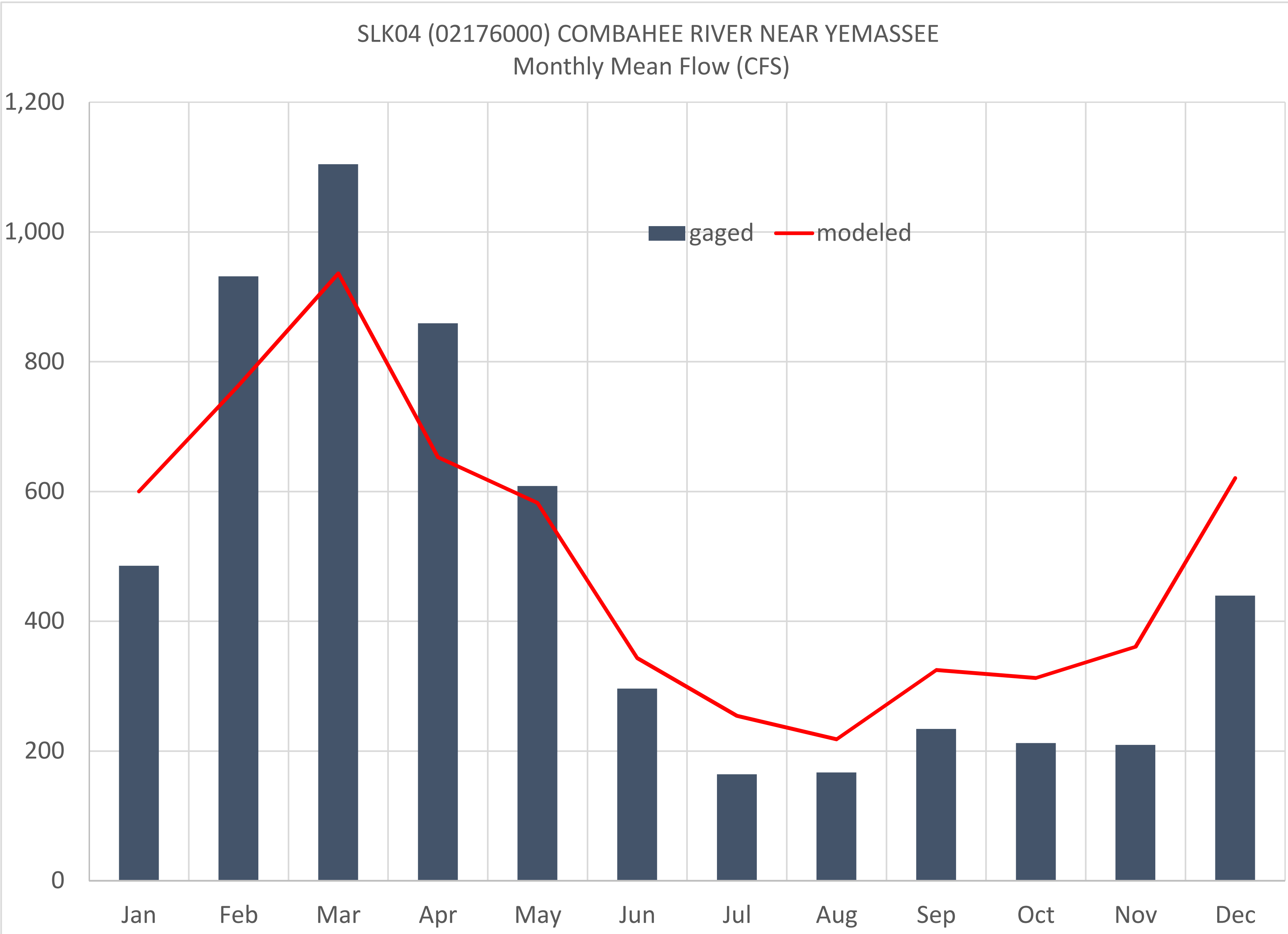


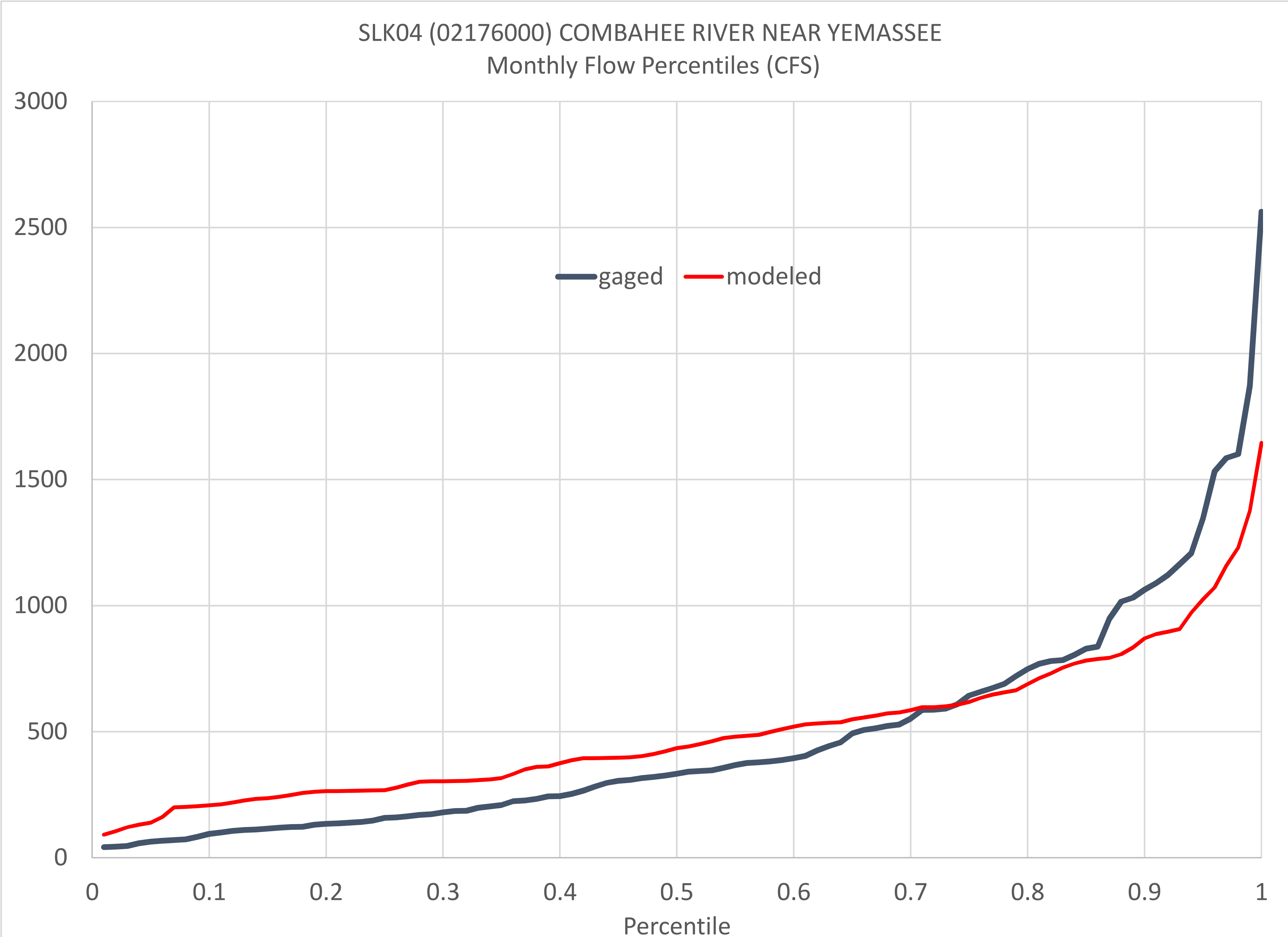
SLK02 (02175500) SALKEHATCHIE RIVER NEAR MILEY (CFS)
Monthly Cumulative Flow (CFS)
modeled (cumulative)
gaged (cumulative)
120,000
100,000
80,000
60,000
40,000
20,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

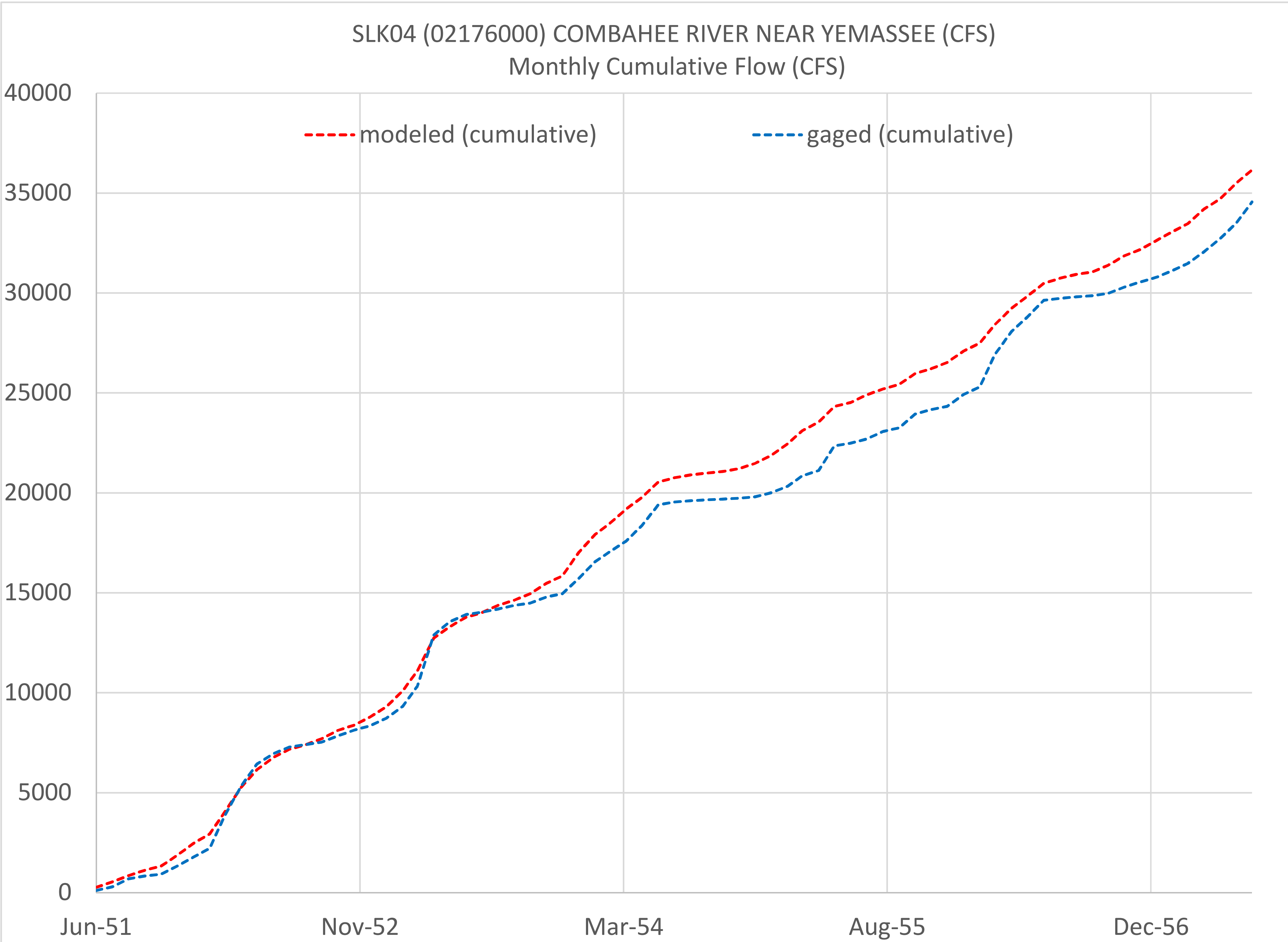

SLK04 (02176000) COMBAHEE RIVER NEAR YEMASSEE (CFS)
3,000
2,500
2,000
1,500
1,000
500
0
modeled
gaged
Feb-51
Jun-52
Oct-53
Mar-55
Jul-56
Dec-57

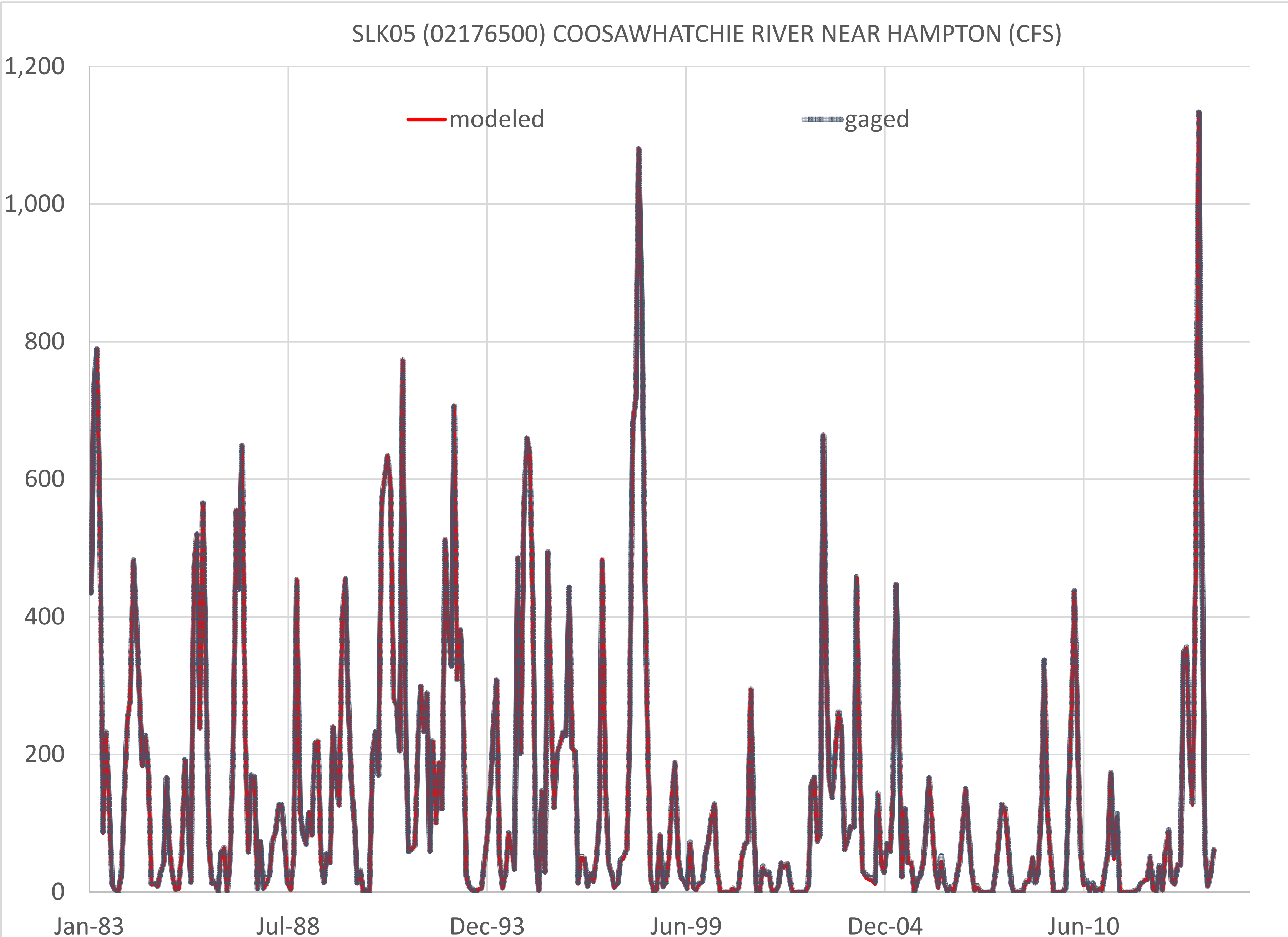


SLK04 (02176000) COMBAHEE RIVER NEAR YEMASSEE (CFS)
Annual Average Flow
gaged
modeled
700
600
500
400
300
200
100
0
1951
1952
1953
1954
1955
1956
1957

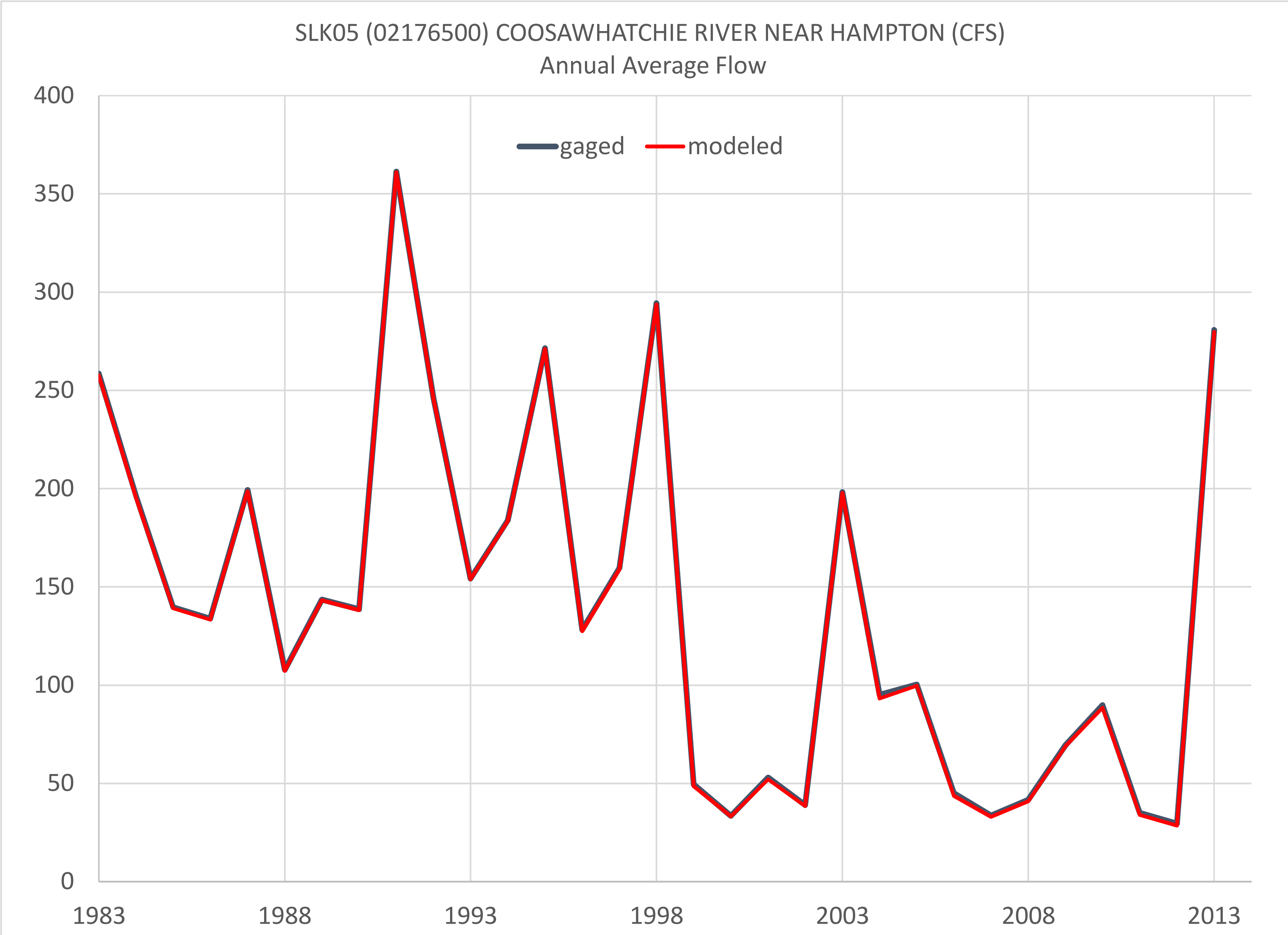

SLK04 (02176000) COMBAHEE RIVER NEAR YEMASSEE
Monthly Mean Flow (CFS)
1,200
1,000
800
600
400
200
0
gaged
modeled
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

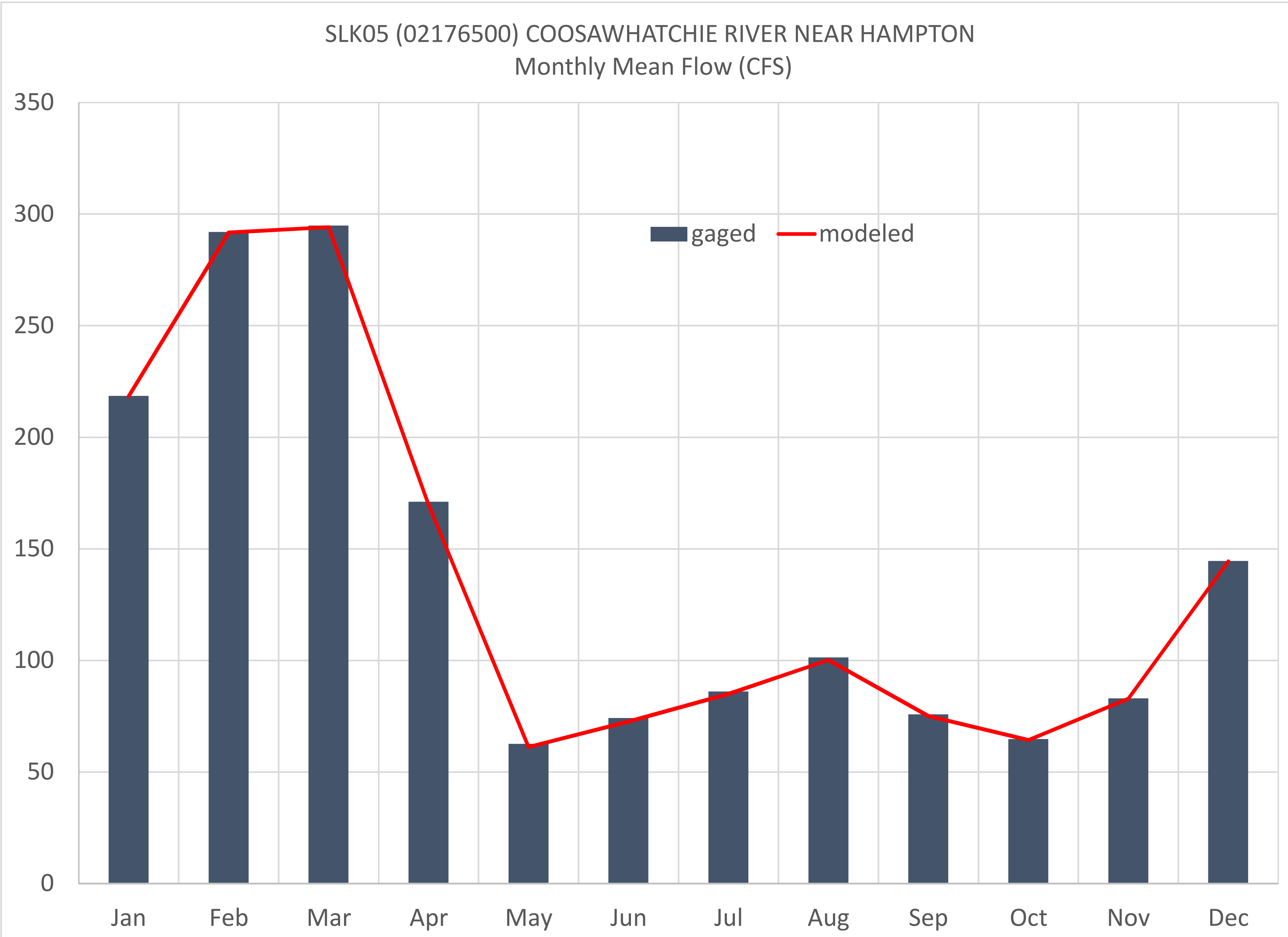

SLK04 (02176000) COMBAHEE RIVER NEAR YEMASSEE
Monthly Flow Percentiles (CFS)
3000
2500
2000
1500
1000
500
0
gaged
modeled
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile


SLK04 (02176000) COMBAHEE RIVER NEAR YEMASSEE (CFS)
Monthly Cumulative Flow (CFS)
modeled (cumulative)
gaged (cumulative)
40000
35000
30000
25000
20000
15000
10000
5000
0
Jun-51
Nov-52
Mar-54
Aug-55
Dec-56

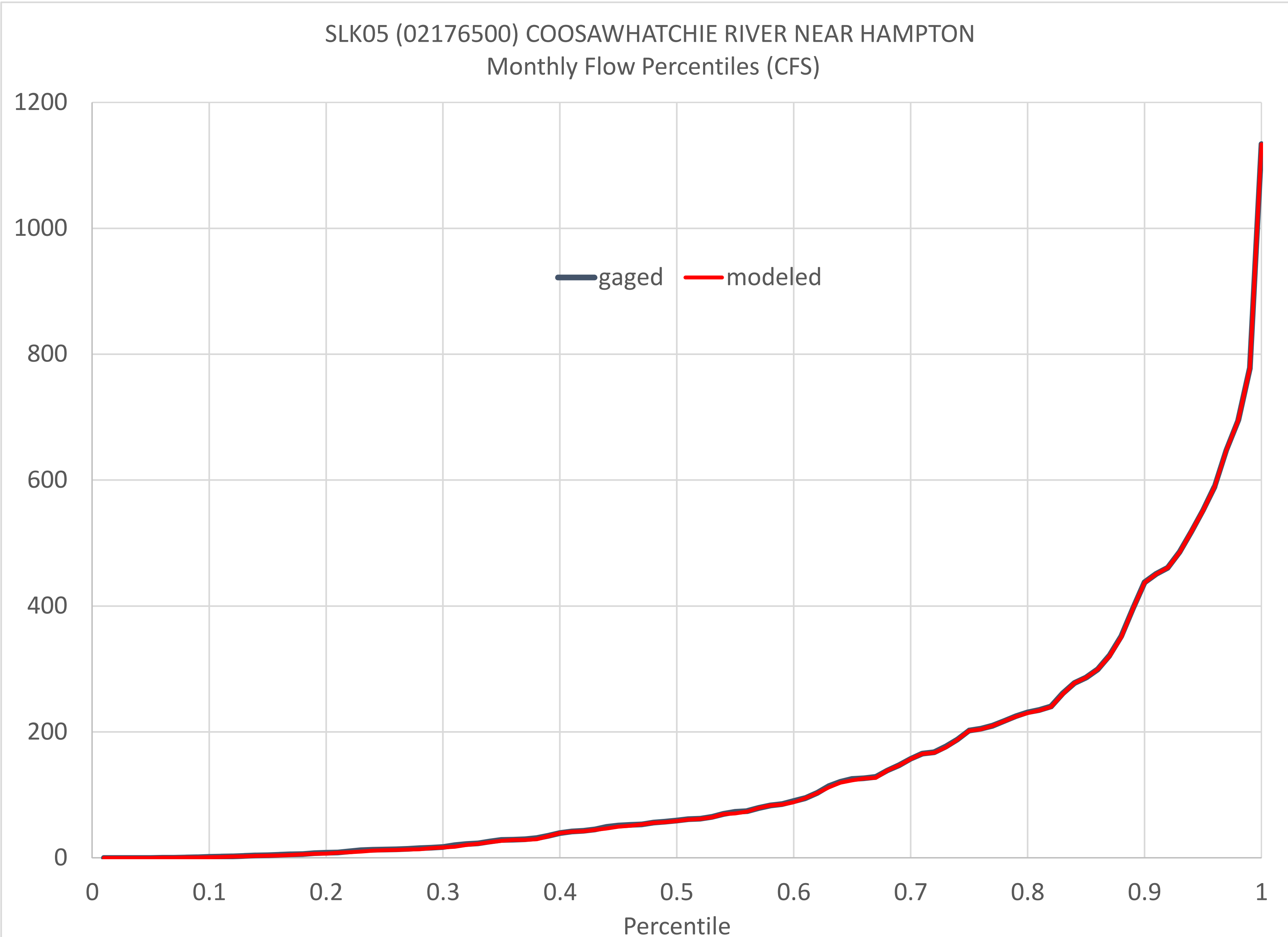


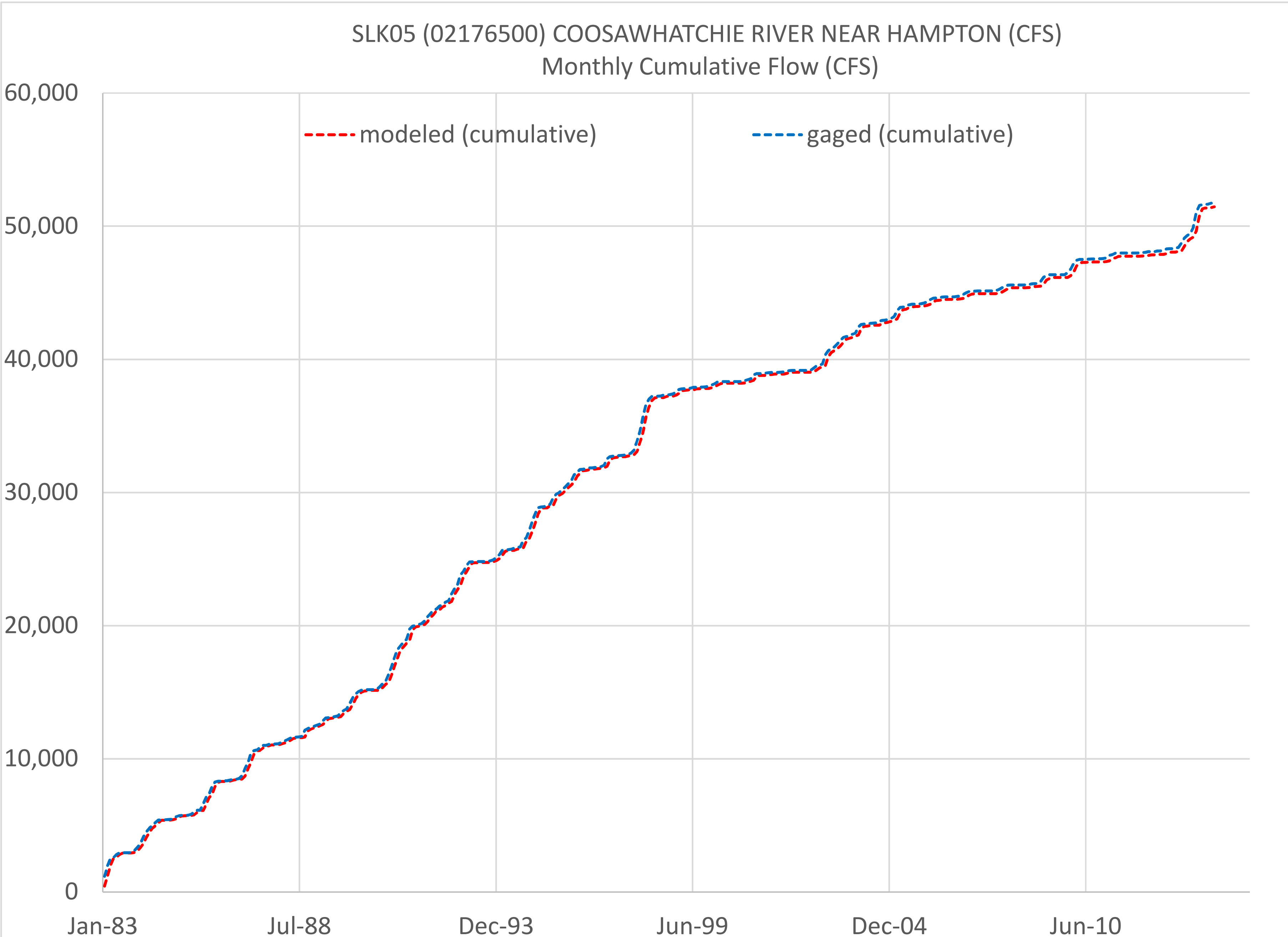
SLK05 (02176500) COOSAWHATCHIE RIVER NEAR HAMPTON (CFS)
1,200
1,000
800
600
400
200
0
modeled
gaged
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

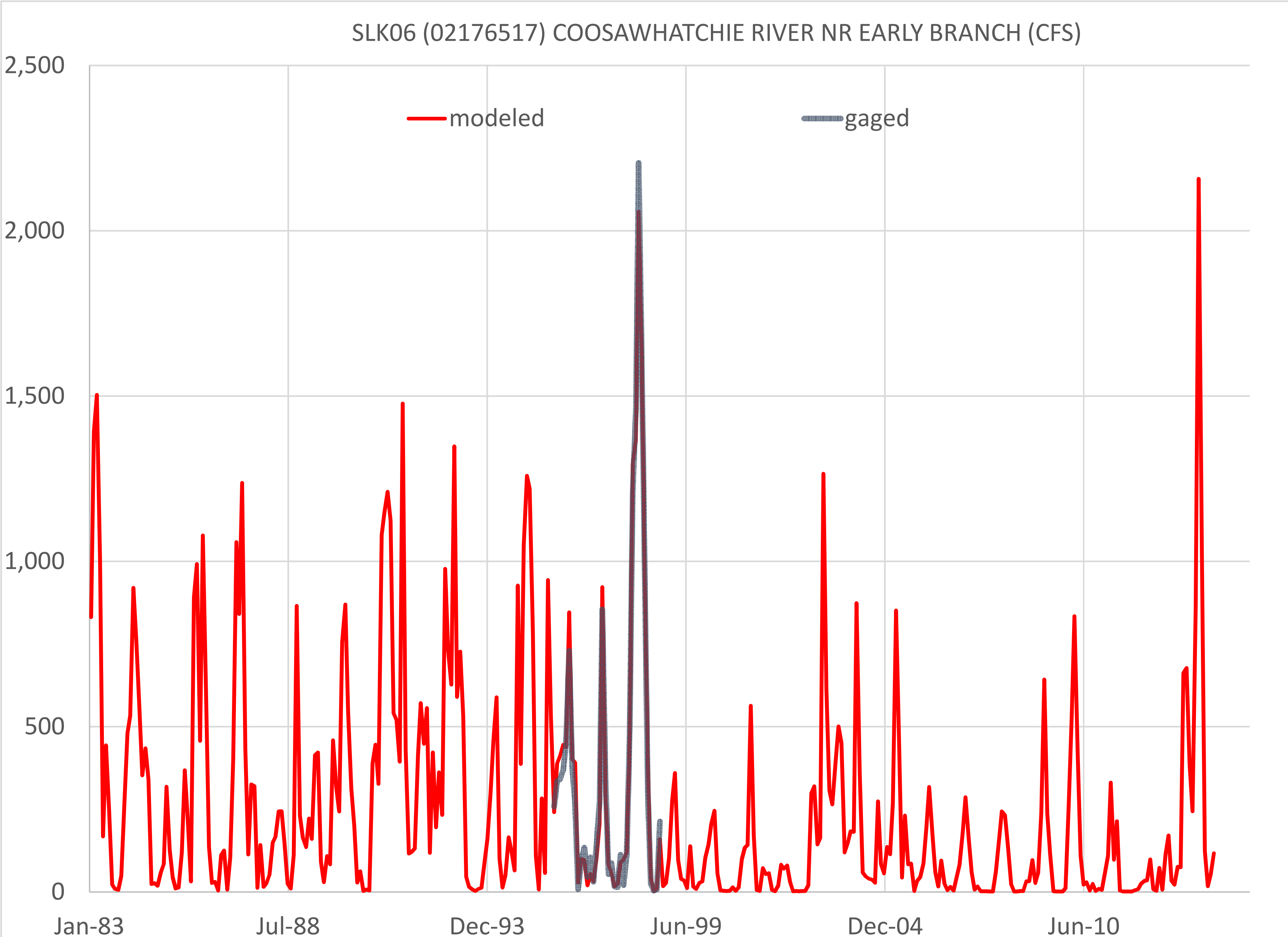

SLK05 (02176500) COOSAWHATCHIE RIVER NEAR HAMPTON (CFS)
Annual Average Flow
gaged
modeled
400
350
300
250
200
150
100
50
0
1983
1988
1993
1998
2003
2008
2013



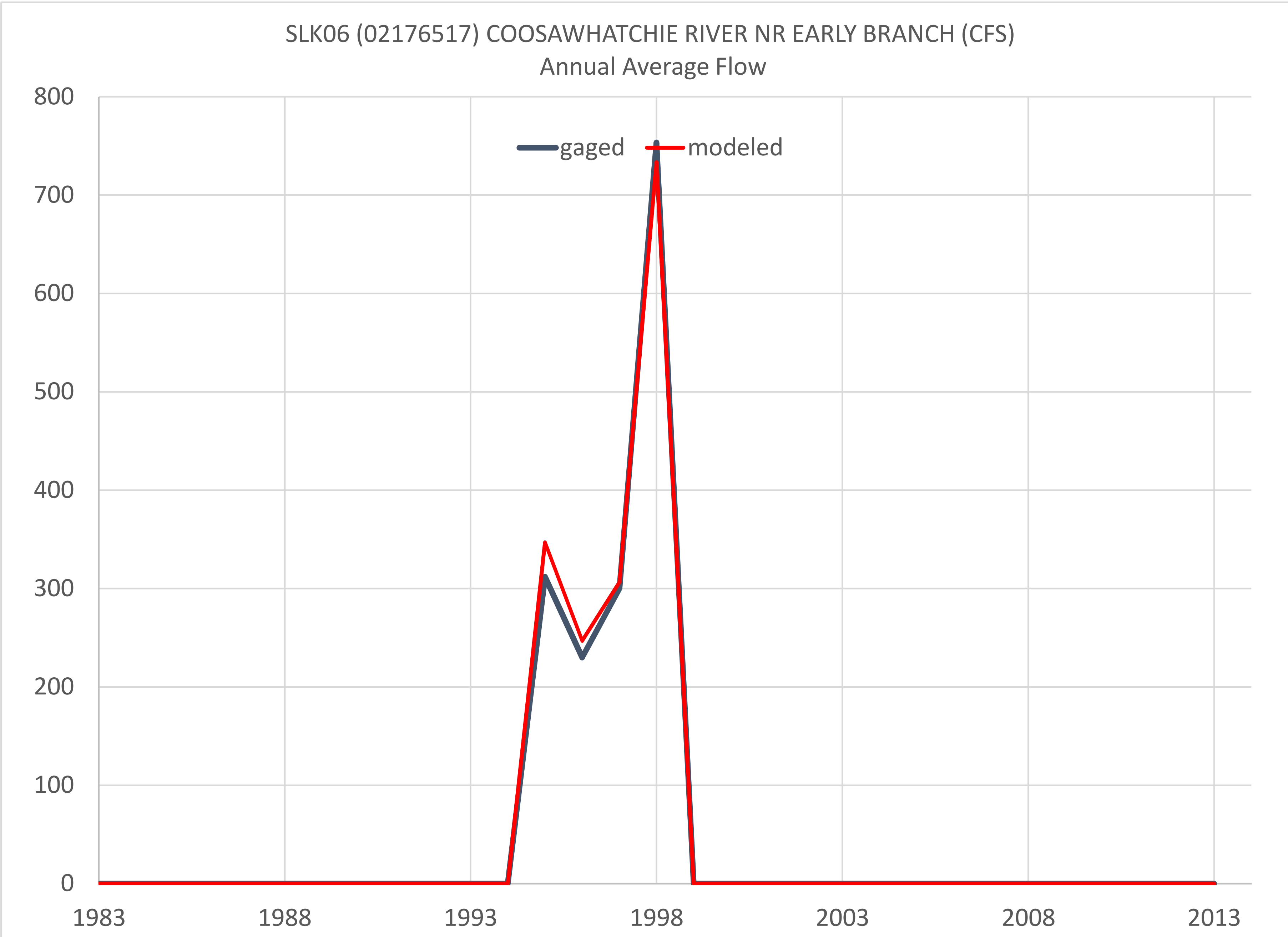
SLK05 (02176500) COOSAWHATCHIE RIVER NEAR HAMPTON
Monthly Mean Flow (CFS)
gaged
modeled
350
300
250
200
150
100
50
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

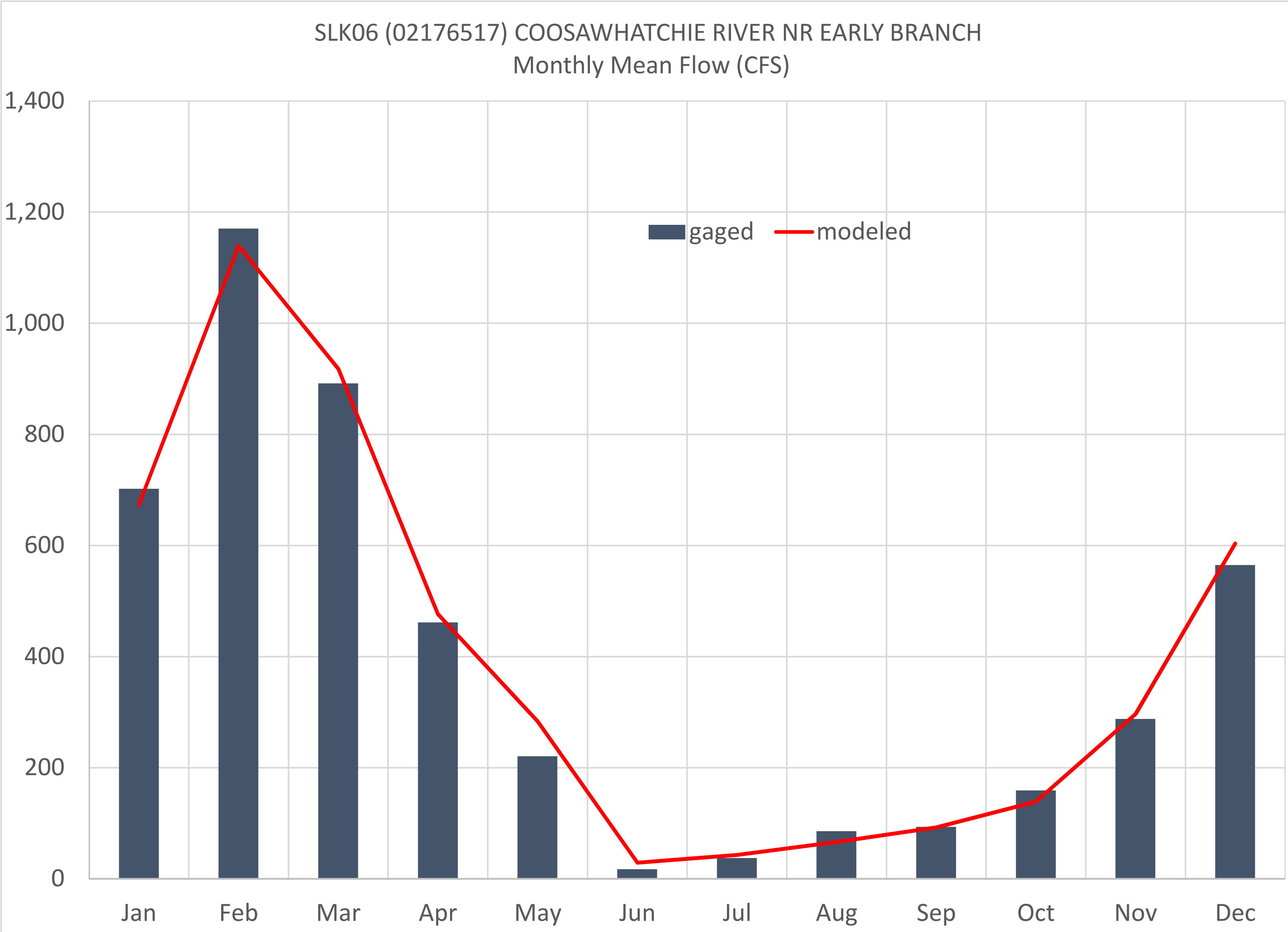

SLK05 (02176500) COOSAWHATCHIE RIVER NEAR HAMPTON
Monthly Flow Percentiles (CFS)
1200
1000
800
600
400
200
0
gaged
modeled
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile


SLK05 (02176500) COOSAWHATCHIE RIVER NEAR HAMPTON (CFS)
Monthly Cumulative Flow (CFS)
modeled (cumulative)
gaged (cumulative)
60,000
50,000
40,000
30,000
20,000
10,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

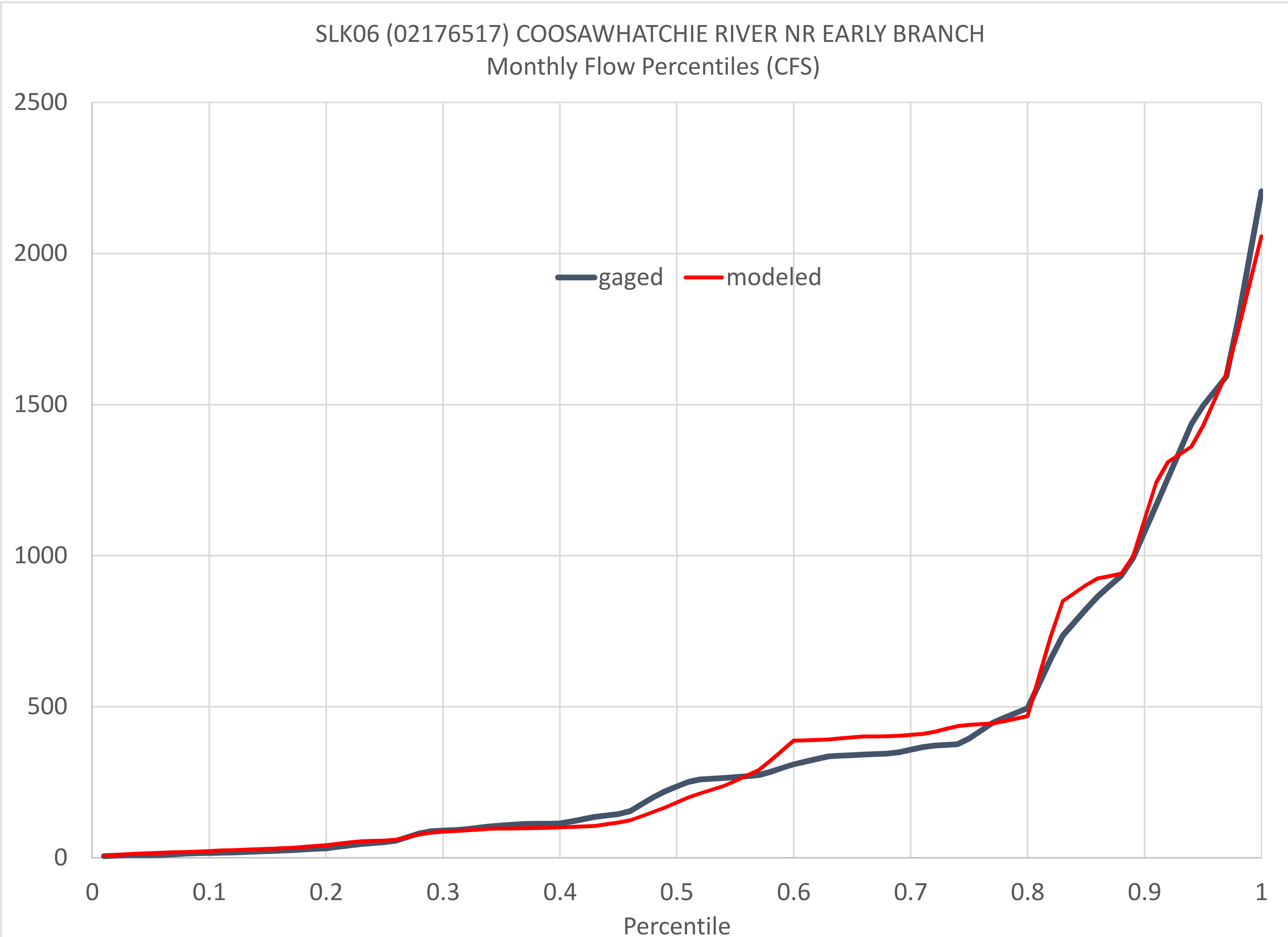


SLK06 (02176517) COOSAWHATCHIE RIVER NR EARLY BRANCH (CFS)
modeled
gaged
2,500
2,000
1,500
1,000
500
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

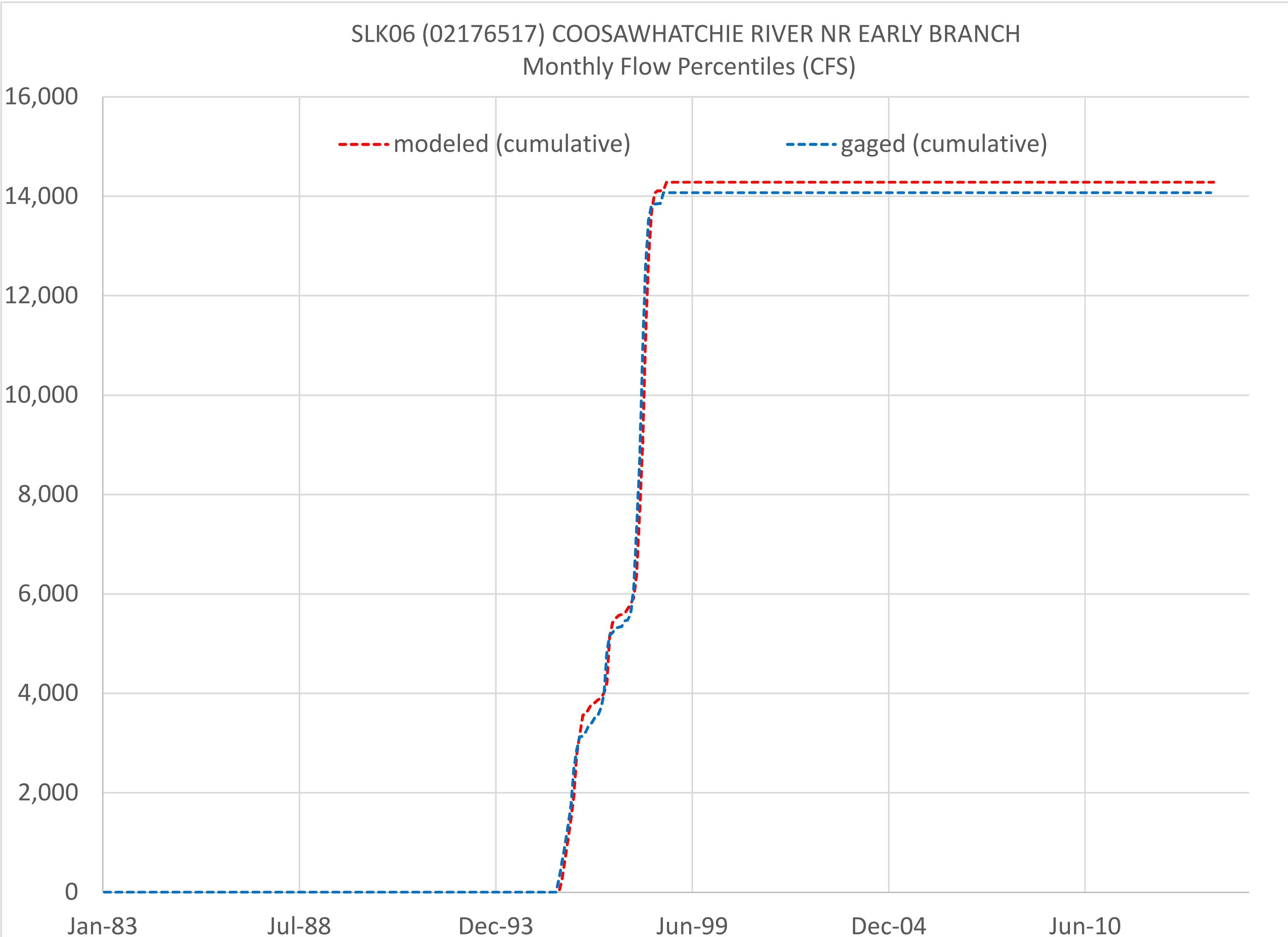

SLK06 (02176517) COOSAWHATCHIE RIVER NR EARLY BRANCH (CFS)
Annual Average Flow
gaged
modeled
800
700
600
500
400
300
200
100
0
1983
1988
1993
1998
2003
2008
2013



SLK06 (02176517) COOSAWHATCHIE RIVER NR EARLY BRANCH
Monthly Mean Flow (CFS)
1,400
1,200
1,000
800
600
400
200
0
gaged
modeled
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec



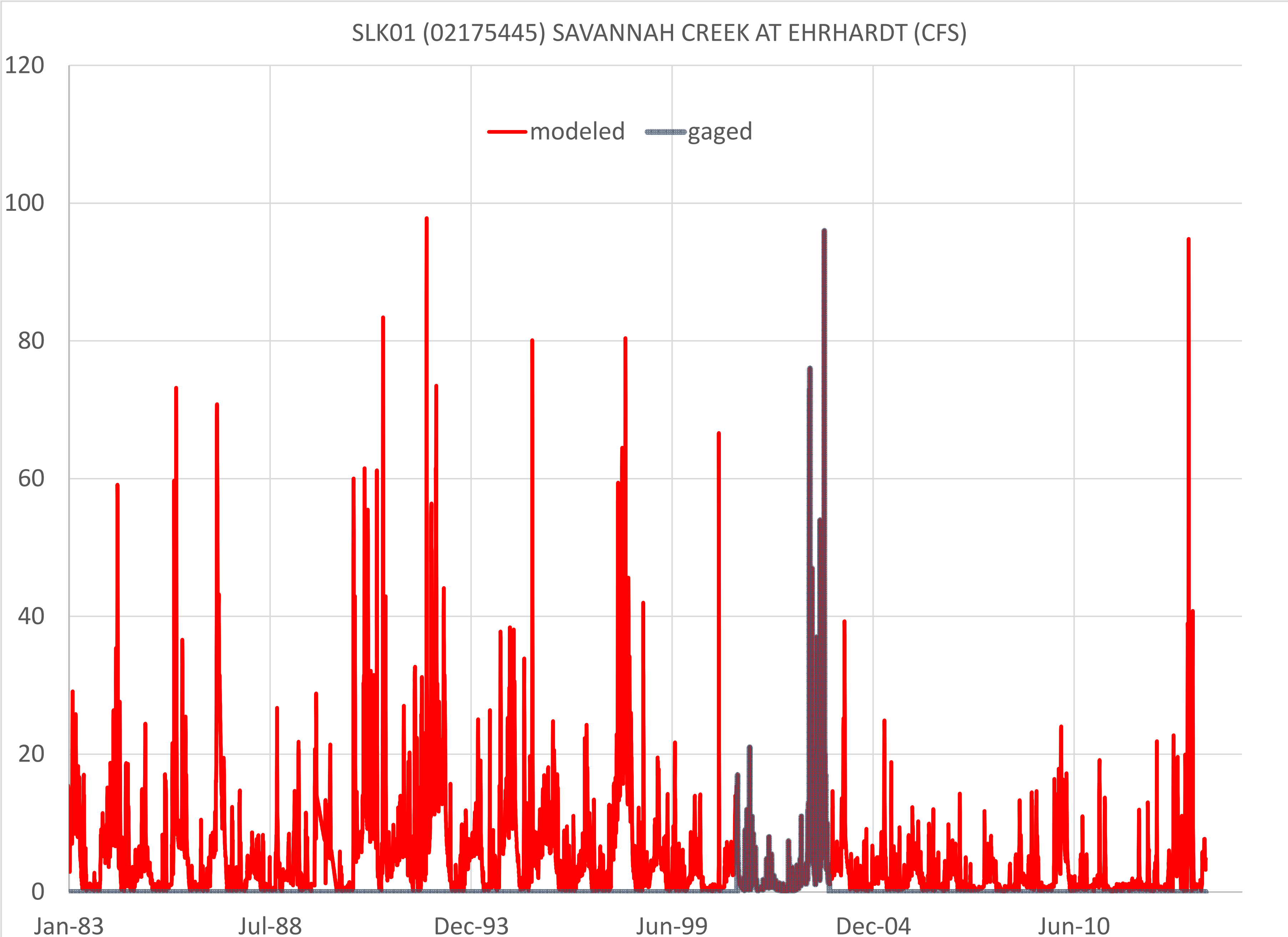
SLK06 (02176517) COOSAWHATCHIE RIVER NR EARLY BRANCH
Monthly Flow Percentiles (CFS)
2500
2000
1500
1000
500
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile
gaged
modeled


SLK06 (02176517) COOSAWHATCHIE RIVER NR EARLY BRANCH
Monthly Flow Percentiles (CFS)
modeled (cumulative)
gaged (cumulative)
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

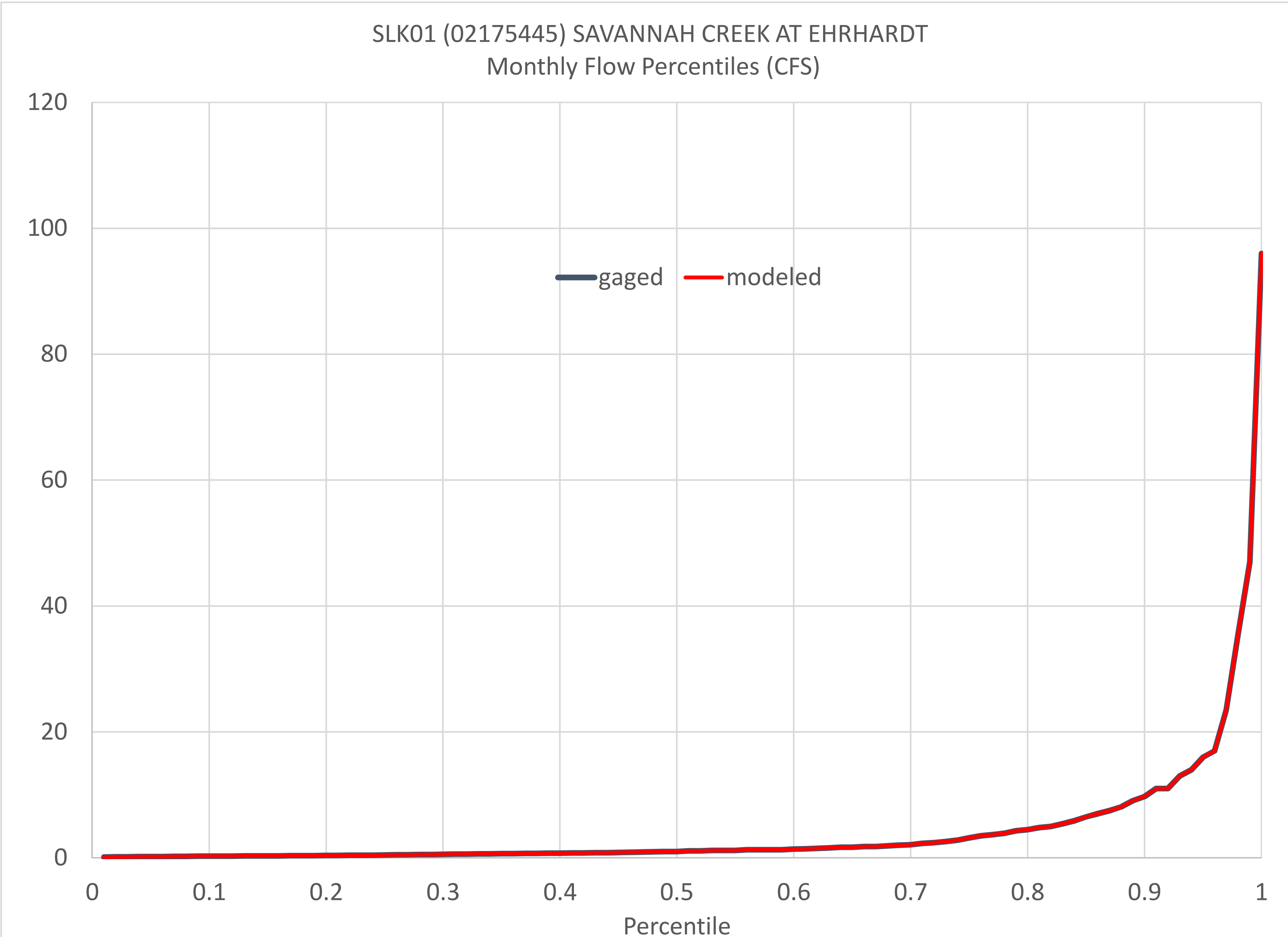
Appendix B

Salkehatchie River Basin Model
Daily Calibration Results

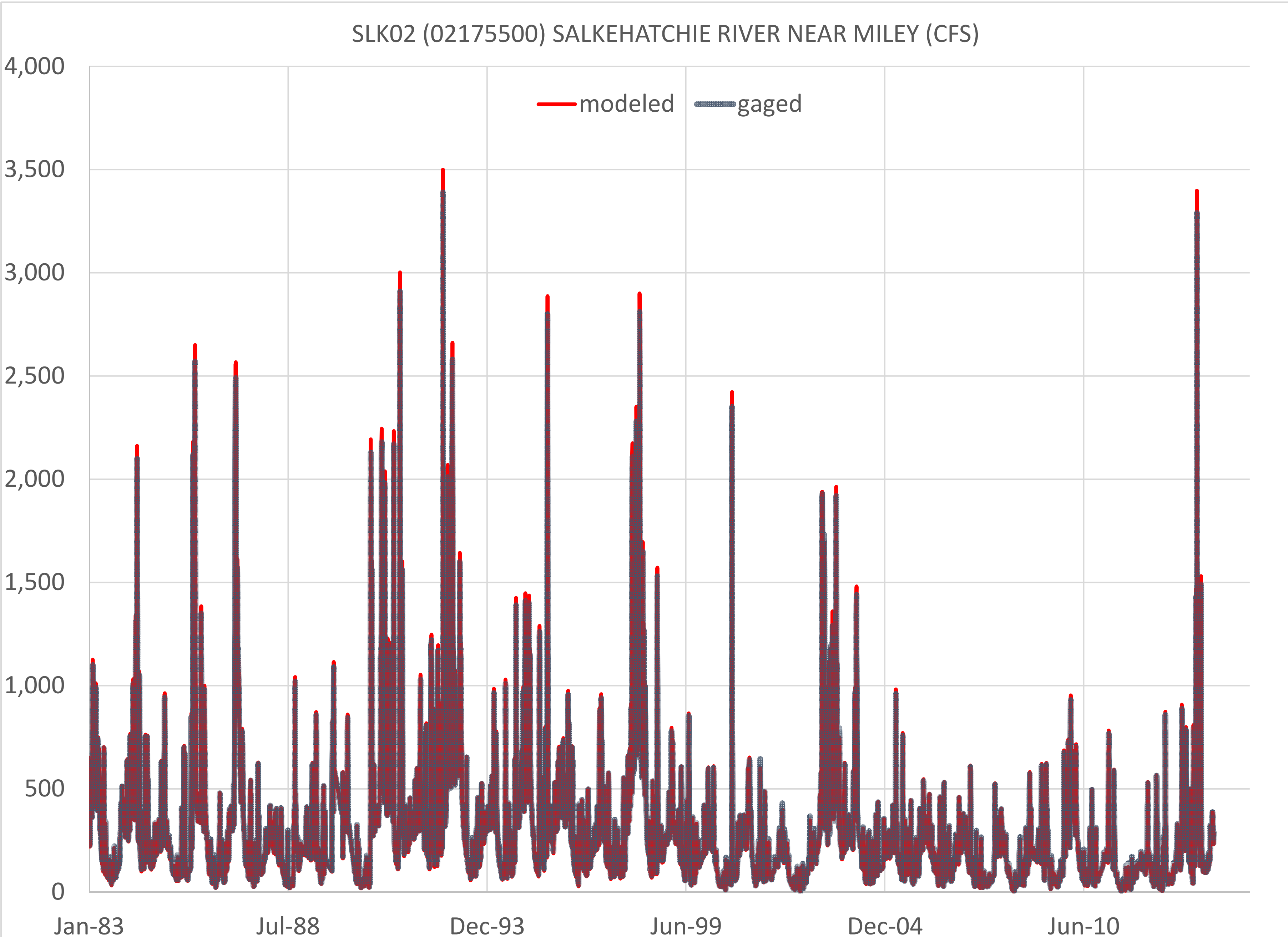
CDM Smith



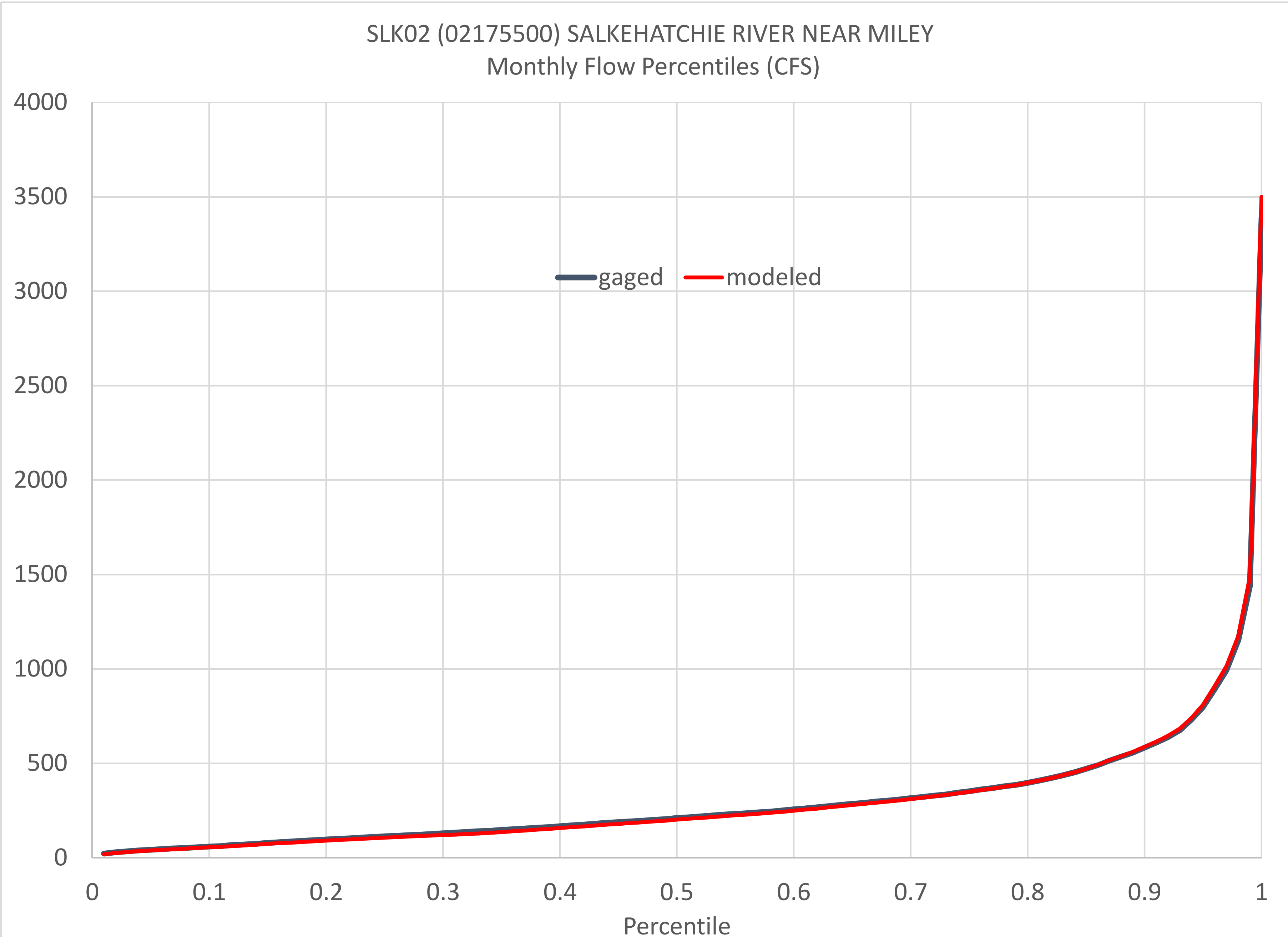
SLK01 (02175445) SAVANNAH CREEK AT EHRHARDT (CFS)
modeled
gaged
120
100
80
60
40
20
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

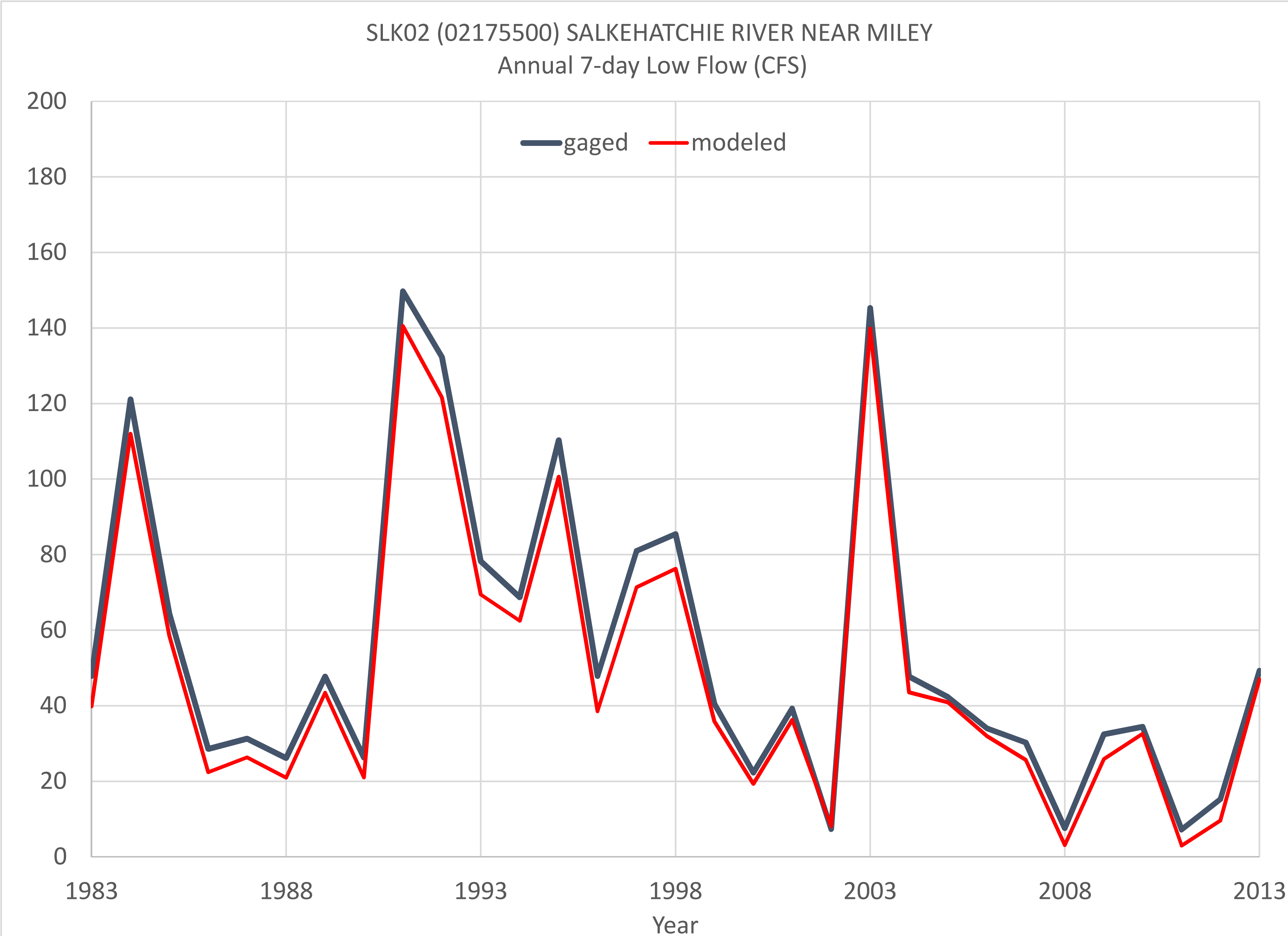


SLK01 (02175445) SAVANNAH CREEK AT EHRHARDT
Monthly Flow Percentiles (CFS)
gaged
modeled
0
20
40
60
80
100
120
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

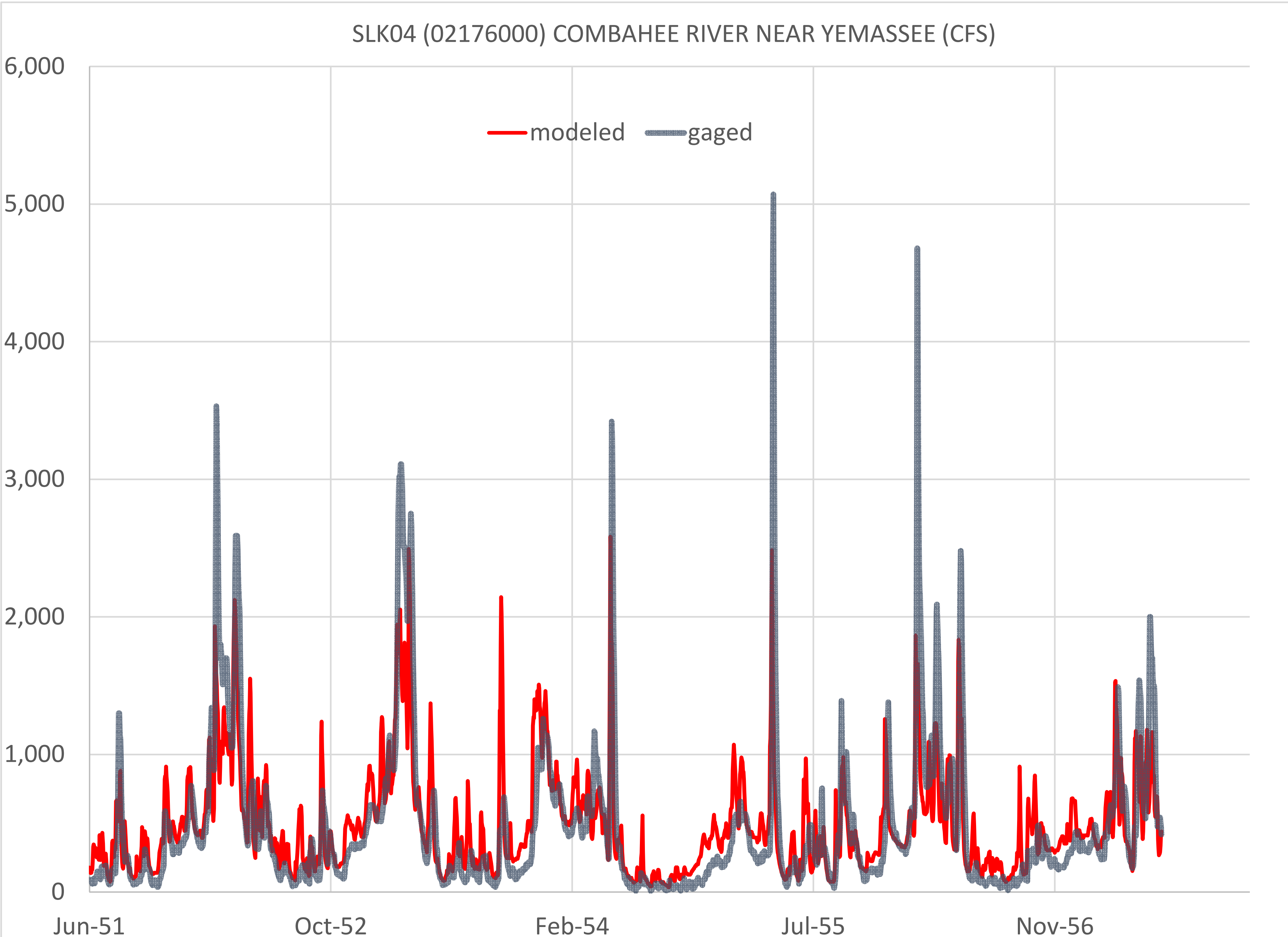


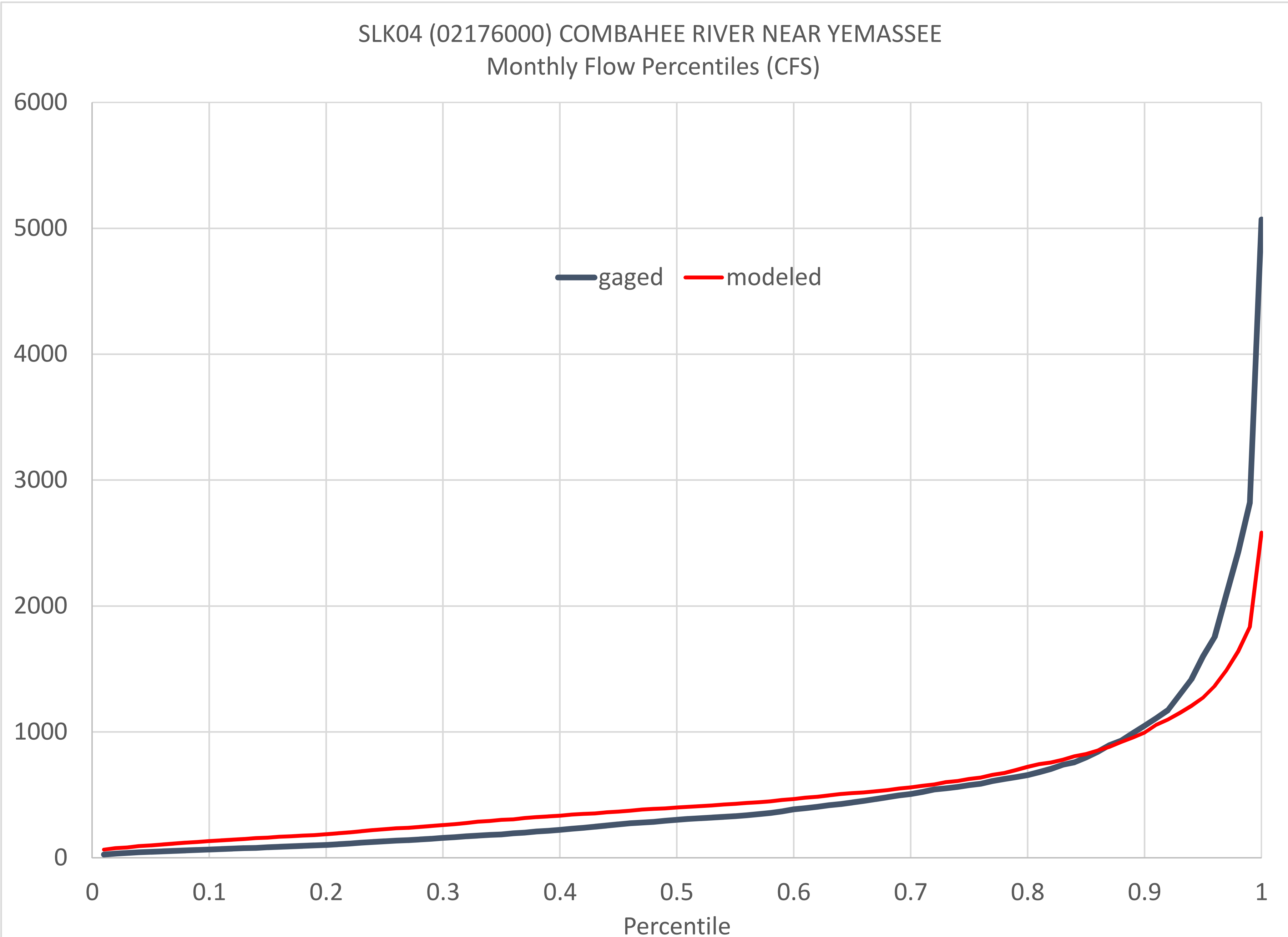
SLK02 (02175500) SALKEHATCHIE RIVER NEAR MILEY (CFS)
modeled
gaged
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

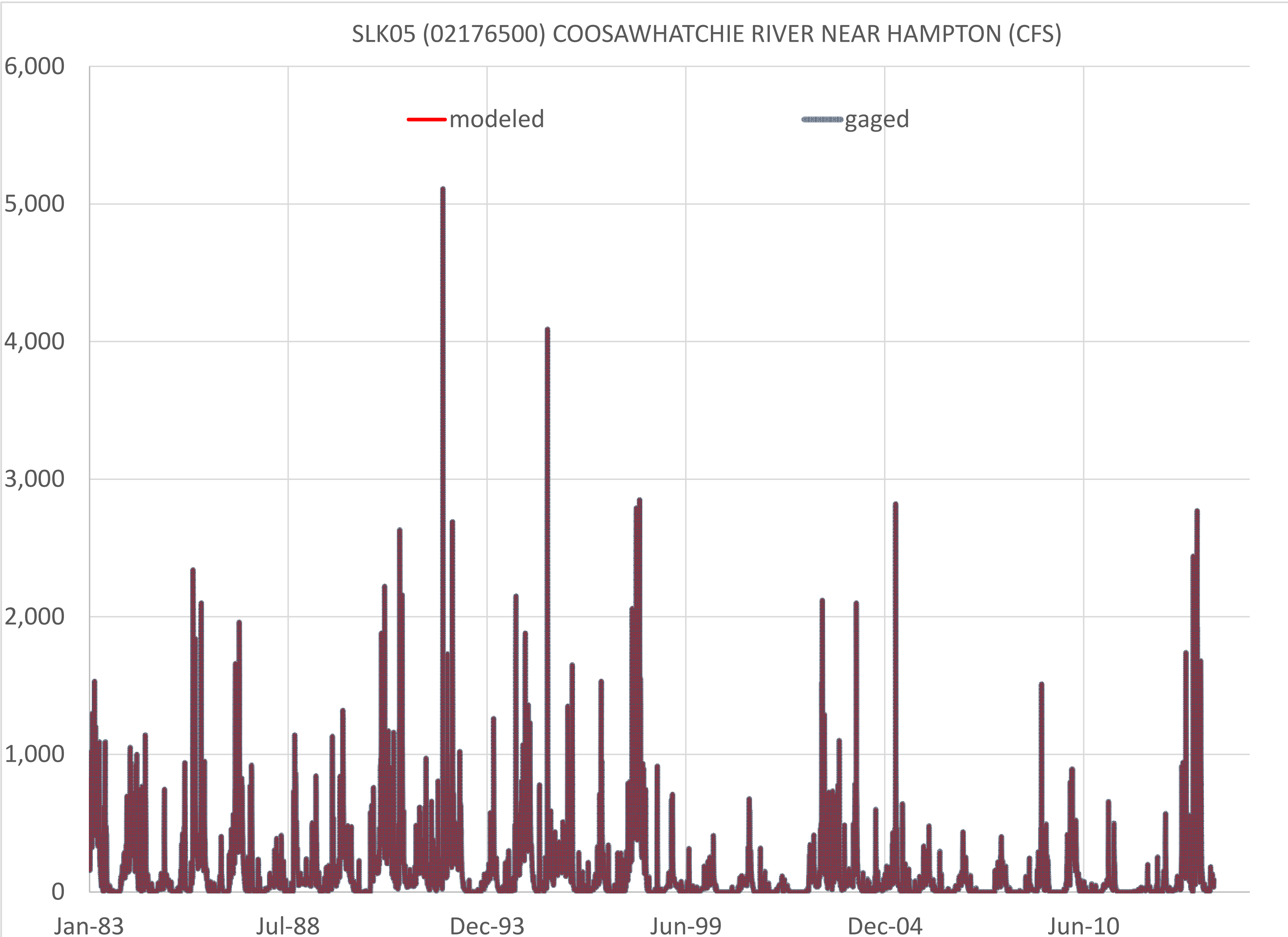

SLK02 (02175500) SALKEHATCHIE RIVER NEAR MILEY
Monthly Flow Percentiles (CFS)
4000
3500
3000
2500
2000
1500
1000
500
0
gaged
modeled
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

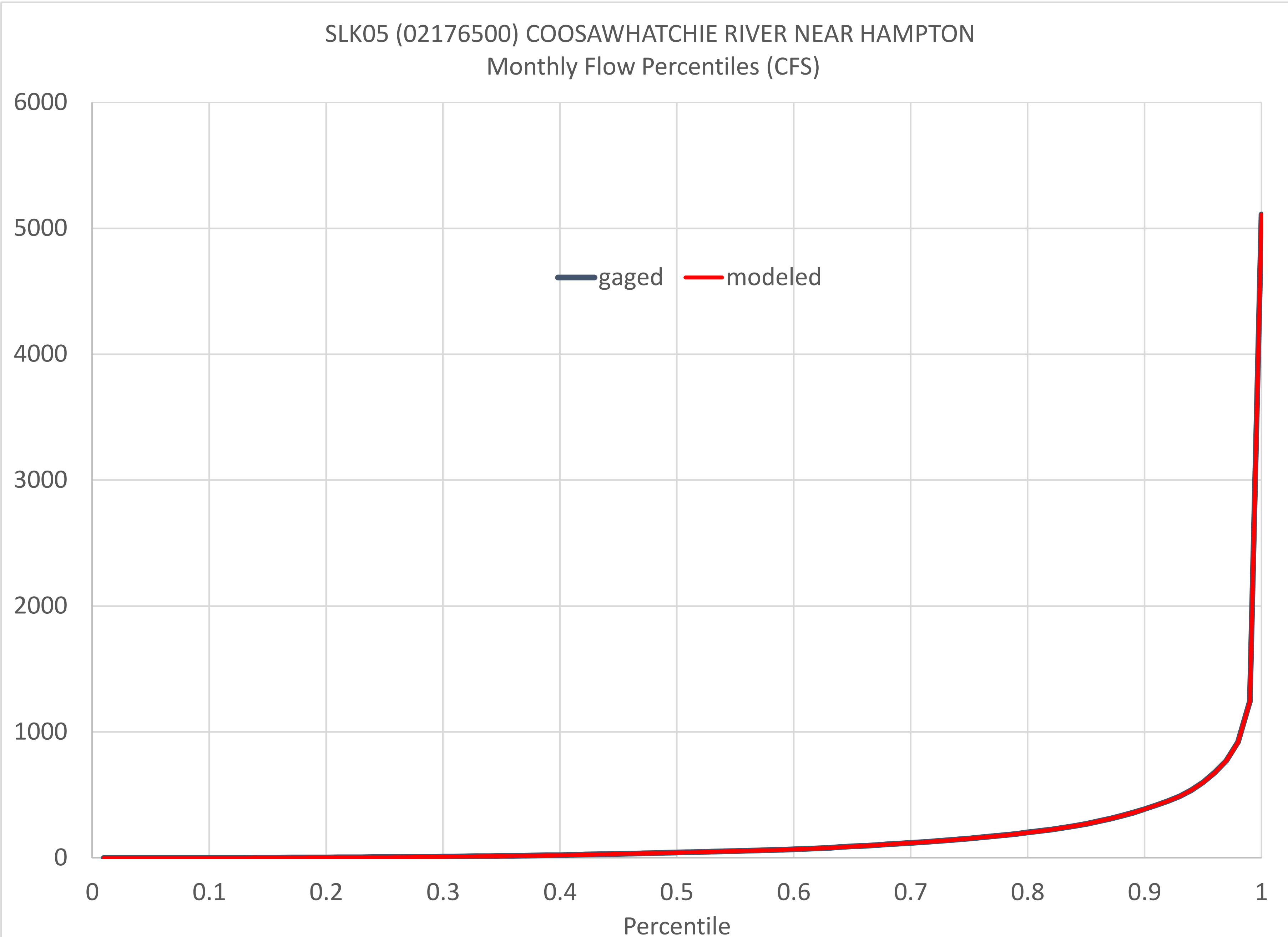


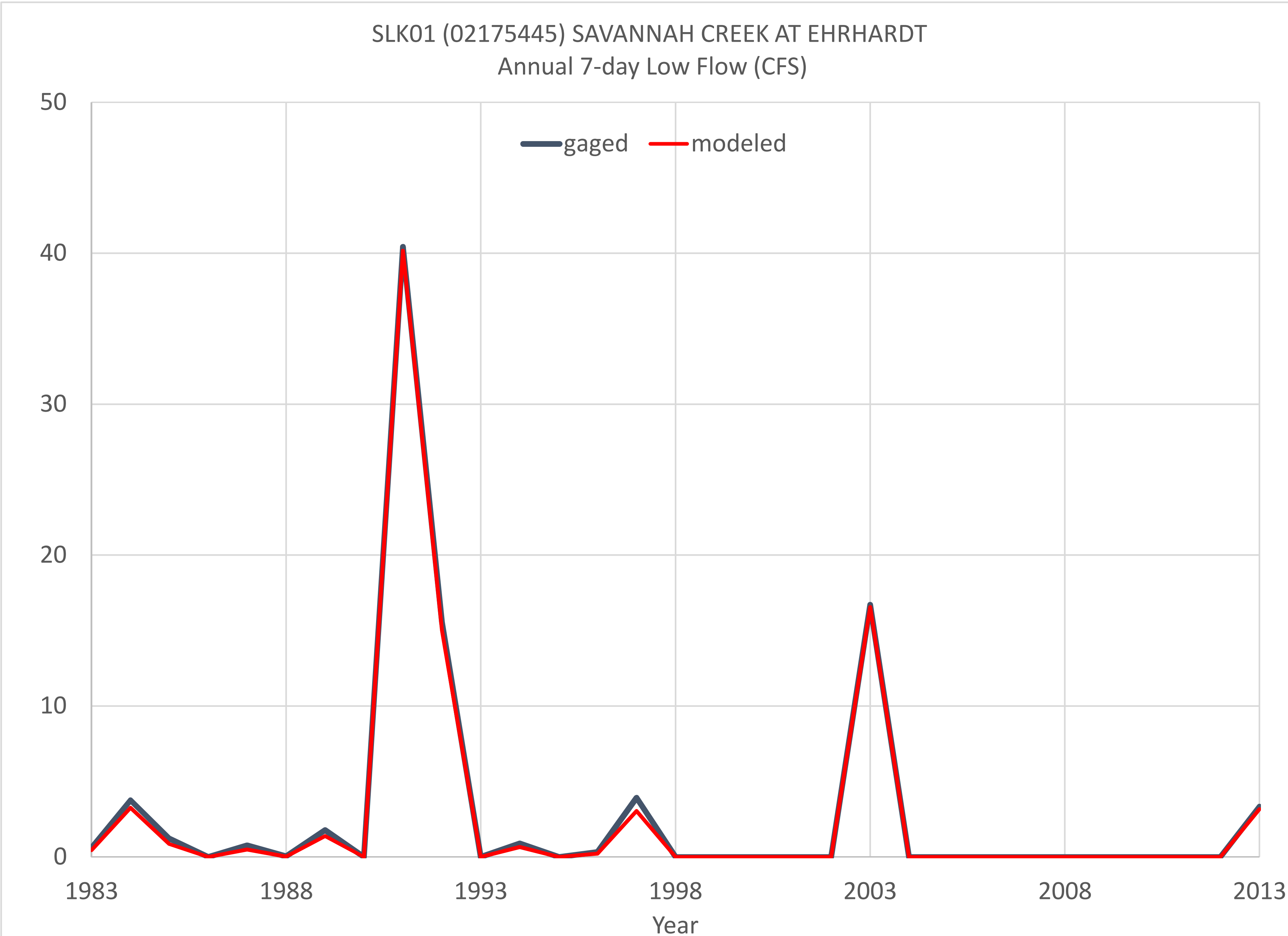
SLK02 (02175500) SALKEHATCHIE RIVER NEAR MILEY
Annual 7-day Low Flow (CFS)
gaged
modeled
200
180
160
140
120
100
80
60
40
20
0
1983
1988
1993
1998
2003
2008
2013
Year


SLK04 (02176000) COMBAHEE RIVER NEAR YEMASSEE (CFS)
modeled
gaged
6,000
5,000
4,000
3,000
2,000
1,000
0
Jun-51
Oct-52
Feb-54
Jul-55
Nov-56

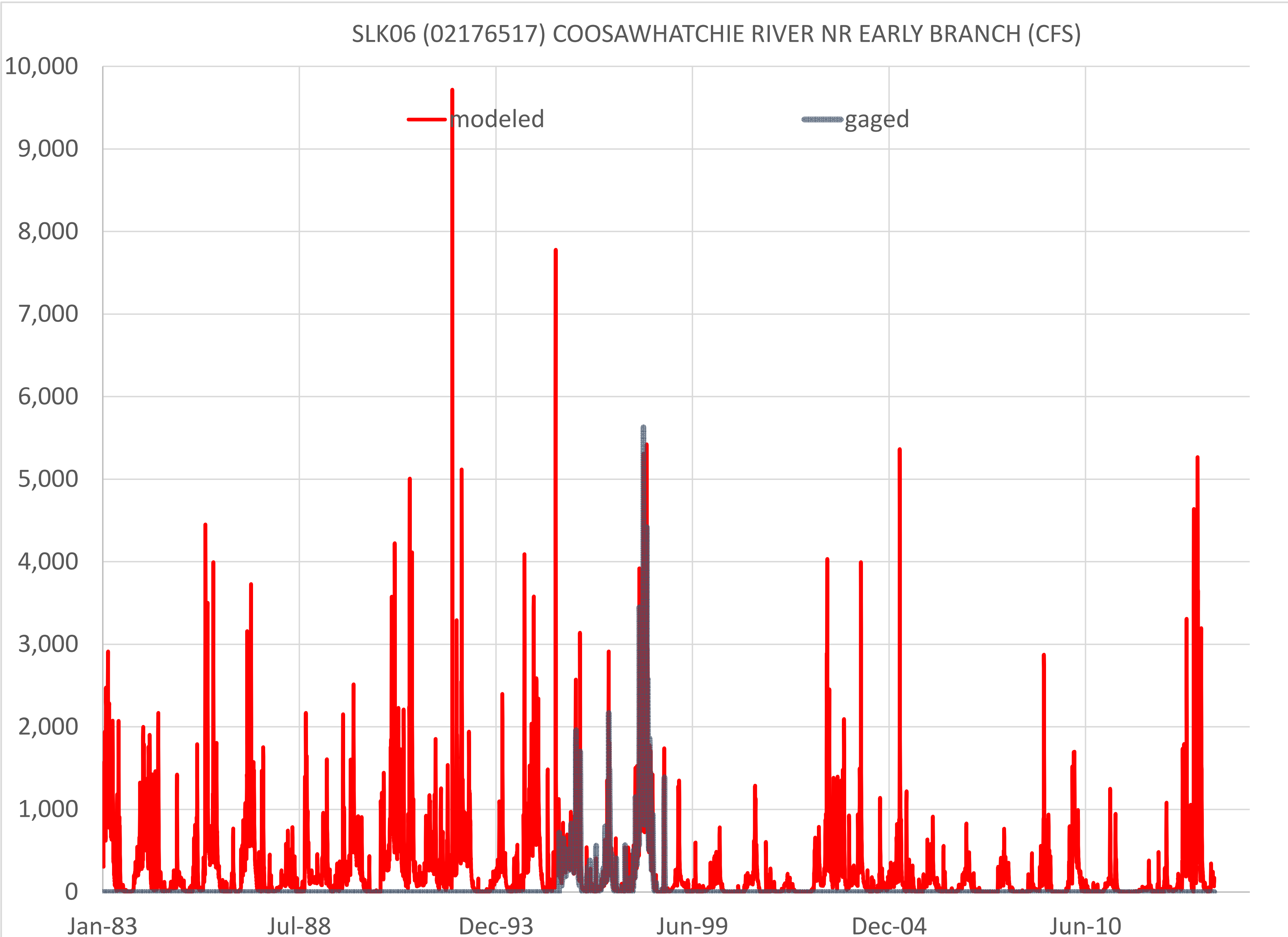

SLK04 (02176000) COMBAHEE RIVER NEAR YEMASSEE
Monthly Flow Percentiles (CFS)
6000
5000
4000
3000
2000
1000
0
gaged
modeled
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile


SLK05 (02176500) COOSAWHATCHIE RIVER NEAR HAMPTON (CFS)
modeled
gaged
6,000
5,000
4,000
3,000
2,000
1,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

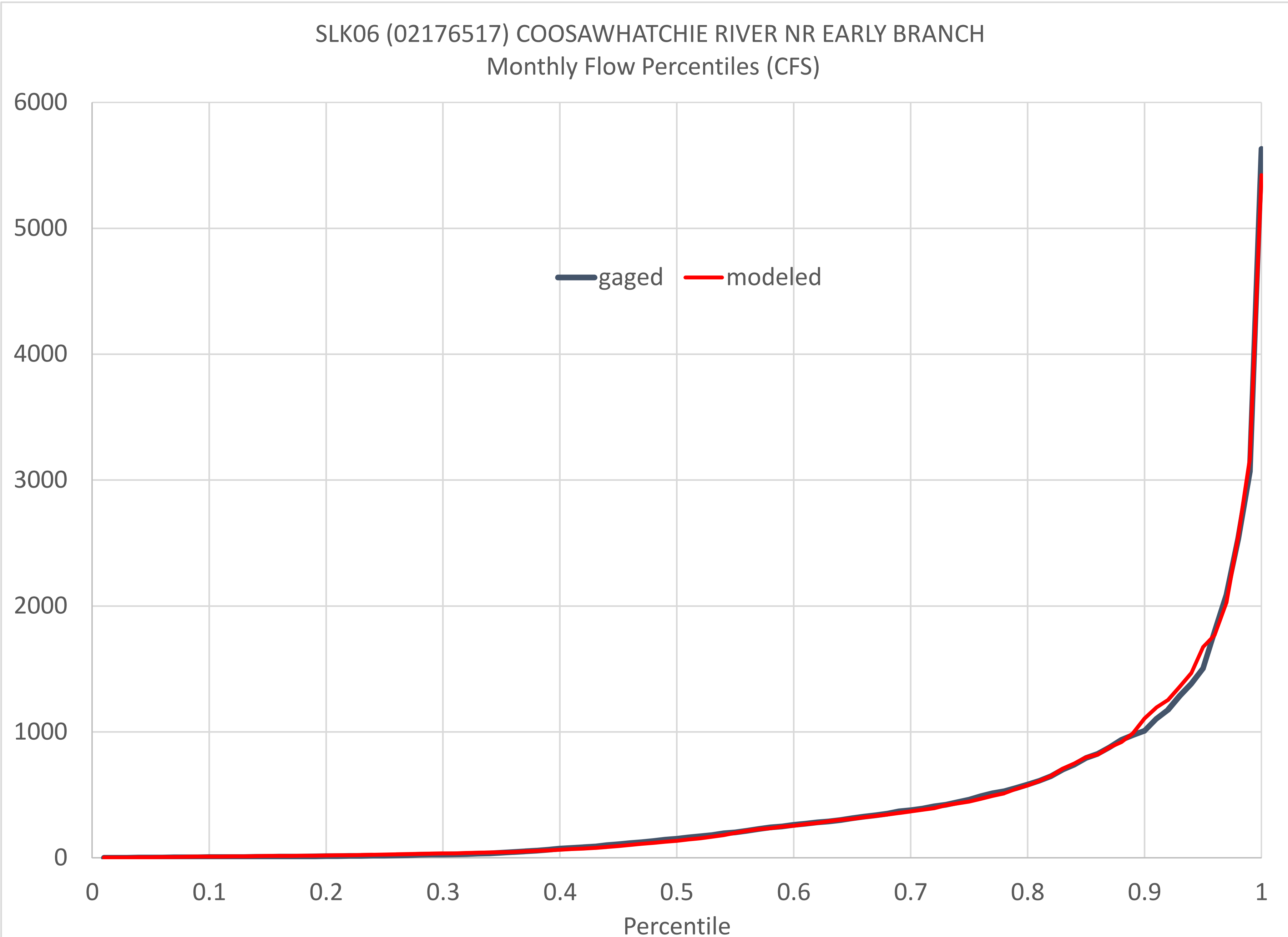

SLK05 (02176500) COOSAWHATCHIE RIVER NEAR HAMPTON
Monthly Flow Percentiles (CFS)
6000
5000
4000
3000
2000
1000
0
gaged
modeled
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile



SLK01 (02175445) SAVANNAH CREEK AT EHRHARDT
Annual 7-day Low Flow (CFS)
gaged
modeled
50
40
30
20
10
0
1983
1988
1993
1998
2003
2008
2013
Year



SLK06 (02176517) COOSAWHATCHIE RIVER NR EARLY BRANCH (CFS)
modeled
gaged
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10


SLK06 (02176517) COOSAWHATCHIE RIVER NR EARLY BRANCH
Monthly Flow Percentiles (CFS)
6000
5000
4000
3000
2000
1000
0
gaged
modeled
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

Appendix C

Guidelines for Representing Multi-Basin Water Users in SWAM

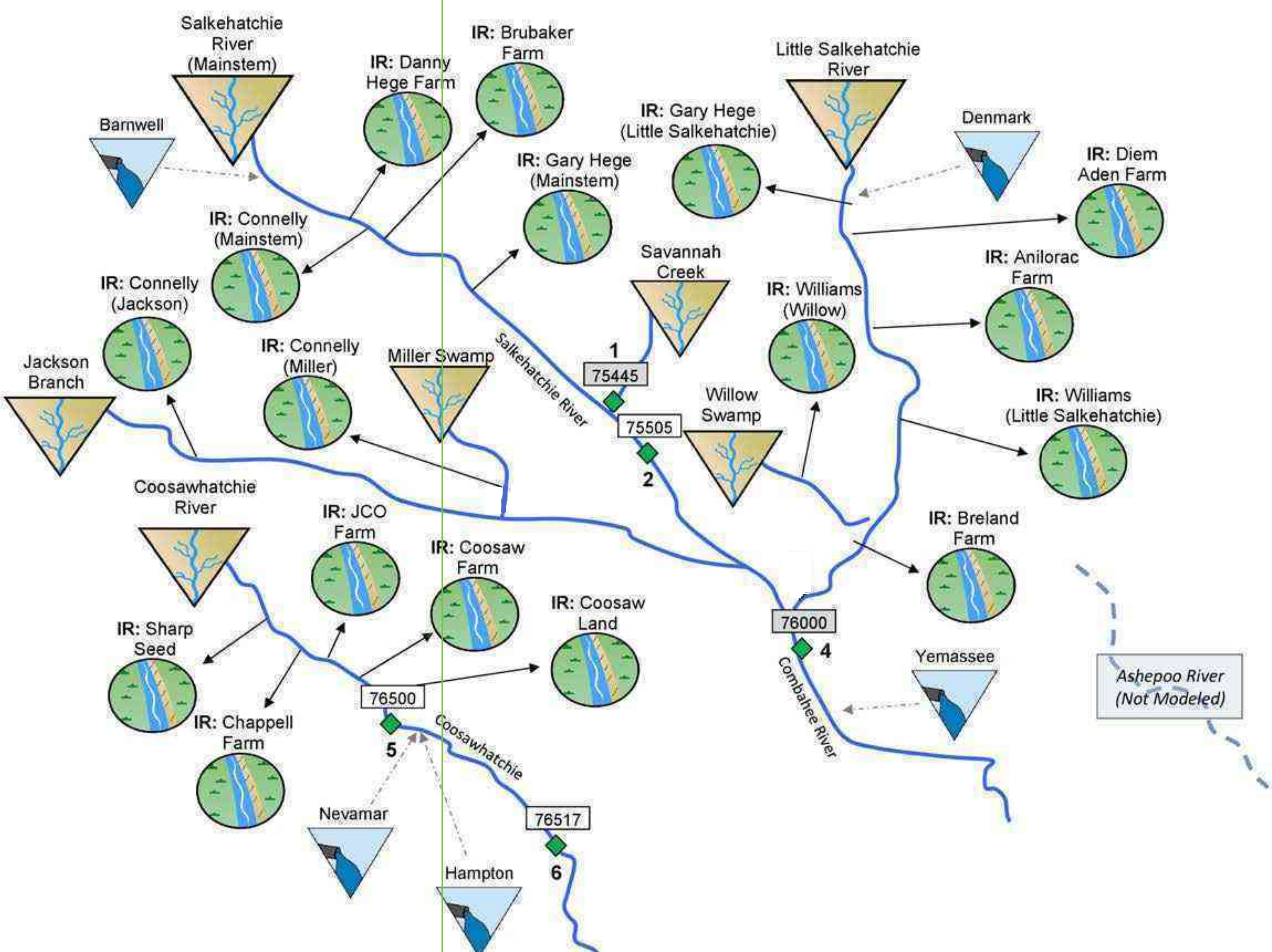
CDM Smith

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.



Salkehatchie River (Mainstem)
IR: Brubaker Farm
IR: Danny Hege Farm
Little Salkehatchie River
IR: Gary Hege (Little Salkehatchie)
Denmark
Barnwell
IR: Gary Hege (Mainstem)
IR: Diem Aden Farm
IR: Connelly (Mainstem)
Savannah Creek
IR: Anilorac Farm
IR: Connelly (Jackson)
IR: Williams (Willow)
IR: Connelly (Miller)
Miller Swamp
Salkehatchie River
1
75445
Jackson Branch
Willow Swamp
75505
IR: Williams (Little Salkehatchie)
2
Coosawhatchie River
IR: JCO Farm
IR: Coosaw Farm
IR: Breland Farm
IR: Coosaw Land
IR: Sharp Seed
76000
4
Yemassee
Ashepoo River (Not Modeled)
Combahee River
76500
IR: Chappell Farm
5
Coosawhatchie
Nevamar
76517
Hampton
6

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