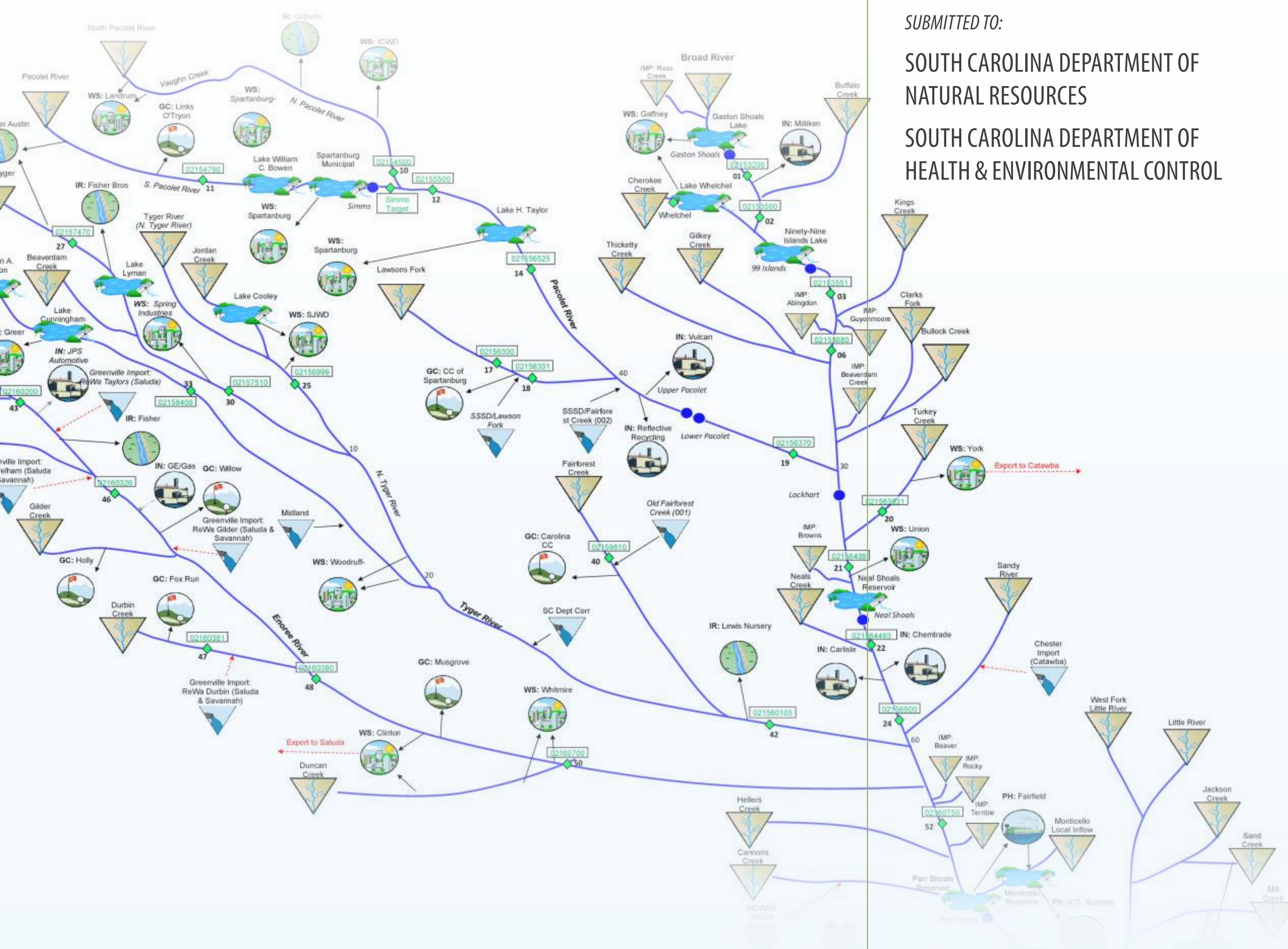
SOUTH CAROLINA
SURFACE WATER QUANTITY MODELS
BROAD RIVER BASIN MODEL



SUBMITTED TO:

SOUTH CAROLINA DEPARTMENT OF NATURAL RESOURCES

SOUTH CAROLINA DEPARTMENT OF HEALTH & ENVIRONMENTAL CONTROL

MAY 2016

PREPARED BY:

CDM Smith

DRAFT

Table of Contents

List of Tables

List of Figures

Appendices

Section 1

Purpose

This document, the Broad 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 Broad 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 Broad 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 Broad 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 Broad 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 Broad River and its 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 1929 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 Broad 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 Broad 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 model developed for the Edisto River Basin. The enhanced procedures and guidelines, and the "lessons learned" were applied to the Broad River Basin – especially, with regard to model calibration and validation.

Section 4

Broad Model Framework

The initial Broad River Basin SWAM Model Framework was developed in collaboration with South Carolina DNR and DHEC, and was presented in the memorandum *Broad Basin SWAM Model Framework* (CDM Smith, July 2015). The proposed framework was developed as a starting point for representing the Broad Basin river network and its significant water withdrawals and discharges. The guiding principles in determining what elements of the Broad 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. This includes most primary tributaries to the Broad and its major branches, and some secondary tributaries.

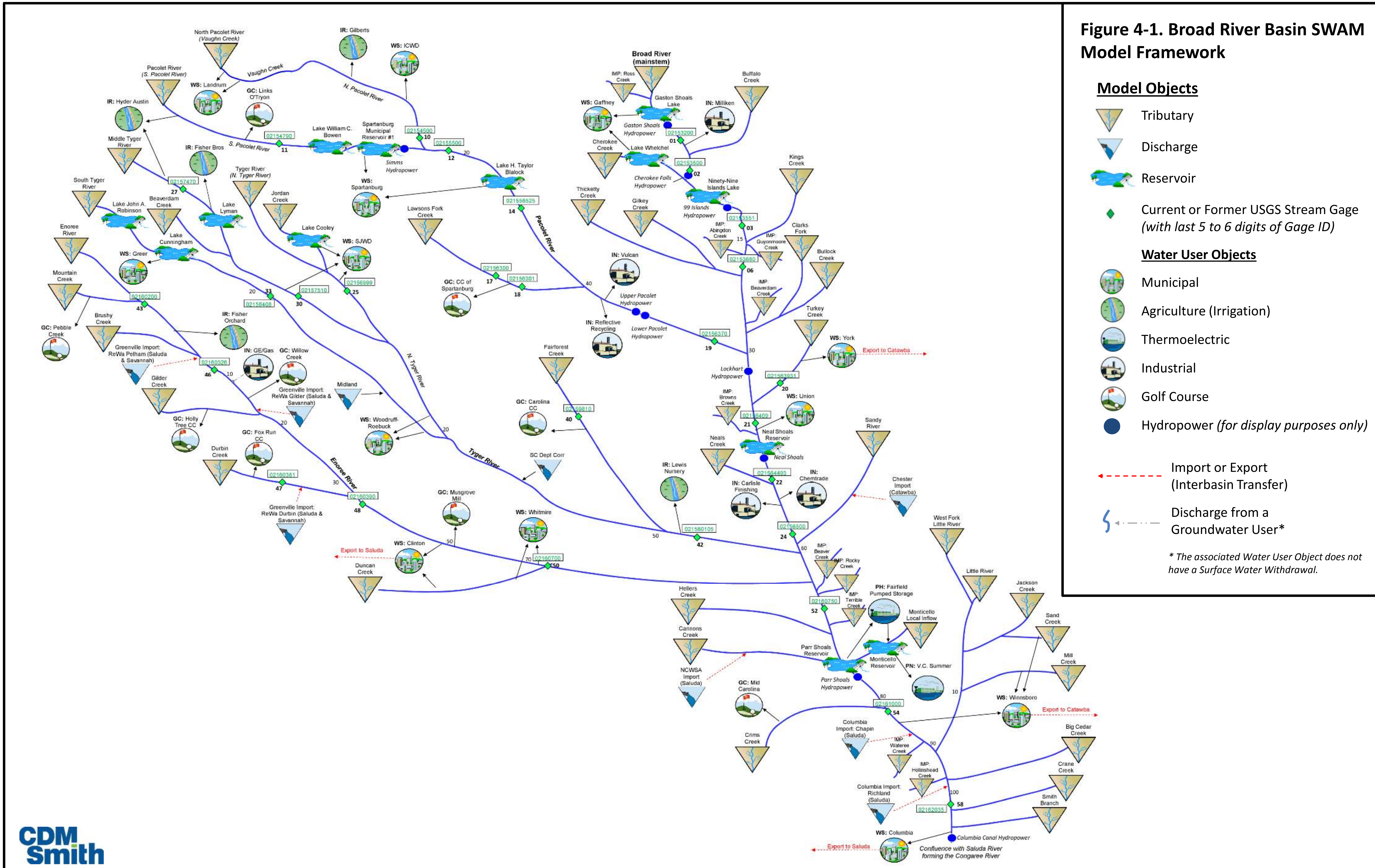
4. Generally, tributaries that are unused are not included explicitly, but the hydrologic contributions from these tributaries is embedded in the unimpaired flows (or reach gains) in downstream locations. As unimpaired flows (UIFs) are developed throughout the Broad, some additional tributaries may be 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 withdrawals include those that have a permit or registration – which indicated that they may withdraw over 3 million gallons in any month. For several of the municipal water users represented in Broad Model, withdrawal data includes both water used directly by that water user and water sold to other major municipal water users who are included as separate objects in the model. For example, permit #42WS012 associated with the Spartex-Jackson-Wellford-Duncan (SJWD) User object, includes water used directly by SJWD as well as water occasionally sold to Woodruff-Roebuck, who has their own withdrawal permit.

Figure 4-1. Broad River Basin SWAM Model Framework



Based on feedback from DNR, DHEC, and the Technical Advisory Committee (TAC), the decision was made to represent water withdrawals based on the permit holder rather than the ultimate water user. In this regard, the Water User objects reflect the withdrawals associated with their permit. In the example above, the water purchased by Woodruff-Roebuck from SJWD is accounted for under SJWD's Water User object. The alternative approach would have been to associate all of Woodruff-Roebuck demand as part of their own Water User object, including the water purchased from SJWD. The disadvantage of this approach is that the withdrawal permits associated with these conditions would be somewhat disaggregated in the model. Changes to a single permit limit, for example, would need to be applied for multiple users in the model. For this reason, the permit-based approach was selected for representing water withdrawals.

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 Broad 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:

- One industrial discharge – Midland, was 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.

- Water withdrawn by Greenville Water from Lake Keowee in the Savannah Basin and the Middle Saluda Reservoir and Table Rock Reservoir in the Saluda Basin, and then discharged in the Broad Basin is represented by three separate Discharge objects. These discharge objects represent wastewater discharges by Renewable Water Resources (ReWa) at their Pelham, Gilder Creek and Durbin Creek wastewater treatment facilities.

- Water withdrawn by the Newberry County Water and Sewer Authority (NCWSA) in the Saluda River Basin, and then discharged in the Broad Basin to Cannons Creek is represented by a Discharge object.

- Water withdrawn by the City of Columbia from Lake Murray in the Saluda River Basin, and then discharged in the Broad Basin at the Town of Chapin and Richland County wastewater treatment facilities is represented by two Discharge objects.

- Water withdrawn by the Chester Metropolitan District (CMD) in the Catawba River Basin, and then discharged in the Broad Basin to Sandy Creek is represented by a Discharge object.

4.3 Representation of Hydropower Facilities

In the original model framework, the hydropower facilities in the Broad Basin were represented with Instream Flow objects. The use of an Instream Flow object allows for the inclusion of a minimum release which can be prioritized or at least closely tracked in the model. Since the original framework was developed, several enhancements were added to the SWAM model to provide additional user flexibility with regard to reservoir and hydropower operating rules. Additionally, as operational information was collected for each hydropower facility, it became clear that many of the facilities in the Broad operate essentially as run-of-river facilities where inflow equals outflow on a daily basis. Since these run-of-river hydropower facilities do not substantially impact the water balance (limited or no storage) nor have associated minimum flow requirements or consumption, they are not explicitly included in the model, but are still shown in the model's visual framework. These facilities include:

- Cherokee Falls (Broad River)
- Columbia (Broad River/Columbia Canal Diversion)
- Simms (South Pacolet River)
- Upper and Lower Pacolet (Pacolet River)
  - *Note that there are minimum release requirements associated with the Pacolet Developments, however, they are operated in an approximate run-of-river mode on a daily basis. During peaking operations, which occur no more than 75 days out of the year, there are additional minimum release requirements; however, these deemed to have only minor influence on daily flows, and no impact on monthly flows.*
- Lockhart Minimum Flow Unit and Lockhart Hydro (Broad River)

The following hydropower facilities are *essentially* operated as run-of-river, but have a rule curve or other minor operating requirements, which are discussed further in Section 6. The rules for these facilities are specified within the Reservoir objects associated with the hydropower facility.

- Ninety Nine Islands (Broad River)
- Neal Shoals (Broad River)
- Parr Shoals (Broad River)

Note that the Parr Shoals reservoir elevations generally fluctuate within a 24-hour period, due to the nighttime pumping to, and daytime release from, the Monticello Reservoir via the Fairfield Pumped Storage Facility (discussed below); however, the modeled run-of-river operations should generally reflect actual operations on a daily basis.

Finally, the following list of hydropower facilities are not considered run-of-river. Each facility has minimum flow requirements and unique release/operating rules, which are discussed further in Section 6. The rules for these facilities are specified within the Reservoir objects associated with the hydropower facility.

- Gaston Shoals (Broad River)

- Fairfield Pumped Storage Facility (Broad River)

Note that the Fairfield Pumped Storage Facility is unique in that it pumps water from Parr Reservoir to Lake Monticello at night when power demand is low and releases it through the hydropower facility back to Parr Reservoir during the day. Its withdrawals and returns are specified as part of the **PH: Fairfield Pumped Storage** Water User object.

4.4 Groundwater Users and Associated Discharge

Although the Broad 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 withdrawal groundwater, the "Groundwater" option is selected in the Source Water Type section of the "Source Water" tab.

In the Broad Basin, only one significant industrial groundwater withdrawal was identified – GE/Gas, which had a corresponding, significant discharge to surface water. It is represented by a Water User object.

4.5 Implicit Tributaries

At certain locations along the main stem of the Broad River, new implicit tributary objects were added to capture ungaged drainage areas and tributary inputs not included in the original model framework. The list of implicit tributaries included in the Broad Model is provided in Section 6. These are tributaries which are not as likely to support future use as the explicitly represented tributaries; however, their contribution of flow to the main stem is important to include.

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 1929, the start of the hydrologic record for the Broad 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 (2005 – 2014) 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, were include (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 Broad 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 Broad 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).

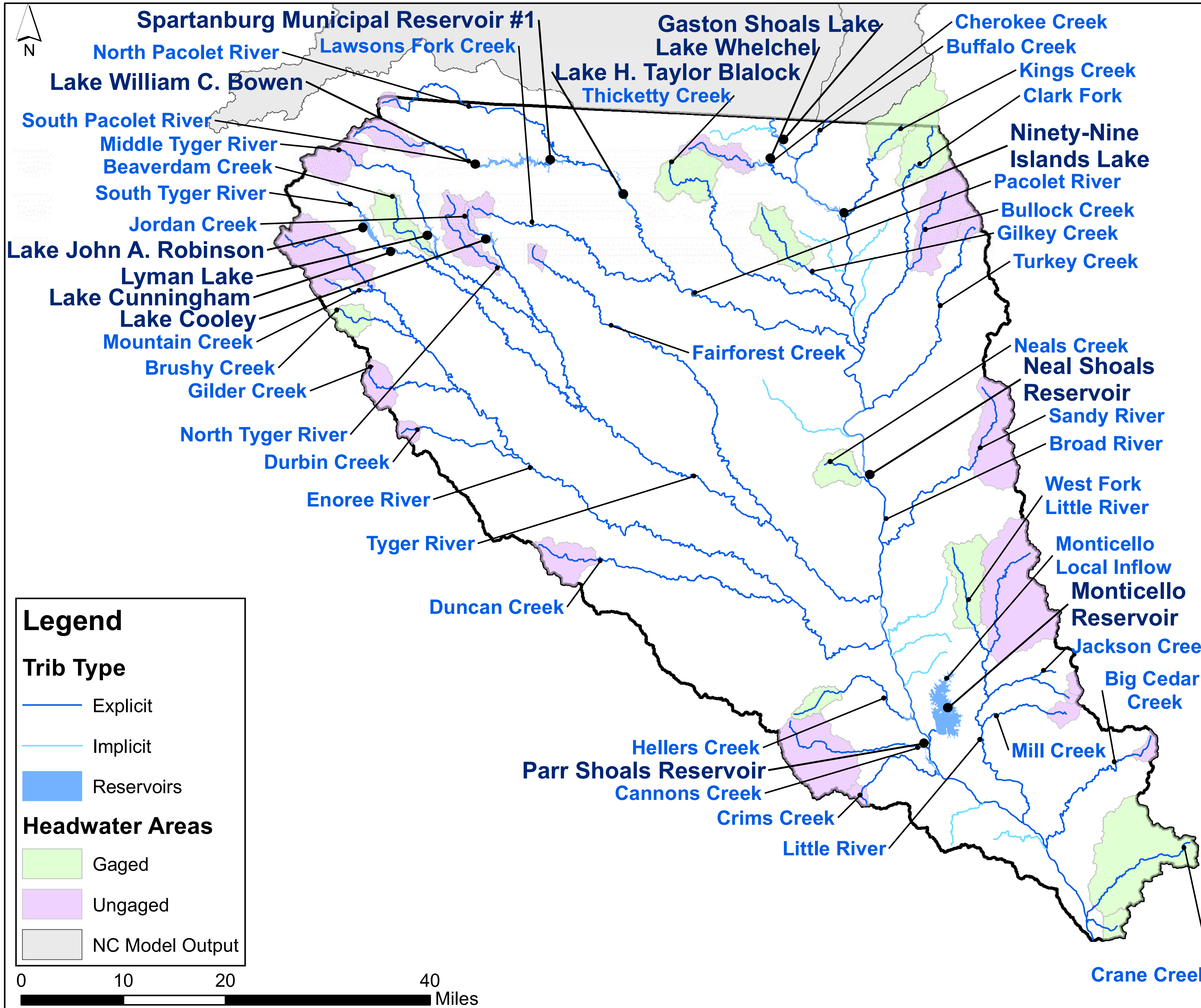
6.1.1 Explicit Tributary Objects: Headwater Flows

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. As the Broad River Basin has drainage from North Carolina, the mainstem and Buffalo Creek use model output from the North Carolina OASIS model, which represents the managed (impaired) flow coming from North Carolina. The unimpaired flows from the North Carolina OASIS model were used when developing UIFs for 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

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

<table>
<tr><th></th><th colspan="3">Headwater Input</th><th colspan="3">USGS Reference Gage (Unimpaired)</th></tr>
<tr><th>Project ID</th><th>Type</th><th>USGS Gage Number</th><th>SWAM Tributary</th><th>Project Gage ID</th><th>USGS Gage Number</th><th>Stream</th></tr>
<tr><td>Node 500</td><td>OASIS output</td><td>-</td><td>Mainstem</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Node 610</td><td>OASIS output</td><td>-</td><td>Buffalo Creek</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>BRD201</td><td>Ungaged</td><td>-</td><td>Cherokee Creek</td><td>BRD07</td><td>02153700</td><td>Thicketty Creek</td></tr>
<tr><td>BRD209</td><td>Ungaged</td><td>-</td><td>Bullock Creek</td><td>BRD08</td><td>02153780</td><td>Clarks Fork</td></tr>
<tr><td>BRD210</td><td>Ungaged</td><td>-</td><td>North Pacolet River</td><td>BRD10</td><td>02154500</td><td>North Pacolet</td></tr>
<tr><td>BRD211</td><td>Ungaged</td><td>-</td><td>Pacolet River</td><td>BRD11</td><td>02154790</td><td>Pacolet River</td></tr>
<tr><td>BRD216</td><td>Ungaged</td><td>-</td><td>Lawsons Fork Creek</td><td>BRD16</td><td>02156050</td><td>Lawsons Fork</td></tr>
<tr><td>BRD220</td><td>Ungaged</td><td>-</td><td>Turkey Creek</td><td>BRD20</td><td>021563931</td><td>Turkey Creek</td></tr>
<tr><td>BRD225</td><td>Ungaged</td><td>-</td><td>Jordan Creek</td><td rowspan="2">BRD25</td><td rowspan="2">02156999</td><td rowspan="2">Tyger River</td></tr>
<tr><td>BRD226</td><td>Ungaged</td><td>-</td><td>Tyger River</td></tr>
<tr><td>BRD227</td><td>Ungaged</td><td>-</td><td>Middle Tyger River</td><td>BRD27</td><td>02157470</td><td>Middle Tyger River</td></tr>
<tr><td>BRD233</td><td>Ungaged</td><td>-</td><td>South Tyger River</td><td>BRD34</td><td>02158410</td><td>South Tyger River</td></tr>
<tr><td>BRD239</td><td>Ungaged</td><td>-</td><td>Fairforest Creek</td><td>BRD40</td><td>02159810</td><td>Fairforest Creek</td></tr>
<tr><td>BRD243</td><td>Ungaged</td><td>-</td><td>Mountain Creek</td><td>BRD44</td><td>02160325</td><td>Brushy Creek</td></tr>
<tr><td>BRD248</td><td>Ungaged</td><td>-</td><td>Enoree River</td><td>BRD46</td><td>02160326</td><td>Enoree River</td></tr>
<tr><td>BRD246</td><td>Ungaged</td><td>-</td><td>Gilder Creek</td><td rowspan="3">BRD47</td><td rowspan="3">02160381</td><td rowspan="3">Durbin Creek</td></tr>
<tr><td>BRD247</td><td>Ungaged</td><td>-</td><td>Durbin Creek</td></tr>
<tr><td>BRD250</td><td>Ungaged</td><td>-</td><td>Duncan Creek</td></tr>
<tr><td>BRD254</td><td>Ungaged</td><td>-</td><td>Cannons Creek</td><td rowspan="2">BRD53</td><td rowspan="2">02160775</td><td rowspan="2">Hellers Creek</td></tr>
<tr><td>BRD255</td><td>Ungaged</td><td>-</td><td>Crims Creek</td></tr>
<tr><td>BRD224</td><td>Ungaged</td><td>-</td><td>Sandy River</td><td rowspan="3">BRD56</td><td rowspan="3">02161700</td><td rowspan="3">West Fork Little River</td></tr>
<tr><td>BRD263</td><td>Ungaged</td><td>-</td><td>Little River</td></tr>
<tr><td>BRD401</td><td>Ungaged</td><td>-</td><td>Monticello Local Inflow</td></tr>
<tr><td>BRD257</td><td>Ungaged</td><td>-</td><td>Big Cedar Creek</td><td rowspan="4">BRD57</td><td rowspan="4">02162010</td><td rowspan="4">Cedar Creek</td></tr>
<tr><td>BRD260</td><td>Ungaged</td><td>-</td><td>Sand Creek</td></tr>
<tr><td>BRD261</td><td>Ungaged</td><td>-</td><td>Jackson Creek</td></tr>
<tr><td>BRD262</td><td>Ungaged</td><td>-</td><td>Mill Creek</td></tr>
<tr><td>BRD04</td><td>Gaged</td><td>02153590</td><td>Kings Creek</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>BRD05</td><td>Gaged</td><td>021536097</td><td>Gilkey Creek</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>BRD07</td><td>Gaged</td><td>02153700</td><td>Thicketty Creek</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>BRD08</td><td>Gaged</td><td>02153780</td><td>Clarks Fork</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>BRD23</td><td>Gaged</td><td>02156450</td><td>Neals Creek</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>BRD28</td><td>Gaged</td><td>02157490</td><td>Beaverdam Creek</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>BRD44</td><td>Gaged</td><td>02160325</td><td>Brushy Creek</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>BRD53</td><td>Gaged</td><td>02160775</td><td>Hellers Creek</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>BRD56</td><td>Gaged</td><td>02161700</td><td>West Fork Little River</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>BRD59</td><td>Gaged</td><td>02162080</td><td>Crane Creek</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>BRD60</td><td>Gaged</td><td>02162093</td><td>Smith Branch</td><td>-</td><td>-</td><td>-</td></tr>
</table>



ID	SWAM Trib	Type	Area (ac)
BRD04	Kings Creek	USGS	17829
BRD05	Gilkey Creek	USGS	13097
BRD07	Thicketty Creek	USGS	15605
BRD23	Neals Creek	USGS	7733
BRD28	Beaverdam Creek	USGS	10149
BRD44	Brushy Creek	USGS	5849
BRD53	Hellers Creek	USGS	5298
BRD56	West Fork Little River	USGS	16313
BRD59	Crane Creek	USGS	42543
BRD60	Smith Branch	USGS	3550
BRD201	Cherokee Creek	Ungaged	7139
BRD209	Bullock Creek	Ungaged	23959
BRD210	North Pacolet River	Ungaged	1658
BRD211	Pacolet River	Ungaged	8776
BRD216	Lawsons Fork Creek	Ungaged	2717
BRD220	Turkey Creek	Ungaged	3033
BRD224	Sandy River	Ungaged	22984
BRD225	Jordan Creek	Ungaged	1919
BRD226	Tyger River	Ungaged	12302
BRD227	Middle Tyger River	Ungaged	2989
BRD232	Maple Creek	Ungaged	5034
BRD233	South Tyger River	Ungaged	7859
BRD239	Fairforest Creek	Ungaged	2014
BRD243	Mountain Creek	Ungaged	2413
BRD246	Gilder Creek	Ungaged	7172
BRD247	Durbin Creek	Ungaged	2422
BRD248	Enoree River	Ungaged	24006
BRD250	Duncan Creek	Ungaged	10726
BRD254	Cannons Creek	Ungaged	27559
BRD255	Crims Creek	Ungaged	1880
BRD257	Big Cedar Creek	Ungaged	2610
BRD260	Sand Creek	Ungaged	833
BRD261	Jackson Creek	Ungaged	1444
BRD262	Mill Creek	Ungaged	3509
BRD263	Little River	Ungaged	43925
BRD400	Monticello Local Inflow	Ungaged	4440
Node 610	Buffalo Creek	NC Model Output	103400
Node 500	Mainstem	NC Model Output	807120

CDM Smith

Figure 6-1. Headwater Areas for Explicit Tributaries in the Broad River Basin 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

For implicit tributaries, all input confluence flows were estimated from reference UIFs. **Table 6-2** lists which unimpaired USGS gage was used as a reference gage for calculating flows for each implicit tributary object. **Figure 6-2** shows drainage areas for the ten implicit tributaries. The inset table provides the corresponding drainage area in acres.

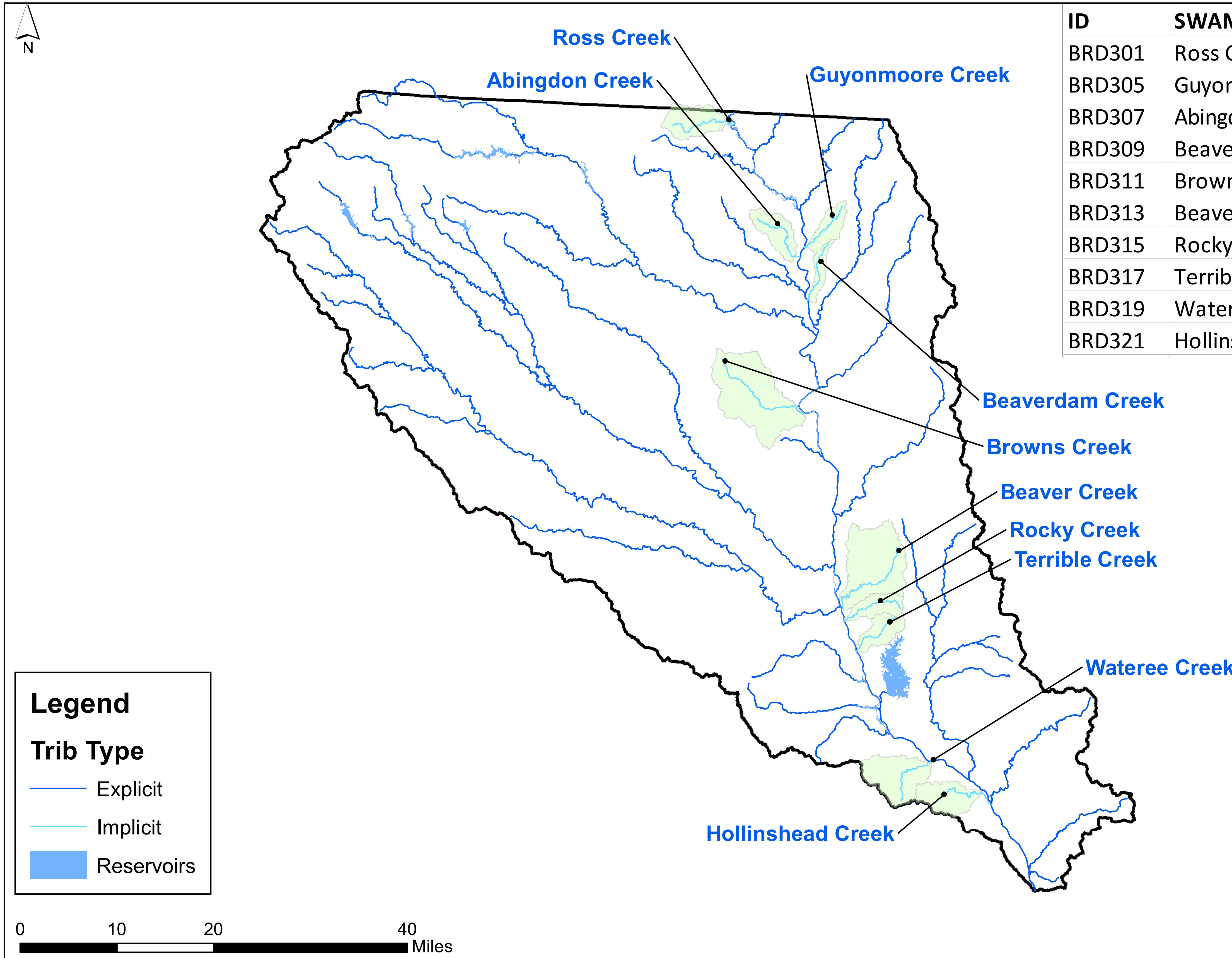
Table 6-2. Reference Gages Used for Confluence Flows on Implicit Tributaries

	Ungaged Basin	USGS Reference Gage (Unimpaired)		
Project ID	**SWAM Tributary**	**Project Gage ID**	**USGS Gage Number**	**Stream**
BRD301	Ross Creek	BRD04	02153590	Kings Creek
BRD305	Guyonmoore Creek	BRD08	02153780	Clarks Fork
BRD307	Abingdon Creek			
BRD309	Beaverdam Creek			
BRD311	Browns Creek	BRD23	02156450	Neals Creek
BRD313	Beaver Creek	BRD56	02161700	West Fork Little River
BRD315	Rocky Creek			
BRD317	Terrible Creek			
BRD319	Wateree Creek	BRD57	02162010	Cedar Creek
BRD321	Hollinshead Creek			

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



ID	SWAM Trib	Trib Type	Area (ac)
BRD301	Ross Creek	Implicit	11212
BRD305	Guyonmoore Creek	Implicit	6644
BRD307	Abingdon Creek	Implicit	8738
BRD309	Beaverdam Creek	Implicit	4115
BRD311	Browns Creek	Implicit	33975
BRD313	Beaver Creek	Implicit	27946
BRD315	Rocky Creek	Implicit	7186
BRD317	Terrible Creek	Implicit	7290
BRD319	Wateree Creek	Implicit	16623
BRD321	Hollinshead Creek	Implicit	10963

CDM Smith

Figure 6-2. Implicit Tributaries in the Broad 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 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 Figures 6-1 and 6-2 and corresponding tributary and mainstem flow factors are summarized in **Table 6-3**.

6.2 Reservoirs

Thirteen reservoirs are represented in the Broad River Basin Model: Gaston Shoals Lake, Lake Whelchel, Ninety-Nine Islands Lake, Neal Shoals Reservoir, Parr Shoals Reservoir, Lake Monticello, Lake William C. Bowen, Spartanburg Municipal Reservoir #1, Lake H. Taylor Blalock, Lake Lyman, Lake Cooley, Lake John A. Robinson, and Lake Cunningham. **Table 6-4** 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.

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 6-4.**

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. Since Lake Monticello, the largest reservoir in the Broad River Basin, covers the majority of the Frees Creek watershed, direct precipitation to the surface of Lake Monticello was included as part of the local inflow tributary object. The local runoff aspect of this tributary object is typically estimated via area proration of an appropriate unimpaired flow. Given the nature of runoff from a ring of unsubmerged land surrounding an impounded watershed, local runoff was instead estimated via the rational method, i.e., only producing runoff during precipitation events.

Direct precipitation to the other twelve, much smaller reservoirs was considered negligible, and not explicitly included in the model. However, precipitation rates were factored into the calculation of

Table 6-3. 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)
Broad River (Mainstem)	Explicit	None	None	3,412,000	None	8	-	0.02*
						15	-	-0.001*
						47.8	-	0.015*
						53.4	-	0.005*
						500	-	0*
Beaverdam Creek	Explicit	Middle Tyger River	15.2	10,350	BRD28	0.3	1.0	1.0
Big Cedar Creek	Explicit	Mainstem	94.5	61,529	BRD257	20	23.6	23.6
Brushy Creek	Explicit	Enoree River	8.8	9,622	BRD44	5.5	1.6	1.6
Buffalo Creek	Explicit	Mainstem	6.3	113,347	Node 610	6.5	1.5	1.8
Bullock Creek	Explicit	Mainstem	29.1	72,085	BRD209	11.1	1.9	1.9
Cannons Creek	Explicit	Mainstem	77.4	43,023	BRD254	7.8	1.6	1.6
Cherokee Creek	Explicit	Mainstem	8.6	14,876	BRD201	1.9	1.5	6
						7.2	2.1	2.1
Clarks Fork	Explicit	Bullock Creek	0.1	27,248	BRD08	10	1.8	1.8
Crane Creek	Explicit	Mainstem	102.4	41,602	BRD59	1.1	1.0	1.0
Crims Creek	Explicit	Mainstem	80.4	21,949	BRD255	11	11.7	11.7
Duncan Creek	Explicit	Enoree River	75	76,647	BRD250	25.2	7.1	7.1
Durbin Creek	Explicit	Enoree River	32.3	33,279	BRD247	2.6	3.4	3.4
						11.5	13.7	13.7
Enoree River	Explicit	Mainstem	65.5	468,153	BRD248	0.8	1.0	1.35
						9.2	1.5	2
						33	3.7	3
						73.1	8.9	5.7
						92.7	13.4	13.36
Fairforest Creek	Explicit	Tyger River	50.7	139,857	BRD239	11.4	11.3	8.5
						22.2	27.2	20.4
						35.3	55.2	41.4
						46.5	69.5	52.1
Gilder Creek	Explicit	Enoree River	18.1	20,378	BRD246	8.3	2.8	2.8
Gilkey Creek	Explicit	Thicketty Creek	23.7	17,177	BRD05	4.8	1.3	1.3
Hellers Creek	Explicit	Mainstem	74	26,160	BRD53	10.8	4.9	4.9
Indian Creek	Explicit	Enoree River	82.5	62,182	BRD51	6.5	1.5	1.5
Jackson Creek	Explicit	Little River	5.9	22,437	BRD261	8.1	12.6	12.6
Jordan Creek	Explicit	Tyger River	0.1	8,084	BRD225	4.7	4.2	4.2
Kings Creek	Explicit	Mainstem	15.4	43,792	BRD04	10.8	2.5	2.5
Lawsons Fork Creek	Explicit	Pacolet River	40.1	54,463	BRD216	20.5	17.5	18
						27.1	20.0	20
Little River	Explicit	Mainstem	90.7	150,558	BRD263	24.6	2.2	2.2
Middle Tyger River	Explicit	Tyger River	10.6	54,673	BRD227	9.7	7.0	7
						14.4	9.7	8.5
						21.8	11.3	10.6
						34.5	14.8	12
Mill Creek	Explicit	Little River	10	11,599	BRD262	8	3.3	3.3
Monticello Local Inflow	Explicit	Mainstem	78	11,243	BRD400	8	1.0	0.9
Mountain Creek	Explicit	Enoree River	10.2	7,554	BRD243	5.1	3.1	7
Neals Creek	Explicit	Mainstem	48.1	8,036	BRD23	0.9	1.0	1.0
North Pacolet River	Explicit	Pacolet River	18.5	74,997	BRD210	25.2	44.0	44
						27	45.2	45.2
Pacolet River	Explicit	Mainstem	30.5	329,990	BRD211	6.3	4.0	4.05
						18.7	6.7	6.8
						28.1	11.2	9.6
						40	15.5	13
						68	22.8	16
Sand Creek	Explicit	Jackson Creek	2.9	4,200	BRD260	3.9	5.0	5.0
Sandy River	Explicit	Mainstem	55.1	100,753	BRD224	16.1	4.4	4.4
Smith Branch	Explicit	Mainstem	103	4,759	BRD60	2.1	1.3	1.3

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

Table 6-3. Model Tributary Inputs (continued)

SWAM Tributary Object	Tributary Type	Confluence Stream	Confluence Location (mile)	Area (ac)	Headwater ID	End Mile	Original Drainage Ratio	Subbasin Flow Factor (unitless)
South Tyger River	Explicit	Tyger River	22.3	107,411	BRD233	7.3	3.9	3.9
						14.7	5.7	5.7
						21.7	7.8	7.7
						46.3	13.7	11
Thicketty Creek	Explicit	Mainstem	25.6	100,885	BRD07	26.2	5.4	5.4
Turkey Creek	Explicit	Mainstem	38.3	91,831	BRD220	1.3	1.2	11
						12.3	6.9	6.9
						17.9	17.3	17.3
						24.8	30.3	30.3
Tyger River	Explicit	Mainstem	60.7	515,006	BRD226	2.2	1.1	1.1
						10.5	2.6	1.5
						22.2	3.9	2
						50.6	10.7	8.5
						68.7	16.7	12
West Fork Little River	Explicit	Little River	0.1	21,394	BRD56	3.4	1.3	1.3
Abingdon Creek	Implicit	Mainstem	20.8	8,738	none	0	1.0	1.0
Beaver Creek	Implicit	Mainstem	65.8	27,946	none	0	1.0	1.0
Beaverdam Creek	Implicit	Mainstem	26.3	4,115	none	0	1.0	1.0
Browns Creek	Implicit	Mainstem	42.1	33,975	none	0	1.0	1.0
Guyonmoore Creek	Implicit	Mainstem	19.5	6,644	none	0	1.0	1.0
Hollinshead Creek	Implicit	Mainstem	94.4	10,963	none	0	1.0	1.0
Rocky Creek	Implicit	Mainstem	67.1	7,186	none	0	1.0	1.0
Ross Creek	Implicit	Mainstem	2.2	11,212	none	0	1.0	1.0
Terrible Creek	Implicit	Mainstem	70.5	7,290	none	0	1.0	1.0
Wateree Creek	Implicit	Mainstem	85.8	16,623	none	0	1.0	1.0

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 thirteen reservoirs are summarized in **Table 6-5**. 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. Lake Blalock, Lake Robinson and Lake Cunningham have only known capacities and areas at full. For these lakes, area-capacity curves are represented by a simplified linear relationship. Additionally, Lake Blalock underwent multiple years of construction during the calibration period, which included raising the dam and changing the lake capacity. As information on the previous characteristics of the lake is limited, the calibration model reflects the current capacity of the lake.

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 modeled reservoirs except Neal Shoals, no specific volume to flood control outflow relationships were assigned. The Neal Shoals Reservoir has a full pool capacity at 515 million gallons (MG), but at 94%, what would be considered its normal pool, flood control outflow of 3,060 cfs was assigned, based on information presented Broad River CHEOPS Model Operations Report (HDR, 2007).

Table 6-4. Reservoir Inputs

Reservoir	Purpose	Receiving Stream	Temperature Station for Evaporation	Evaporation Station	Precipitation Station	Release Location (mi)	Storage Capacity (MG)	Dead Pool (MG)	Operating Rules
Gaston Shoals Lake	Power, recreation, and water supply	Mainstem (Broad)	Santuck USC00387722	Clemson USC00381770	Gaston Shoals USC00383433	4	815	378	Advanced
Lake Whelchel	Water supply	Cherokee Creek	Santuck USC00387722	Clemson USC00381770	Gaston Shoals USC00383433	1.9	815	10	Simple
Ninety-Nine Islands Lake	Power and recreation	Mainstem (Broad)	Santuck USC00387722	Clemson USC00381770	99 Islands USC00386293/ Gaffney USC00383356	14.9	750	600	Advanced
Neal Shoals Reservoir	Power	Mainstem (Broad)	Santuck USC00387722	Clemson USC00381770	Santuck USC00387722/ Lockhart USC00385232	47.7	515	363	Advanced
Parr Shoals Reservoir	Power and recreation	Mainstem (Broad)	Little Mountain USC00385200	Blackville USC00380764	Blair USC00380772/ Parr USC00386688	79	10,427	970	Advanced
Lake Monticello	Power and recreation	Monticello Local Inflow	Little Mountain USC00385200	Blackville USC00380764	Blair USC00380772/ Parr USC00386688	7	130,000	0	Advanced
Lake William C. Bowen	Recreation and water supply	Pacolet River (S. Pacolet River)	Clemson USC00381770	Clemson USC00381770	Rainbow Lake USC00387113/ Simms USC00387885/ Clemson USC00381625	14.4	7,780	2,800	Advanced
Spartanburg Municipal Reservoir #1	Recreation and water supply	Pacolet River (S. Pacolet River)	Clemson USC00381770	Clemson USC00381770	Rainbow Lake USC00387113/ Simms USC00387885/ Clemson USC00381625	18	816	642	Simple
Lake H. Taylor Blalock	Recreation and water supply	Pacolet River	Clemson USC00381770	Clemson USC00381770	Rainbow Lake USC00387113/ Simms USC00387885/ Clemson USC00381625	27.6	5,500	0	Simple
Lake Lyman	Recreation and water supply	Middle Tyger River	Clemson USC00381770	Clemson USC00381770	Cleveland USC00381804	14.4	1,367	0	Advanced
Lake Cooley	Recreation and flood control	Jordan Creek	Clemson USC00381770	Clemson USC00381770	Greer USW00003870	2.1	1,727	40	Advanced
Lake John A. Robinson	Recreation and water supply	South Tyger River	Clemson USC00381770	Clemson USC00381770	Cleveland USC00381804	7.2	4,495	0	Simple
Lake Cunningham	Recreation and water supply	South Tyger River	Clemson USC00381770	Clemson USC00381770	Cleveland USC00381804	10.9	248	0	Simple

Note: For all reservoirs, the "Simple" area-capacity relationship table was used.

Table 6-5. Reservoir Area-Capacity Relationship

Reservoir	Volume (MG)	Area (Acres)
Gaston Shoals Lake[1]	0	0
	378	45
	815	300
Lake Whelchel[1]	0	0
	3	1
	16	4
	41	9
	81	18
	130	28
	228	50
	358	78
	554	120
	815	177
Ninety-Nine Islands Lake[2]	0	0
	9	4
	18	7
	42	20
	64	34
	97	56
	152	97
	237	157
	401	231
	652	325
	750	433
Neal Shoals Reservoir[2]	0	0
	20	21
	72	82
	332	391
	515	613
Parr Shoals Reservoir[2]	0	0
	261	800
	1,151	1,850
	3,314	2,727
	8,903	4,116
	16,656	5,402
Lake Monticello[2]	0	37
	283	137
	961	279
	6,553	943
	14,875	1,682
	38,939	3,320
	50,735	3,920
	64,486	4,520
	80,257	5,160
	98,244	5,880
	118,300	6,430
	140458	7170

Reservoir	Volume (MG)	Area (Acres)
Lake William C. Bowen[3]	2,925	698
	2,947	768
	3,508	897
	4,122	979
	4,810	1,100
	5,551	1,180
	6,373	1,300
	7,256	1,400
	7,780	1,440
Spartanburg Municipal Reservoir #1[3]	161	62
	205	72
	256	86
	319	104
	397	131
	503	180
	640	228
	808	271
	815	276
Lake H. Taylor Blalock[1]	0	0
	5,500	1,105
Lake Lyman[1]	0	0
	1	5
	16	24
	41	44
	104	87
	167	120
	301	160
	616	227
	1,051	314
	1,367	357
Lake Cooley[1]	0	0
	57.5	35.8
	164	72
	311	110
	719	190
	1,062	249
	1,509	309
	1,727	335
Lake John A. Robinson[1]	0	0
	4,495	810
Lake Cunningham[1]	0	0
	248	132

Sources

1 - User correspondence

2 - HDR, 2007

3 - FERC Application

For Gaston Shoals, area-capacity needed to be inferred from the current FERC documentation, as silt accumulations have added uncertainty to previously-estimated bathymetry. A simple linear estimate was made given knowledge of full pond capacity and available storage with a two foot drawdown. The same may apply to other reservoirs along the Broad, but until similar information arises, area-capacities follow those listed in the 2007 HDR report.

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. Of the thirteen Broad River Basin reservoirs, eight have these advanced rules: Gaston Shoals Lake, Ninety-Nine Islands Lake, Neal Shoals Reservoir, Parr Shoals Reservoir, Lake Monticello, Lake Bowen, Lake Lyman, and Lake Cooley. **Table 6-6** 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.

6.2.4.1 Duke Energy Reservoirs

Duke Energy owns and operates two reservoirs on the Broad River: Gaston Shoals Lake about 4 miles downstream of the North Carolina border and Ninety-Nine Islands Lake about 15 miles downstream of the border. Both projects were relicensed in 1990's and since then have generally been operated within one or two feet of full pond. Gaston Shoals does not have appreciable storage capacity due to silt and is operated as a modified peaking plant for power generation. Gaston Shoals also serves as a secondary municipal water supply for Gaffney CPW (**WS: Gaffney**). Unlike Ninety-Nine Islands, Gaston Shoals does not have an immediate upstream USGS streamflow gage from which inflow rules can be based. The current FERC license for each reservoir specifies instantaneous minimum flows, which given SWAM's smallest timestep of daily, becomes a daily (or monthly in the monthly model) average. Project datum for these two reservoirs are defined as 100.0 ft = 605.2 ft NGVD29 for Gaston Shoals and 100.0 ft = 511.1 ft for Ninety-Nine Islands.

6.2.4.2 SCE&G Reservoirs

SCE&G owns and operates three reservoirs in the basin: Neal Shoals located approximately 20 river miles south of the confluence with the Pacolet River, and a pumped storage system between Parr Shoals and Lake Monticello below the confluence of the Enoree River. Neal Shoals primarily operates as a run-of-river facility with non-seasonal release rules and a general storage target. Neal Shoals also serves to mitigate impacts from Lockhart Dam upstream, which is not modeled.

In addition to hydropower at the Parr Dam, the Fairfield Pumped Storage (FFPS) project pumps water from Parr Reservoir up to Lake Monticello, typically at night when energy is cheapest, and releases down to Parr during the day through turbines for energy production. SCE&G provided daily pumped/released amounts from 2006 onward and also estimates for increased evaporation caused by heated waters discharged from the V.C Summer Nuclear Station on Monticello. These pumped amounts are represented by the Water User object **PH: Fairfield Pumped Storage**. Given uncertainty from quantifying total evaporative loss, estimating true local runoff/direct precipitation gains to Monticello, and unknown pumped/released values before 2006, it is difficult to assess whether Monticello could remain full without the FFPS, over the entire calibration period. Additionally,

Table 6-6. Advanced Reservoir Rules

Reservoir	Priority	Type	Target	Months	Conditioned On:
Gaston Shoals	1	Minimum Release (cfs)	868	Jan - Feb	Storage above 668 MG (98')
			868	Mar - Apr	Storage above 741 MG (99')
			651	May	Storage above 741 MG (99')
			651	Jun, Dec	Storage above 668 MG (98')
			434	Jul - Nov	Storage above 668 MG (98')
	2	Minimum Release (cfs)	150	Jan - Feb	Storage below 668 MG (98')
			350	Mar - May	Storage below 741 MG (99')
			150	Jun - Dec	Storage below 668 MG (98')
	3	Storage Curve (MG)	741 (99')	Jan - Feb	
			778 (99.5')	Mar - May	
			741 (99')	Jun - Dec	
Ninety-Nine Islands Lake	1	Minimum Release (cfs)	1	Jan - Jun	BRD02 flow below 483 CFS
			1	Dec	BRD02 flow below 483 CFS
	2	Minimum Release (cfs)	483	Jan - Jun	BRD02 flow above 482 CFS
			483	Dec	BRD02 flow above 482 CFS
	3	Minimum Release (cfs)	966	Jan - Feb	Storage above 561.4 MG (98')
			966	Mar -Apr	Storage above 660.6 MG (99')
			725	May	Storage above 660.6 MG (99')
			725	Jun, Dec	Storage above 561.4 MG (98')
			483	Jul - Nov	Storage above 561.4 MG (98')
Neal Shoals Reservoir	1	Minimum Release (cfs)	1	Jan - Dec	BRD21 flow below 730 CFS
	2	Minimum Release (cfs)	730	Jan - Dec	BRD21 flow above 729 CFS
	3	Storage Curve (MG)	484.4 (334')	Jan - Dec	
Parr Shoals Reservoir	1	Minimum Release (cfs)	1	Jan - Feb	BRD52 flow below 800 CFS
			1	Mar - May	BRD52 flow below 1000 CFS
			1	Jun - Dec	BRD52 flow below 800 CFS
	2	Minimum Release (cfs)	800	Jan - Feb	BRD52 flow above 799 CFS
			1,000	Mar - May	BRD52 flow above 999 CFS
			800	Jun - Dec	BRD52 flow above 799 CFS
	3	Storage Curve (MG)	4,644 (261.2')	Jan	
			5,471 (261.9')	Feb	
			5,527 (262')	Mar	
			5,421 (261.9')	Apr	
			5,192 (261.7')	May	
			5,404 (261.9')	Jun	
			5,214 (261.7')	Jul	
			4,834 (261.4')	Aug	
			4,667 (261.2')	Sep	
			5,633 (262.1')	Oct	
			4,851 (261.4')	Nov	
			5,930 (262.3')	Dec	

Table 6-6. Advanced Reservoir Rules (continued)

Reservoir	Rule Set	Type	Target	Months	Conditioned On:
Lake Monticello	1	Storage Curve (MG)	125,956 (423.5')	Jan	
			125,722 (423.3')	Feb	
			124,926 (423.0')	Mar	
			125,284 (423.2')	Apr	
			125,319 (423.2')	May	
			125,157 (423.1')	Jun	
			124,933 (423.0')	Jul	
			125,184 (423.1')	Aug	
			125,710 (423.3')	Sep	
			124,688 (422.9')	Oct	
			125,203 (423.1')	Nov	
			124,933 (423.0')	Dec	
Lake William C. Bowen	1	Minimum Release (cfs)	5	Jan - Dec	Reservoir #1 Storage between 816 & 810.1 MG
			15	Jan - Dec	Reservoir #1 Storage between 810 & 805.1 MG
			20	Jan - Dec	Reservoir #1 Storage between 805 & 800.1 MG
			25	Jan - Dec	Reservoir #1 Storage between 800 & 795.1 MG
			30	Jan - Dec	Reservoir #1 Storage between 795 & 790.1 MG
			45	Jan - Dec	Reservoir #1 Storage below 790 MG
Lake Lyman	1	Instream Flow (CFS)	10 cfs at BRD30	Jan - Dec	
Lake Cooley	1	Instream Flow (CFS)	5 cfs at BRD25	Jan - Dec	

historical lake levels indicate these two lakes are operated to stay within a certain range (256-266 ft for Parr and 420-425 ft for Monticello). The historic levels indicate a pattern of seasonality; therefore, to capture this relationship, both reservoirs were assigned storage targets based on historic monthly medians. Returns from the **PH: Fairfield Pumped Storage** Water User object are routed through the Monticello Local Inflow object, below Lake Monticello, to the Parr Reservoir.

6.2.4.3 Municipal Reservoirs

The Startex-Jackson-Wellford-Duncan Water District (**WS: SJWD**) operates two reservoirs for their municipal supply: Lake Lyman on the Middle Tyger River and Lake Cooley on Jordan Creek. SJWD releases water from the reservoirs to support their intakes on the Middle Tyger River and North Tyger River. Rather than specify a fixed release for these two reservoirs, they instead have an instream flow target ruleset that ensures a minimum flow downstream after the intake location.

Spartanburg CPW (**WS: Spartanburg**) operates three reservoirs: Lake Bowen and Municipal Reservoir #1 on the South Pacolet River and Lake Blalock on the Pacolet River. Lake Bowen, the most upstream of the two reservoirs on the South Pacolet River, is operated to generally maintain a constant level at Reservoir #1, which supports both their municipal water supply withdrawal and the

Simms Hydropower facility. This system is modeled using a tiered minimum release rule set for Lake Bowen. For ranges of increasing drawdown predicted downstream in Reservoir #1, a set of increasing releases are specified for Lake Bowen.

6.3 Water Users

6.3.1 Sources of Supply

Table 6-7 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, only several minor differences exist between the calibration and baseline model with respect to water users. Startex-Jackson-Wellford-Duncan Water District (**WS: SJWD**) purchased an intake from Spring Industries (**WS: Spring Industries**) on the Middle Tyger River in 1998 and reported withdrawals under their permit ID for several years. For the calibration model only, the object **WS: Spring Industries** represents withdrawals from this intake. For the baseline model, it is included within the **WS: SJWD** object. Additionally **WS: JPS Automotive** ceased withdrawals in 1996 and exists only as an object in the calibration model. Several out-of-basin sources are represented as Discharge objects (discussed below) and therefore do not appear in **Table 6-7**.

6.3.2 Demands

Table 6-8 presents the monthly demand for Municipal (WS), Industrial (IN), Mining (MI), and Nuclear (PN) Water User objects in the baseline model. Generally, demands for hydropower are not included, but given the complicated nature of the paired SCE&G reservoirs, a Fairfield Pumped Storage object (**PH: Fairfield Pumped Storage**) is included to represent water pumped up to Lake Monticello. Monthly irrigation demands for Golf Course (GC) and Agricultural (IR) Water User objects are presented in **Table 6-9**. 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 a few exceptions. Given key changes in water usage, three users have their baseline defined as 2007 through 2013: Spartanburg CPW (**WS: Spartanburg**), Startex-Jackson-Wellford-Duncan Water District (**WS: SJWD**), and Greer CPW (**WS: Greer**). **PH: Fairfield Pumped Storage** has a baseline of 2006 through 2013, based on the availability of SCE&G data. The Woodruff-Roebuck Water District (**WS: Wooduff-Roebuck**) only started withdrawing water in 2013, thus values from that year form its baseline values. The Inman Campobello Water District (**WS: ICWD**) has a water withdrawal permit, but as of 2013 was still purchasing water and therefore does not yet have baseline demands.

In the calibration model, demands for the calibration period (1983 through 2013) 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.

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 Broad River Basin Model, several water users import water from outside the basin and exist only as Discharge objects, as their water is sourced exclusively from other basins with return flows to the Broad River Basin. Newberry County Water and Sewer Authority (**NCWSA Import**) and Greenville Water (**Greenville Import [Durbin], Greenville Import [Gilder], Greenville Import [Pelham]**)

Table 6-7. Water User Objects and Sources of Supply Included in the Broad River Basin Model

Model Object ID	Facility Name	Source of Supply	Intake ID	Diversion Location (mi)	Permit Limit (MGM)	Note
GC: Carolina CC	CAROLINA COUNTRY CLUB	Fairforest Creek	42GC010S01	11.5	49.1	1
GC: CC of Spartanburg	THE COUNTRY CLUB OF SPARTANBURG	Lawsons Fork Creek	42GC005S01	20.7	71.4	1
GC: Fox Run CC	FOX RUN COUNTRY CLUB	Durbin Creek	23GC003S01	0.1	19	1
GC: Holly Tree CC	HOLLY TREE COUNTY CLUB	Gilder Creek	23GC009S01	0.1	6.25	1
GC: Links O'Tryon	LINKS O'TRYON	Pacolet River (South Pacolet River)	42GC015S01	5.8	11.83	1
GC: Mid Carolina	MID CAROLINA GOLF CLUB	Crims Creek	36GC050S01	0.1	32.364	1
GC: Musgrove Mill	MUSGROVE MILL GOLF CLUB	Enoree River	30GC003S02	52.1	24.55	1
GC: Pebble Creek	PEBBLE CREEK GOLF CLUB	Mountain Creek	23GC011S01	1.2	53.57	1
		Mountain Creek	23GC011S02	1.2	35.7	1
		Mountain Creek	23GC011S03	1.2	35.7	1
GC: Willow Creek	WILLOW CREEK GOLF CLUB	Enoree River	42GC013S01	15.2	33.48	1
IN: Carlisle Finishing	CARLISLE FINISHING LLC	Broad River	44IN003S01	52.3	178.56	1
IN: Chemtrade	CHEMTRADE	Broad River	12IN002S01	51.5	6.696	1
		Broad River	12IN002S02	51.5	15.624	1
IN: JPS Automotive	JPS AUTOMOTIVE TAYLORS PLANT 2	Enoree River	23IN032S01	2.1	-	2
IN: Milliken	MILLIKEN - MAGNOLIA PLANT	Broad River	11IN002S01	6.1	232	1
IN: Reflective Recycling	REFLECTIVE RECYCLING LLC	Pacolet River	42IN075S01	41.9	4.46	1
IR: Fisher Bros	FISHER BROTHERS FARMS	Middle Tyger River	23IR002S01	11	220	1,4
IR: Fishers Orchard	FISHERS ORCHARD	Enoree River	23IR008S01	5.2	8.15	1,4
IR: Gilberts	GILBERTS NURSERY INC	North Pacolet River	42IR026S01	19.3	30	1,4
		North Pacolet River	42IR026S02	19.3	19	1,4
		North Pacolet River	42IR026S03	19.3	5	1,4
		North Pacolet River	42IR026S04	19.3	4	1,4
		North Pacolet River	42IR026S05	19.3	1.8	1,4
IR: Hyder Austin	HYDER AUSTIN FARMS INC	Pacolet River (South Pacolet River)	23IR007S01	0.6	4	1,4
		Middle Tyger River	23IR007S02	0.7	4.64	1,4
		Pacolet River (South Pacolet River)	23IR007S03	0.6	7.49	1,4
		Middle Tyger River	23IR007S04	0.7	3.8	1,4
IR: Lewis Nursery	LEWIS NURSERY & FARM	Tyger River	36IR010S01	58.3	3	1,4
MI: Vulcan	VULCAN CONSTRUCTION MATERIALS	Pacolet River	42MI001S01	41.6	59.4	1
		Pacolet River	42MI001S02	41.6	59.5	1
PN: V.C. Summer	SCE&G - V.C. SUMMER NUCLEAR STATION	Monticello Reservoir	20PN001S01	76.1	26194.76	1
		Monticello Reservoir	20PN001S02	76.1	49.1	1
WS: Clinton	CITY OF CLINTON WTP	Enoree River	30WS001S01	47	310	1
		Duncan Creek	30WS001S02	0.1	105	1
WS: Columbia	City of Columbia - Lake Murray Water Plant	Saluda River/Lake Murray	40WS002S02	169	3875	1,3
	CITY OF COLUMBIA - CANAL WATER PLANT	Broad River	40WS054S01	104.9	3875	1
WS: Gaffney	GAFFNEY WTP	Lake Welchel (Cherokee Creek)	11WS001S01	1.9	620	1
		Gaston Shoals Lake (Broad River)	11WS001S02	2.8	651	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, and was included in the calibration model.
Note 3 indicates the withdrawal occurs outside the Broad Basin.
Note 4 indicates registered limit for irrigation.

Table 6-7. Water User Objects and Sources of Supply Included in the Broad River Basin Model (continued)

Model Object ID	Facility Name	Source of Supply	Intake ID	Diversion Location (mi)	Permit Limit (MGM)	Note
WS: Greer	GREER CPW - WATER TREATMENT PLANT	Lake Cunningham (S. Tyger River)	23WS004S01	10.9	1682.86	1
WS: ICWD	INMAN CAMPOBELLO N SPARTANBURG PROJECT #1	North Pacolet River	42WS001S01	22.2	248	1
WS: Landrum	CITY OF LANDRUM (SPARTANBURG CPW)	North Pacolet River (Vaughn Creek)	42WS008S01	1	34.41	1
		North Pacolet River (Vaughn Creek)	42WS008S02	1	4.65	1
WS: SJWD	SJWD MIDDLE TYGER WTP	Middle Tyger River	42WS012S01	21.7	713	1
		Tyger River (North Tyger River)	42WS012S02	2.2	620	1
		Lake Cooley (Jordan Creek)	42WS012S03	2.1	434	1
WS: Spartanburg	SPARTANBURG CPW	Lake Blalock (Pacolet River)	42WS004S01	27.6	2790	1
		Lake Bowen/Reservoir #1 (Pacolet River)	42WS014S01	18	5673	1
WS: Spring Industries	SPRING TREATMENT PLANT	Middle Tyger River	42IN005S02	21.7	-	2
WS: Union	CITY OF UNION WTP	Broad River	44WS001S01	41.3	446	1
WS: Whitmire	TOWN OF WHITMIRE WTP	Enoree River	36WS003S01	72.5	68.2	1
		Duncan Creek	36WS003S02	21.9	31	1
WS: Winnsboro	TOWN OF WINNSBORO WTP	Sand Creek	20WS001S01	0.1	62	1
		Mill Creek	20WS001S03	1.2	124	1
		Broad River	20WS001S05	81.6	310	1
WS: Woodruff-Roebuck	WOODRUFF-ROEBUCK WTP	Tyger River (North Tyger River)	42WS005S01	21	279	1
		South Tyger River	42WS005S02	44.6	279	1
WS: York	CITY OF YORK WTP	Turkey Creek	46WS002S01	1.4	93	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, and was included in the calibration model.
Note 3 indicates the withdrawal occurs outside the Broad Basin.
Note 4 indicates registered limit for irrigation.

represent source water from the Saluda and Savannah basins for the three Greenville objects. The City of Chester (**Chester Import**) represents return flows of water sourced from the Catawba River Basin.

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 or specified within a Discharge object. **Table 6-10** 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., Auriga Polymers, Clifton WWTP, Cowpens, and Chesnee WWTF for Spartanburg returns were all combined). Spartanburg also has a different number of return flow locations in the calibration model compared to the baseline model. The newer Fairforest plant (SC0020435-002) discharges to a different tributary than its older pipe (001), thus these two, along with the now-inactive Lawson Fork plant, are all represented as Discharge objects and not within Water User objects. For the baseline model, the Fairforest plant is included within the

Table 6-8. Baseline Model Average Monthly Demand for IN, MI, PH, PN, and WS Water Users

Month	IN: Carlisle Finishing	IN: Chemtrade	IN: Milliken	IN: Reflective Recycling	MI: Vulcan	PH: Fairfield Pumped Storage	PN: V.C. Summer	WS: Clinton	WS: Columbia	WS: Gaffney
	Baseline Model Average Monthly Demand (MGD)									
Permit Limit (MGD)	5.9	0.7	7.6	0.1	3.9	-	863.3	13.7	254.9	41.8
Jan	1.2	0.1	1.4	-	0.1	1401.3	820.7	2.1	25.7	6.2
Feb	1.2	0.1	1.6	-	0.1	1265.8	837.3	2.2	25.4	6.0
Mar	1.3	0.1	1.6	-	0.1	1345.1	834.4	2.1	27.2	6.2
Apr	1.2	0.1	1.7	-	0.1	1732.8	767.4	2.3	31.6	6.9
May	1.2	0.2	1.5	-	0.1	2350.3	624.5	2.6	34.7	7.2
Jun	1.3	0.3	1.8	-	0.1	2966.7	797.8	2.7	36.7	8.3
Jul	1.0	0.3	1.6	-	0.1	2920.2	834.4	2.8	38.6	8.4
Aug	1.3	0.2	1.6	-	0.1	3040.9	834.4	2.8	38.3	8.3
Sep	1.1	0.2	1.7	-	0.1	2583.1	780.9	2.7	35.6	7.3
Oct	1.2	0.2	1.6	-	0.1	1753.2	585.2	2.4	32.9	6.9
Nov	1.2	0.2	1.8	-	0.1	1257.4	570.5	2.2	29.2	6.3
Dec	0.9	0.1	1.6	-	0.1	1334.2	728.9	2.1	25.2	5.7

Month	WS: Greer	WS: ICWD	WS: Landrum	WS: SJWD	WS: Spartanburg	WS: Union	WS: Whitmire	WS: Winnsboro	WS: Woodruff-Roebuck	WS: York
	Baseline Model Average Monthly Demand (MGD)									
Permit Limit (MGD)	55.4	8.2	1.3	58.1	278.4	14.7	3.3	16.3	18.4	3.1
Jan	7.0	-	0.4	5.1	26.2	2.9	0.5	1.7	0.5	1.1
Feb	7.0	-	0.4	5.1	25.7	2.8	0.5	1.7	1.1	1.0
Mar	7.1	-	0.4	5.2	25.5	2.8	0.5	1.6	1.0	1.0
Apr	8.1	-	0.4	6.4	27.1	3.0	0.5	1.8	1.1	1.1
May	9.2	-	0.5	6.8	30.1	3.3	0.5	1.9	1.0	1.2
Jun	10.8	-	0.5	7.7	33.6	3.6	0.5	2.1	1.1	1.2
Jul	10.9	-	0.5	6.9	34.9	3.8	0.5	2.2	1.1	1.2
Aug	10.3	-	0.5	7.1	34.8	3.8	0.5	2.1	1.2	1.2
Sep	9.8	-	0.5	7.1	33.2	3.6	0.5	2.0	2.0	1.2
Oct	8.7	-	0.5	6.3	30.0	3.3	0.5	1.9	2.4	1.0
Nov	7.7	-	0.4	5.9	27.5	3.1	0.4	1.8	2.2	0.8
Dec	7.1	-	0.4	5.2	25.4	2.9	0.4	1.6	2.1	0.8

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

Table 6-9. Baseline Model Average Monthly Demand for GC and IR Water Users

Month	IR: Fisher Bros	IR: Hyder Austin	IR: Lewis Nursery	IR: Gilberts Nursery	GC: Fox Run CC	GC: Holly Tree CC	GC: Pebble Creek	GC: Musgrove Mill	GC: Mid Carolina	GC: CC of Spartanburg	GC: Carolina CC	GC: Willow Creek	GC: Links O'Tryon
	Baseline Model Average Monthly Demand (MGD)												
Jan	0.00	0.00	0.00	0.04	0.01	0.00	0.04	0.00	0.00	0.03	0.01	0.01	0.00
Feb	0.00	0.00	0.00	0.08	0.00	0.01	0.07	0.00	0.00	0.03	0.02	0.03	0.00
Mar	0.00	0.00	0.00	0.13	0.02	0.02	0.15	0.00	0.00	0.10	0.05	0.06	0.00
Apr	0.00	0.00	0.00	0.18	0.04	0.03	0.25	0.01	0.00	0.16	0.13	0.07	0.00
May	0.04	0.01	0.00	0.23	0.06	0.04	0.27	0.03	0.01	0.23	0.13	0.09	0.00
Jun	0.19	0.01	0.00	0.34	0.08	0.05	0.56	0.06	0.04	0.22	0.14	0.12	0.00
Jul	0.27	0.01	0.00	0.40	0.09	0.06	0.43	0.06	0.08	0.20	0.12	0.19	0.00
Aug	0.11	0.01	0.00	0.44	0.06	0.06	0.44	0.06	0.08	0.25	0.11	0.19	0.00
Sep	0.01	0.00	0.00	0.46	0.07	0.05	0.32	0.03	0.07	0.21	0.13	0.22	0.00
Oct	0.00	0.00	0.00	0.34	0.03	0.03	0.22	0.01	0.02	0.21	0.09	0.16	0.00
Nov	0.00	0.00	0.00	0.25	0.02	0.01	0.07	0.00	0.01	0.16	0.07	0.07	0.00
Dec	0.00	0.00	0.00	0.16	0.00	0.00	0.04	0.00	0.00	0.07	0.04	0.02	0.00

Table 6-10. 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: Milliken	MILLIKEN/MAGNOLIA FINISHING PLANT	SC0003182-001	11IN002	Broad River	6.4	100
WS: Gaffney	BLACKSBURG/CANOE CREEK (NEW)	SC0047457-001	11WS001	Broad River	7.2	5.5
WS: Gaffney	GAFFNEY/CLARY WWTF	SC0031551-001	11WS001	Thicketty Creek	1.3	52.4
WS: Gaffney	GAFFNEY/PEOPLES CRK-BROAD RVR	SC0047091-001	11WS001	Broad River	10.2	42.1
IN: Chemtrade	CHEMTRADE PERF CHEMICALS/LEEDS	SC0022756-001	12IN002	Broad River	51.9	100
PN: V.C. Summer	SCE&G/V C SUMMER NUCLEAR STAT	SC0030856	20PN001	Monticello Local Inflow	6.0	100
WS: Winnsboro	WINNSBORO/JACKSON CREEK PLAN	SC0020125-001	20WS001	Jackson Creek	0.1	92.1
WS: Winnsboro	RIDGEWAY, TOWN OF	SC0022900-001	20WS001	Big Cedar Creek	0.2	7.9
WS: Greer/WS: SJWD	GREER/MAPLE CREEK PLANT	SC0046345-001	23WS004/ 42WS012	South Tyger River	19.6	74.8/10
WS: Greer/Greenville Import	ReWa/PELHAM WWTF	SC0033804-001	23WS004	Enoree River	8.9	22.4
WS: Greer	UNITED UTILS/N GREENVILLE COLL	SC0026565-001	23WS004	South Tyger River	1	2.8
WS: Clinton	LAURENS CO W&S/CLINTON-JOANN	SC0037974-001	30WS001	Broad River	**999**	100
WS: Whitmire	WHITMIRE, TOWN OF	SC0022390-001	36WS003	Duncan Creek	22.5	100
WS: Columbia	COLUMBIA/METRO PLANT	SC0020940-001	40WS054	Broad River	**1000**	100
WS: Columbia	EAST RICH CO PSD/GILLS CREEK	SC0038865-001	40WS054	Broad River	**1000**	100
MI: Vulcan	VULCAN MATERIALS - PACOLET Quarry	SCG730293	42MI001	Pacolet River	41.7	100
WS: ICWD	INMAN, CITY OF	SC0021601-001	42WS001	Lawsons Fork Creek	2.0	100
WS: ICWD	MILLIKEN/DEWEY PLANT	SC0003581-001	42WS001	Lawsons Fork Creek	2.0	100
WS: Spartanburg*	SSSD/FAIRFOREST PLANT	SC0020435-002	42WS014	Pacolet River	41.5	66.9
WS: Spartanburg	SIMMS WTP	SCG646049	42WS014	Pacolet River	18.6	17.9
WS: Spartanburg	AURIGA POLYMERS INC./SPARTANBURG	SC0002798-002	42WS004	Pacolet River	33.7	7.2
WS: Spartanburg	SSSD/CLIFTON WWTP	SC0042668-001	42WS014/ 42WS004	Pacolet River	33.7	7.2
WS: Spartanburg	SSSD/COWPENS-PACOLET RIVER	SC0045624-001	42WS014/ 42WS004	Pacolet River	33.7	7.2
WS: Spartanburg	CHESNEE WWTF	SC0025763-001	42WS004	Pacolet River	33.7	7.2
WS: Spartanburg/ WS: SJWD	SSSD/LOWER N TYGER RIVER WWTP	SC0048143-001	42WS014/ 42WS012	Tyger River (North Tyger Rive	14.0	7.5/9.8
WS: Woodruff-Roebuck	WOODRUFF/ENOREE RIVER	SC0045802-001	42WS005	Enoree River	29.0	100
WS: Landrum	SSSD/PAGE CREEK WWTP	SC0026875-001	42WS008	North Pacolet River	11.3	88.9
WS: Landrum	SWS LANDRUM WTP	SCG64500	42WS008	Vaughn Creek	3.1	11.1
WS: SJWD	LYMAN, CITY OF	SC0021300-001	42WS012	Middle Tyger River	22.5	49.3
WS: SJWD	SJWD WTP	SCG646023	42WS012	Middle Tyger River	22.5	28.1
WS: SJWD	SSSD/S. TYGER RV REGIONAL WWTP	SC0047732-001	42WS012	South Tyger River	32.4	2.9
IN: Carlisle Finishing	CONE MILLS CORP/CARLISLE PLANT	SC0001368-001	44IN003	Broad River	52.8	100.0
WS: Union	UNION/TOSCH'S CREEK WWTP	SC0047244-001	44WS001	Fairforest Creek	39.8	74.3
WS: Union	CITY OF UNION WTP	SCG646042	44WS001	Broad River	7.1	15.6
WS: Union	JONESVILLE, TOWN OF	SC0024988-001	44WS001	Pacolet River	28.3	4.2
WS: Union	LOCKHART TREATMENT FACILITY	SC0003051-001	44WS001	Broad River	36.7	5.9
IN: Reflective Recycling	REFLECTIVE RECYCLING OF SC LLC	SC0049174-002	42IN075	Pacolet River	42.0	100
IN: GE/Gas	GE/GAS TURBINE MFG OPERATION	SC0003484-001	23IN058G	Enoree River	11.1	100
WS: York	YORK/FISHING CREEK WWTF	SC0038156-001	46WS002	Broad River	**1001**	100

Note: Returns outside of the Broad River Basin are indicated in ***bold***.

** Only represented in the calibration model*

*** Represented by a Discharge object in the calibration model and a return in a Water User object in the baseline model.*

Table 6-10. Returns and Associated Model Objects (continued)

Model Object ID	Facility Name	NPDES Pipe ID	Associated Water Permit	Discharge Tributary	Model River Mile	% of Return Flow
Transbasin Imports Represented by Discharge Objects						
Chester Import	CHESTER/SANDY RIVER WWTF	SC0036081-001	12WS002	Sandy River	0.1	-
Greenville Import (Durbin)	ReWa/DURBIN CREEK	SC0040002-001	23WS007	Durbin Creek	3.5	-
Greenville Import (Gilder)	ReWa/GILDER CREEK	SC0040525-001	23WS007	Enoree River	17.2	-
Greenville Import (Pelham)	ReWa/PELHAM WWTF	SC0033804-001	23WS007	Enoree River	8.9	-
Greenville Import (Taylors)*	ReWa/TAYLORS AREA PLANT	SC0024309-001	23WS007	Enoree River	2.6	-
NCWSA Import	NCW&SA/CANNONS CREEK WWTP	SC0048313-001	36WS002	Cannons Creek	0.2	-
Columbia Import	RICHLAND CO/BROAD RIVER WWTF	SC0046621-001	40WS002	Broad River	94.8	-
Columbia Import	CHAPIN, TOWN OF	SC0040631-001	40WS002	Broad River	85.6	-
In-basin Returns Represented by Individual or Aggregated Discharge Objects						
SSSD/Lawson Fork*	SSSD/LAWSON FORK PLANT	SC0020427-001	42WS014	Lawsons Fork Creek	21	-
Old Fairforest Creek (001)*	SSSD/FAIRFOREST PLANT	SC0020435-001	42WS014	Fairforest Creek	10	-
SSSD/Fairforest Creek (002)**	SSSD/FAIRFOREST PLANT	SC0020435-002	42WS014	Pacolet River	42	-
Midland	MIDLAND CAPITAL LLC/MOORE PLANT	SC0036145-001	*none*	South Tyger River	37	-
SC Dept Corr	SC DEPT CORR/TYGER RIVER CORRE	SC0036773-001	*none*	Tyger River	31	-

*Note: Returns outside of the Broad River Basin are indicated in **bold**.*

** Only represented in the calibration model*

*** Represented by a Discharge object in the calibration model and a return in a Water User object in the baseline model.*

Spartanburg object. No returns are assumed for golf course and agricultural irrigation (i.e., 100% consumptive use).

Table 6-11 presents the monthly percent consumptive use for water users with known return flows. For all municipal and industrial water users, consumptive use was calculated from DHEC-reported withdrawals and discharges over the baseline period (2004 through 2013). The one mine, Vulcan, has a general use discharge permit, which have flows that do not require reporting to DHEC. Instead, returns for this water user is defined by the estimated percent of return flow indicated in its surface water withdrawal permit. For **WS:Woodruff-Roebuck** and **WS: ICWD** in the calibration model, demands were set to equal the known return flows for associated discharge facilities.

Table 6-12 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 Broad 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 Broad River Basin model, these calibration inputs only included reach hydrologic gain/loss factors and, to a very limited extent, reservoir operating rule targets.

Table 6-11. Baseline Model Monthly Consumptive Use Percentage

Month	Monthly Consumptive Use (%)									
	IN: Carlisle Finishing	IN: Chemtrade	IN: Milliken	IN: Reflective Recycling	MI: Vulcan	PH: Fairfield Pumped Storage	PN: V.C. Summer	WS: Clinton	WS: Columbia	WS: Gaffney
Jan	23.1	87.7	100.0	-	90.0	0.0	20.0	38.0	59.7	34.0
Feb	18.7	88.5	100.0	-	90.0	0.0	21.2	32.9	49.5	33.8
Mar	12.5	91.1	100.0	-	90.0	0.0	21.6	28.1	51.1	30.7
Apr	13.4	93.5	100.0	-	90.0	0.0	18.9	40.7	72.7	39.4
May	21.6	95.2	100.0	-	90.0	0.0	13.2	50.9	92.4	42.8
Jun	31.9	92.9	100.0	-	90.0	0.0	12.6	52.9	94.1	51.0
Jul	22.5	91.4	100.0	-	90.0	0.0	11.8	54.7	89.5	53.4
Aug	18.5	92.3	100.0	-	90.0	0.0	12.6	52.8	86.5	52.3
Sep	21.3	93.4	100.0	-	90.0	0.0	10.2	53.7	88.7	46.1
Oct	24.1	91.2	100.0	-	90.0	0.0	10.4	50.2	86.2	42.9
Nov	17.7	91.1	100.0	-	90.0	0.0	19.2	44.9	76.7	40.6
Dec	24.2	92.3	100.0	-	90.0	0.0	16.9	33.7	63.2	31.6

Month	Monthly Consumptive Use (%)									
	WS: Greer	WS: ICWD	WS: Landrum	WS: SJWD	WS: Spartanburg	WS: Union	WS: Whitmire	WS: Winnsboro	WS: Woodruff-Roebuck	WS: York
Jan	66.7	-	25.3	42.5	35.7	44.1	28.1	50.3	19.6	24.1
Feb	67.6	-	24.5	39.3	33.1	42.8	24.8	49.0	68.5	24.1
Mar	65.7	-	20.9	39.7	28.9	41.0	21.2	48.3	69.2	24.1
Apr	71.1	-	26.9	50.0	36.8	50.0	27.7	57.5	72.3	24.1
May	74.2	-	33.7	45.4	44.7	54.1	30.7	62.4	63.2	24.1
Jun	78.8	-	36.8	53.9	49.4	57.2	35.0	63.6	65.1	24.1
Jul	78.0	-	40.1	53.7	51.0	62.3	36.5	64.4	66.4	24.1
Aug	78.1	-	37.0	59.3	51.1	62.4	33.7	62.0	75.7	24.1
Sep	78.4	-	34.1	57.8	52.0	59.8	35.4	60.3	86.7	24.1
Oct	76.7	-	33.9	54.0	46.9	58.5	35.5	60.5	88.5	24.1
Nov	73.2	-	33.0	51.0	44.1	54.5	32.8	54.2	86.2	24.1
Dec	66.6	-	24.8	39.3	34.8	43.8	24.8	47.5	80.5	24.1

Table 6-12. Baseline Model Monthly Return Flows for Discharge Objects

	Monthly Return Flow (MGD)								
Month	Greenville Import: ReWa Pelham	Greenville Import: ReWa Gilder	Greenville Import: ReWa Durbin	Midland	SC Dept Corr	Chester Import	NCW&SA Import	Columbia Import: Chapin	Columbia Import: Richland
Jan	4.9	2.7	1.1	0.0	0.1	0.6	0.2	0.3	1.1
Feb	4.8	2.6	1.0	0.0	0.1	0.6	0.2	0.4	1.2
Mar	5.0	2.7	1.1	0.0	0.1	0.6	0.2	0.3	1.1
Apr	4.8	2.5	0.9	0.0	0.1	0.5	0.2	0.3	1.0
May	5.1	2.4	1.0	0.0	0.1	0.5	0.2	0.3	1.0
Jun	5.1	2.4	1.0	0.0	0.1	0.5	0.2	0.3	1.0
Jul	5.0	2.4	0.9	0.0	0.1	0.5	0.2	0.3	1.0
Aug	5.0	2.4	0.9	0.0	0.1	0.5	0.2	0.3	1.1
Sep	4.7	2.4	0.9	0.0	0.1	0.4	0.2	0.3	1.0
Oct	4.6	2.4	0.9	0.0	0.1	0.4	0.2	0.3	1.0
Nov	4.7	2.4	0.9	0.0	0.1	0.5	0.2	0.3	1.0
Dec	5.2	2.7	1.2	0.0	0.1	0.6	0.2	0.4	1.0

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

For the model calibration exercise, the fully constructed and parameterized Broad Basin model, as described in Sections 5 and 6, was used to simulate the 1983 to 2013 historical 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.

7.2.1 Calibration Steps

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. New implicit tributary objects were added, as needed and based on visual inspection of GIS mapping, to capture ungaged drainage areas and tributary inputs not included in the original model framework. Note that a list of implicit tributaries included in the Broad Basin model is provided in Section 6.

3. 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.

4. 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.

5. Simulated reservoir operating rules were reviewed based on monthly reservoir level modeled vs. measured comparisons.

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

7. 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.

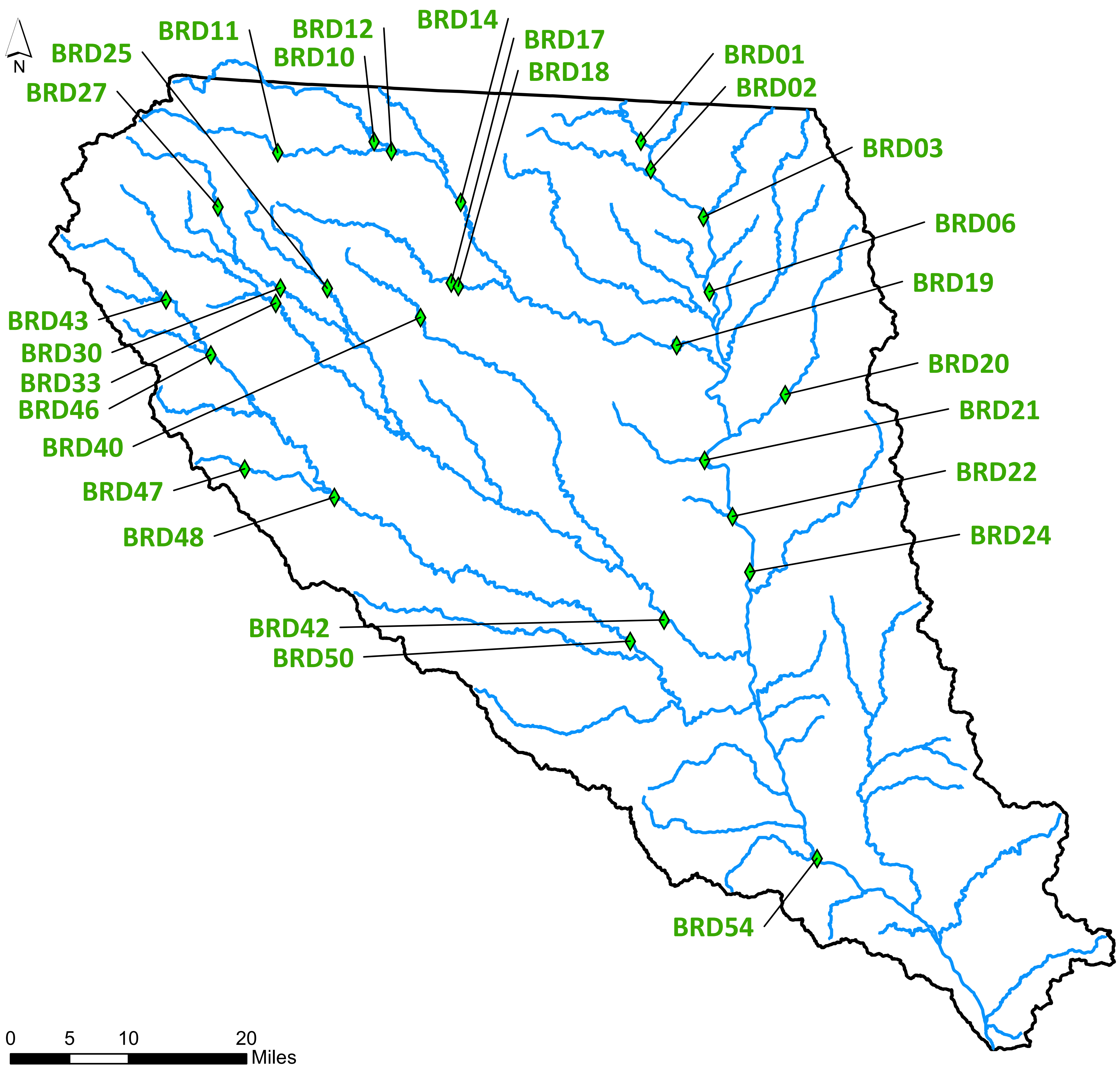
All USGS flow gages at downstream locations in the basin with reasonable records within the targeted calibration period were used to assess model performance and guide the model calibration steps described above. Two gages on the Broad River were removed from calibration due to known backwater effects: Broad River at Blair (02160750, BRD52) above Parr Shoals Reservoir and Broad River near Columbia above the Canal Plant (02162035, BRD58). 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.

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 Broad 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 operating rules.

- The model also uses a static set of (current) reservoir characteristics throughout the calibration period (e.g., dam height). Construction of new reservoirs and modifications to dams and spillways during the calibration period are not accounted for.



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

Figure 7-1. USGS Streamflow Gages Used in Calibration

CDM Smith

- Uncertainty in withdrawals from and discharges to reservoirs for earlier parts of the calibration period effect reservoir levels, especially in reservoirs with relatively little storage.

Several of these complicating factors are further detailed below. As described in Section 6, Lake Blalock underwent dam construction and repairs from 2004 through 2010. For the calibration model, Lake Blalock was represented by its current capacity for two reasons: 1) limited information was available on its pre-construction state, and 2) the two streamflow gages downstream only have periods of record in the more recent years of the calibration period. The last gage before the confluence with the mainstem, BRD19 (02156370), only had 2012-2013 available for comparison. Calibration of mainstem reach gains and losses also demonstrated significant sensitivity to the subbasin flow factors of the last two flow segments of the Pacolet River downstream of Lake Blalock. In addition to construction on Lake Blalock, model results indicate there were changes of operation upstream from Lake Bowen and Municipal Reservoir #1, possibly for repairs or perhaps releasing/holding back water for filling or withholding water from Blalock during its changes. Lastly, uncertainty with Spartanburg withdrawal data before 1994 made calibration in this area difficult. From 1983-1994, the values reported to DHEC corresponding to intake 42WS004S01 on Lake Blalock appear to belong instead to intake 42WS014S01 on Reservoir #1, which was missing reported values for this period. It was assumed these values belonged to intake 42WS014S01 and that withdrawals started from Blalock in 1994.

Gaston Shoals Reservoir has multiple sources of uncertainty that complicate calibration. The reservoir generally operates as run-of-river, but can have fluctuating levels due to repair work on the wooden flashing at both the middle and the upper dam; drops in levels when a spill gate is open during high water events; or drops below license elevations during low inflows. Additionally, silt accumulation is expected to have reduced usable storage. Adding to the complexity, Gaffney CPW also uses Gaston Shoals as a secondary water supply in conjunction with Lake Whelchel. Lake Whelchel resides on the ungaged Cherokee Creek and no historic lake elevations are available. Without knowledge of drawdowns for Lake Whelchel, it is difficult to determine the interaction between the two water sources and how much changes in volume in Gaston Shoals was due to meeting Gaffney demand.

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 very 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. However, the primary calibration parameters in SWAM are the reach gain/loss factors. Adjustments to other parameters are secondary and often not required. **For the Broad Basin model calibration, only reach gain/loss and subbasin flow factors, and to a very limited extent advanced rules for some reservoirs, were adjusted as part of the calibration process.** The final model reach gains/losses 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, 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. 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 all targeted sites. 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). 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 very 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. Using the monthly timestep, the comparisons indicate that, where there is at least 10 years of gage records, the modeled cumulative flows are within 5% of cumulative measure flows, indicating that the model is not significantly over-or under-predicting flows. The two exceptions to this are:

1. The Tyger River near Delta gage (BRD42), where cumulative modeled flow is 7.4% lower than cumulative measured flow. At BRD42, the discrepancy occurs in the period 1983-2003, where there is much less confidence in the withdrawal and discharge data. Since 2000, cumulative modeled flow is 3.8% higher than cumulative measured flow. Since there is less uncertainty in the more recent data, the subbasin flow factor adjustments were made to best represent the later part of the calibration period.

2. The Broad River near Alston gage (BRD54), where cumulative modeled flow is 6.9% higher than cumulative measured flow. Average annual and cumulative flows are nearly identical over the period 1983 to 2004. Beginning in 2004, there is a bias for over-predicting flows in most years. Additional evaluation may be conducted to identify the source of this bias and make adjustments, where supported.

For two-thirds of the gages (18 of 27), modeled mean flow values, averaged over the full period of record, were within 2% of measured mean flows and 7 of the remaining 9 sites were within 10% of measured mean flows. This indicates that the overall water balance is very well represented and there are no obvious missing or excess sources of flow in the model. The two sites where average modeled vs. measured flows exceeded 10% were Lawson Fork Creek at Spartanburg (BRD18) and Turkey Creek near Lowrys (BRD20). Both gages had few years of records (4 and 9) and average flows below 40 cfs.

Monthly flow percentiles are also well captured by the model across nearly all sites. Monthly flow percentile deviations are all generally within 10 - 25% with no clear bias one way or the other.

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. Separate evaluations in which historic withdrawals or water transfers are used to reproduce observed drawdown and recovery patterns will also be explored to further validate this model prior to conversion into the baseline model for future planning.

Some of the differences in observed and simulated reservoir levels are attributed to anomalies in reservoir operations associated with reservoir construction, 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. Additional testing prior to deploying the models for future planning will replace rules and targets with historic observed withdrawals and releases to further test the dynamics of each reservoir.

Lastly, a key difference between some of the observed and simulated reservoir traces 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 very 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. The reservoirs in the Broad River are 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. Modeled daily percentile plots exhibit excellent agreement with measured data for most mainstem and tributary locations. The few discrepancies are likely primarily attributable to the lack of reach routing and overall simplified representation of hydrologic processes in the model, common to all water allocation models. However, these discrepancies are generally within 20% of gaged flows and deemed acceptable for the daily model.

Modeled regulatory low flow values (7Q10) are within 5.4% to 28.2% of measured values at mainstem (Broad River) gages with 5 or more years of record. At each gage, the model over-predicts the 7Q10 slightly. Modeled 7Q10 flows for the Pacolet River and its tributaries are within 0% to 54.4% of measured values. Modeled 7Q10 flows for the Tyger River and its tributaries are within 0.2% and 58.4% of measured values for gages with 10 or more years of record, with the exception of BRD42, where the modeled 7Q10 is 107 cfs compared to measured 7Q10 of 43 cfs. Modeled 7Q10 flows for the Enoree River and its tributaries are within 2.2% to 47.1% of measured values for gages with 10 or more years of record. A table comparing model and measured 7Q10 flows is provided at the end of Appendix B. It is important to realize that low flows in the model are highly sensitive to modeled basin water use and operations. Small errors in estimated (or reported) withdrawals or modeled reservoir releases can have a significant impact on modeled annual low flows. Consequently, model uncertainty associated with this metric is relatively high and additional model adjustments to improve this calibration fit are generally not justified.

Lastly, the model adequately hindcasts delivered water supply for each of the water users in the model. Simulated supply roughly equals simulated demand for all users, with no significant shortfalls.

Section 8

Use Guidelines for the Baseline Model

The baseline Broad 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 1929 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.

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. In the Broad River Basin, it may be useful to examine flows with either managed or unimpaired flows coming from North Carolina into South Carolina. It may also be useful (for example) to alter boundary condition flows to test the impacts of potential climate variability.

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, November 2014. *South Carolina Surface Water Quantity Models – Modeling Plan.*

CDM Smith, July 2015. *Broad River Basin SWAM Model Framework.*

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

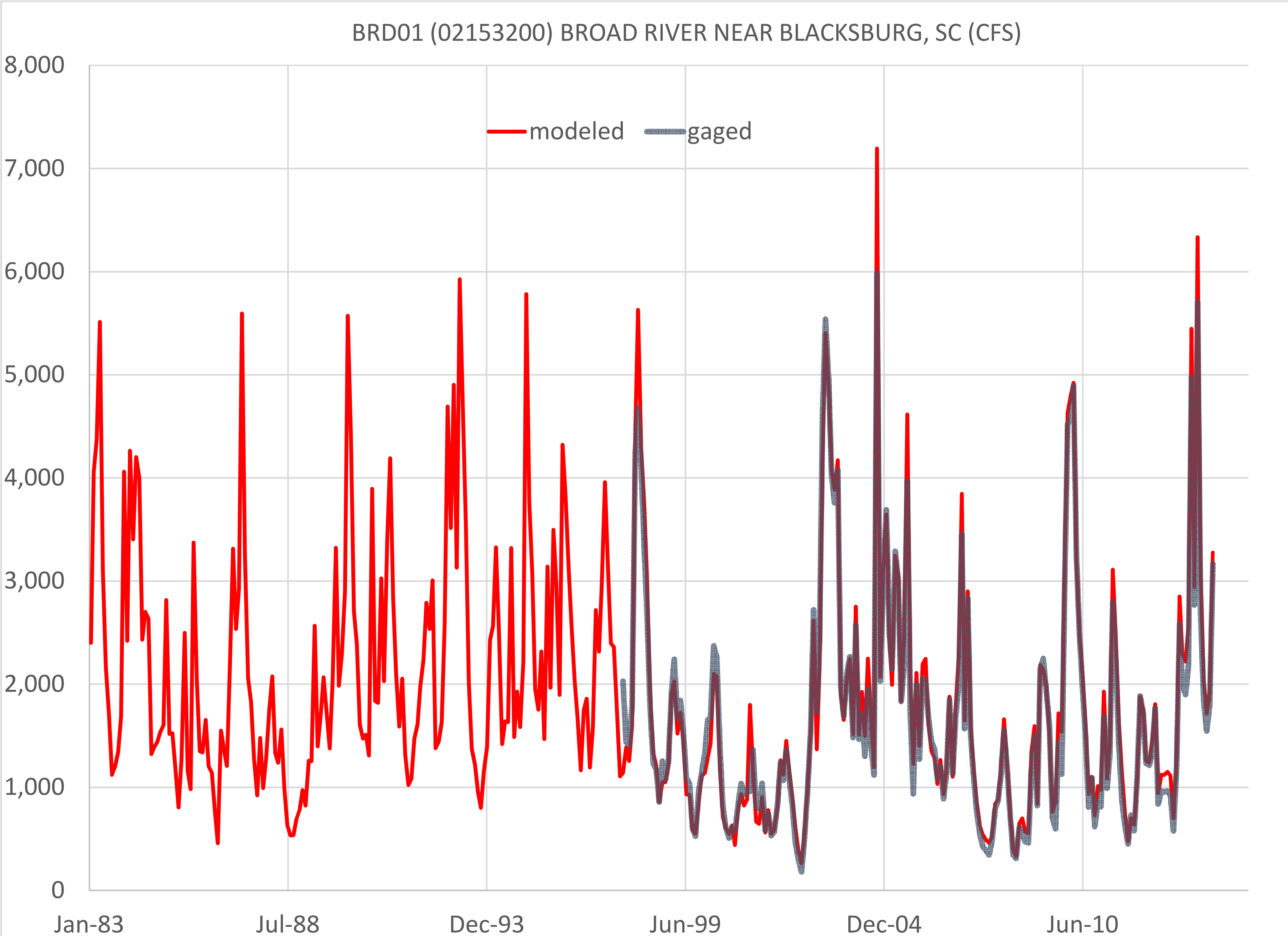
HDR (formerly DTA), 2007. *Broad River CHEOPS Model Operations Report.*

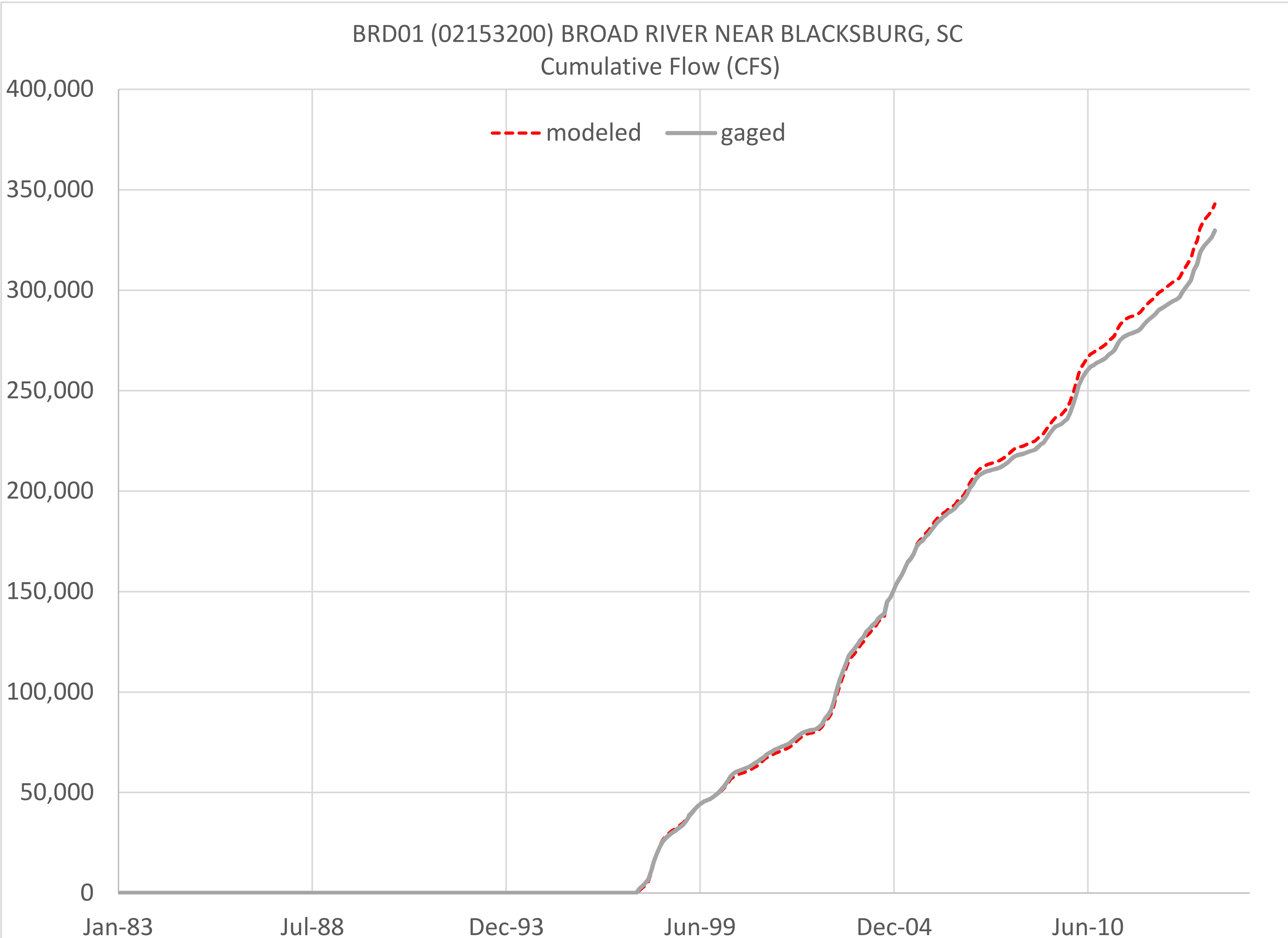
Purvis, John C., undated. *Pan Evaporation Records for the South Carolina Area, Southeast Regional Climate Center Columbia, SC* http://dnr.sc.gov/climate/sco/Publications/pan_evap_records.php

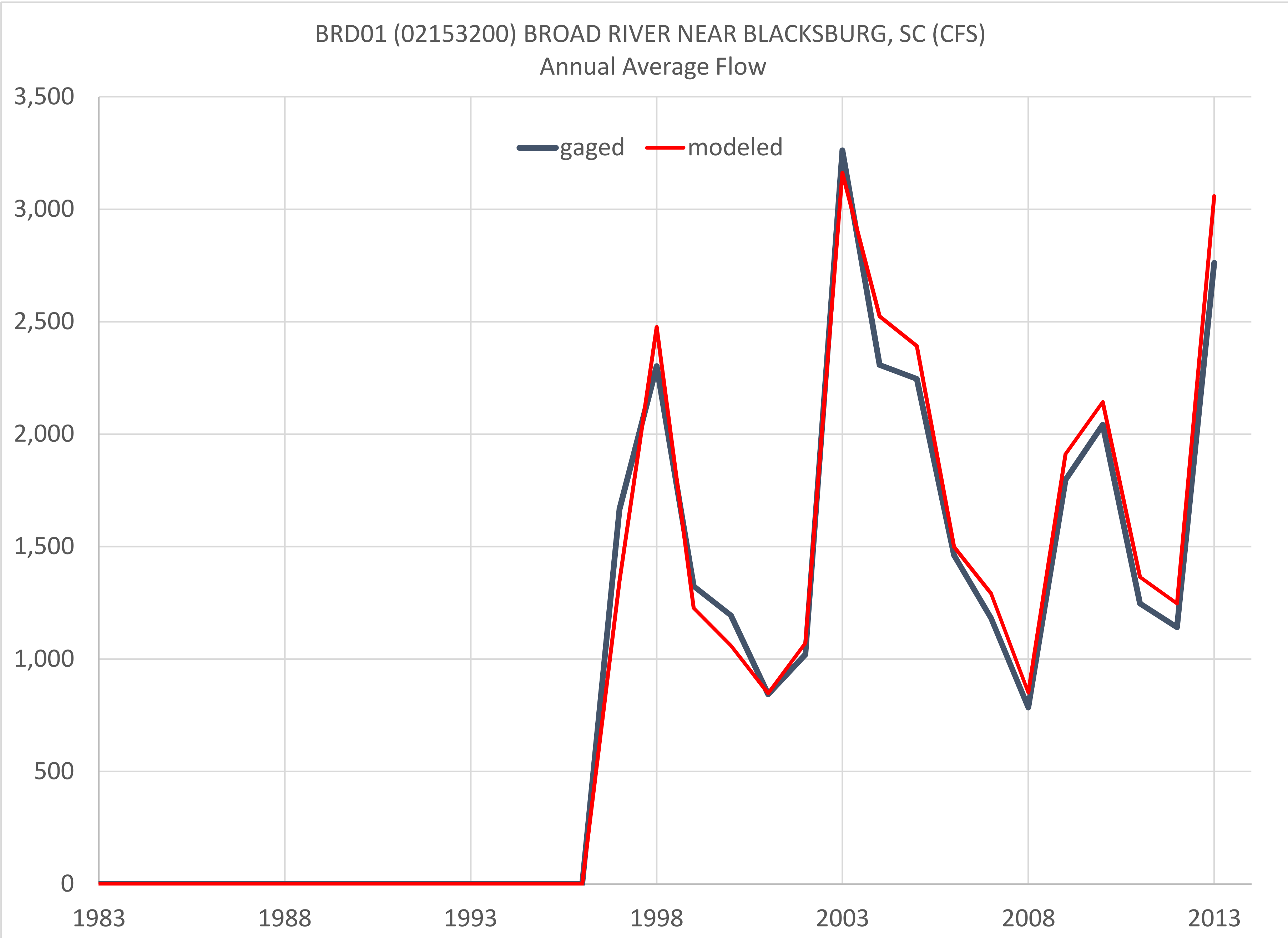
Appendix A

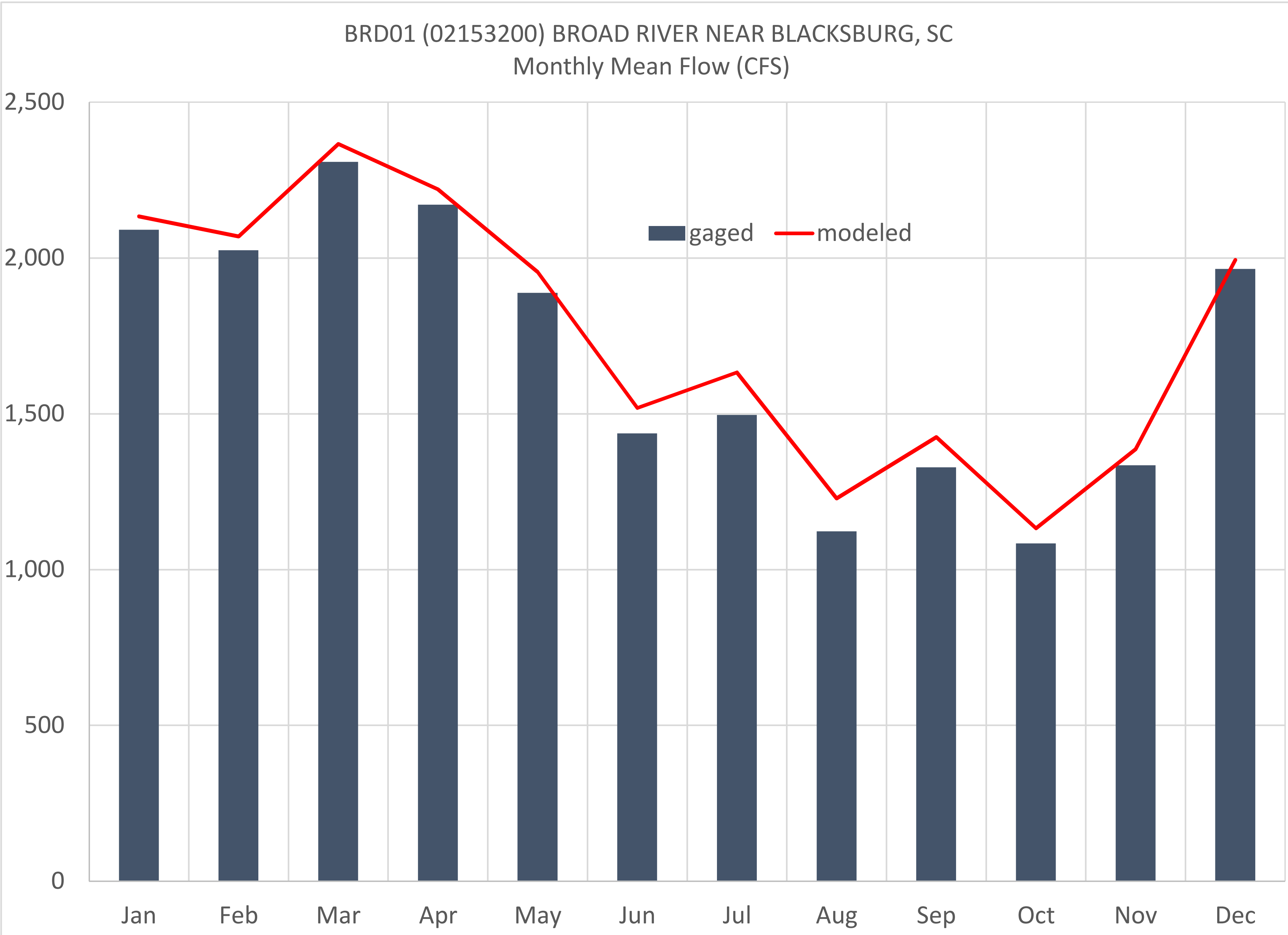
Broad River Basin Model Monthly Calibration Results

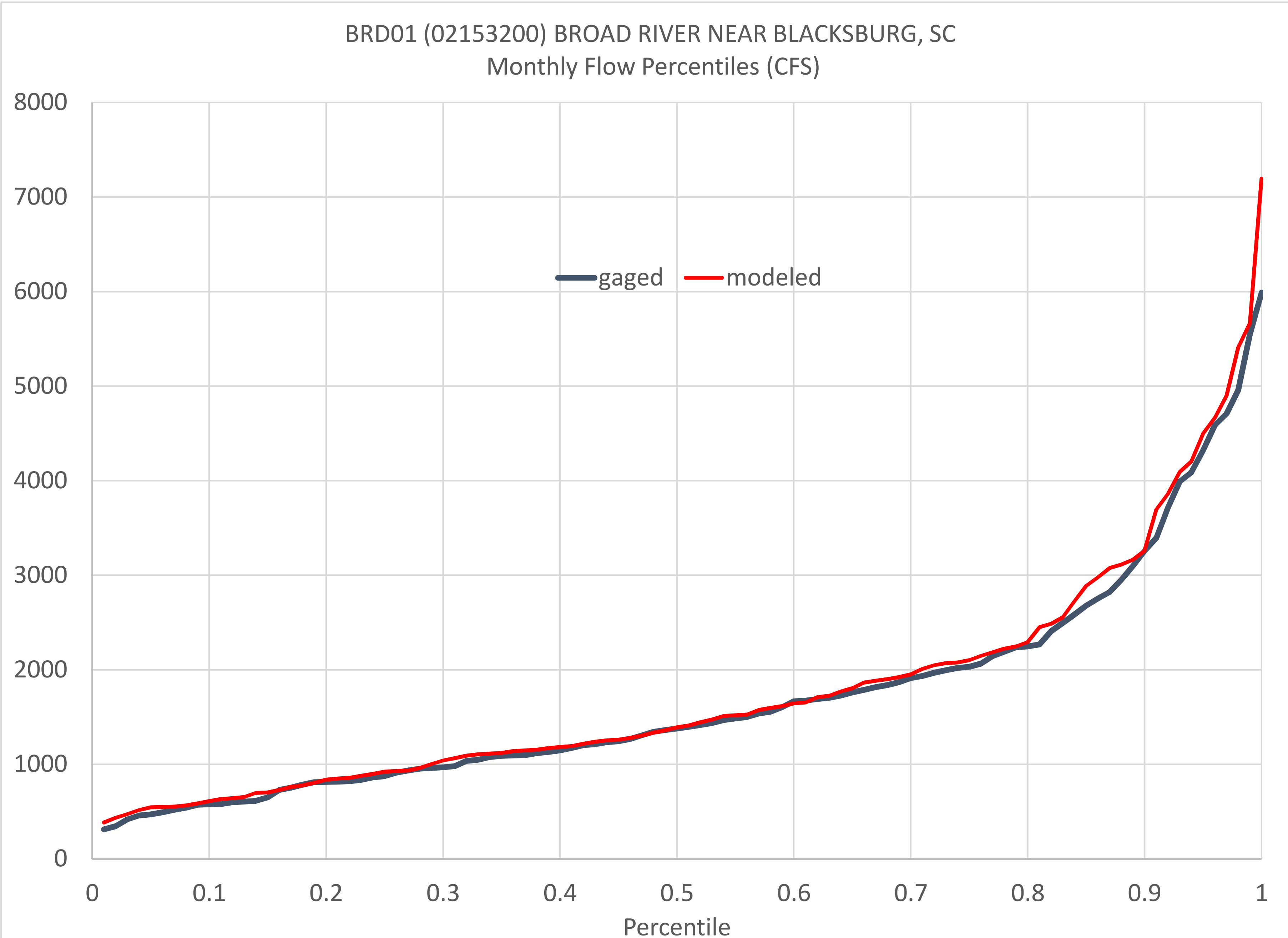
CDM Smith

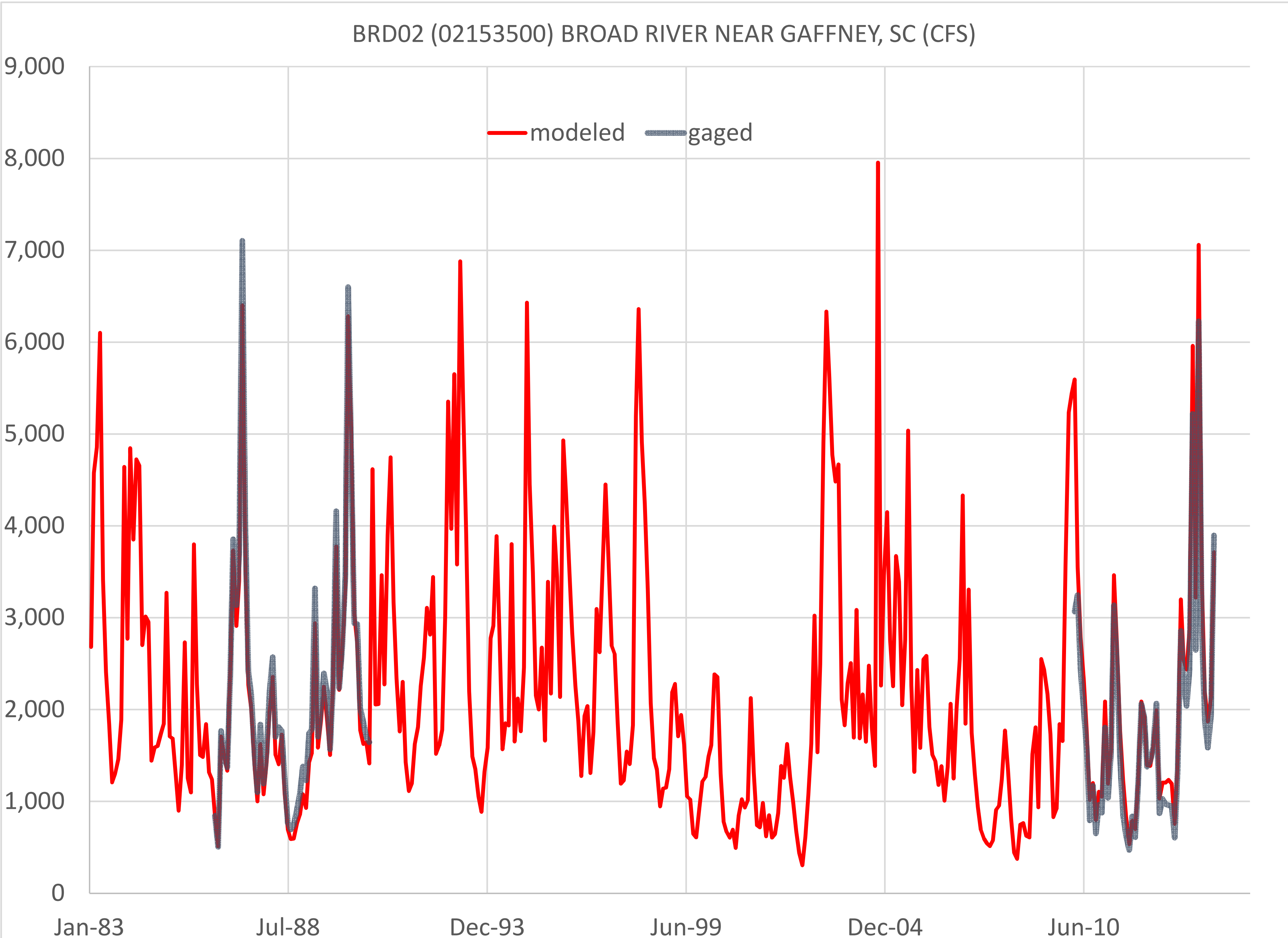

BRD01 (02153200) BROAD RIVER NEAR BLACKSBURG, SC (CFS)
modeled
gaged
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

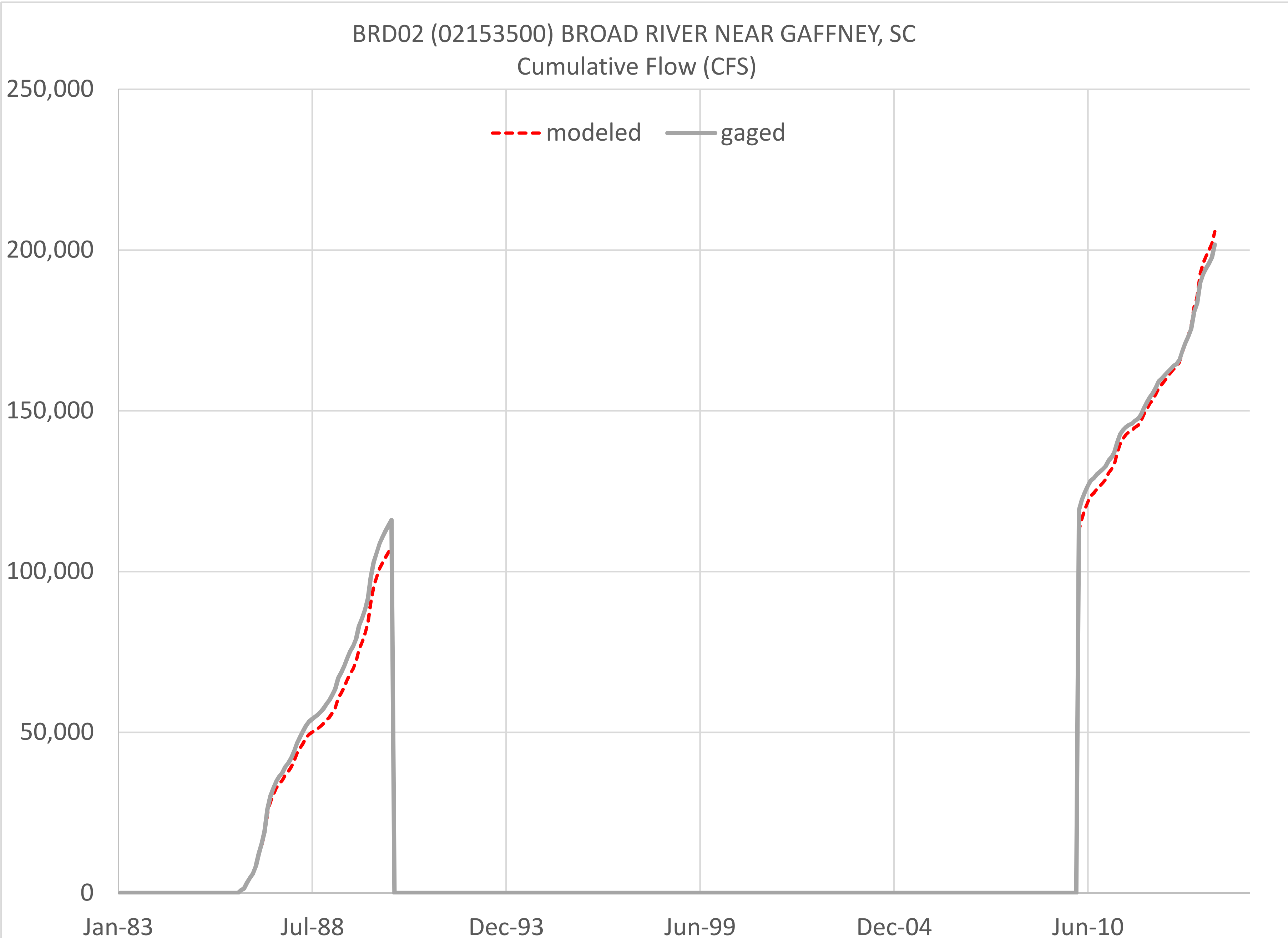

BRD01 (02153200) BROAD RIVER NEAR BLACKSBURG, SC
Cumulative Flow (CFS)
modeled
gaged
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

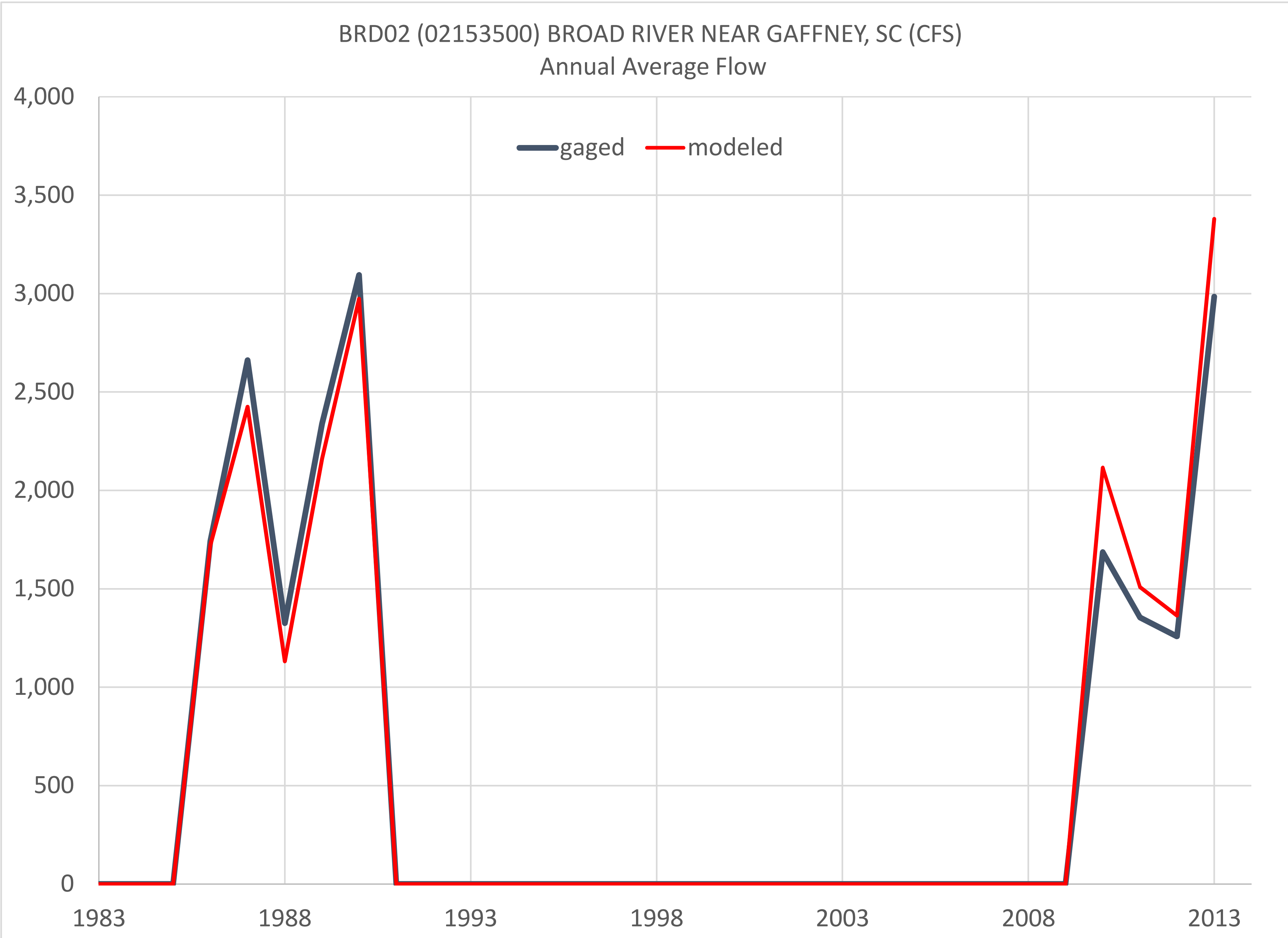

BRD01 (02153200) BROAD RIVER NEAR BLACKSBURG, SC (CFS)
Annual Average Flow
gaged
modeled
3,500
3,000
2,500
2,000
1,500
1,000
500
0
1983
1988
1993
1998
2003
2008
2013


BRD01 (02153200) BROAD RIVER NEAR BLACKSBURG, SC
Monthly Mean Flow (CFS)
gaged
modeled
2,500
2,000
1,500
1,000
500
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

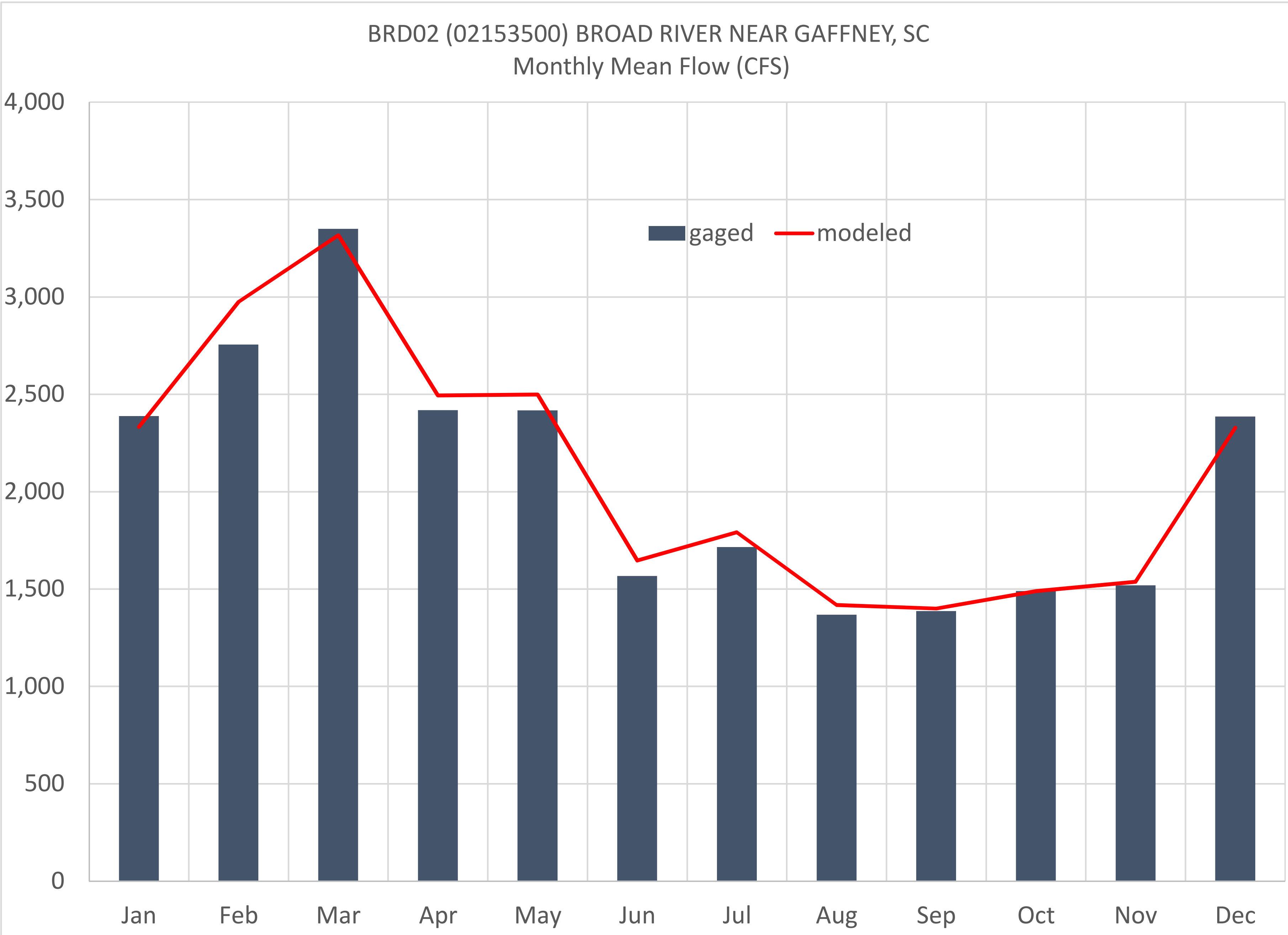

BRD01 (02153200) BROAD RIVER NEAR BLACKSBURG, SC
Monthly Flow Percentiles (CFS)
gaged
modeled
8000
7000
6000
5000
4000
3000
2000
1000
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

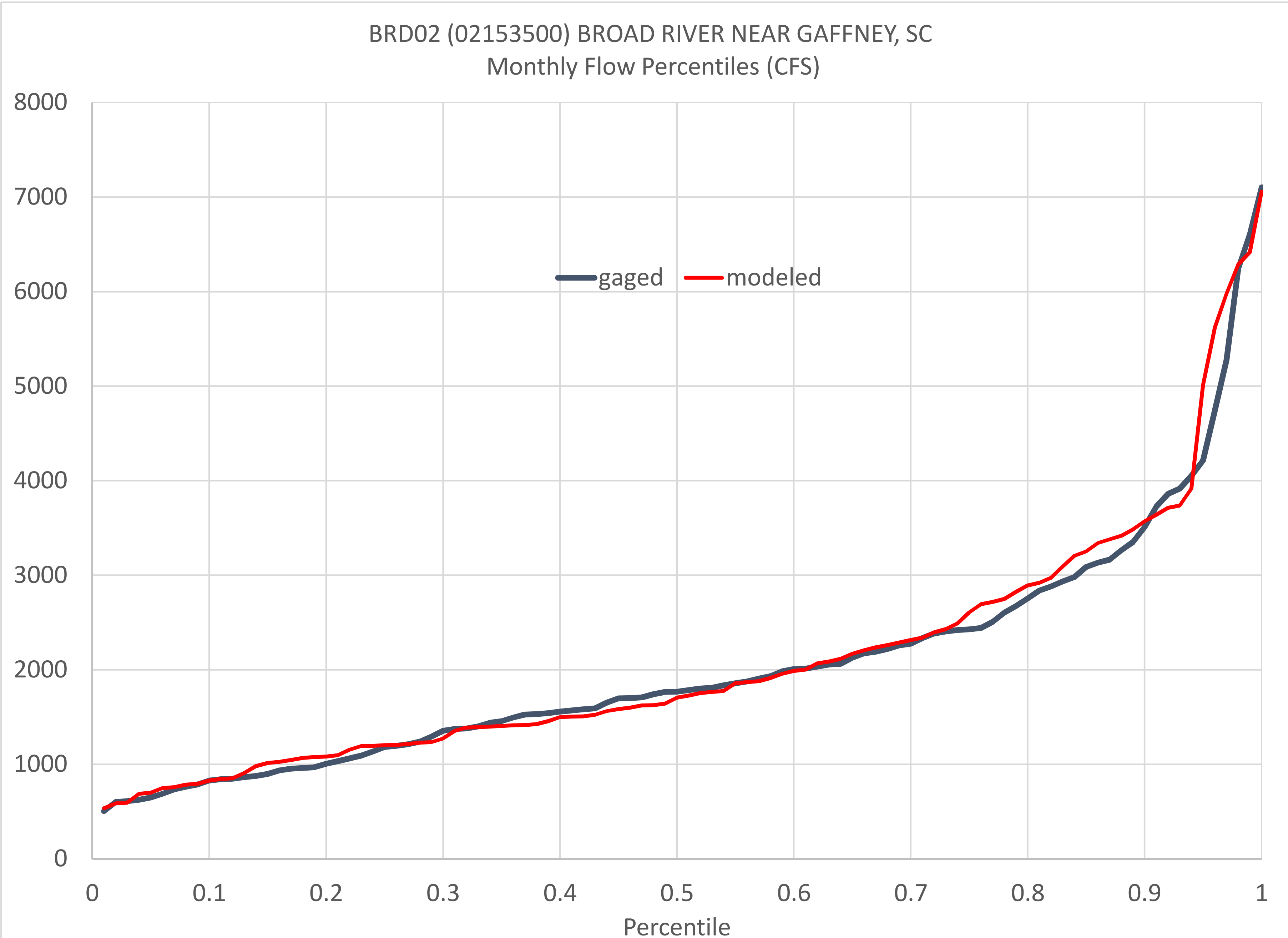

BRD02 (02153500) BROAD RIVER NEAR GAFFNEY, SC (CFS)
modeled
gaged
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

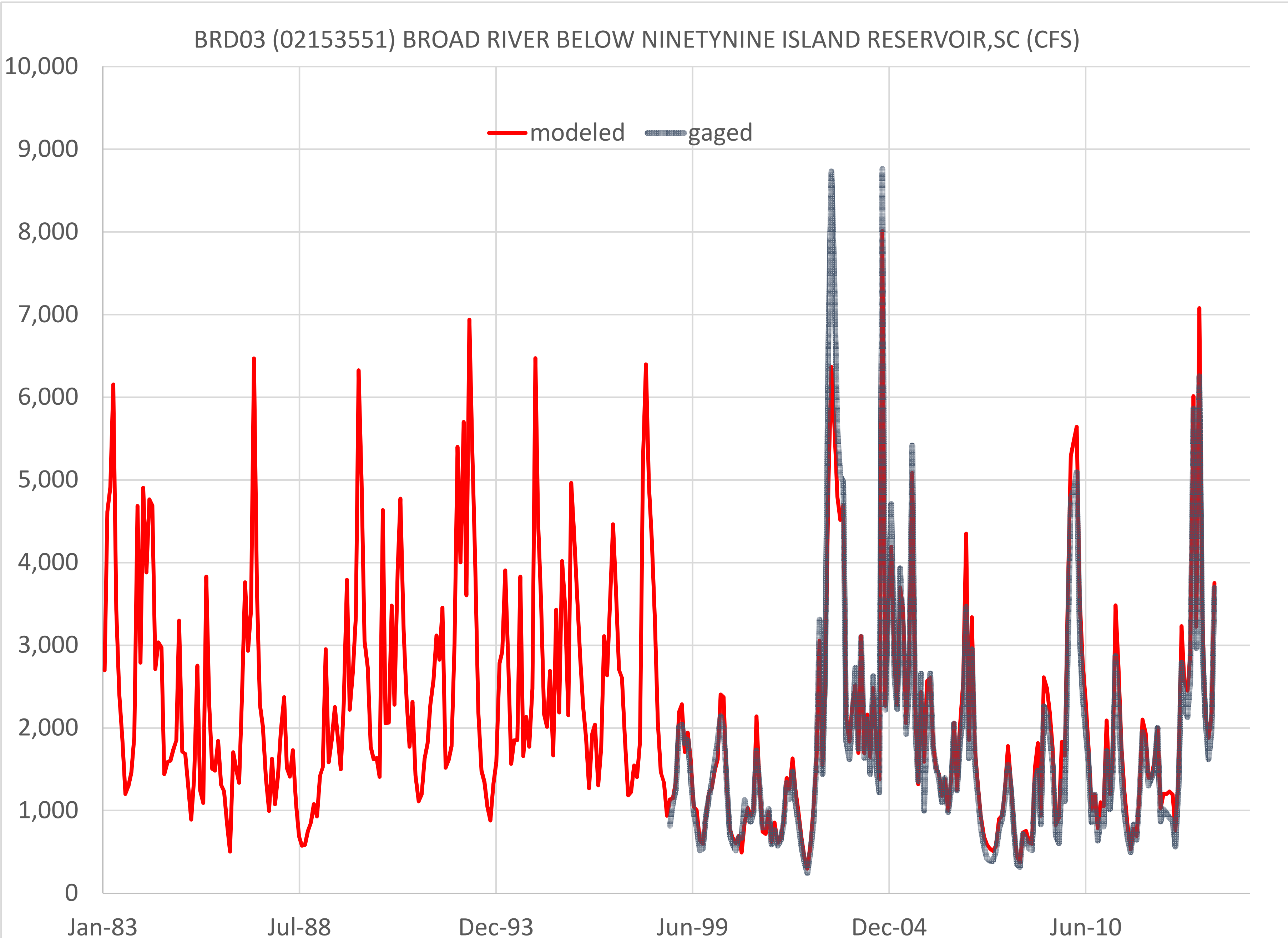

BRD02 (02153500) BROAD RIVER NEAR GAFFNEY, SC
Cumulative Flow (CFS)
modeled
gaged
250,000
200,000
150,000
100,000
50,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10



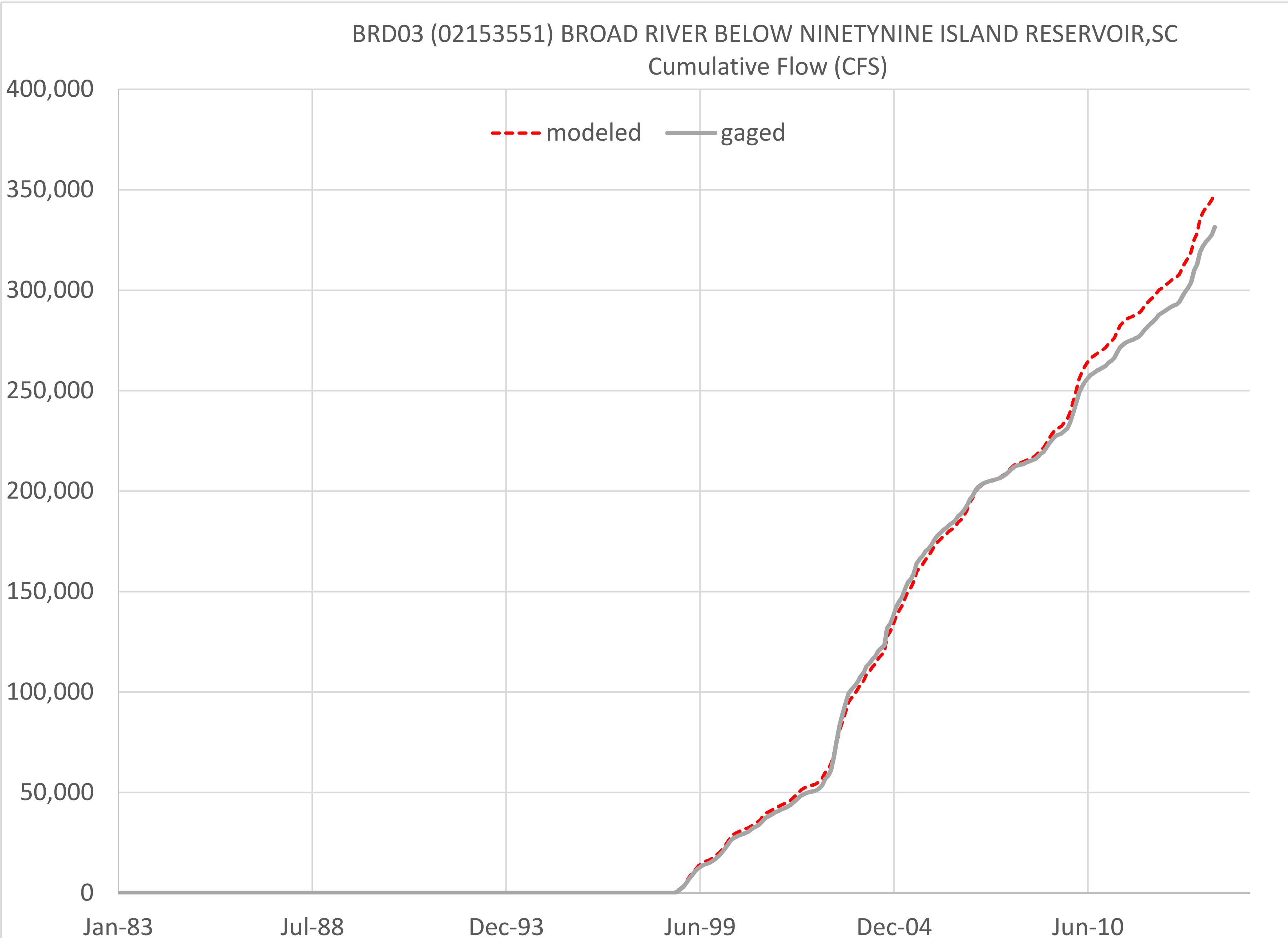
BRD02 (02153500) BROAD RIVER NEAR GAFFNEY, SC (CFS)
Annual Average Flow
gaged
modeled
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
1983
1988
1993
1998
2003
2008
2013

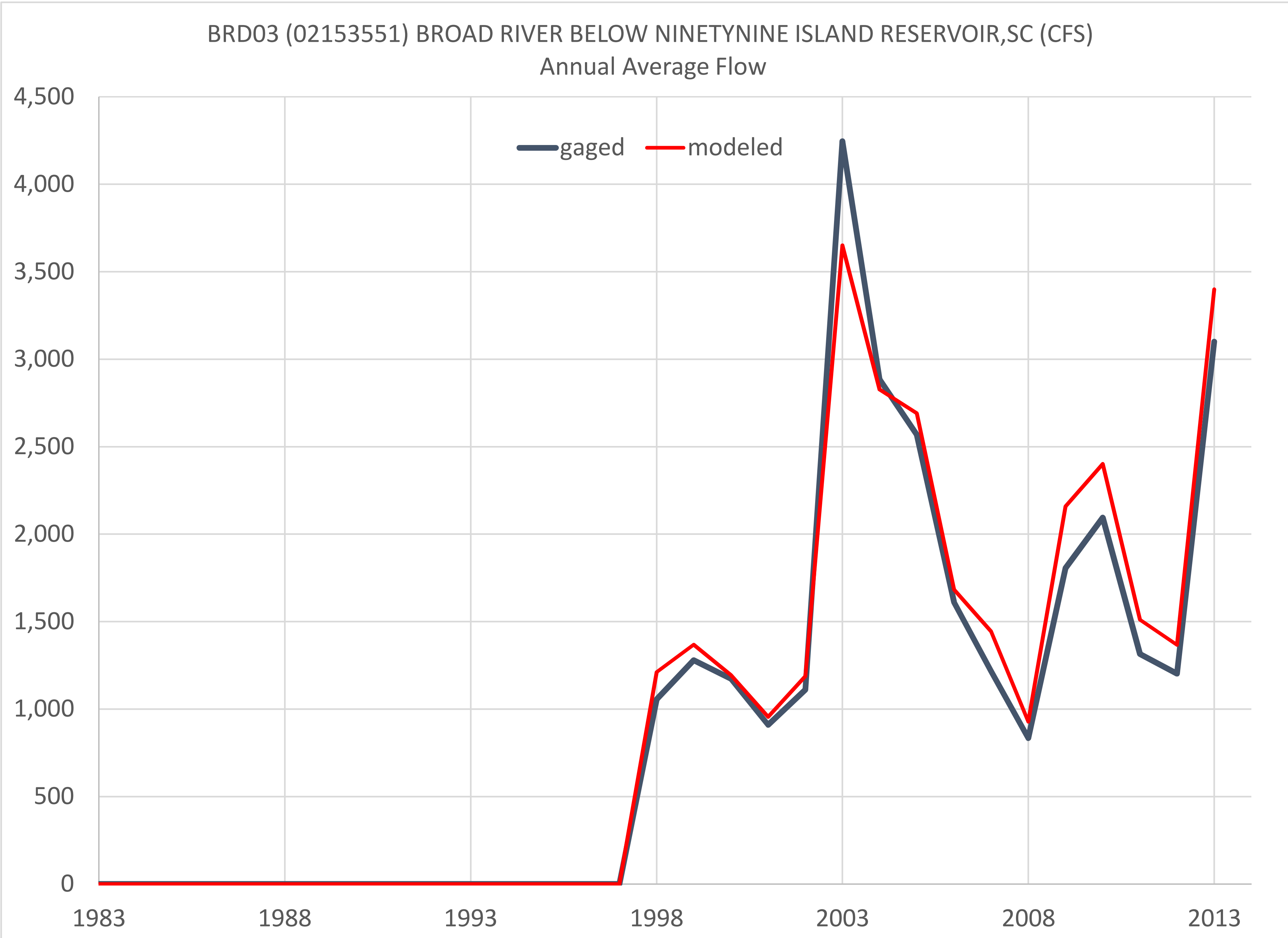

BRD02 (02153500) BROAD RIVER NEAR GAFFNEY, SC
Monthly Mean Flow (CFS)
gaged
modeled
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

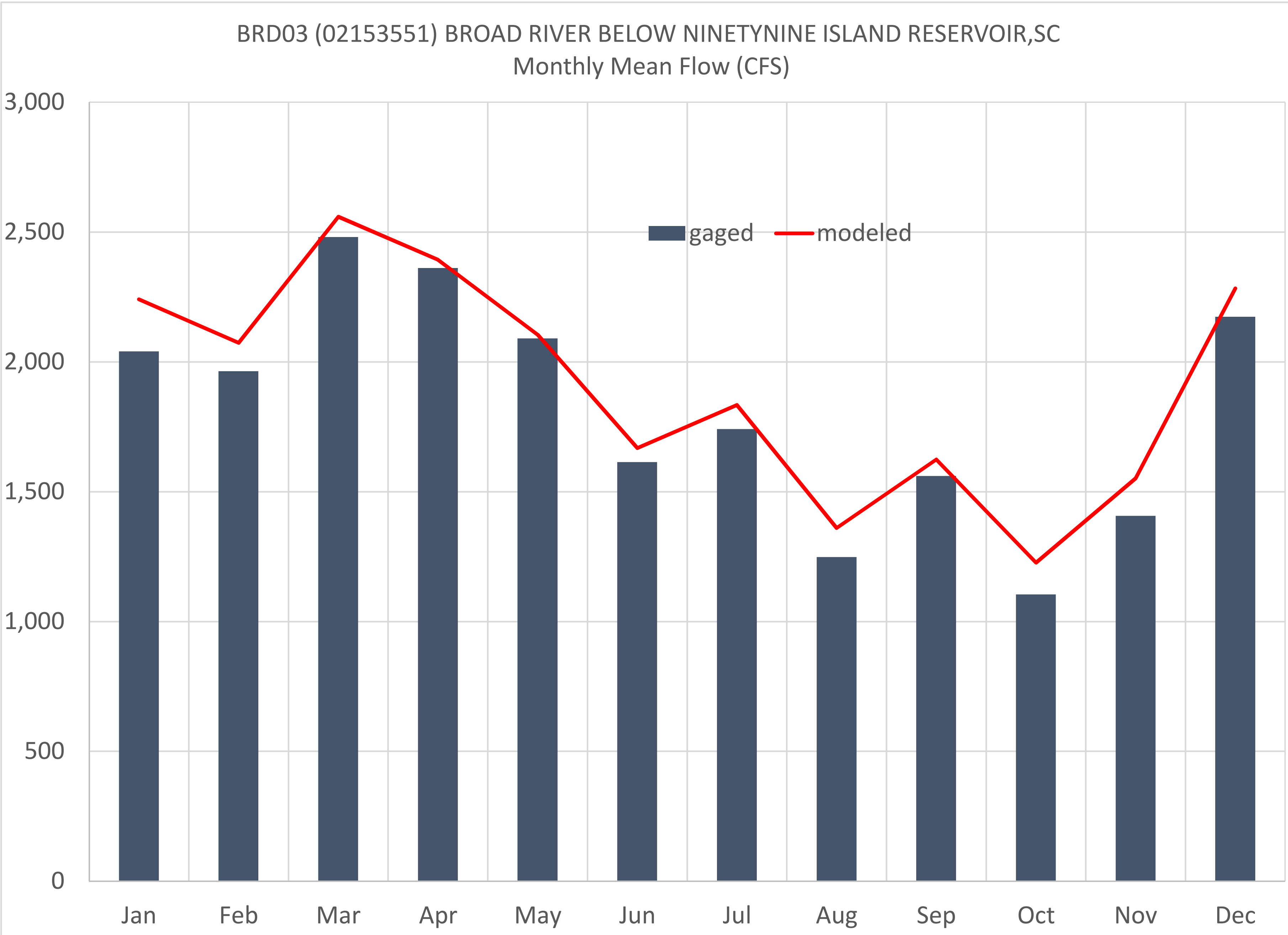

BRD02 (02153500) BROAD RIVER NEAR GAFFNEY, SC
Monthly Flow Percentiles (CFS)
gaged
modeled
8000
7000
6000
5000
4000
3000
2000
1000
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

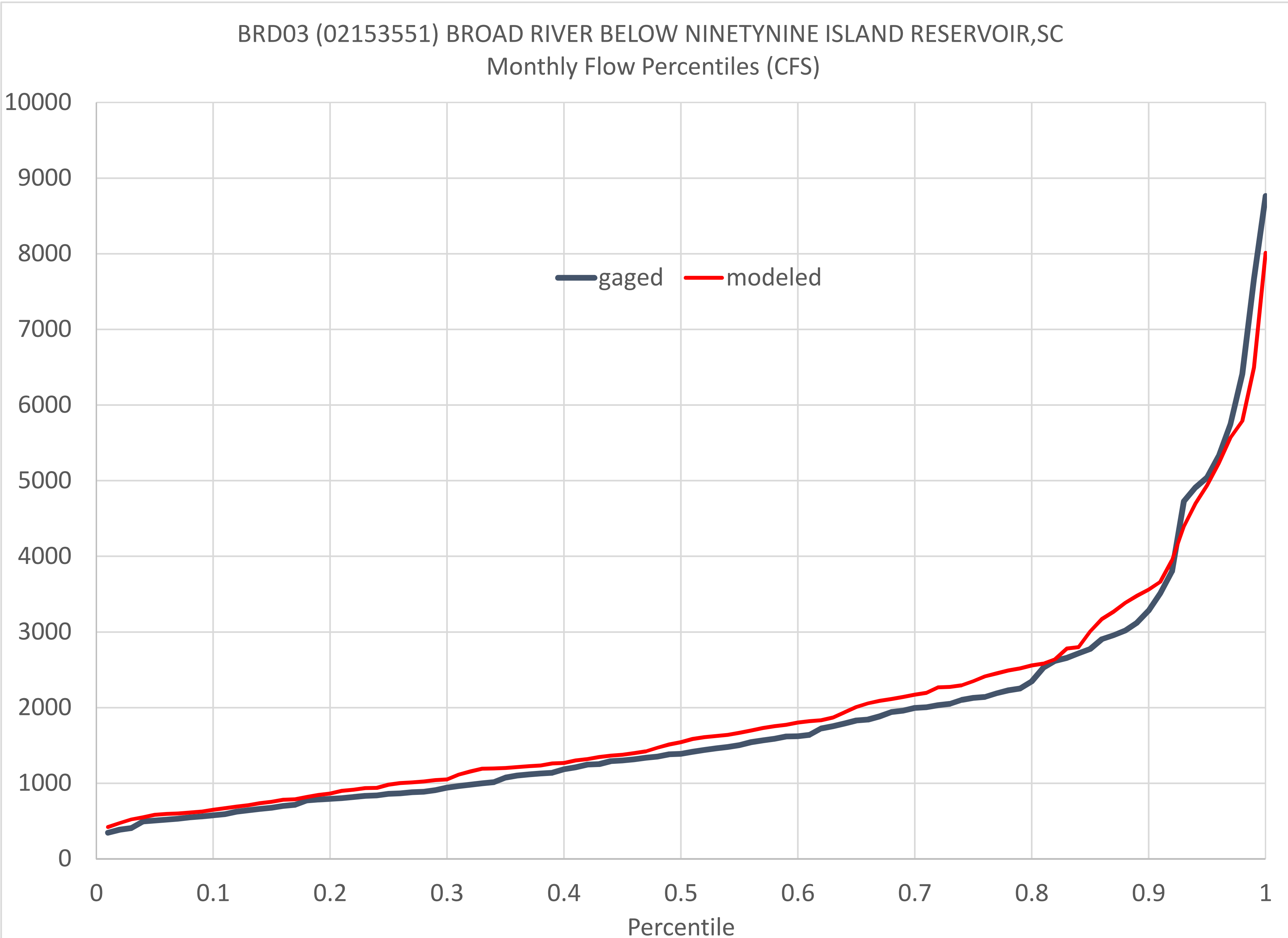


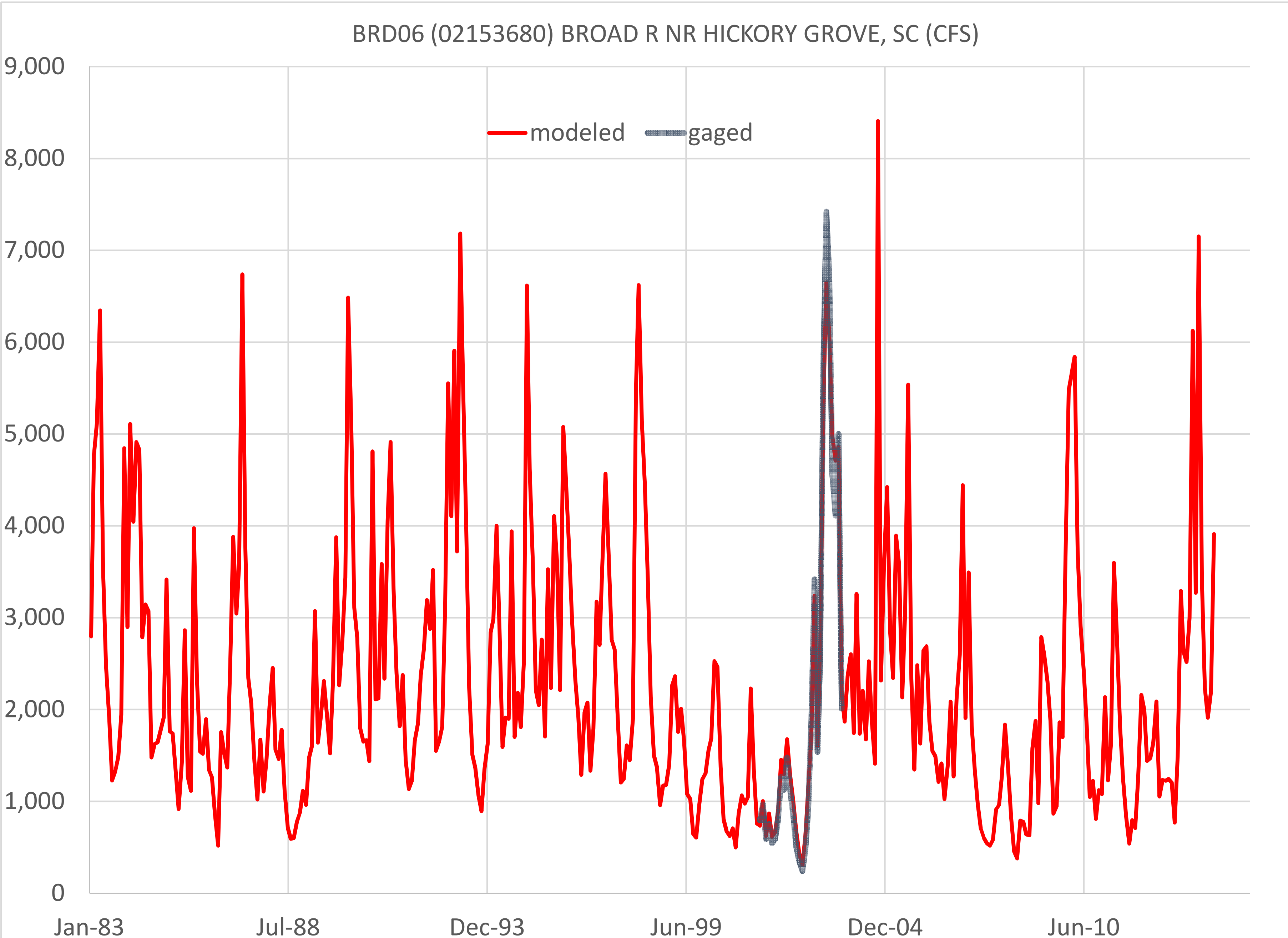
BRD03 (02153551) BROAD RIVER BELOW NINETYNINE ISLAND RESERVOIR,SC (CFS)
modeled
gaged
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

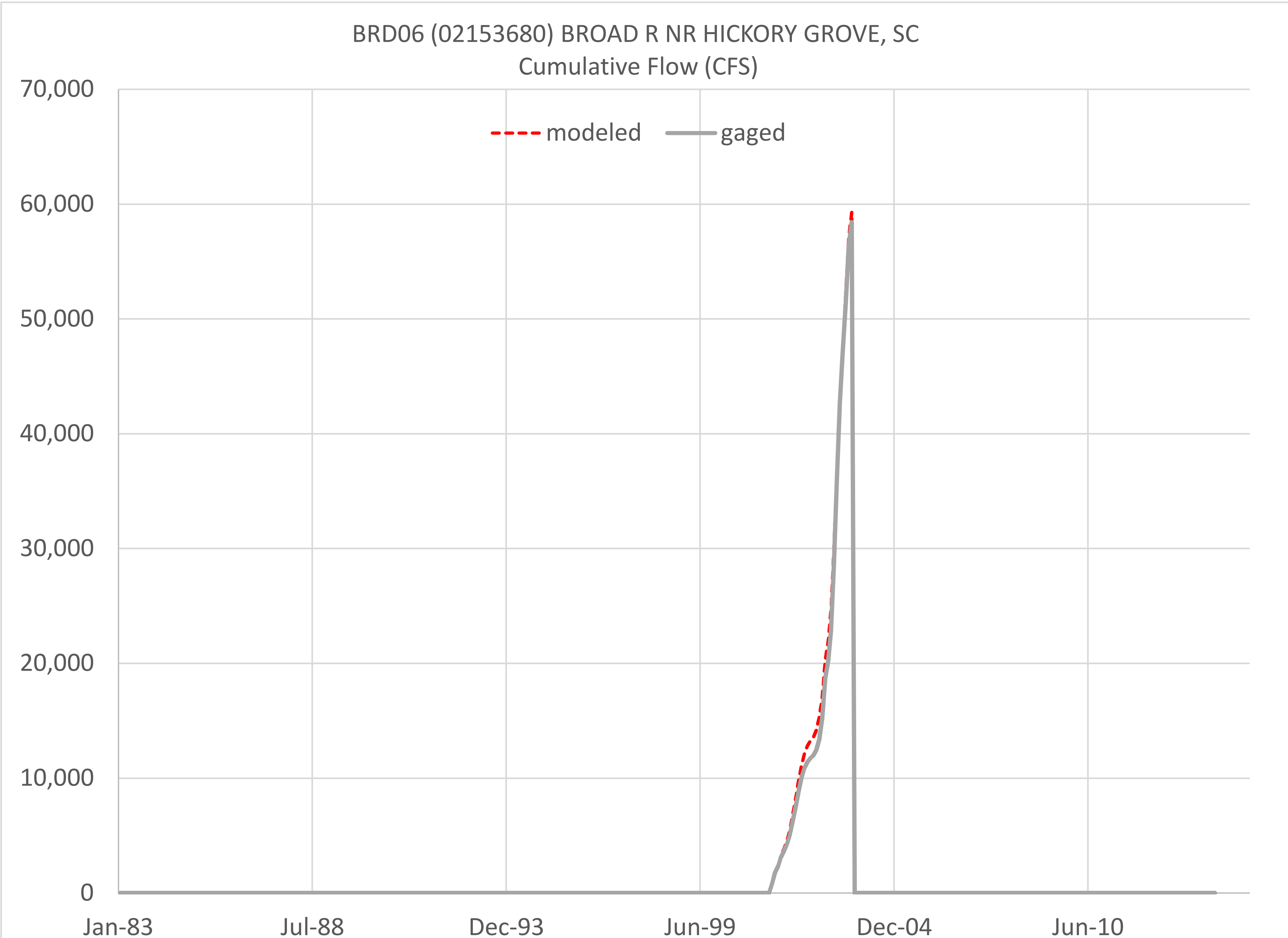

BRD03 (02153551) BROAD RIVER BELOW NINETYNINE ISLAND RESERVOIR,SC
Cumulative Flow (CFS)
modeled
gaged
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10


BRD03 (02153551) BROAD RIVER BELOW NINETYNINE ISLAND RESERVOIR,SC (CFS)
Annual Average Flow
gaged
modeled
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
1983
1988
1993
1998
2003
2008
2013

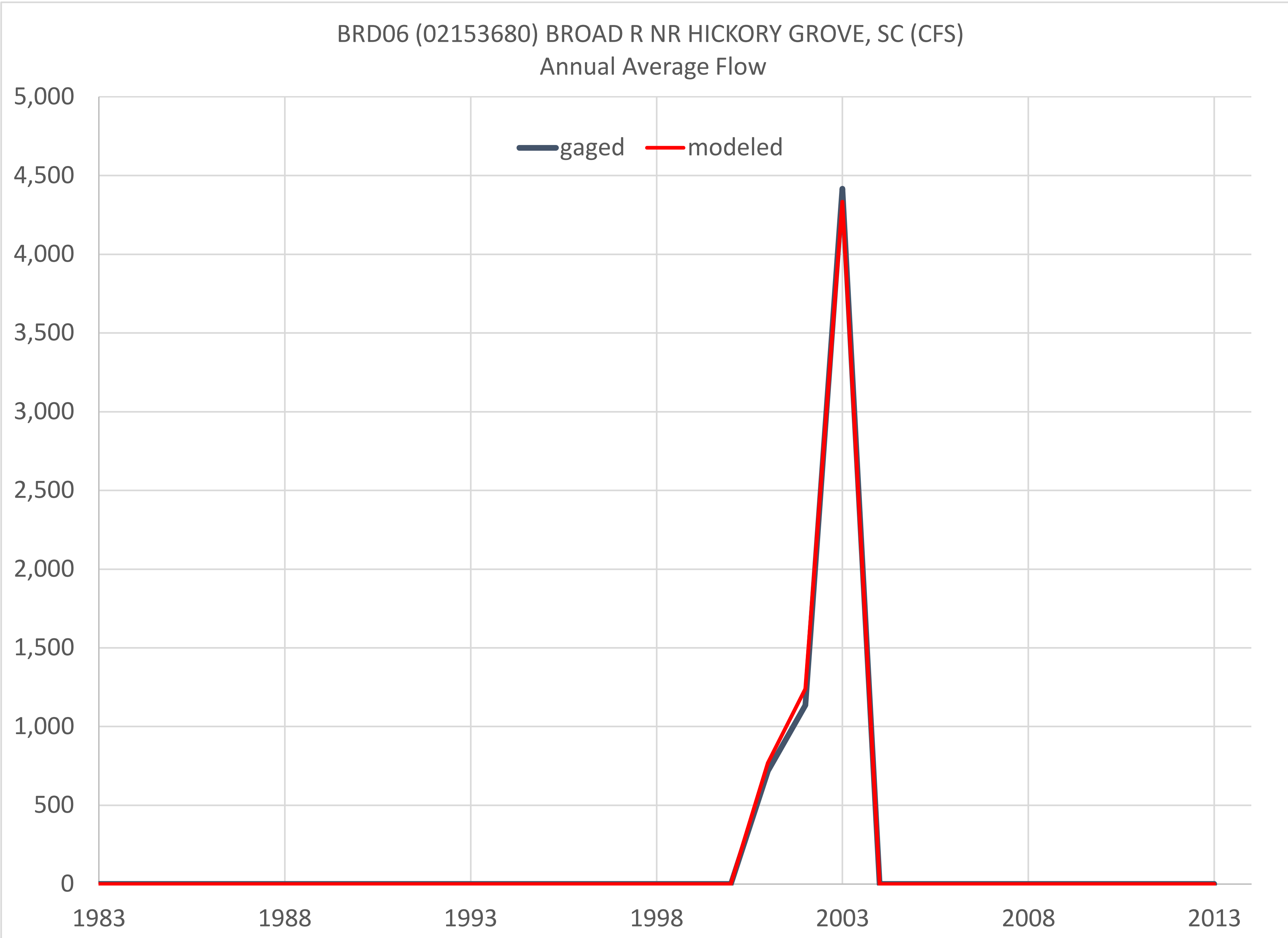

BRD03 (02153551) BROAD RIVER BELOW NINETYNINE ISLAND RESERVOIR,SC
Monthly Mean Flow (CFS)
gaged
modeled
3,000
2,500
2,000
1,500
1,000
500
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

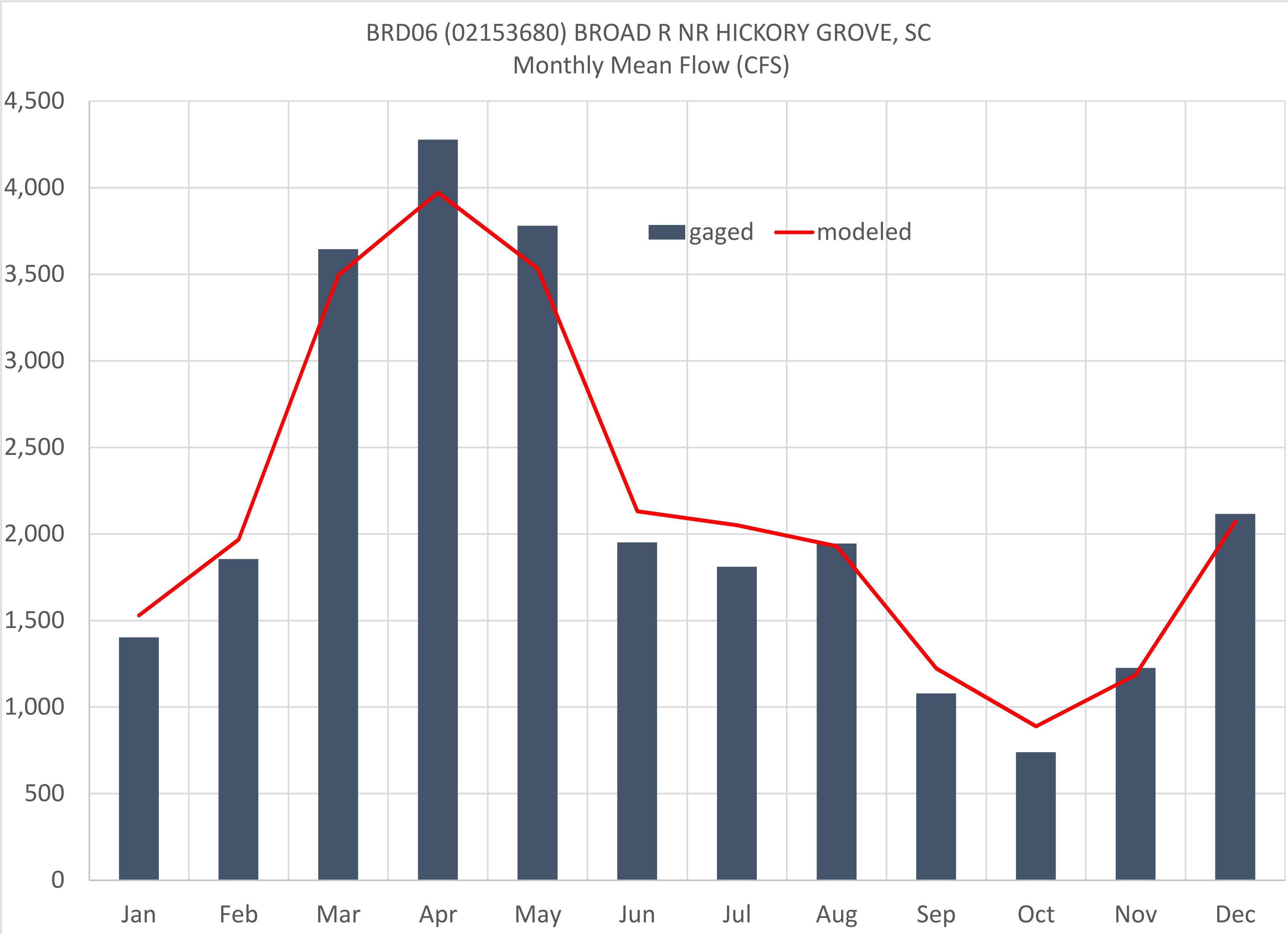

BRD03 (02153551) BROAD RIVER BELOW NINETYNINE ISLAND RESERVOIR,SC
Monthly Flow Percentiles (CFS)
gaged
modeled
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile


BRD06 (02153680) BROAD R NR HICKORY GROVE, SC (CFS)
modeled
gaged
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

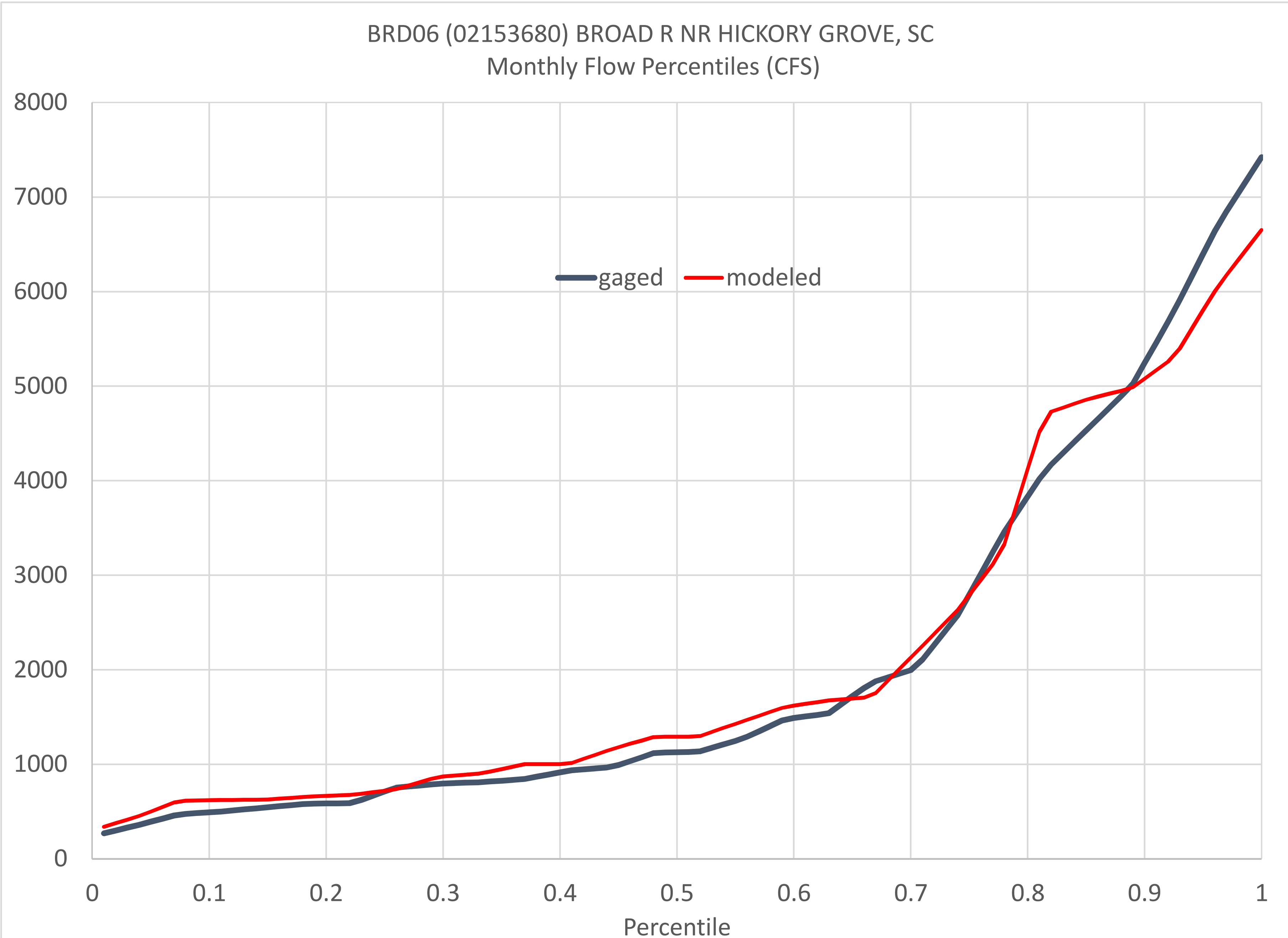


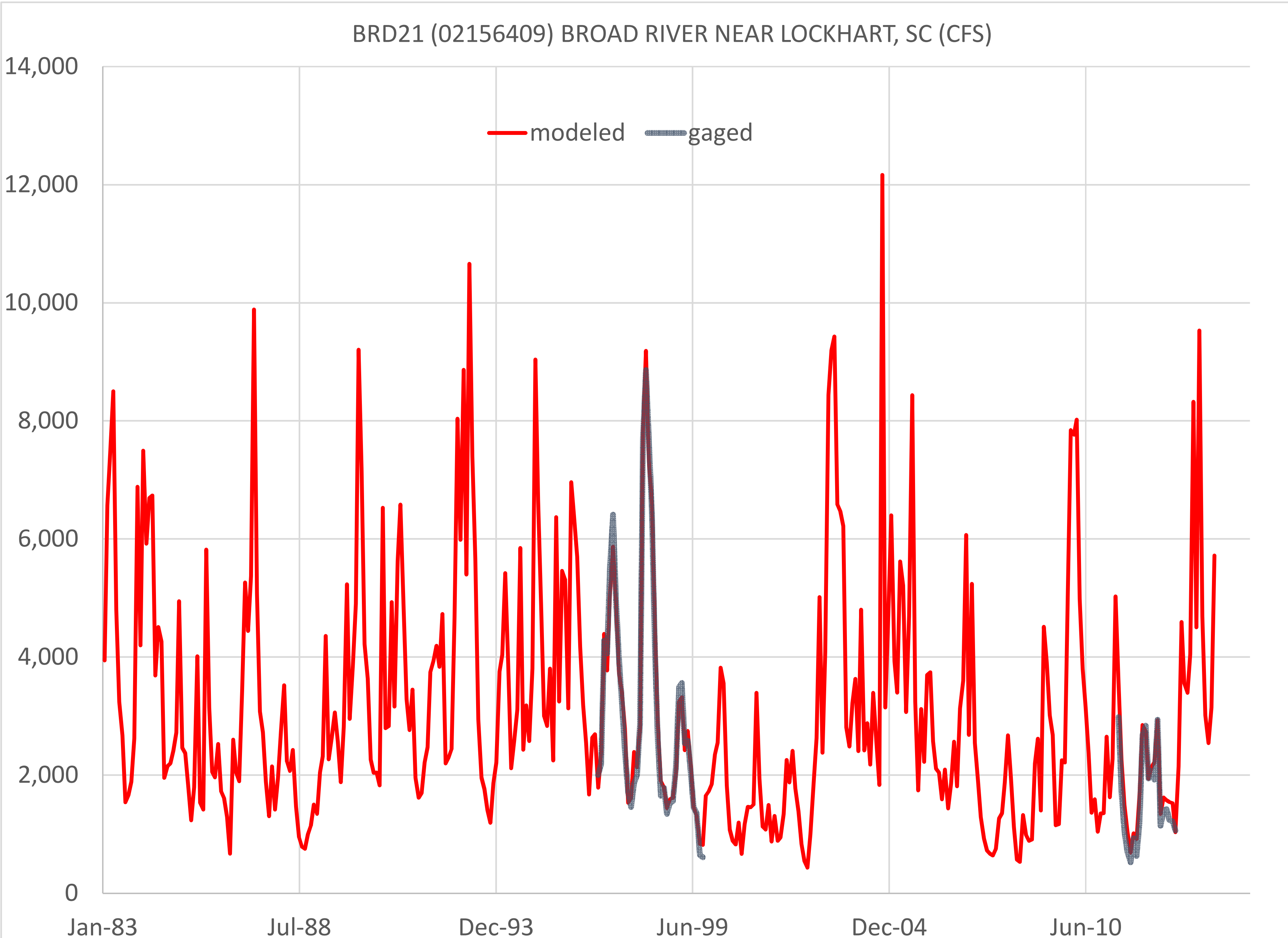
BRD06 (02153680) BROAD R NR HICKORY GROVE, SC
Cumulative Flow (CFS)
modeled
gaged
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

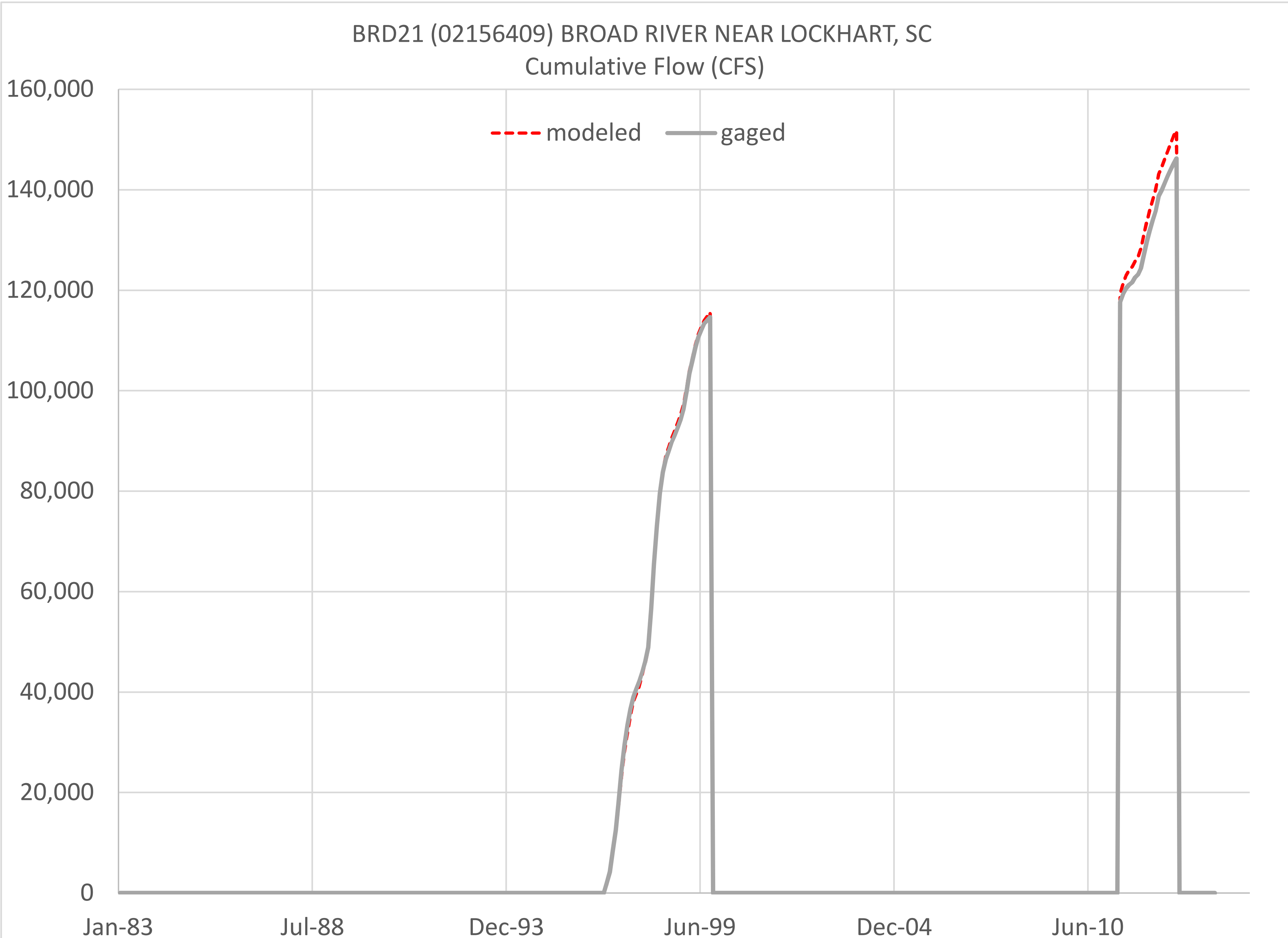

BRD06 (02153680) BROAD R NR HICKORY GROVE, SC (CFS)
Annual Average Flow
gaged
modeled
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
1983
1988
1993
1998
2003
2008
2013

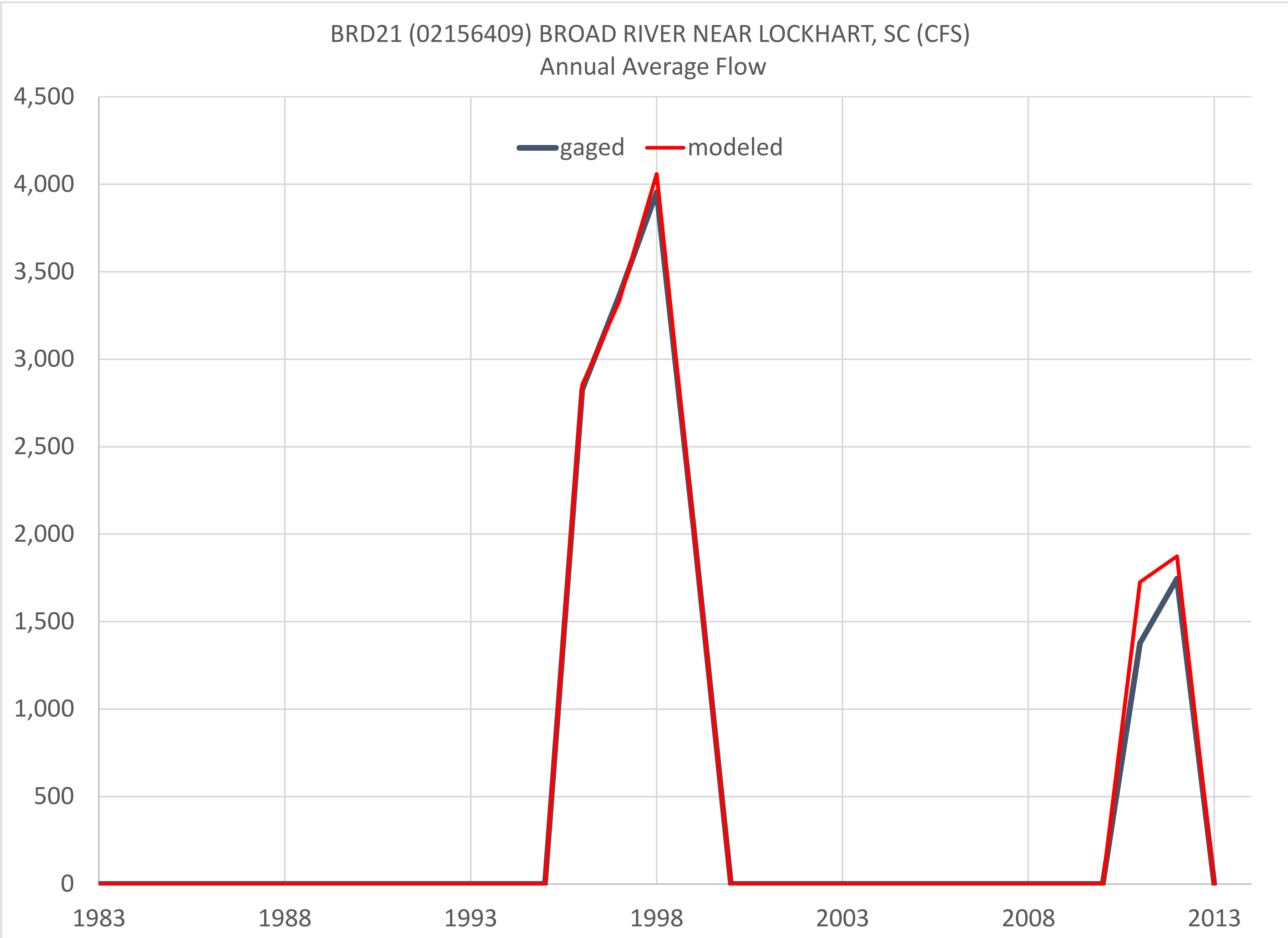


BRD06 (02153680) BROAD R NR HICKORY GROVE, SC
Monthly Mean Flow (CFS)
gaged
modeled
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

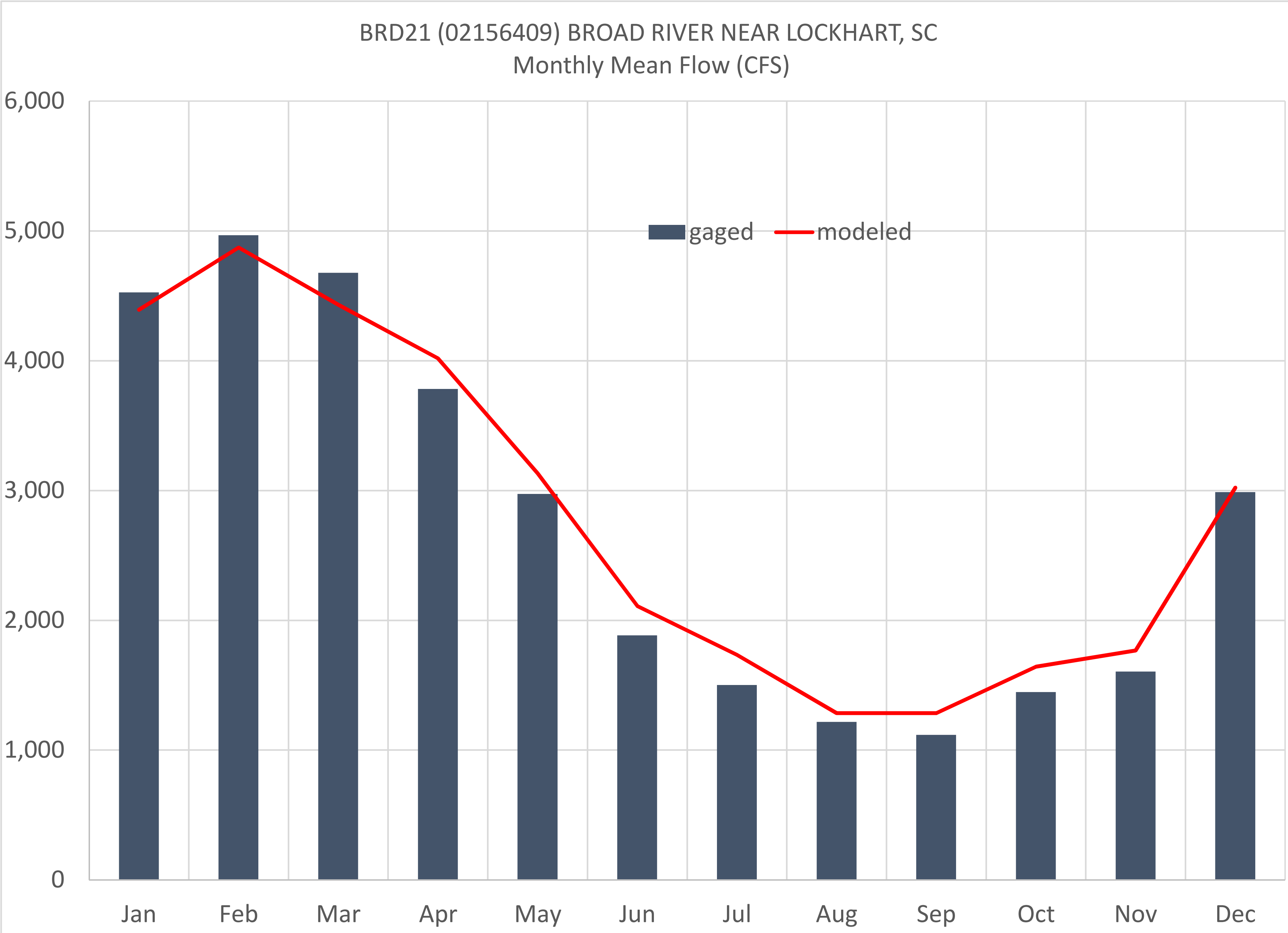

BRD06 (02153680) BROAD R NR HICKORY GROVE, SC
Monthly Flow Percentiles (CFS)
8000
7000
6000
5000
4000
3000
2000
1000
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile
gaged
modeled

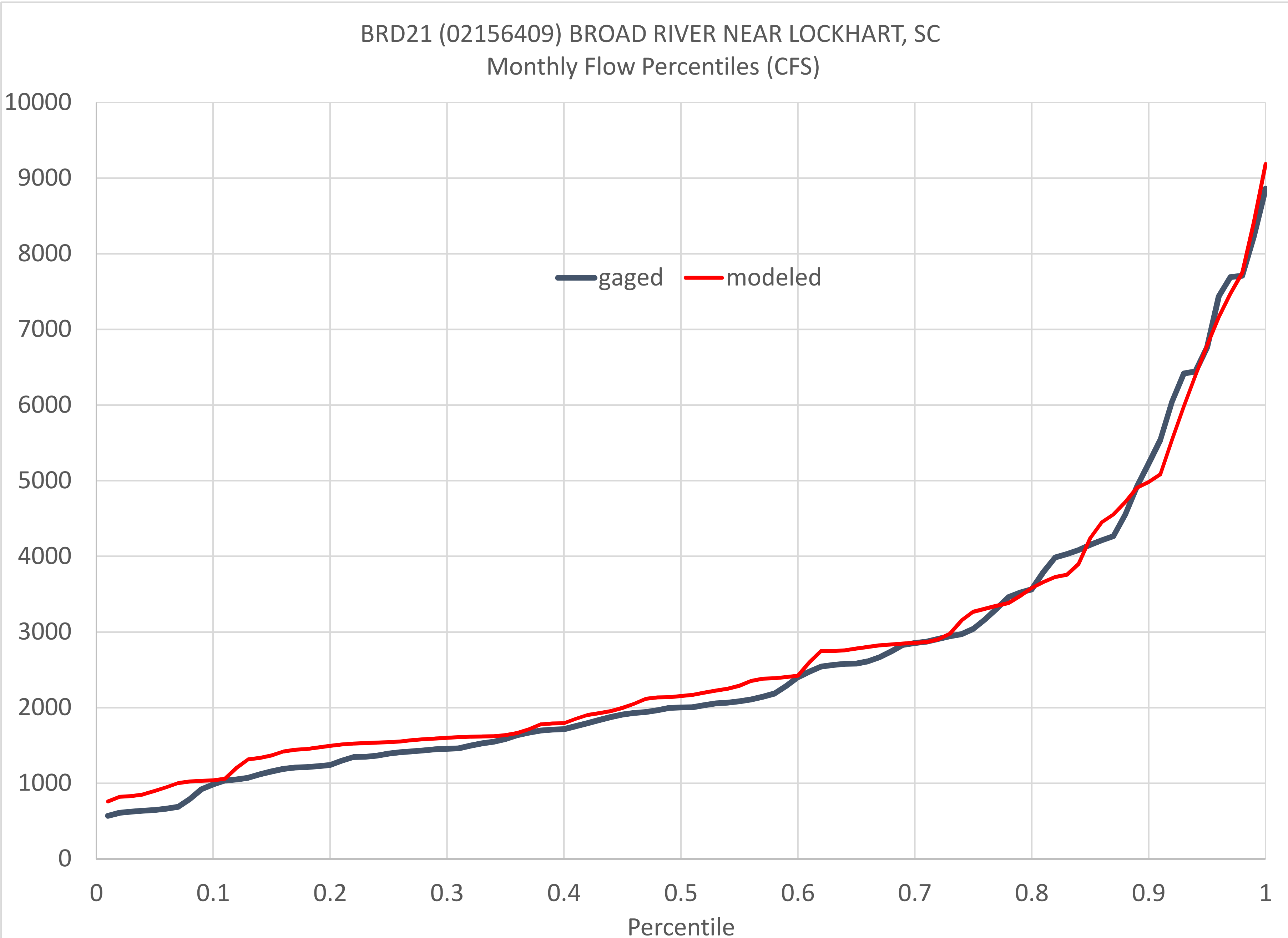

BRD21 (02156409) BROAD RIVER NEAR LOCKHART, SC (CFS)
modeled
gaged
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10


BRD21 (02156409) BROAD RIVER NEAR LOCKHART, SC
Cumulative Flow (CFS)
modeled
gaged
160,000
140,000
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

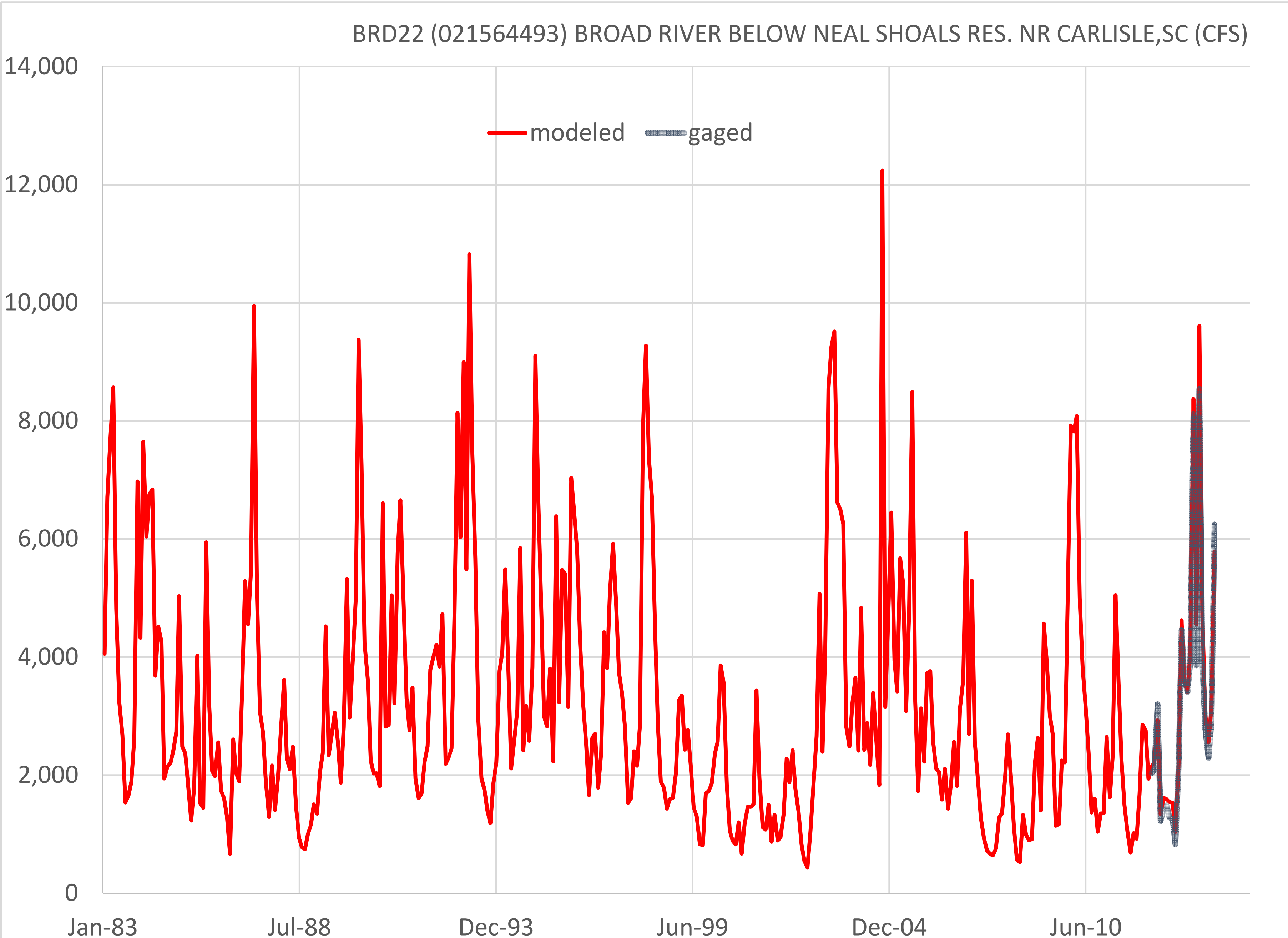


BRD21 (02156409) BROAD RIVER NEAR LOCKHART, SC (CFS)
Annual Average Flow
gaged
modeled
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
1983
1988
1993
1998
2003
2008
2013

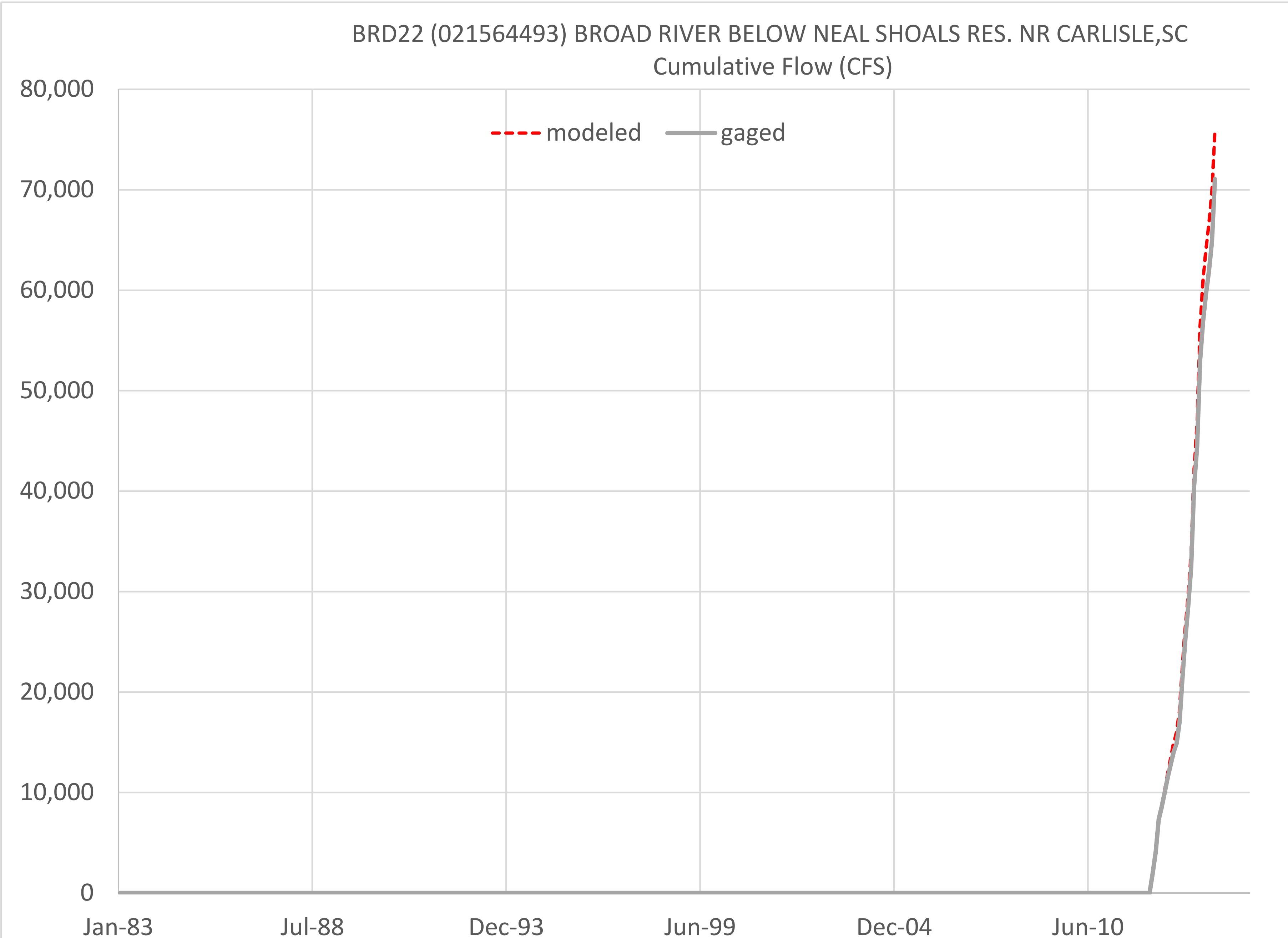

BRD21 (02156409) BROAD RIVER NEAR LOCKHART, SC
Monthly Mean Flow (CFS)
6,000
5,000
4,000
3,000
2,000
1,000
0
gaged
modeled
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

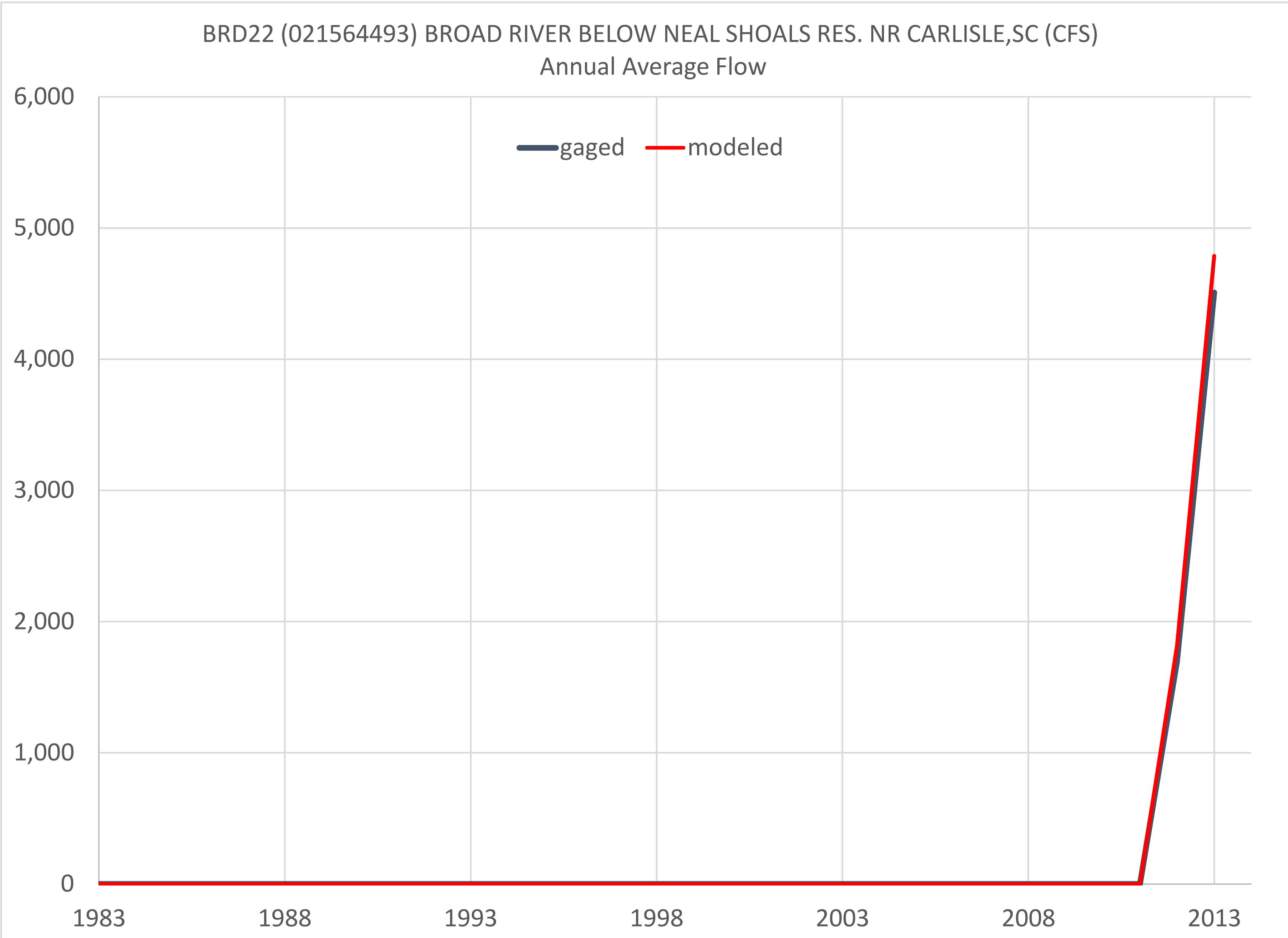


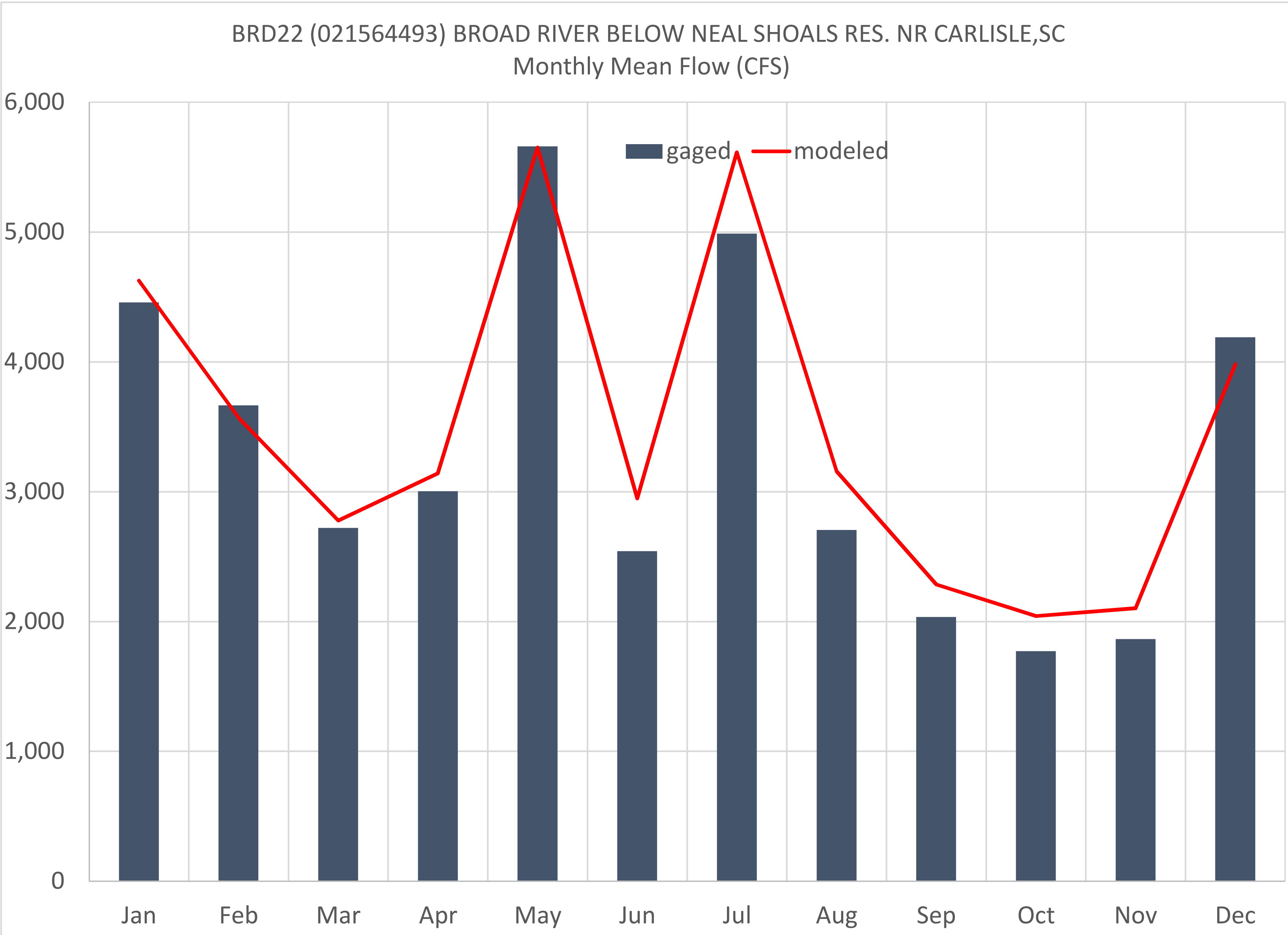
BRD21 (02156409) BROAD RIVER NEAR LOCKHART, SC
Monthly Flow Percentiles (CFS)
gaged
modeled
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

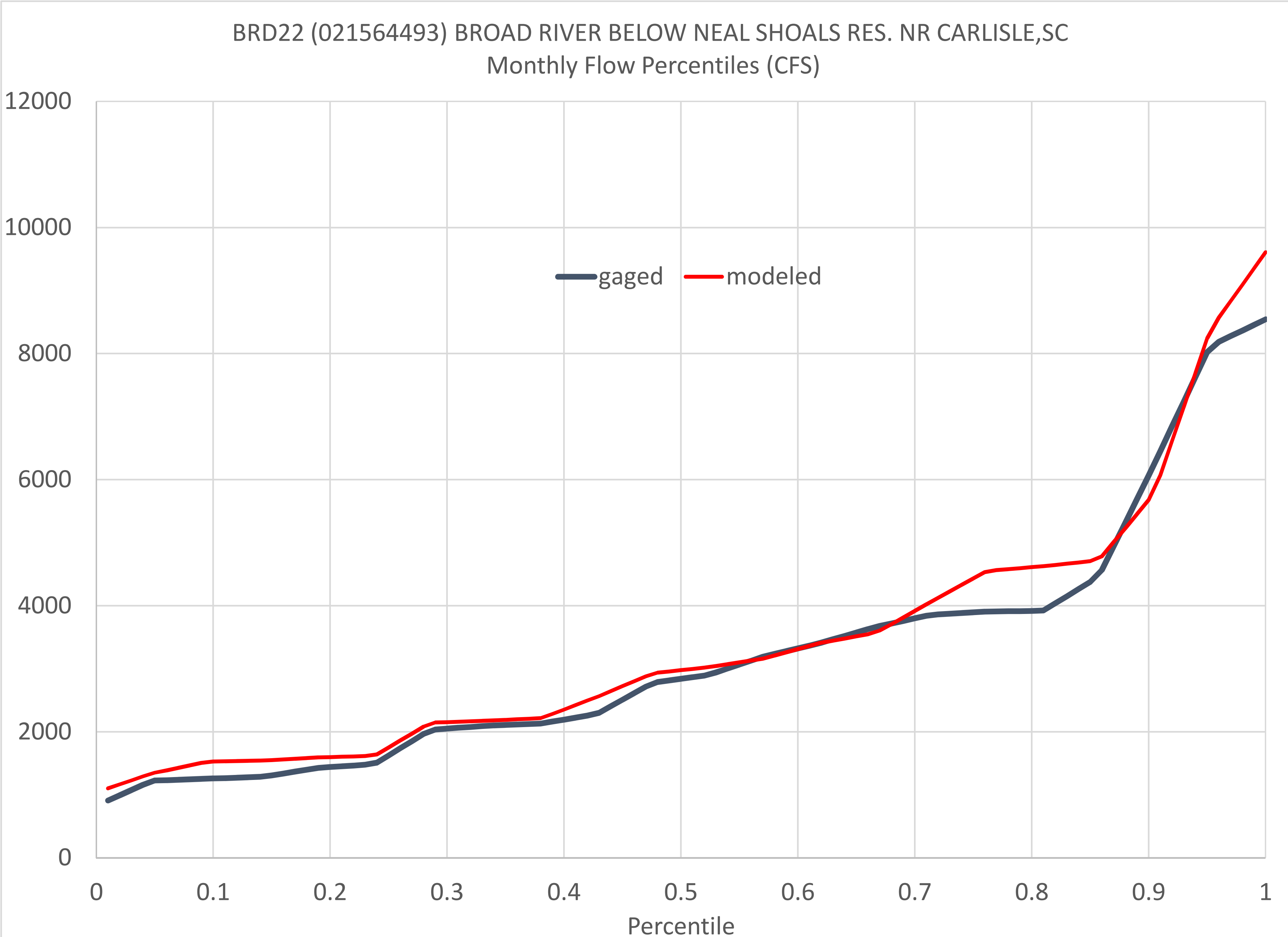


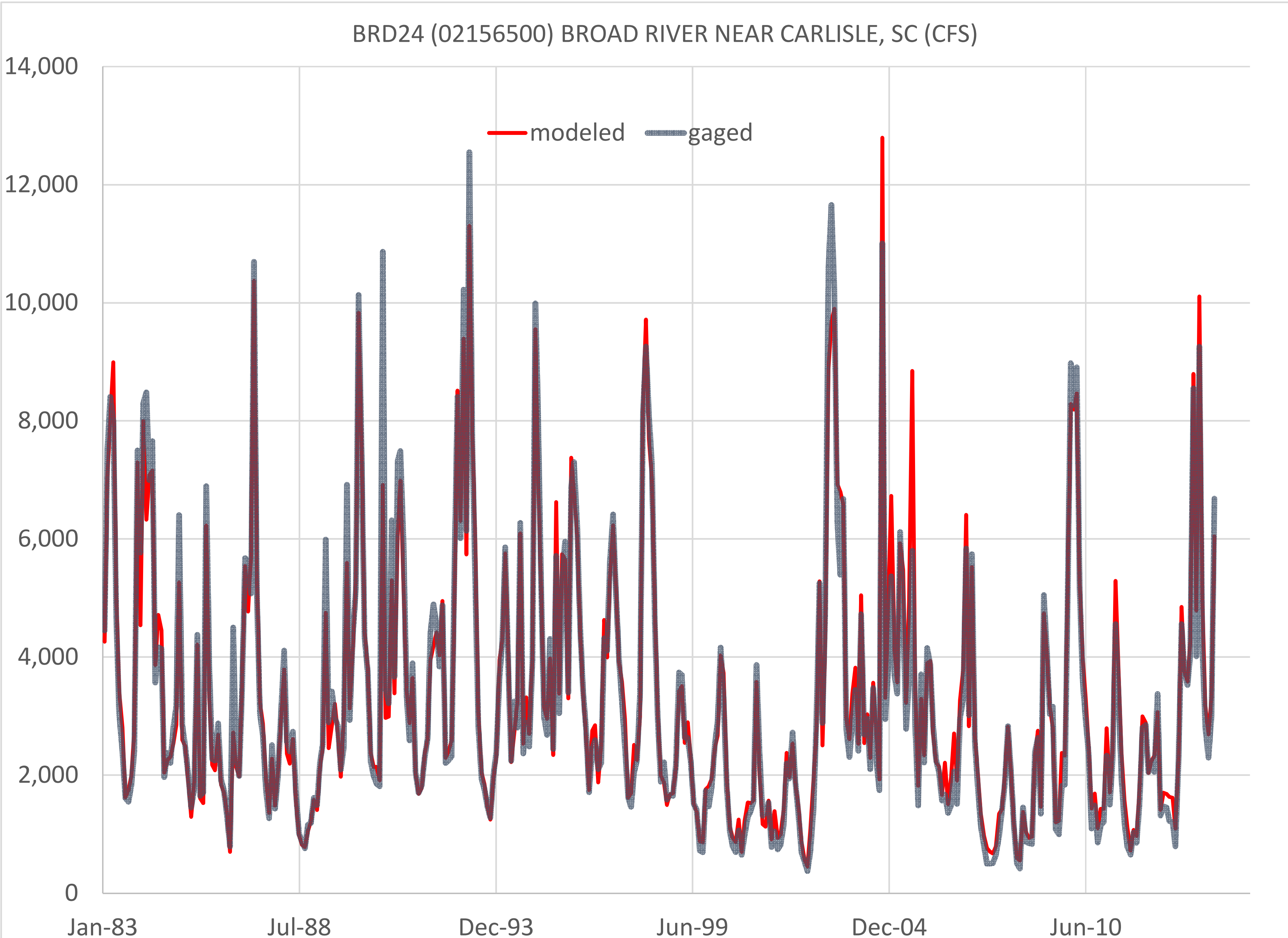
BRD22 (021564493) BROAD RIVER BELOW NEAL SHOALS RES. NR CARLISLE,SC (CFS)
modeled
gaged
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

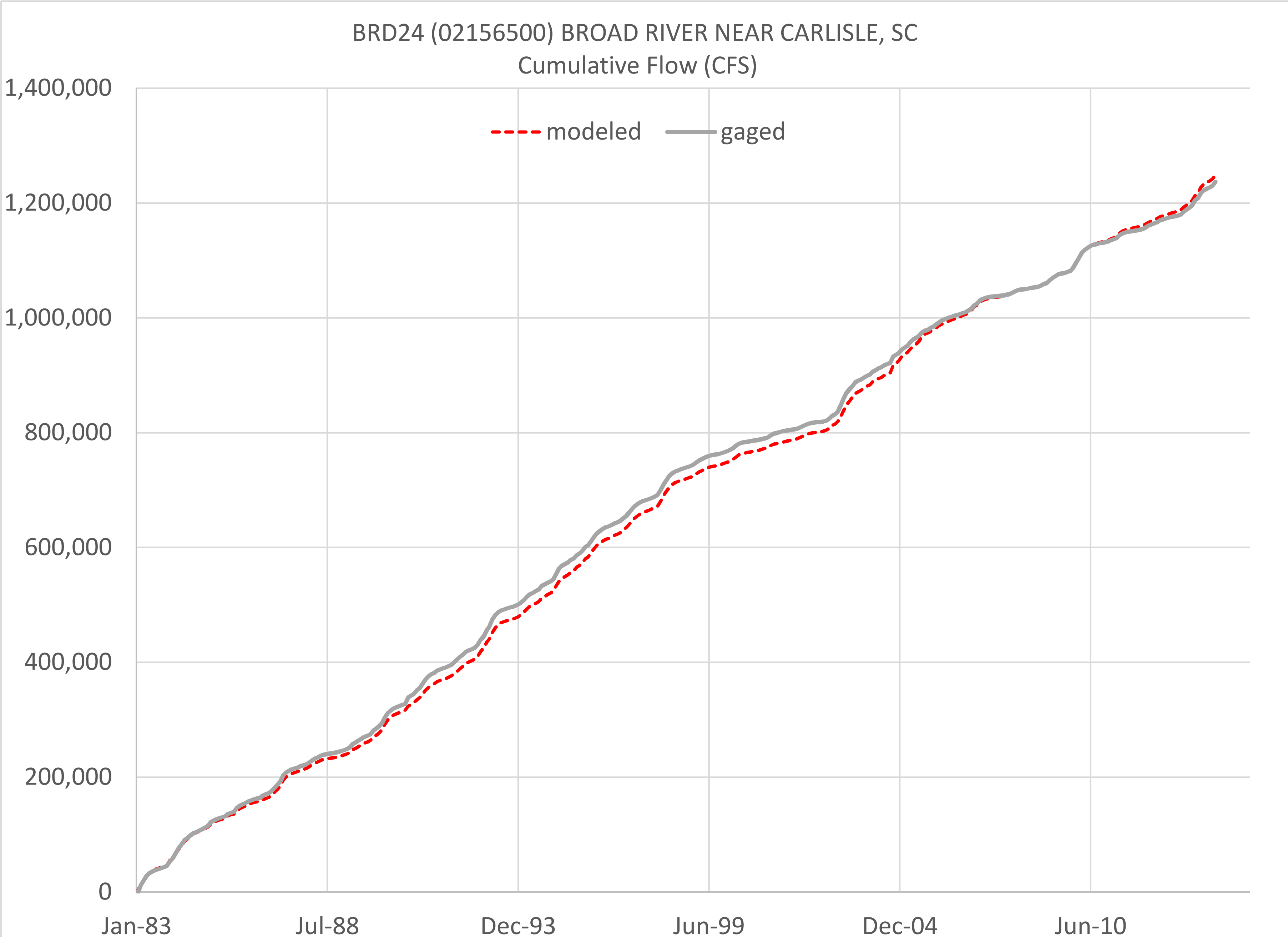

BRD22 (021564493) BROAD RIVER BELOW NEAL SHOALS RES. NR CARLISLE,SC
Cumulative Flow (CFS)
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
modeled
gaged
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

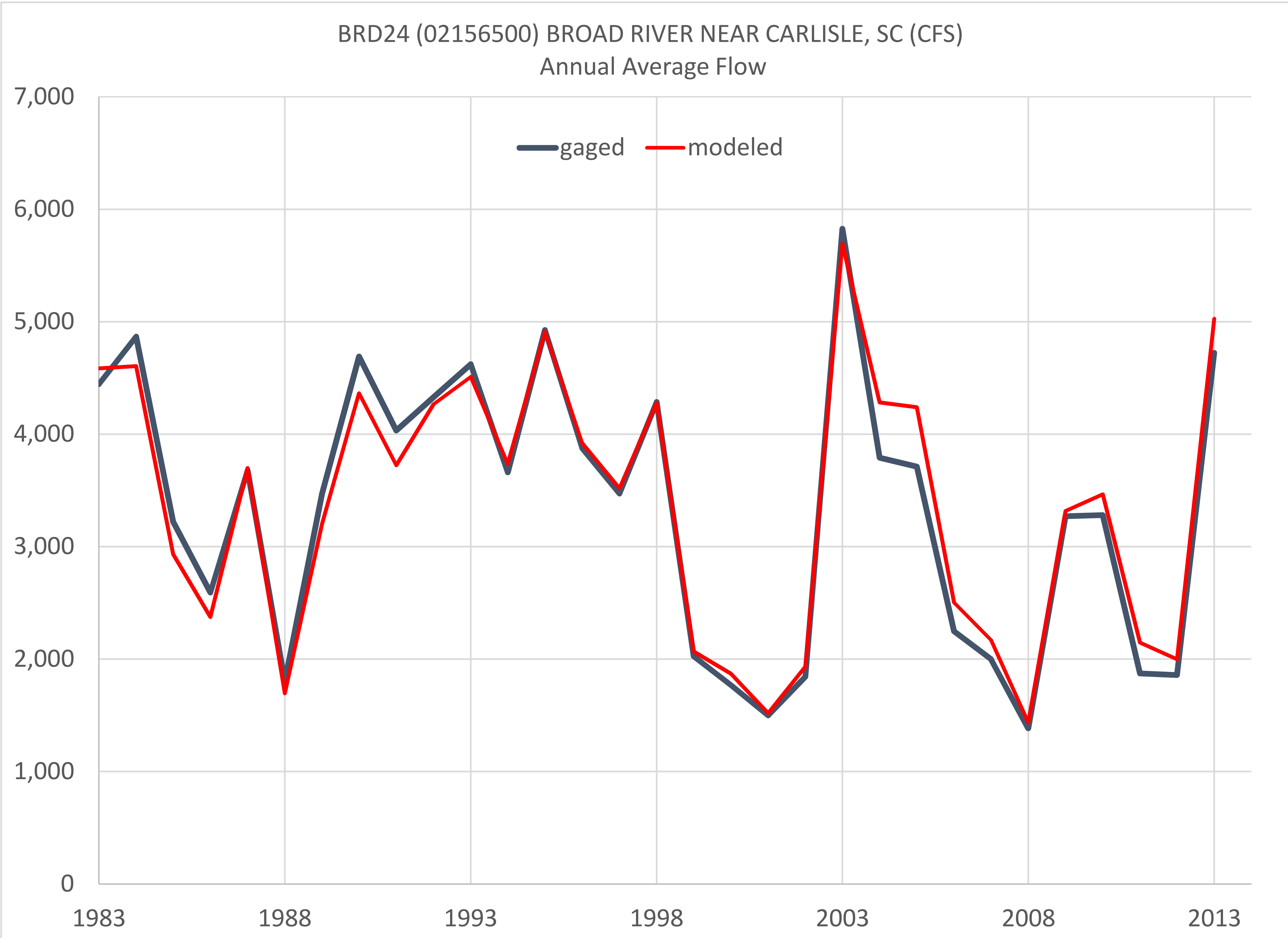

BRD22 (021564493) BROAD RIVER BELOW NEAL SHOALS RES. NR CARLISLE,SC (CFS)
Annual Average Flow
gaged
modeled
6,000
5,000
4,000
3,000
2,000
1,000
0
1983
1988
1993
1998
2003
2008
2013

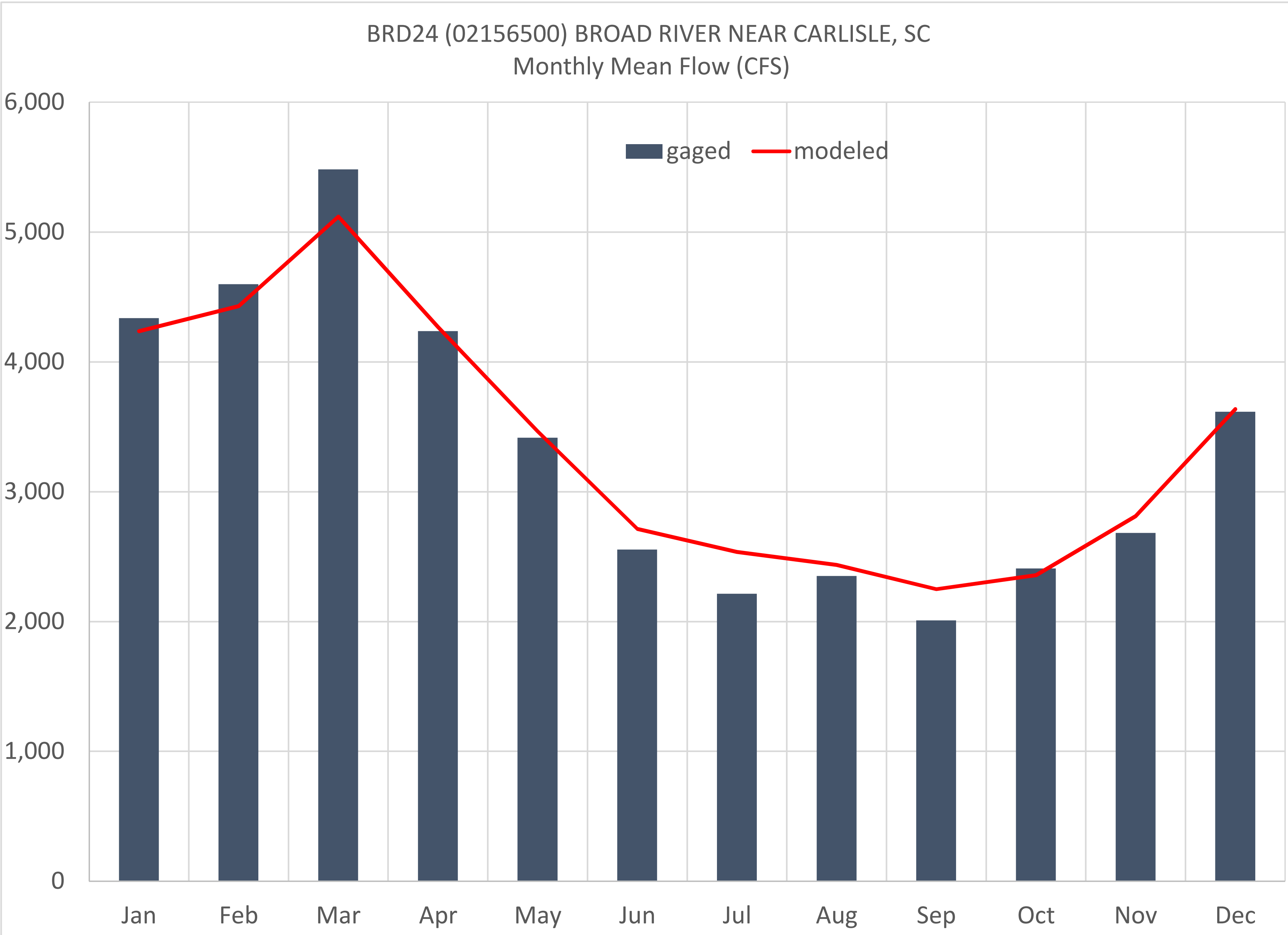

BRD22 (021564493) BROAD RIVER BELOW NEAL SHOALS RES. NR CARLISLE,SC
Monthly Mean Flow (CFS)
gaged
modeled
6,000
5,000
4,000
3,000
2,000
1,000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


BRD22 (021564493) BROAD RIVER BELOW NEAL SHOALS RES. NR CARLISLE,SC
Monthly Flow Percentiles (CFS)
12000
10000
8000
6000
4000
2000
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile
gaged
modeled

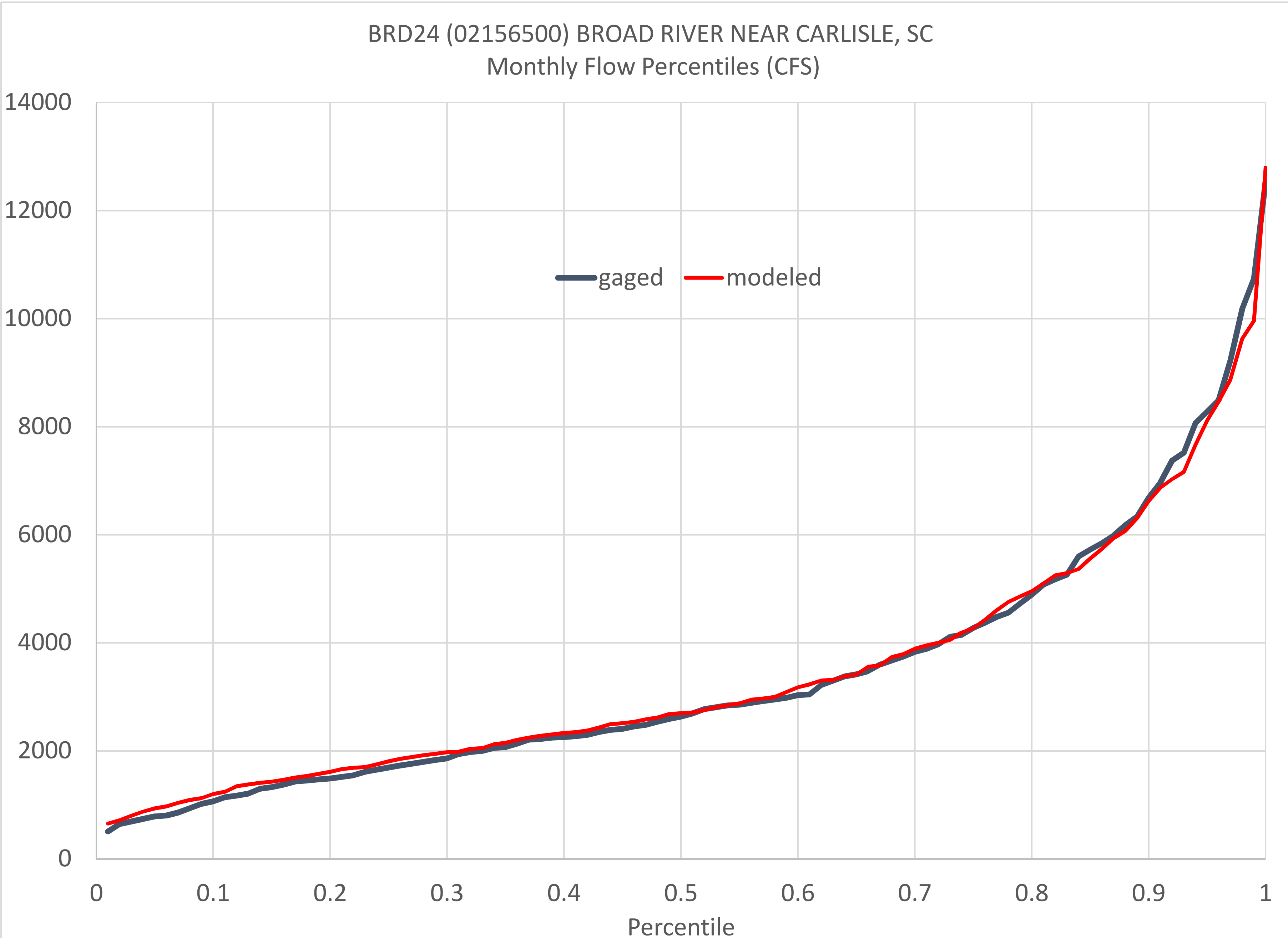

BRD24 (02156500) BROAD RIVER NEAR CARLISLE, SC (CFS)
modeled
gaged
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

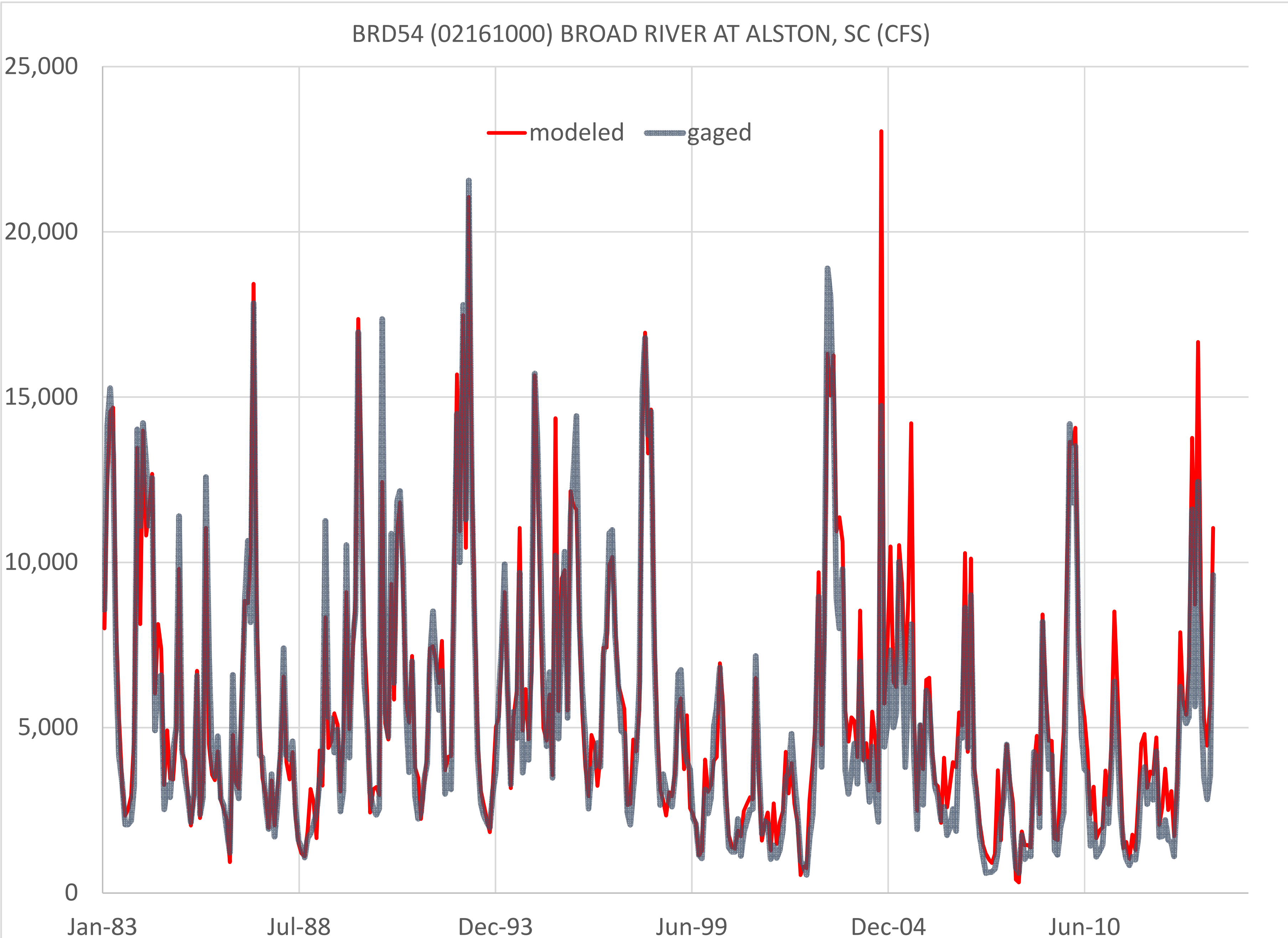

BRD24 (02156500) BROAD RIVER NEAR CARLISLE, SC
Cumulative Flow (CFS)
modeled
gaged
1,400,000
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

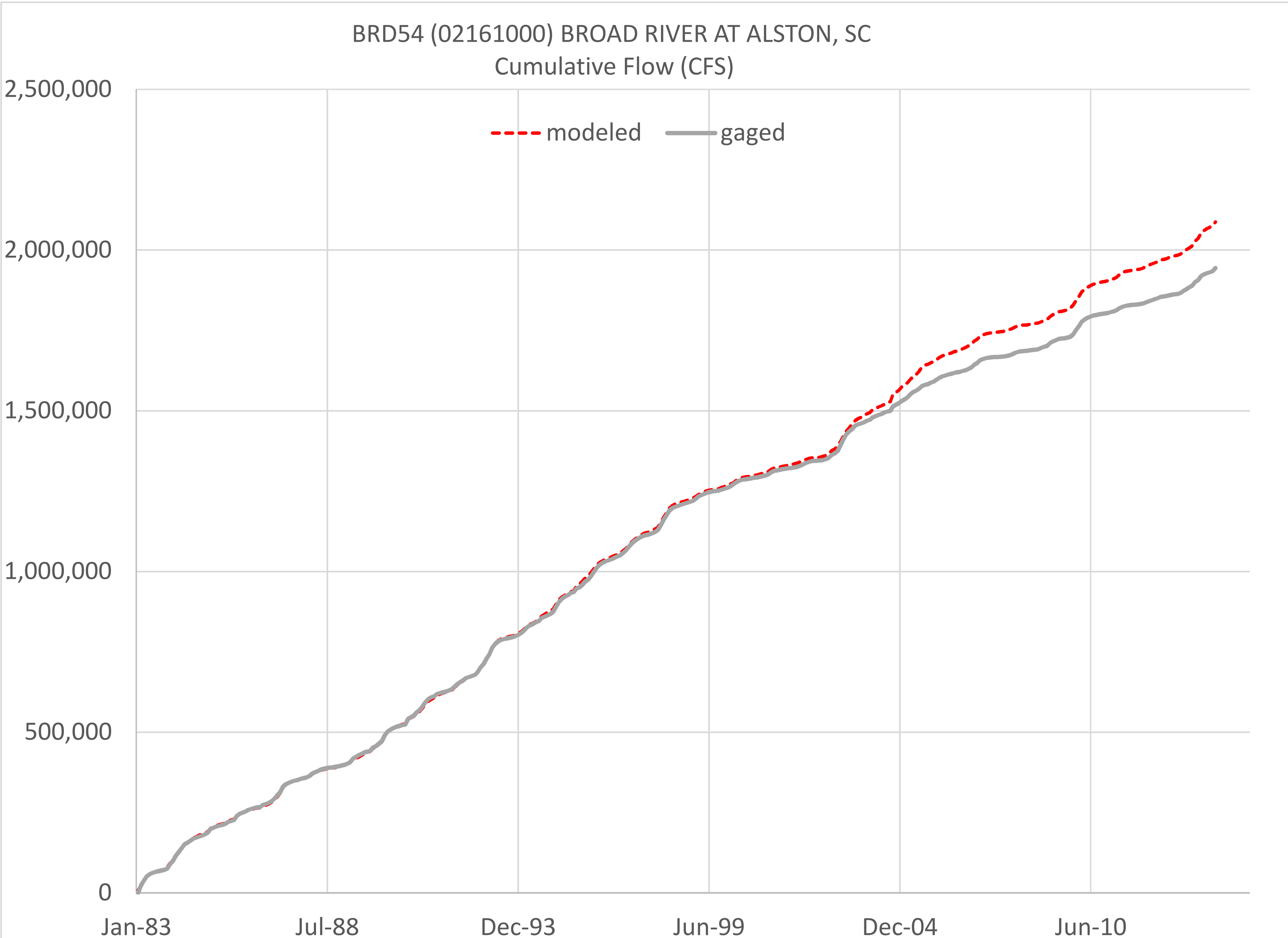

BRD24 (02156500) BROAD RIVER NEAR CARLISLE, SC (CFS)
Annual Average Flow
gaged
modeled
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
1983
1988
1993
1998
2003
2008
2013

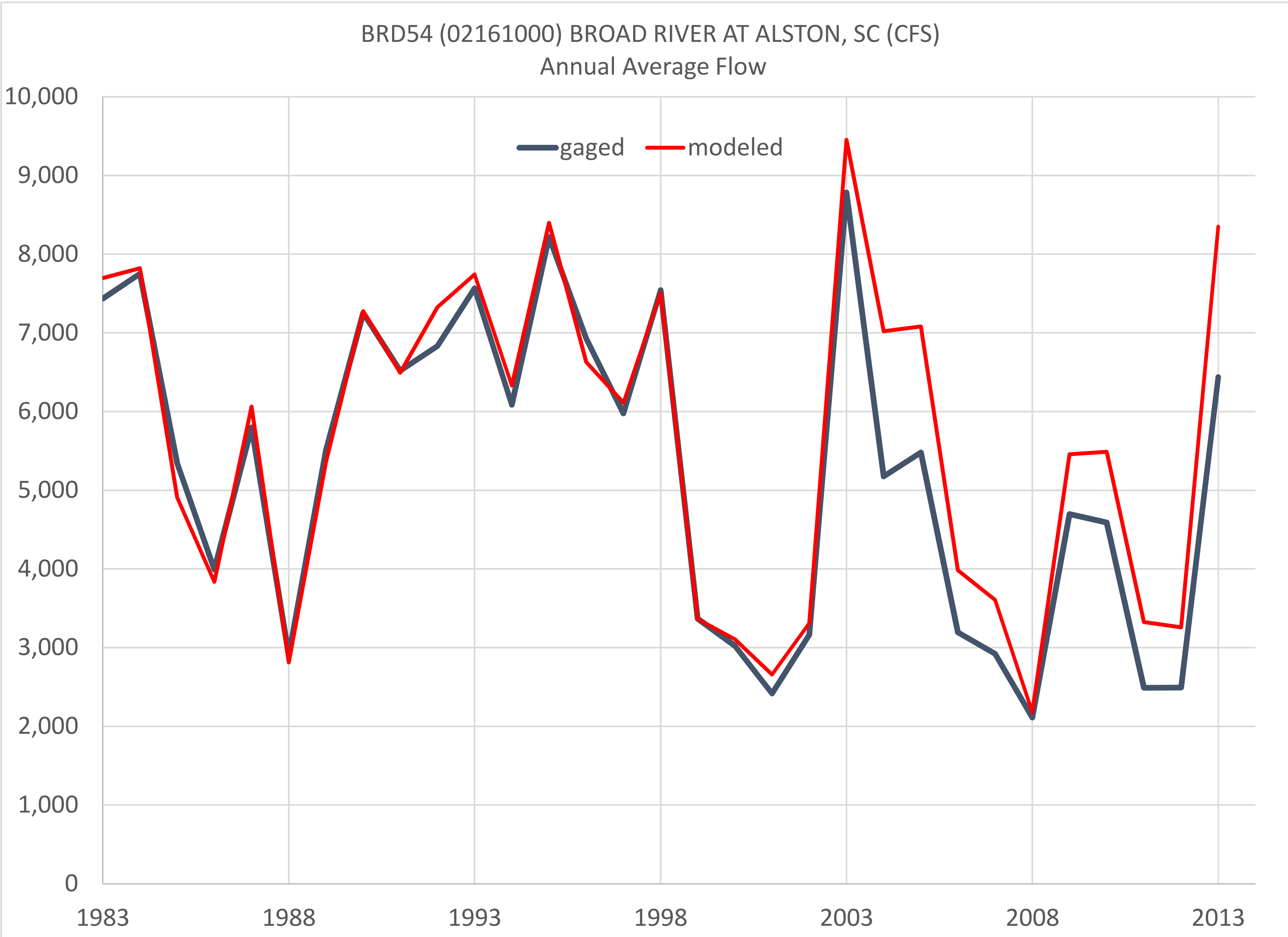


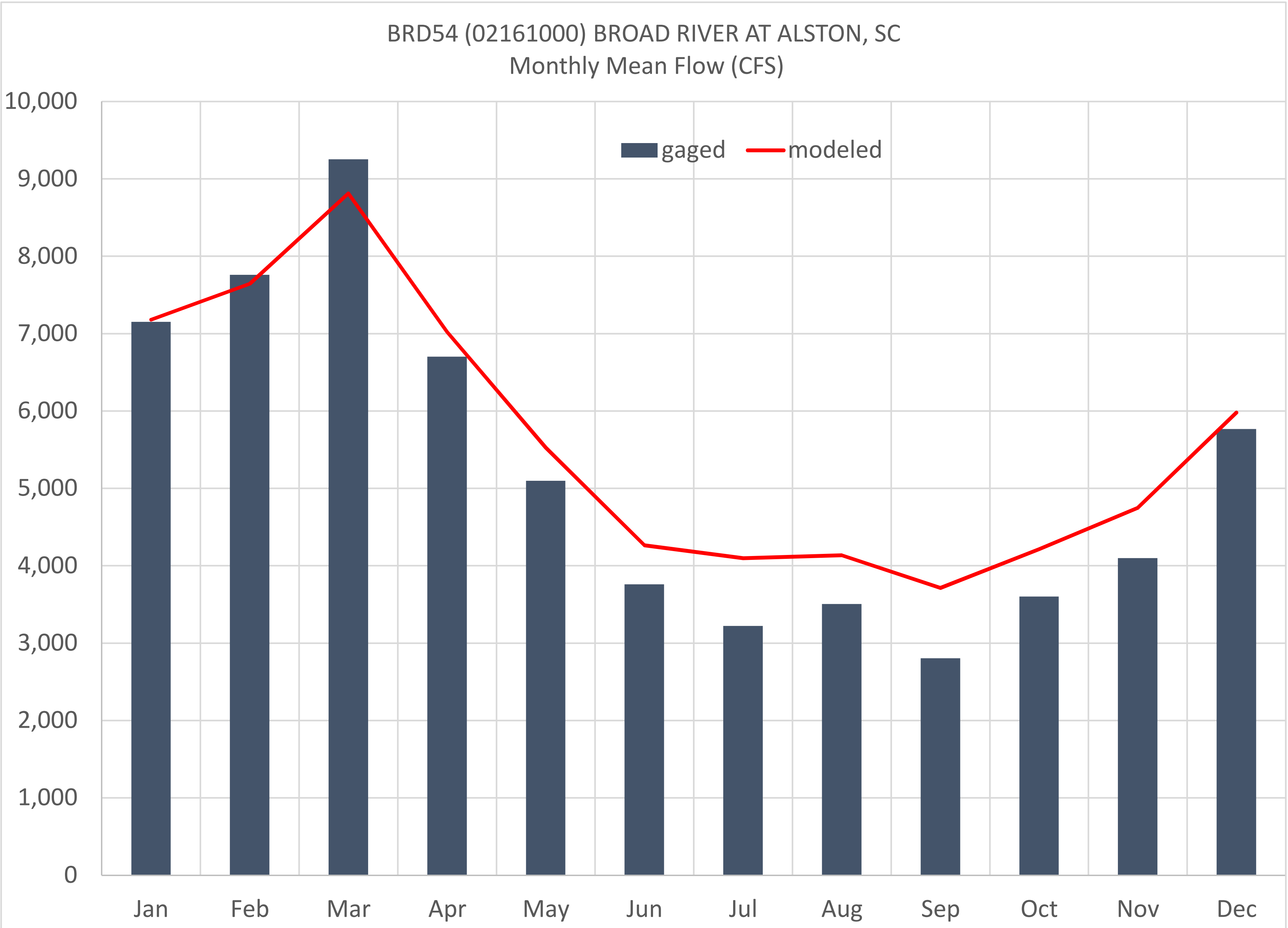
BRD24 (02156500) BROAD RIVER NEAR CARLISLE, SC
Monthly Mean Flow (CFS)
6,000
5,000
4,000
3,000
2,000
1,000
0
gaged
modeled
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

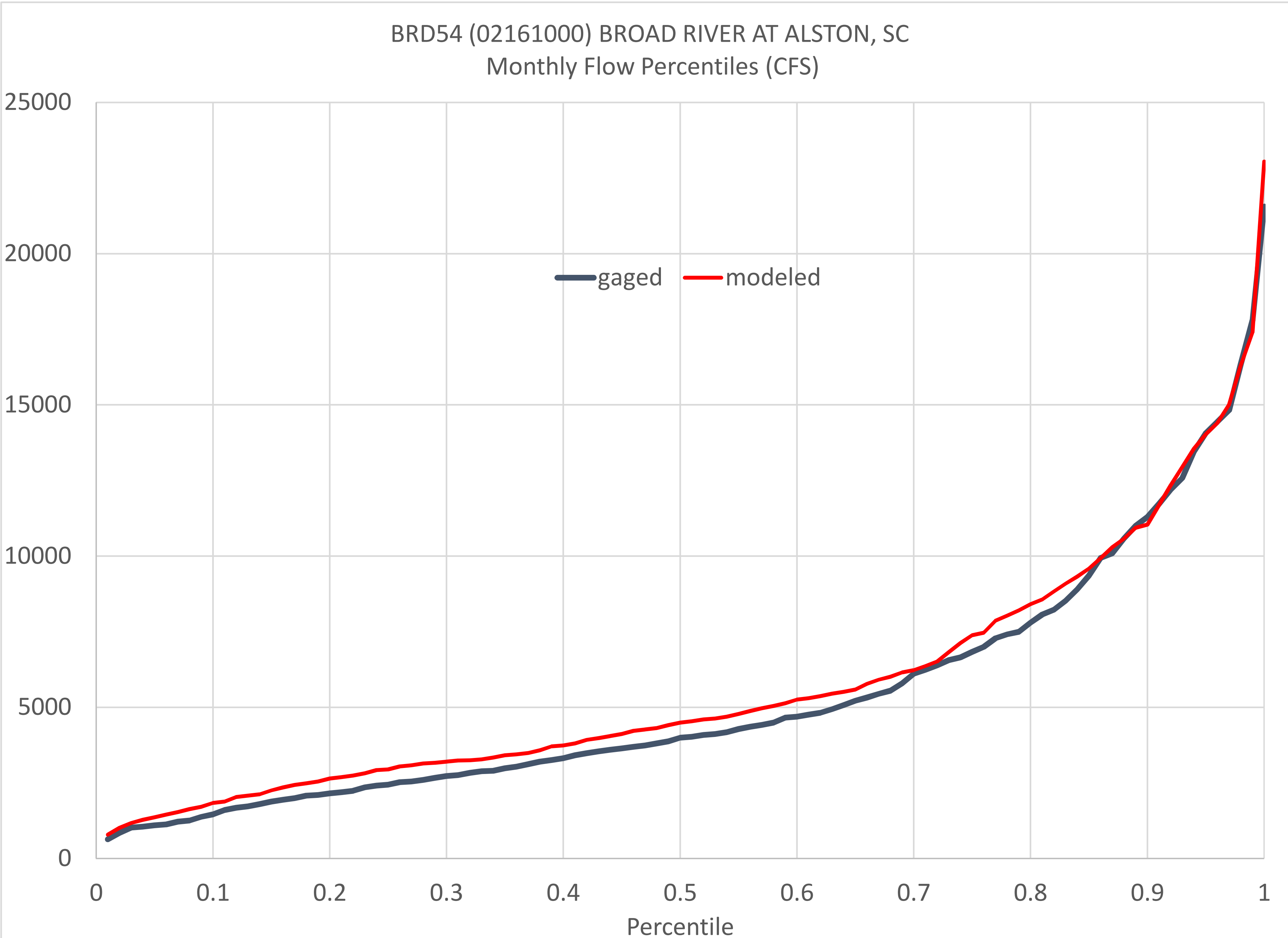

BRD24 (02156500) BROAD RIVER NEAR CARLISLE, SC
Monthly Flow Percentiles (CFS)
gaged
modeled
14000
12000
10000
8000
6000
4000
2000
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

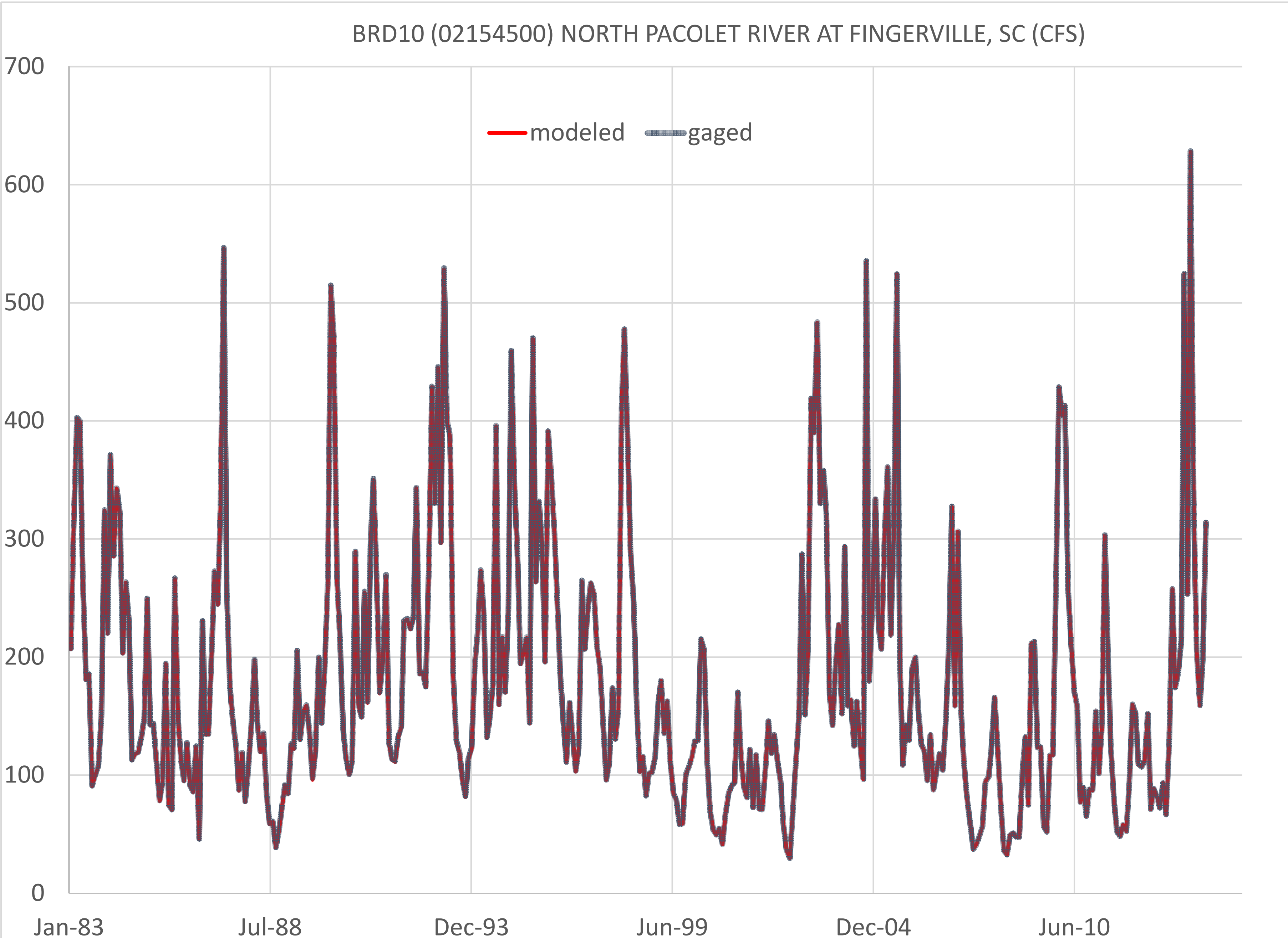

BRD54 (02161000) BROAD RIVER AT ALSTON, SC (CFS)
modeled
gaged
25,000
20,000
15,000
10,000
5,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10


BRD54 (02161000) BROAD RIVER AT ALSTON, SC
Cumulative Flow (CFS)
modeled
gaged
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

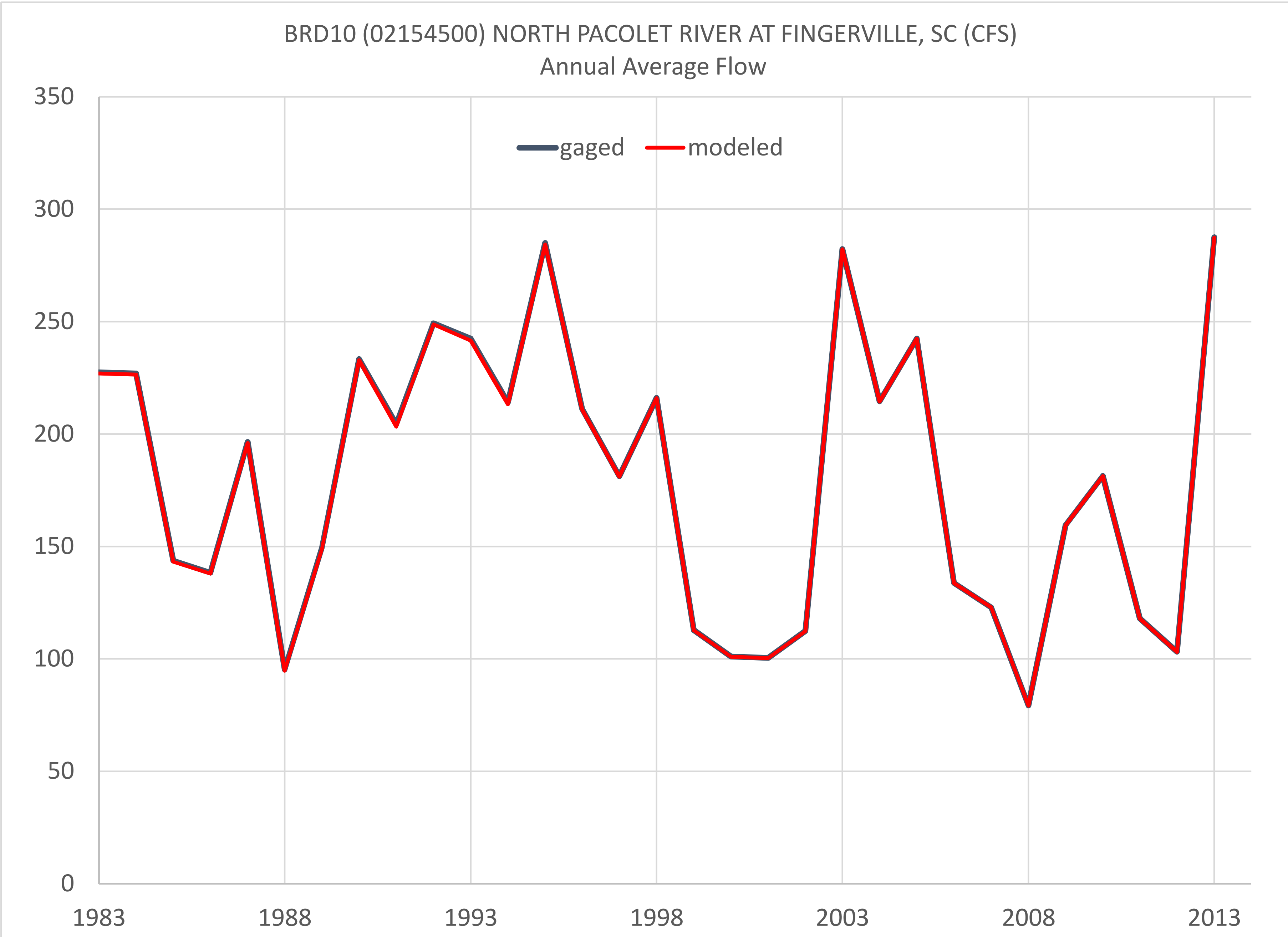

BRD54 (02161000) BROAD RIVER AT ALSTON, SC (CFS)
Annual Average Flow
gaged
modeled
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
1983
1988
1993
1998
2003
2008
2013


BRD54 (02161000) BROAD RIVER AT ALSTON, SC
Monthly Mean Flow (CFS)
gaged
modeled
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

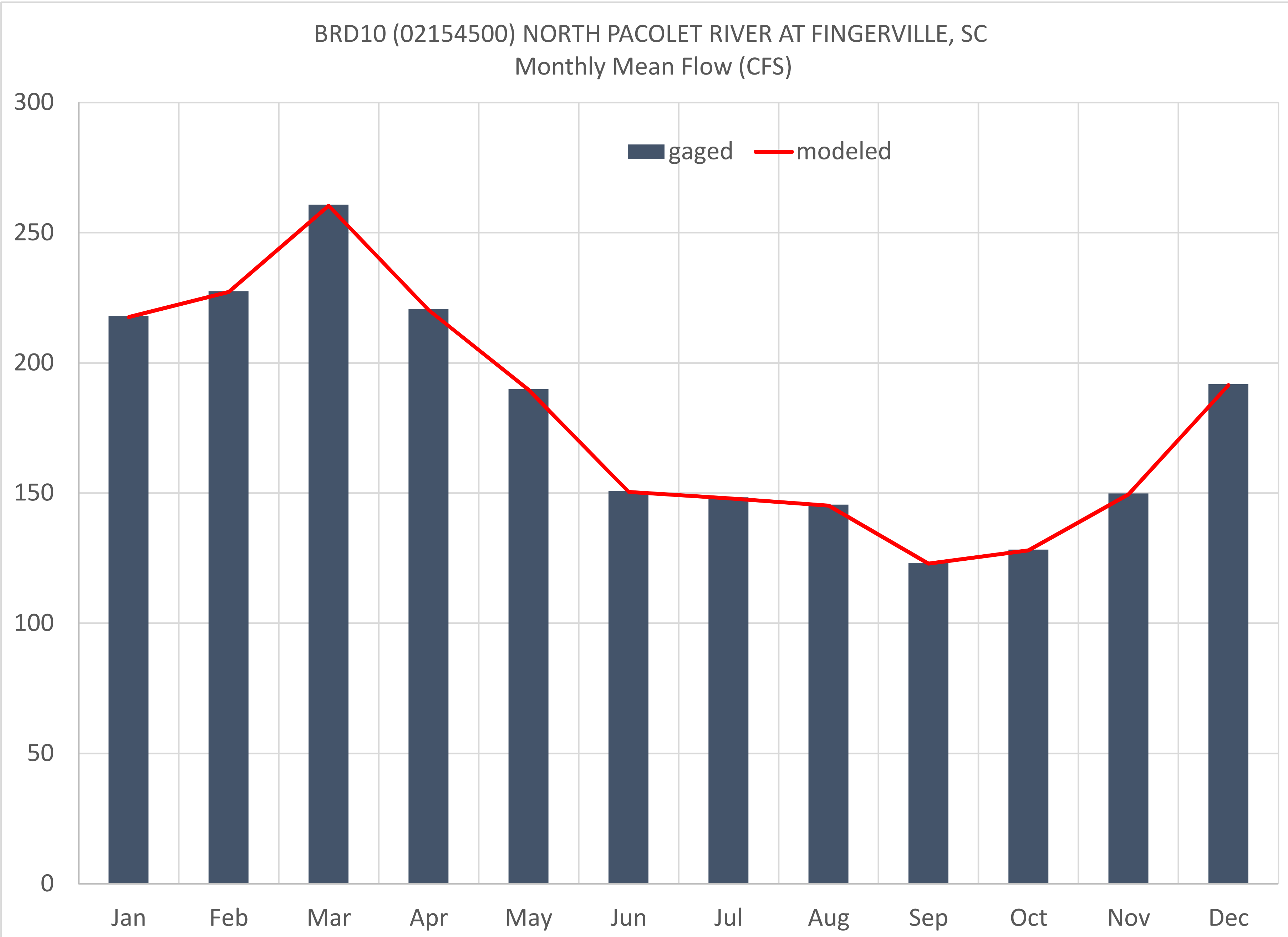

BRD54 (02161000) BROAD RIVER AT ALSTON, SC
Monthly Flow Percentiles (CFS)
gaged
modeled
25000
20000
15000
10000
5000
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

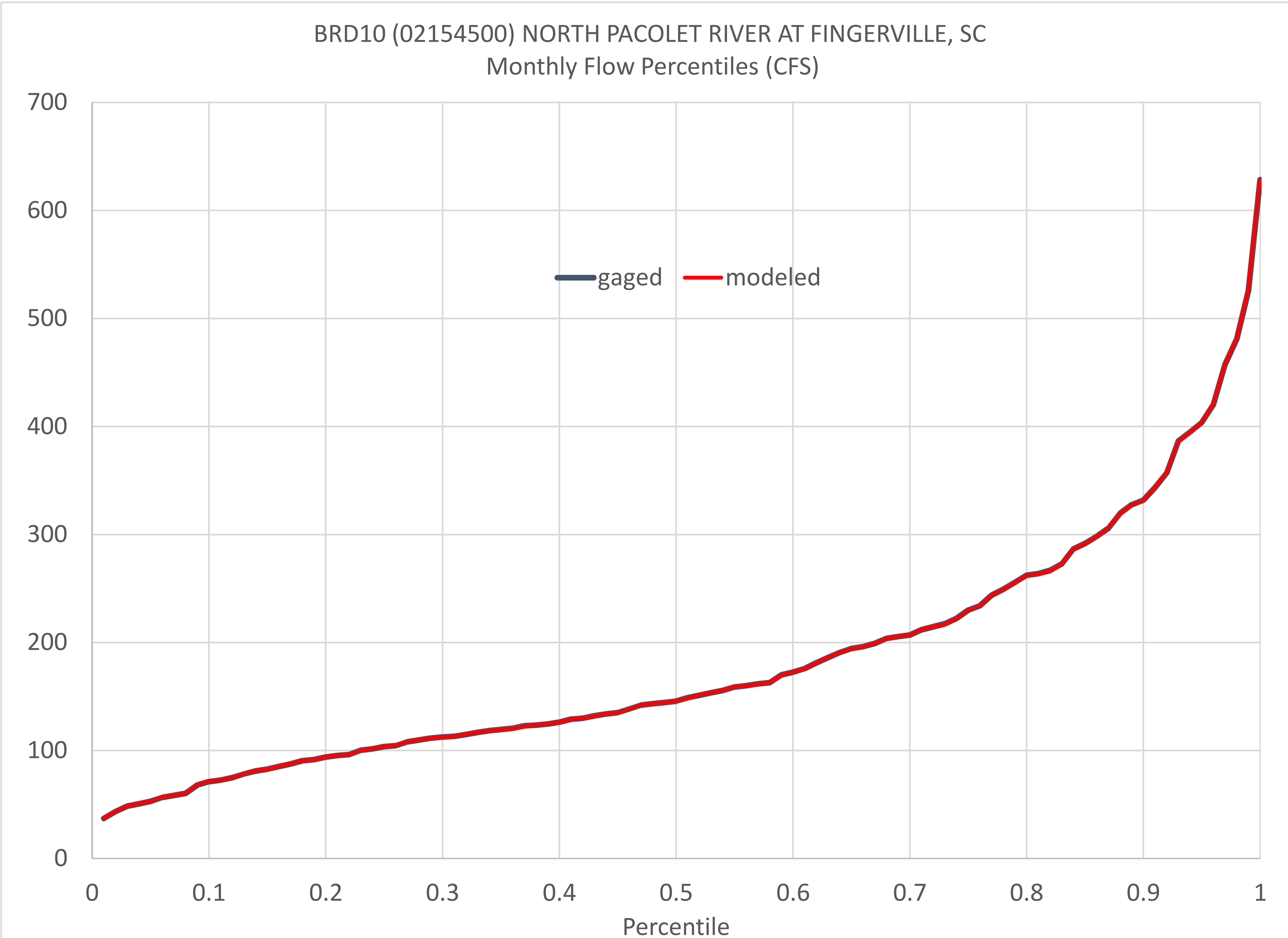


BRD10 (02154500) NORTH PACOLET RIVER AT FINGERVILLE, SC (CFS)
modeled
gaged
700
600
500
400
300
200
100
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

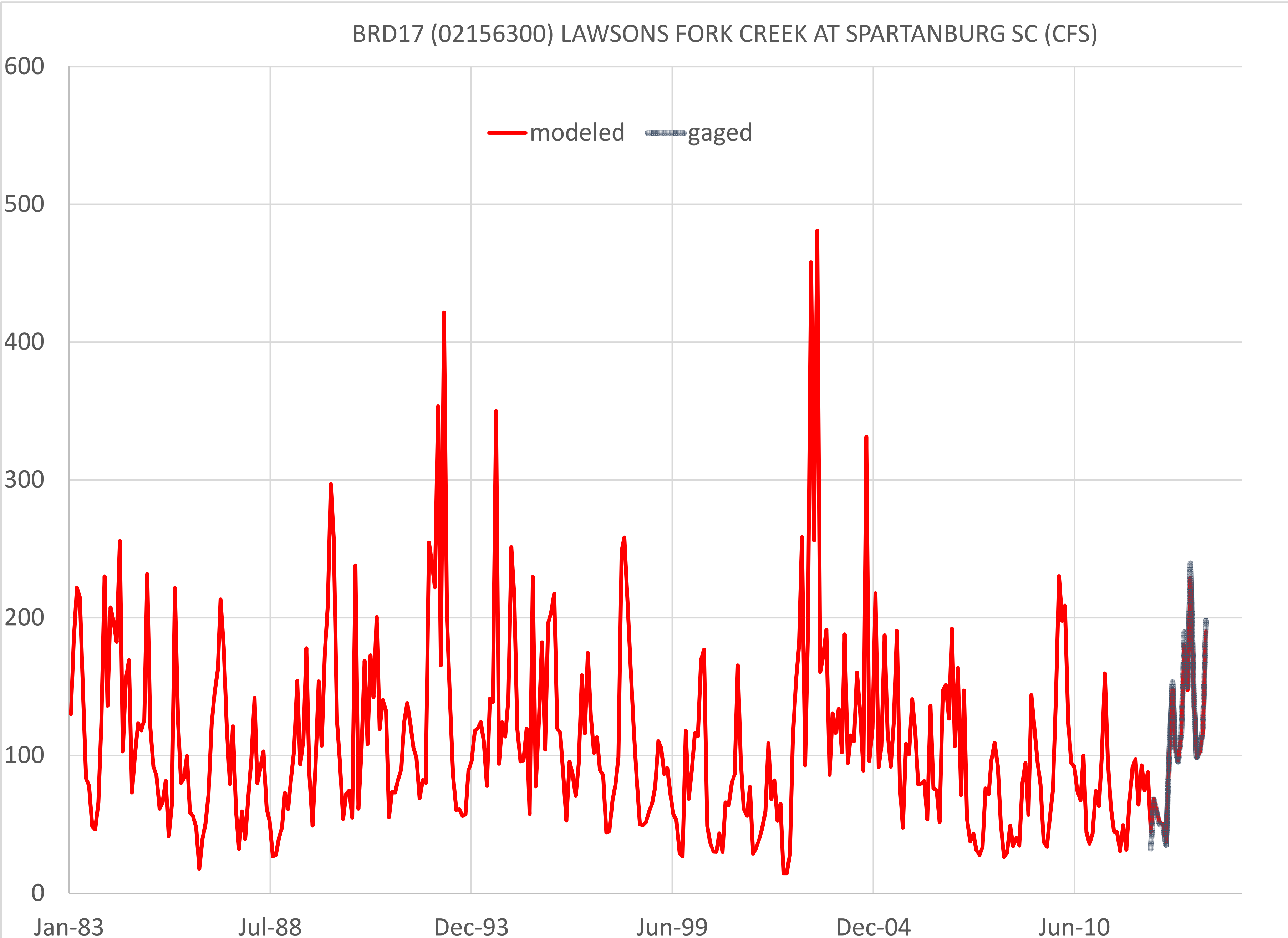


BRD10 (02154500) NORTH PACOLET RIVER AT FINGERVILLE, SC (CFS)
Annual Average Flow
gaged
modeled
350
300
250
200
150
100
50
0
1983
1988
1993
1998
2003
2008
2013

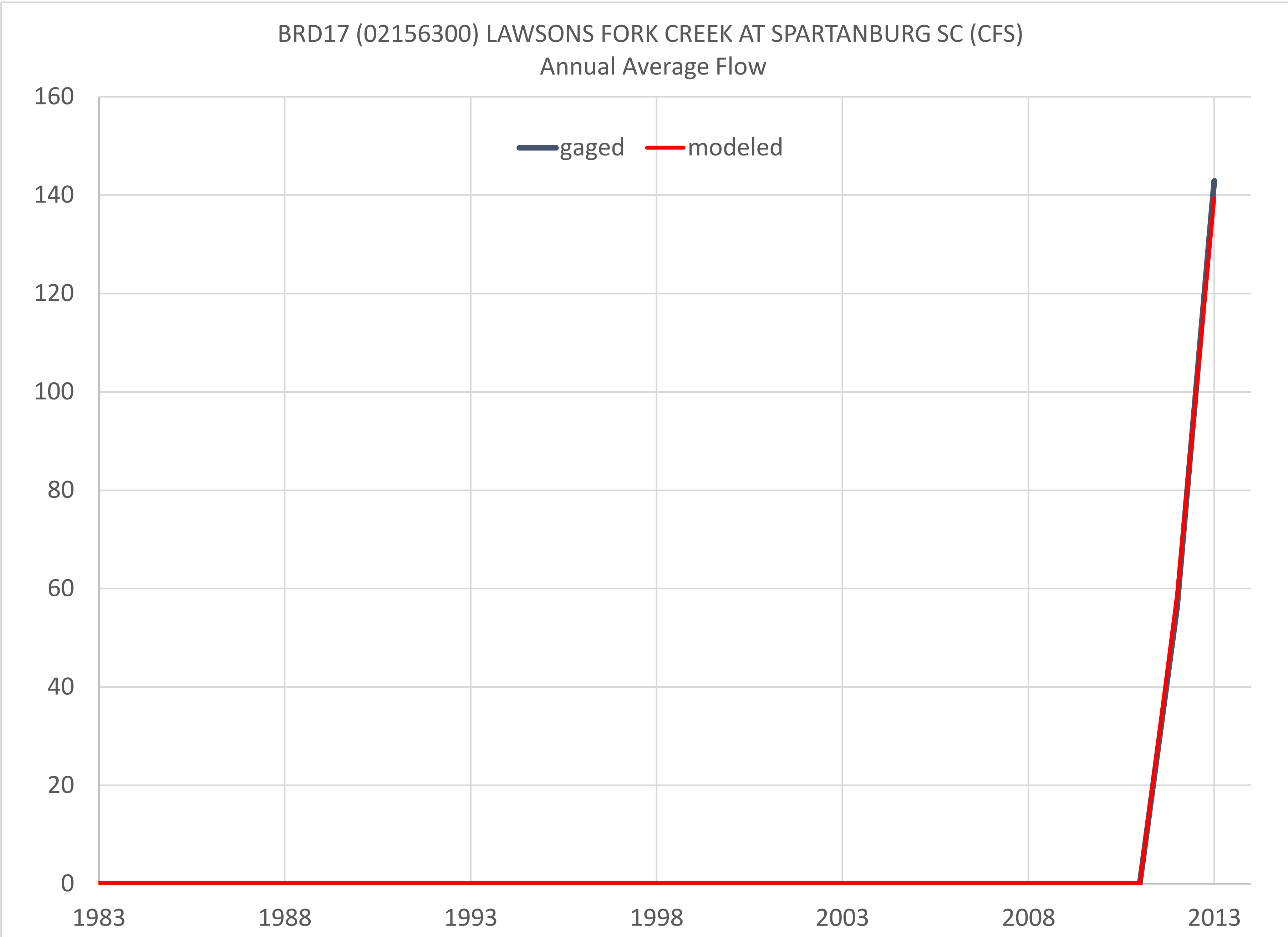

BRD10 (02154500) NORTH PACOLET RIVER AT FINGERVILLE, SC
Monthly Mean Flow (CFS)
gaged
modeled
300
250
200
150
100
50
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

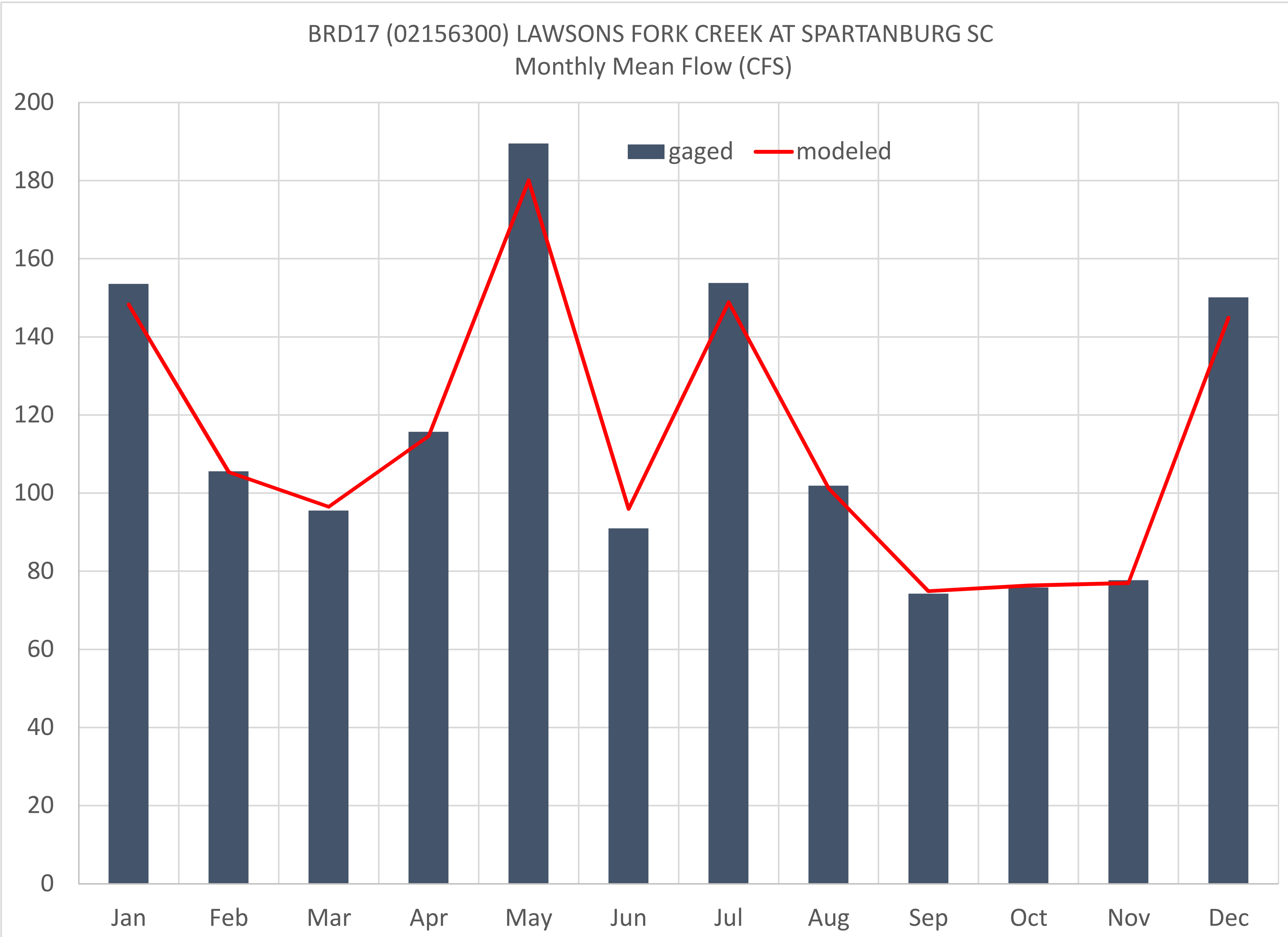


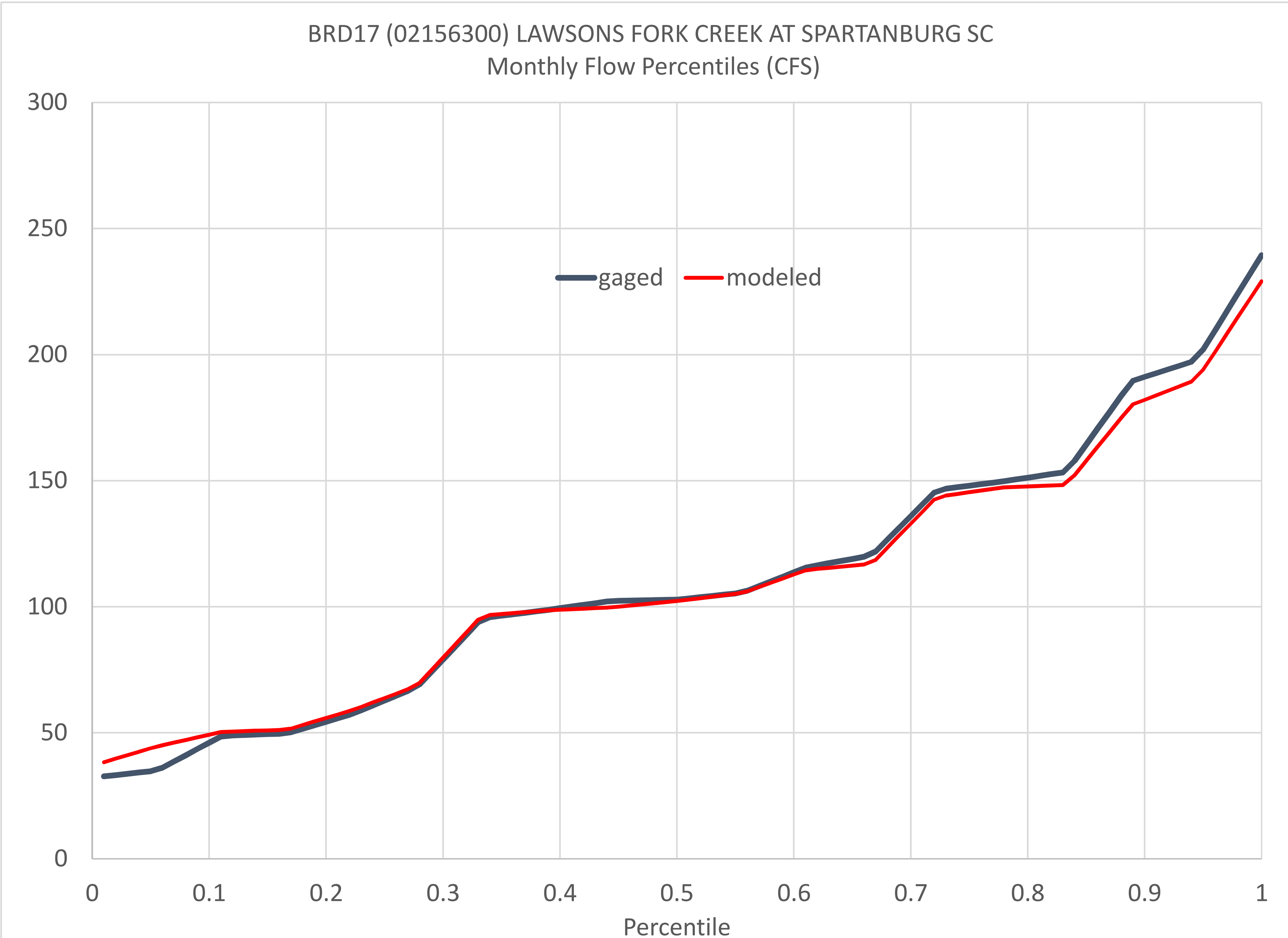
BRD10 (02154500) NORTH PACOLET RIVER AT FINGERVILLE, SC
Monthly Flow Percentiles (CFS)
gaged
modeled
700
600
500
400
300
200
100
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

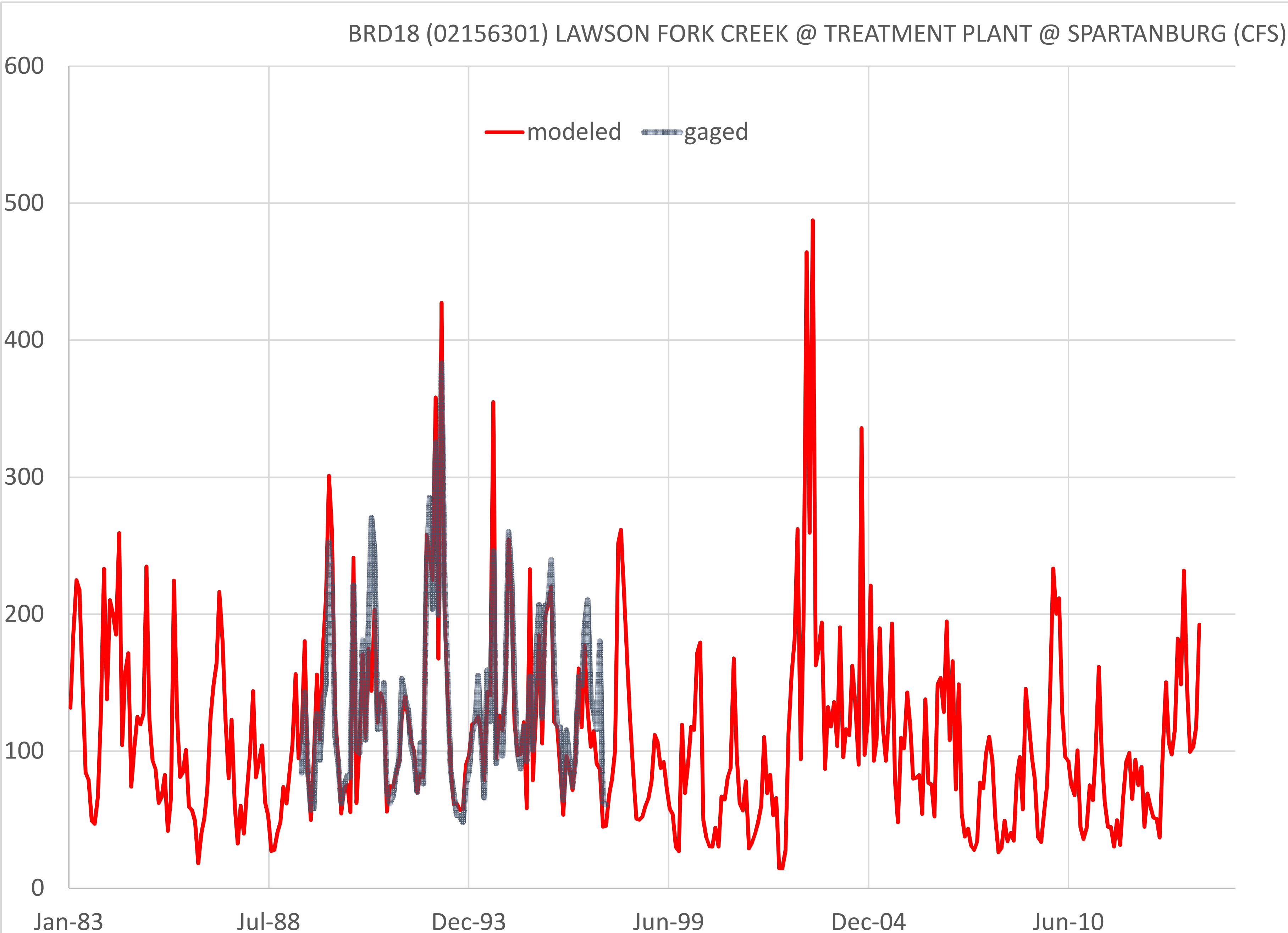


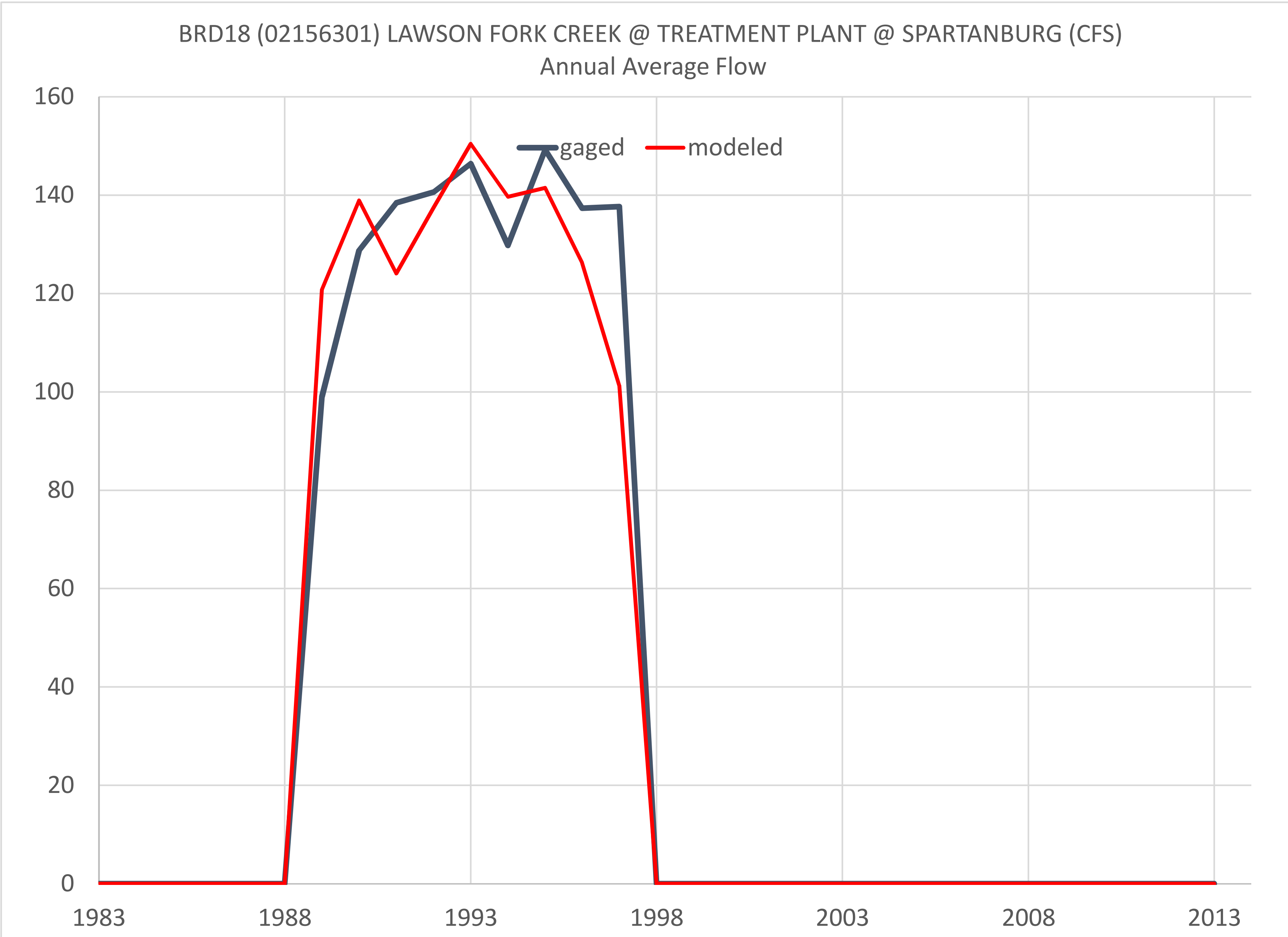
BRD17 (02156300) LAWSONS FORK CREEK AT SPARTANBURG SC (CFS)
modeled
gaged
600
500
400
300
200
100
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

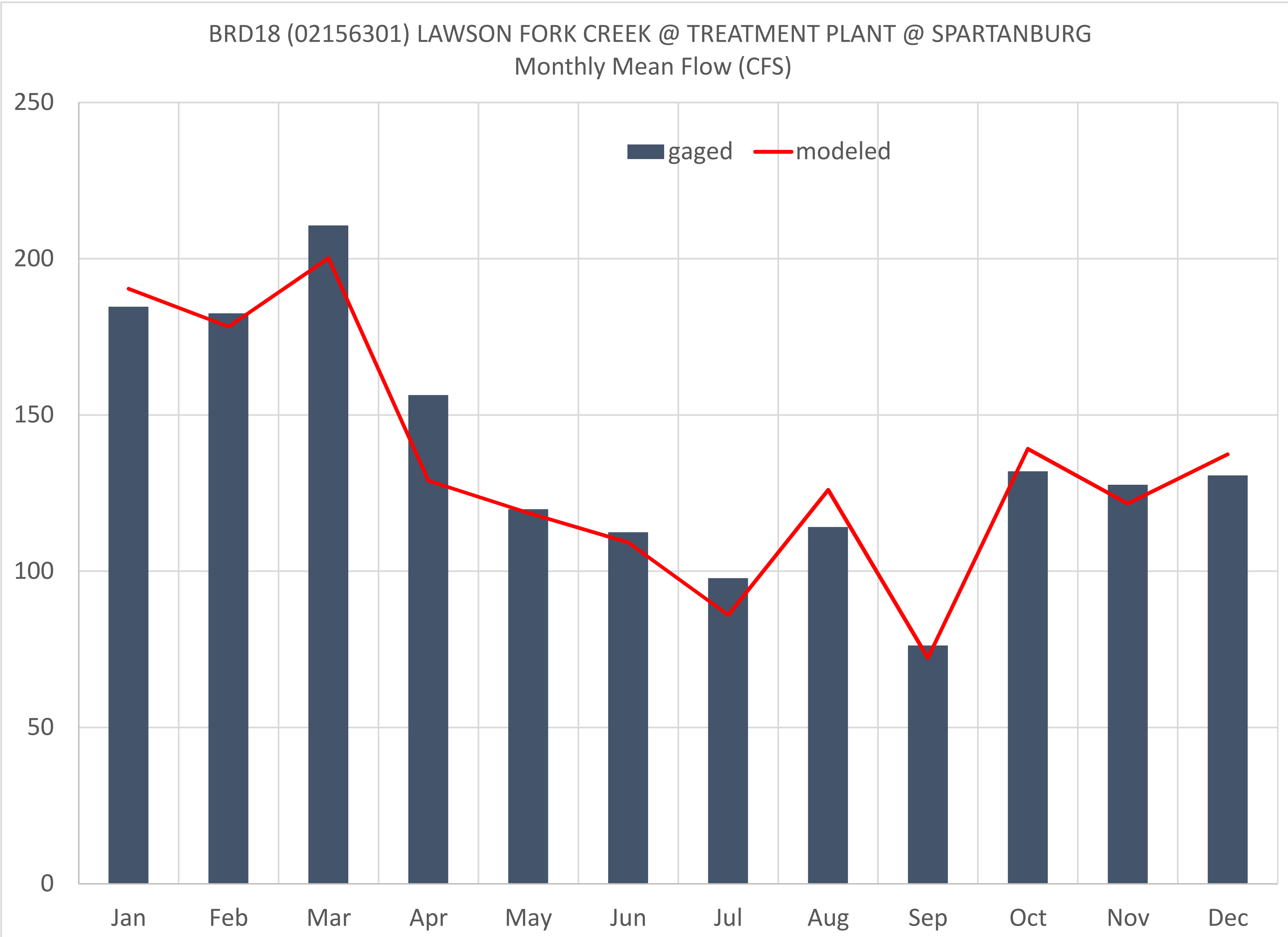

BRD17 (02156300) LAWSONS FORK CREEK AT SPARTANBURG SC (CFS)
Annual Average Flow
gaged
modeled
160
140
120
100
80
60
40
20
0
1983
1988
1993
1998
2003
2008
2013


BRD17 (02156300) LAWSONS FORK CREEK AT SPARTANBURG SC
Monthly Mean Flow (CFS)
gaged
modeled
200
180
160
140
120
100
80
60
40
20
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

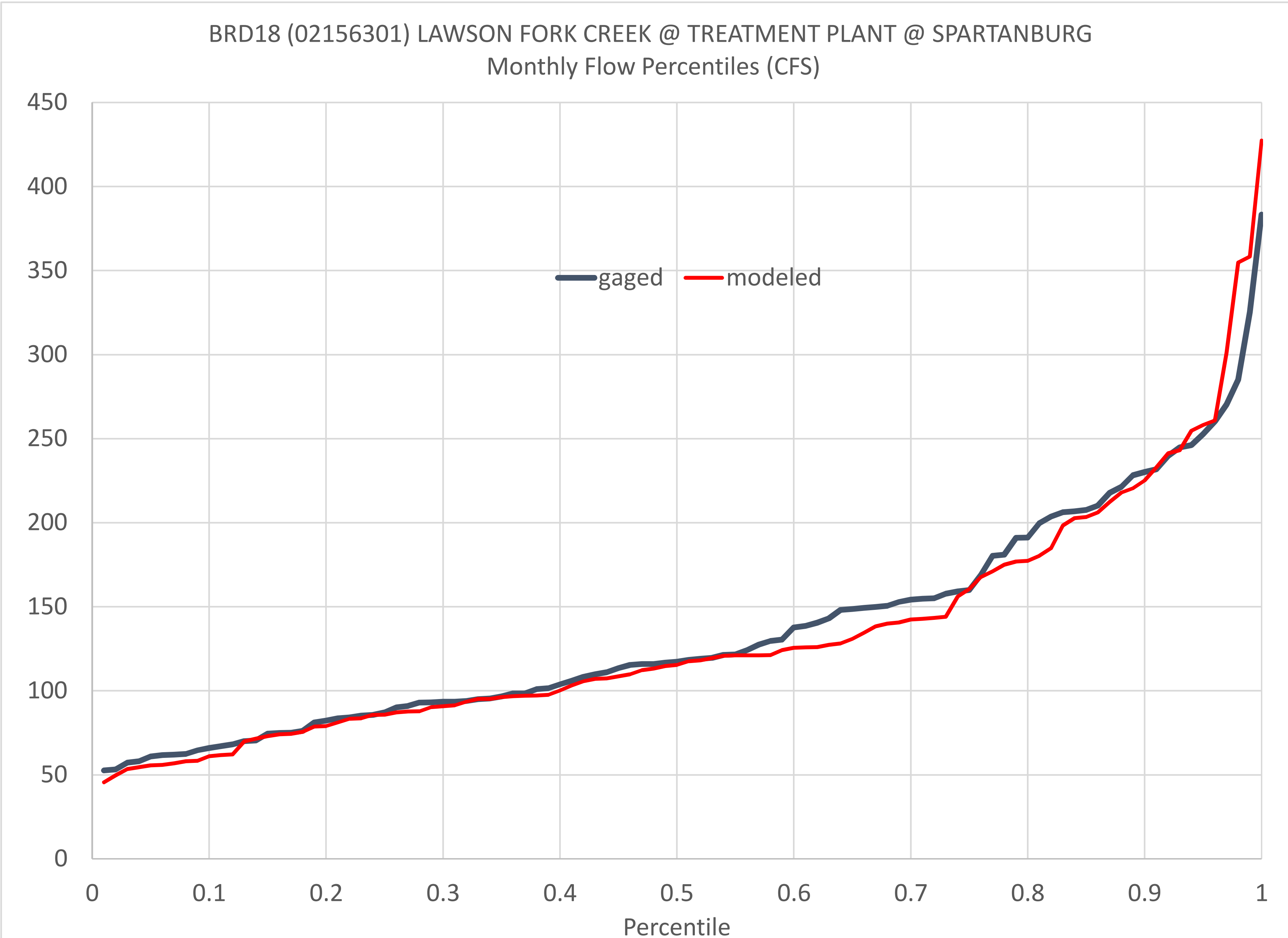

BRD17 (02156300) LAWSONS FORK CREEK AT SPARTANBURG SC
Monthly Flow Percentiles (CFS)
gaged
modeled
300
250
200
150
100
50
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile


BRD18 (02156301) LAWSON FORK CREEK @ TREATMENT PLANT @ SPARTANBURG (CFS)
modeled
gaged
600
500
400
300
200
100
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

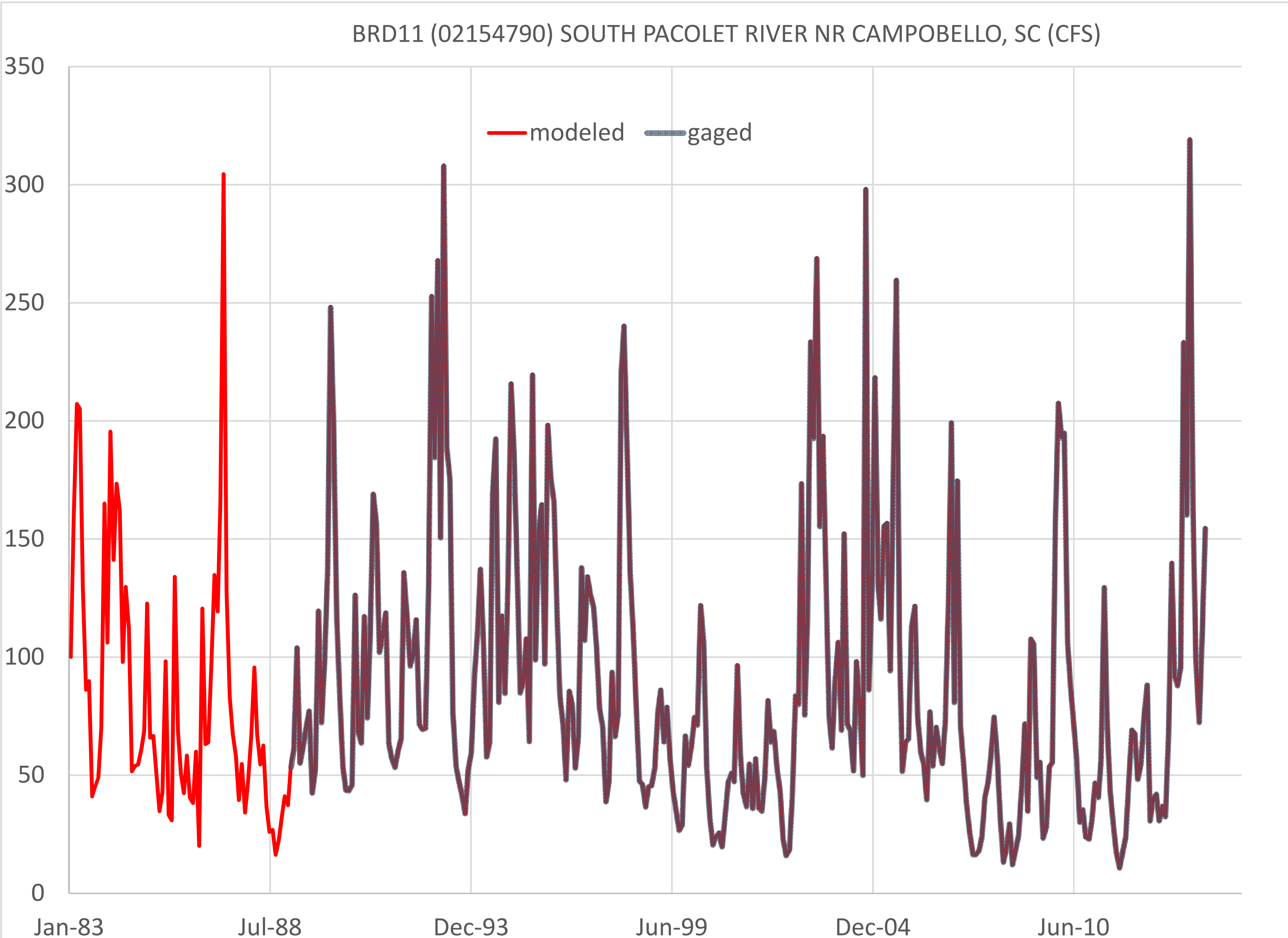

BRD18 (02156301) LAWSON FORK CREEK @ TREATMENT PLANT @ SPARTANBURG (CFS)
Annual Average Flow
gaged
modeled
160
140
120
100
80
60
40
20
0
1983
1988
1993
1998
2003
2008
2013

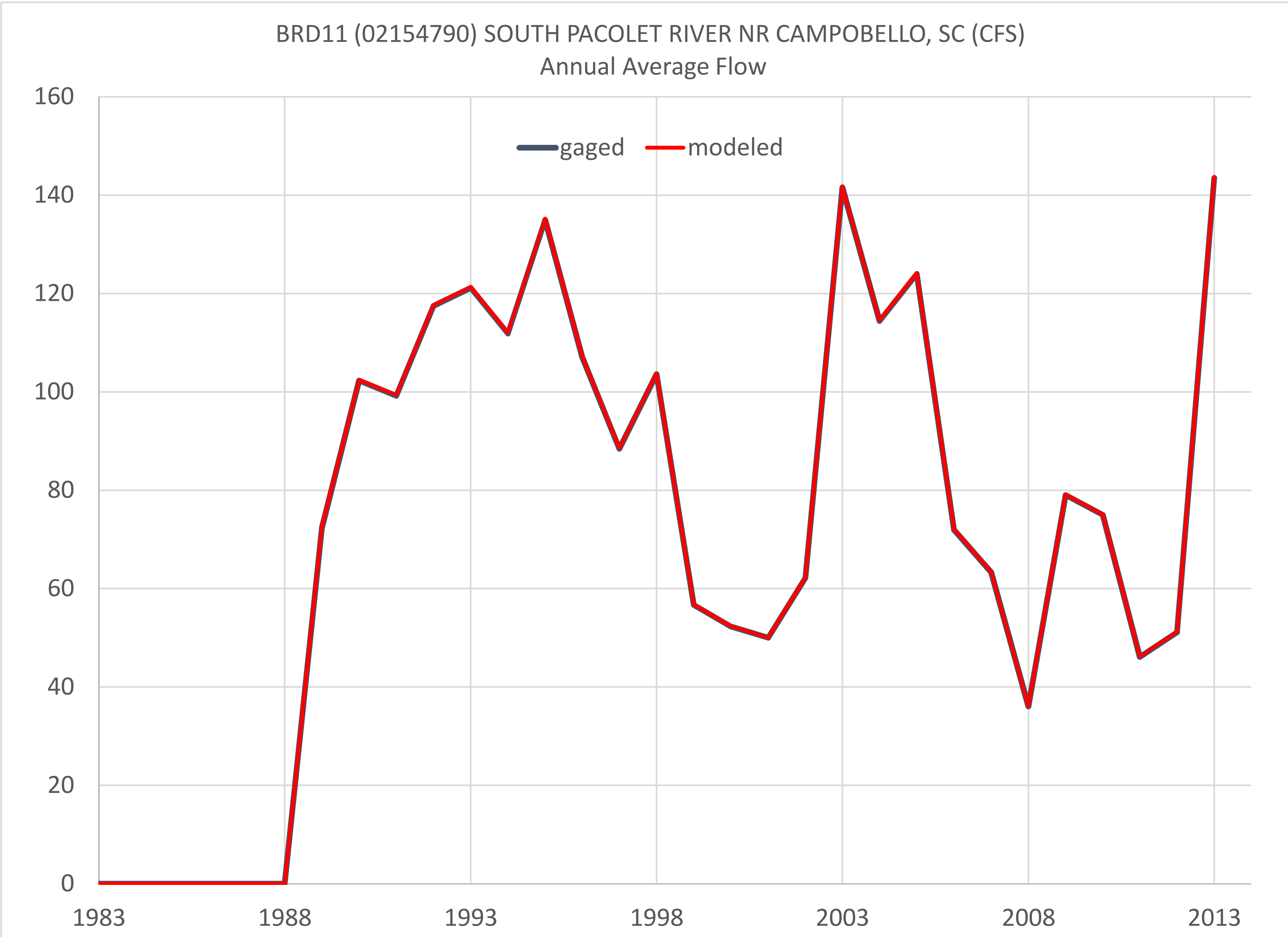


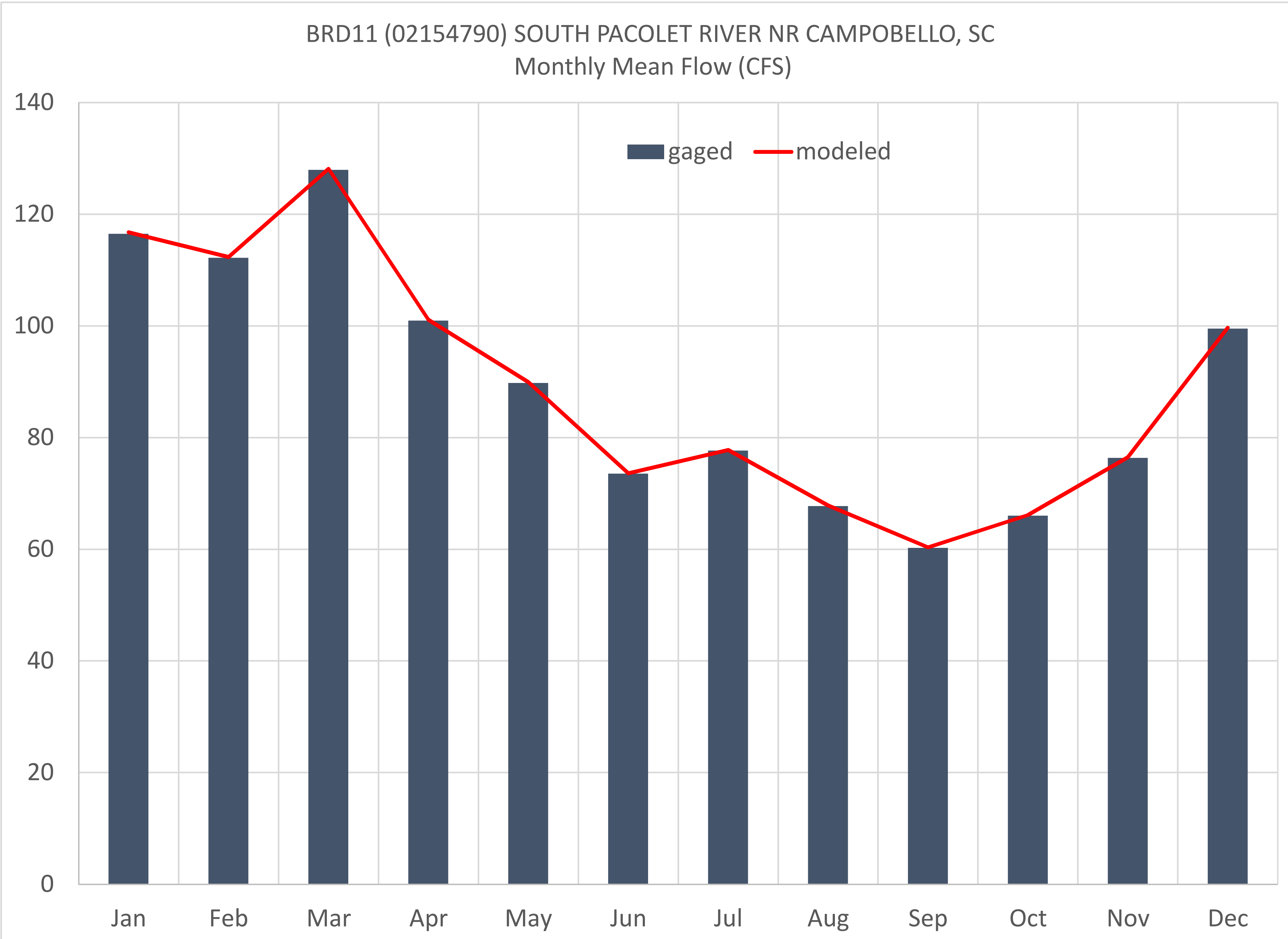
BRD18 (02156301) LAWSON FORK CREEK @ TREATMENT PLANT @ SPARTANBURG
Monthly Mean Flow (CFS)
gaged
modeled
250
200
150
100
50
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

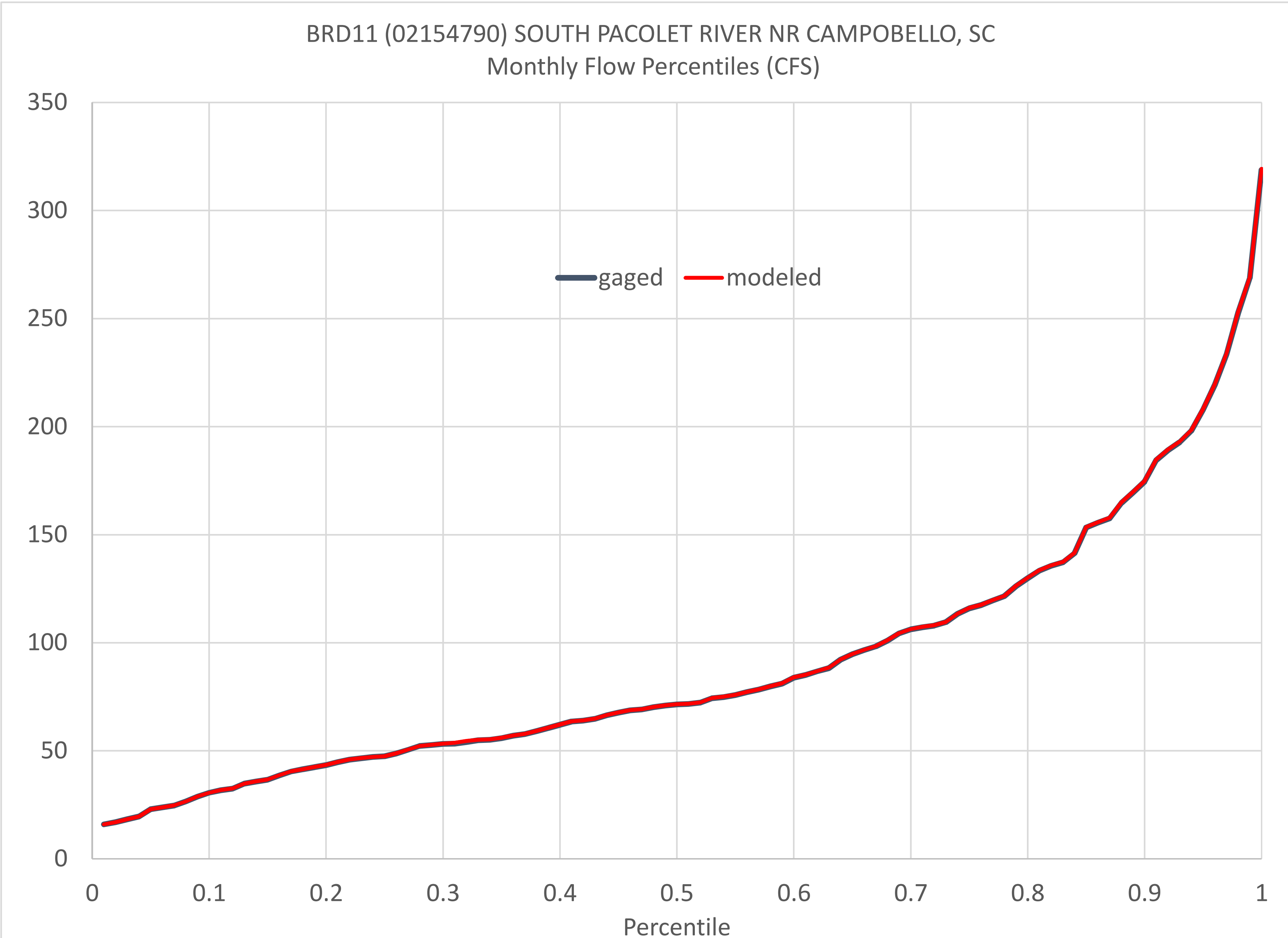


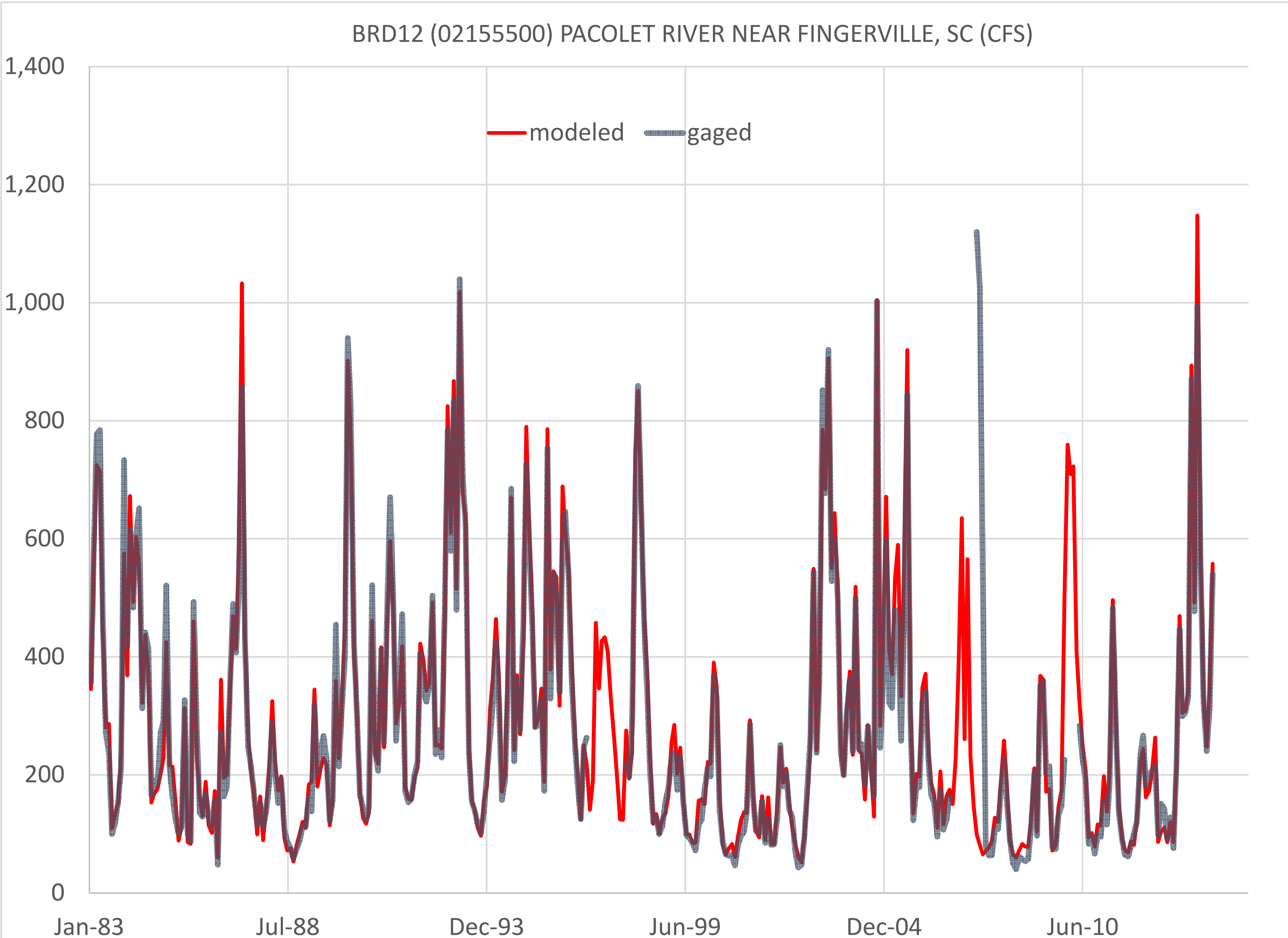
BRD18 (02156301) LAWSON FORK CREEK @ TREATMENT PLANT @ SPARTANBURG
Monthly Flow Percentiles (CFS)
gaged
modeled
450
400
350
300
250
200
150
100
50
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

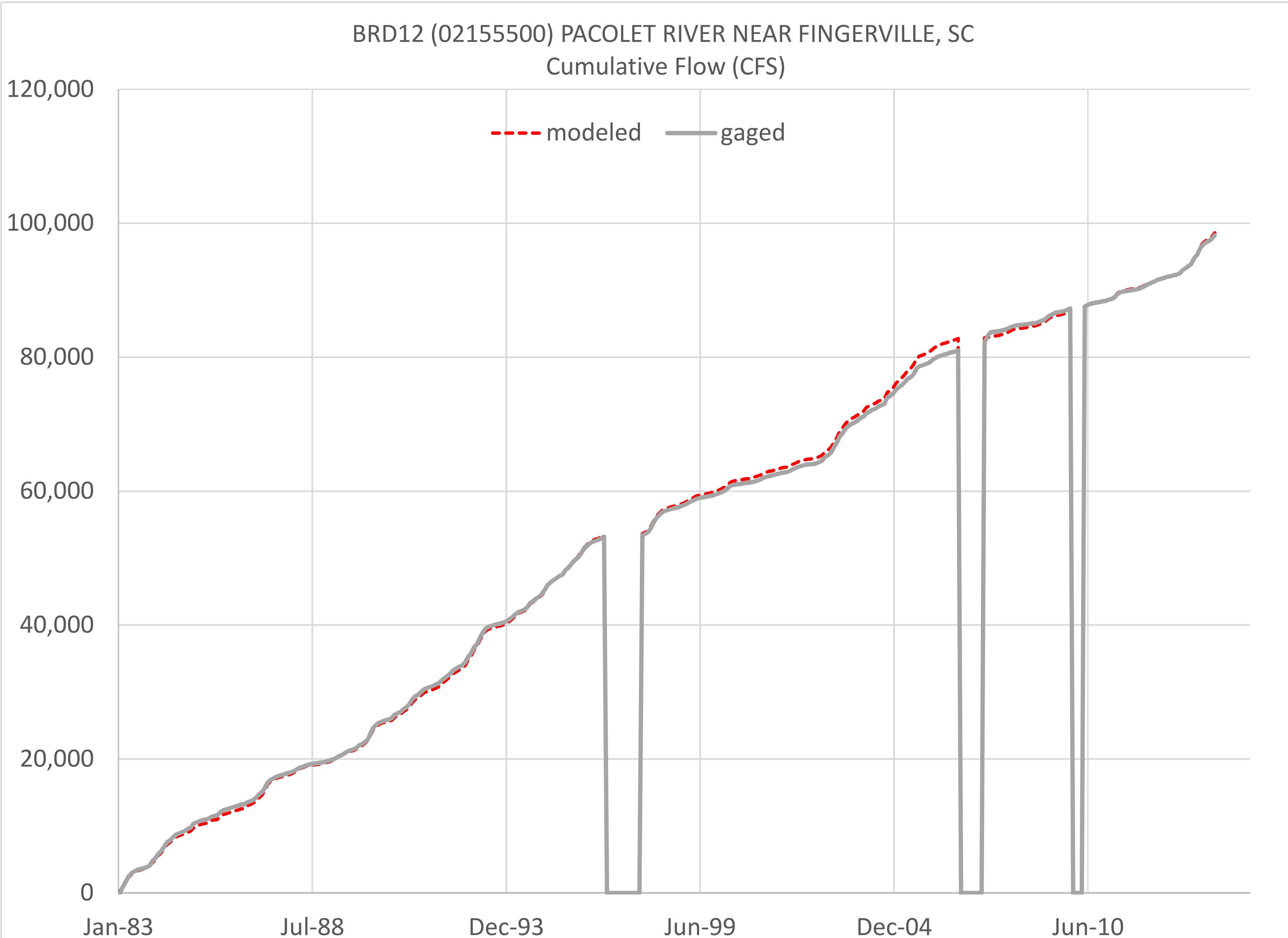

BRD11 (02154790) SOUTH PACOLET RIVER NR CAMPOBELLO, SC (CFS)
modeled
gaged
350
300
250
200
150
100
50
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10


BRD11 (02154790) SOUTH PACOLET RIVER NR CAMPOBELLO, SC (CFS)
Annual Average Flow
gaged
modeled
0
20
40
60
80
100
120
140
160
1983
1988
1993
1998
2003
2008
2013

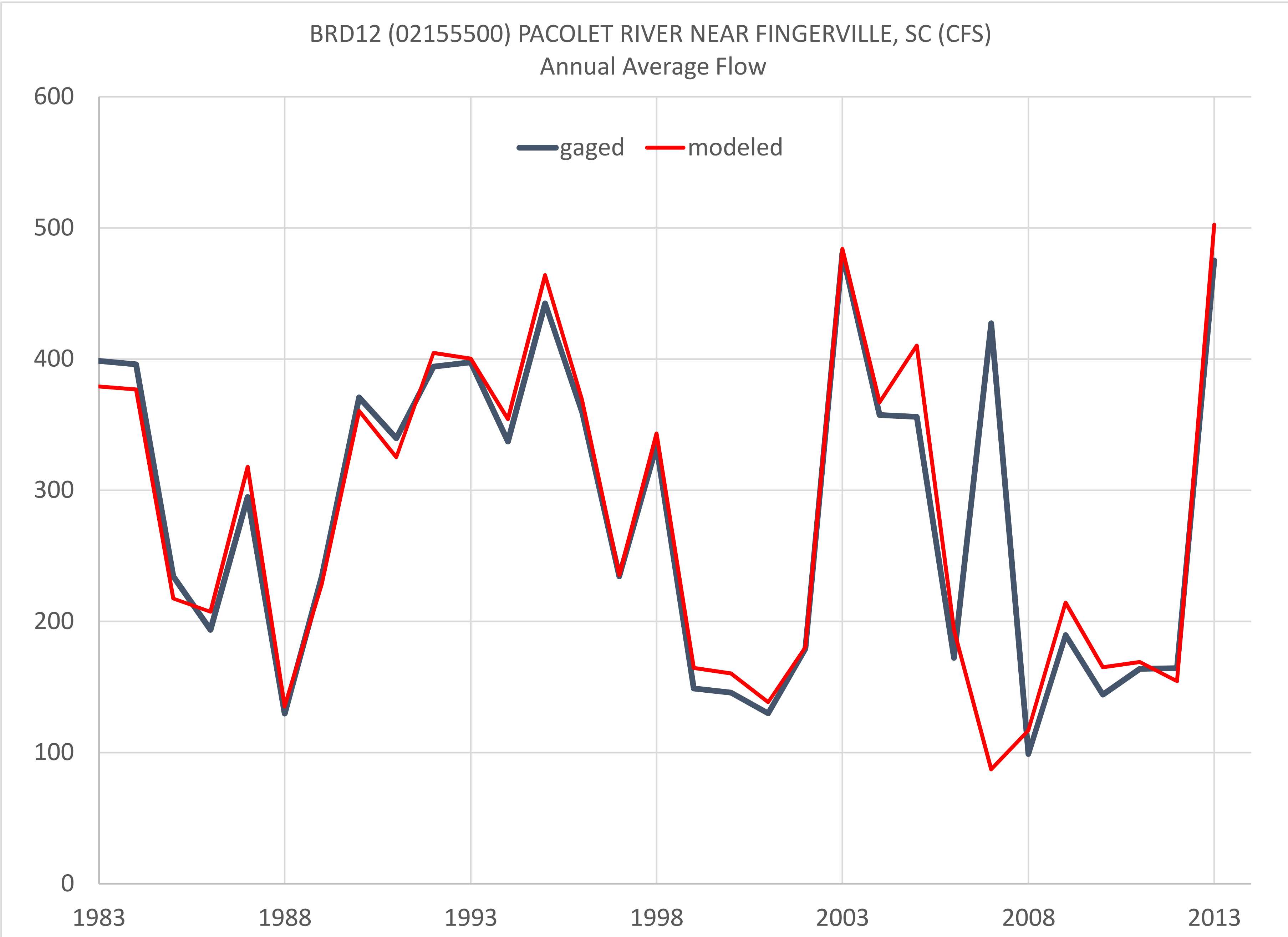

BRD11 (02154790) SOUTH PACOLET RIVER NR CAMPOBELLO, SC
Monthly Mean Flow (CFS)
gaged
modeled
0
20
40
60
80
100
120
140
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

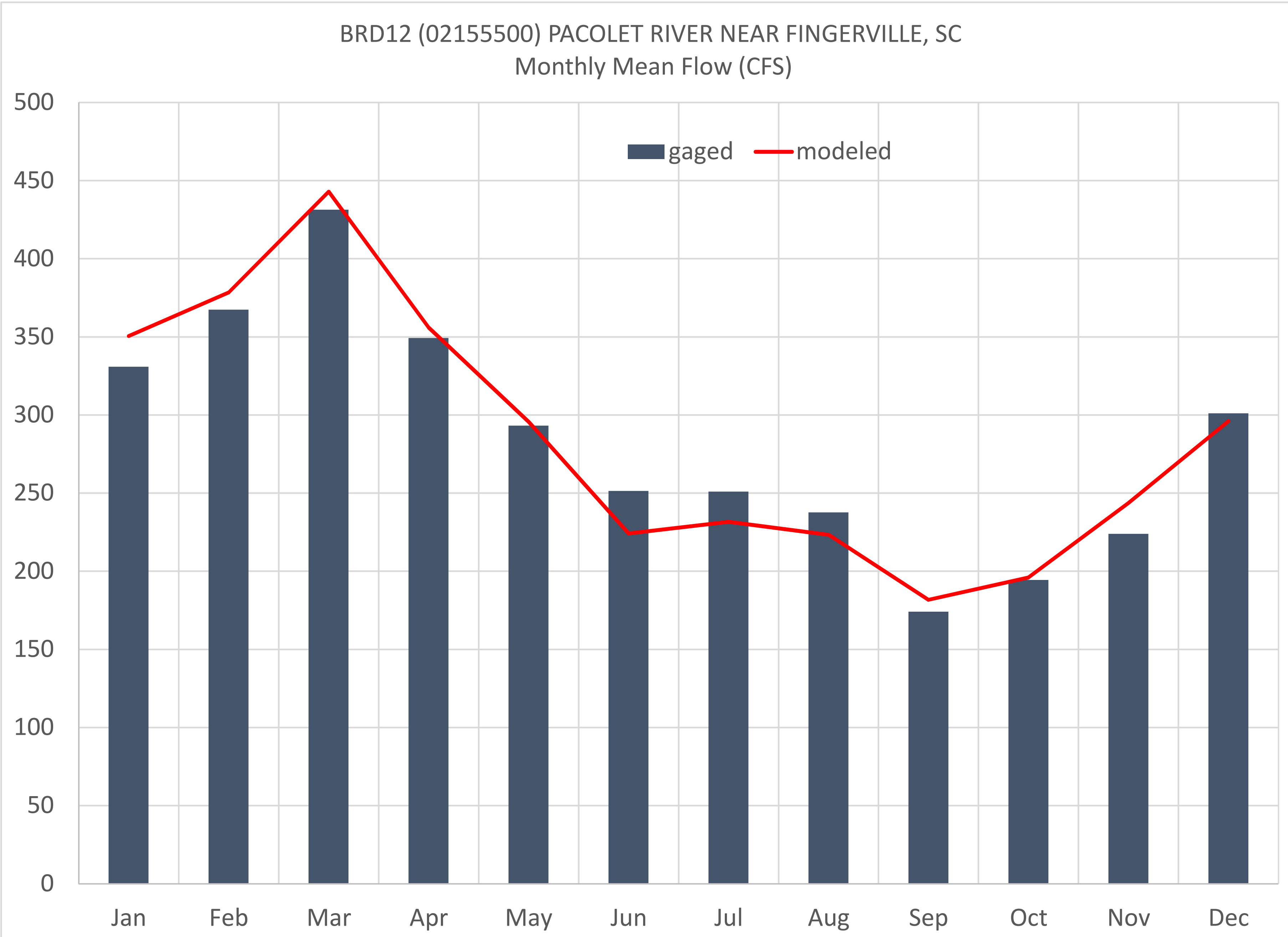

BRD11 (02154790) SOUTH PACOLET RIVER NR CAMPOBELLO, SC
Monthly Flow Percentiles (CFS)
gaged
modeled
350
300
250
200
150
100
50
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile


BRD12 (02155500) PACOLET RIVER NEAR FINGERVILLE, SC (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

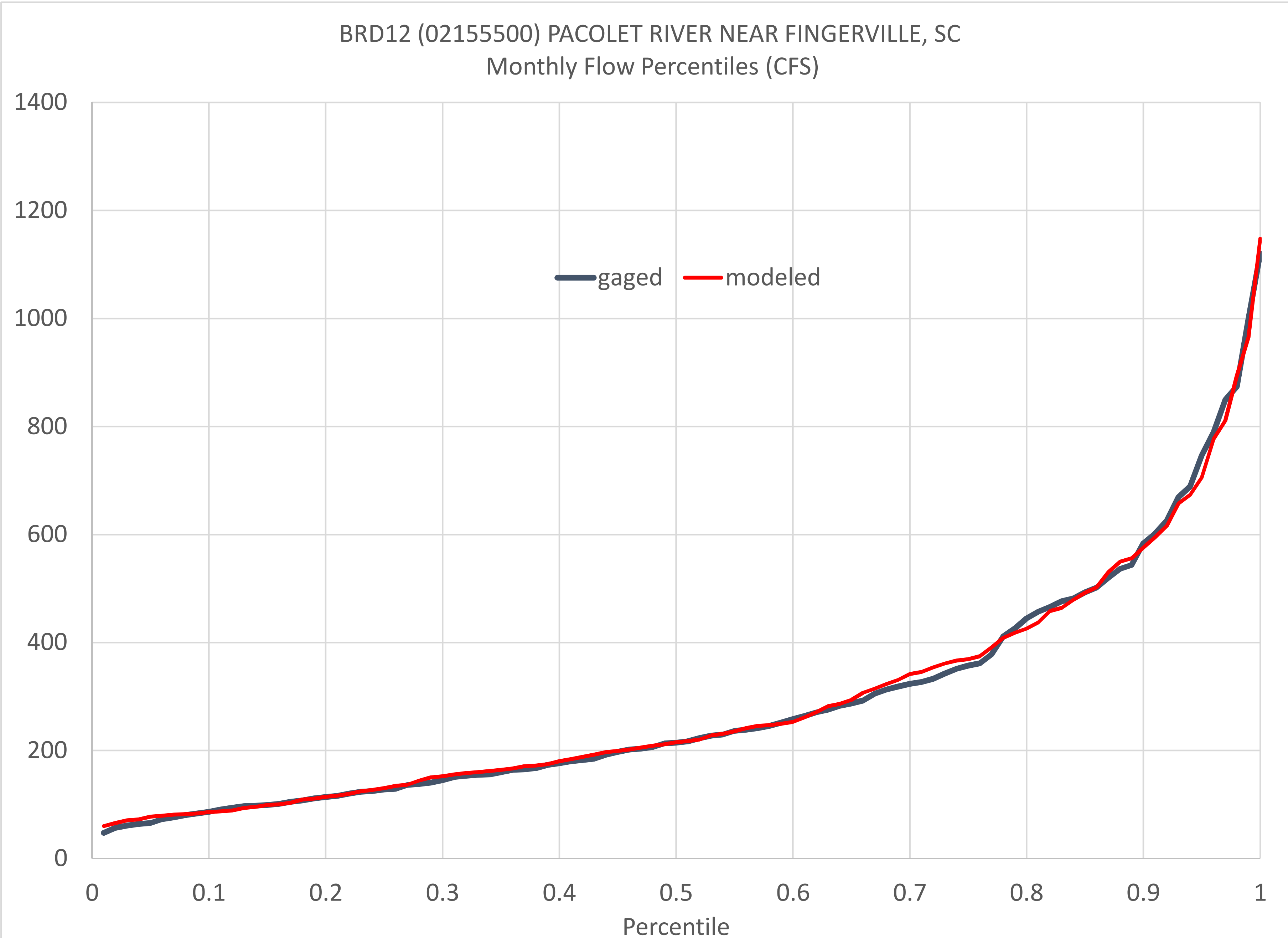


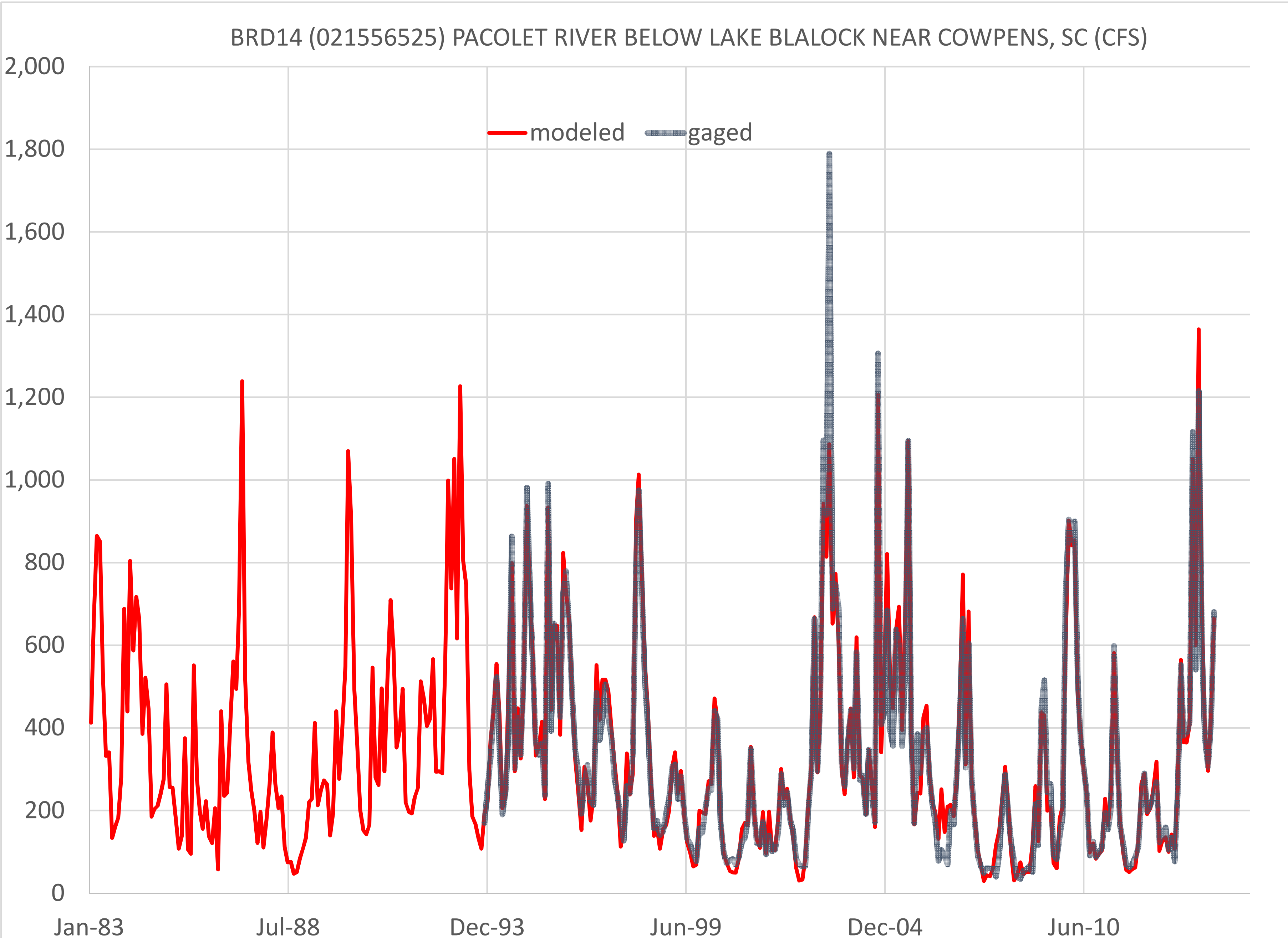
BRD12 (02155500) PACOLET RIVER NEAR FINGERVILLE, SC
Cumulative Flow (CFS)
modeled
gaged
120,000
100,000
80,000
60,000
40,000
20,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

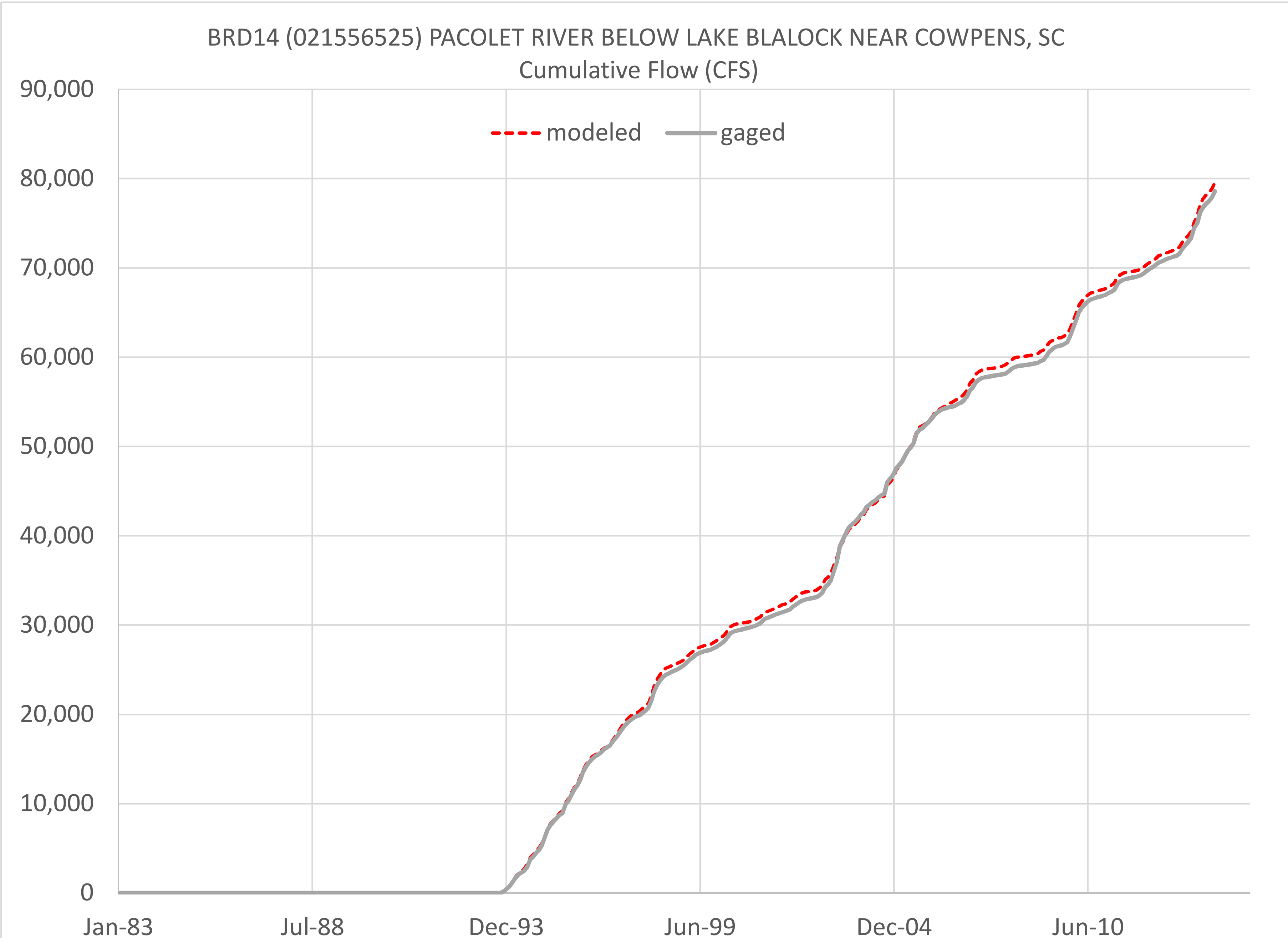

BRD12 (02155500) PACOLET RIVER NEAR FINGERVILLE, SC (CFS)
Annual Average Flow
gaged
modeled
600
500
400
300
200
100
0
1983
1988
1993
1998
2003
2008
2013

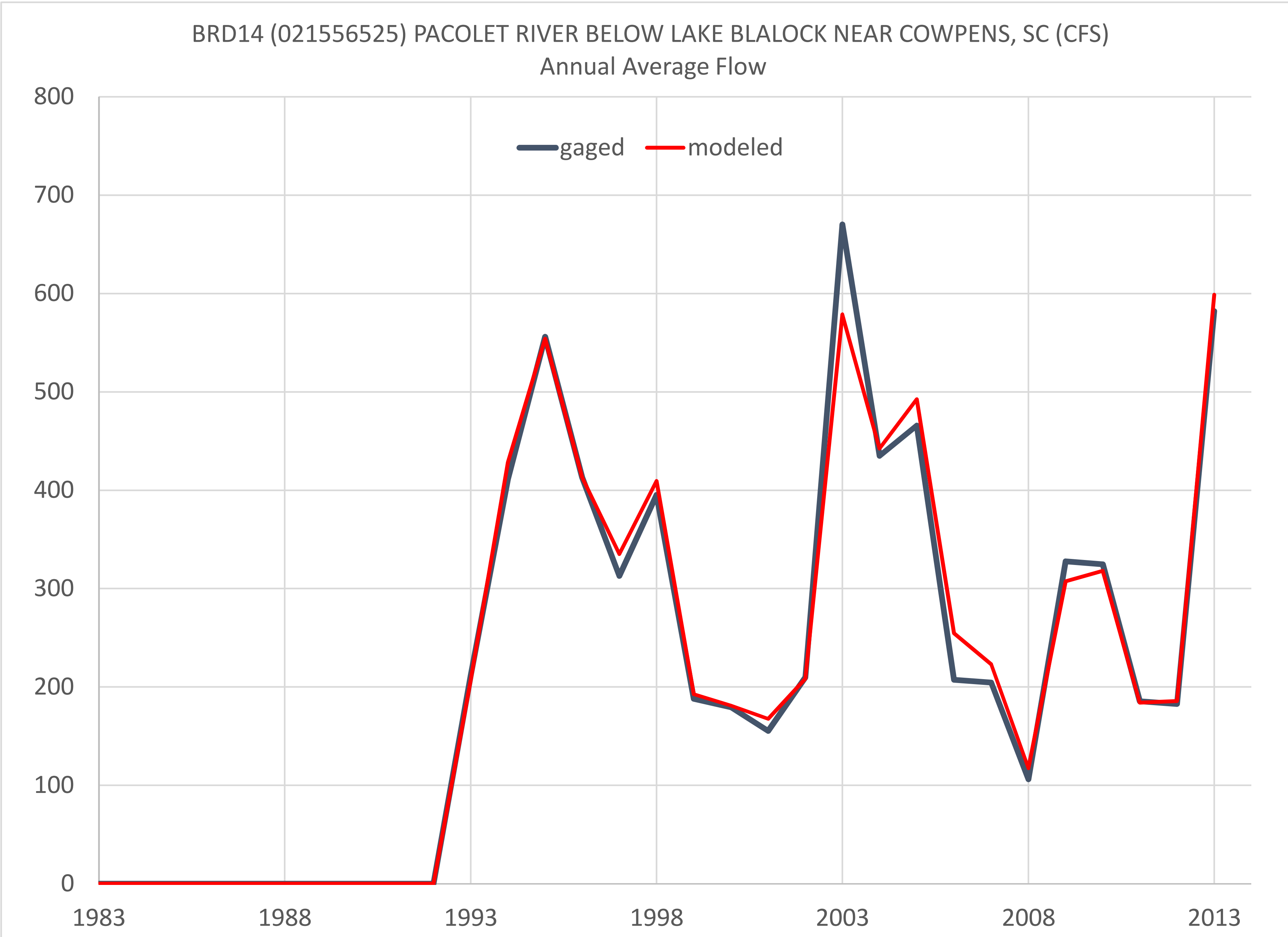


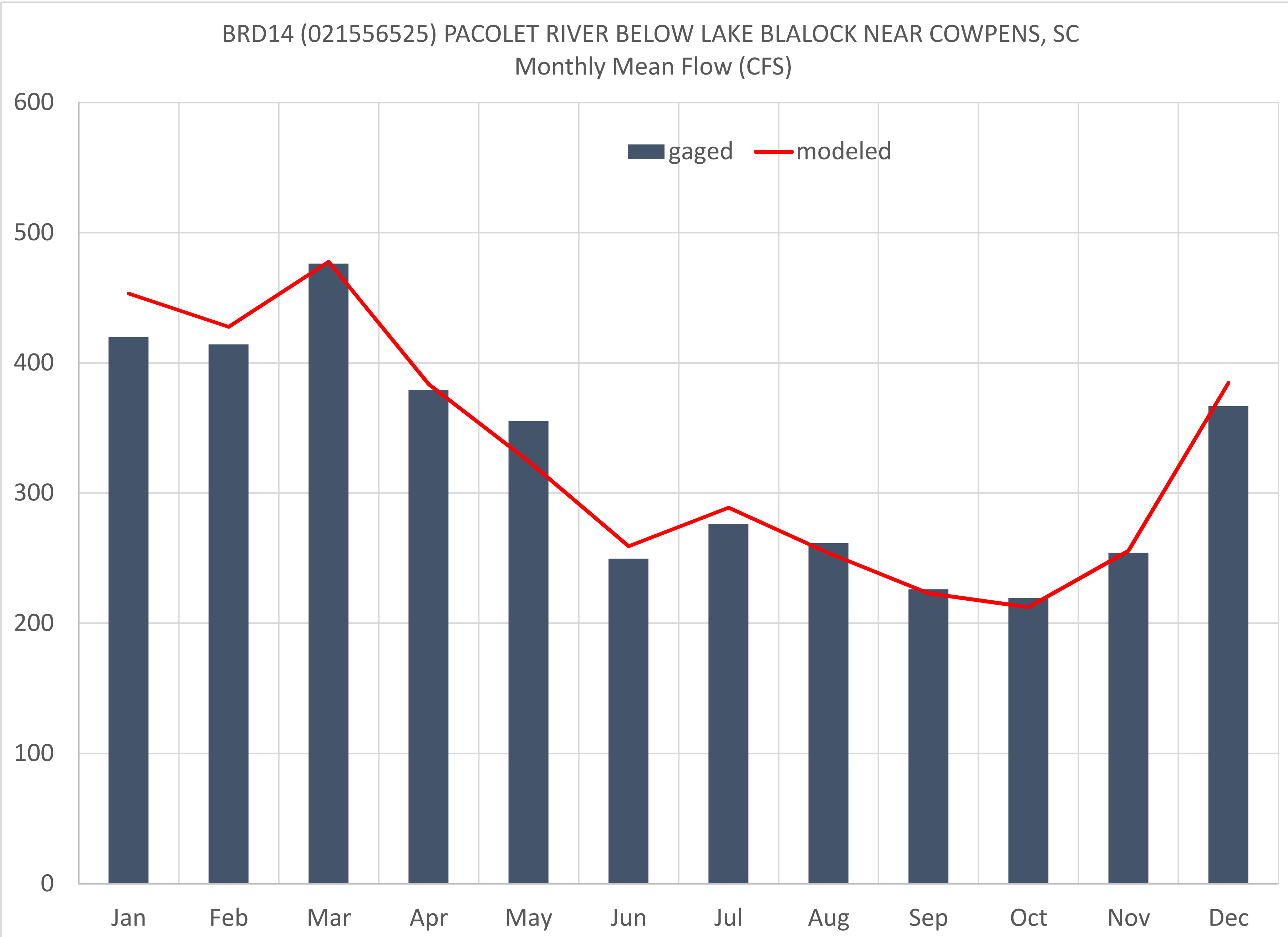
BRD12 (02155500) PACOLET RIVER NEAR FINGERVILLE, SC
Monthly Mean Flow (CFS)
gaged
modeled
0
50
100
150
200
250
300
350
400
450
500
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

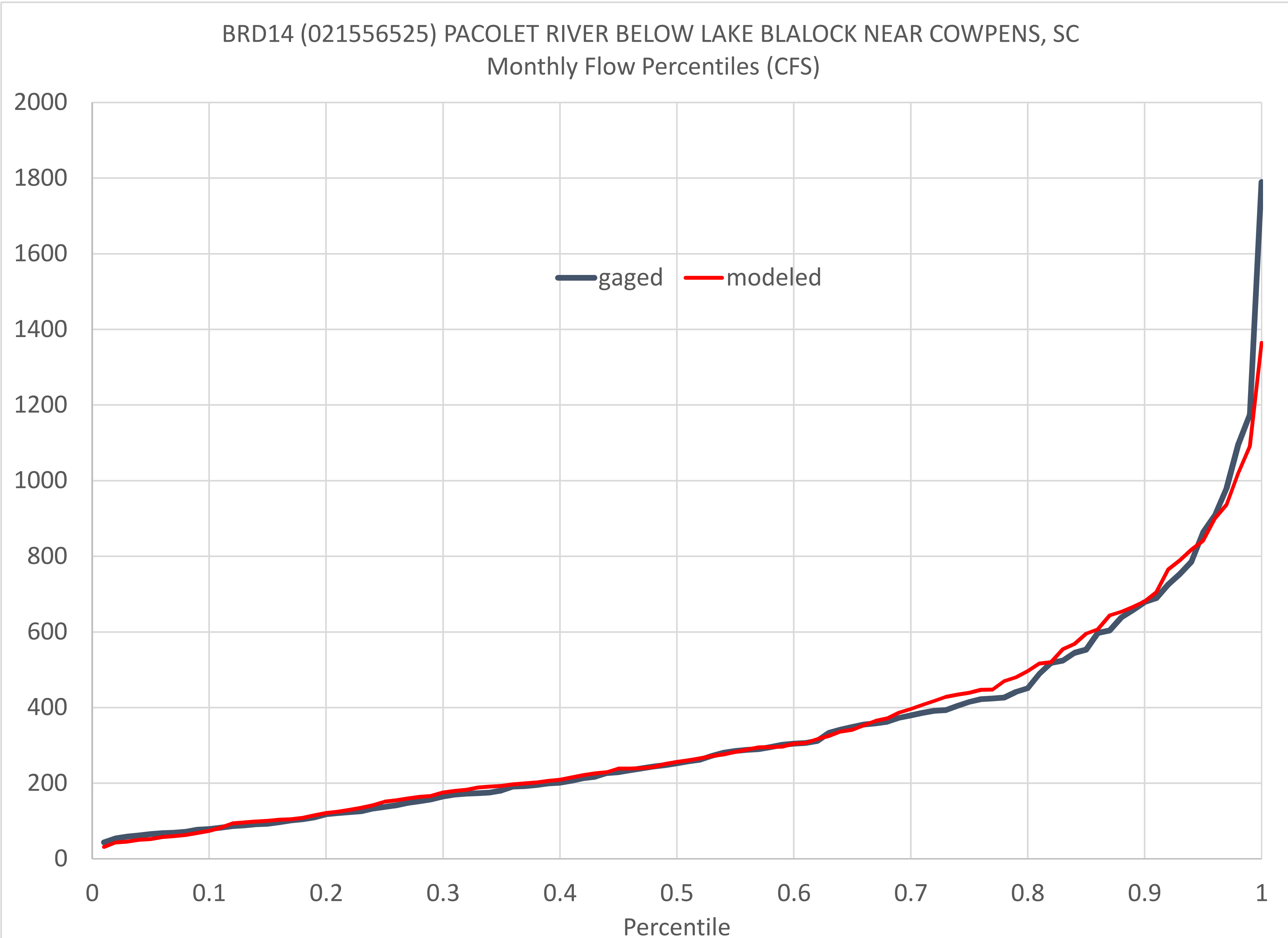

BRD12 (02155500) PACOLET RIVER NEAR FINGERVILLE, SC
Monthly Flow Percentiles (CFS)
gaged
modeled
1400
1200
1000
800
600
400
200
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile


BRD14 (021556525) PACOLET RIVER BELOW LAKE BLALOCK NEAR COWPENS, SC (CFS)
modeled
gaged
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

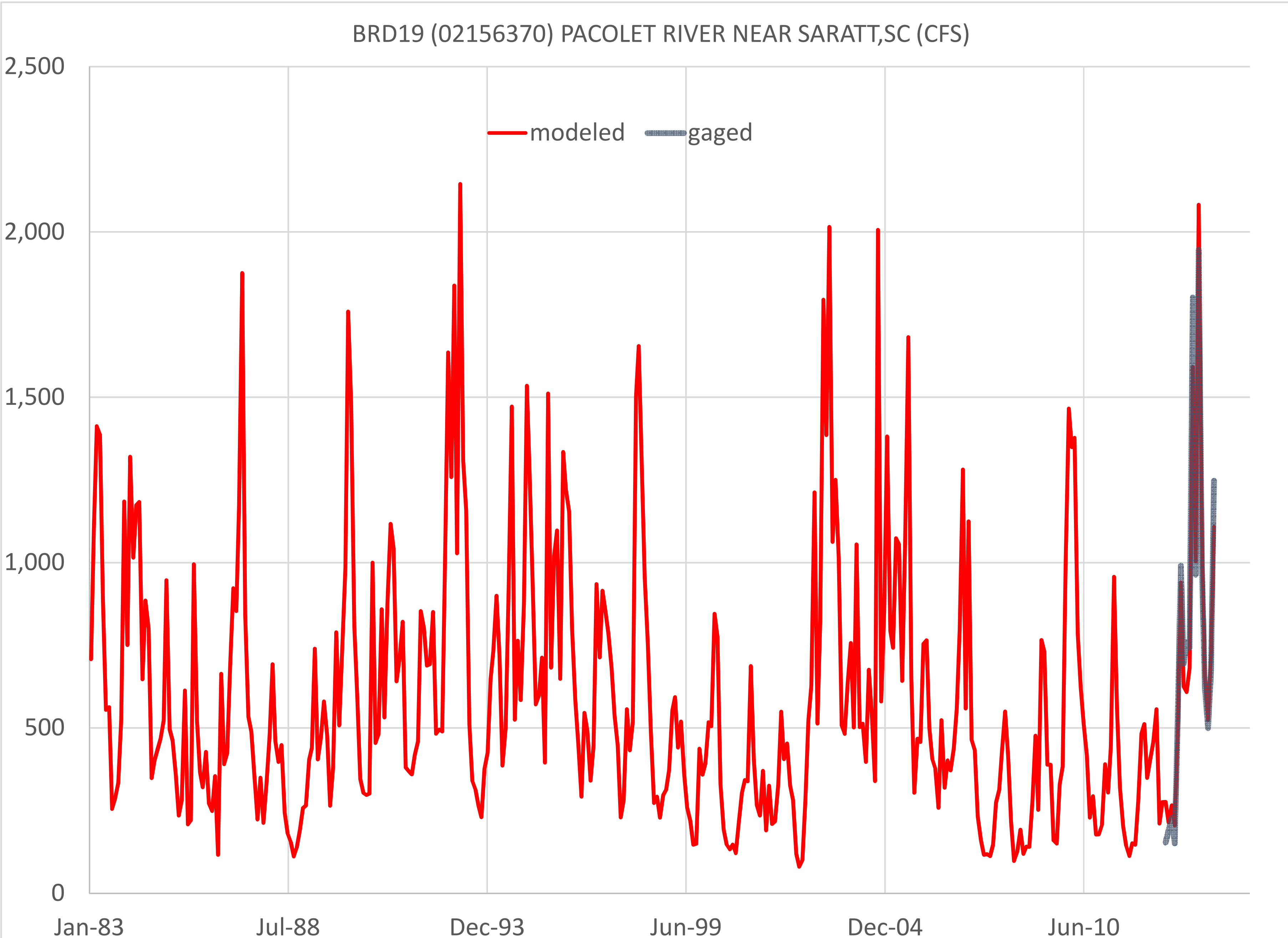

BRD14 (021556525) PACOLET RIVER BELOW LAKE BLALOCK NEAR COWPENS, SC
Cumulative Flow (CFS)
modeled
gaged
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10


BRD14 (021556525) PACOLET RIVER BELOW LAKE BLALOCK NEAR COWPENS, SC (CFS)
Annual Average Flow
gaged
modeled
800
700
600
500
400
300
200
100
0
1983
1988
1993
1998
2003
2008
2013

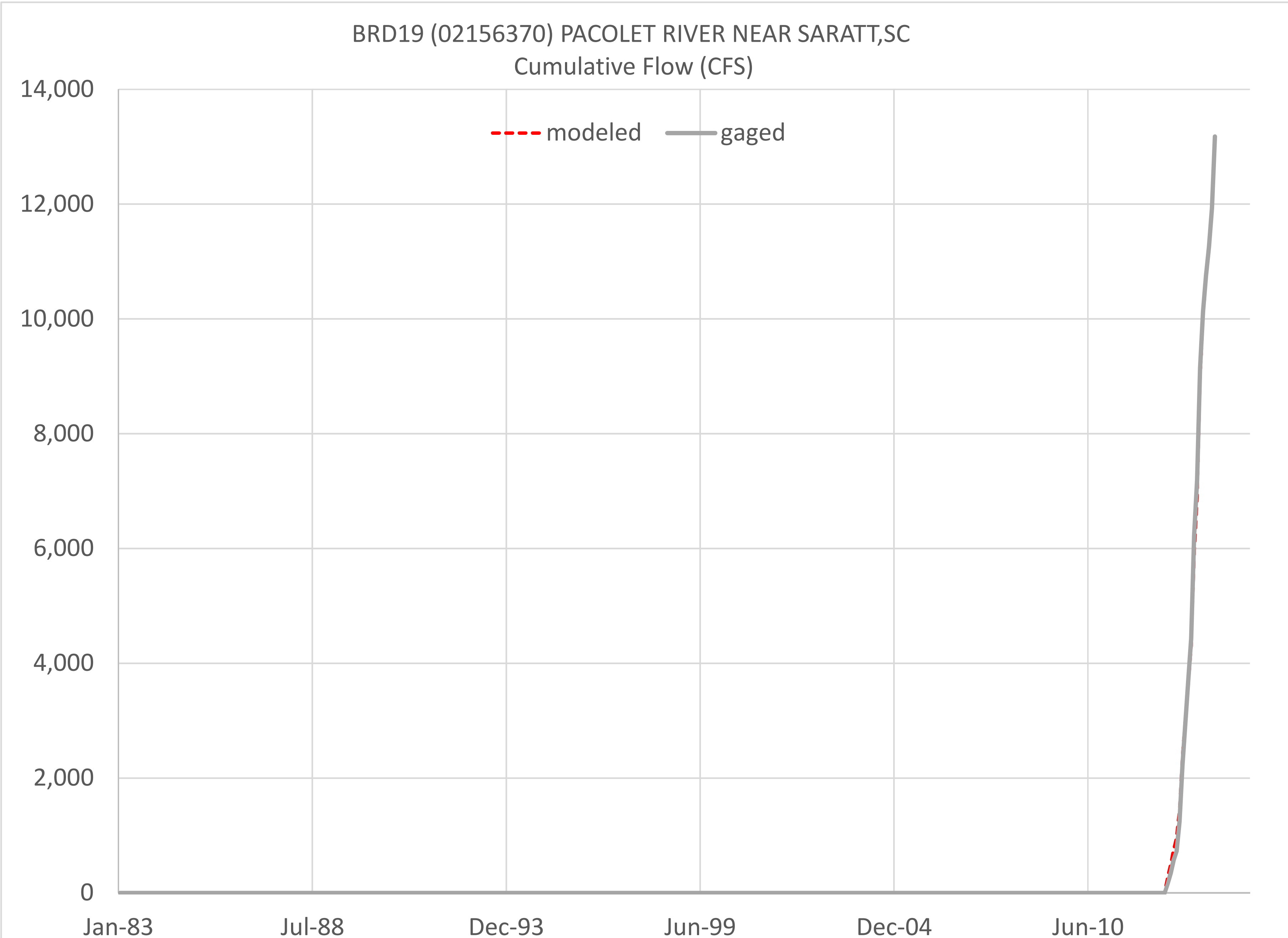

BRD14 (021556525) PACOLET RIVER BELOW LAKE BLALOCK NEAR COWPENS, SC
Monthly Mean Flow (CFS)
gaged
modeled
0
100
200
300
400
500
600
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

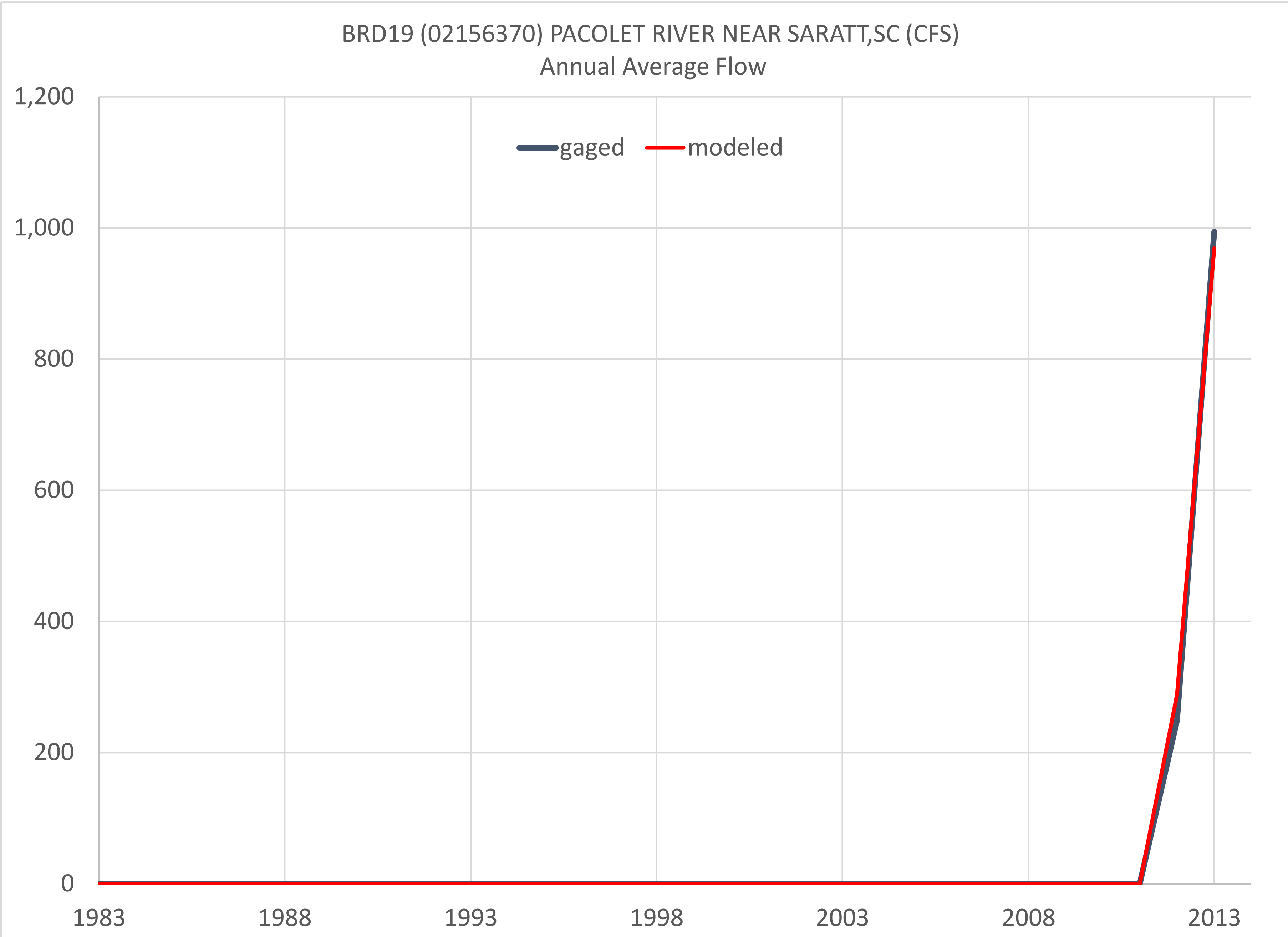


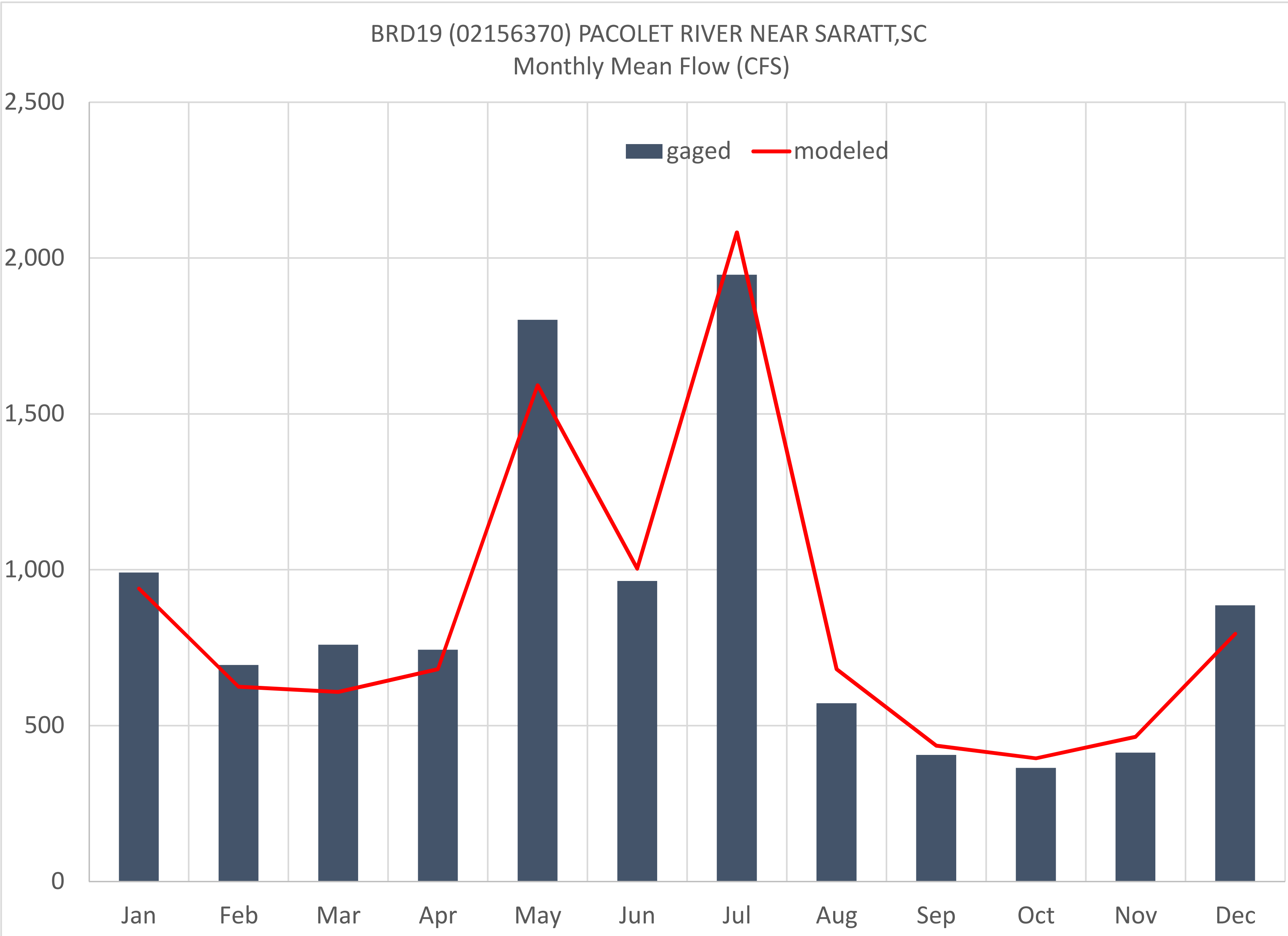
BRD14 (021556525) PACOLET RIVER BELOW LAKE BLALOCK NEAR COWPENS, SC
Monthly Flow Percentiles (CFS)
gaged
modeled
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

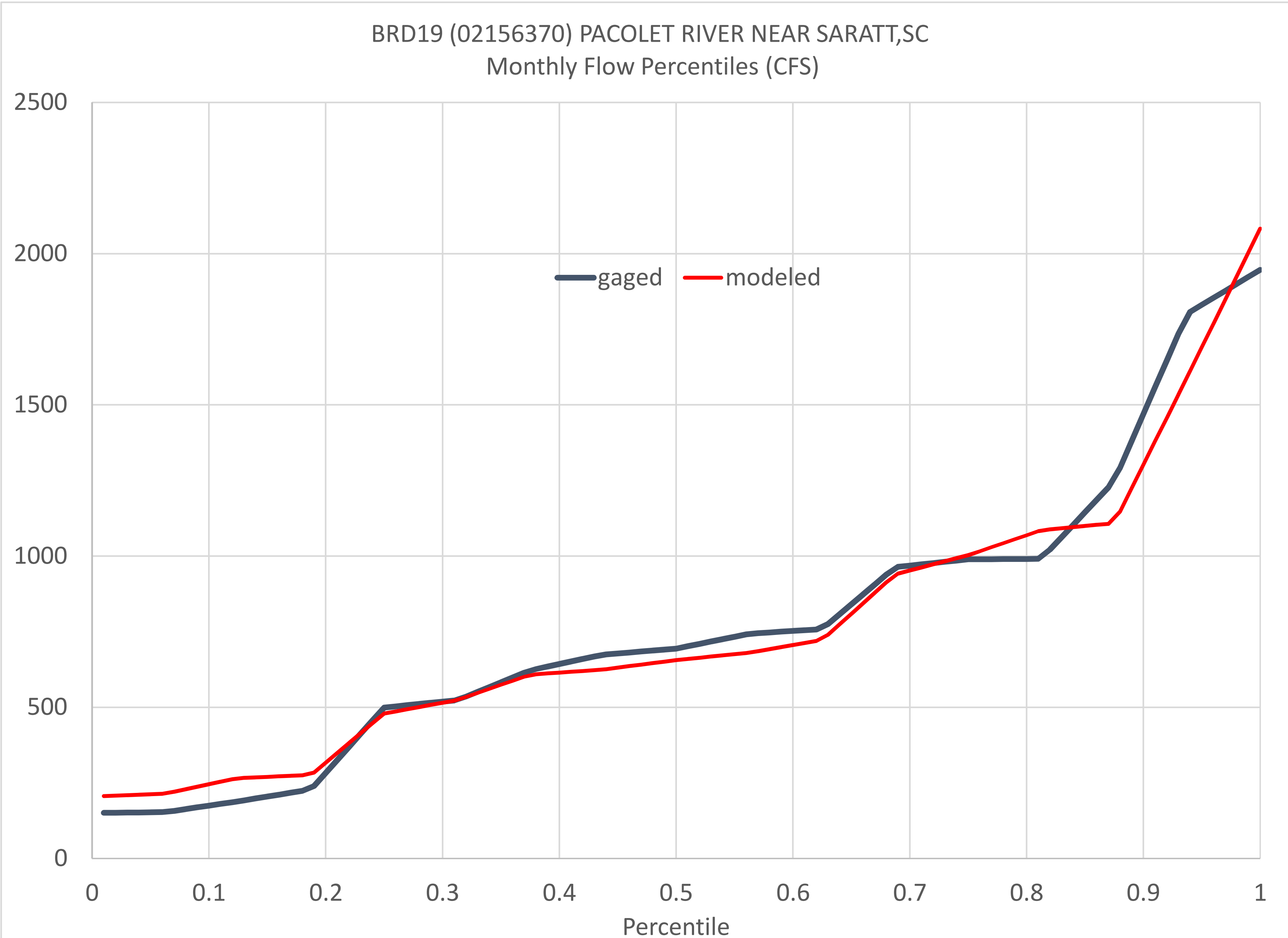


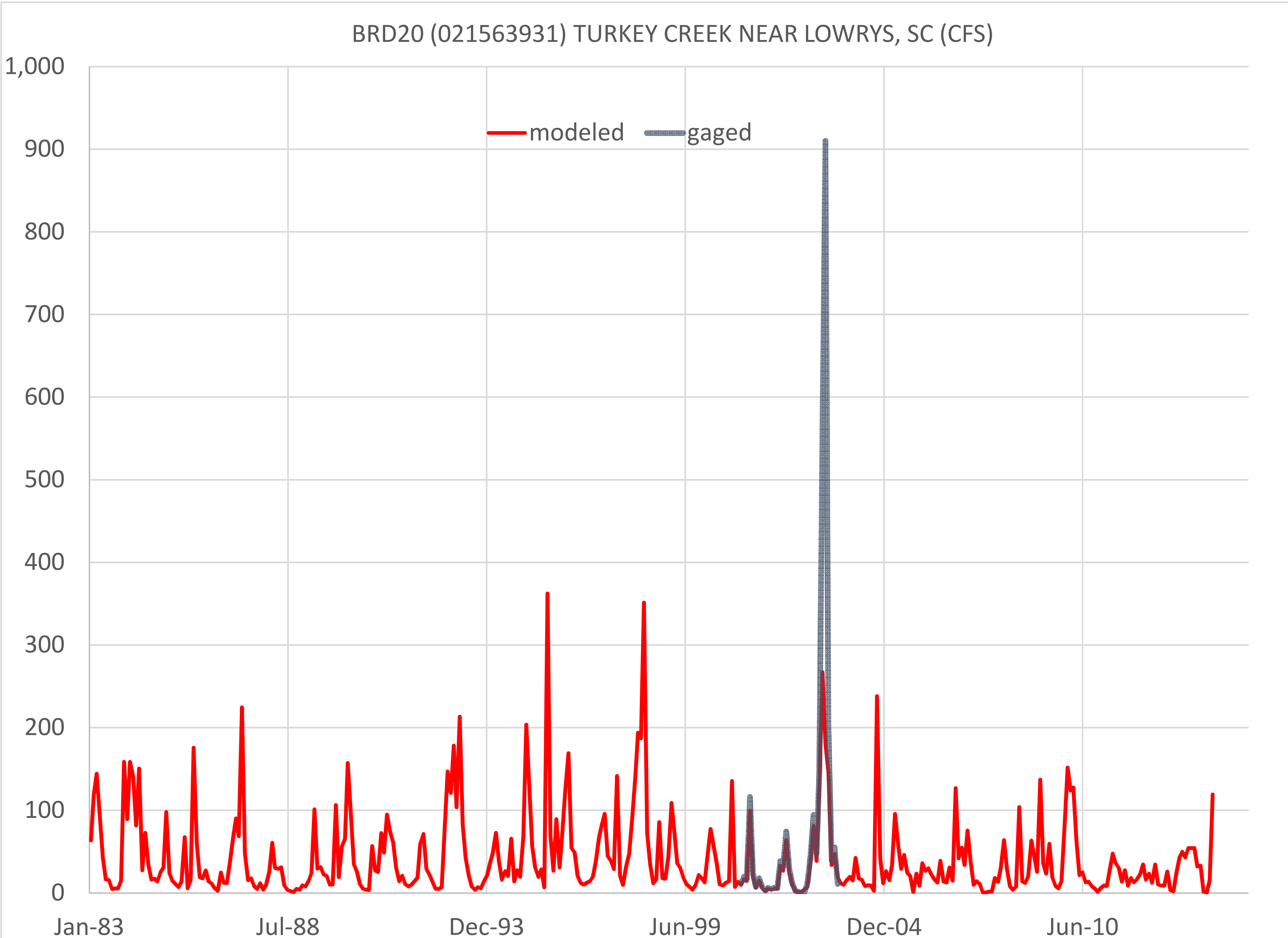
BRD19 (02156370) PACOLET RIVER NEAR SARATT,SC (CFS)
modeled
gaged
2,500
2,000
1,500
1,000
500
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10


BRD19 (02156370) PACOLET RIVER NEAR SARATT,SC
Cumulative Flow (CFS)
modeled
gaged
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

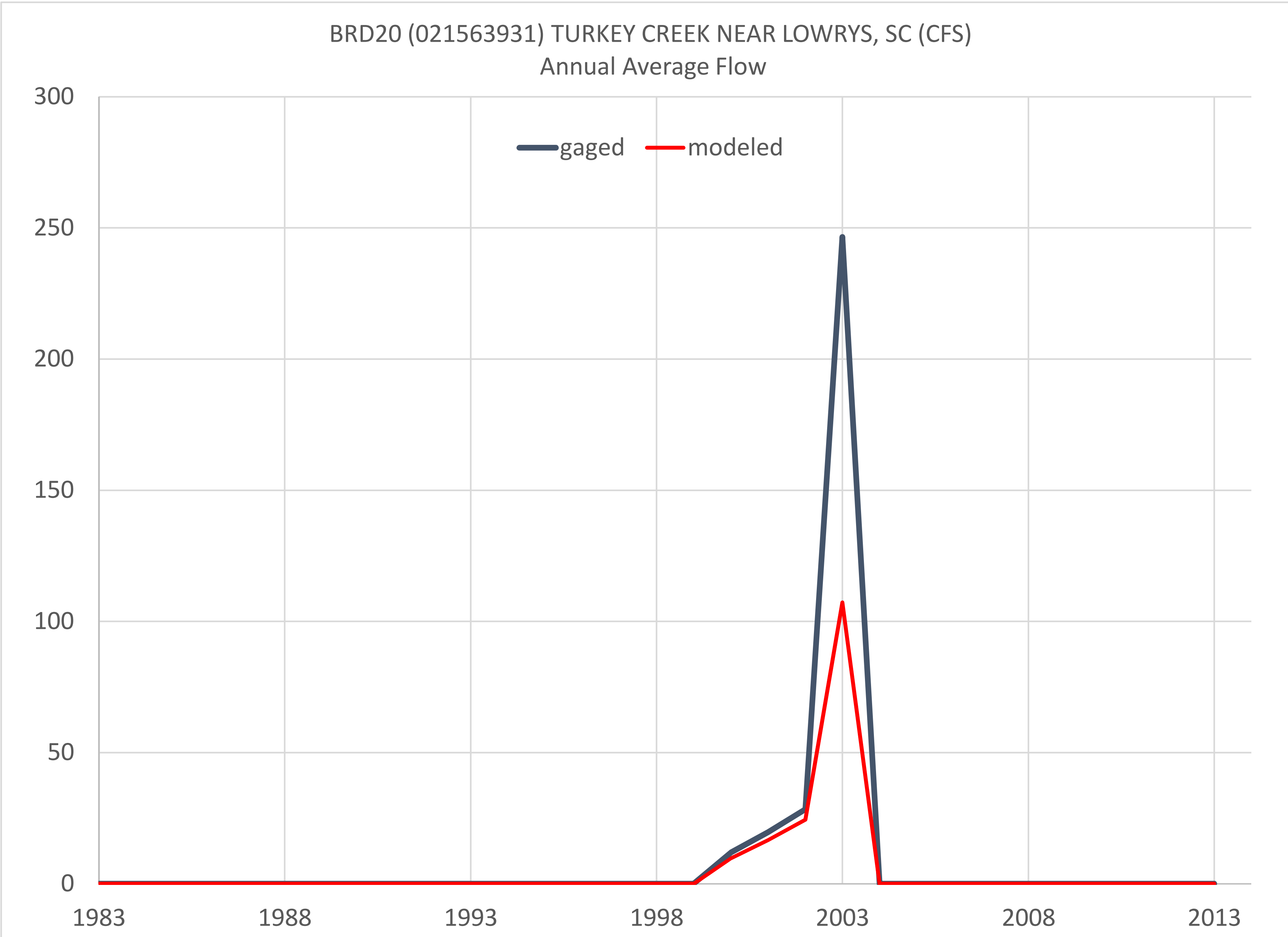

BRD19 (02156370) PACOLET RIVER NEAR SARATT,SC (CFS)
Annual Average Flow
1,200
1,000
800
600
400
200
0
gaged
modeled
1983
1988
1993
1998
2003
2008
2013


BRD19 (02156370) PACOLET RIVER NEAR SARATT,SC
Monthly Mean Flow (CFS)
gaged
modeled
2,500
2,000
1,500
1,000
500
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

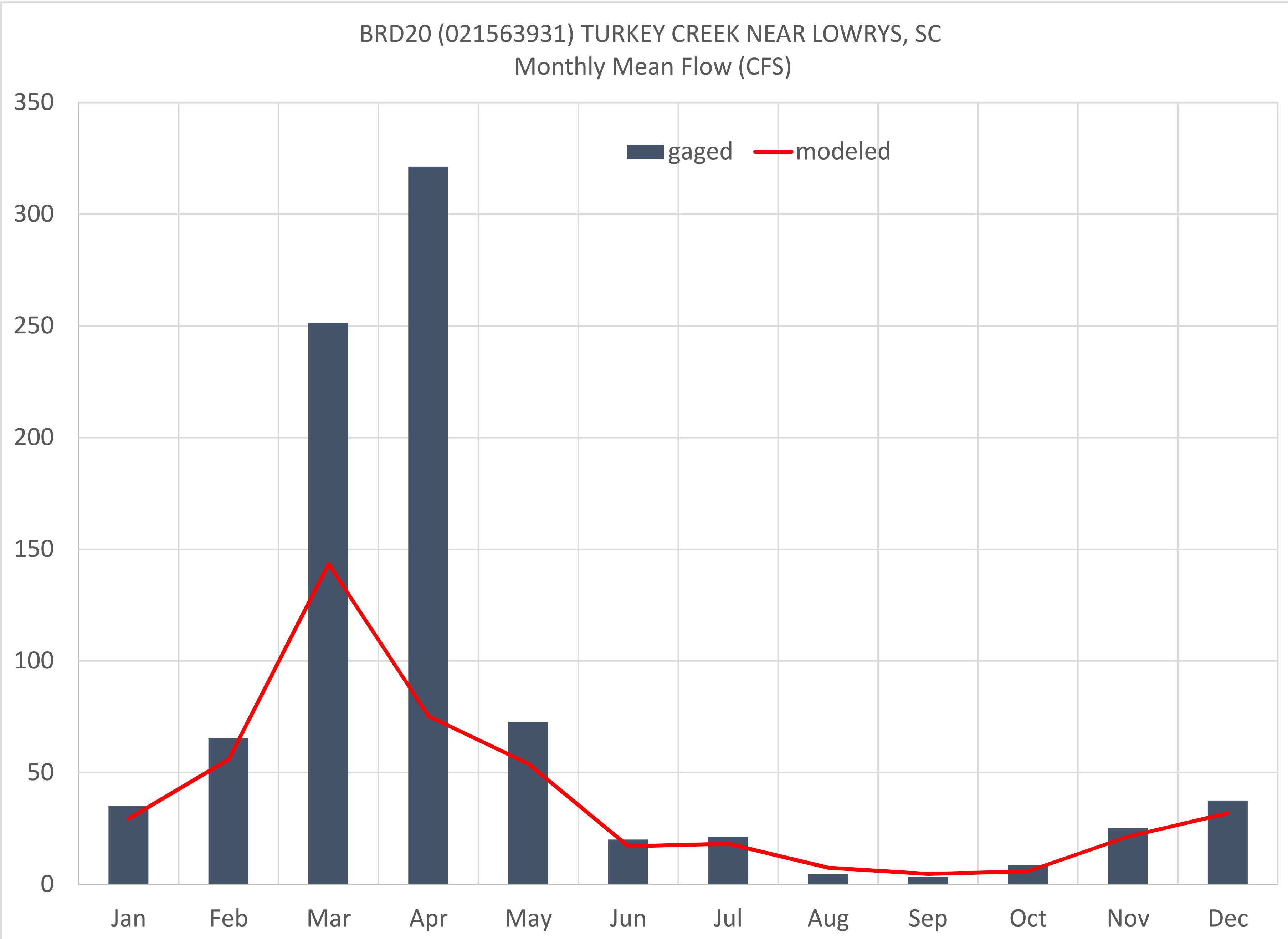

BRD19 (02156370) PACOLET RIVER NEAR SARATT,SC
Monthly Flow Percentiles (CFS)
gaged
modeled
2500
2000
1500
1000
500
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

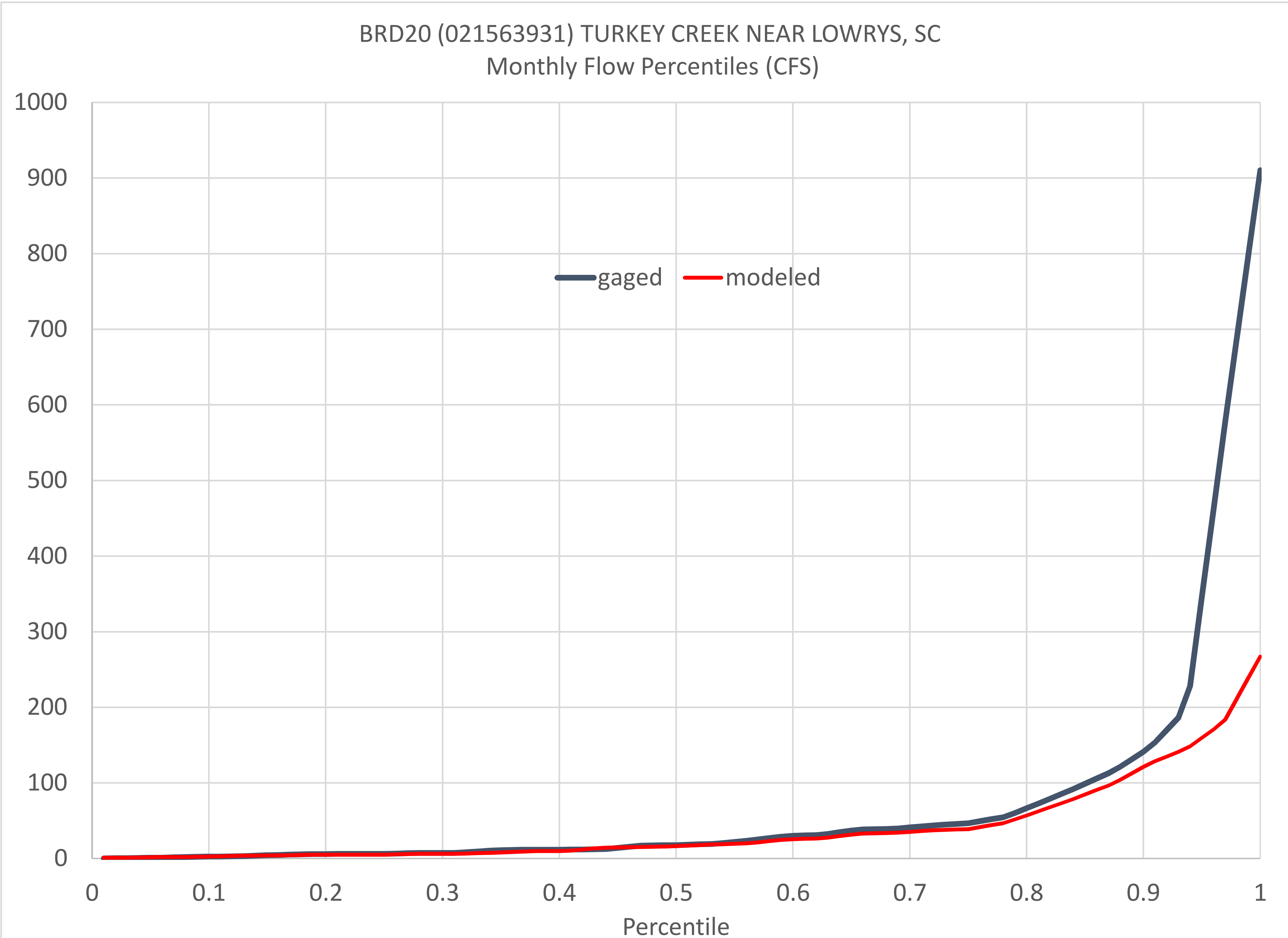


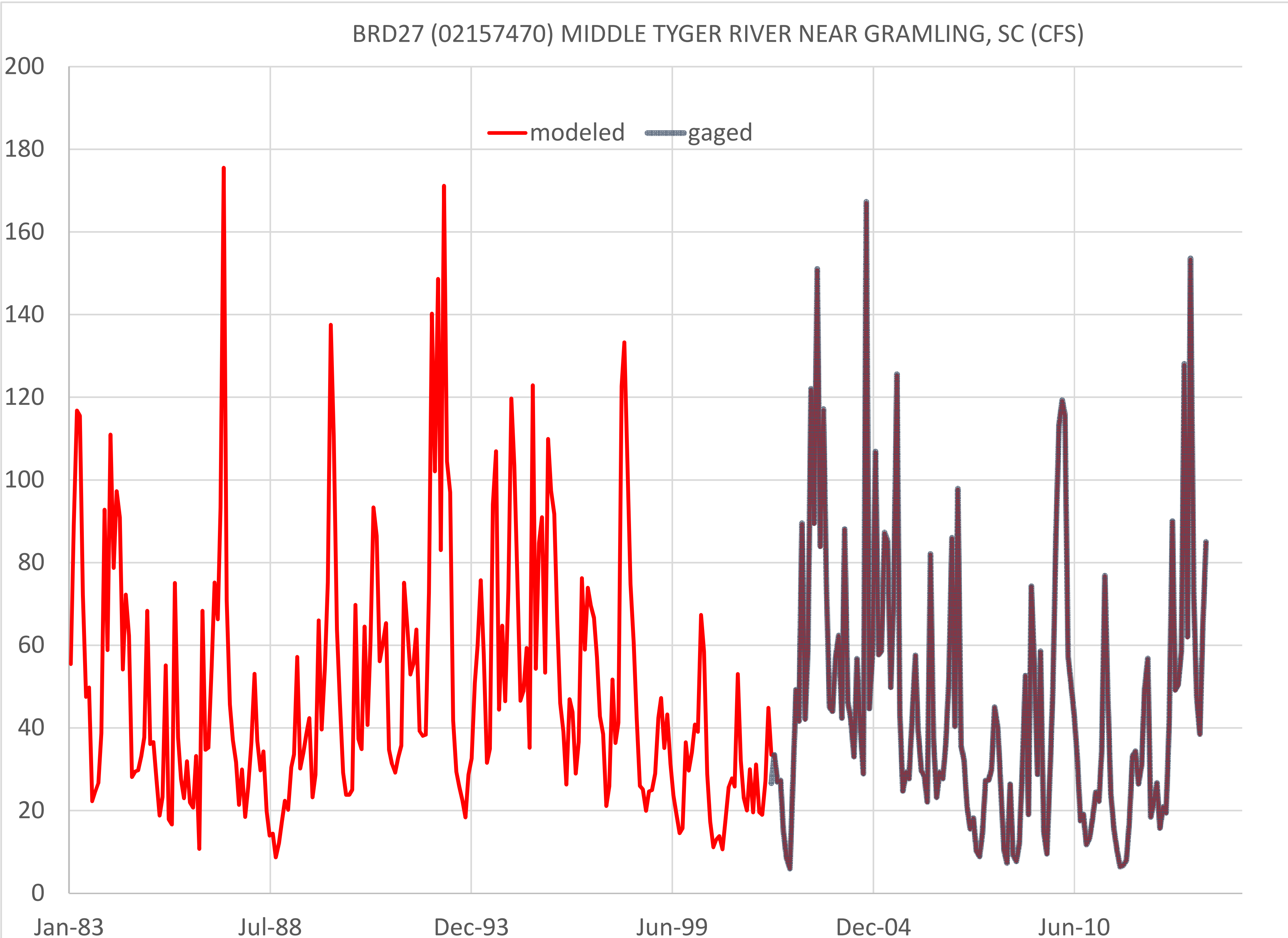
BRD20 (021563931) TURKEY CREEK NEAR LOWRYS, SC (CFS)
modeled
gaged
1,000
900
800
700
600
500
400
300
200
100
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

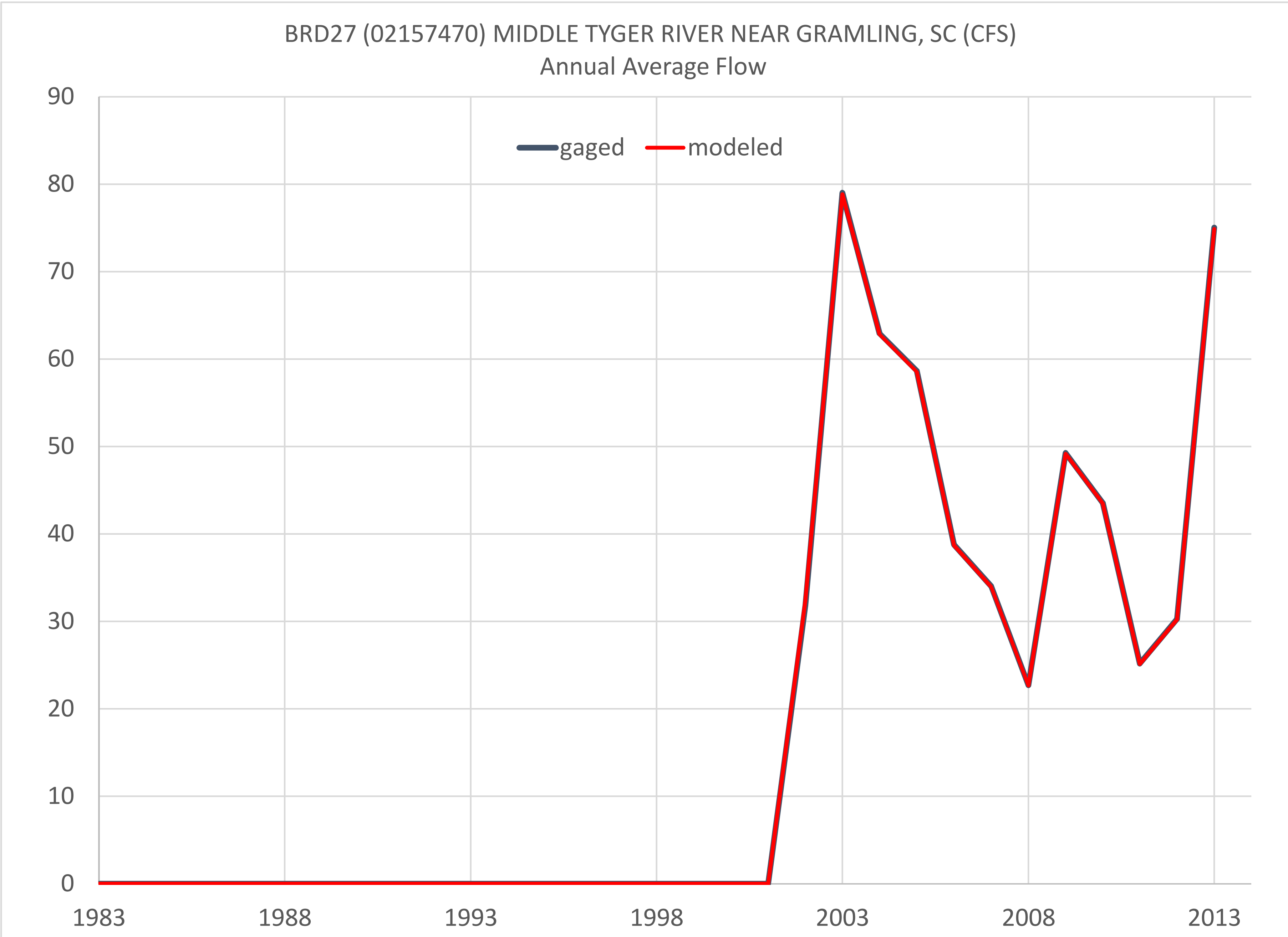


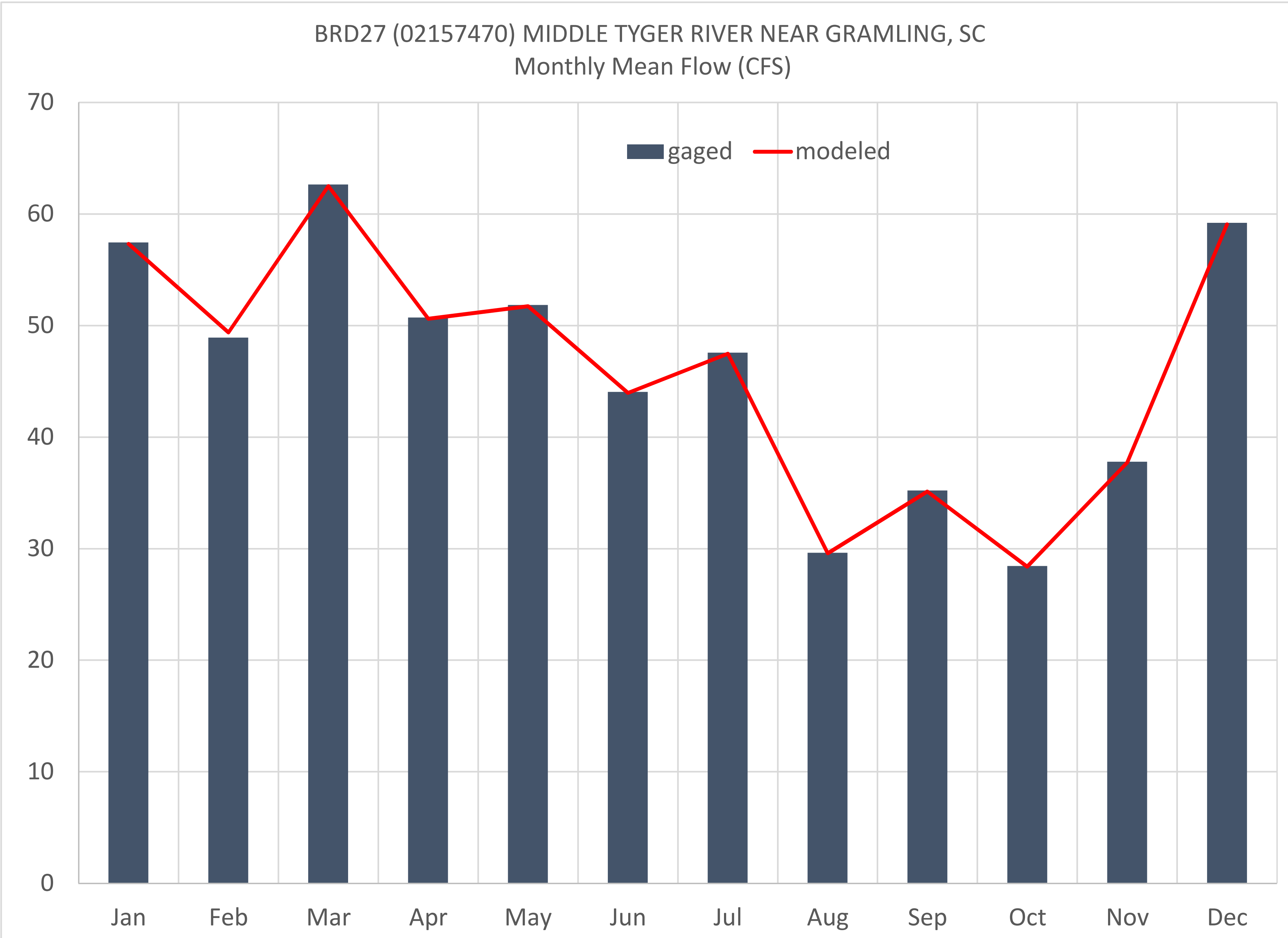
BRD20 (021563931) TURKEY CREEK NEAR LOWRYS, SC (CFS)
Annual Average Flow
gaged
modeled
300
250
200
150
100
50
0
1983
1988
1993
1998
2003
2008
2013

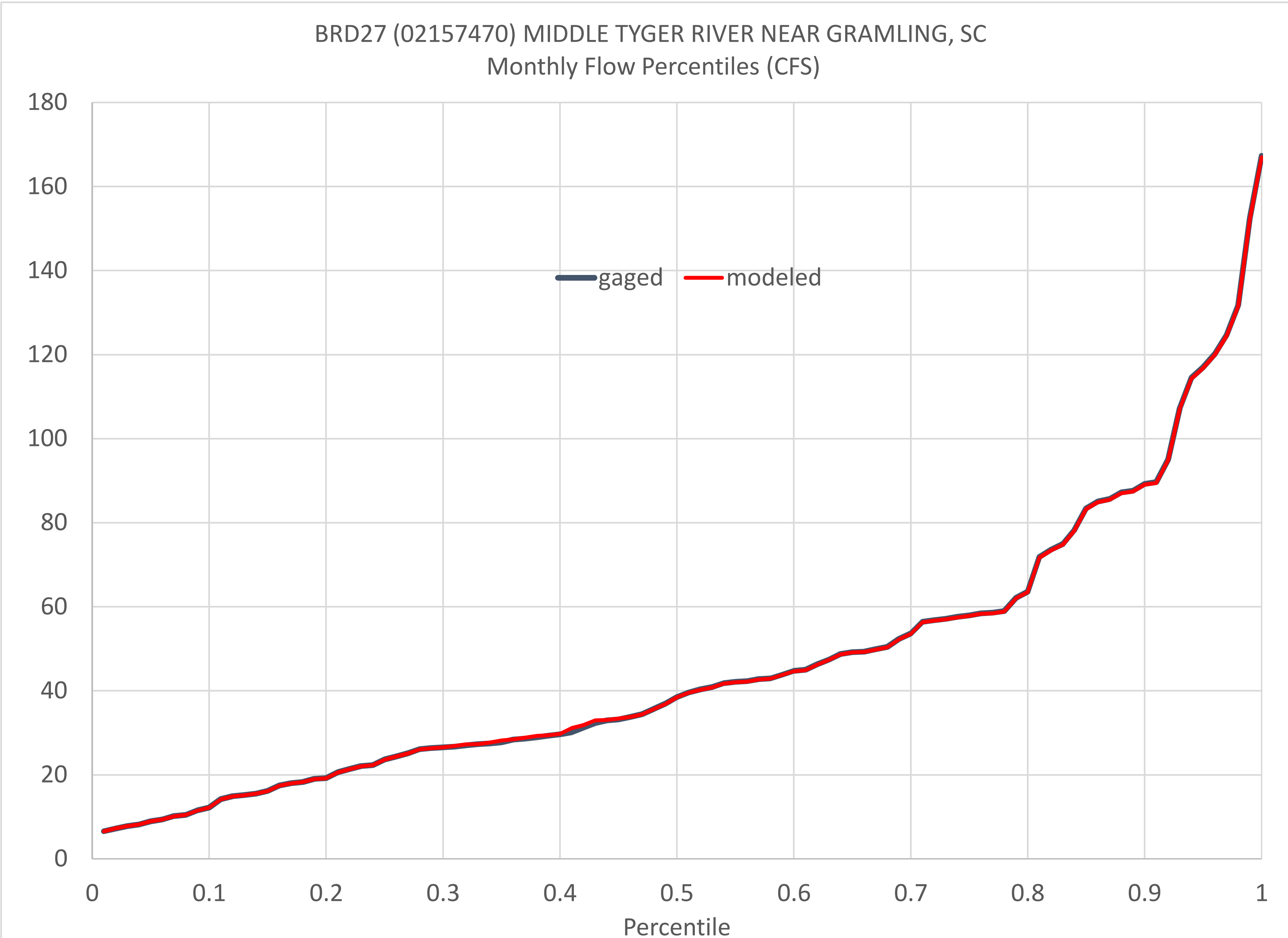

BRD20 (021563931) TURKEY CREEK NEAR LOWRYS, SC
Monthly Mean Flow (CFS)
350
300
250
200
150
100
50
0
gaged
modeled
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

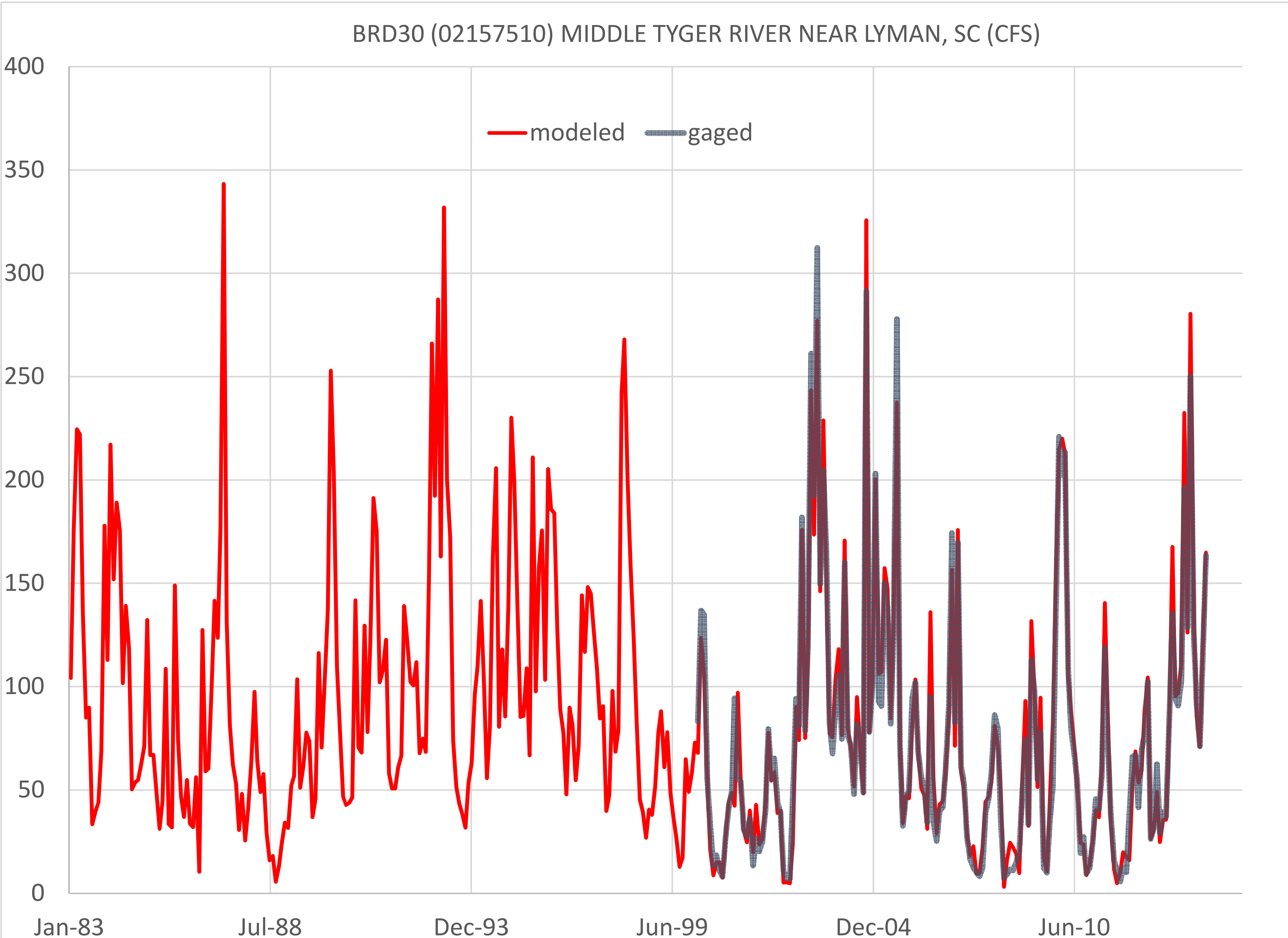

BRD20 (021563931) TURKEY CREEK NEAR LOWRYS, SC
Monthly Flow Percentiles (CFS)
1000
900
800
700
600
500
400
300
200
100
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile
gaged
modeled

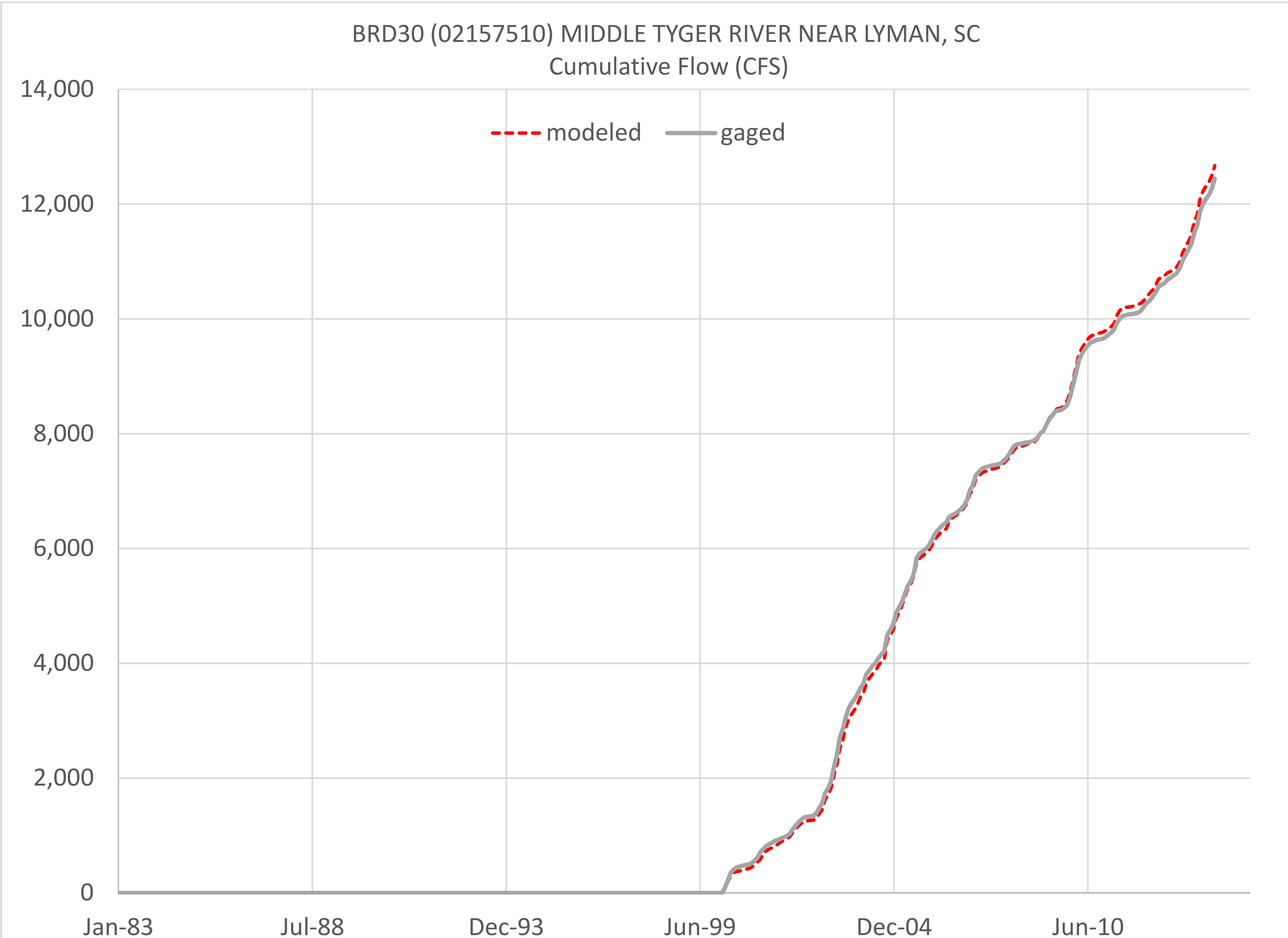

BRD27 (02157470) MIDDLE TYGER RIVER NEAR GRAMLING, SC (CFS)
modeled
gaged
200
180
160
140
120
100
80
60
40
20
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10


BRD27 (02157470) MIDDLE TYGER RIVER NEAR GRAMLING, SC (CFS)
Annual Average Flow
gaged
modeled
0
10
20
30
40
50
60
70
80
90
1983
1988
1993
1998
2003
2008
2013

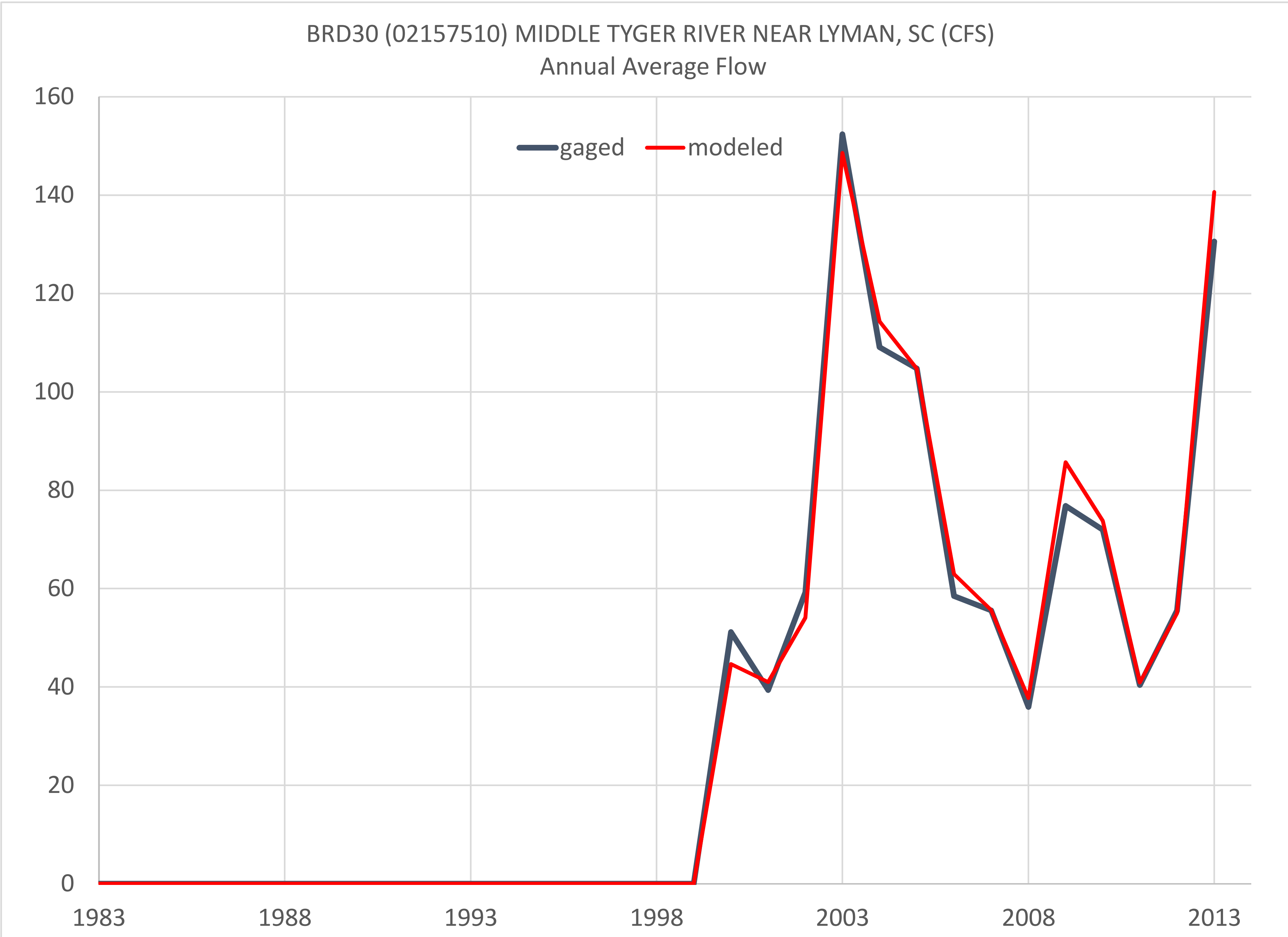

BRD27 (02157470) MIDDLE TYGER RIVER NEAR GRAMLING, SC
Monthly Mean Flow (CFS)
gaged
modeled
0
10
20
30
40
50
60
70
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

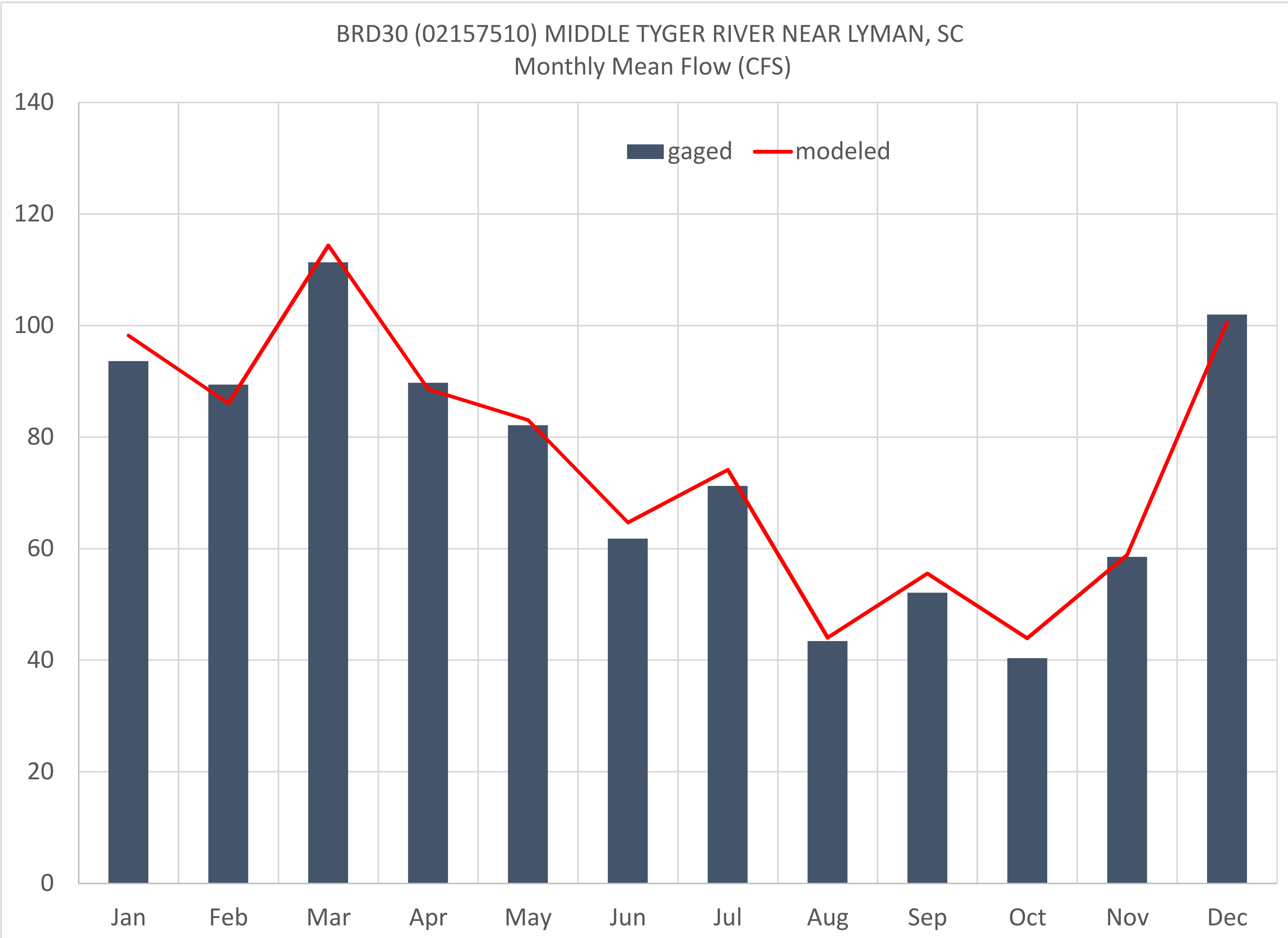

BRD27 (02157470) MIDDLE TYGER RIVER NEAR GRAMLING, SC
Monthly Flow Percentiles (CFS)
gaged
modeled
180
160
140
120
100
80
60
40
20
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

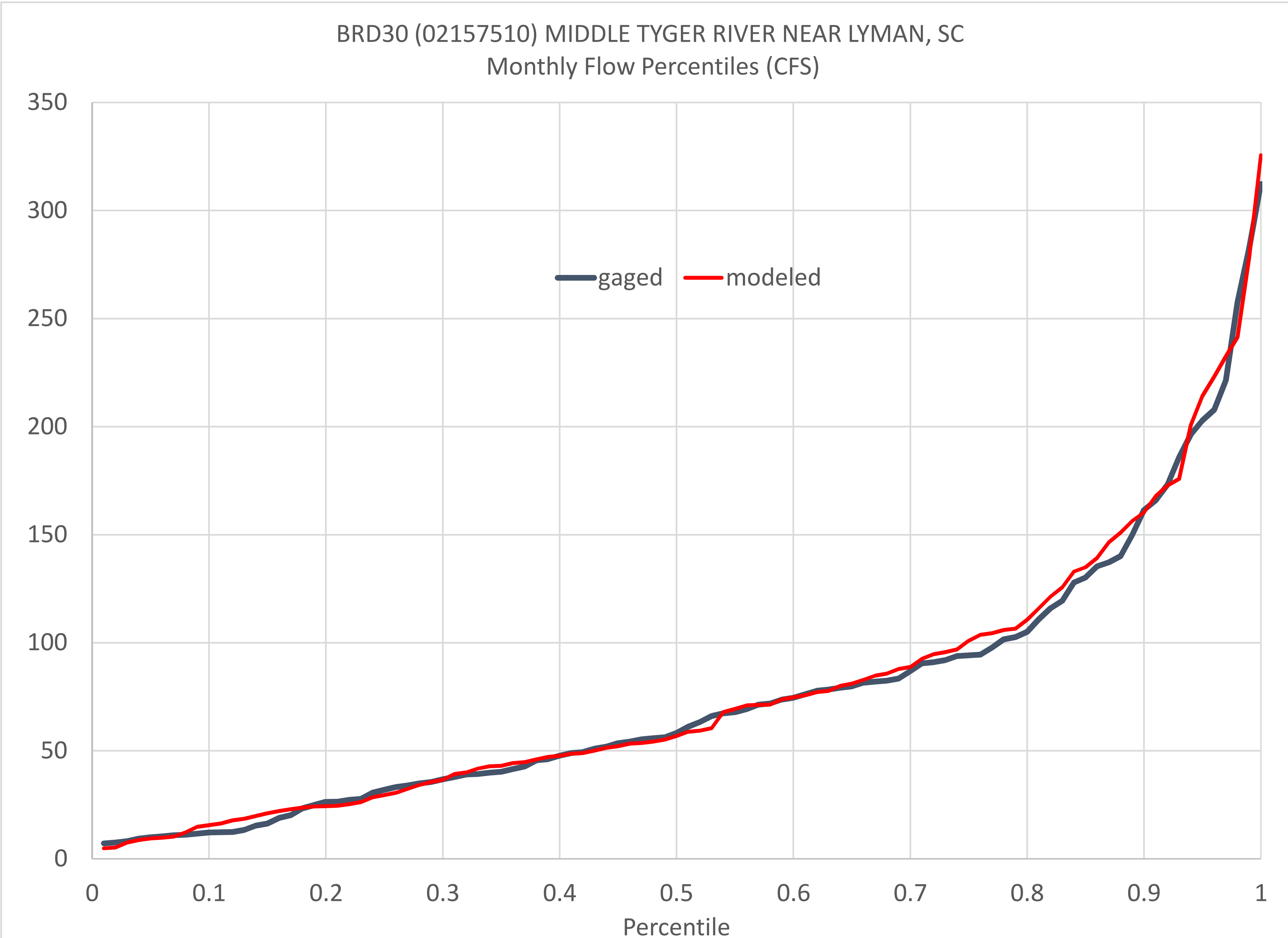

BRD30 (02157510) MIDDLE TYGER RIVER NEAR LYMAN, SC (CFS)
modeled
gaged
400
350
300
250
200
150
100
50
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10



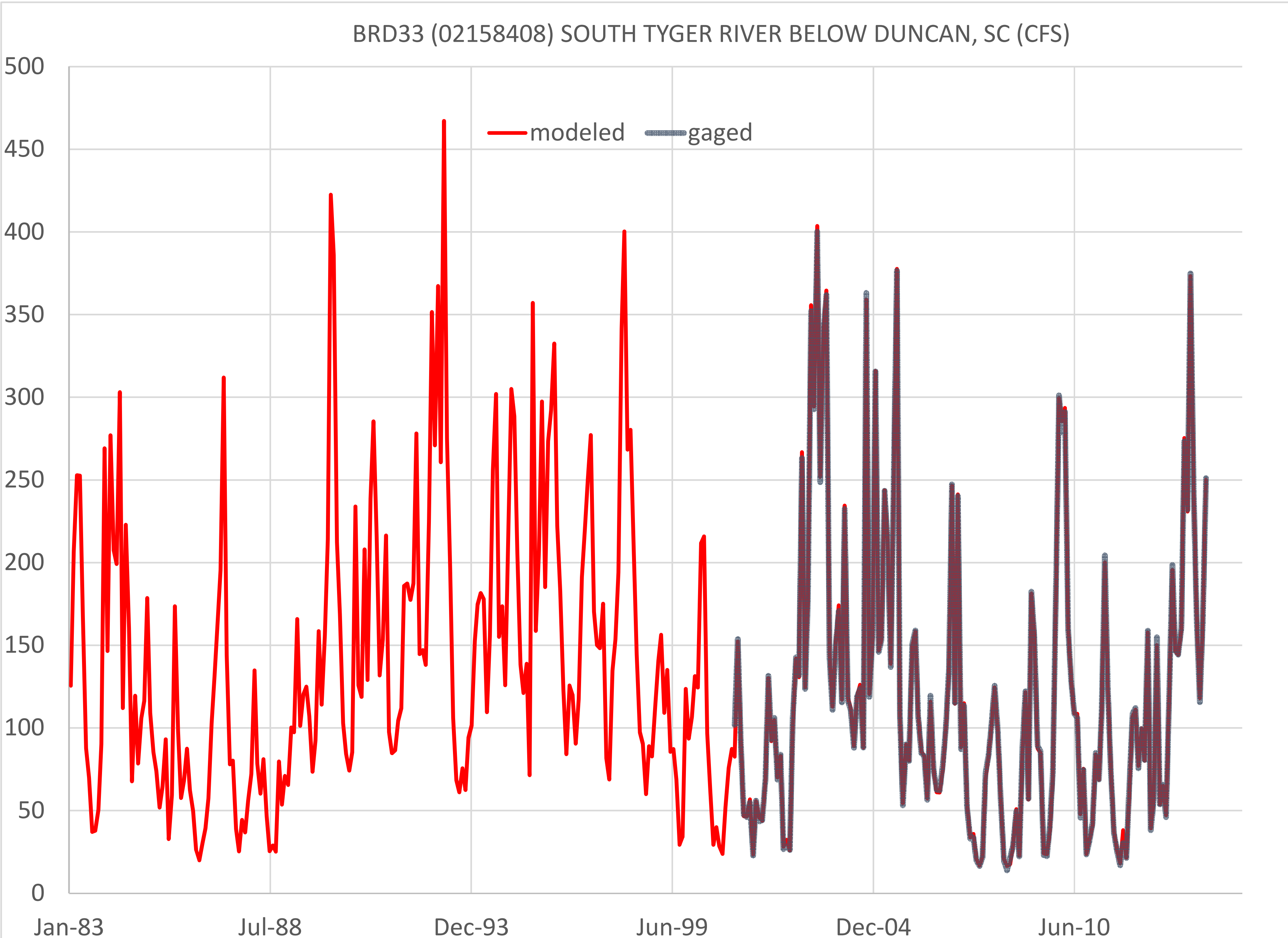
BRD30 (02157510) MIDDLE TYGER RIVER NEAR LYMAN, SC
Cumulative Flow (CFS)
modeled
gaged
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

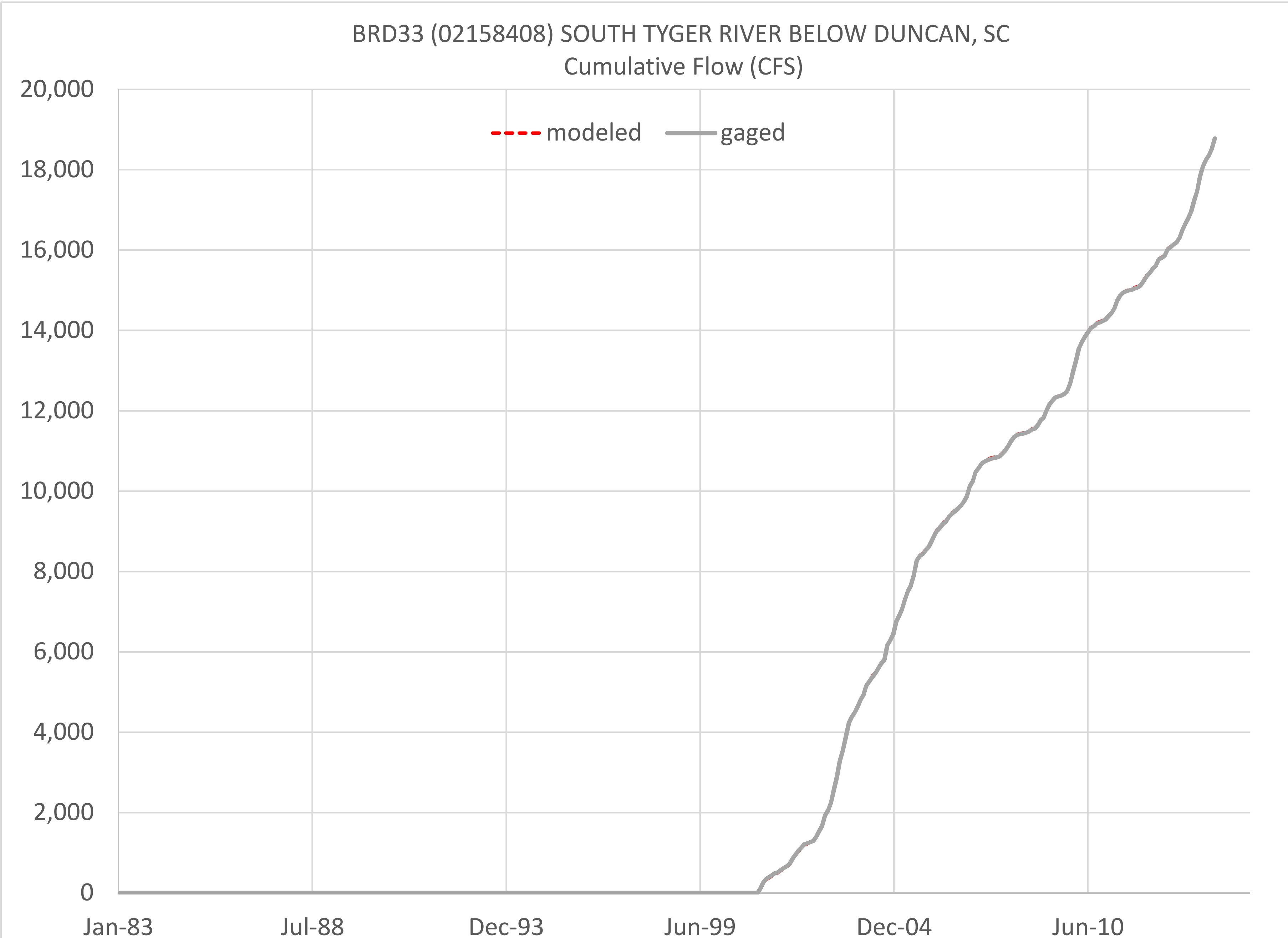

BRD30 (02157510) MIDDLE TYGER RIVER NEAR LYMAN, SC (CFS)
Annual Average Flow
gaged
modeled
160
140
120
100
80
60
40
20
0
1983
1988
1993
1998
2003
2008
2013


BRD30 (02157510) MIDDLE TYGER RIVER NEAR LYMAN, SC
Monthly Mean Flow (CFS)
gaged
modeled
140
120
100
80
60
40
20
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

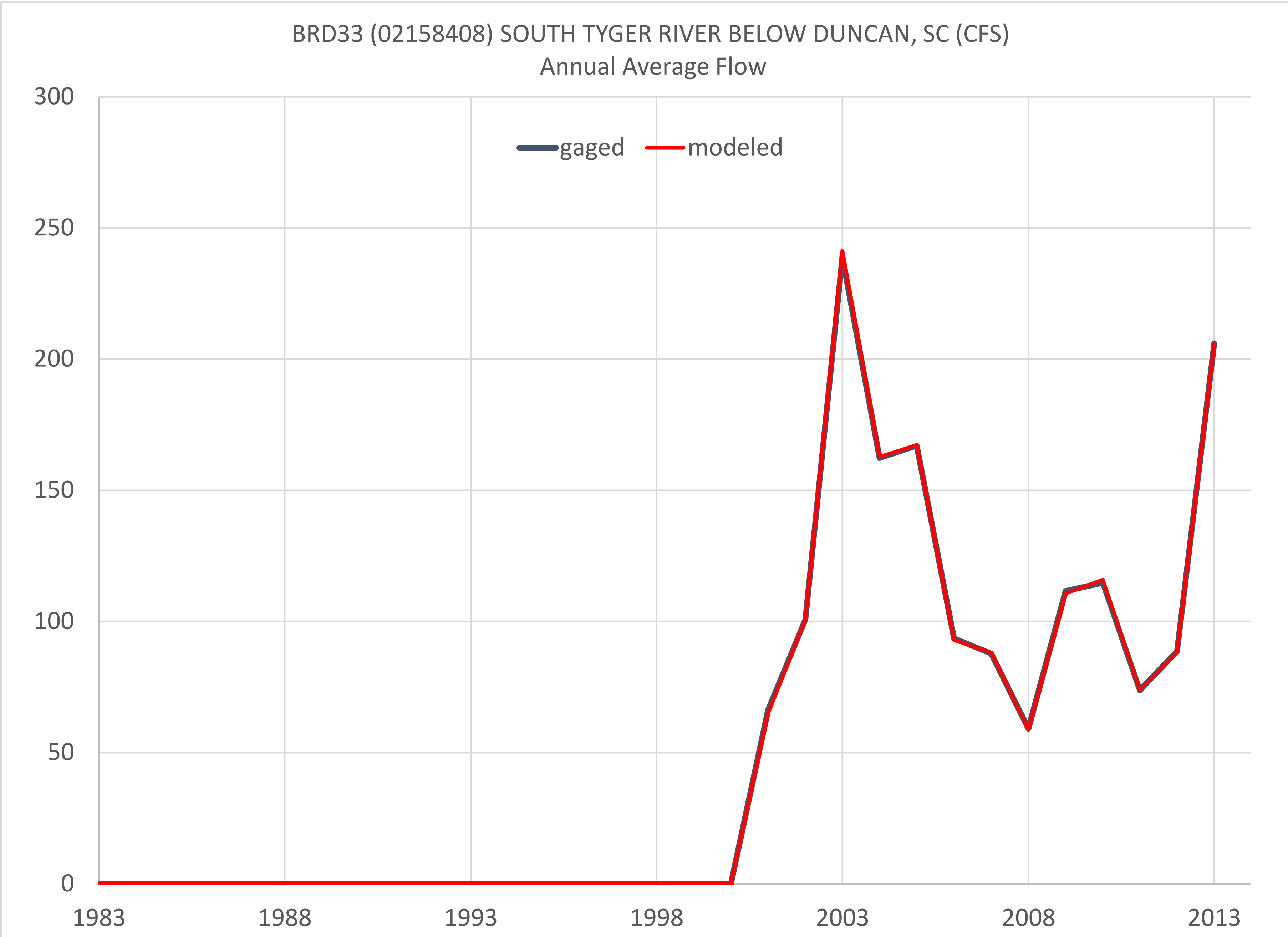


BRD30 (02157510) MIDDLE TYGER RIVER NEAR LYMAN, SC
Monthly Flow Percentiles (CFS)
gaged
modeled
350
300
250
200
150
100
50
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

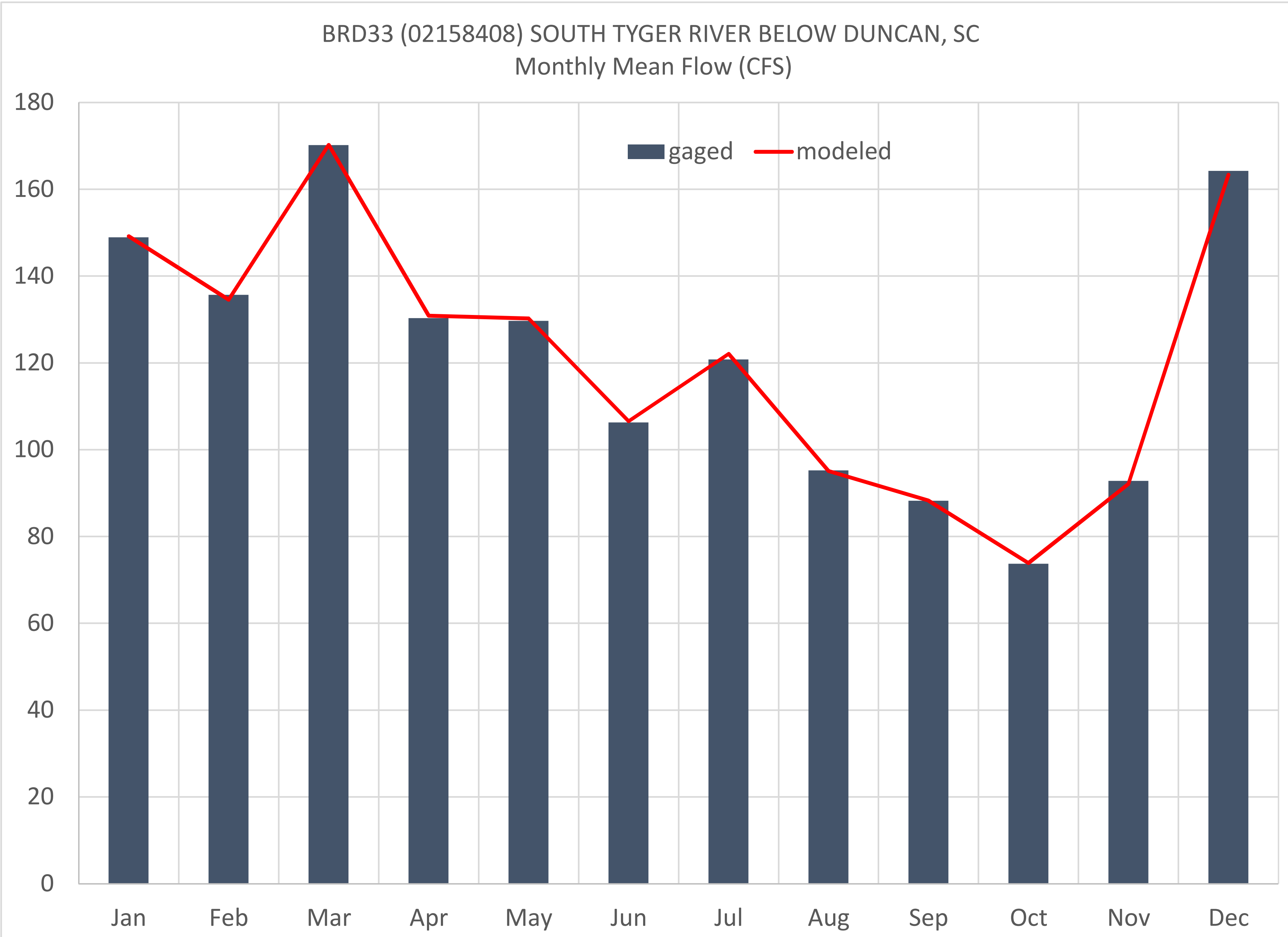

BRD33 (02158408) SOUTH TYGER RIVER BELOW DUNCAN, SC (CFS)
modeled
gaged
500
450
400
350
300
250
200
150
100
50
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

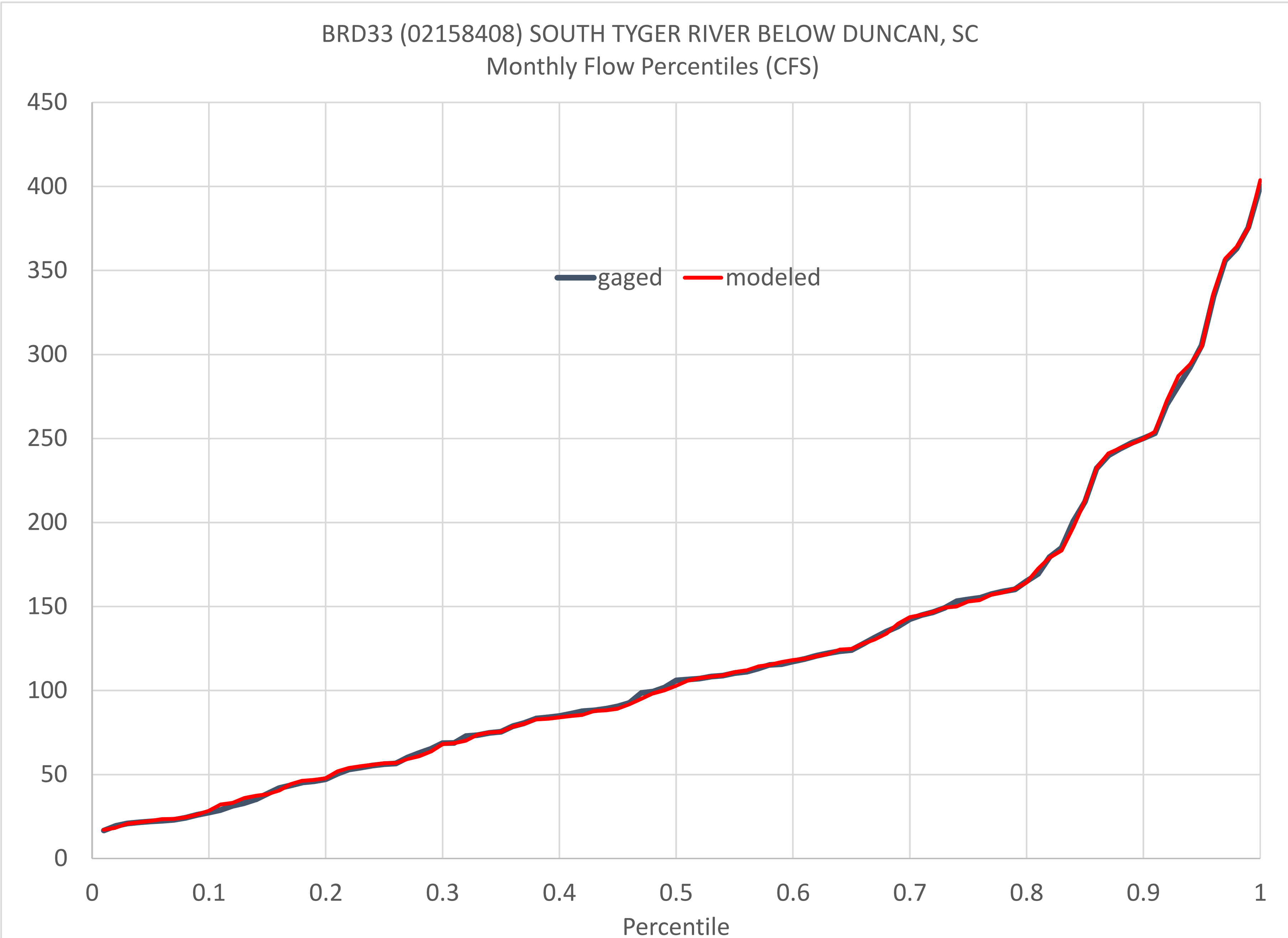


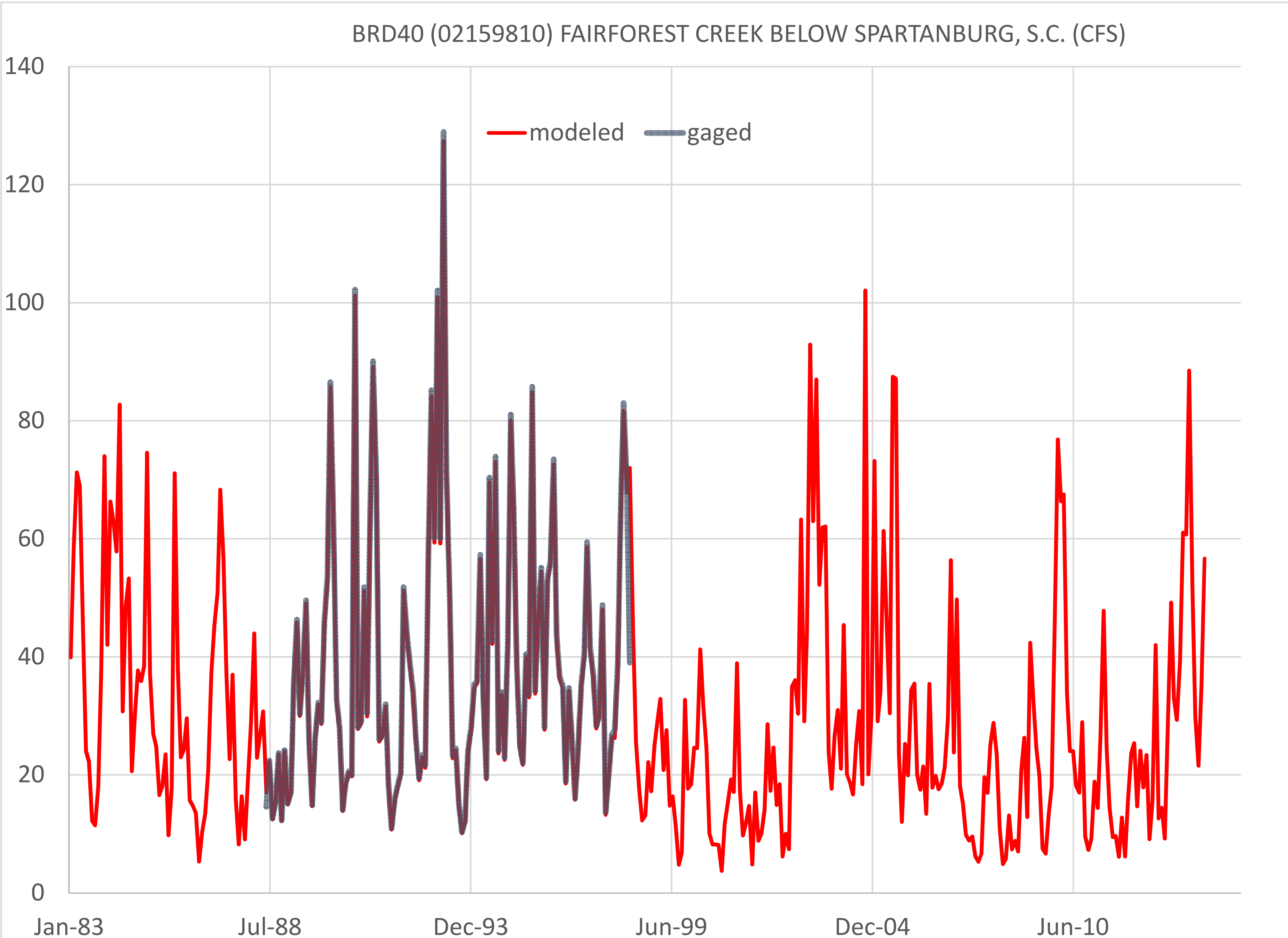
BRD33 (02158408) SOUTH TYGER RIVER BELOW DUNCAN, SC
Cumulative Flow (CFS)
modeled
gaged
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

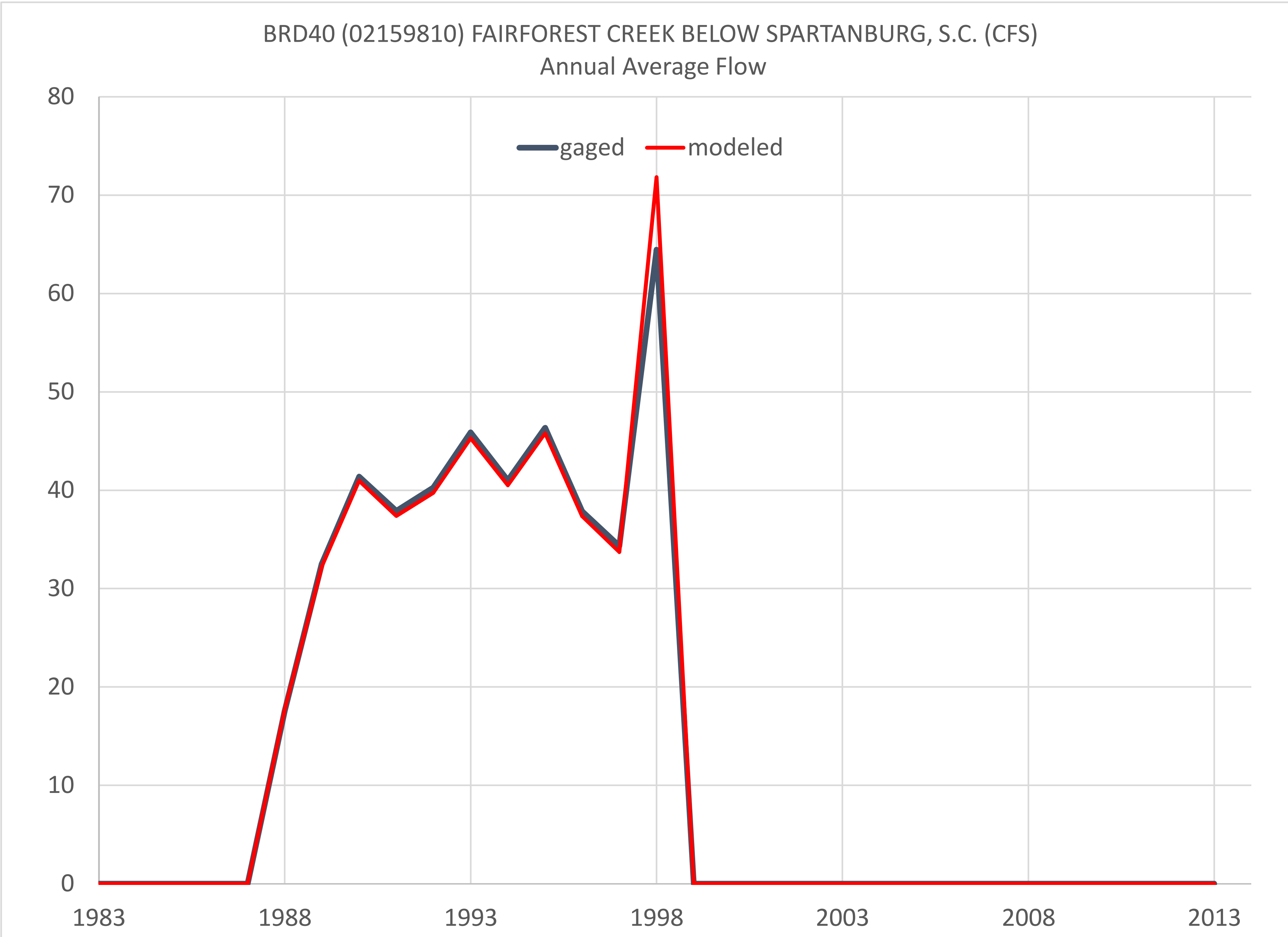


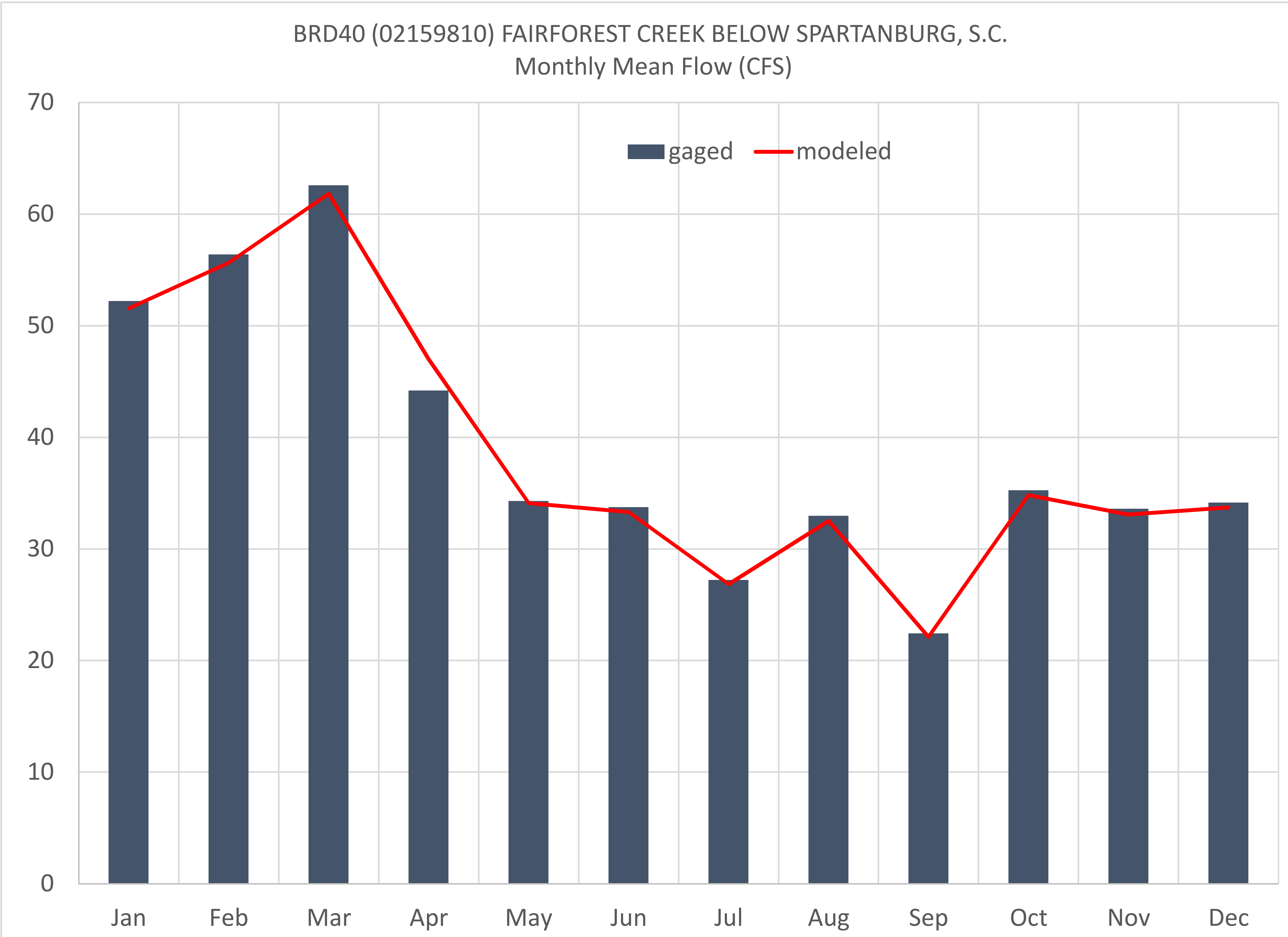
BRD33 (02158408) SOUTH TYGER RIVER BELOW DUNCAN, SC (CFS)
Annual Average Flow
gaged
modeled
300
250
200
150
100
50
0
1983
1988
1993
1998
2003
2008
2013


BRD33 (02158408) SOUTH TYGER RIVER BELOW DUNCAN, SC
Monthly Mean Flow (CFS)
gaged
modeled
0
20
40
60
80
100
120
140
160
180
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

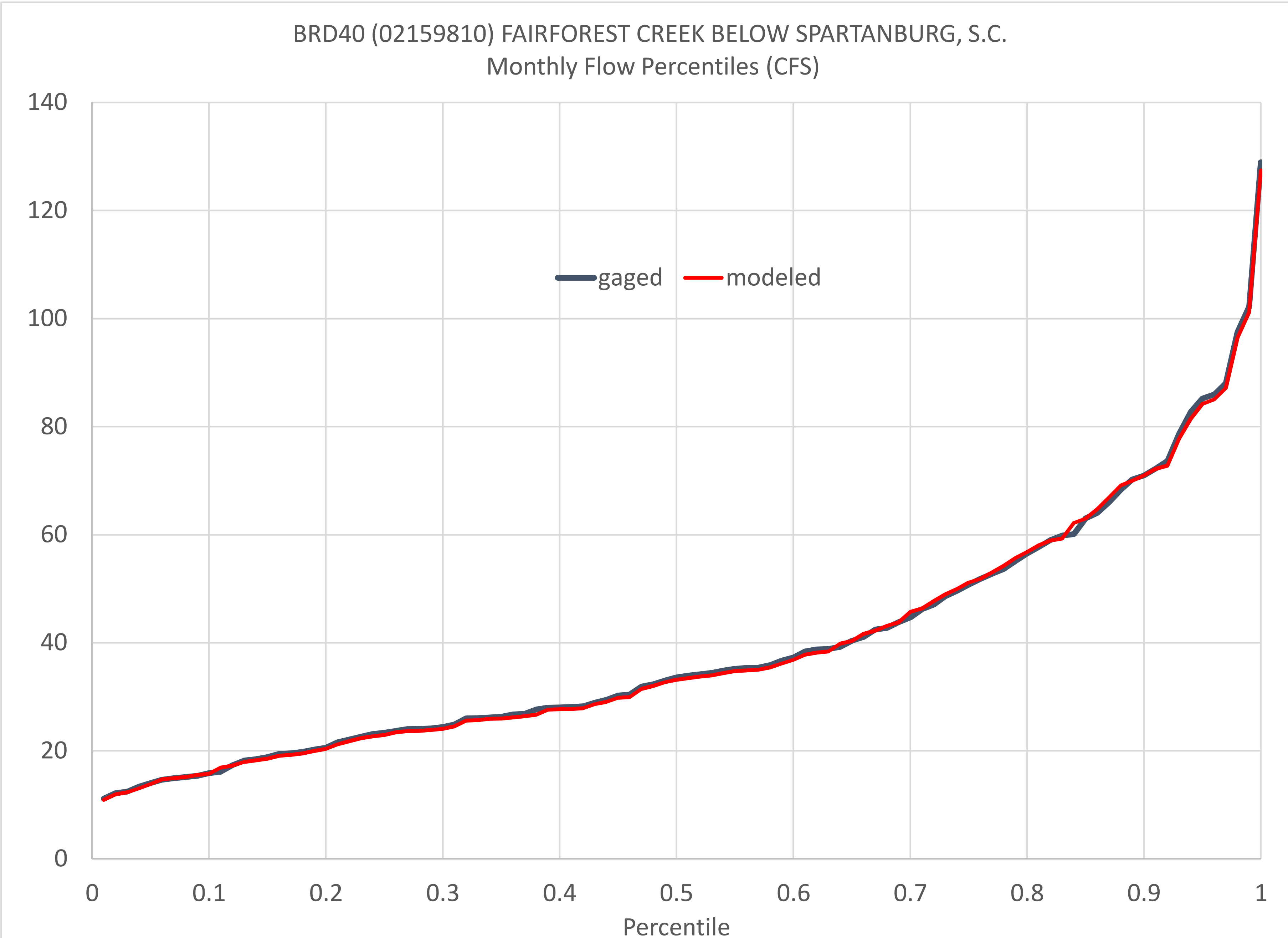

BRD33 (02158408) SOUTH TYGER RIVER BELOW DUNCAN, SC
Monthly Flow Percentiles (CFS)
gaged
modeled
0
50
100
150
200
250
300
350
400
450
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile


BRD40 (02159810) FAIRFOREST CREEK BELOW SPARTANBURG, S.C. (CFS)
modeled
gaged
0
20
40
60
80
100
120
140
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

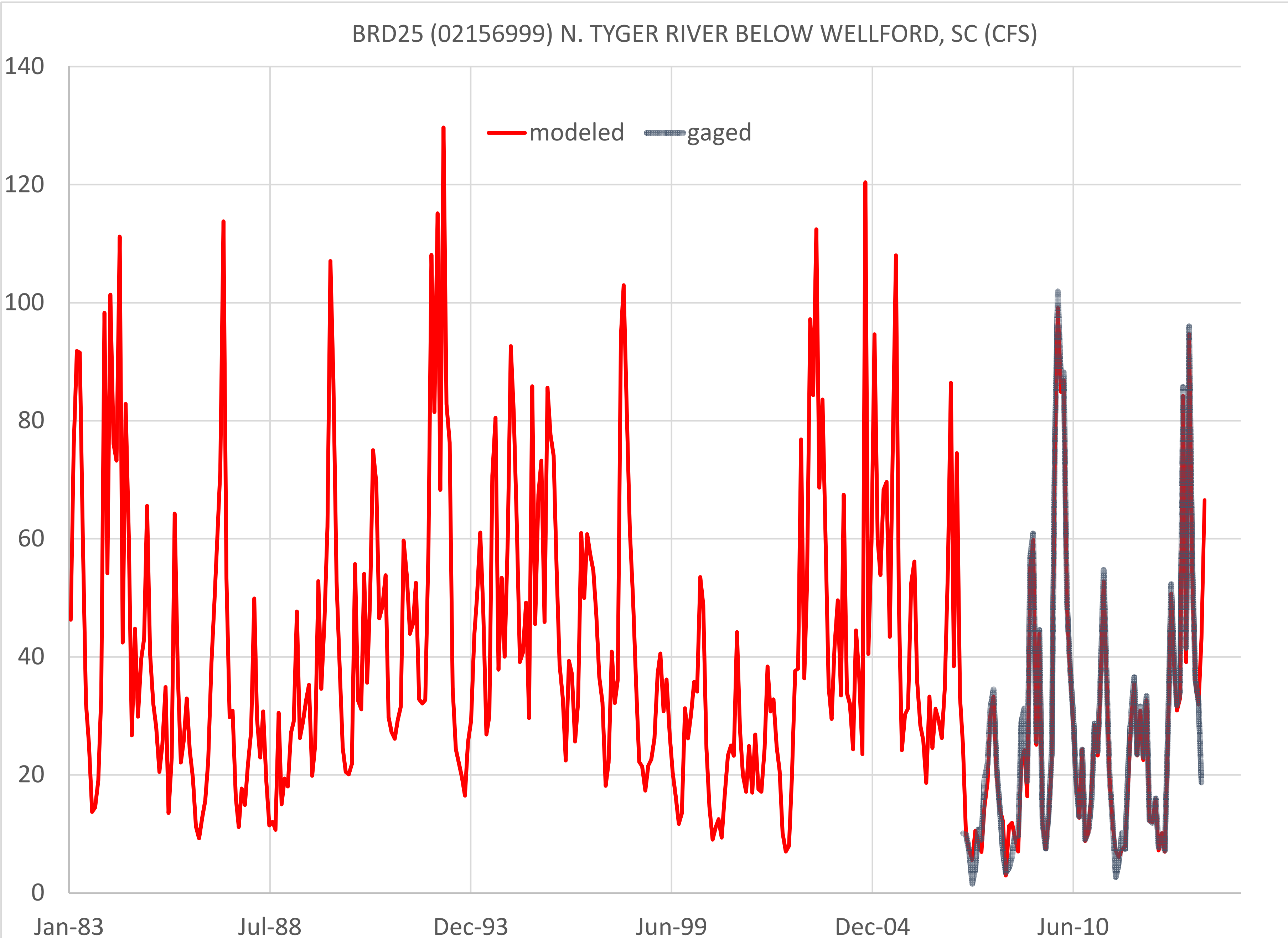

BRD40 (02159810) FAIRFOREST CREEK BELOW SPARTANBURG, S.C. (CFS)
Annual Average Flow
gaged
modeled
0
10
20
30
40
50
60
70
80
1983
1988
1993
1998
2003
2008
2013

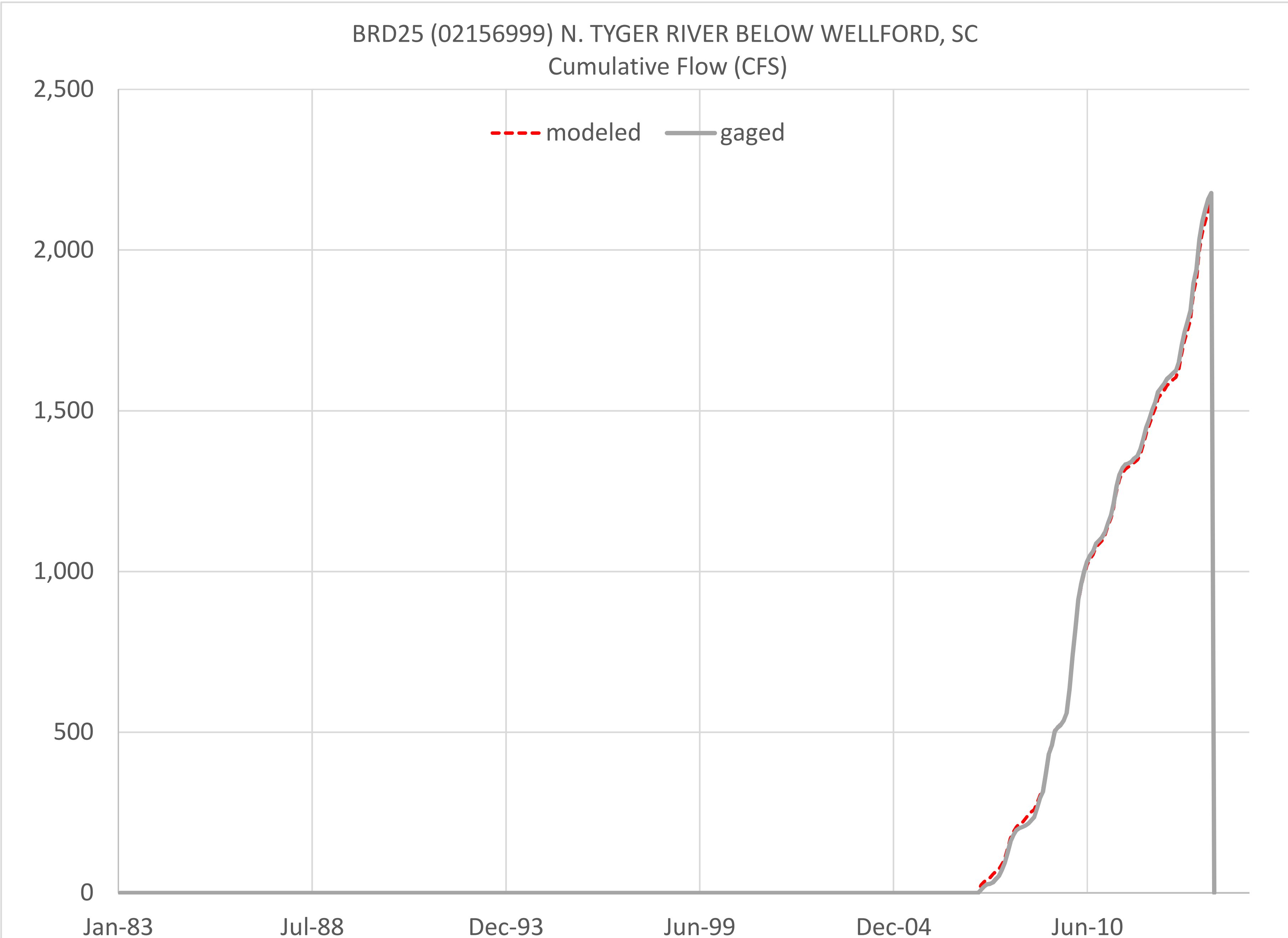


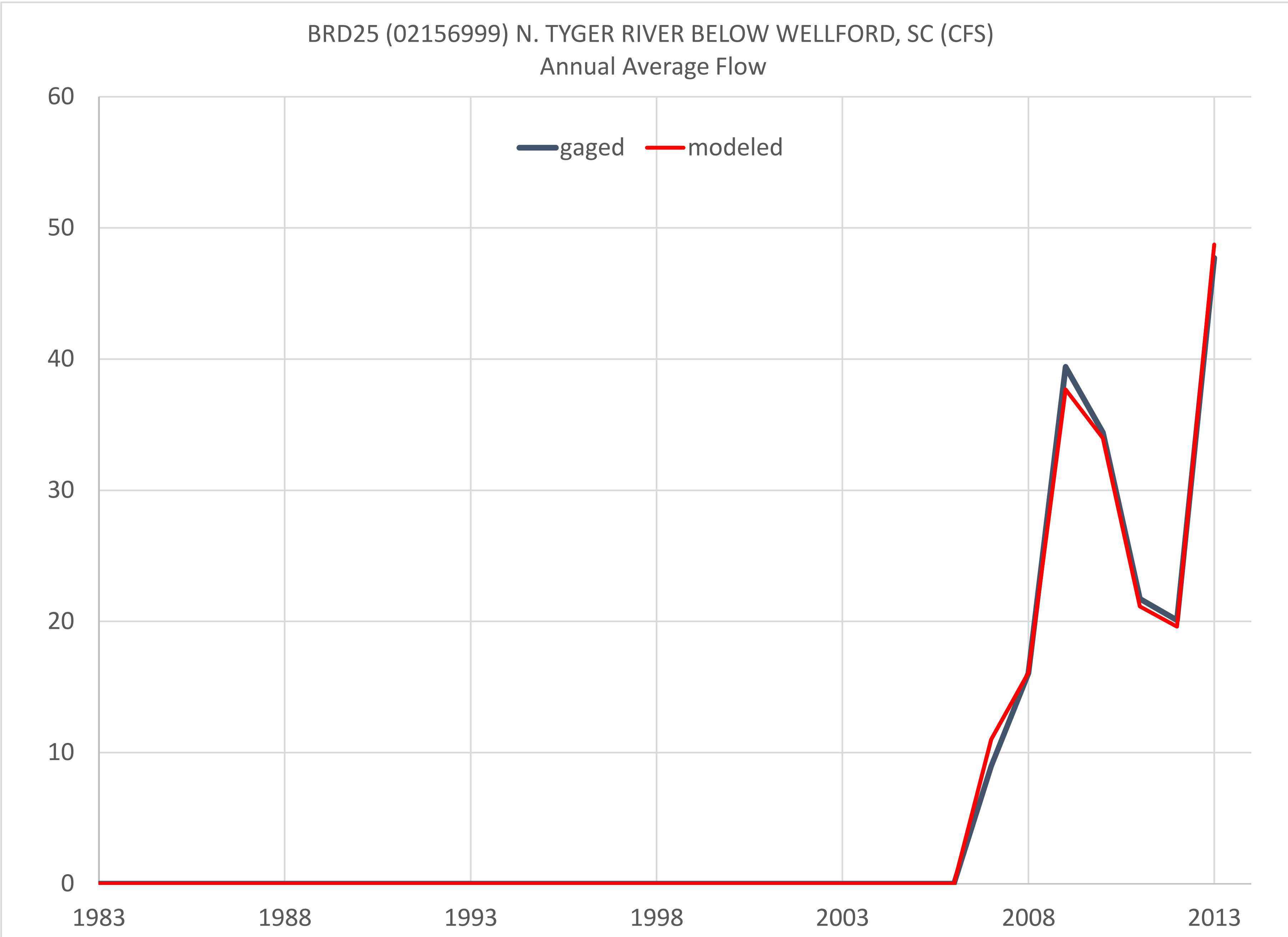
BRD40 (02159810) FAIRFOREST CREEK BELOW SPARTANBURG, S.C.
Monthly Mean Flow (CFS)
gaged
modeled
70
60
50
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

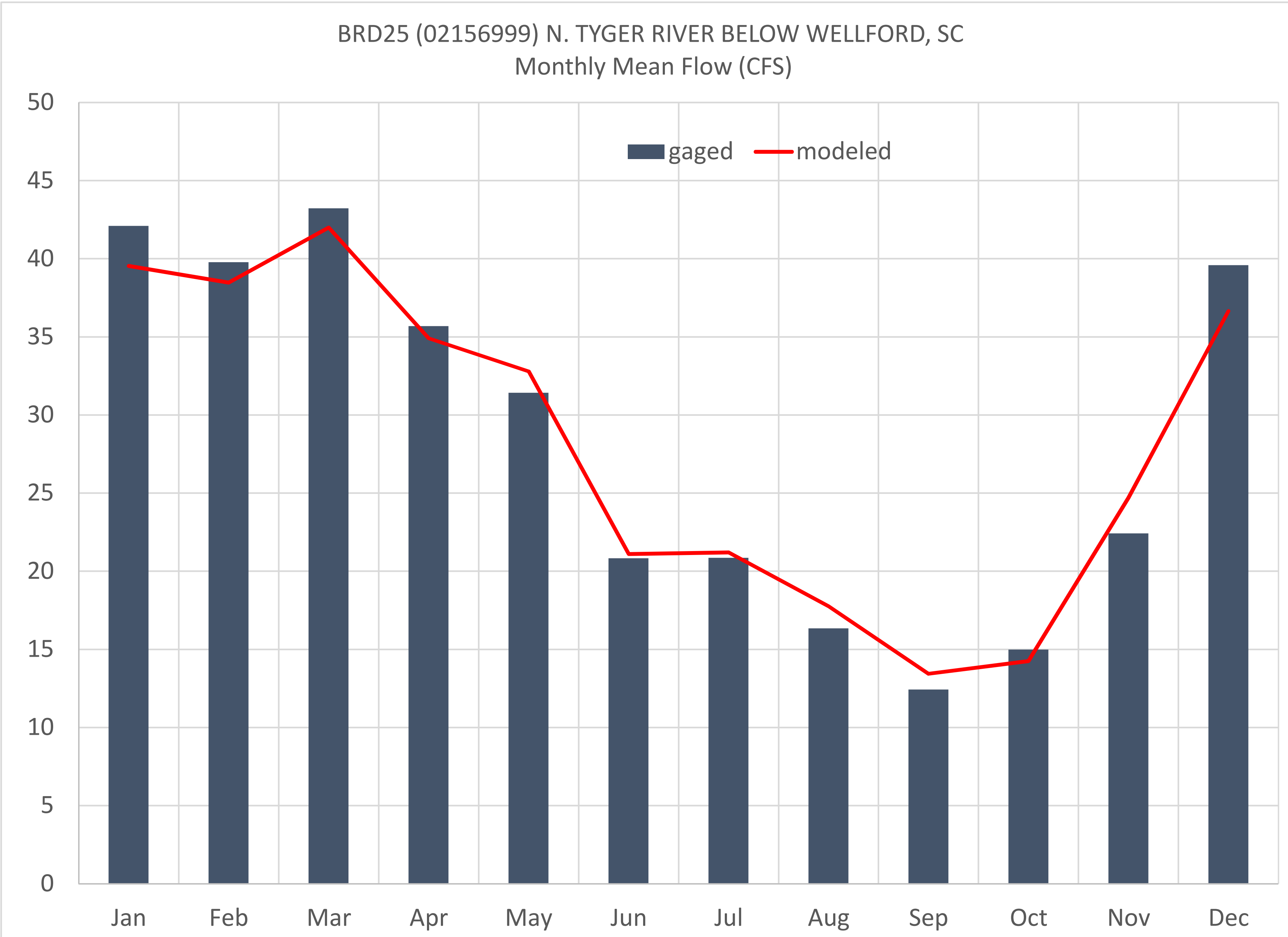


BRD40 (02159810) FAIRFOREST CREEK BELOW SPARTANBURG, S.C.
Monthly Flow Percentiles (CFS)
gaged
modeled
140
120
100
80
60
40
20
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

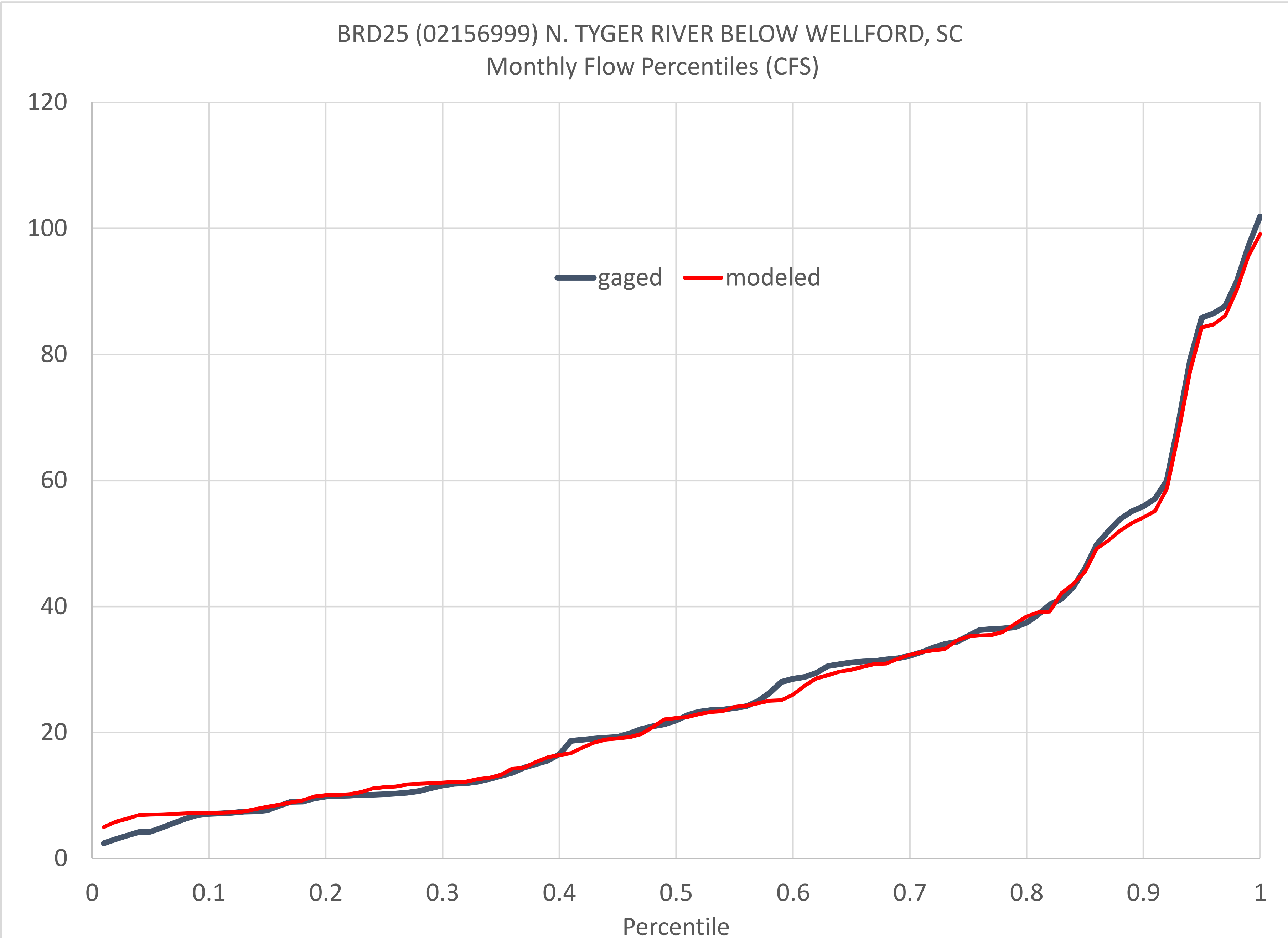

BRD25 (02156999) N. TYGER RIVER BELOW WELLFORD, SC (CFS)
modeled
gaged
140
120
100
80
60
40
20
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10


BRD25 (02156999) N. TYGER RIVER BELOW WELLFORD, SC
Cumulative Flow (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

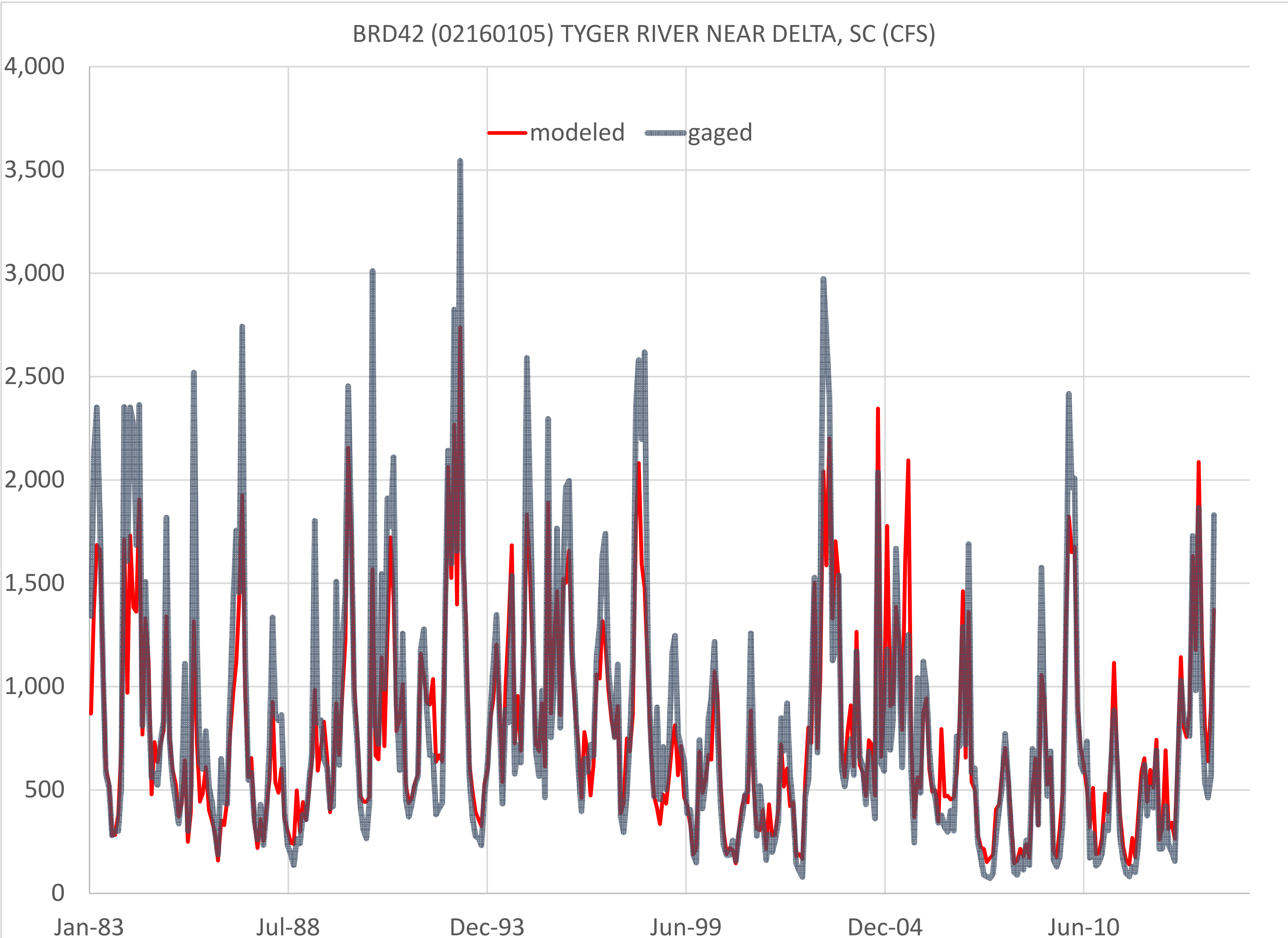

BRD25 (02156999) N. TYGER RIVER BELOW WELLFORD, SC (CFS)
Annual Average Flow
gaged
modeled
0
10
20
30
40
50
60
1983
1988
1993
1998
2003
2008
2013

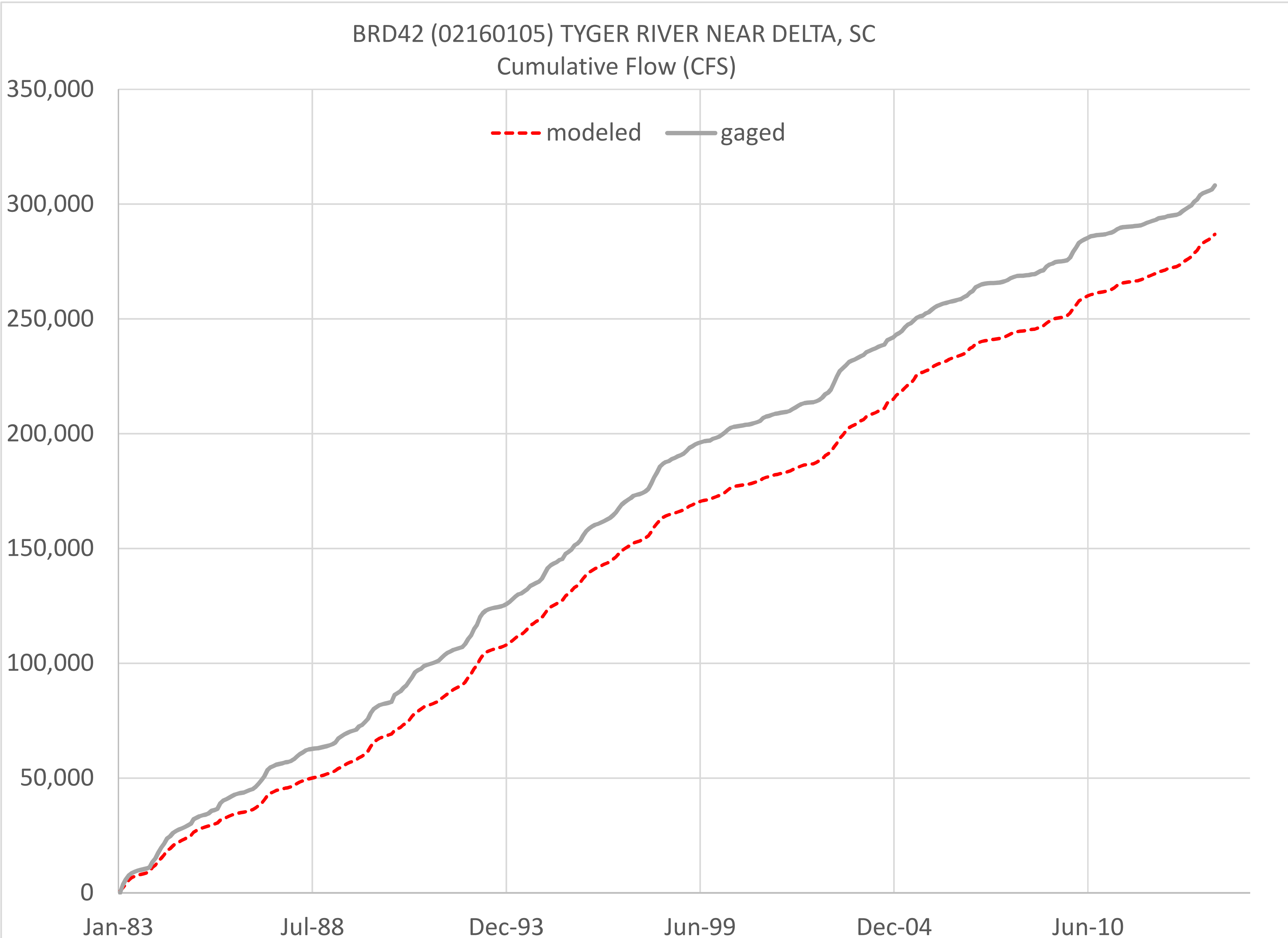


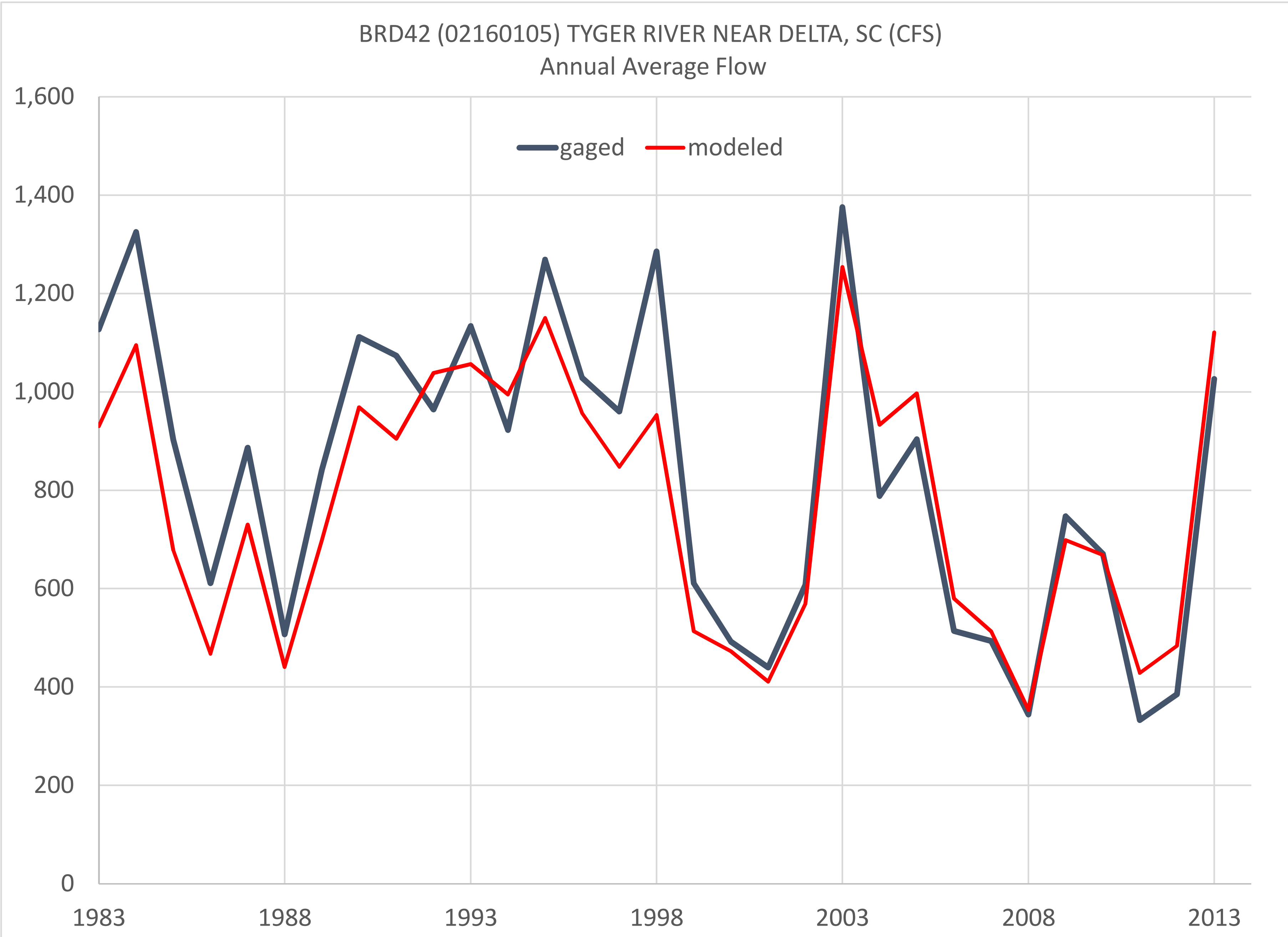
BRD25 (02156999) N. TYGER RIVER BELOW WELLFORD, SC
Monthly Mean Flow (CFS)
gaged
modeled
0
5
10
15
20
25
30
35
40
45
50
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

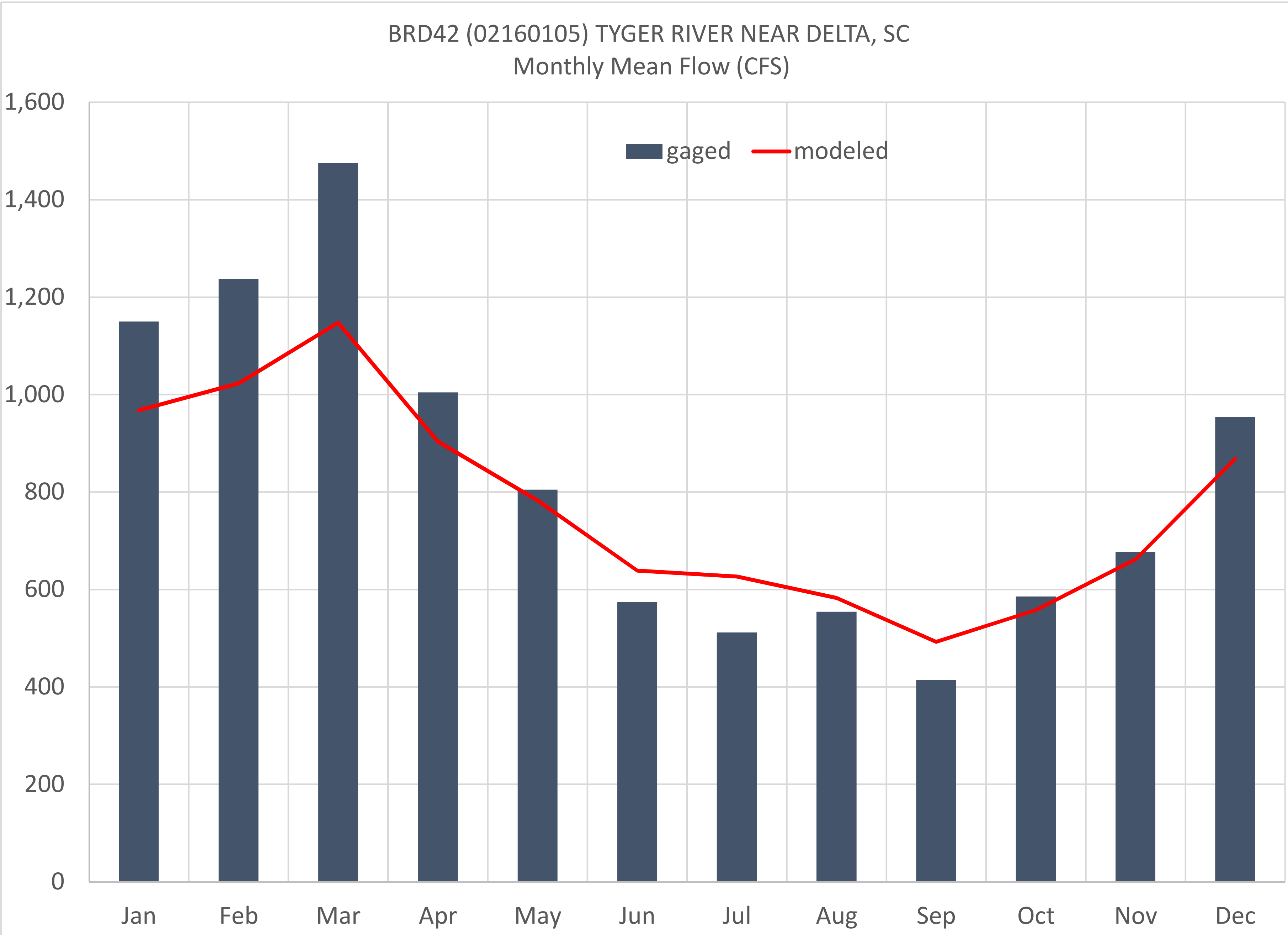


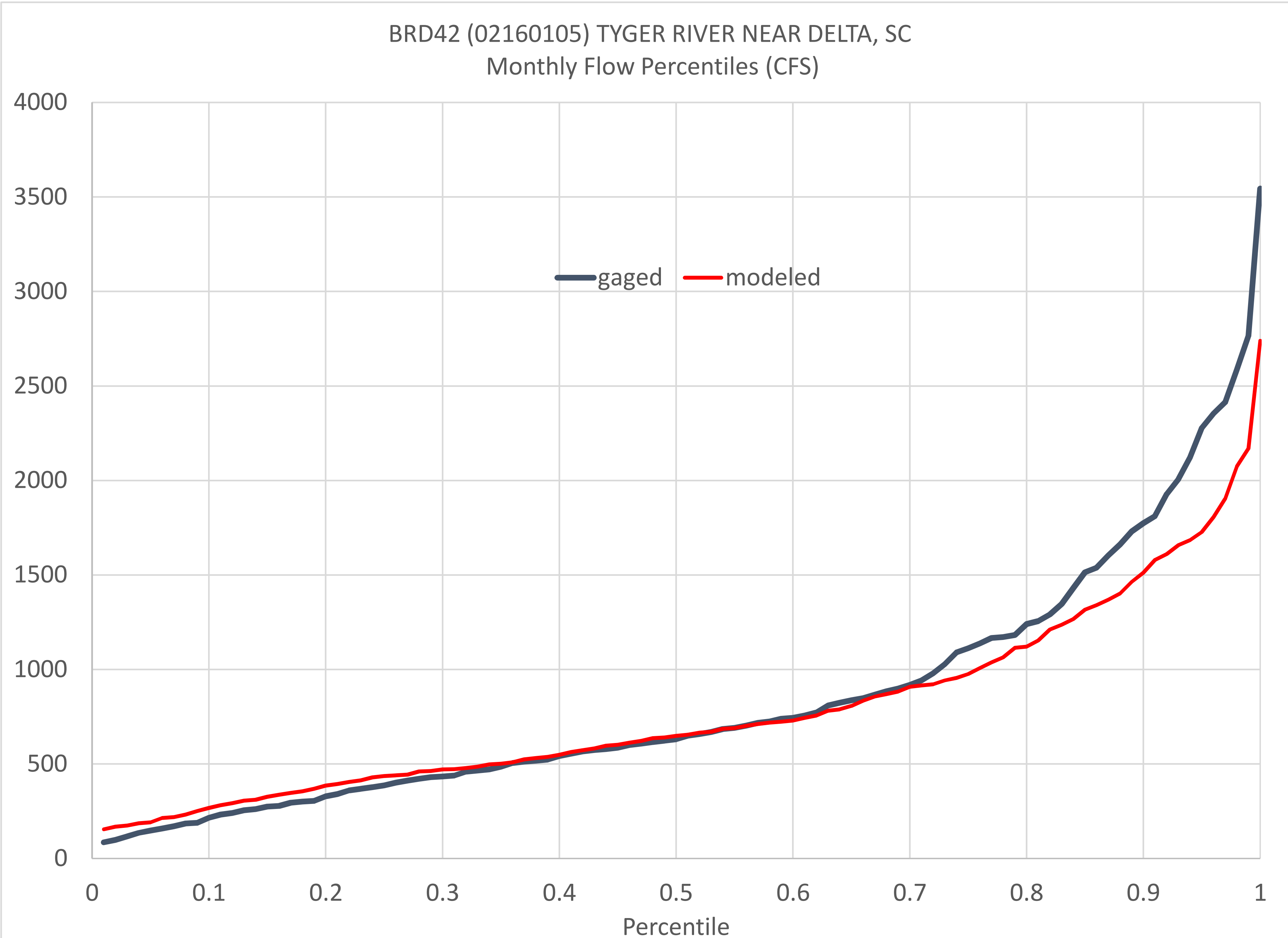
BRD25 (02156999) N. TYGER RIVER BELOW WELLFORD, SC
Monthly Flow Percentiles (CFS)
gaged
modeled
120
100
80
60
40
20
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

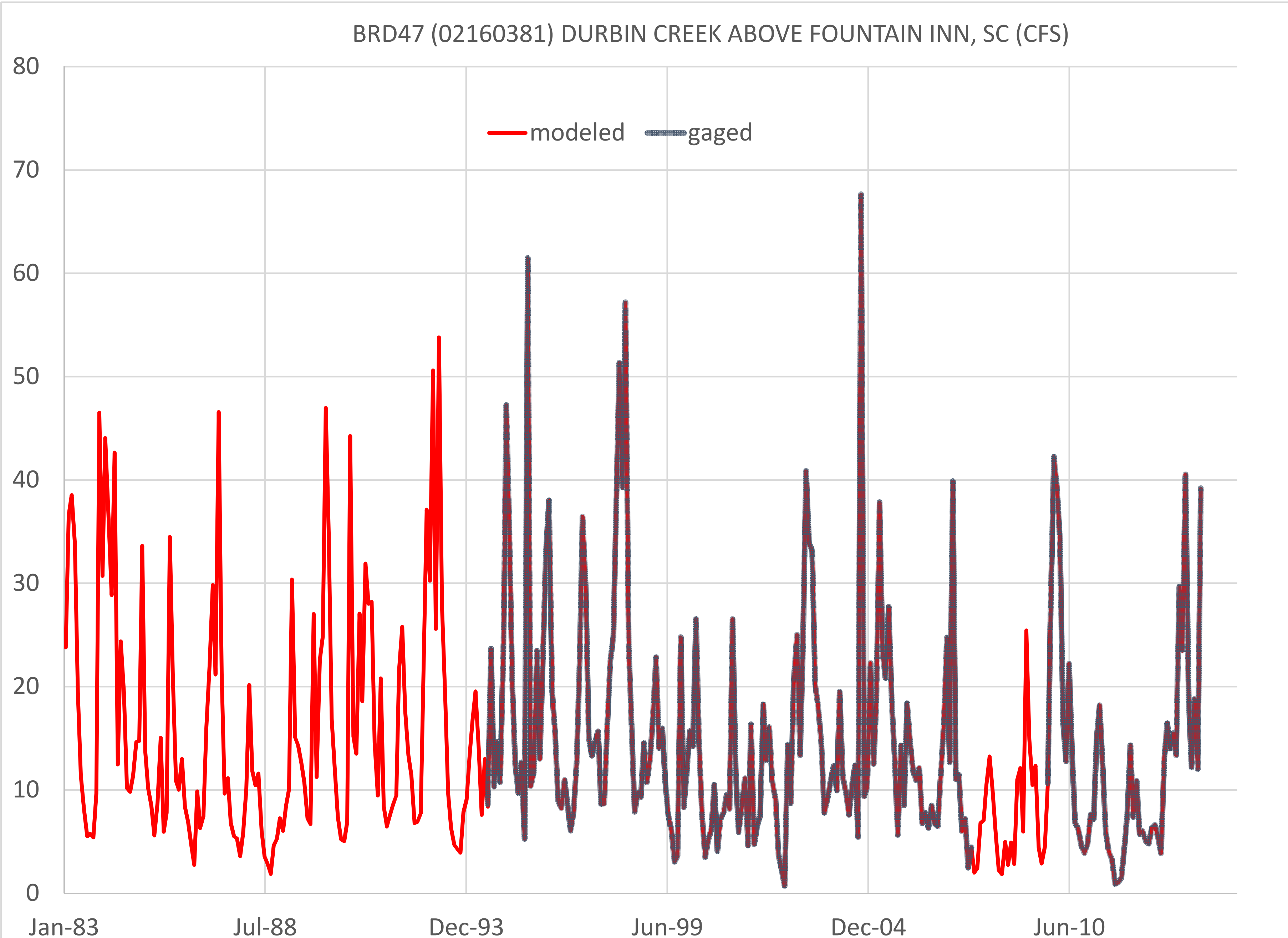

BRD42 (02160105) TYGER RIVER NEAR DELTA, SC (CFS)
modeled
gaged
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

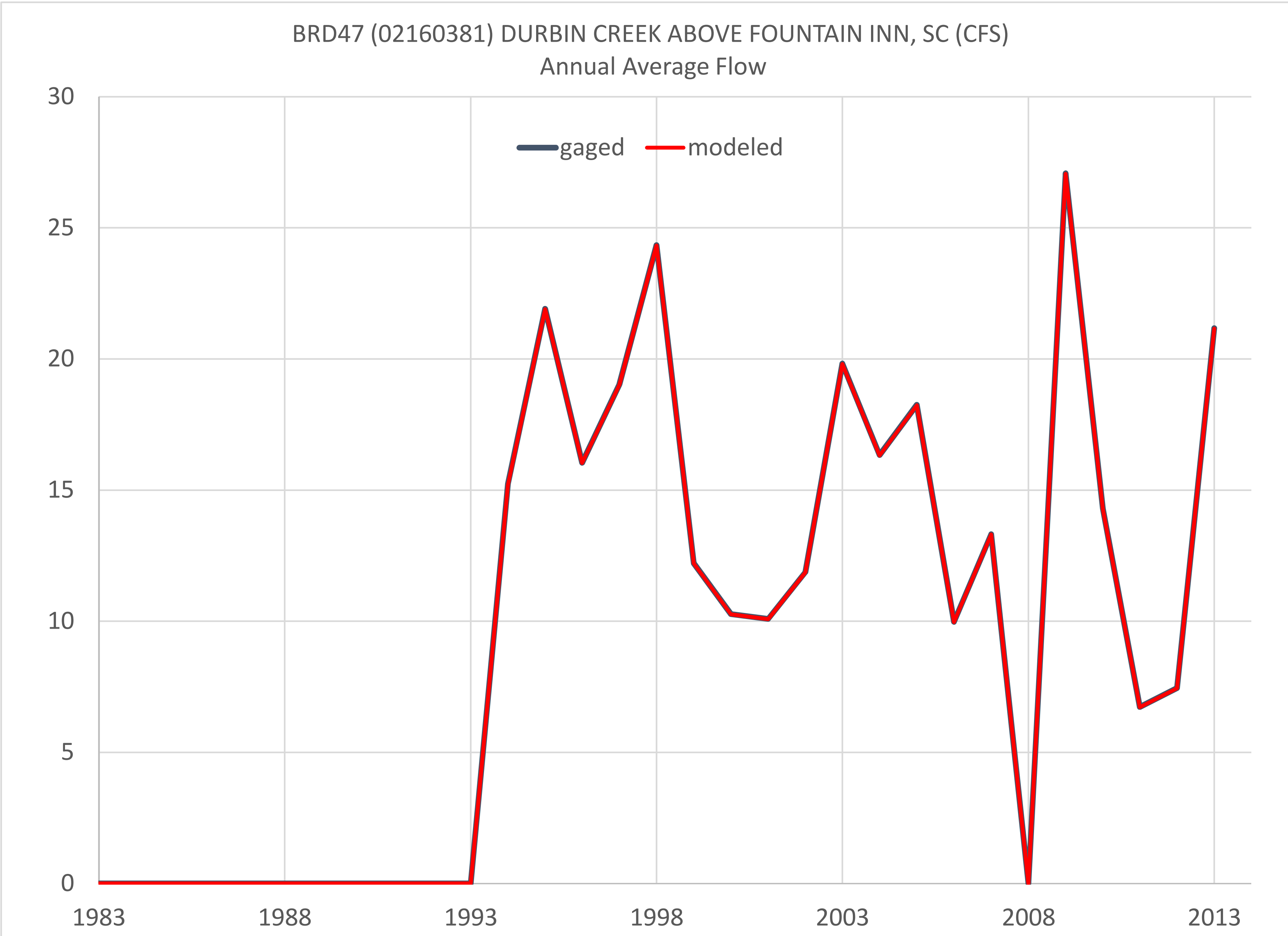

BRD42 (02160105) TYGER RIVER NEAR DELTA, SC
Cumulative Flow (CFS)
modeled
gaged
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

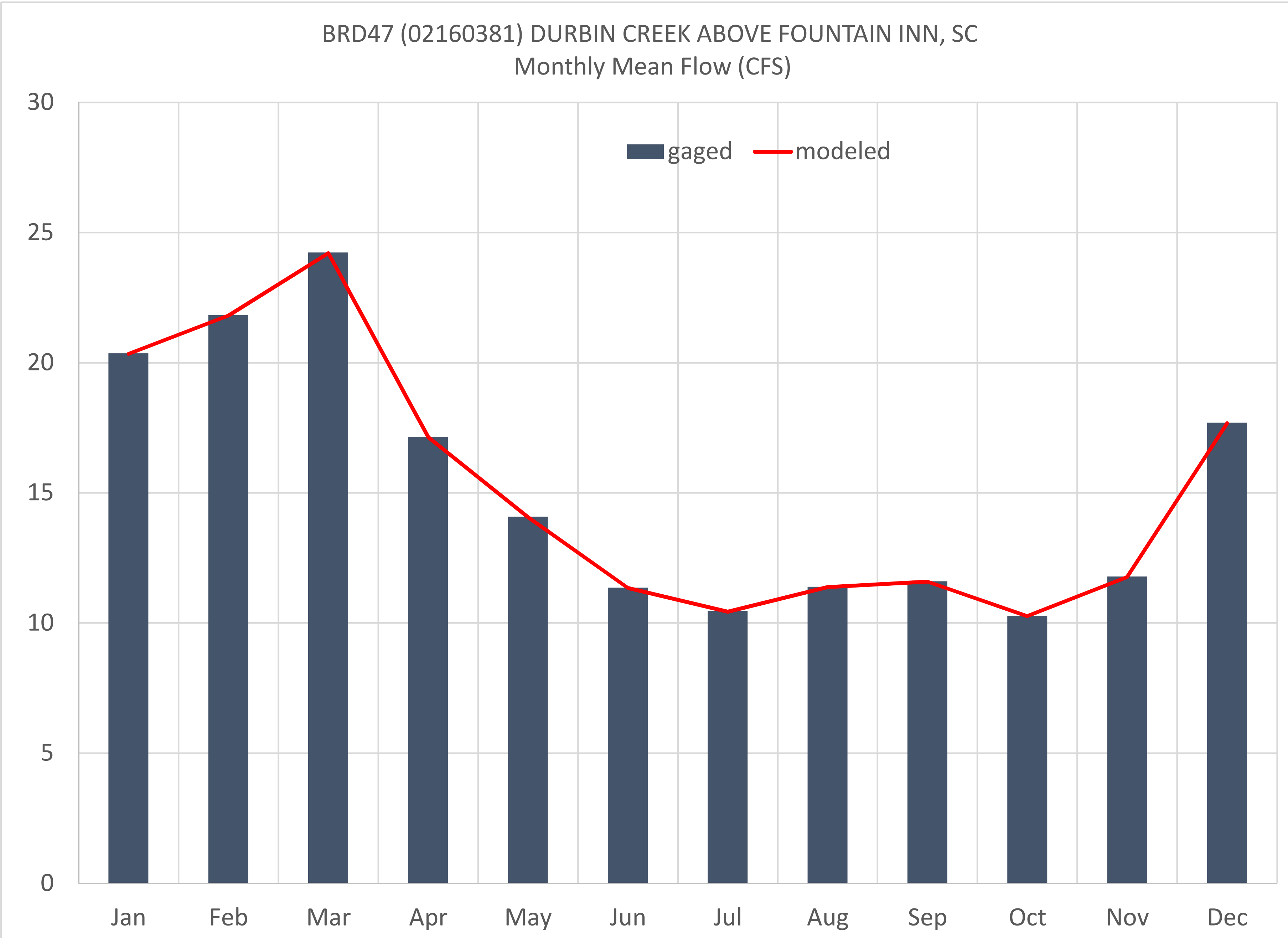

BRD42 (02160105) TYGER RIVER NEAR DELTA, SC (CFS)
Annual Average Flow
gaged
modeled
1,600
1,400
1,200
1,000
800
600
400
200
0
1983
1988
1993
1998
2003
2008
2013

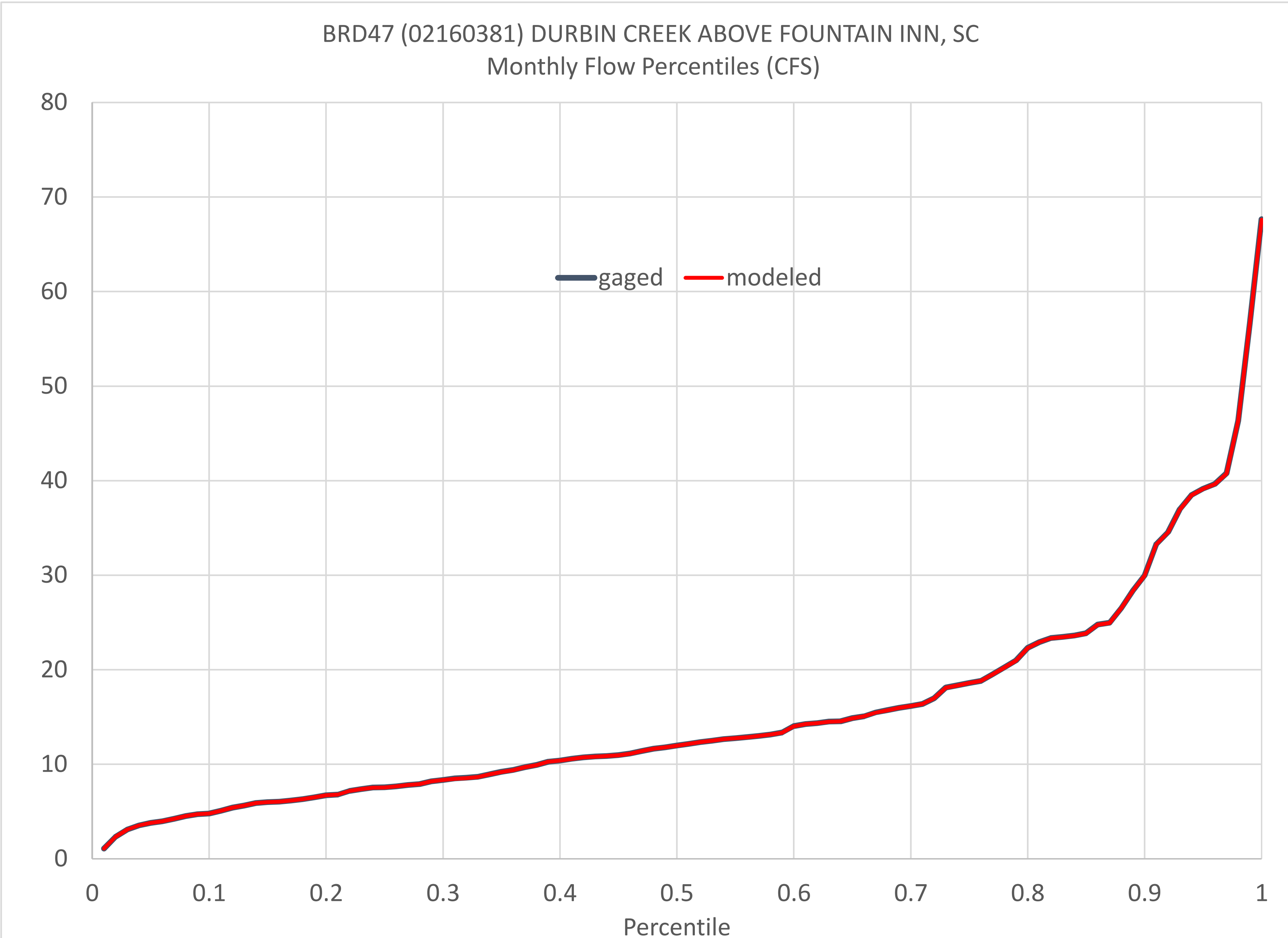

BRD42 (02160105) TYGER RIVER NEAR DELTA, SC
Monthly Mean Flow (CFS)
gaged
modeled
1,600
1,400
1,200
1,000
800
600
400
200
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

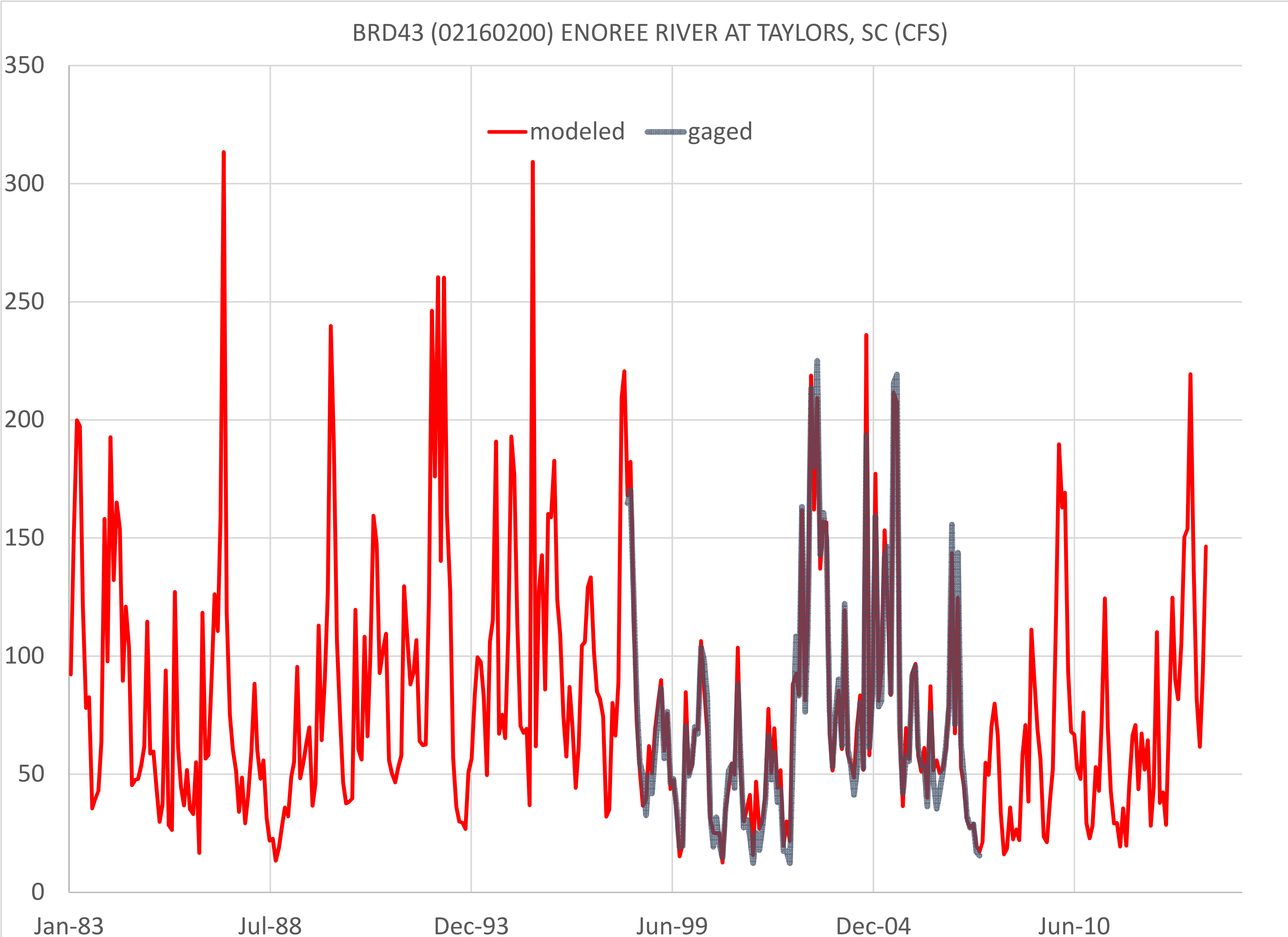

BRD42 (02160105) TYGER RIVER NEAR DELTA, SC
Monthly Flow Percentiles (CFS)
gaged
modeled
4000
3500
3000
2500
2000
1500
1000
500
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

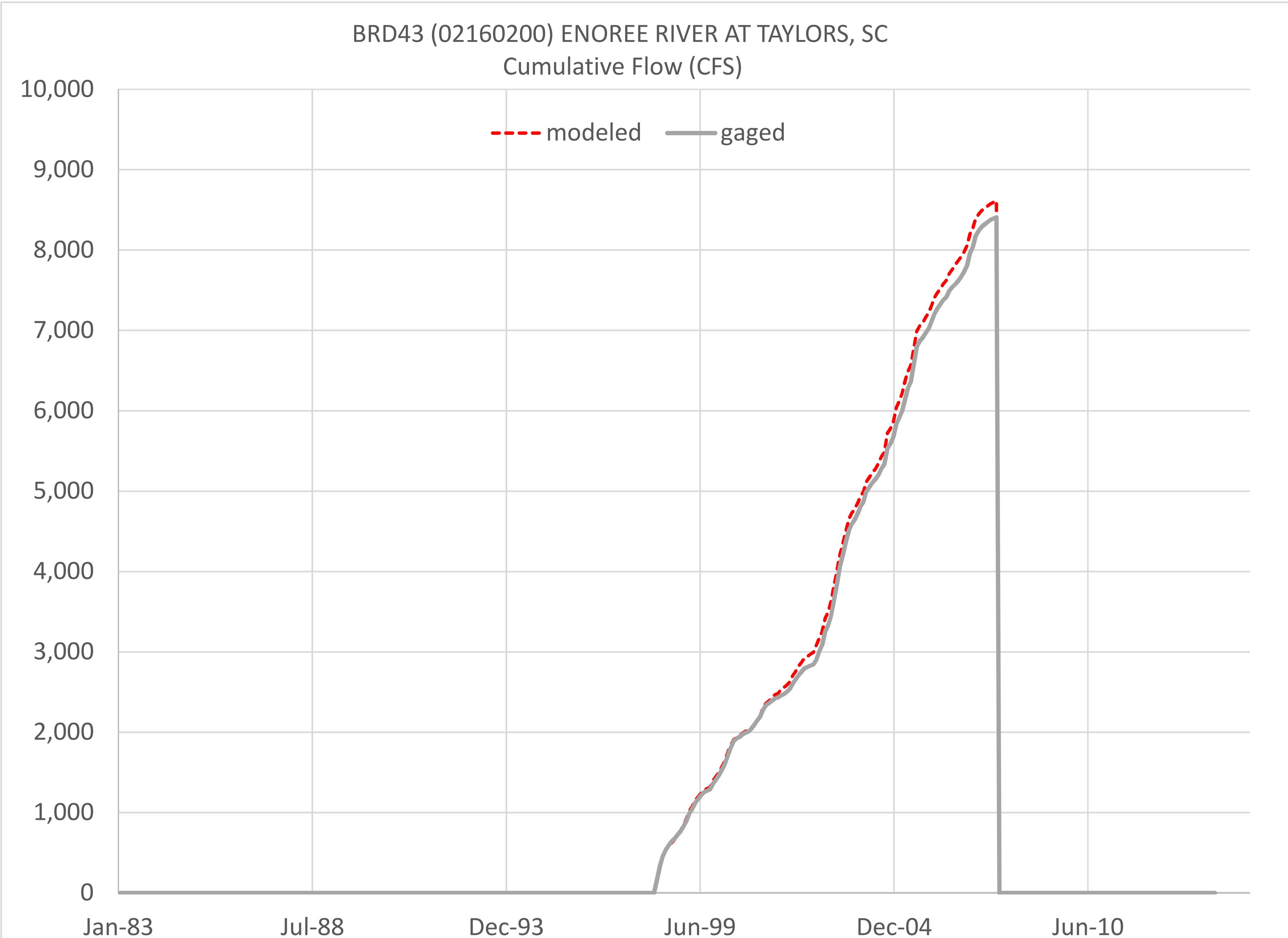

BRD47 (02160381) DURBIN CREEK ABOVE FOUNTAIN INN, SC (CFS)
modeled
gaged
80
70
60
50
40
30
20
10
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

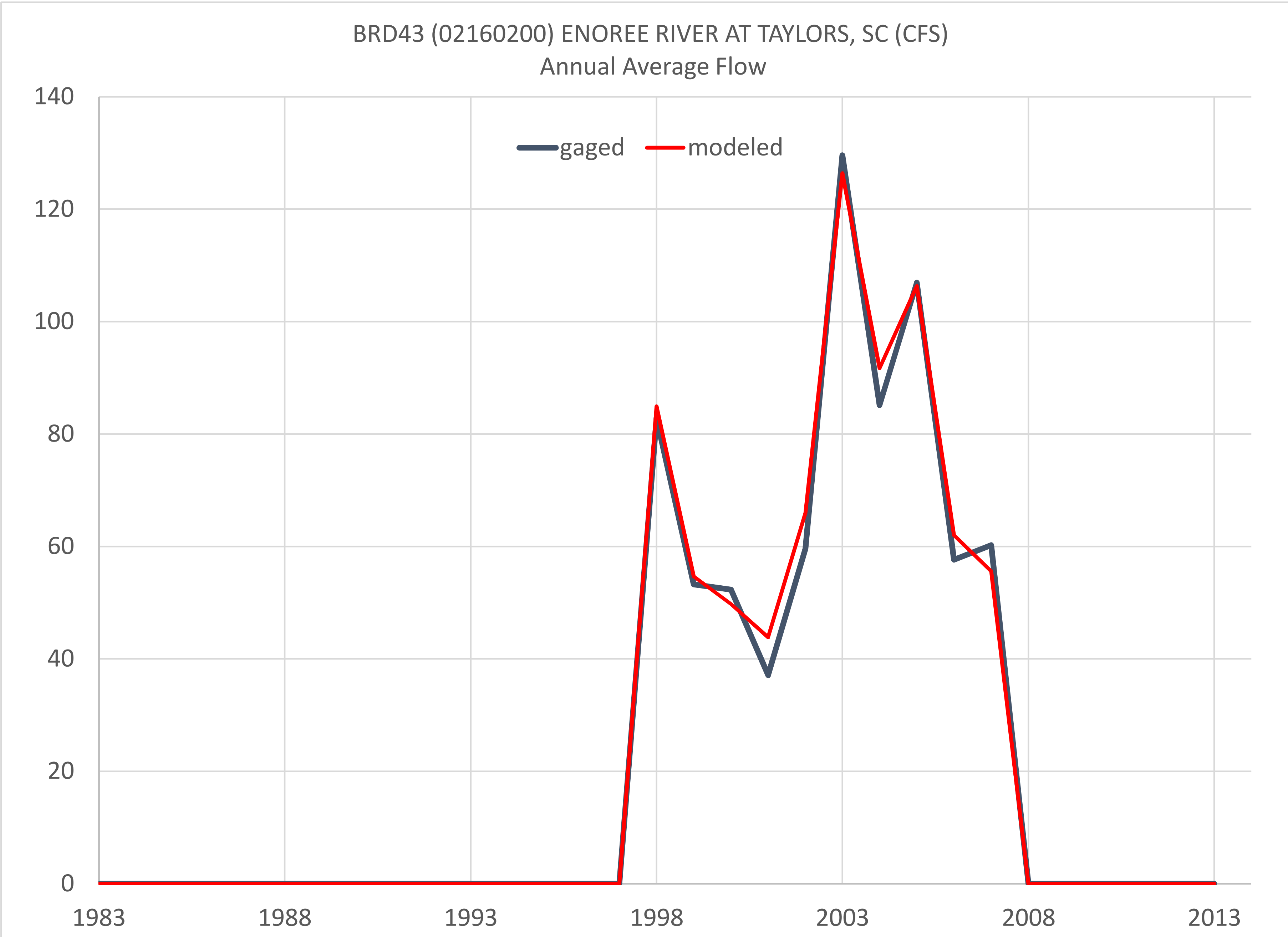

BRD47 (02160381) DURBIN CREEK ABOVE FOUNTAIN INN, SC (CFS)
Annual Average Flow
gaged
modeled
30
25
20
15
10
5
0
1983
1988
1993
1998
2003
2008
2013


BRD47 (02160381) DURBIN CREEK ABOVE FOUNTAIN INN, SC
Monthly Mean Flow (CFS)
gaged
modeled
30
25
20
15
10
5
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

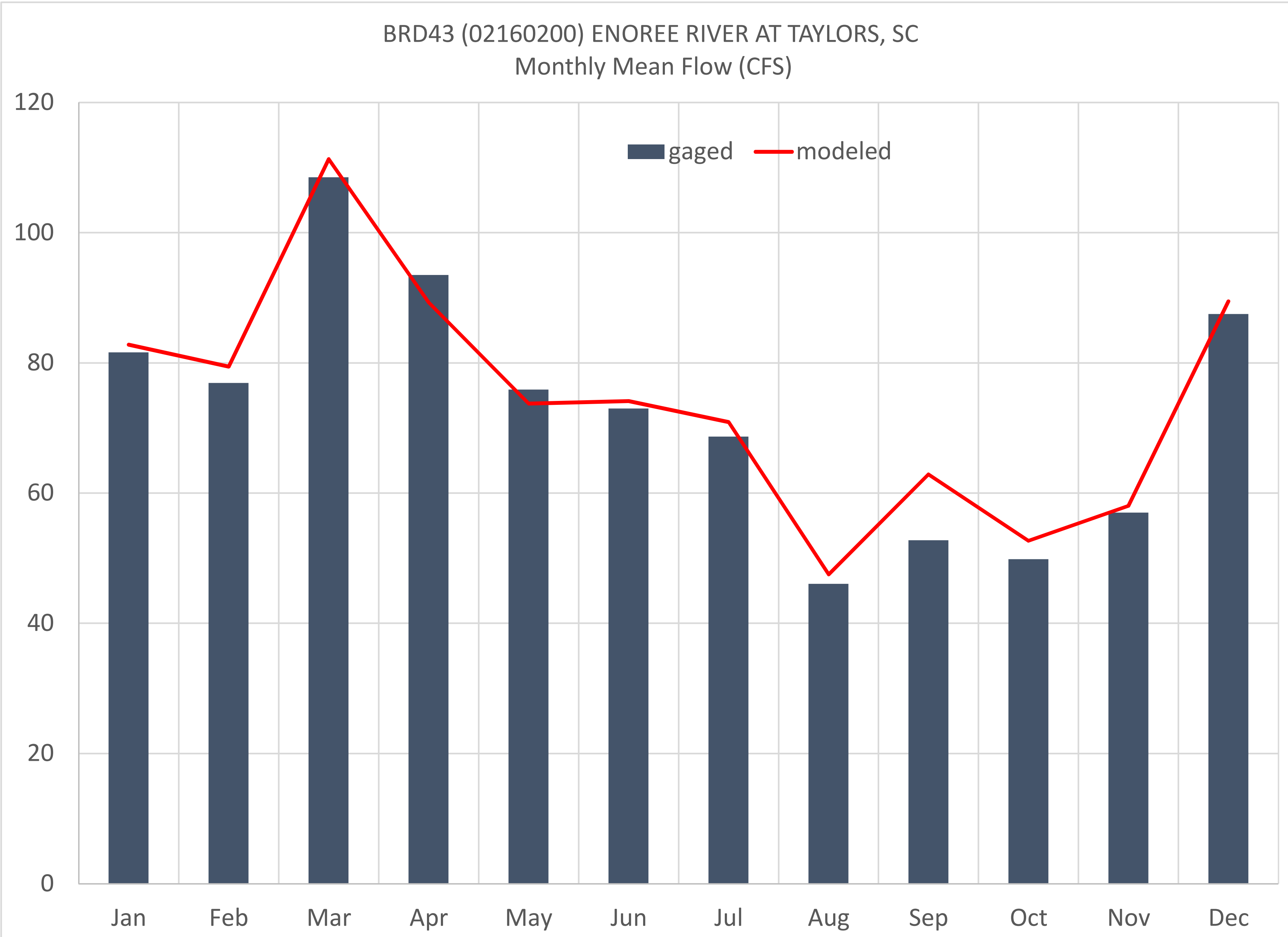

BRD47 (02160381) DURBIN CREEK ABOVE FOUNTAIN INN, SC
Monthly Flow Percentiles (CFS)
80
70
60
50
40
30
20
10
0
gaged
modeled
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

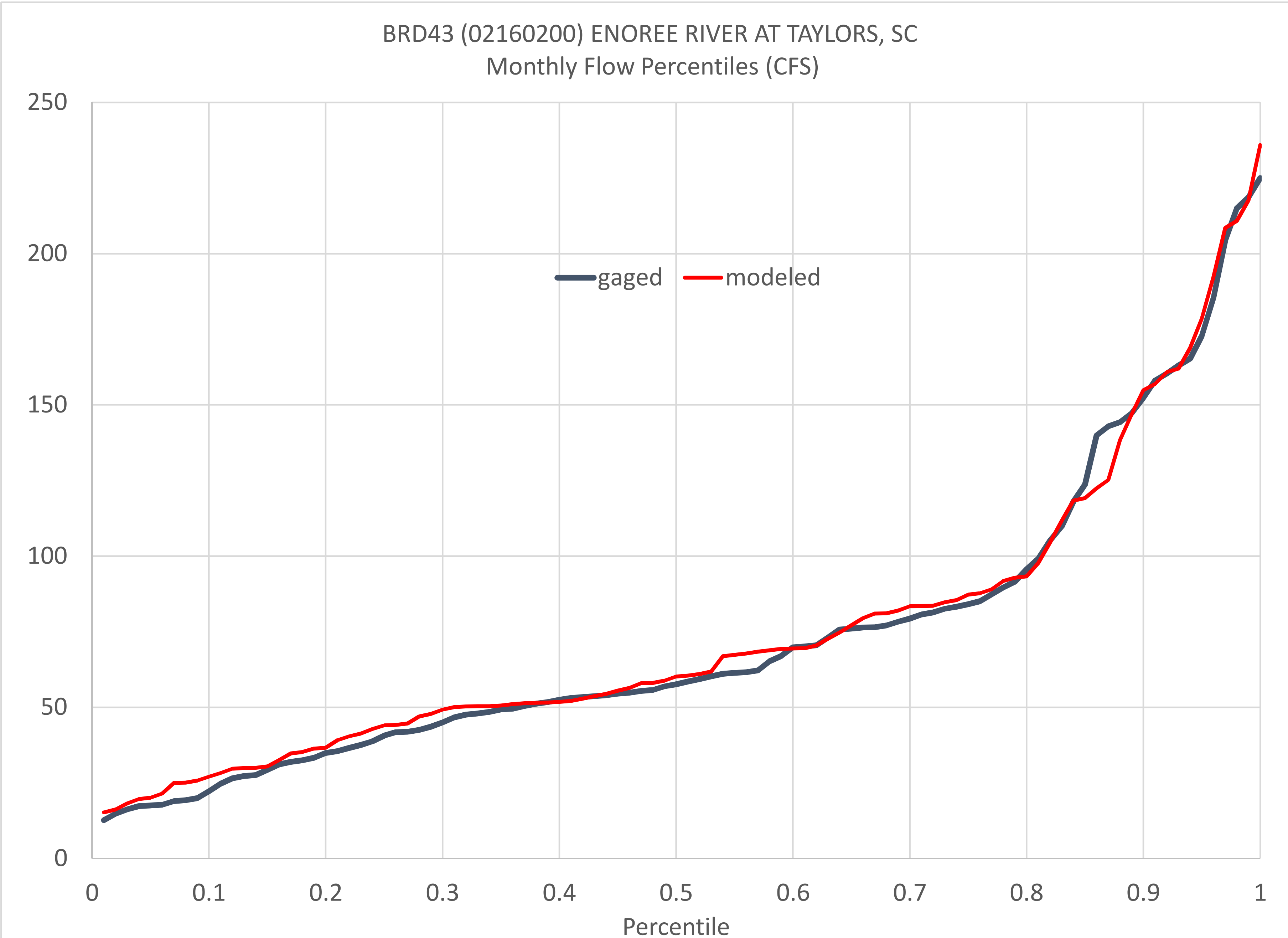

BRD43 (02160200) ENOREE RIVER AT TAYLORS, SC (CFS)
modeled
gaged
350
300
250
200
150
100
50
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10


BRD43 (02160200) ENOREE RIVER AT TAYLORS, SC
Cumulative Flow (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

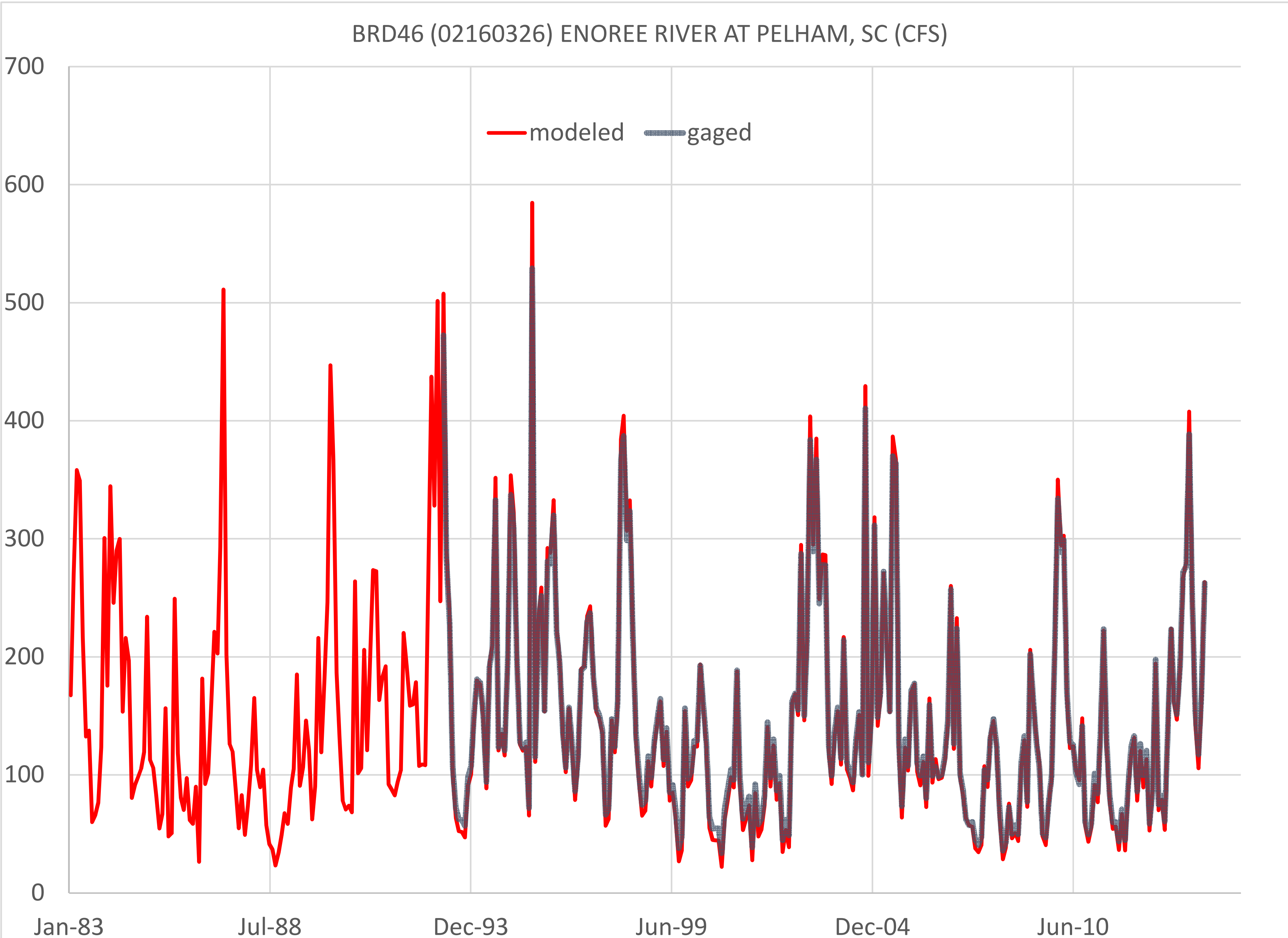


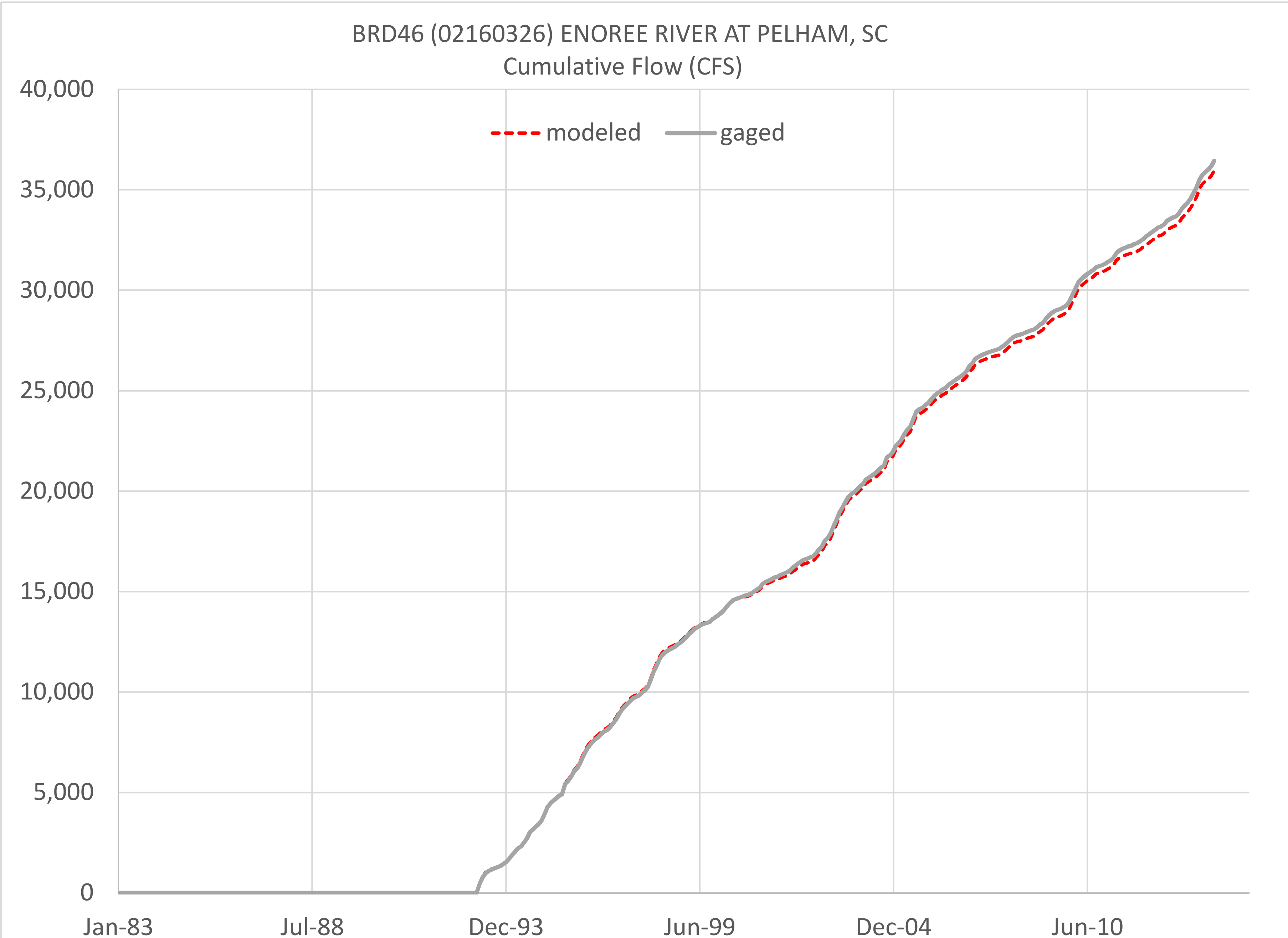
BRD43 (02160200) ENOREE RIVER AT TAYLORS, SC (CFS)
Annual Average Flow
gaged
modeled
140
120
100
80
60
40
20
0
1983
1988
1993
1998
2003
2008
2013


BRD43 (02160200) ENOREE RIVER AT TAYLORS, SC
Monthly Mean Flow (CFS)
gaged
modeled
0
20
40
60
80
100
120
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

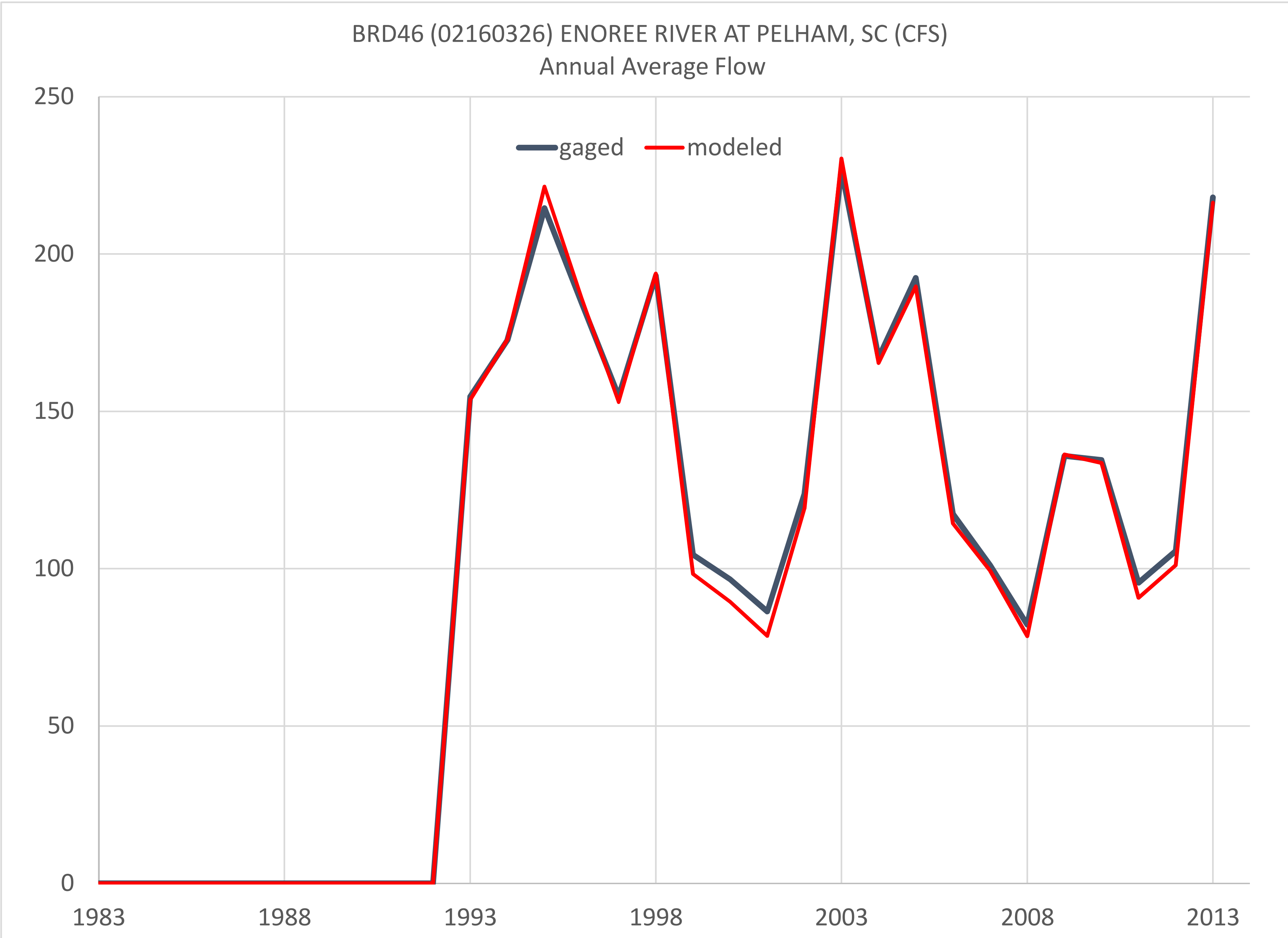


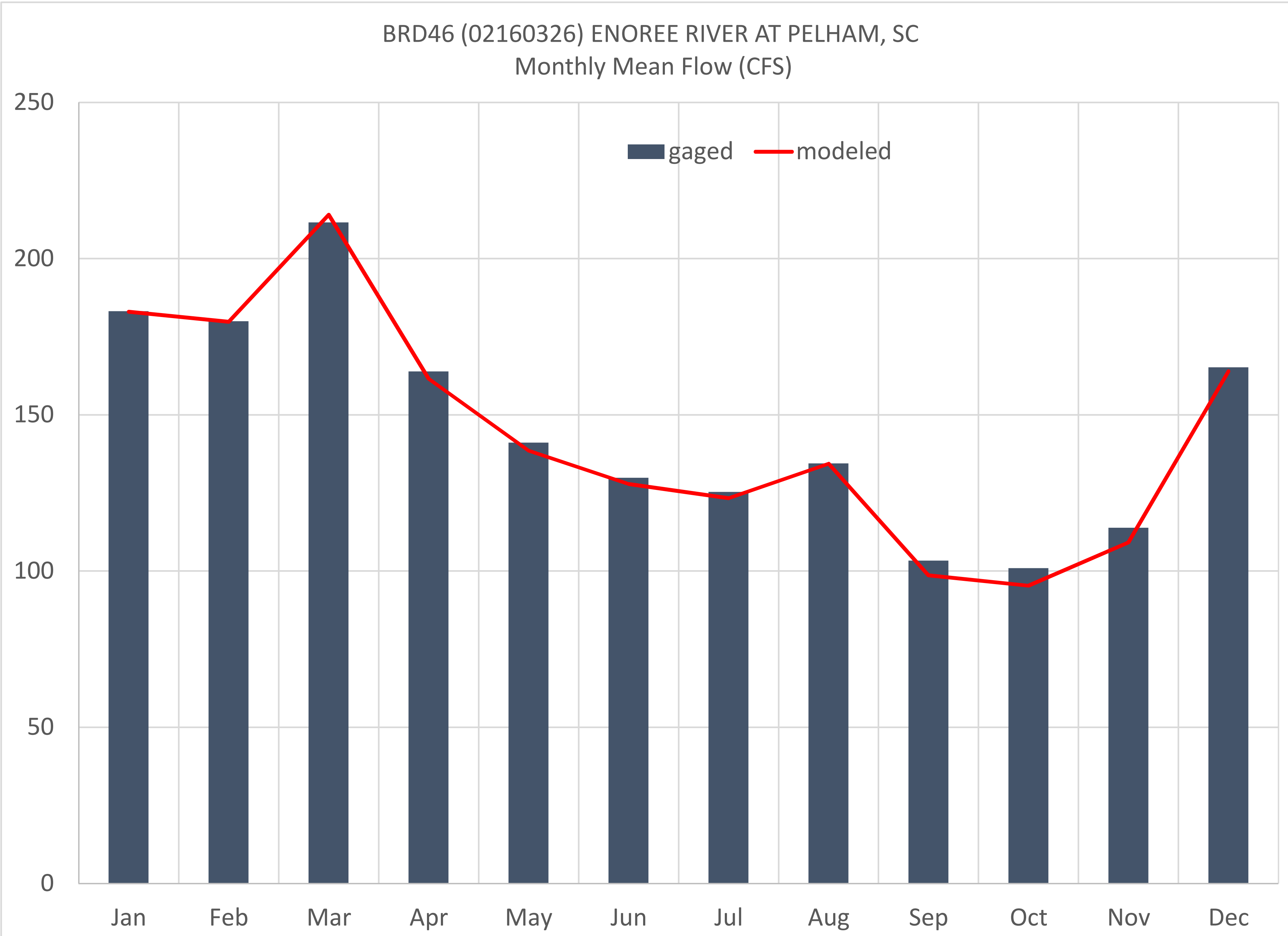
BRD43 (02160200) ENOREE RIVER AT TAYLORS, SC
Monthly Flow Percentiles (CFS)
gaged
modeled
250
200
150
100
50
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

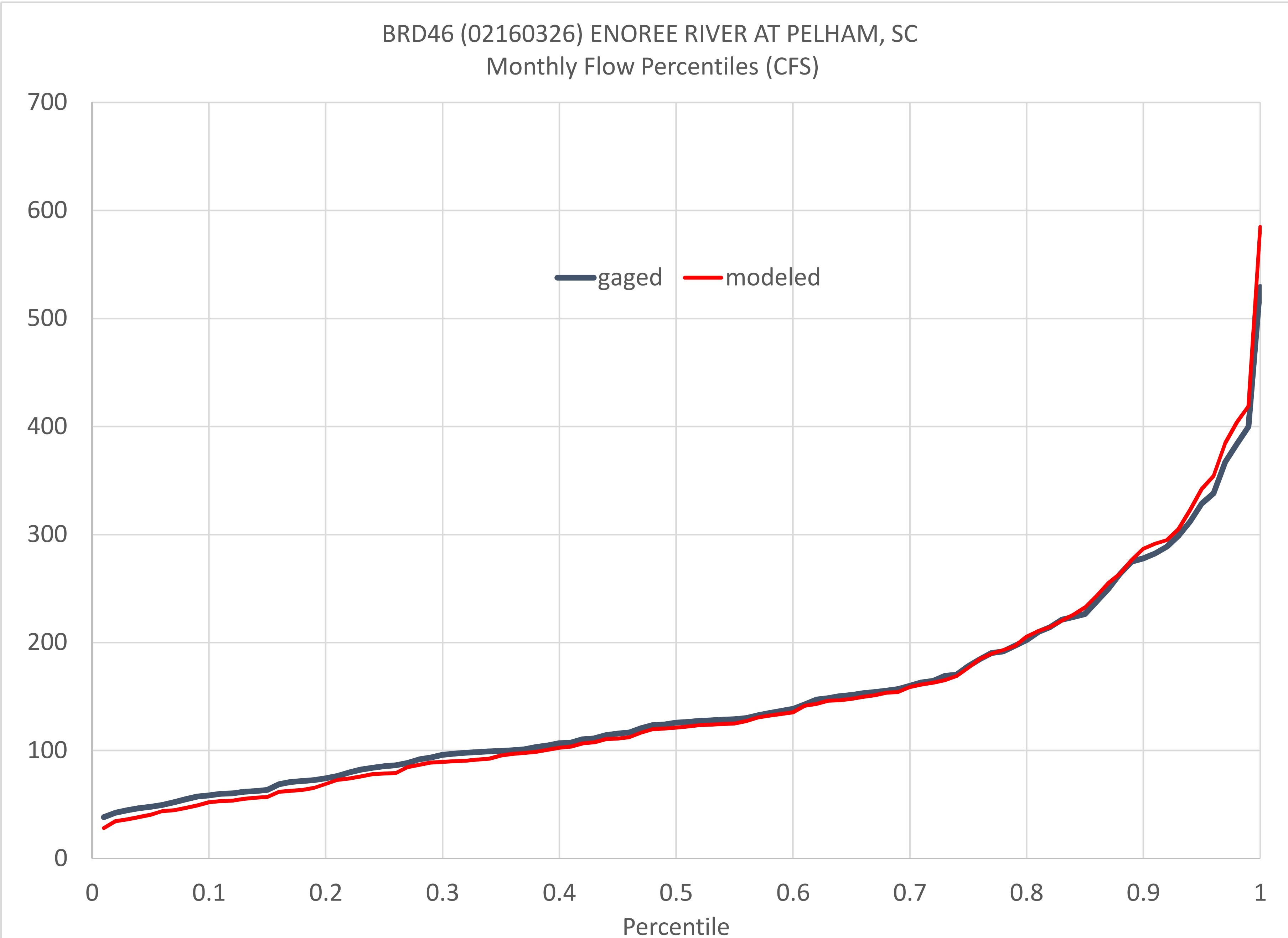

BRD46 (02160326) ENOREE RIVER AT PELHAM, SC (CFS)
modeled
gaged
700
600
500
400
300
200
100
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

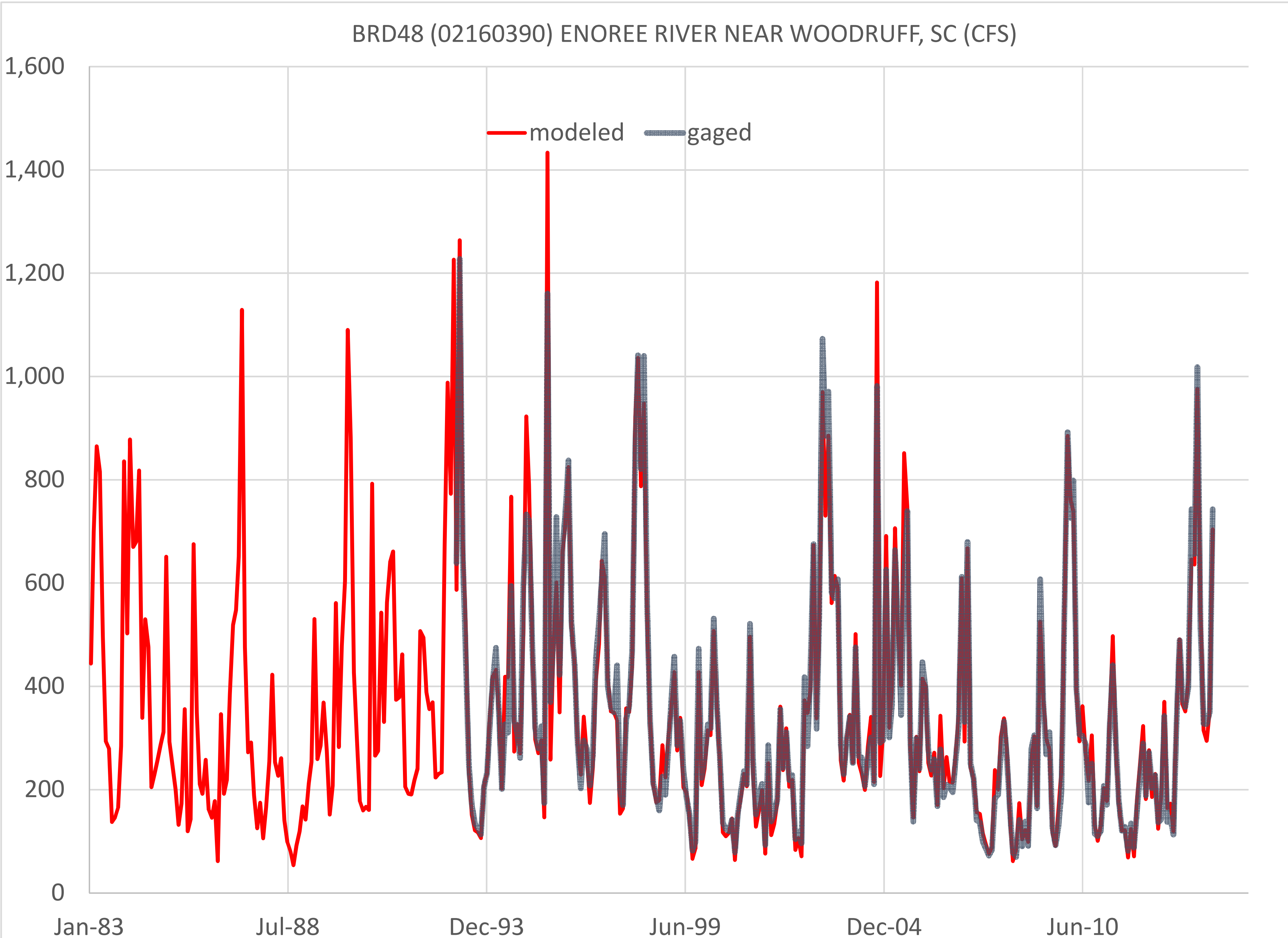


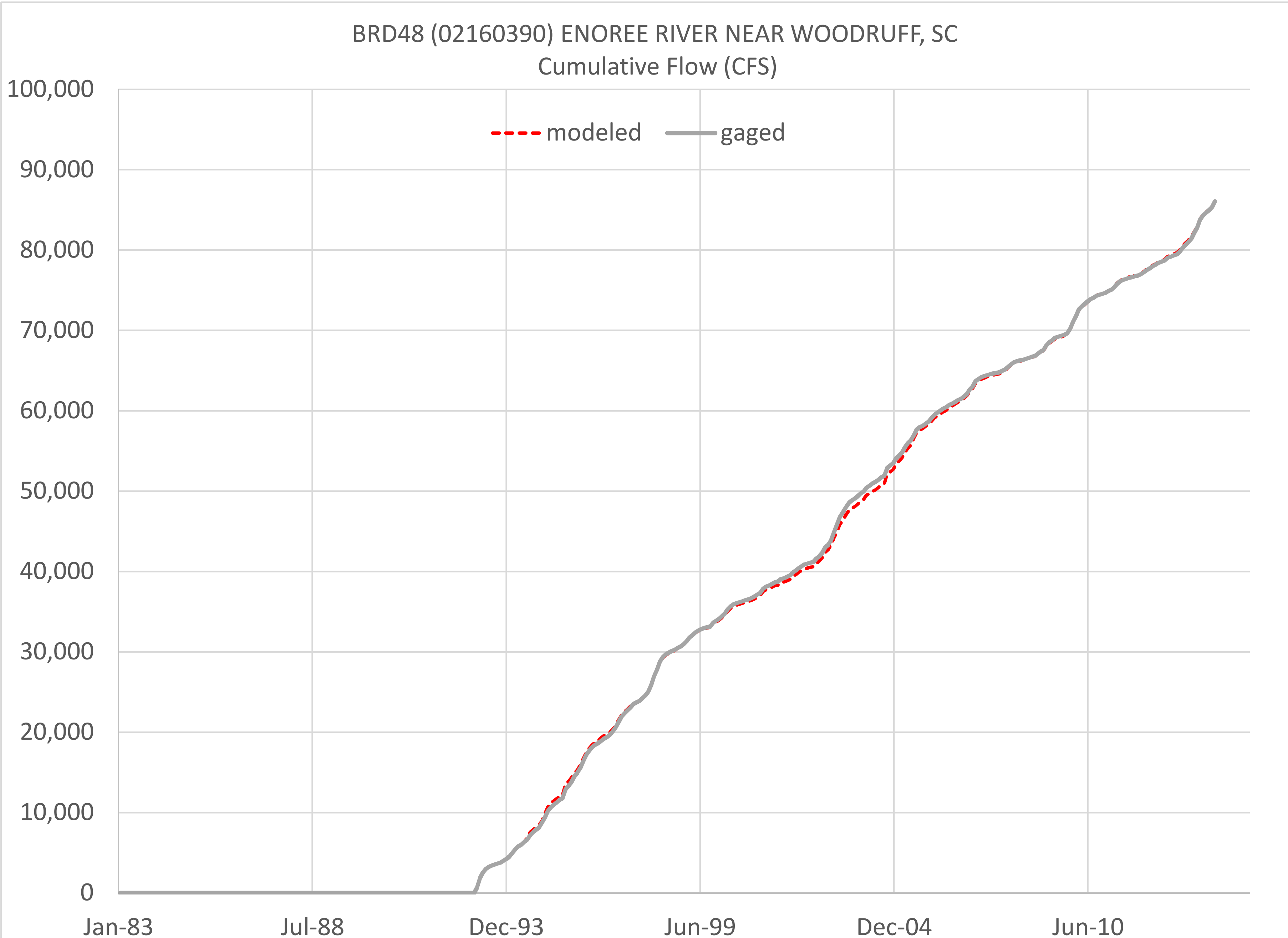
BRD46 (02160326) ENOREE RIVER AT PELHAM, SC
Cumulative Flow (CFS)
modeled
gaged
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10


BRD46 (02160326) ENOREE RIVER AT PELHAM, SC (CFS)
Annual Average Flow
gaged
modeled
250
200
150
100
50
0
1983
1988
1993
1998
2003
2008
2013

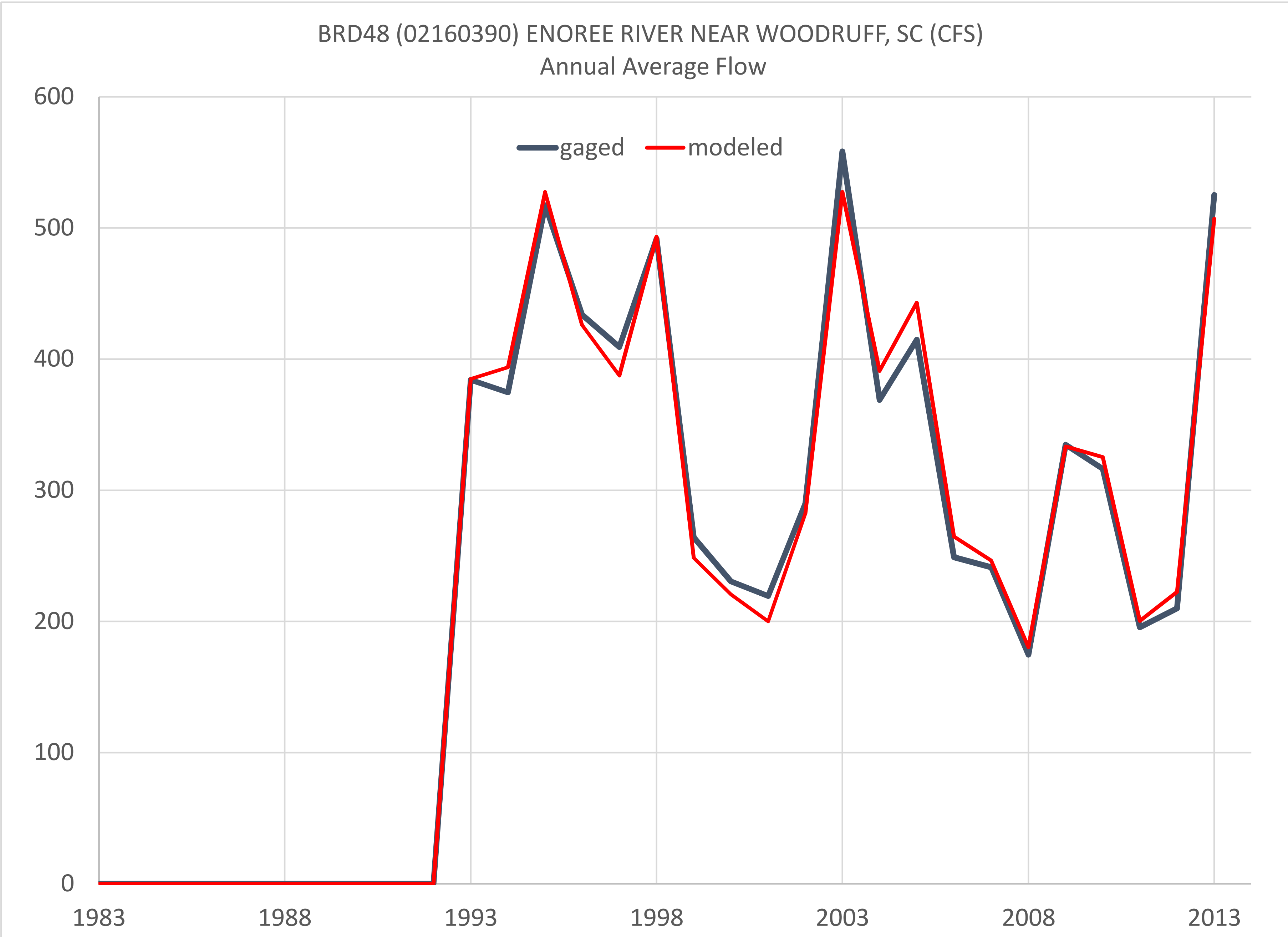

BRD46 (02160326) ENOREE RIVER AT PELHAM, SC
Monthly Mean Flow (CFS)
gaged
modeled
0
50
100
150
200
250
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


BRD46 (02160326) ENOREE RIVER AT PELHAM, SC
Monthly Flow Percentiles (CFS)
gaged
modeled
700
600
500
400
300
200
100
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

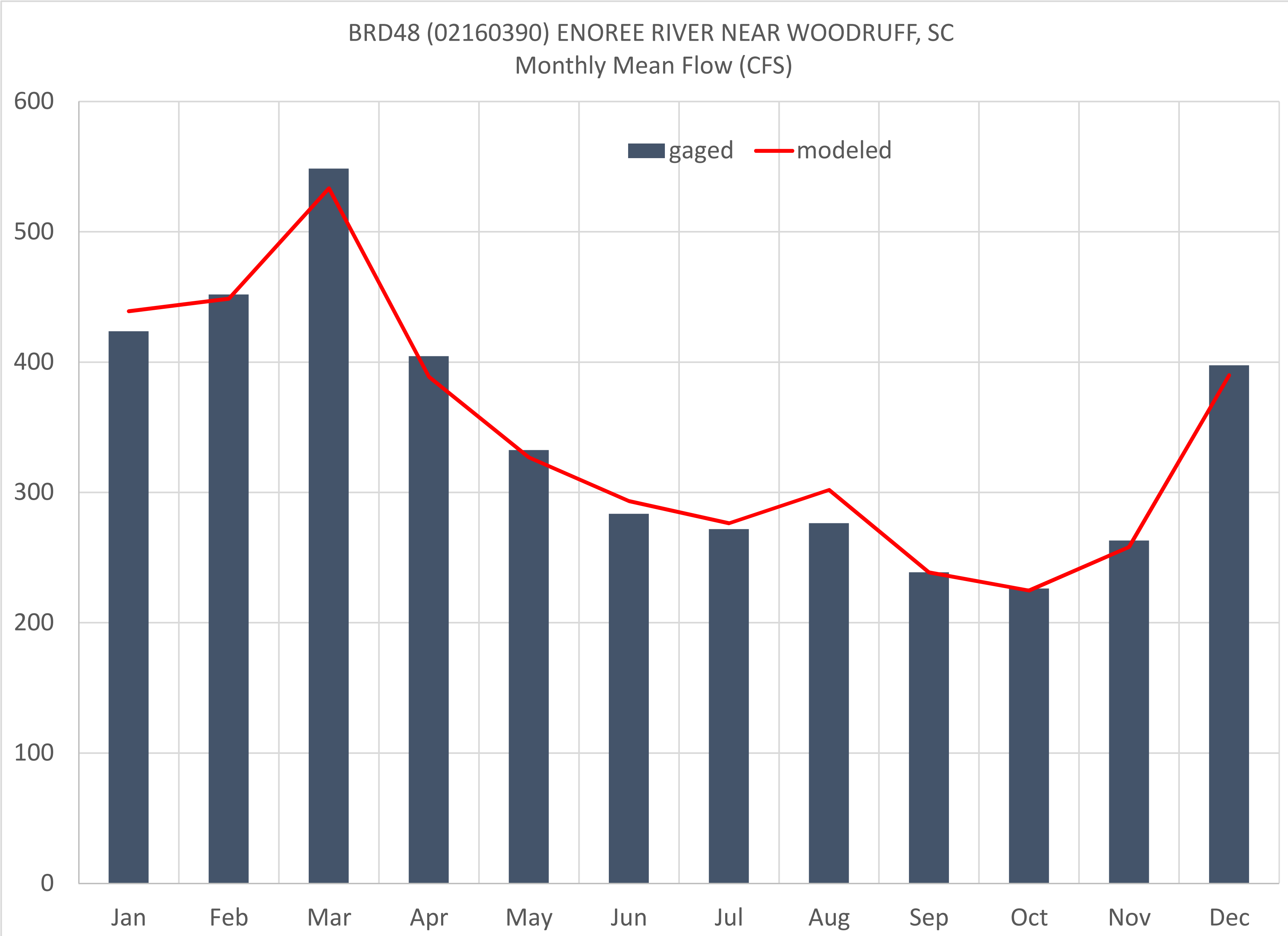

BRD48 (02160390) ENOREE RIVER NEAR WOODRUFF, SC (CFS)
modeled
gaged
1,600
1,400
1,200
1,000
800
600
400
200
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

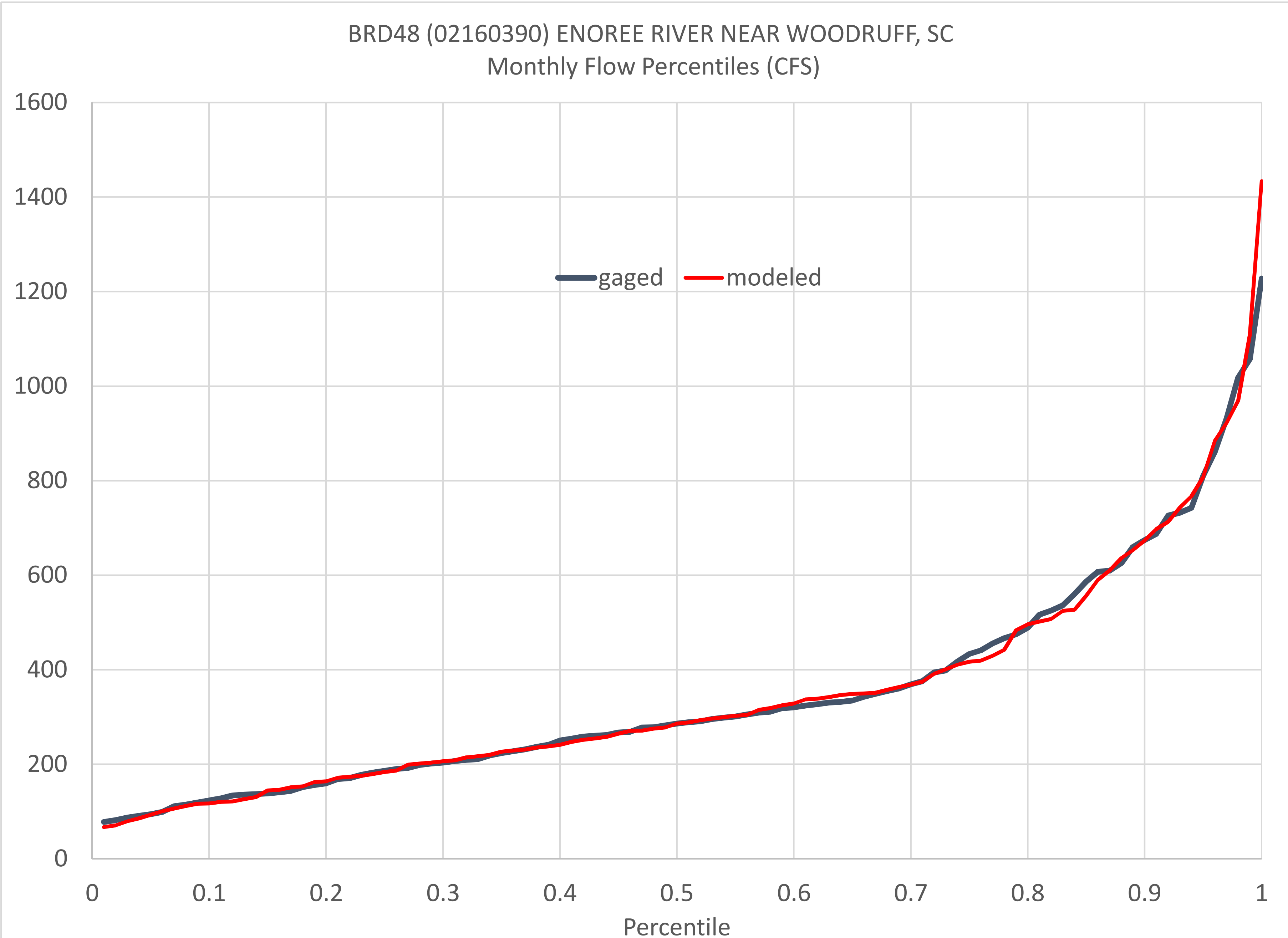


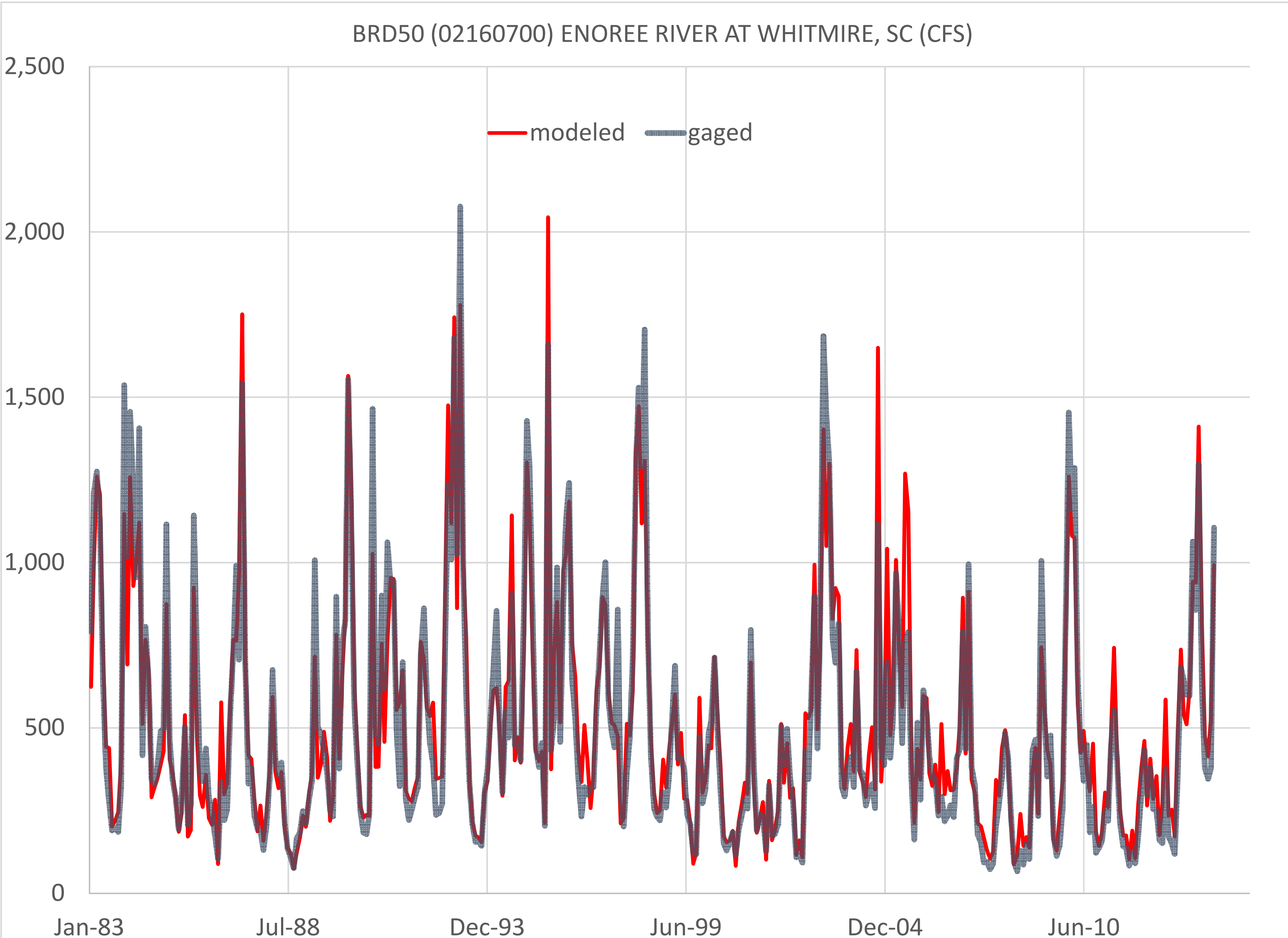
BRD48 (02160390) ENOREE RIVER NEAR WOODRUFF, SC
Cumulative Flow (CFS)
modeled
gaged
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10



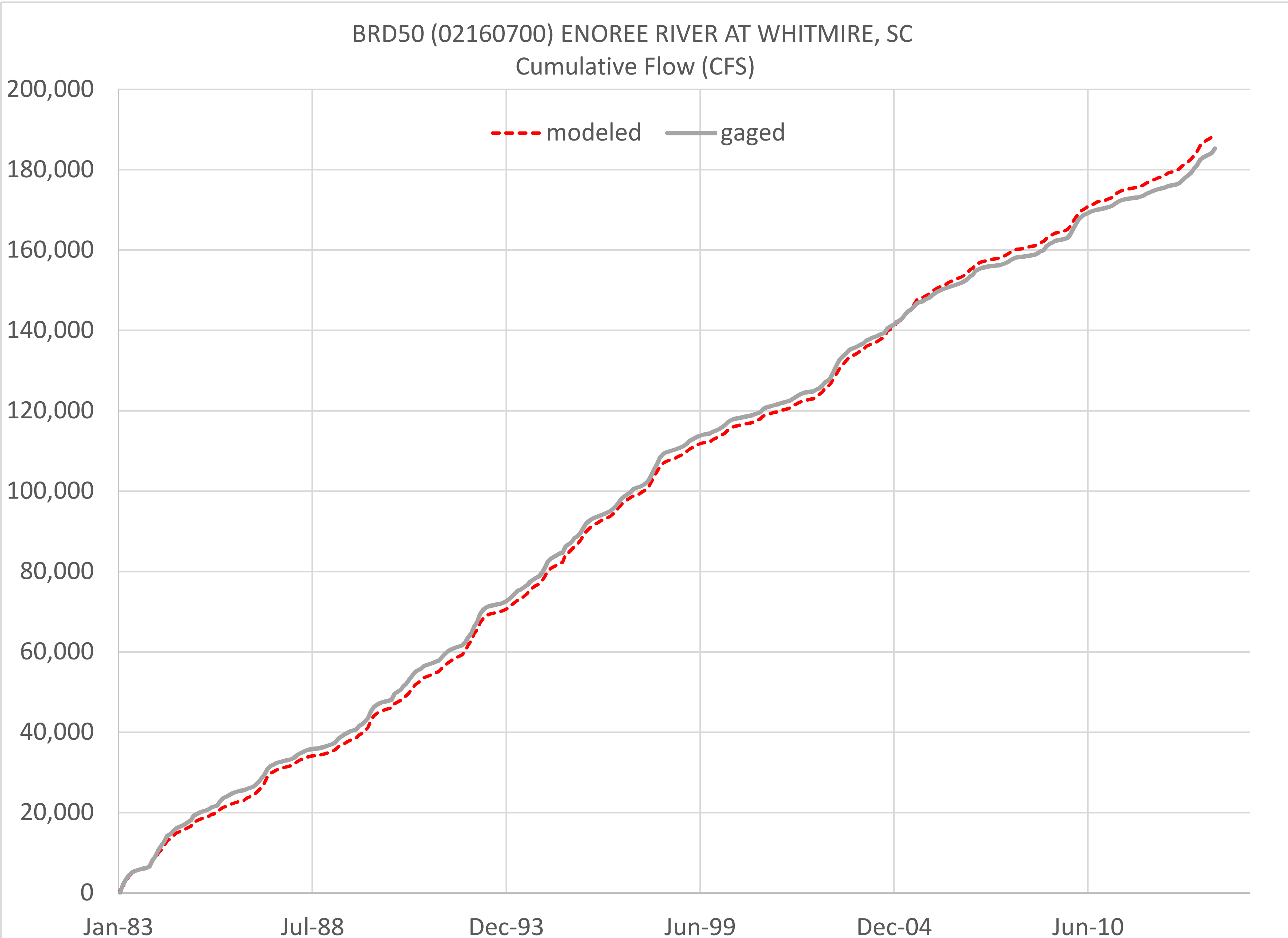
BRD48 (02160390) ENOREE RIVER NEAR WOODRUFF, SC (CFS)
Annual Average Flow
gaged
modeled
600
500
400
300
200
100
0
1983
1988
1993
1998
2003
2008
2013


BRD48 (02160390) ENOREE RIVER NEAR WOODRUFF, SC
Monthly Mean Flow (CFS)
600
500
400
300
200
100
0
gaged
modeled
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

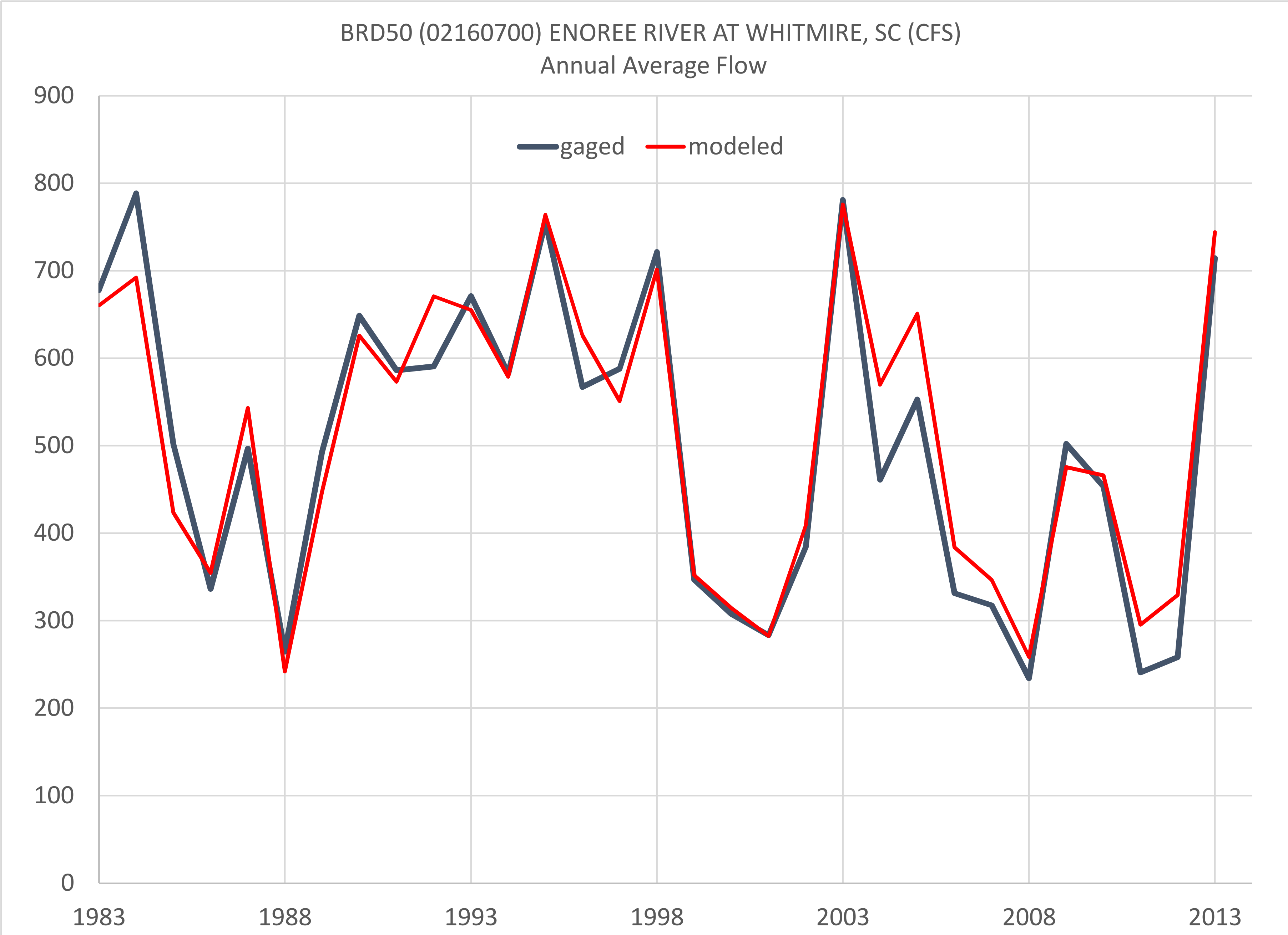

BRD48 (02160390) ENOREE RIVER NEAR WOODRUFF, SC
Monthly Flow Percentiles (CFS)
gaged
modeled
0
200
400
600
800
1000
1200
1400
1600
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

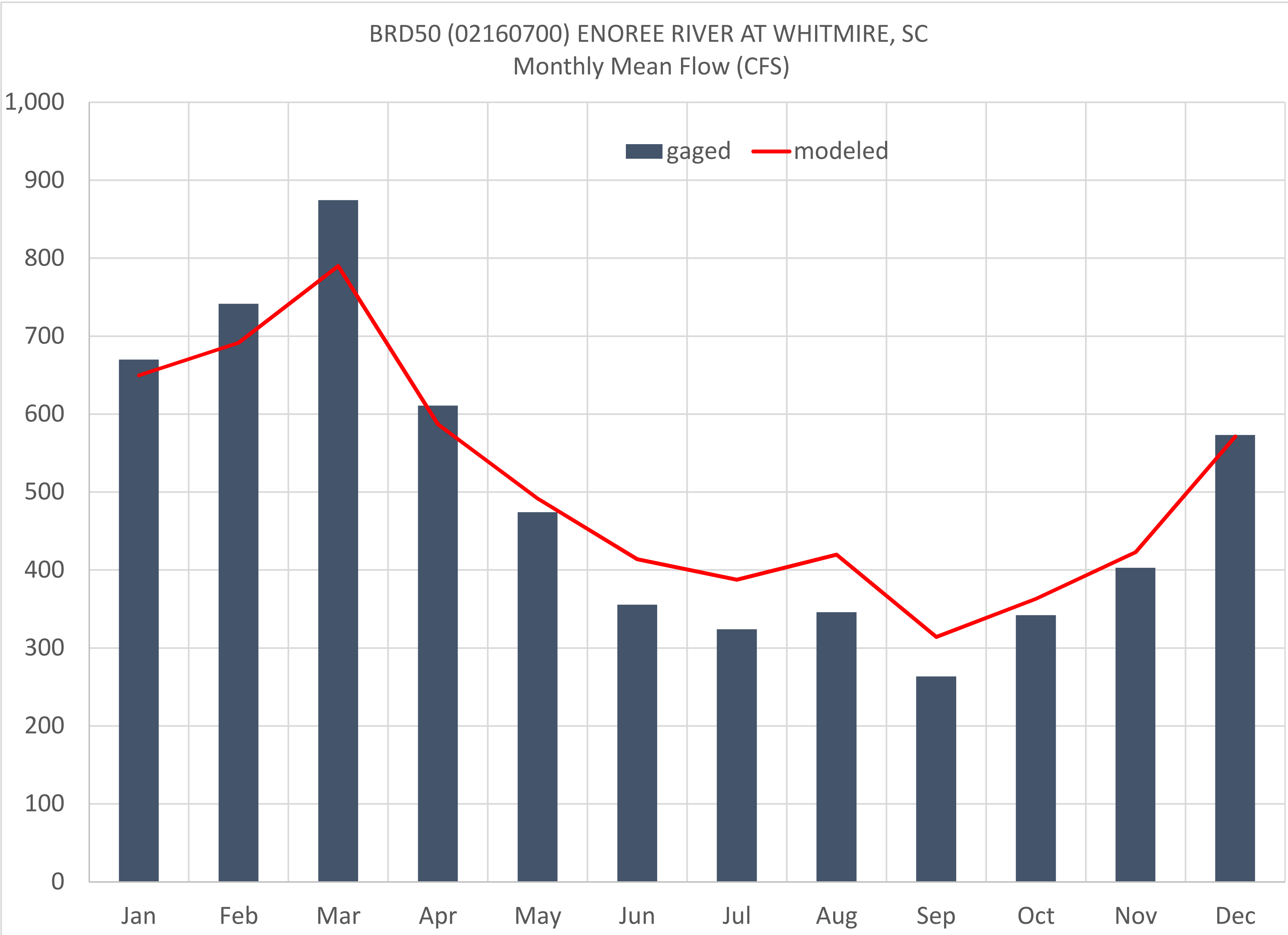


BRD50 (02160700) ENOREE RIVER AT WHITMIRE, SC (CFS)
modeled
gaged
2,500
2,000
1,500
1,000
500
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

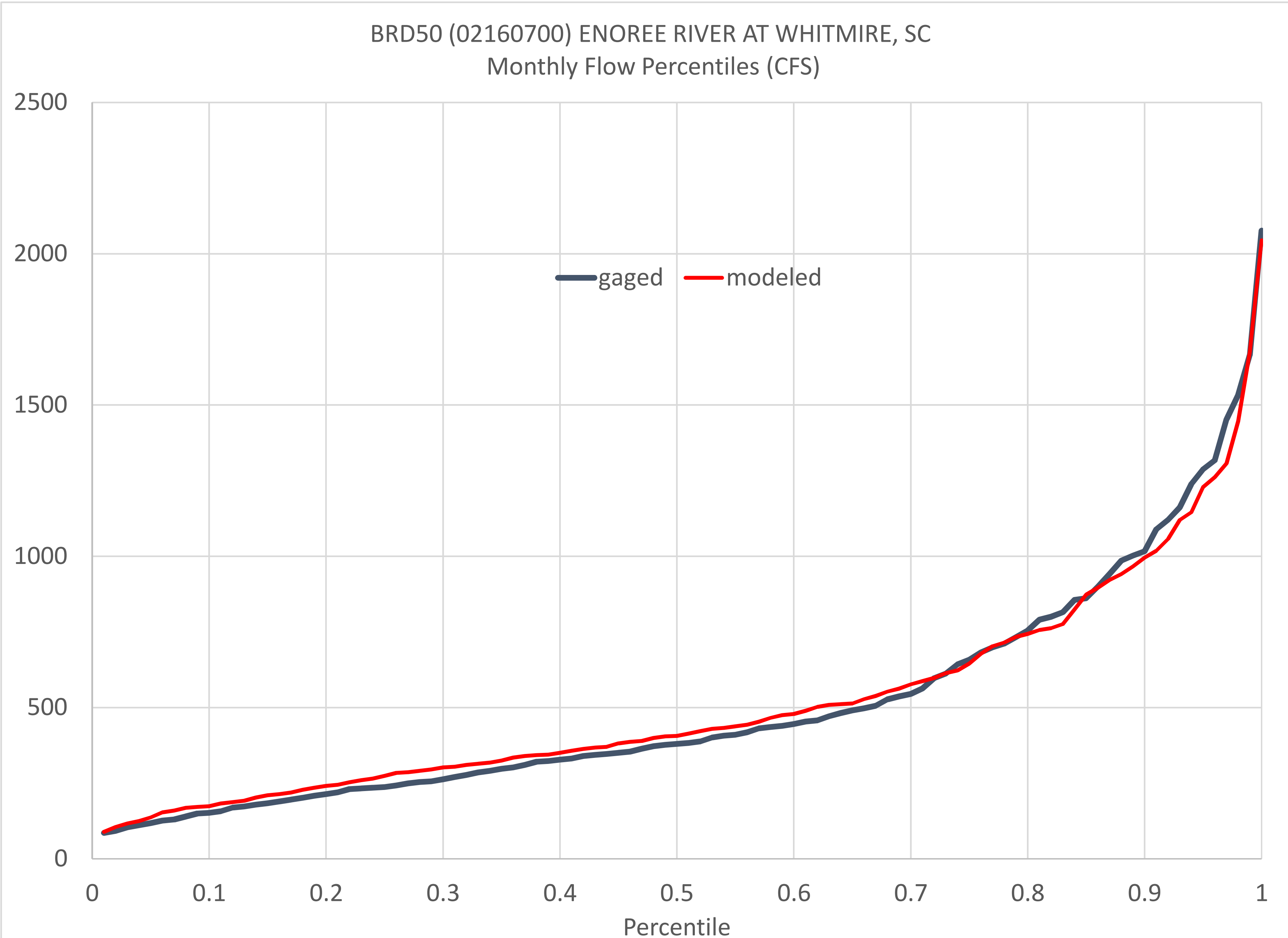


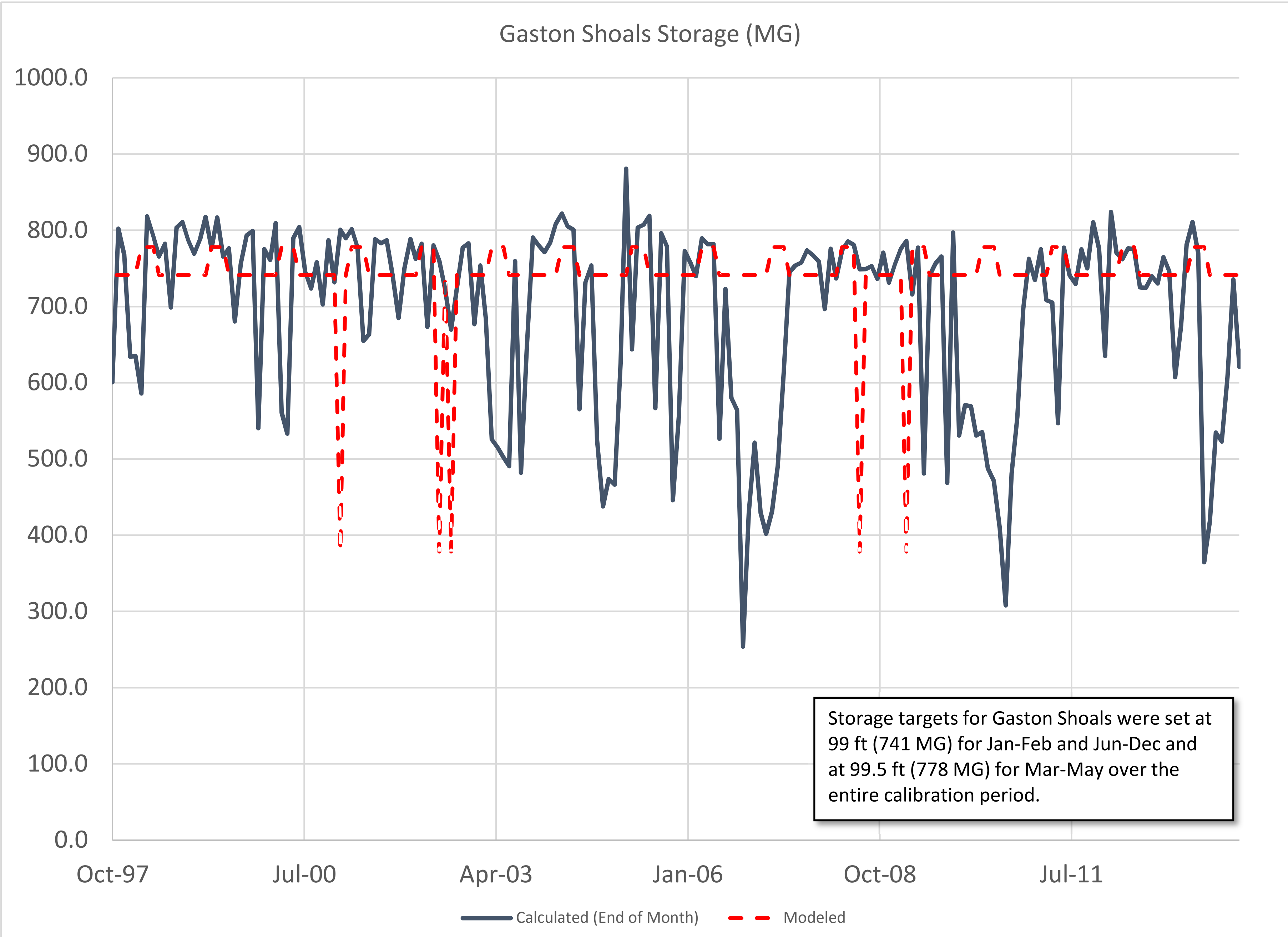
BRD50 (02160700) ENOREE RIVER AT WHITMIRE, SC
Cumulative Flow (CFS)
modeled
gaged
200,000
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

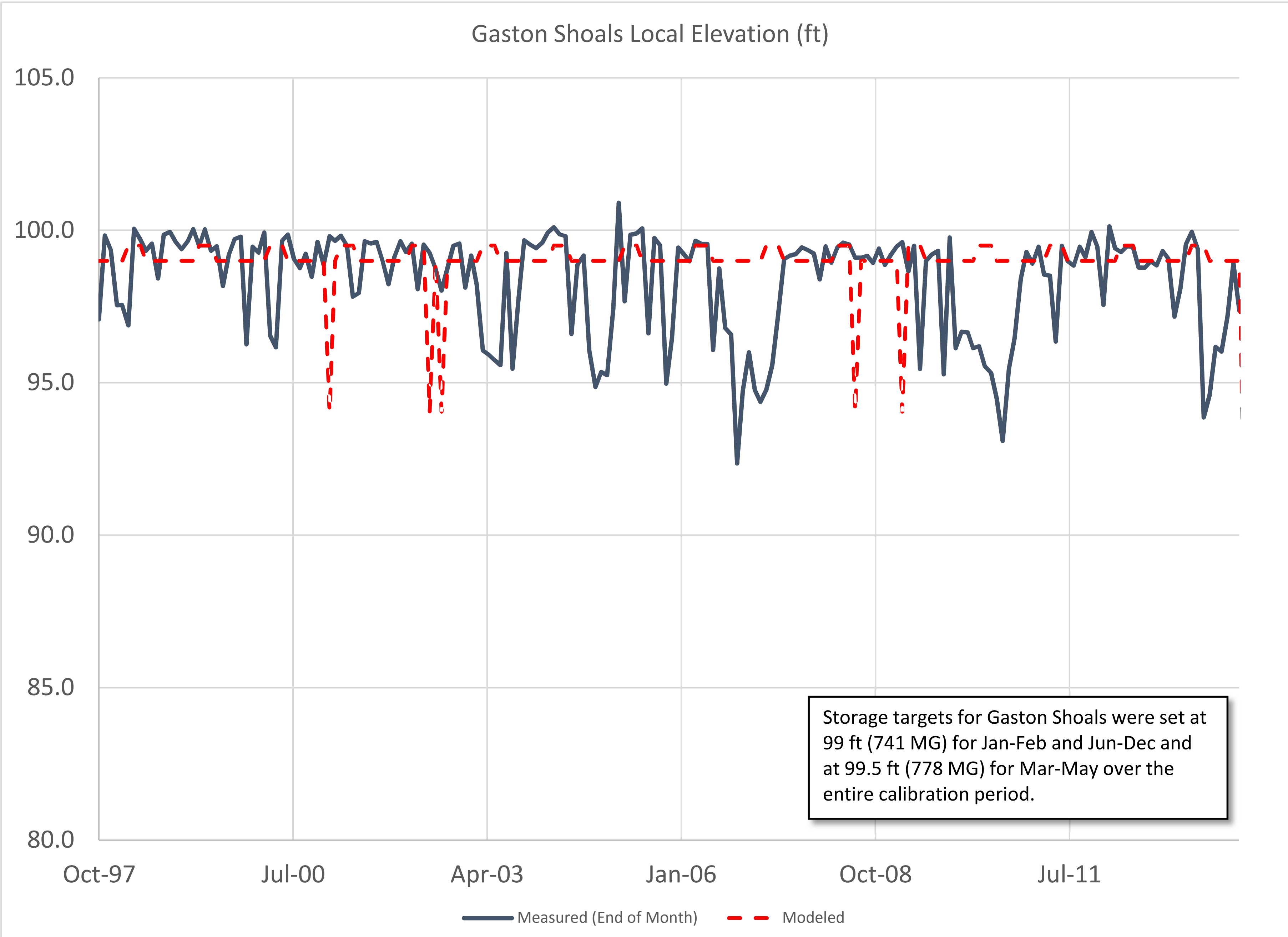

BRD50 (02160700) ENOREE RIVER AT WHITMIRE, SC (CFS)
Annual Average Flow
gaged
modeled
900
800
700
600
500
400
300
200
100
0
1983
1988
1993
1998
2003
2008
2013

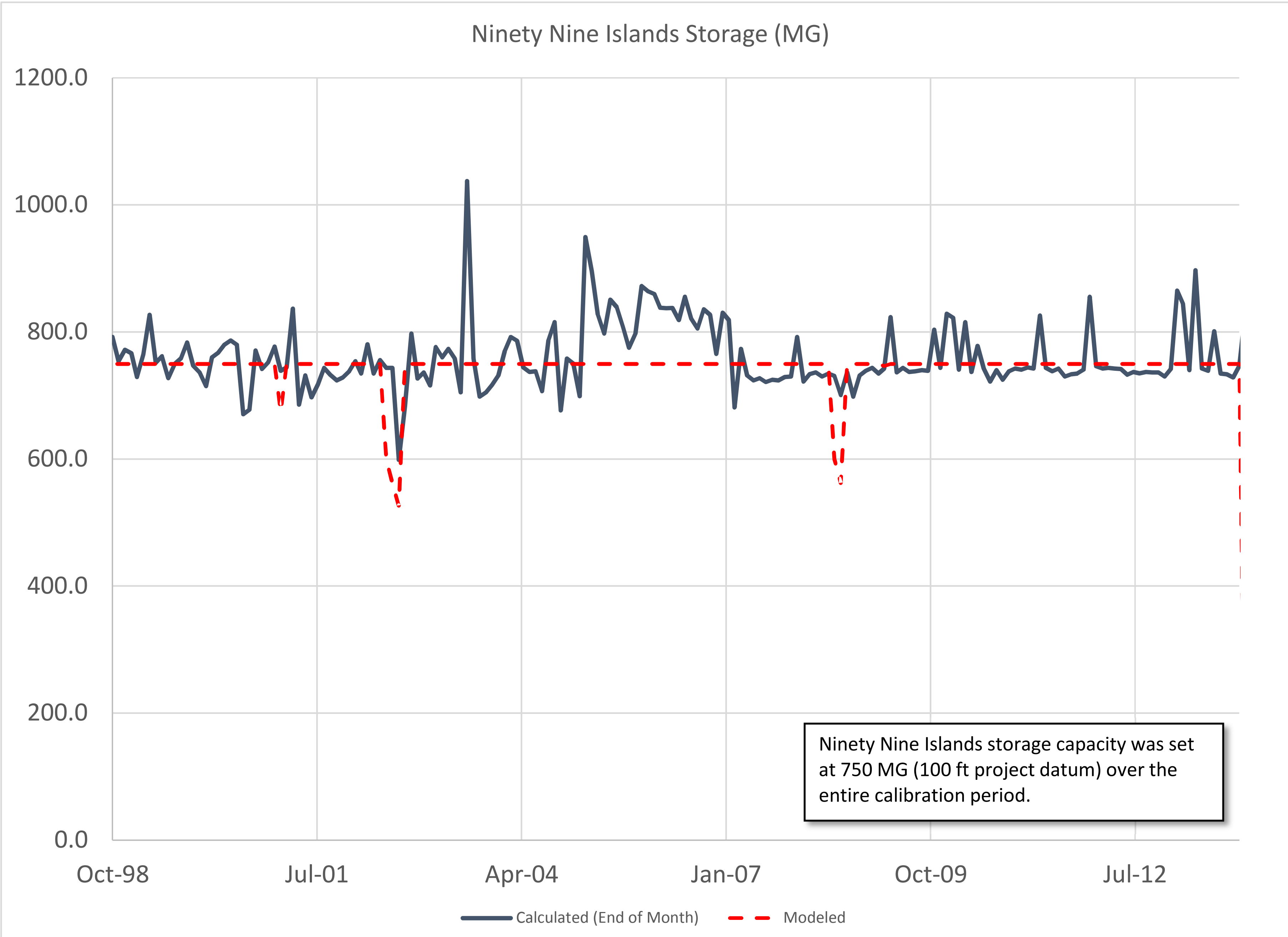


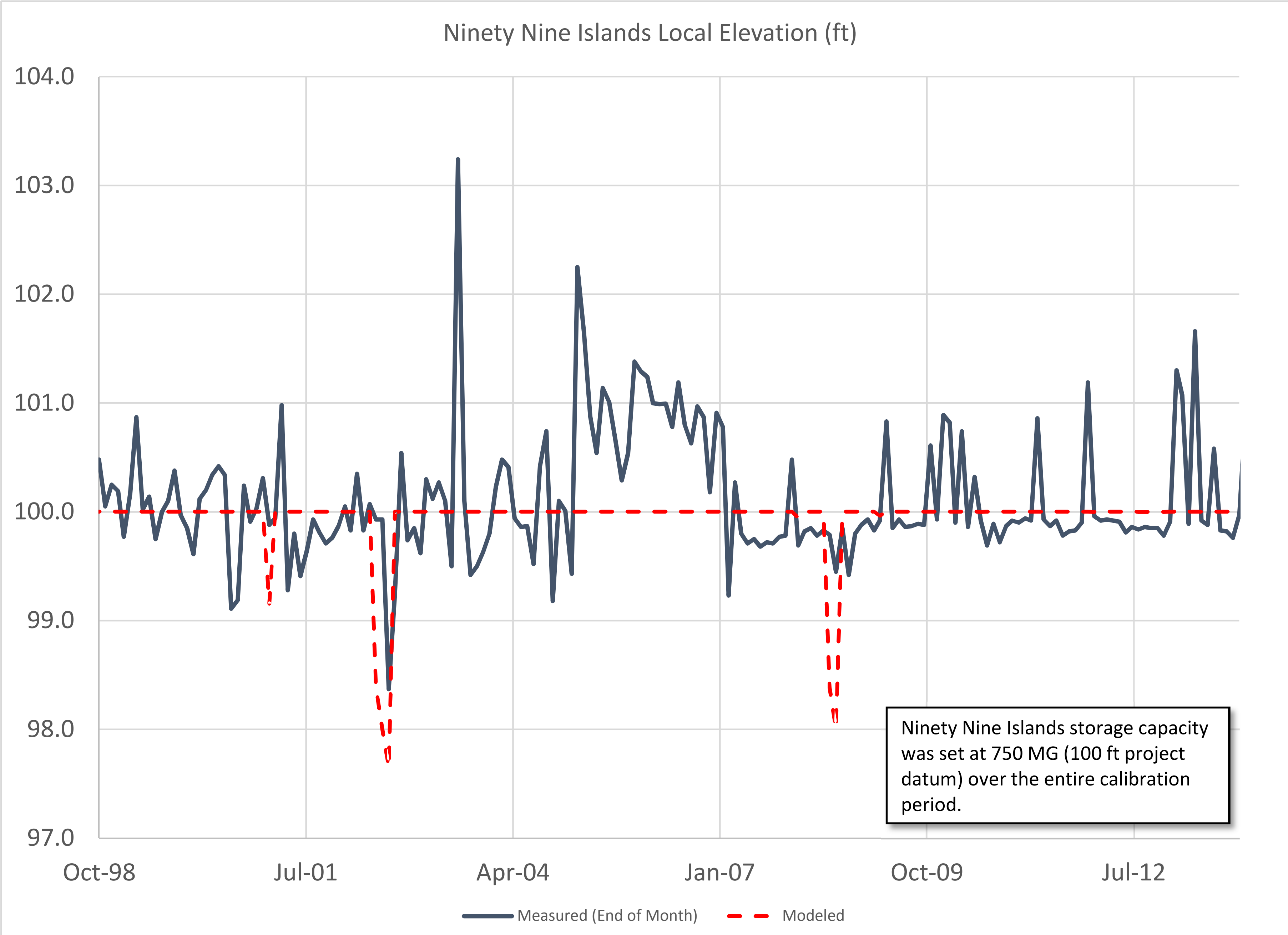
BRD50 (02160700) ENOREE RIVER AT WHITMIRE, SC
Monthly Mean Flow (CFS)
1,000
900
800
700
600
500
400
300
200
100
0
gaged
modeled
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


BRD50 (02160700) ENOREE RIVER AT WHITMIRE, SC
Monthly Flow Percentiles (CFS)
gaged
modeled
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

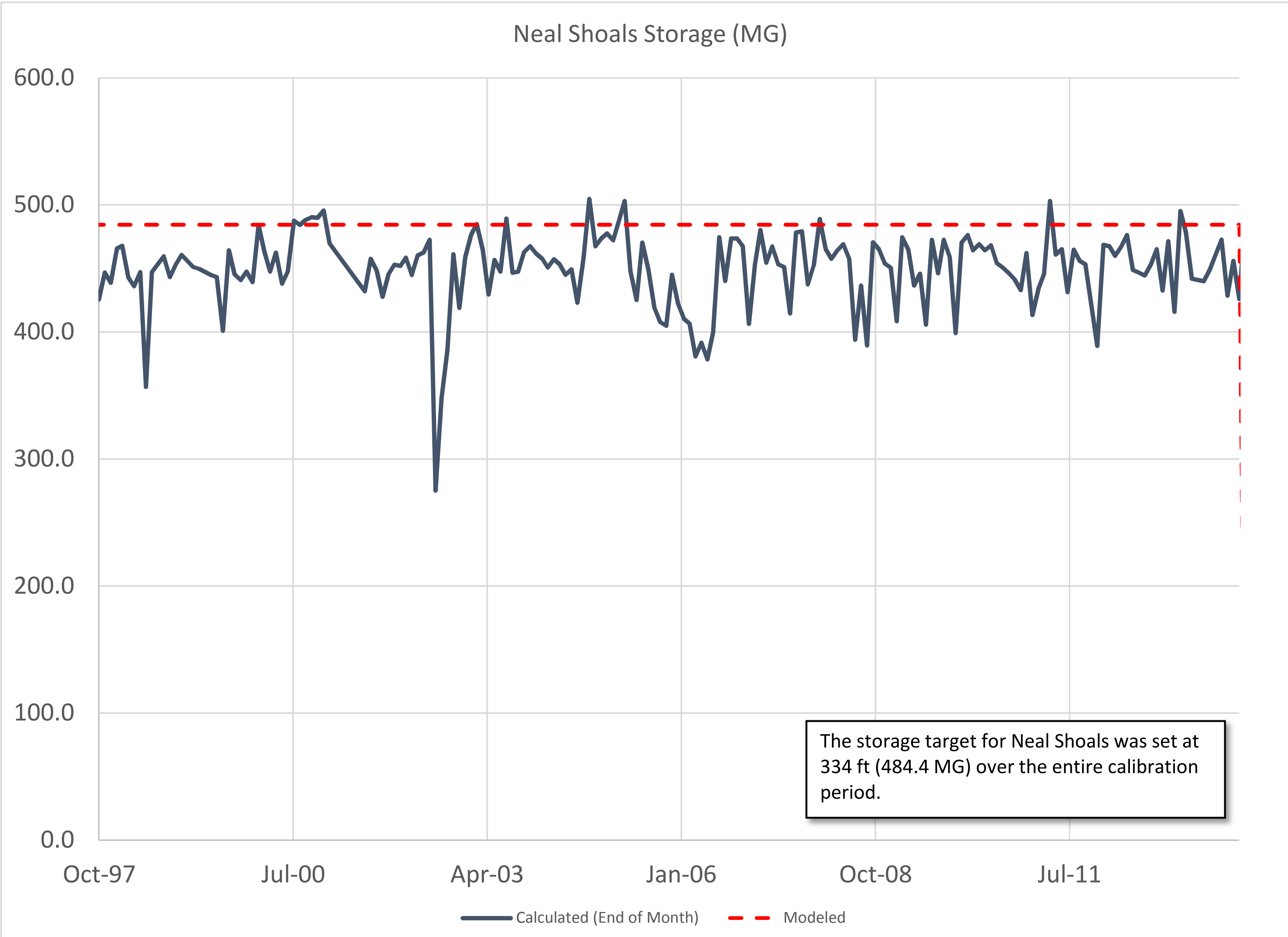

Gaston Shoals Storage (MG)
1000.0
900.0
800.0
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0
Oct-97
Jul-00
Apr-03
Jan-06
Oct-08
Jul-11
Calculated (End of Month)
Modeled
Storage targets for Gaston Shoals were set at 99 ft (741 MG) for Jan-Feb and Jun-Dec and at 99.5 ft (778 MG) for Mar-May over the entire calibration period.


Gaston Shoals Local Elevation (ft)
105.0
100.0
95.0
90.0
85.0
80.0
Oct-97
Jul-00
Apr-03
Jan-06
Oct-08
Jul-11
Storage targets for Gaston Shoals were set at 99 ft (741 MG) for Jan-Feb and Jun-Dec and at 99.5 ft (778 MG) for Mar-May over the entire calibration period.
Measured (End of Month)
Modeled

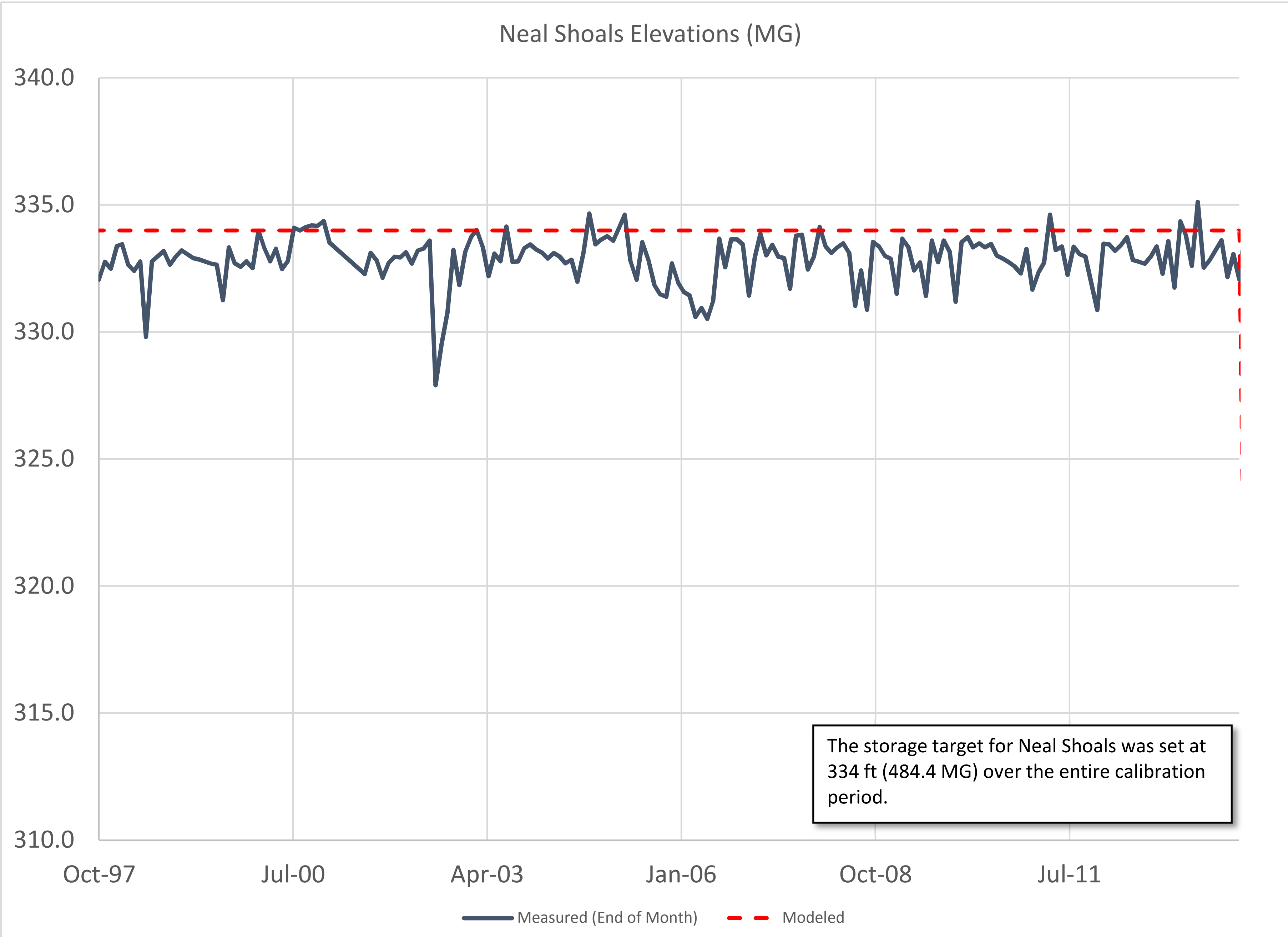

Ninety Nine Islands Storage (MG)
1200.0
1000.0
800.0
600.0
400.0
200.0
0.0
Oct-98
Jul-01
Apr-04
Jan-07
Oct-09
Jul-12
Calculated (End of Month)
Modeled
Ninety Nine Islands storage capacity was set at 750 MG (100 ft project datum) over the entire calibration period.

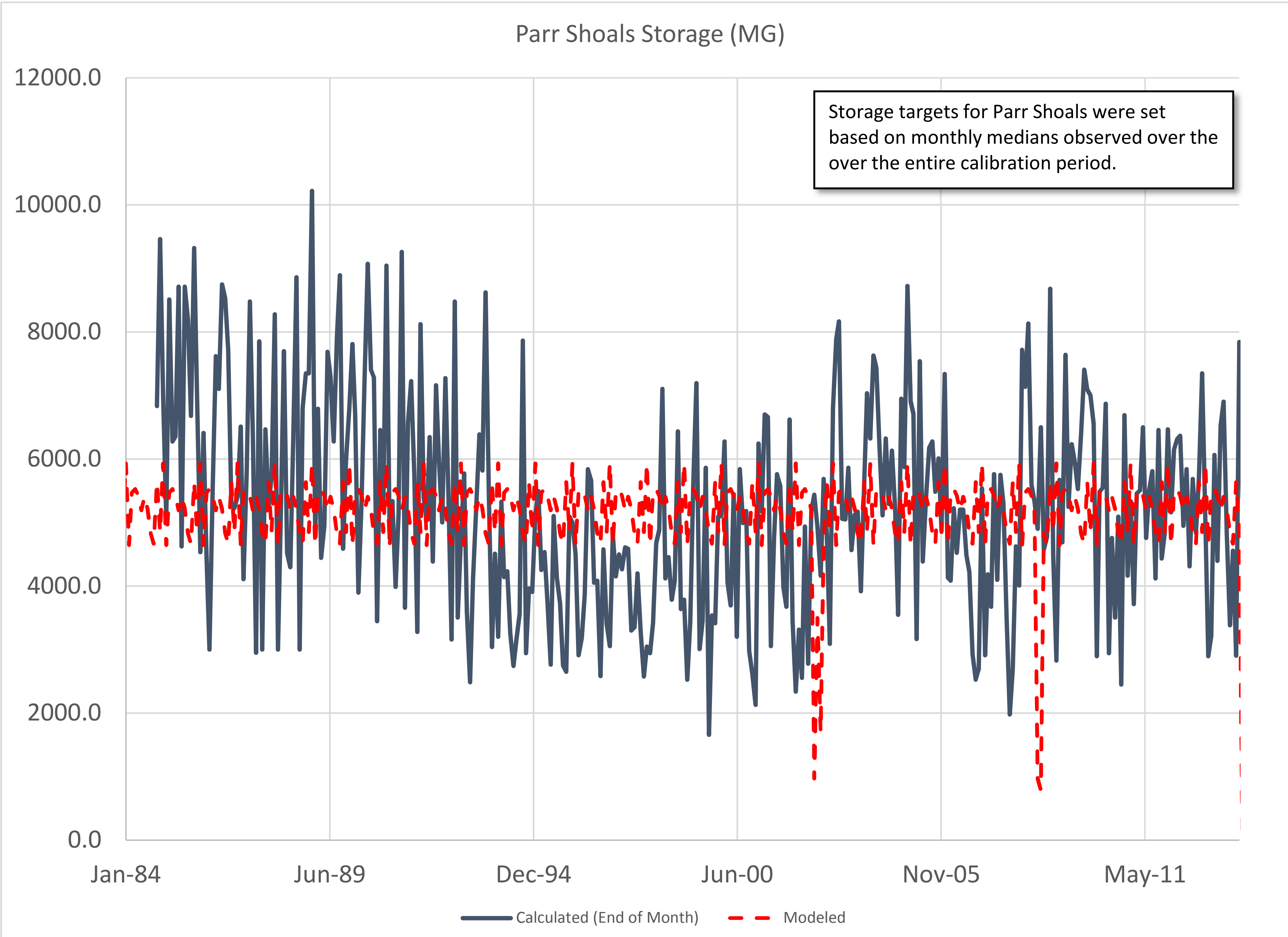


Ninety Nine Islands Local Elevation (ft)
104.0
103.0
102.0
101.0
100.0
99.0
98.0
97.0
Oct-98
Jul-01
Apr-04
Jan-07
Oct-09
Jul-12
Measured (End of Month)
Modeled
Ninety Nine Islands storage capacity was set at 750 MG (100 ft project datum) over the entire calibration period.

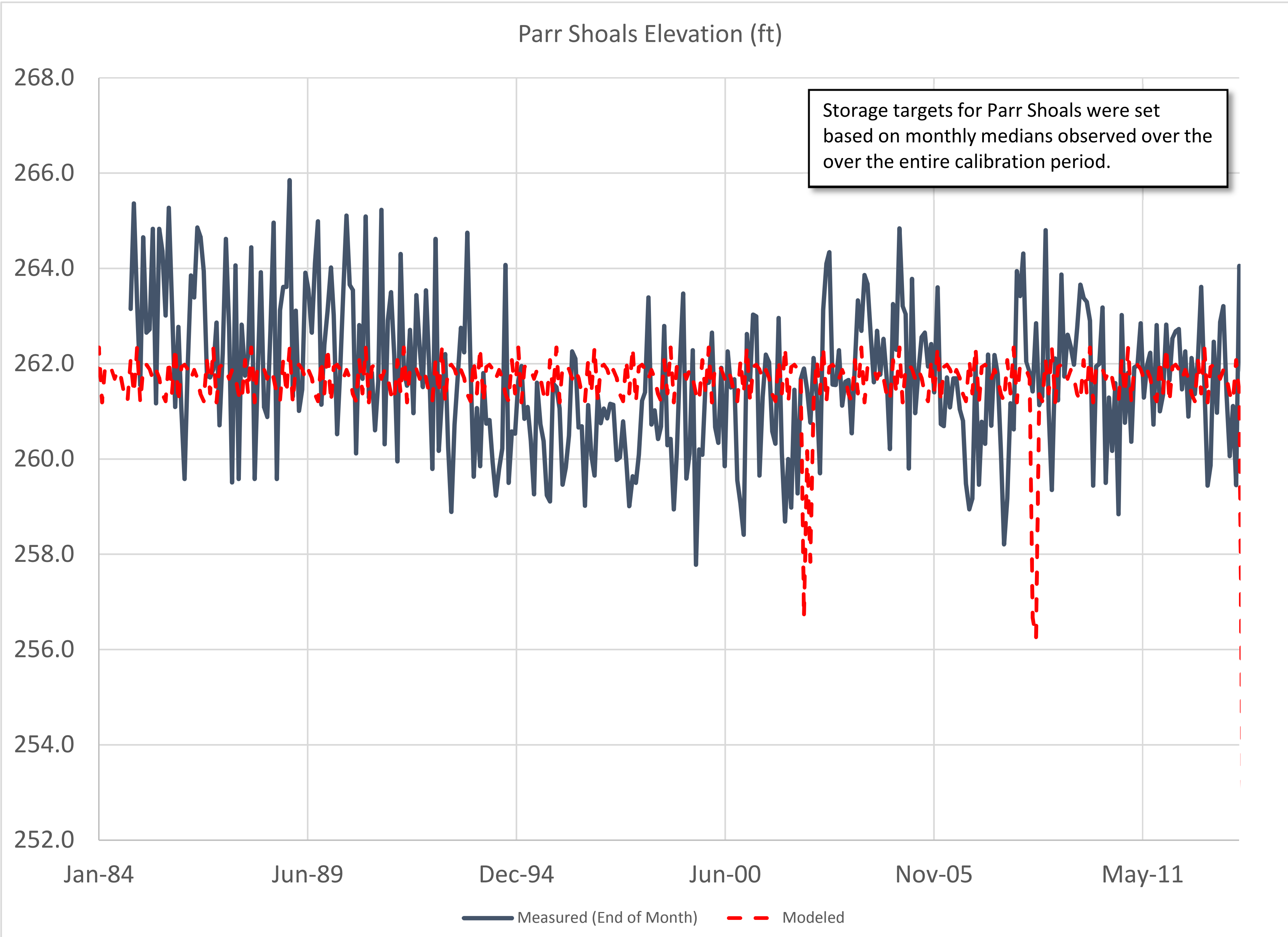


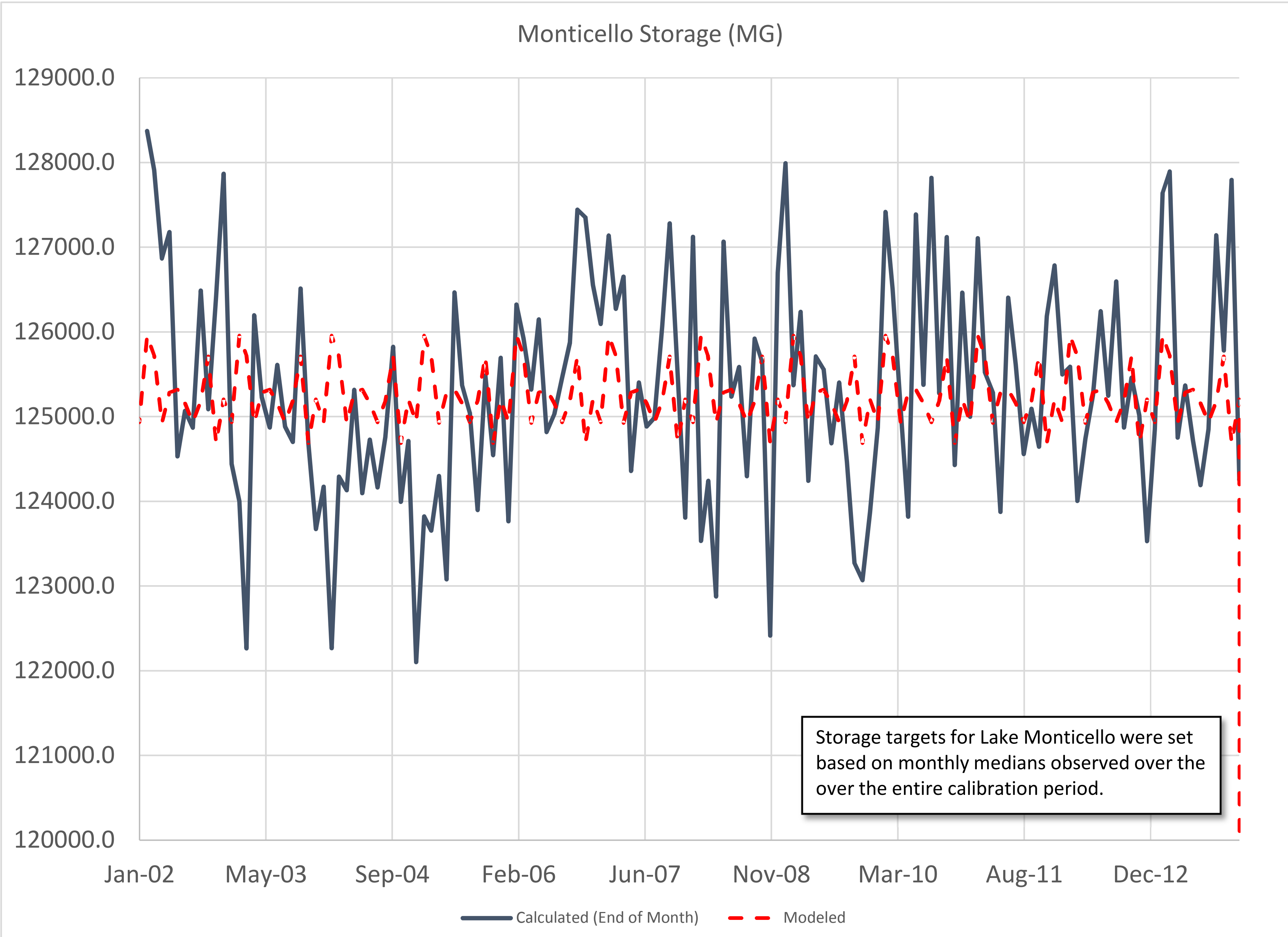
Neal Shoals Storage (MG)
600.0
500.0
400.0
300.0
200.0
100.0
0.0
Oct-97
Jul-00
Apr-03
Jan-06
Oct-08
Jul-11
The storage target for Neal Shoals was set at 334 ft (484.4 MG) over the entire calibration period.
Calculated (End of Month)
Modeled


Neal Shoals Elevations (MG)
340.0
335.0
330.0
325.0
320.0
315.0
310.0
Oct-97
Jul-00
Apr-03
Jan-06
Oct-08
Jul-11
Measured (End of Month)
Modeled
The storage target for Neal Shoals was set at 334 ft (484.4 MG) over the entire calibration period.

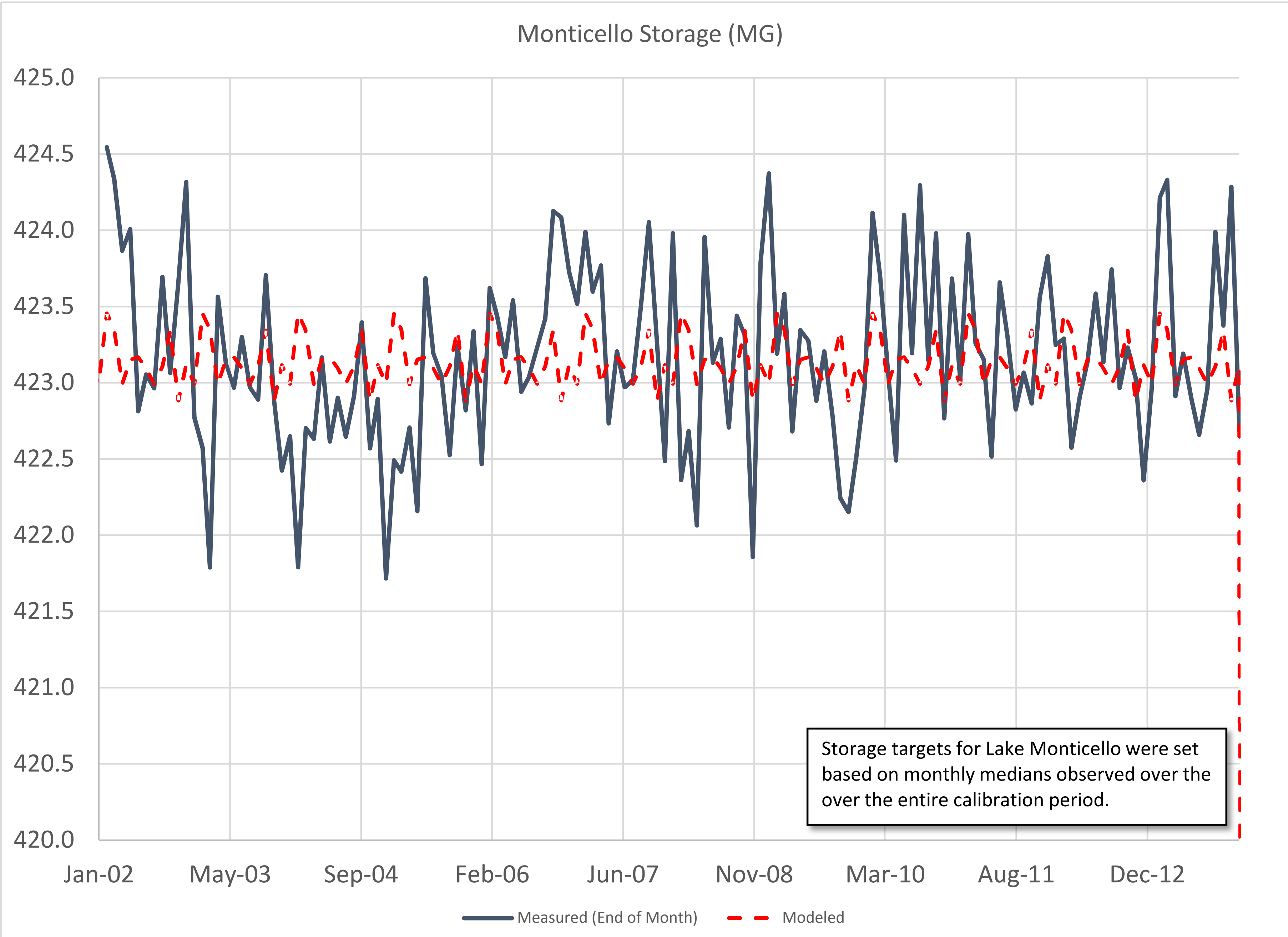


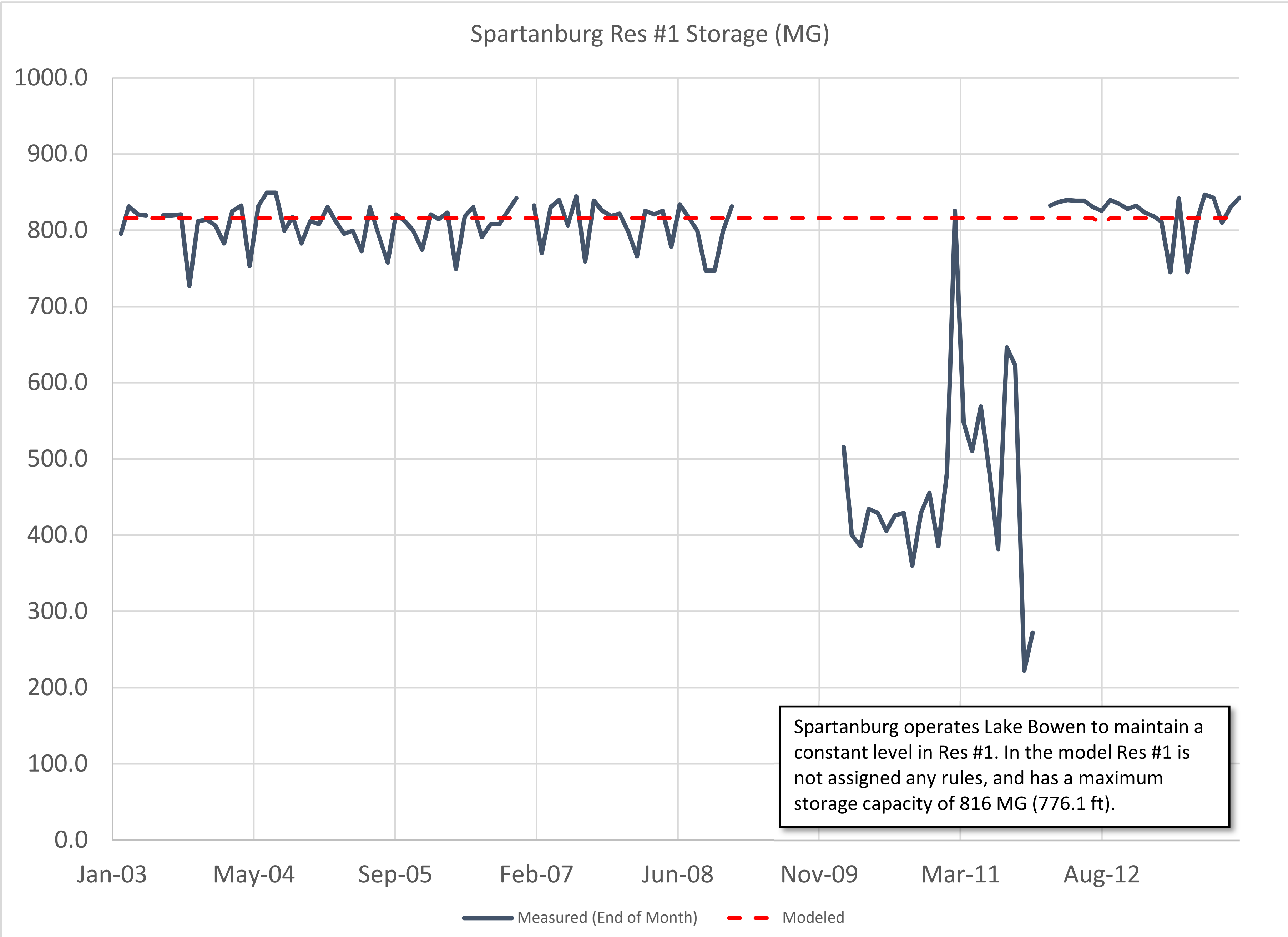
Parr Shoals Storage (MG)
12000.0
10000.0
8000.0
6000.0
4000.0
2000.0
0.0
Jan-84
Jun-89
Dec-94
Jun-00
Nov-05
May-11
Storage targets for Parr Shoals were set based on monthly medians observed over the over the entire calibration period.
Calculated (End of Month)
Modeled

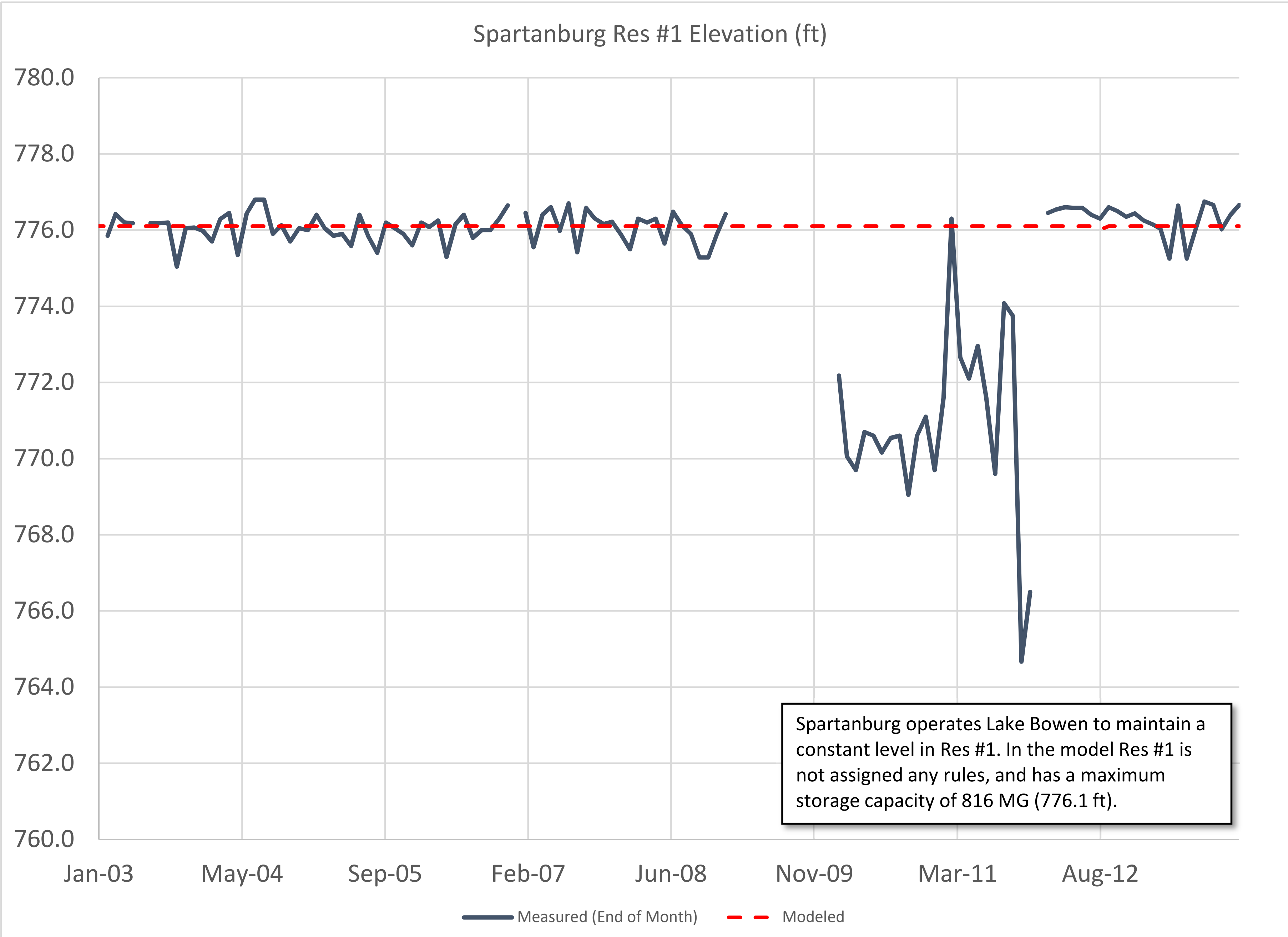

Parr Shoals Elevation (ft)
268.0
266.0
264.0
262.0
260.0
258.0
256.0
254.0
252.0
Jan-84
Jun-89
Dec-94
Jun-00
Nov-05
May-11
Storage targets for Parr Shoals were set based on monthly medians observed over the over the entire calibration period.
Measured (End of Month)
Modeled

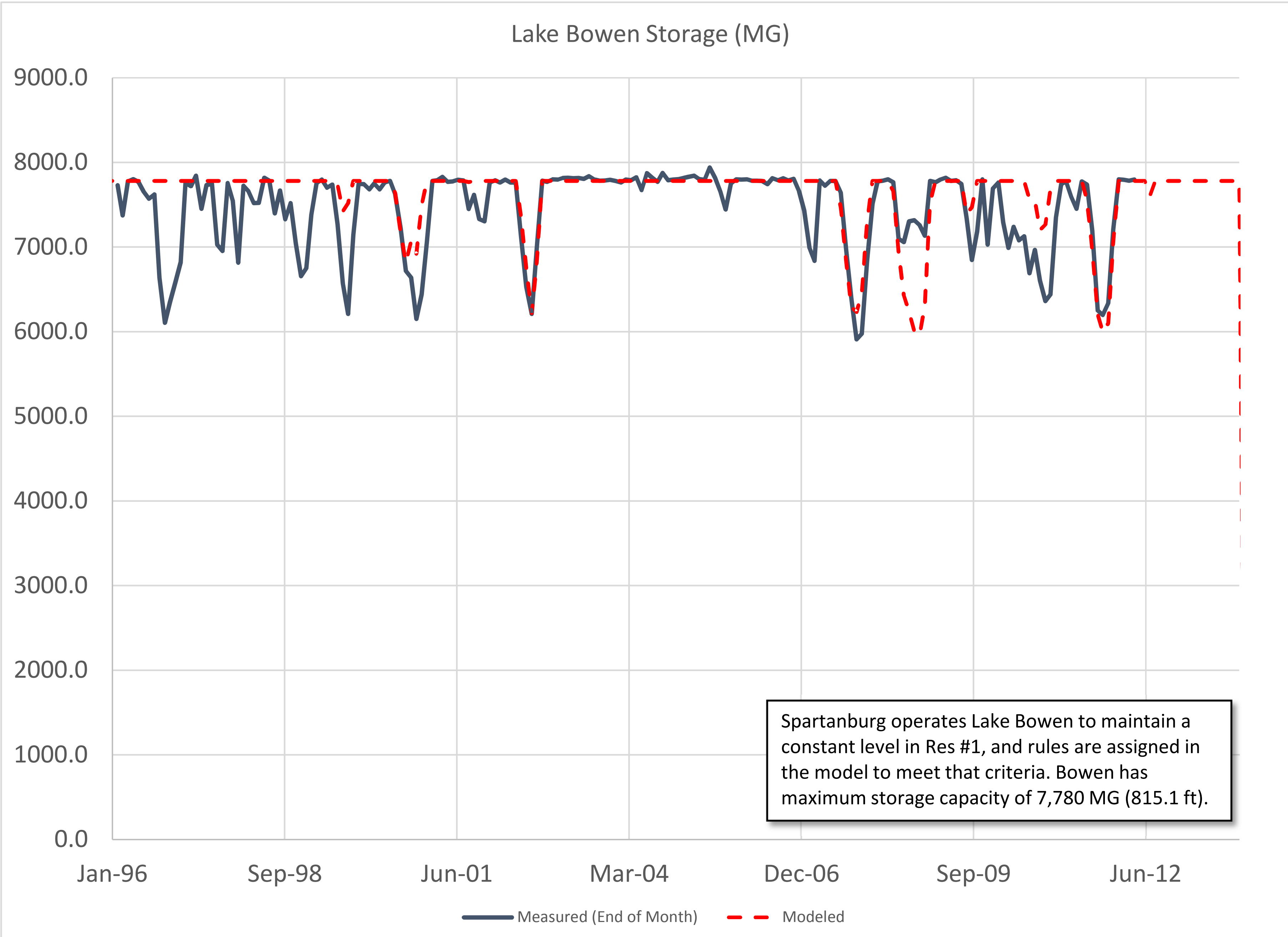


Monticello Storage (MG)
129000.0
128000.0
127000.0
126000.0
125000.0
124000.0
123000.0
122000.0
121000.0
120000.0
Jan-02
May-03
Sep-04
Feb-06
Jun-07
Nov-08
Mar-10
Aug-11
Dec-12
Storage targets for Lake Monticello were set based on monthly medians observed over the over the entire calibration period.
Calculated (End of Month)
Modeled

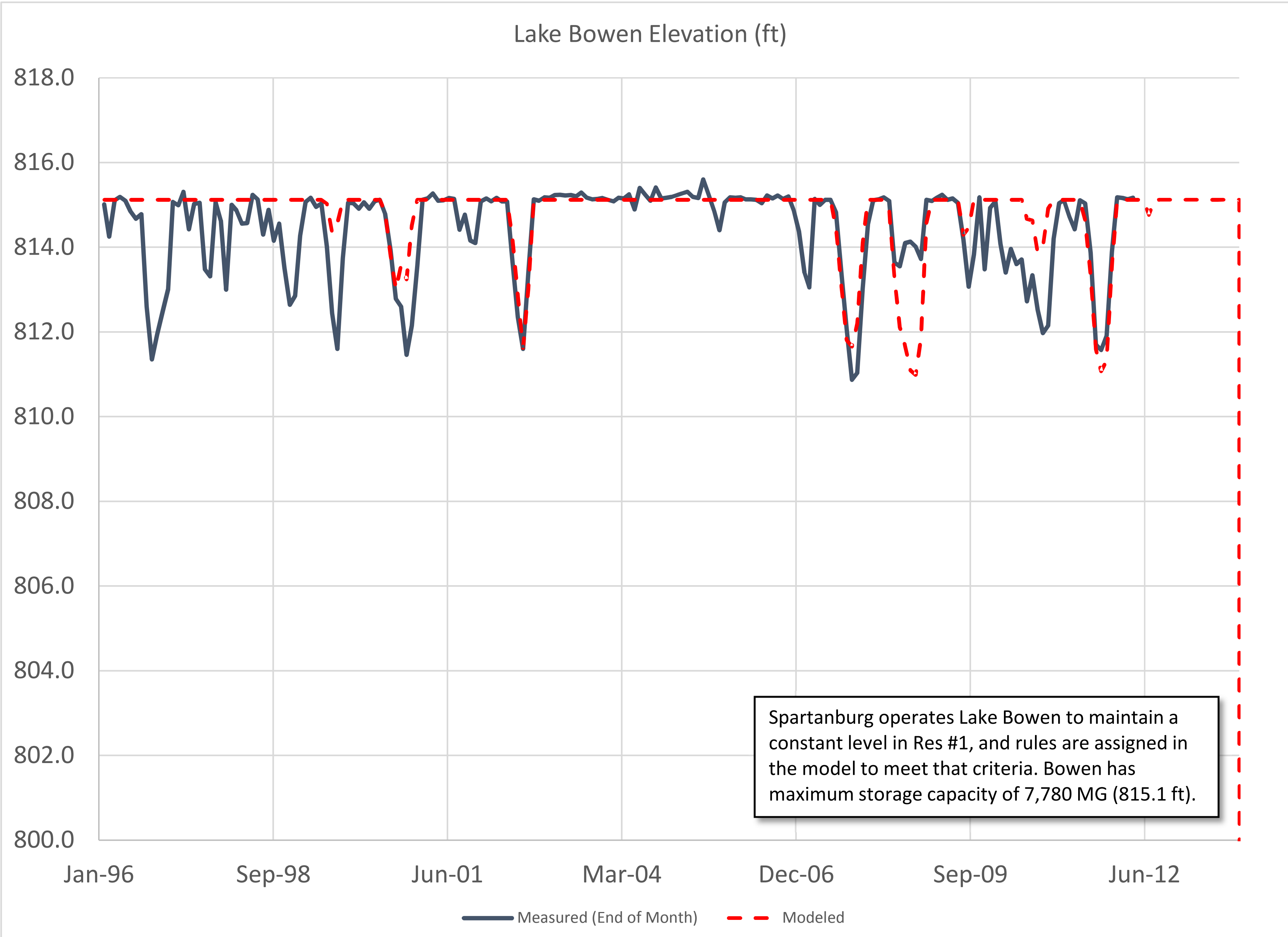

Monticello Storage (MG)
425.0
424.5
424.0
423.5
423.0
422.5
422.0
421.5
421.0
420.5
420.0
Jan-02
May-03
Sep-04
Feb-06
Jun-07
Nov-08
Mar-10
Aug-11
Dec-12
Storage targets for Lake Monticello were set based on monthly medians observed over the over the entire calibration period.
Measured (End of Month)
Modeled

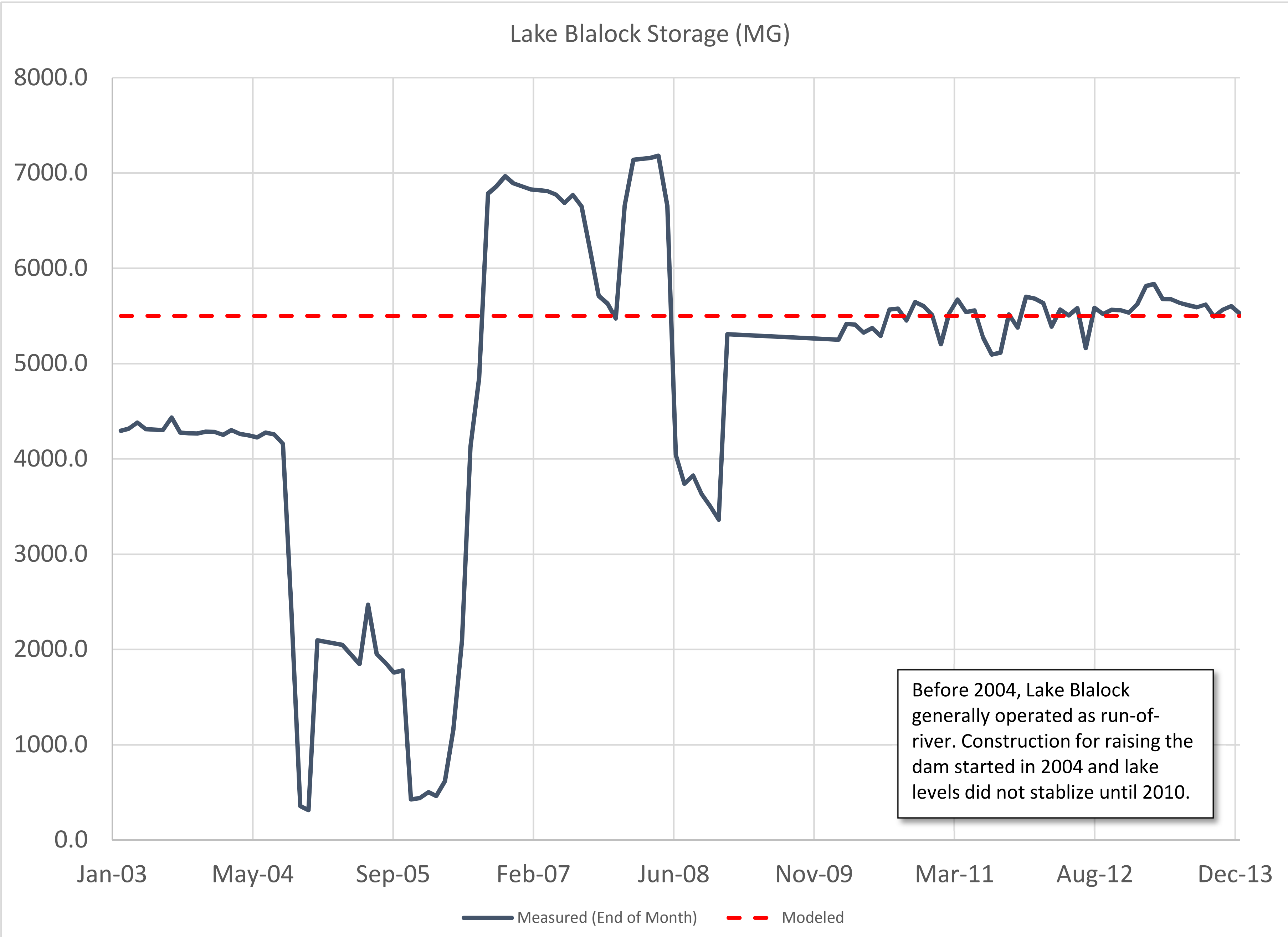

Spartanburg Res #1 Storage (MG)
1000.0
900.0
800.0
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0
Jan-03
May-04
Sep-05
Feb-07
Jun-08
Nov-09
Mar-11
Aug-12
Measured (End of Month)
Modeled
Spartanburg operates Lake Bowen to maintain a constant level in Res #1. In the model Res #1 is not assigned any rules, and has a maximum storage capacity of 816 MG (776.1 ft).


Spartanburg Res #1 Elevation (ft)
780.0
778.0
776.0
774.0
772.0
770.0
768.0
766.0
764.0
762.0
760.0
Jan-03
May-04
Sep-05
Feb-07
Jun-08
Nov-09
Mar-11
Aug-12
Spartanburg operates Lake Bowen to maintain a constant level in Res #1. In the model Res #1 is not assigned any rules, and has a maximum storage capacity of 816 MG (776.1 ft).
Measured (End of Month)
Modeled



Lake Bowen Storage (MG)
9000.0
8000.0
7000.0
6000.0
5000.0
4000.0
3000.0
2000.0
1000.0
0.0
Jan-96
Sep-98
Jun-01
Mar-04
Dec-06
Sep-09
Jun-12
Spartanburg operates Lake Bowen to maintain a constant level in Res #1, and rules are assigned in the model to meet that criteria. Bowen has maximum storage capacity of 7,780 MG (815.1 ft).
Measured (End of Month)
Modeled


Lake Bowen Elevation (ft)
818.0
816.0
814.0
812.0
810.0
808.0
806.0
804.0
802.0
800.0
Jan-96
Sep-98
Jun-01
Mar-04
Dec-06
Sep-09
Jun-12
Measured (End of Month)
Modeled
Spartanburg operates Lake Bowen to maintain a constant level in Res #1, and rules are assigned in the model to meet that criteria. Bowen has maximum storage capacity of 7,780 MG (815.1 ft).

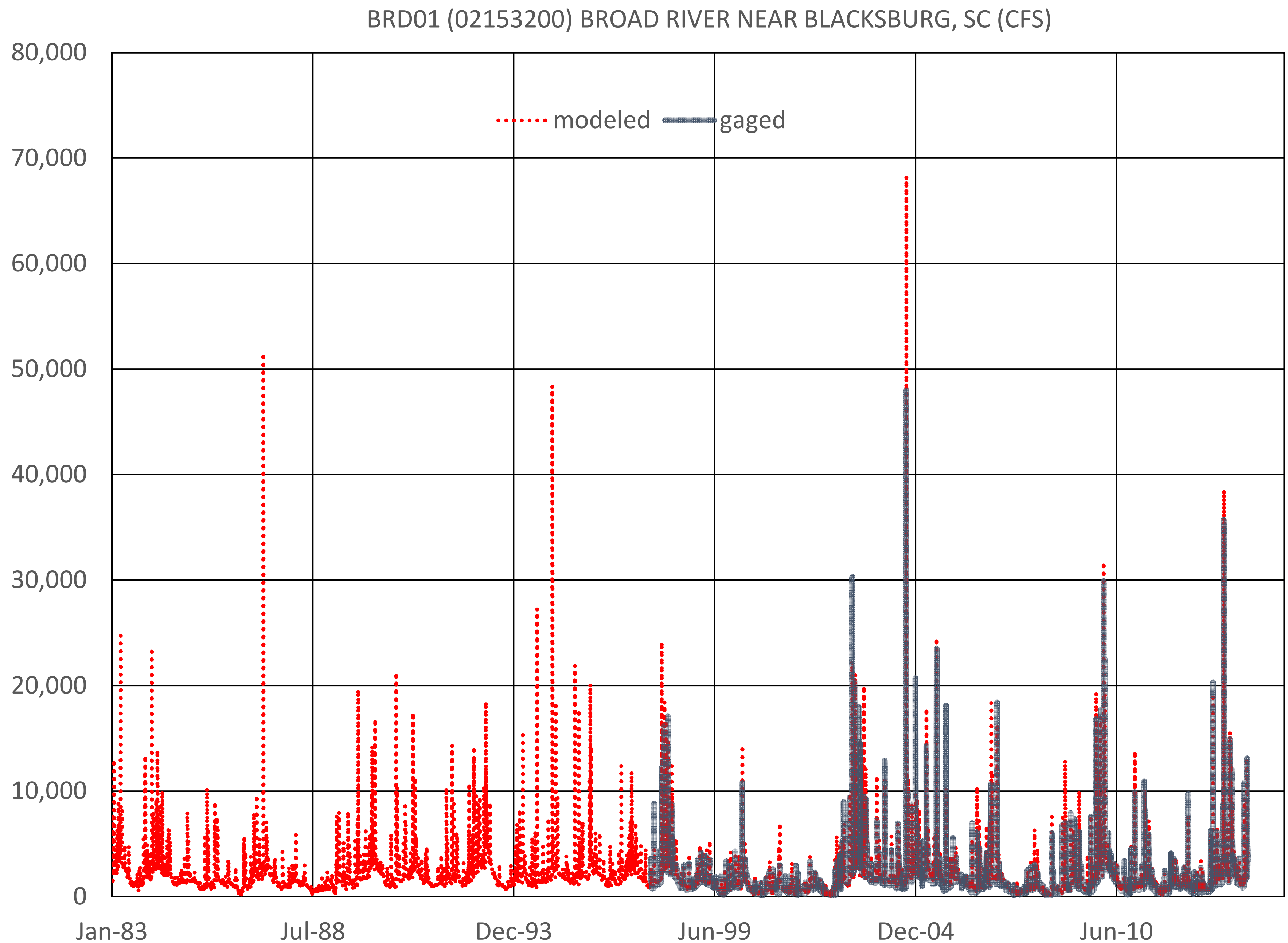


Lake Blalock Storage (MG)
8000.0
7000.0
6000.0
5000.0
4000.0
3000.0
2000.0
1000.0
0.0
Jan-03
May-04
Sep-05
Feb-07
Jun-08
Nov-09
Mar-11
Aug-12
Dec-13
Before 2004, Lake Blalock generally operated as run-of-river. Construction for raising the dam started in 2004 and lake levels did not stablize until 2010.
Measured (End of Month)
Modeled

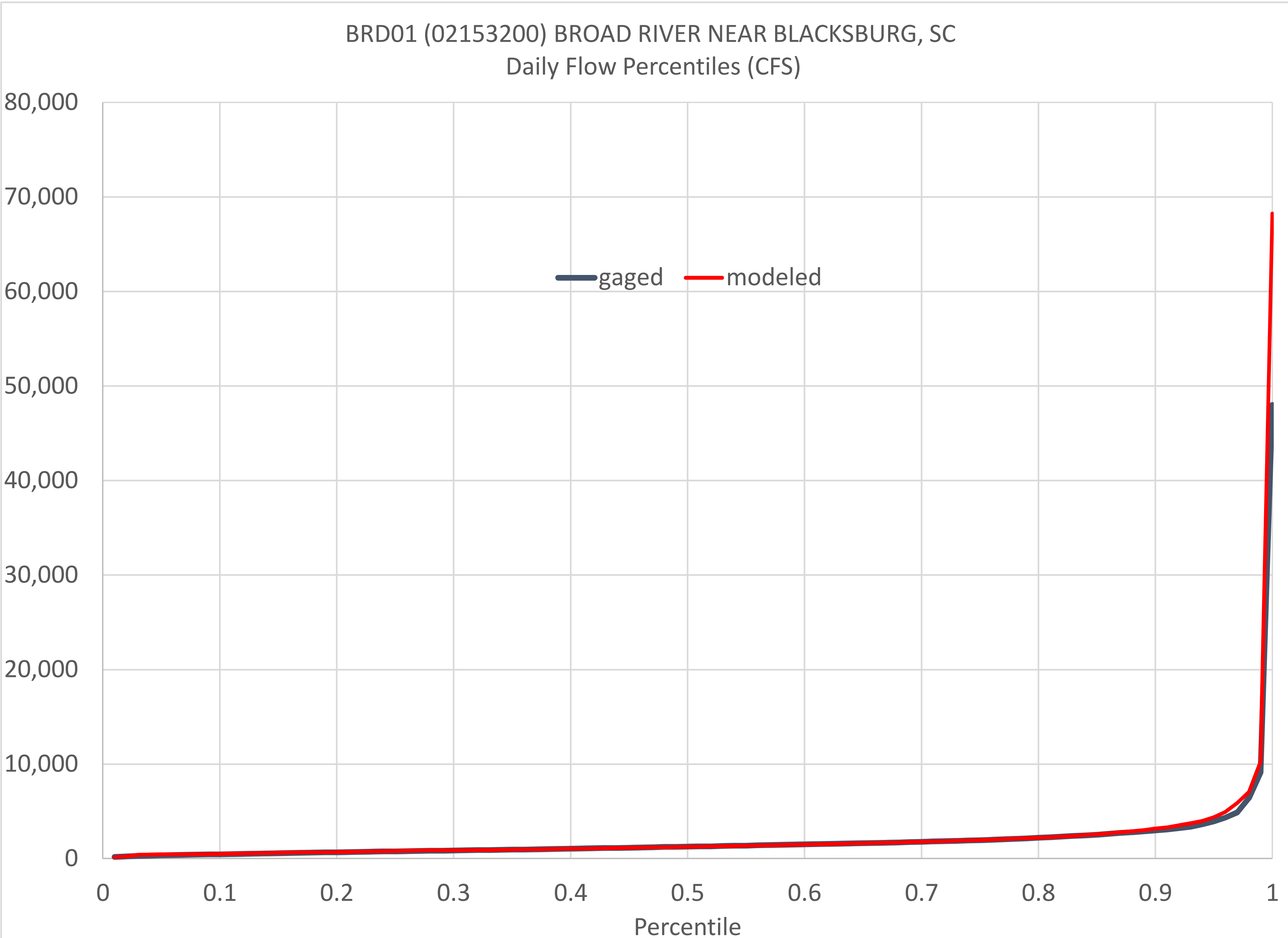
Appendix B

Broad River Basin Model Daily Calibration Results

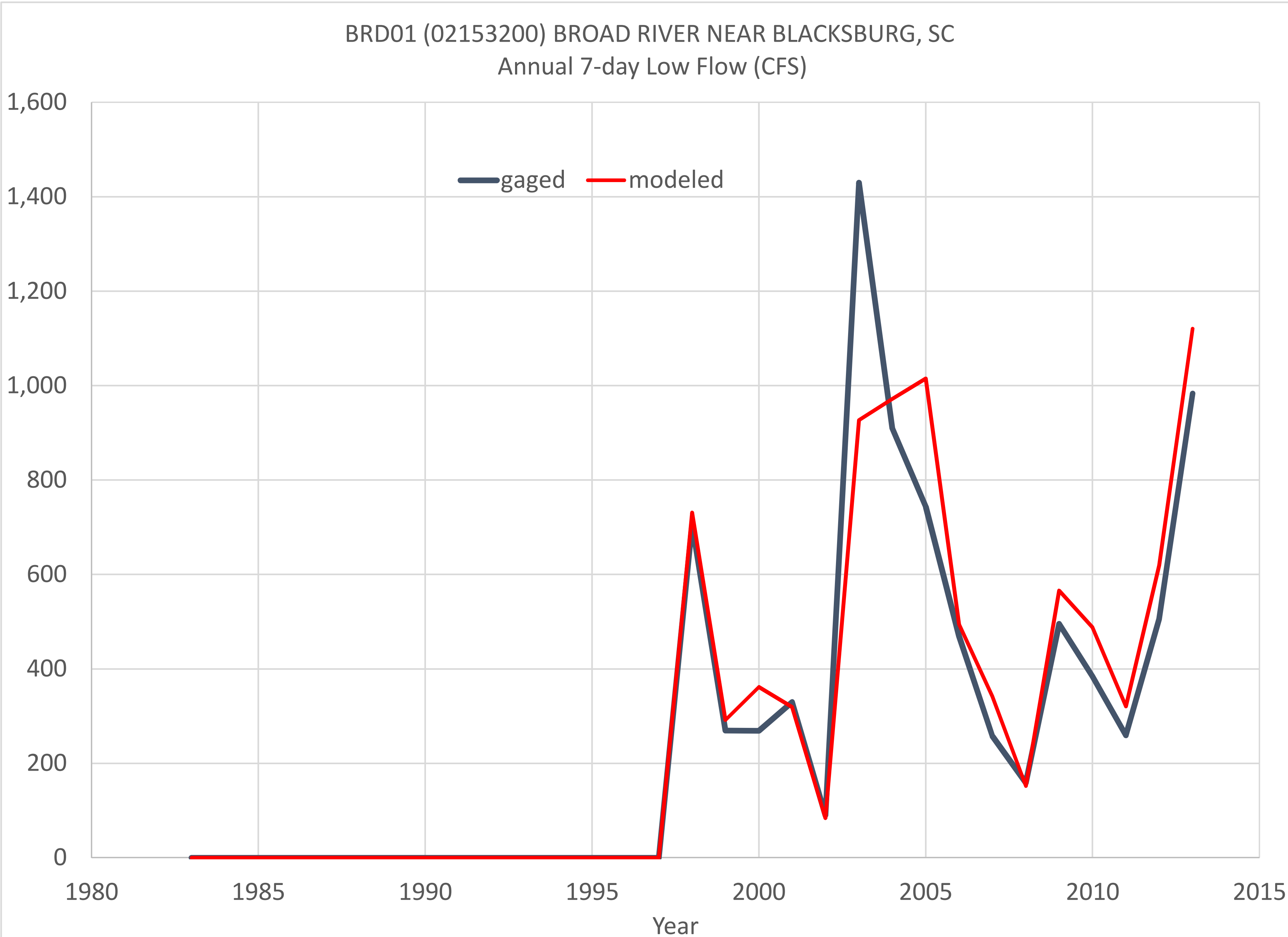
CDM Smith



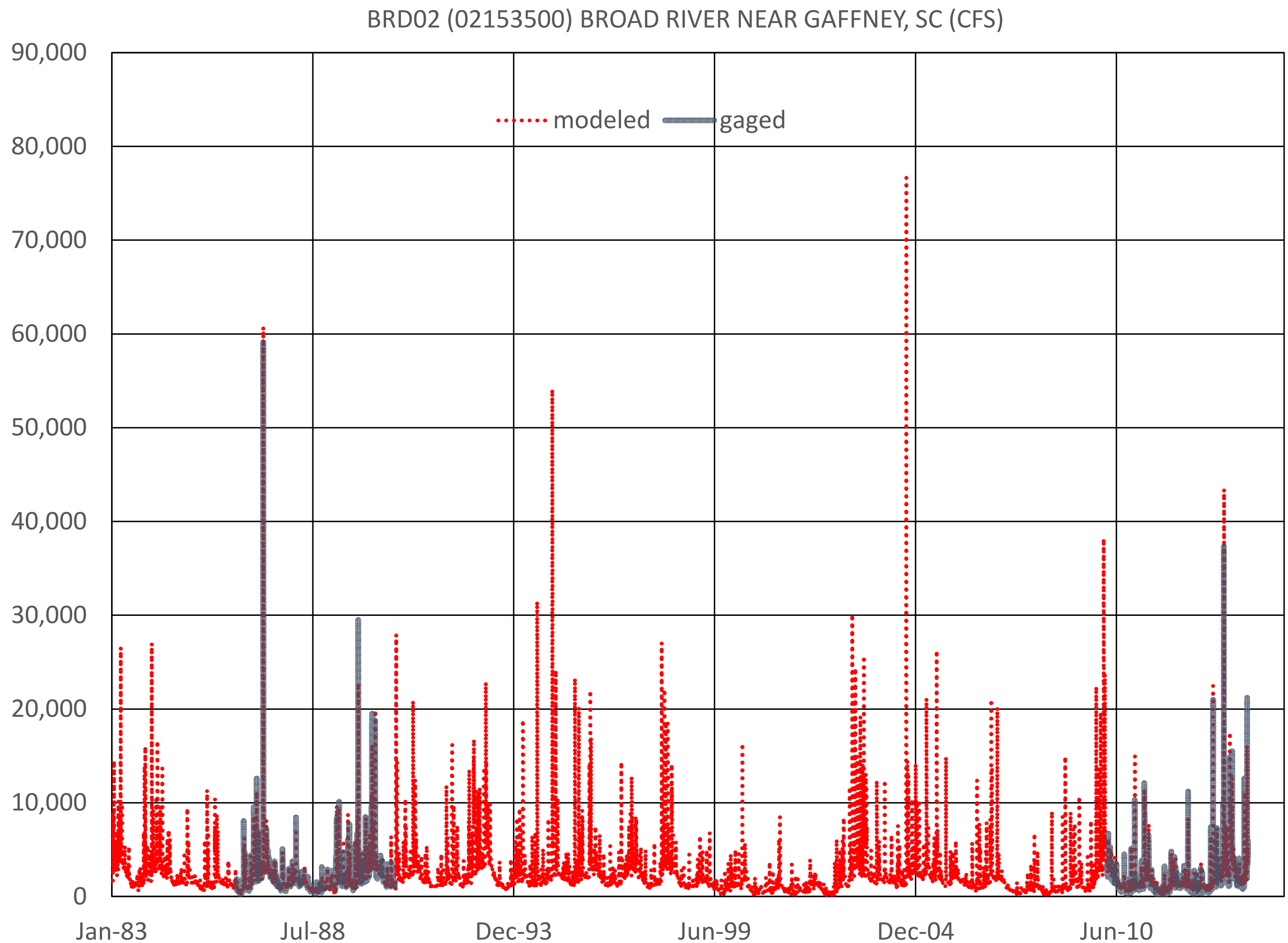
BRD01 (02153200) BROAD RIVER NEAR BLACKSBURG, SC (CFS)
modeled
gaged
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

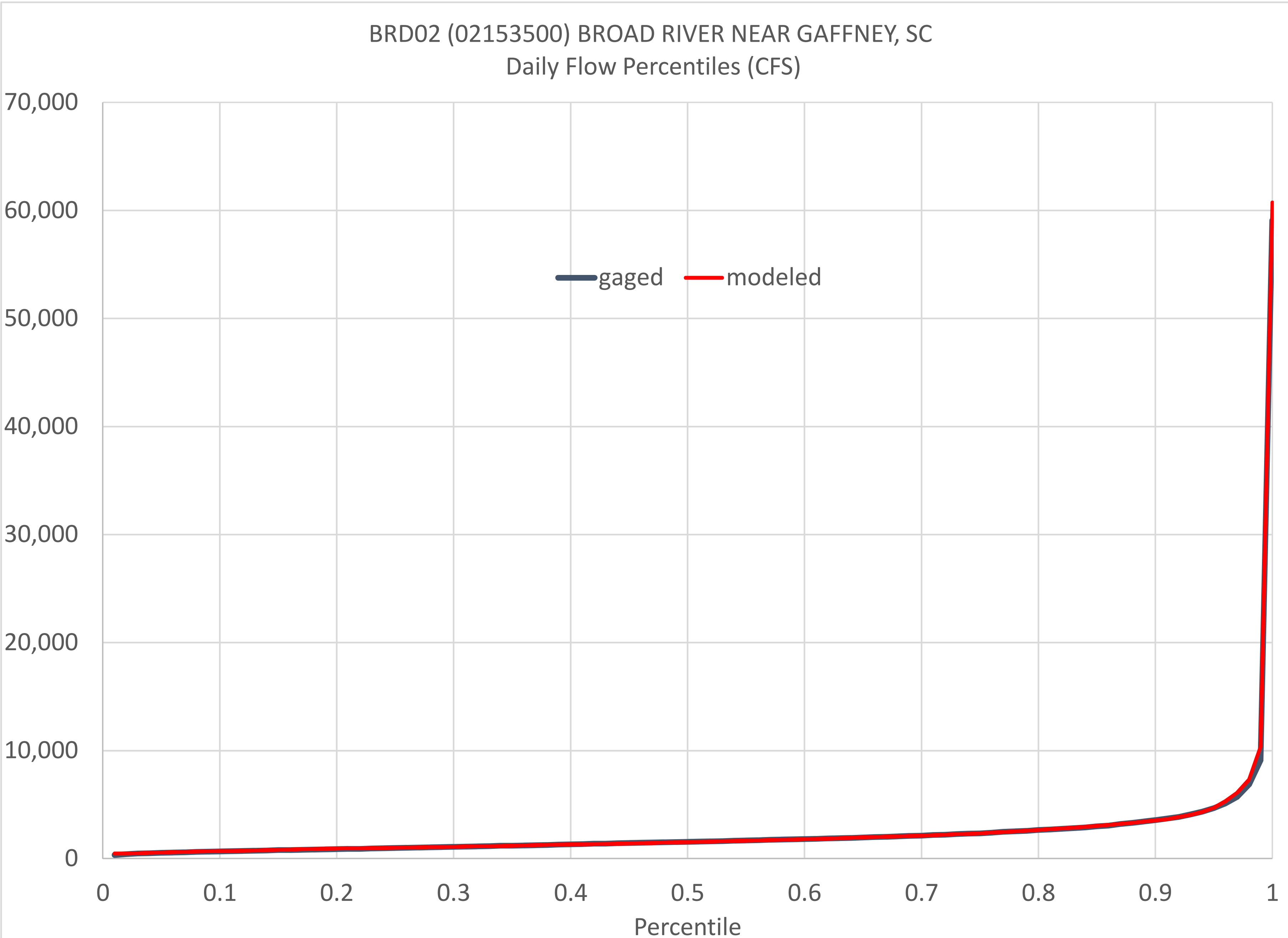


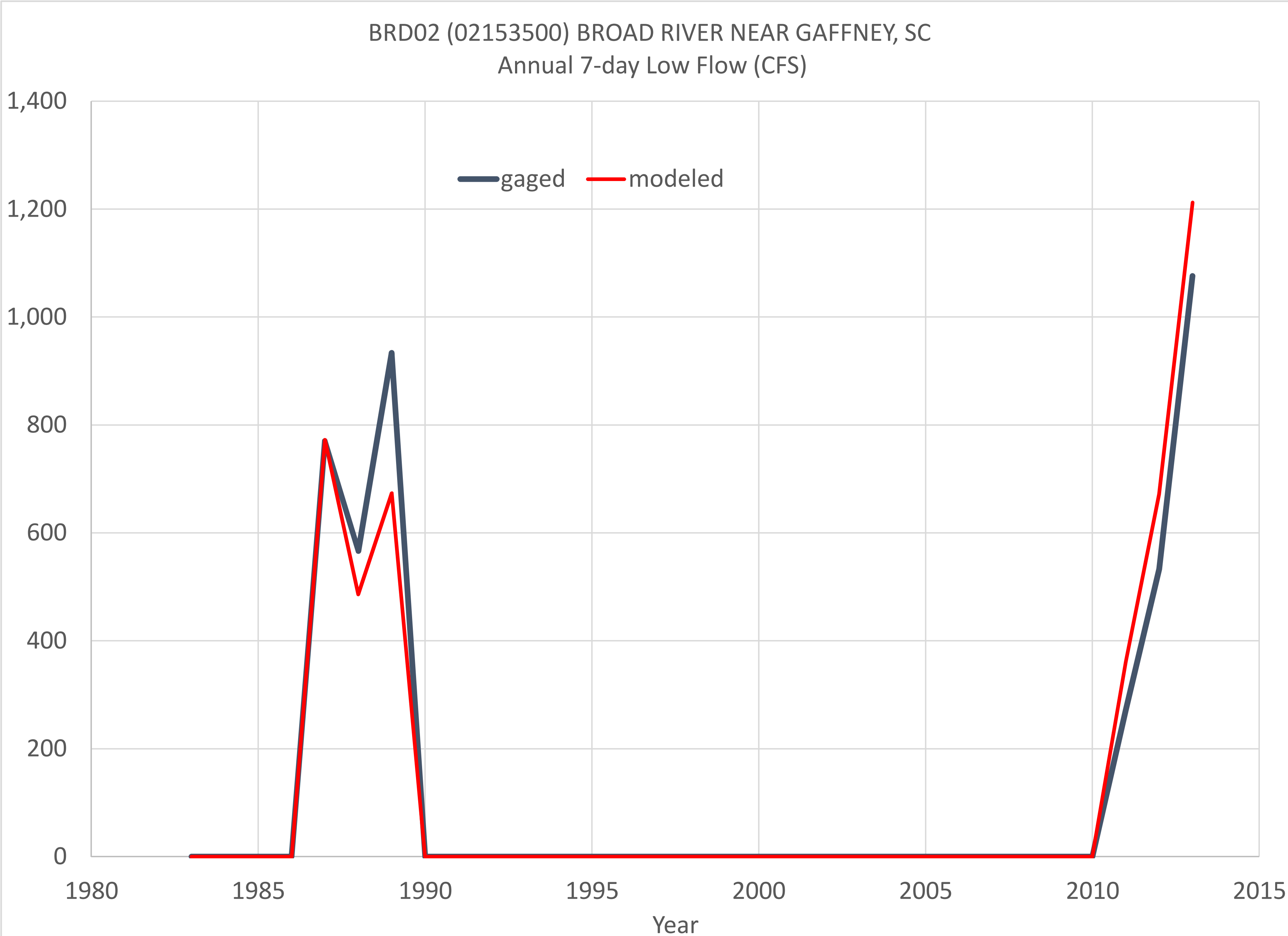
BRD01 (02153200) BROAD RIVER NEAR BLACKSBURG, SC
Daily Flow Percentiles (CFS)
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
gaged
modeled
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

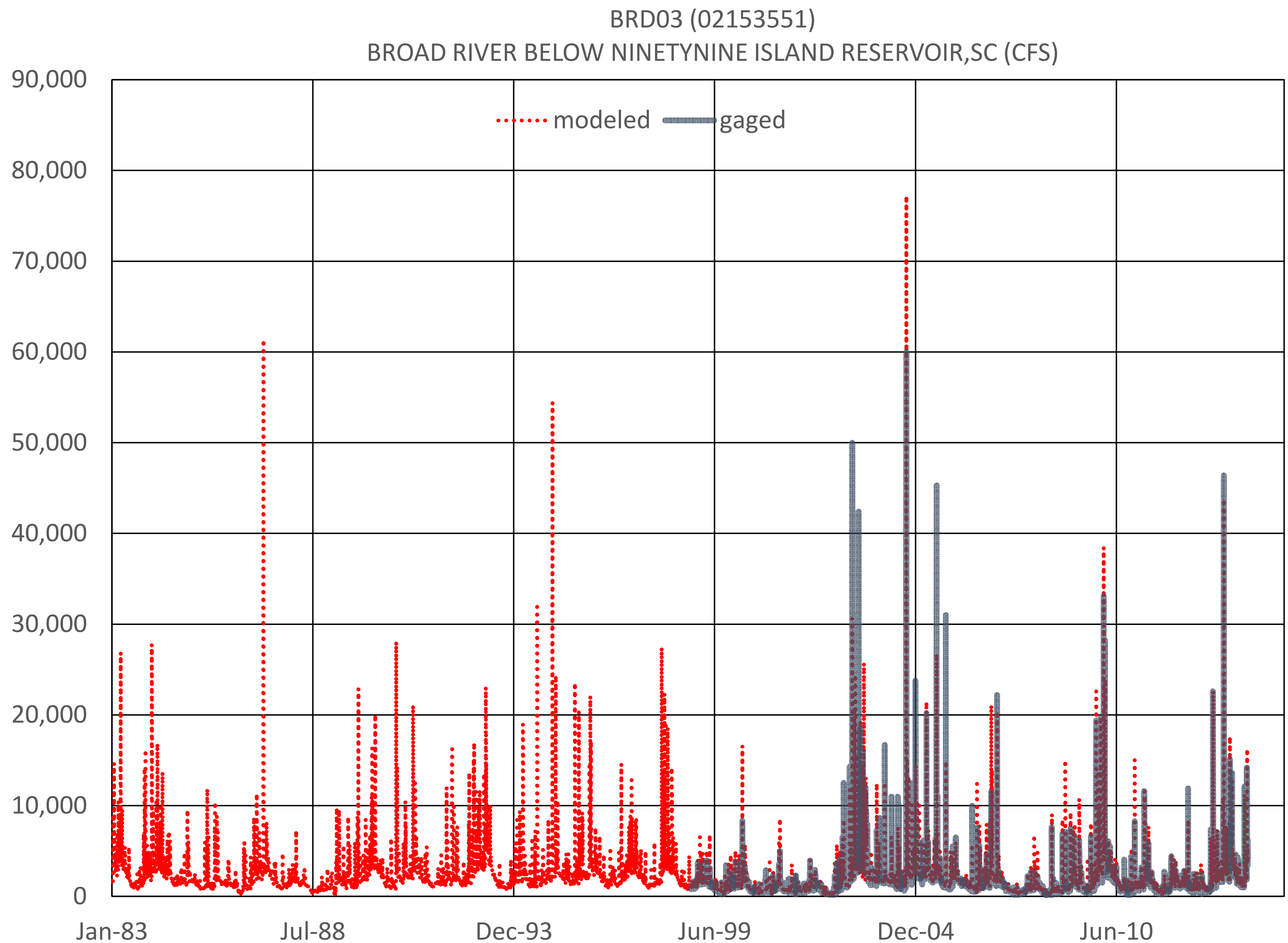


BRD01 (02153200) BROAD RIVER NEAR BLACKSBURG, SC
Annual 7-day Low Flow (CFS)
gaged
modeled
1,600
1,400
1,200
1,000
800
600
400
200
0
1980
1985
1990
1995
2000
2005
2010
2015
Year

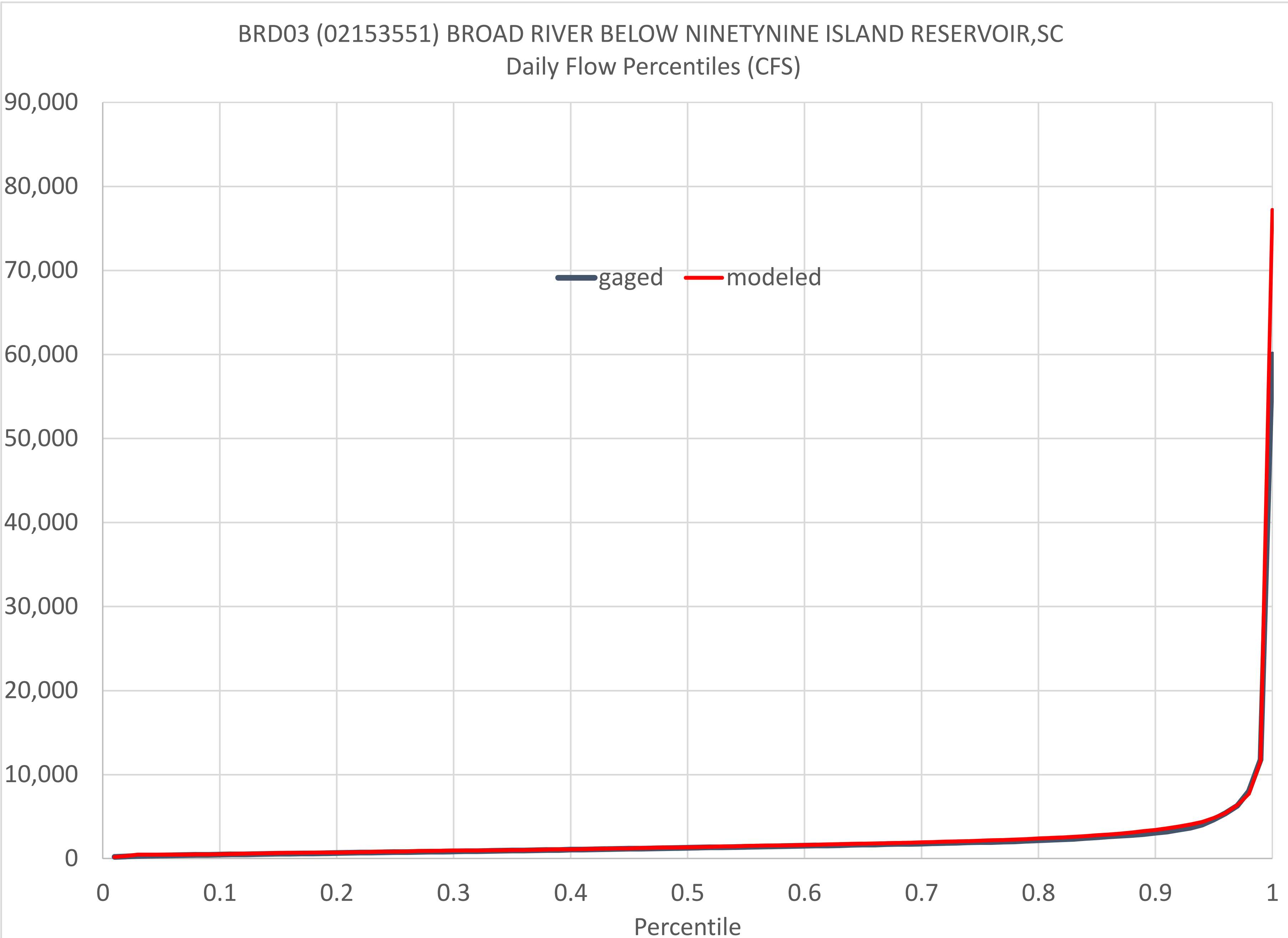

BRD02 (02153500) BROAD RIVER NEAR GAFFNEY, SC (CFS)
modeled
gaged
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10


BRD02 (02153500) BROAD RIVER NEAR GAFFNEY, SC
Daily Flow Percentiles (CFS)
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
gaged
modeled
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

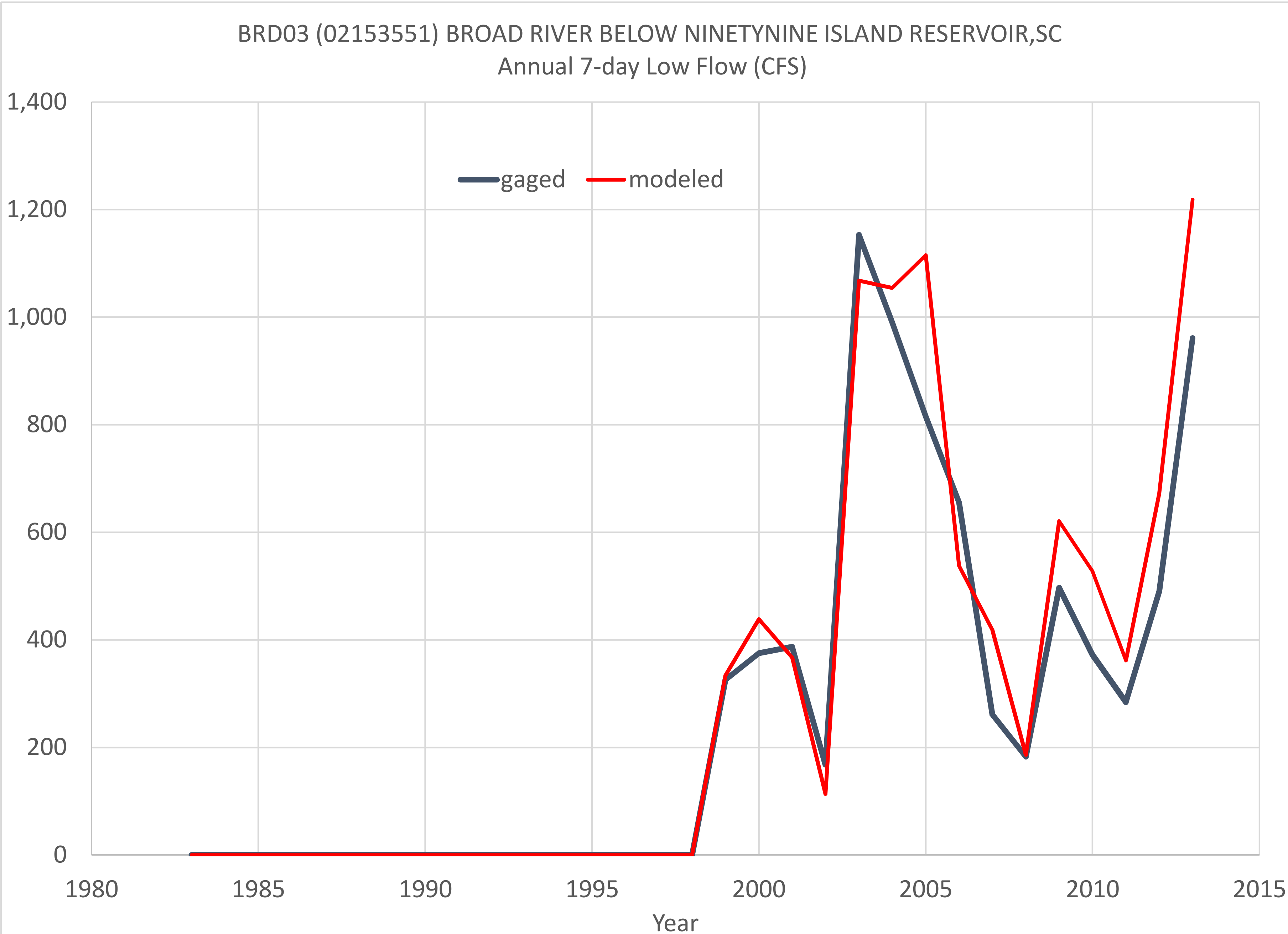

BRD02 (02153500) BROAD RIVER NEAR GAFFNEY, SC
Annual 7-day Low Flow (CFS)
gaged
modeled
1,400
1,200
1,000
800
600
400
200
0
1980
1985
1990
1995
2000
2005
2010
2015
Year

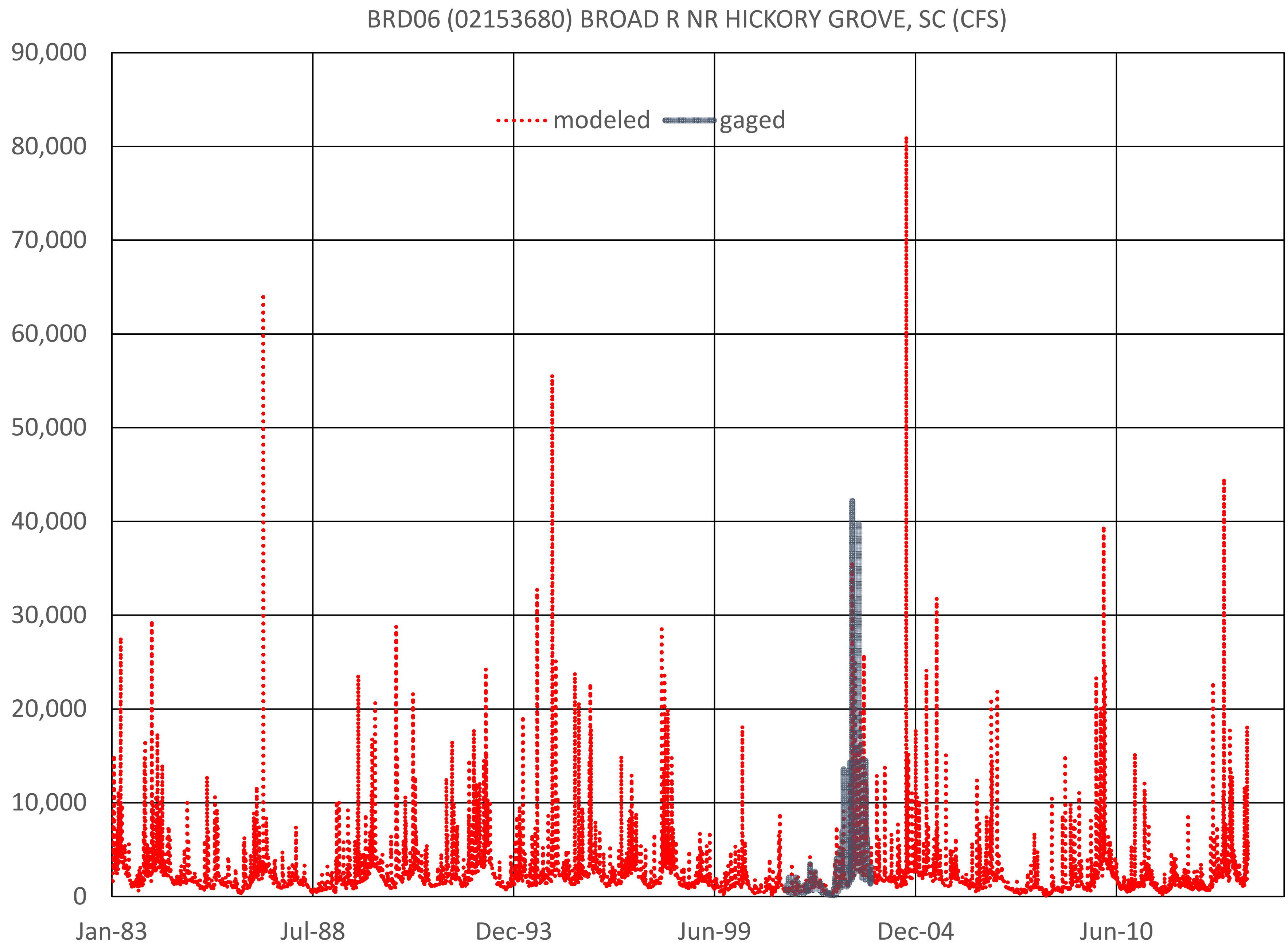


BRD03 (02153551)
BROAD RIVER BELOW NINETYNINE ISLAND RESERVOIR,SC (CFS)
modeled
gaged
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

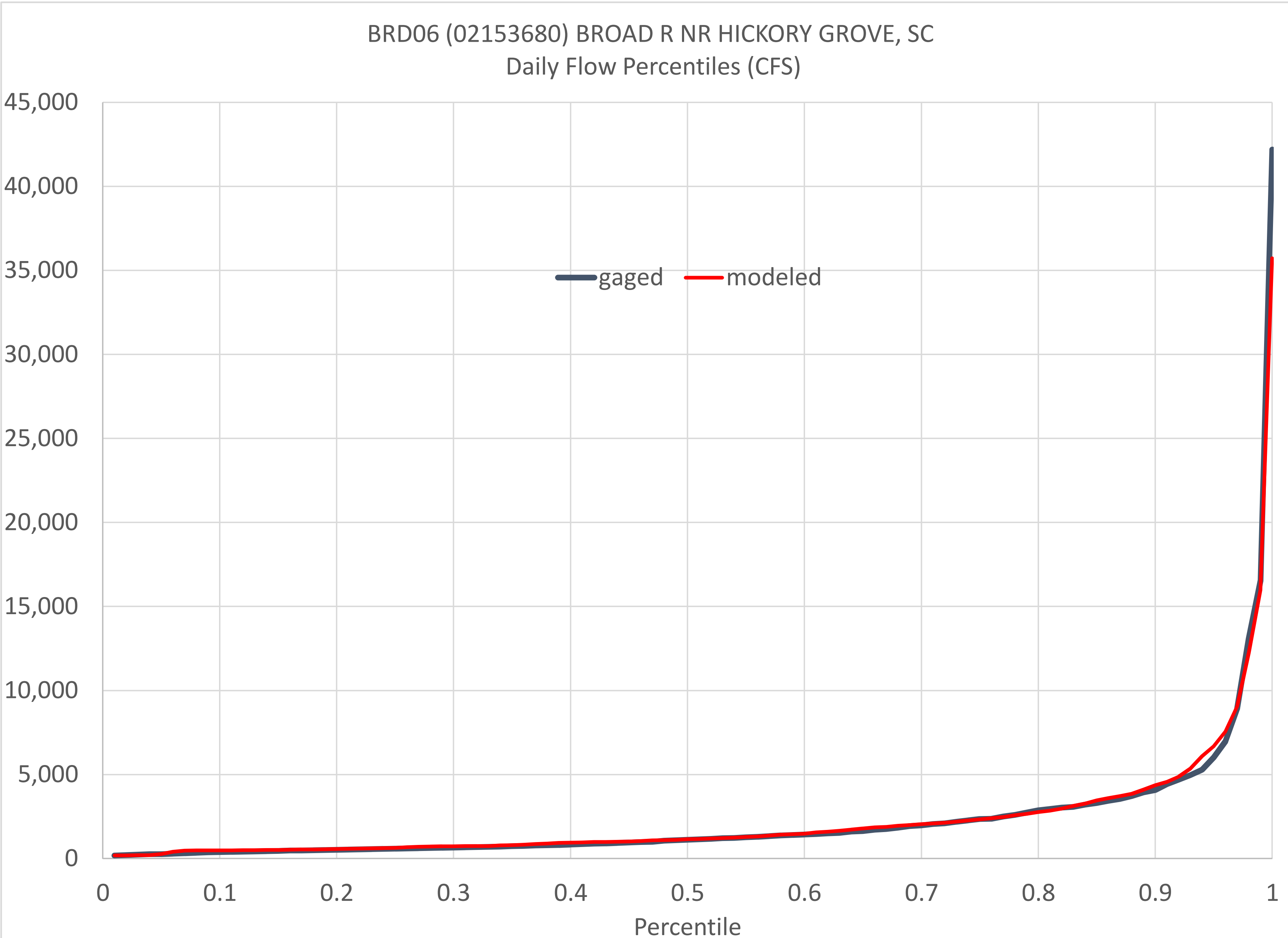


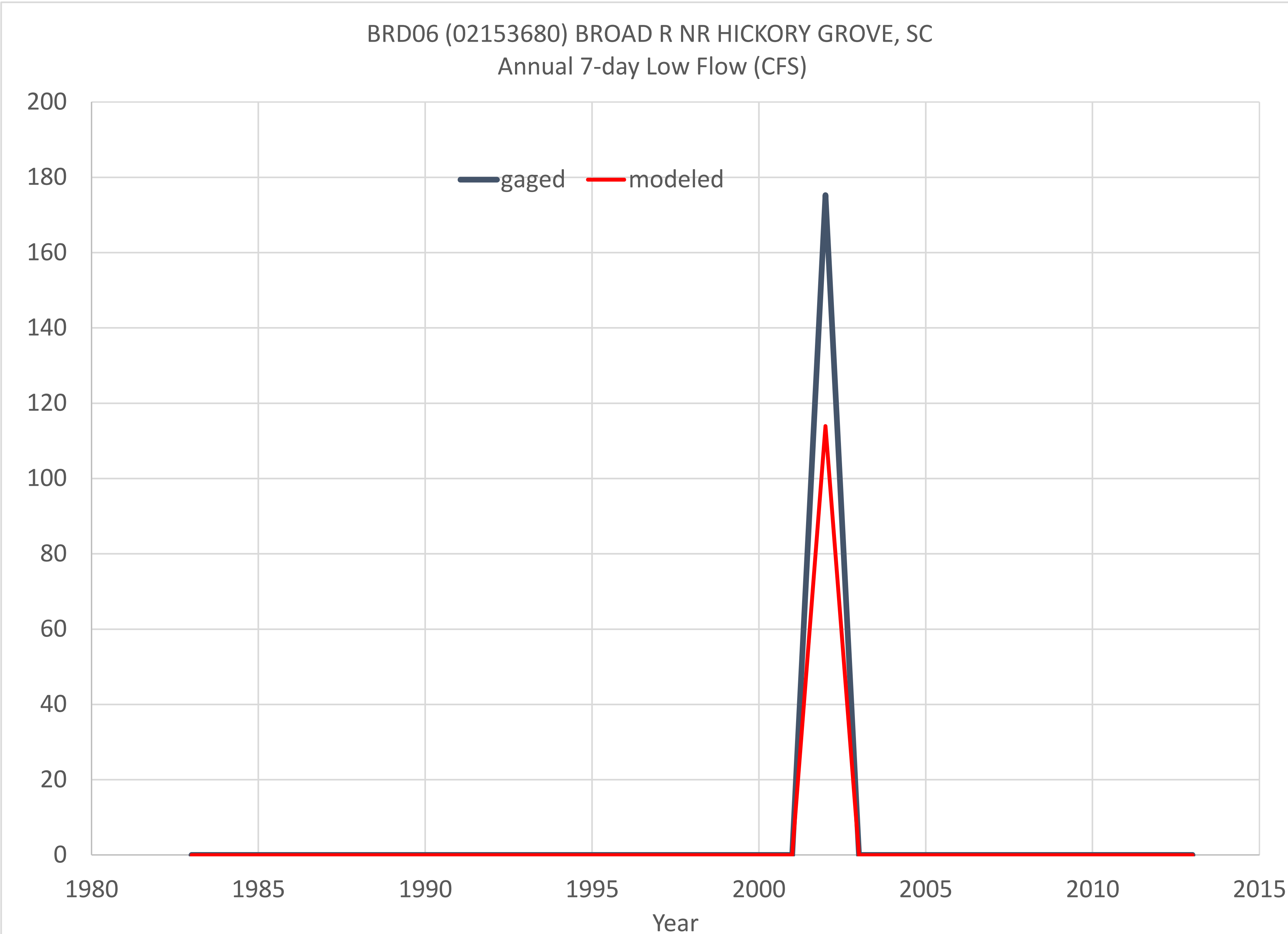
BRD03 (02153551) BROAD RIVER BELOW NINETYNINE ISLAND RESERVOIR,SC
Daily Flow Percentiles (CFS)
gaged
modeled
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

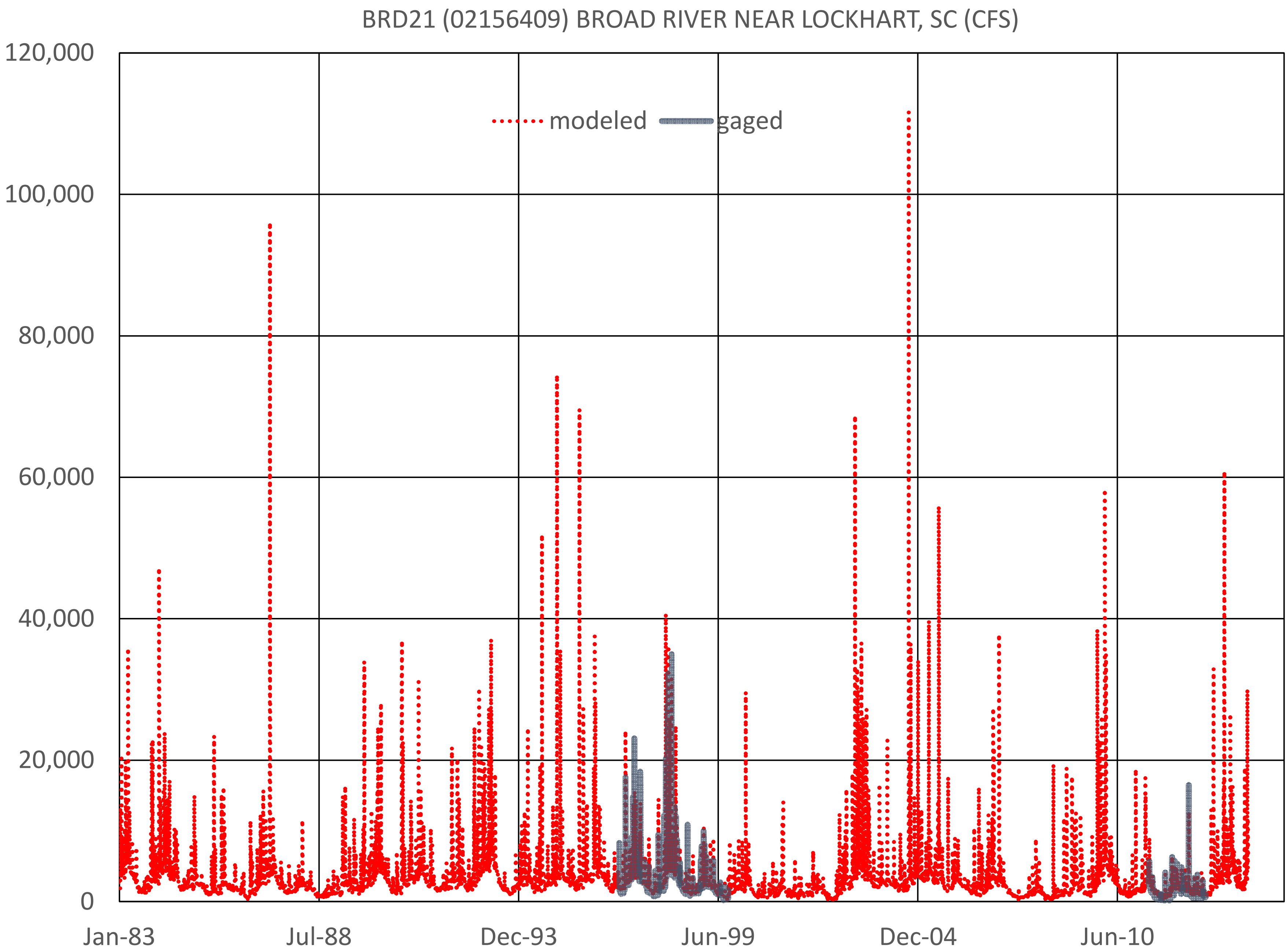

BRD03 (02153551) BROAD RIVER BELOW NINETYNINE ISLAND RESERVOIR,SC
Annual 7-day Low Flow (CFS)
gaged
modeled
1,400
1,200
1,000
800
600
400
200
0
1980
1985
1990
1995
2000
2005
2010
2015
Year



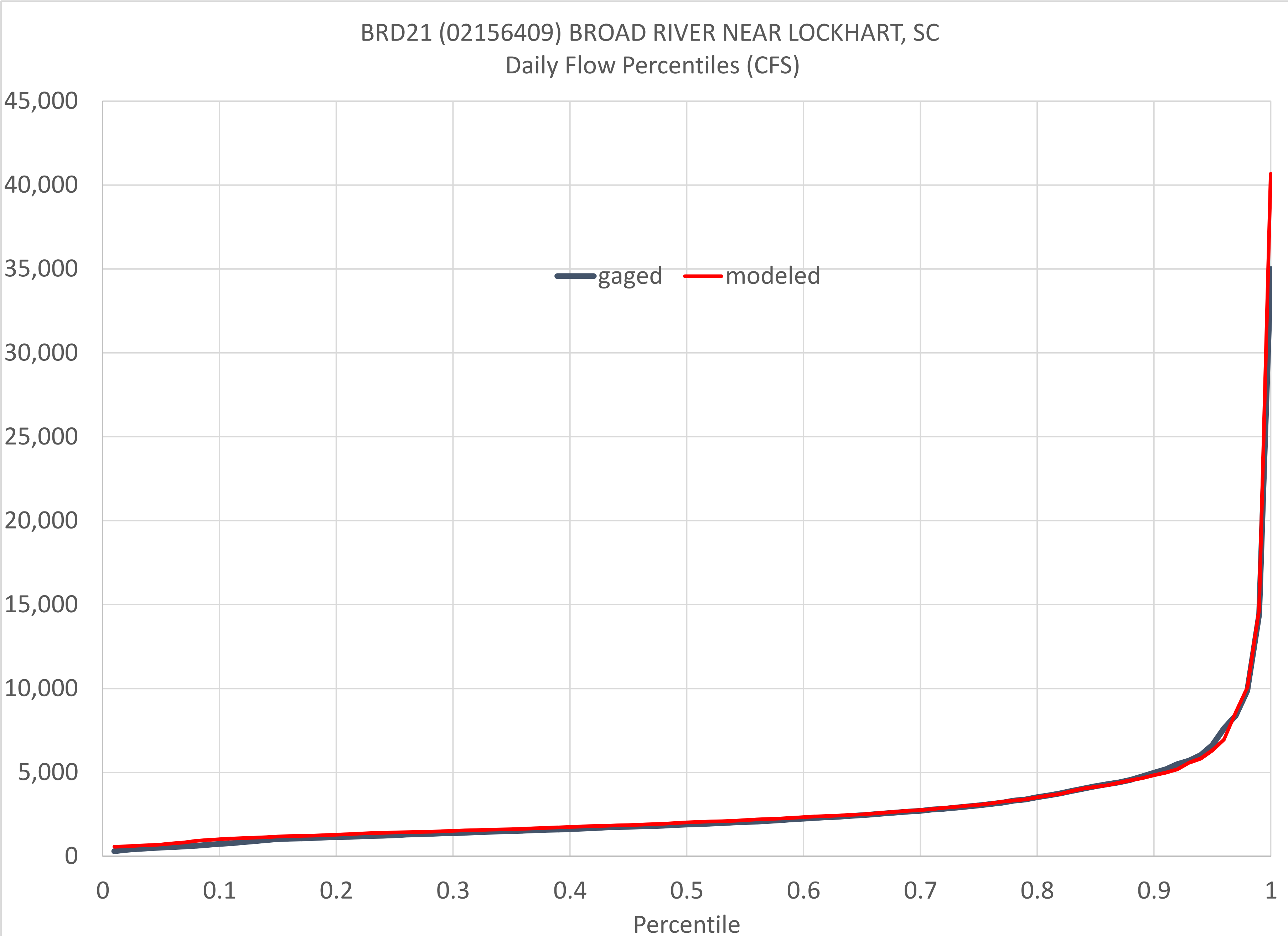
BRD06 (02153680) BROAD R NR HICKORY GROVE, SC (CFS)
modeled
gaged
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

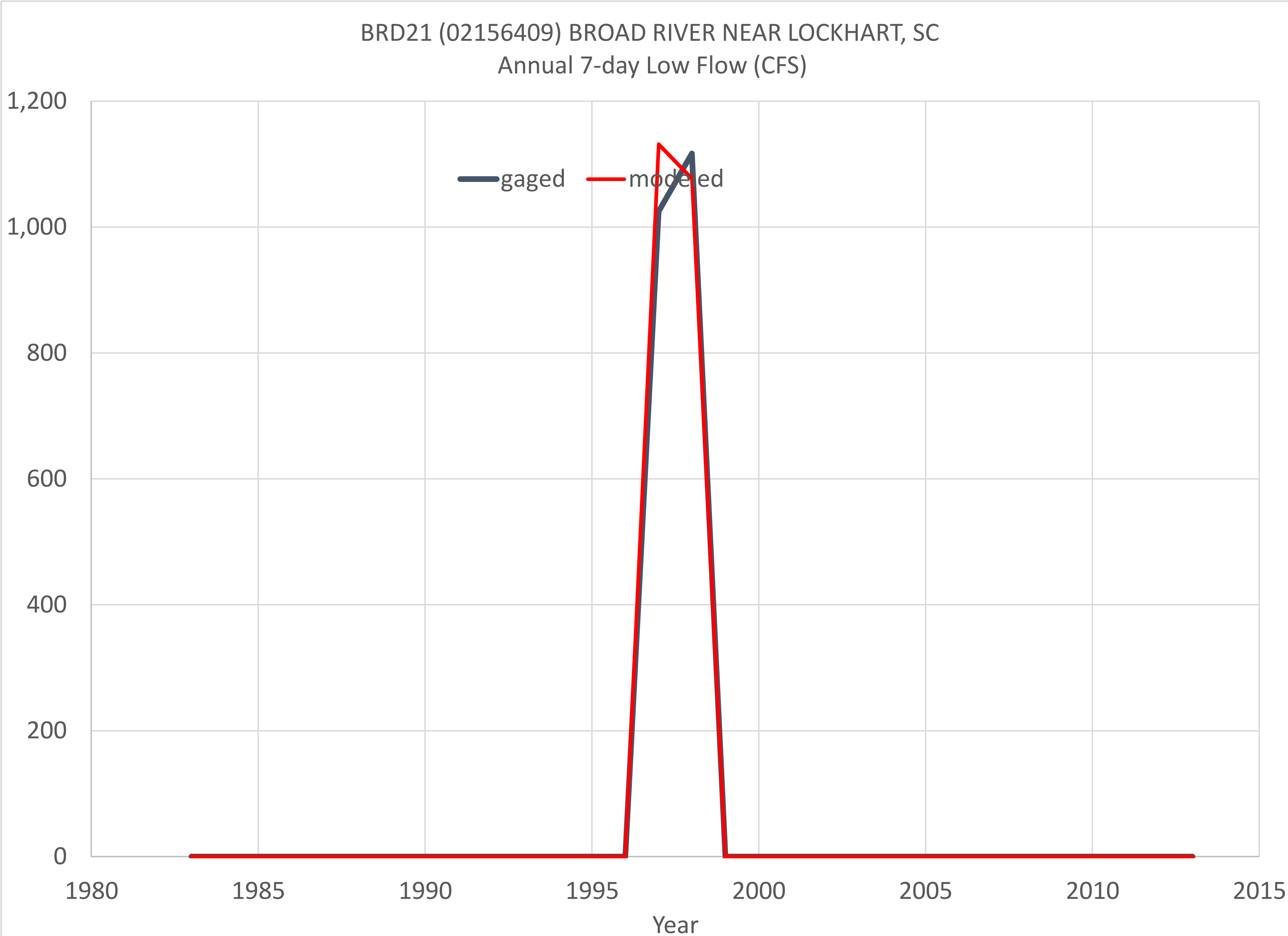

BRD06 (02153680) BROAD R NR HICKORY GROVE, SC
Daily Flow Percentiles (CFS)
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
gaged
modeled
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile


BRD06 (02153680) BROAD R NR HICKORY GROVE, SC
Annual 7-day Low Flow (CFS)
gaged
modeled
200
180
160
140
120
100
80
60
40
20
0
1980
1985
1990
1995
2000
2005
2010
2015
Year

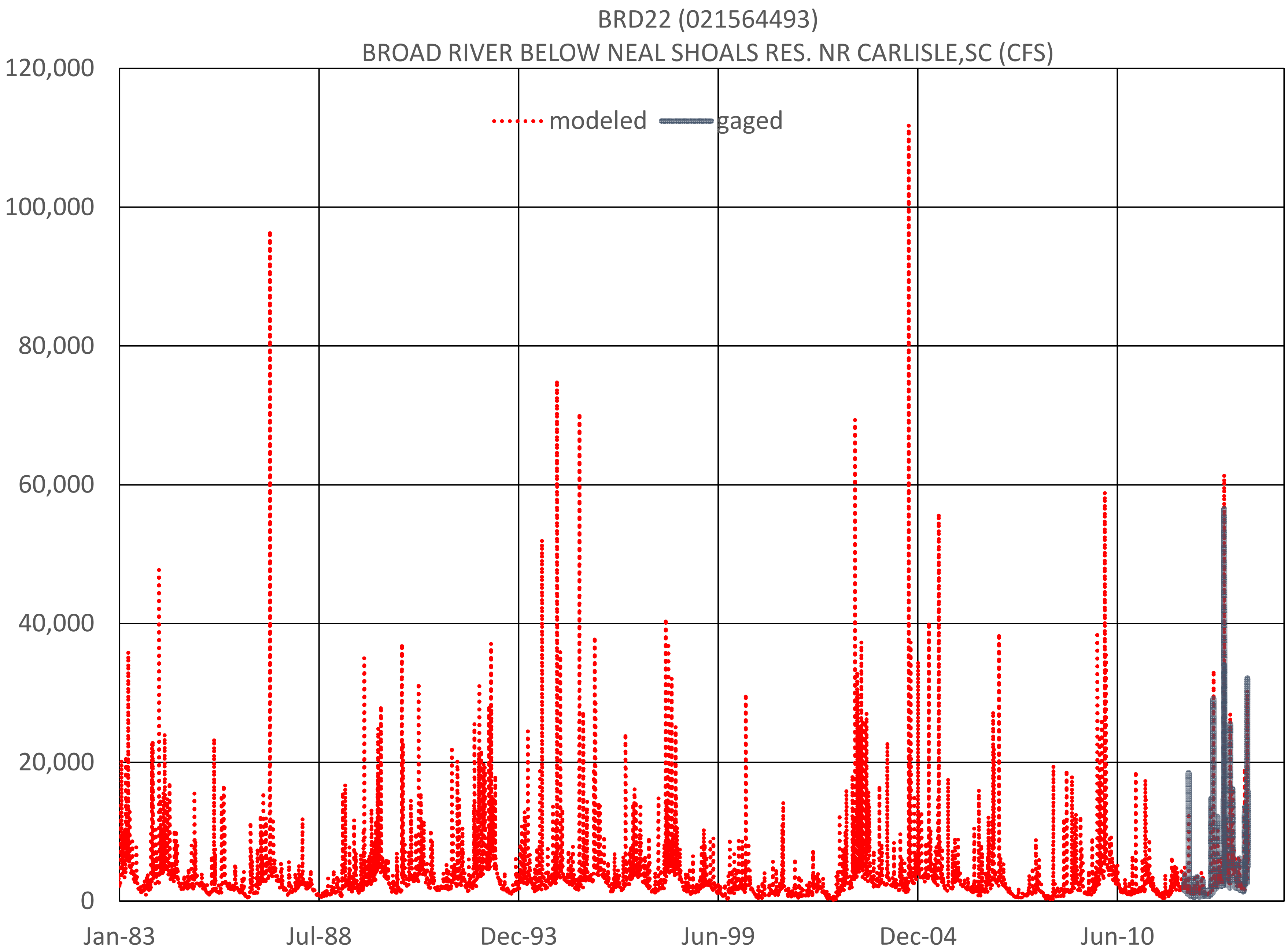


BRD21 (02156409) BROAD RIVER NEAR LOCKHART, SC (CFS)
modeled
gaged
120,000
100,000
80,000
60,000
40,000
20,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

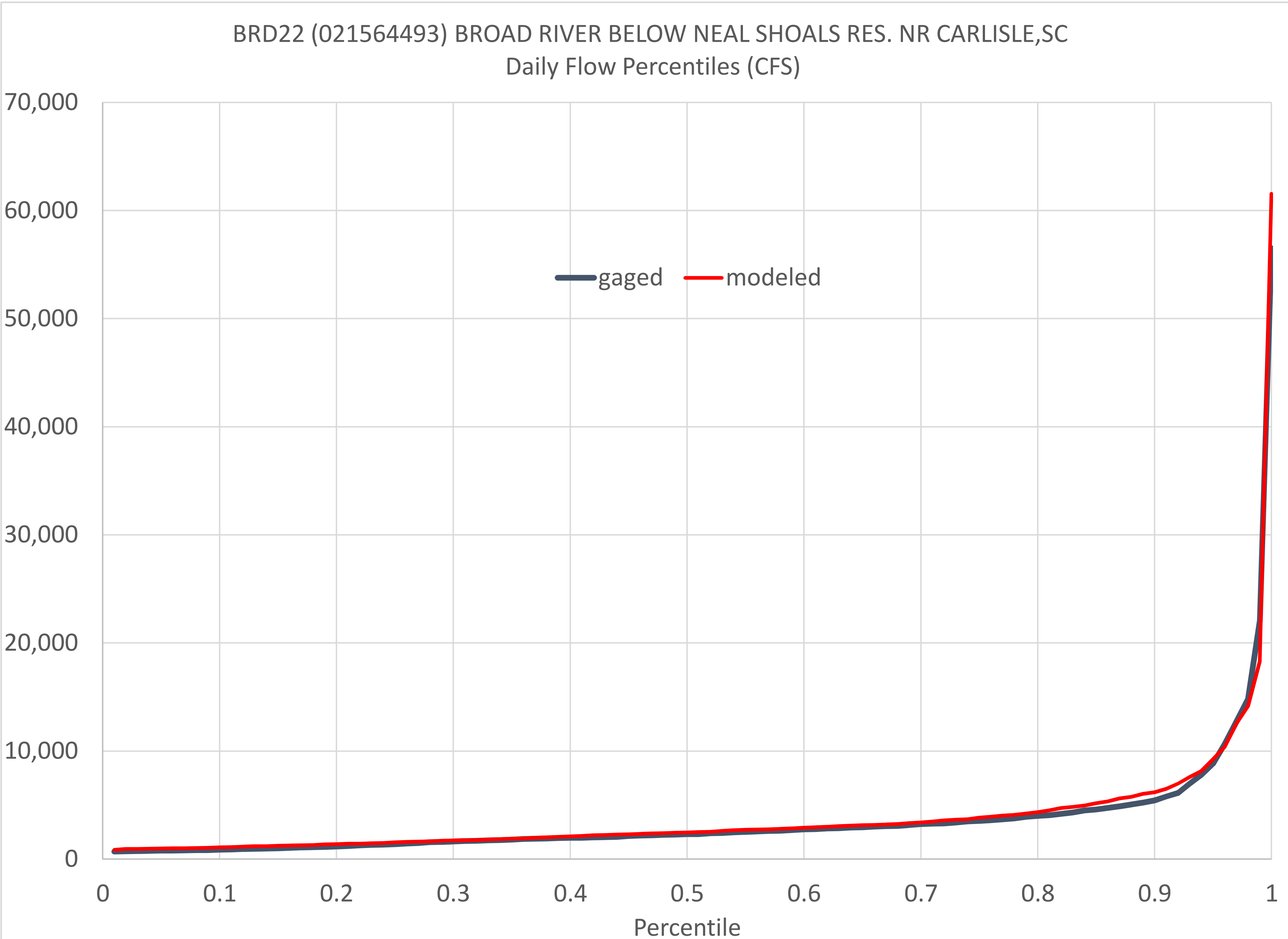

BRD21 (02156409) BROAD RIVER NEAR LOCKHART, SC
Daily Flow Percentiles (CFS)
gaged
modeled
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile



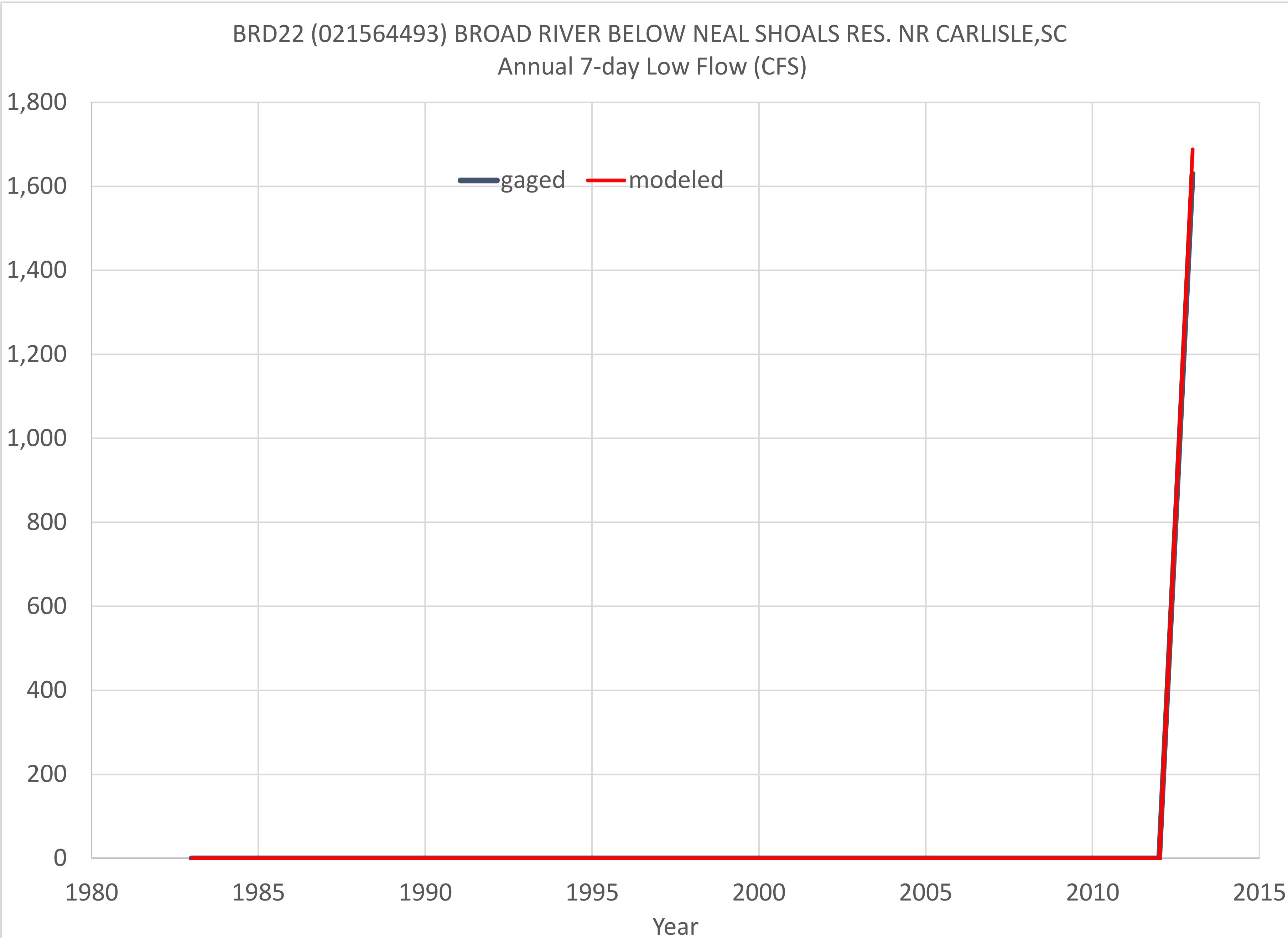
BRD21 (02156409) BROAD RIVER NEAR LOCKHART, SC
Annual 7-day Low Flow (CFS)
1,200
1,000
800
600
400
200
0
1980
1985
1990
1995
2000
2005
2010
2015
Year
gaged
modeled

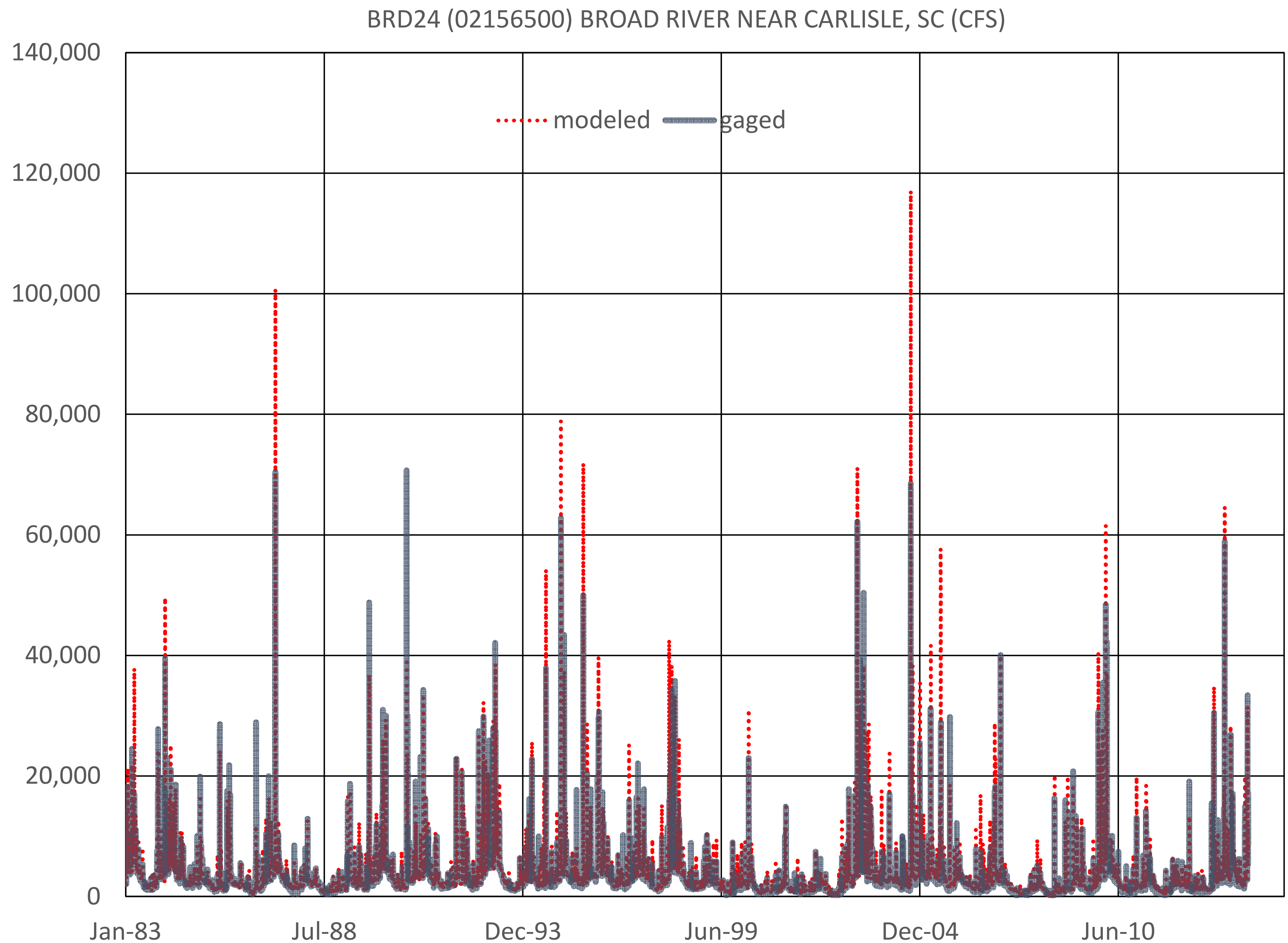


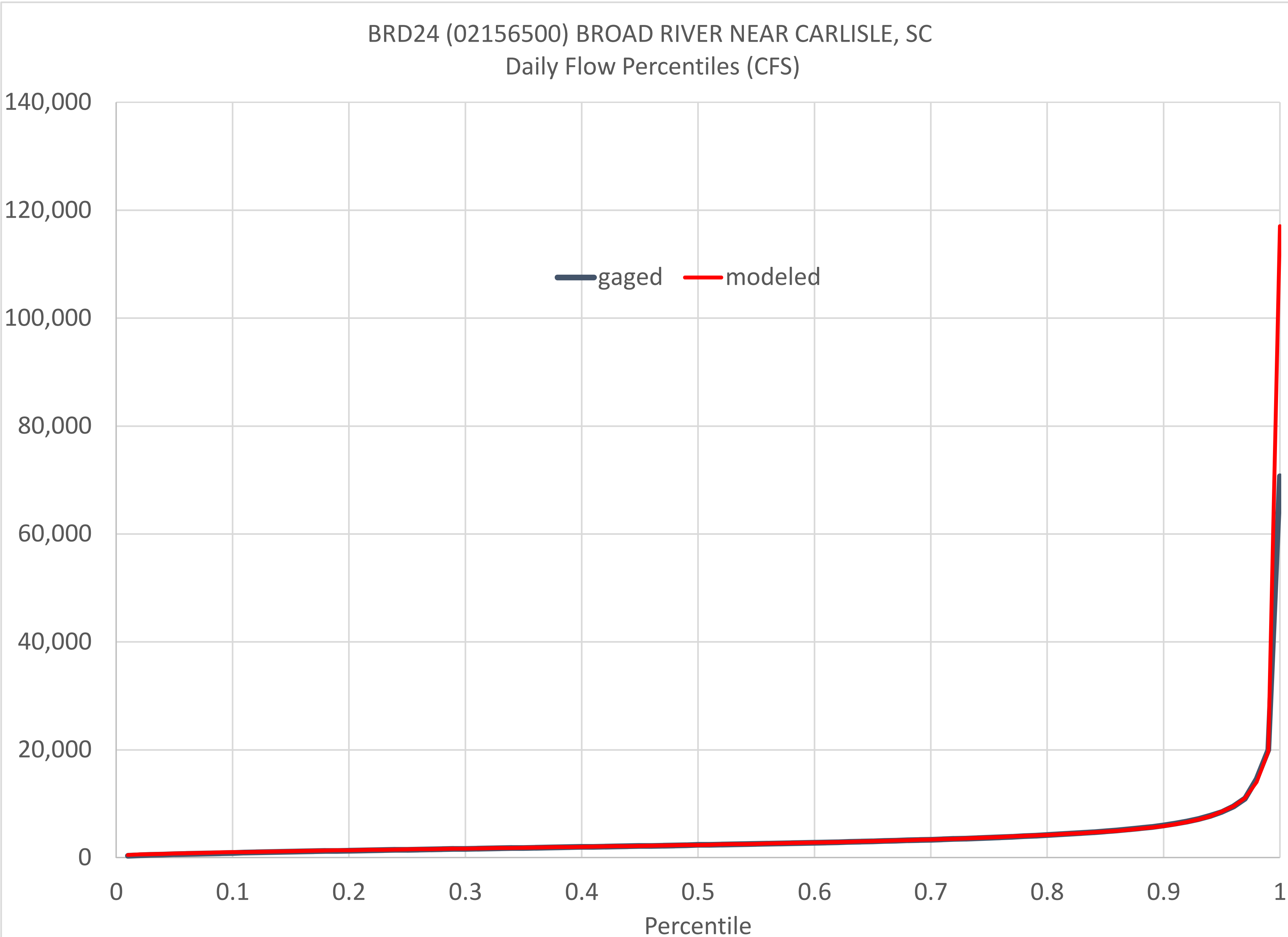
BRD22 (021564493)
BROAD RIVER BELOW NEAL SHOALS RES. NR CARLISLE,SC (CFS)
modeled
gaged
120,000
100,000
80,000
60,000
40,000
20,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10



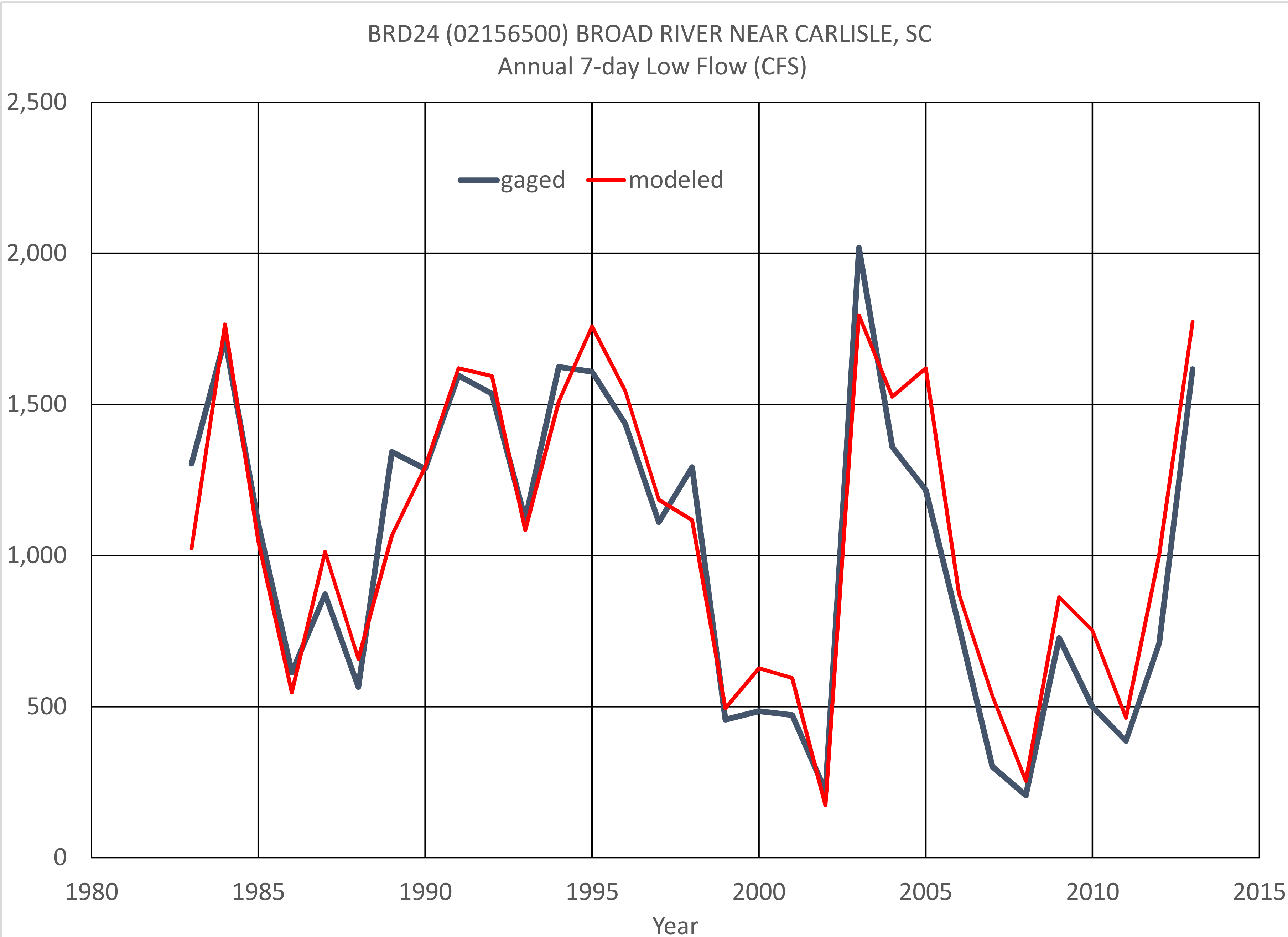
BRD22 (021564493) BROAD RIVER BELOW NEAL SHOALS RES. NR CARLISLE,SC
Daily Flow Percentiles (CFS)
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
gaged
modeled
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

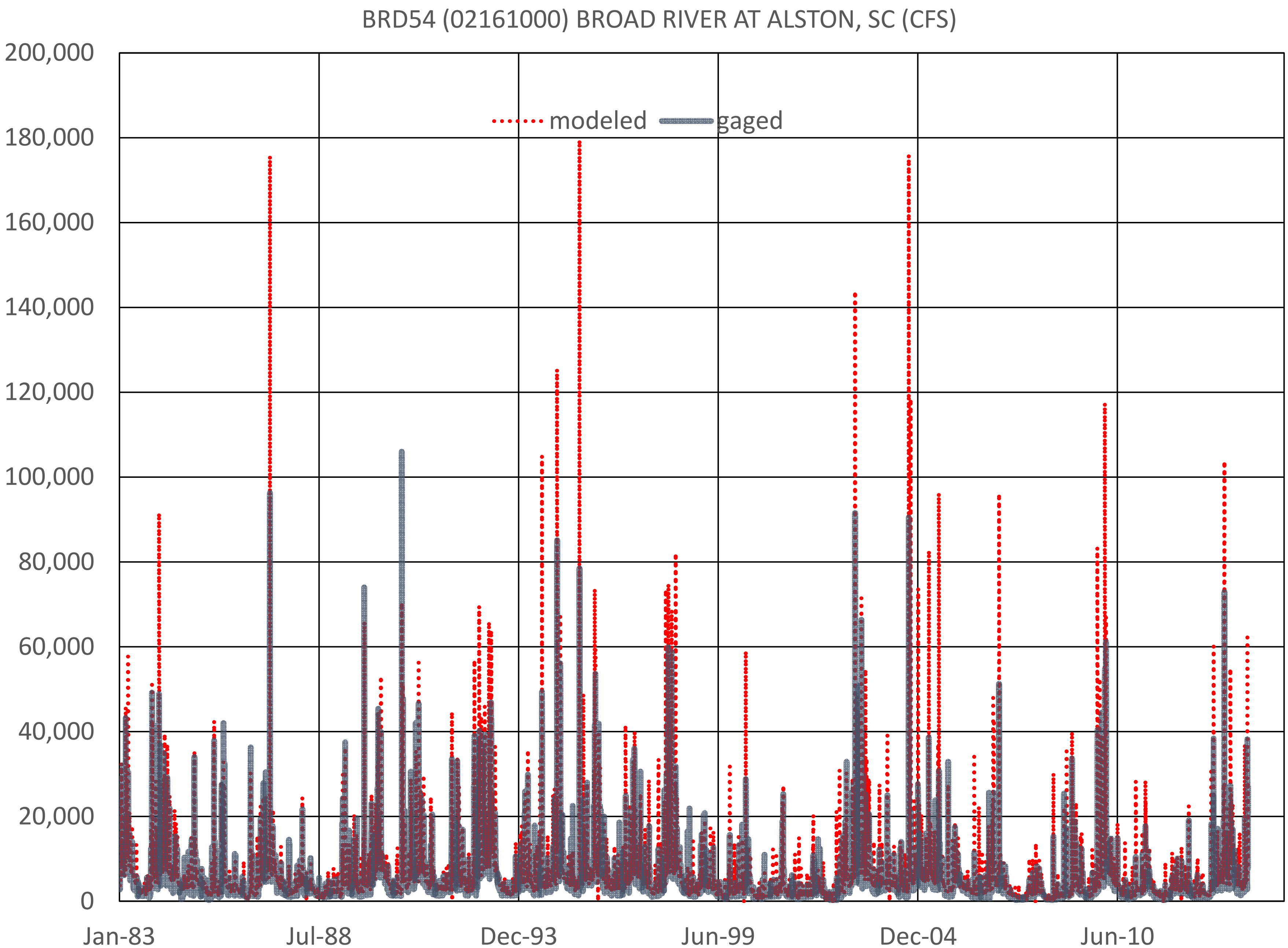

BRD22 (021564493) BROAD RIVER BELOW NEAL SHOALS RES. NR CARLISLE,SC
Annual 7-day Low Flow (CFS)
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
gaged
modeled
1980
1985
1990
1995
2000
2005
2010
2015
Year


BRD24 (02156500) BROAD RIVER NEAR CARLISLE, SC (CFS)
modeled
gaged
140,000
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

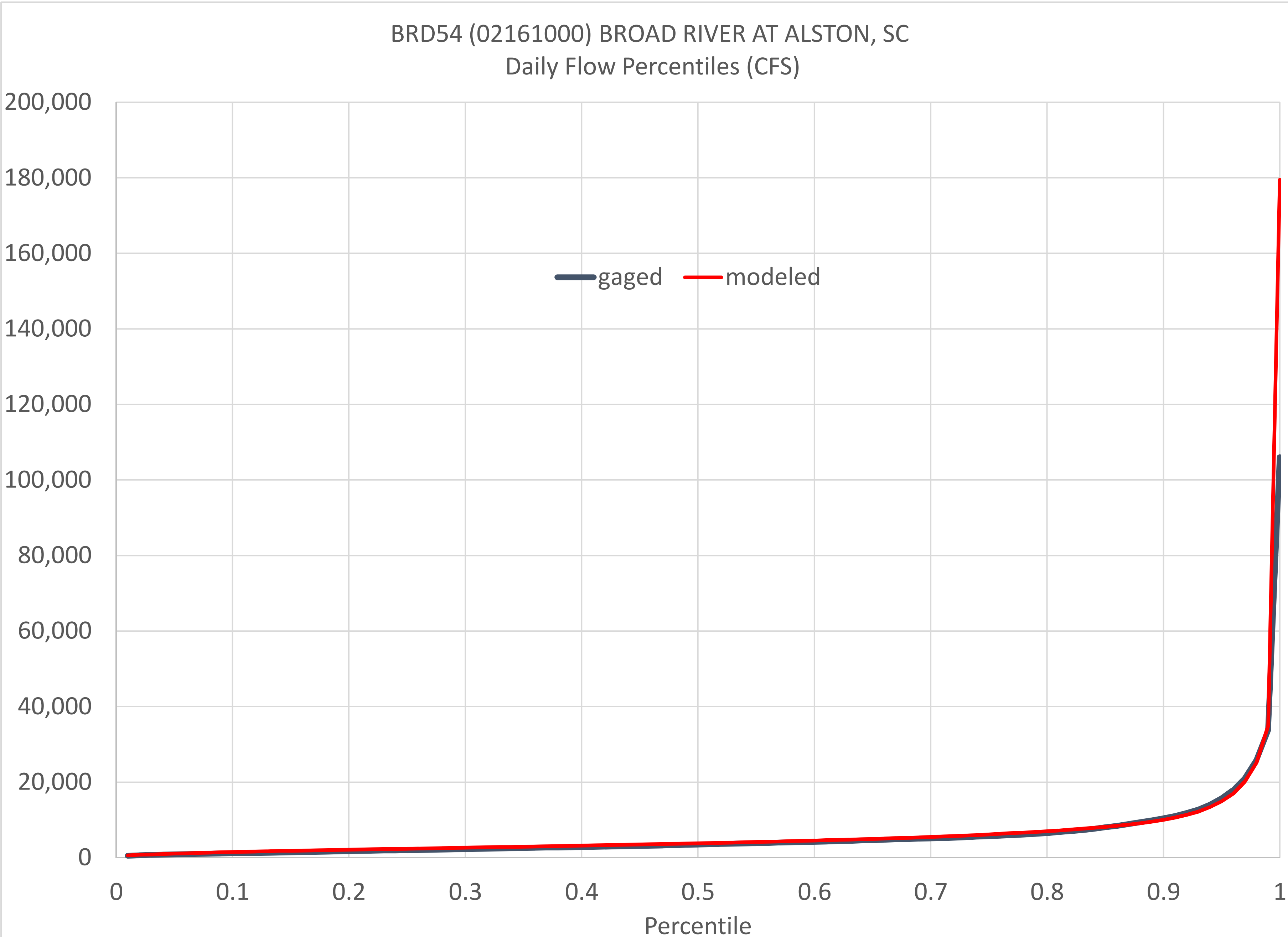


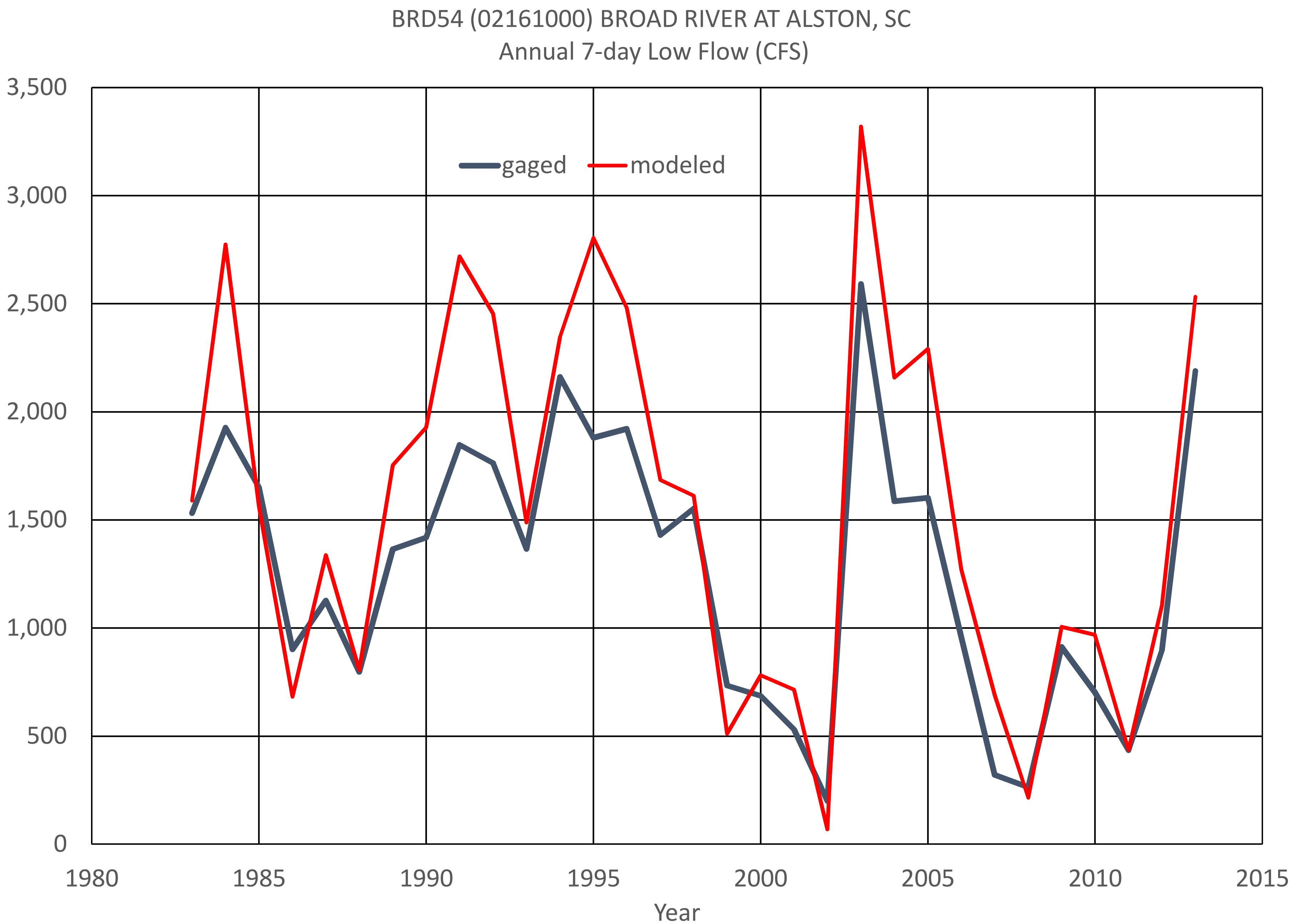
BRD24 (02156500) BROAD RIVER NEAR CARLISLE, SC
Daily Flow Percentiles (CFS)
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile
gaged
modeled


BRD24 (02156500) BROAD RIVER NEAR CARLISLE, SC
Annual 7-day Low Flow (CFS)
gaged
modeled
2,500
2,000
1,500
1,000
500
0
1980
1985
1990
1995
2000
2005
2010
2015
Year

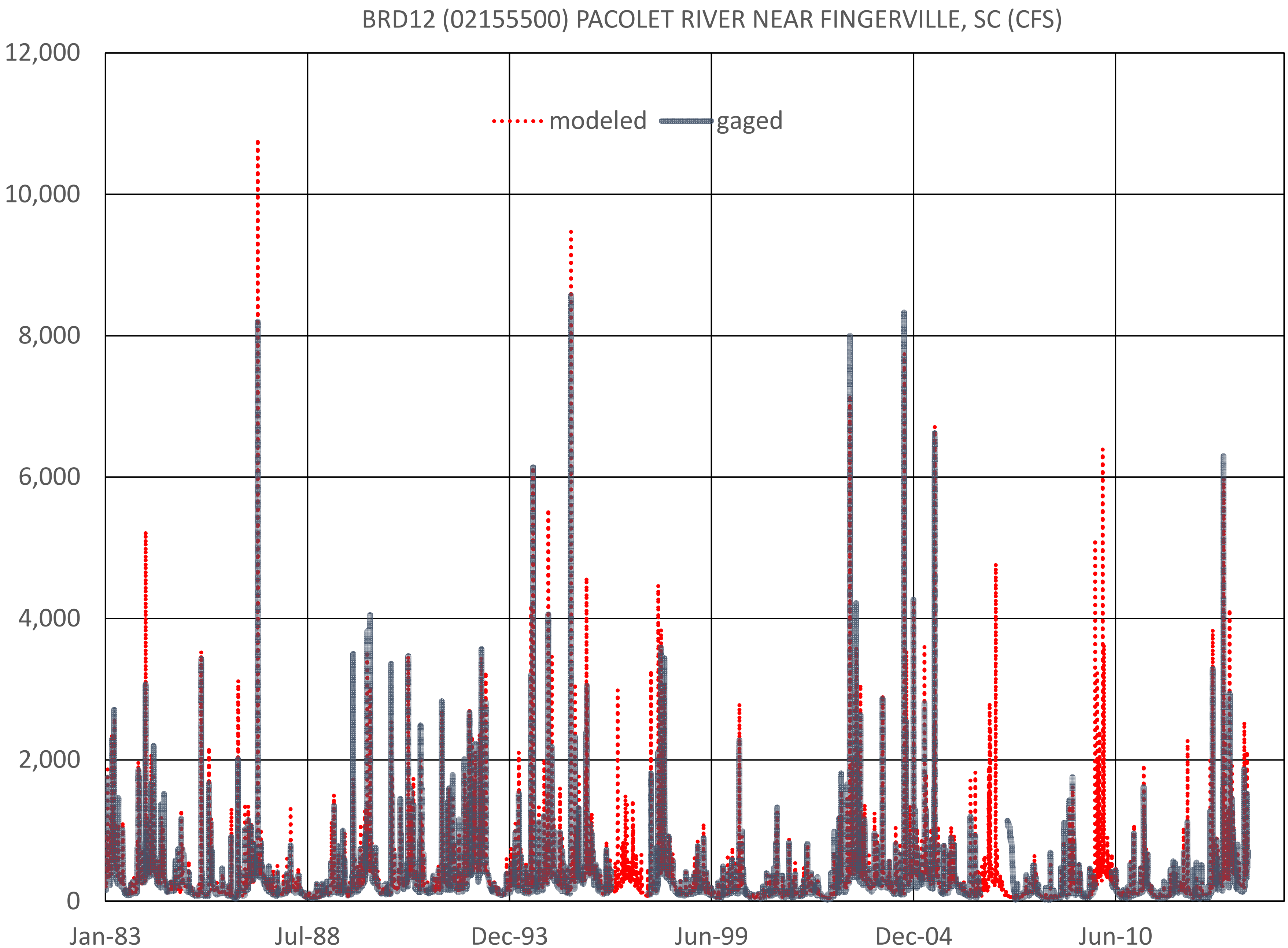


BRD54 (02161000) BROAD RIVER AT ALSTON, SC (CFS)
modeled
gaged
200,000
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

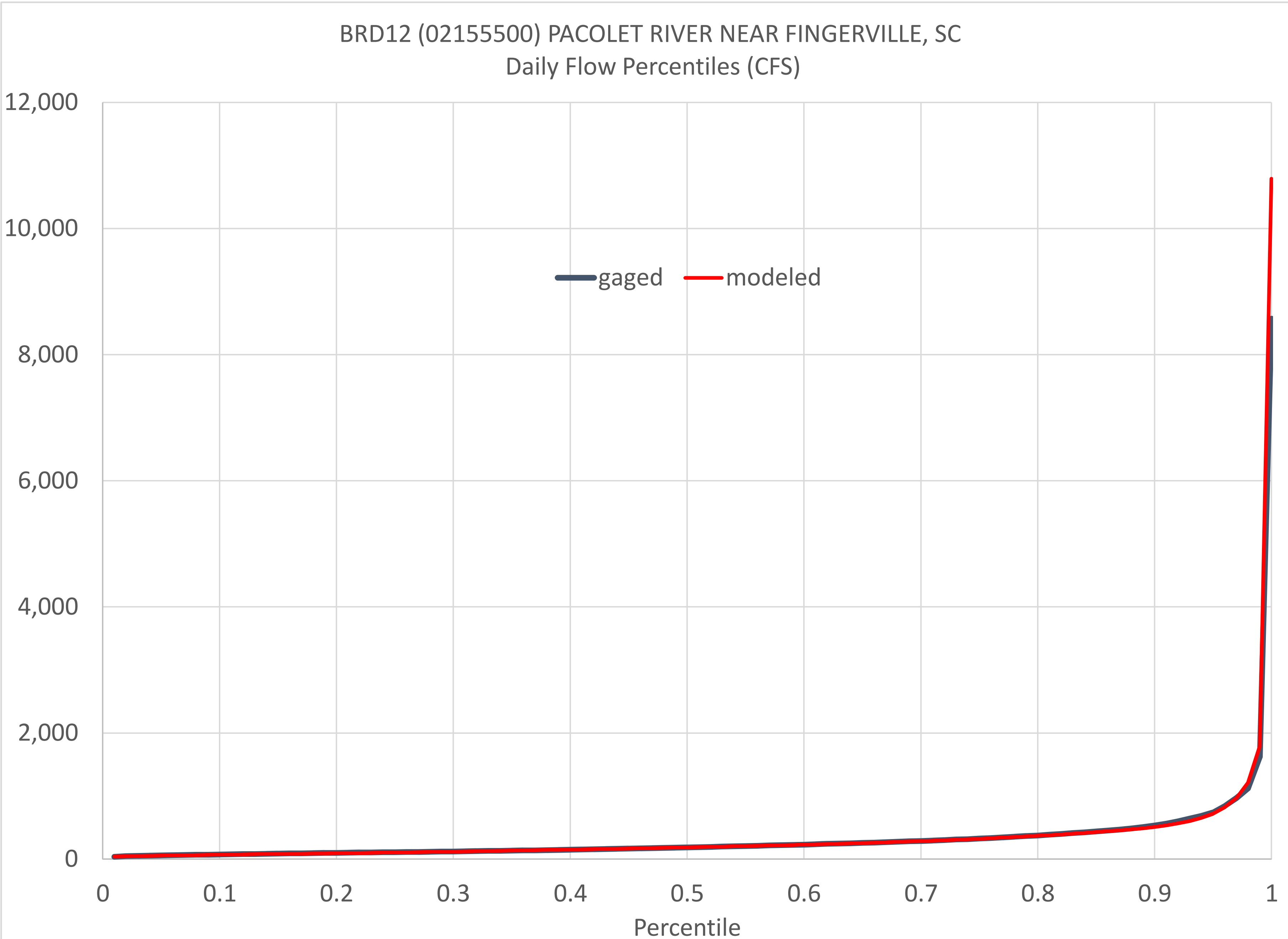

BRD54 (02161000) BROAD RIVER AT ALSTON, SC
Daily Flow Percentiles (CFS)
gaged
modeled
200,000
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

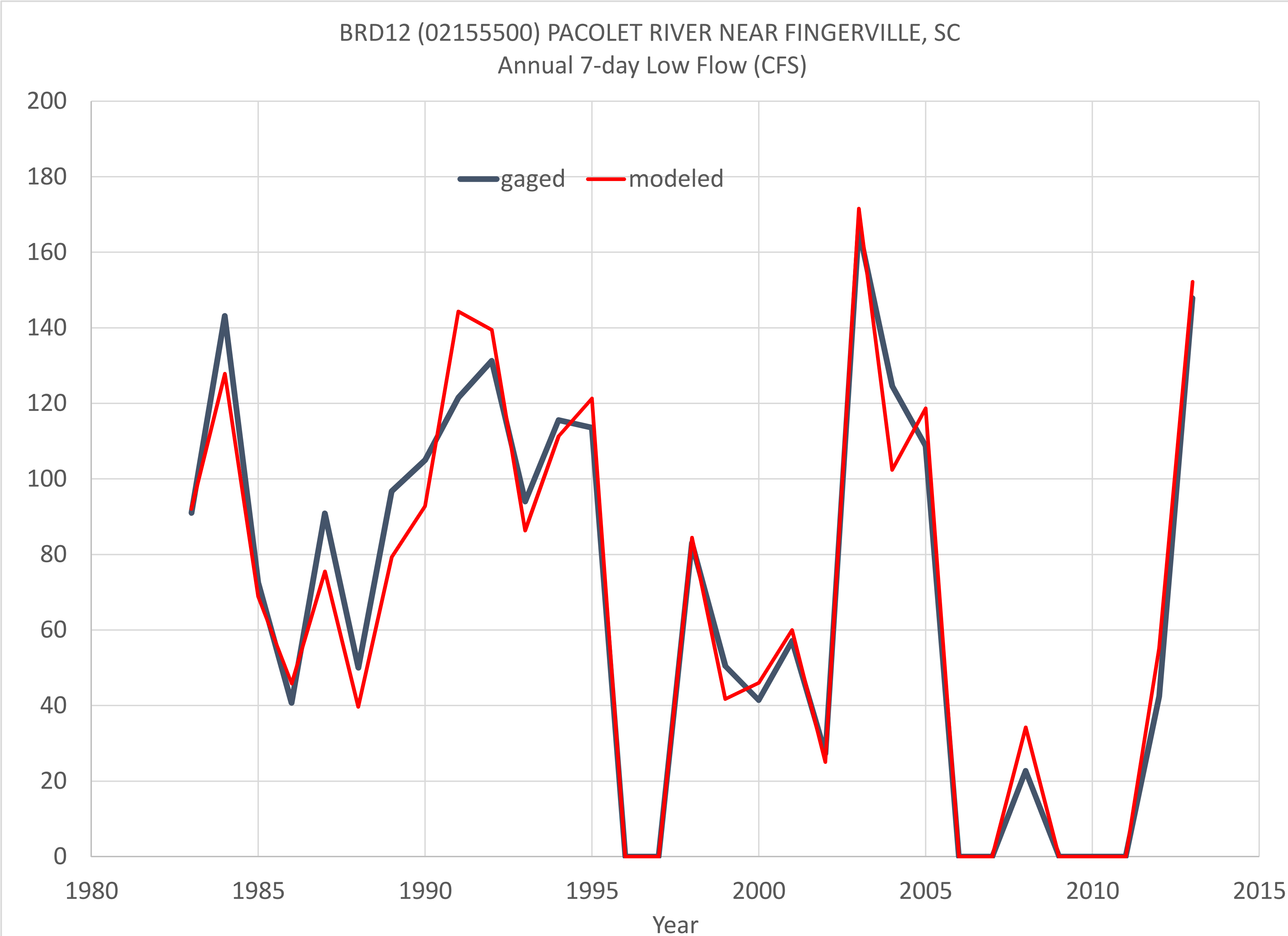


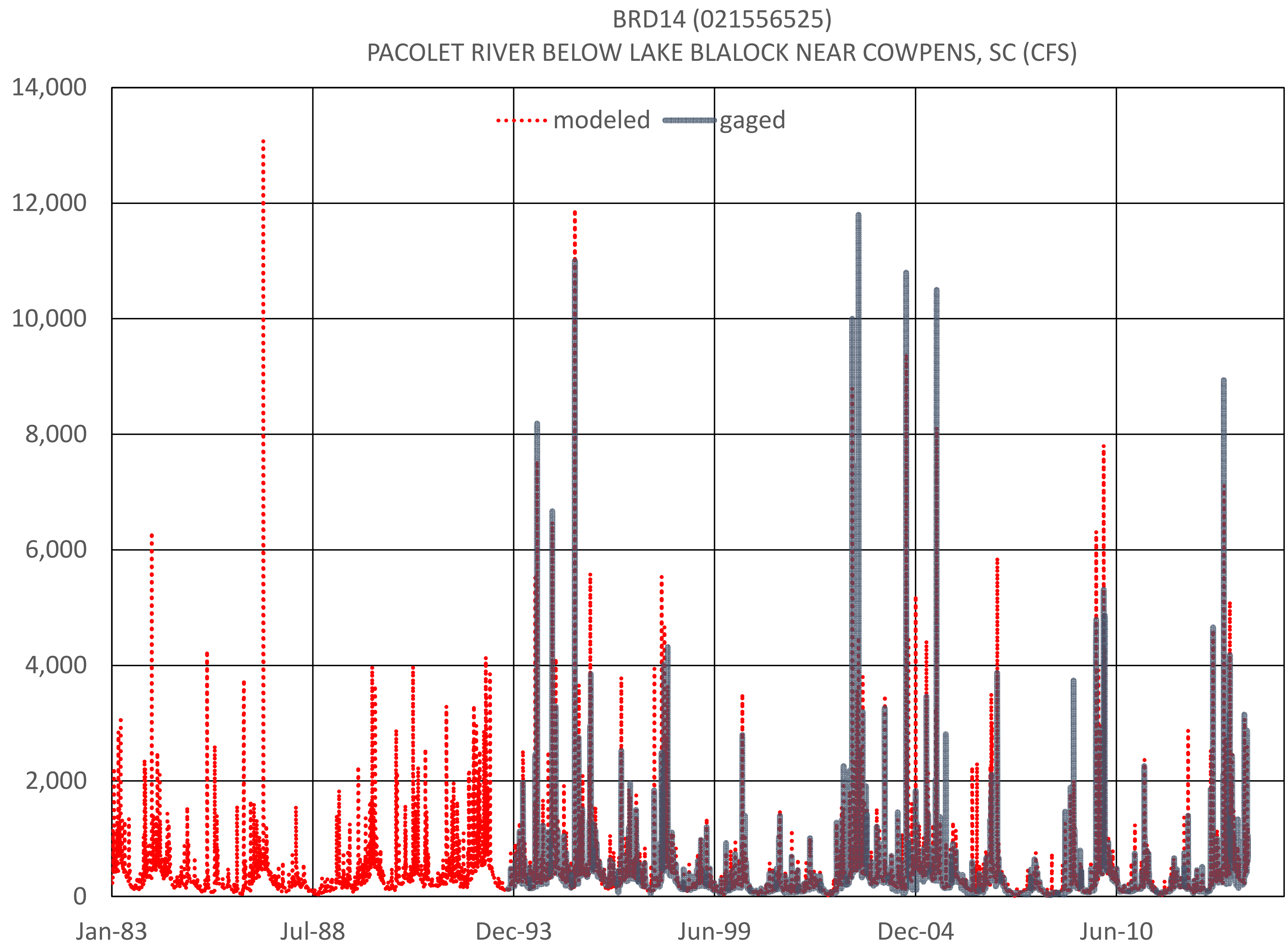
BRD54 (02161000) BROAD RIVER AT ALSTON, SC
Annual 7-day Low Flow (CFS)
gaged
modeled
3,500
3,000
2,500
2,000
1,500
1,000
500
0
1980
1985
1990
1995
2000
2005
2010
2015
Year



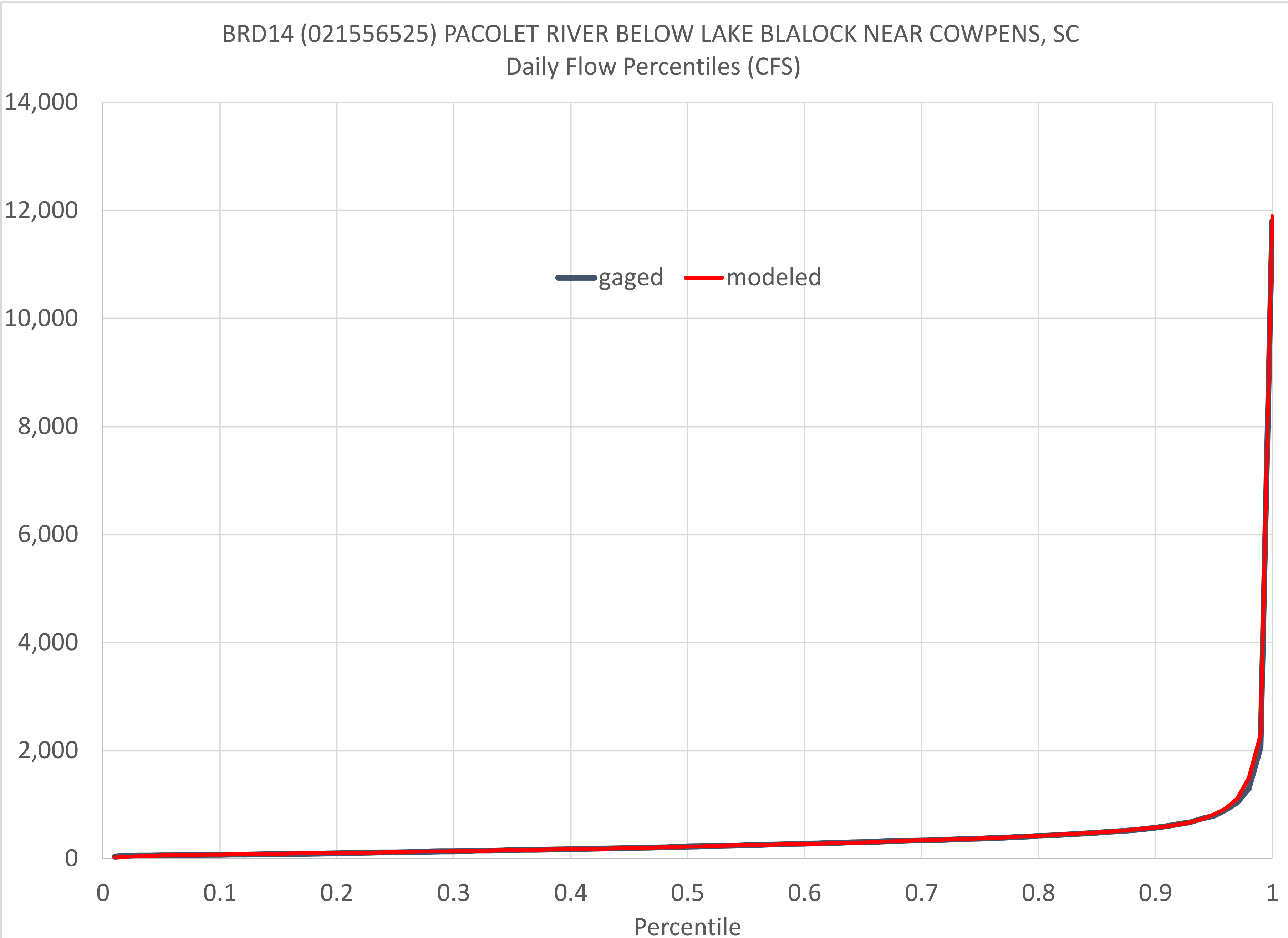
BRD12 (02155500) PACOLET RIVER NEAR FINGERVILLE, SC (CFS)
modeled
gaged
12,000
10,000
8,000
6,000
4,000
2,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

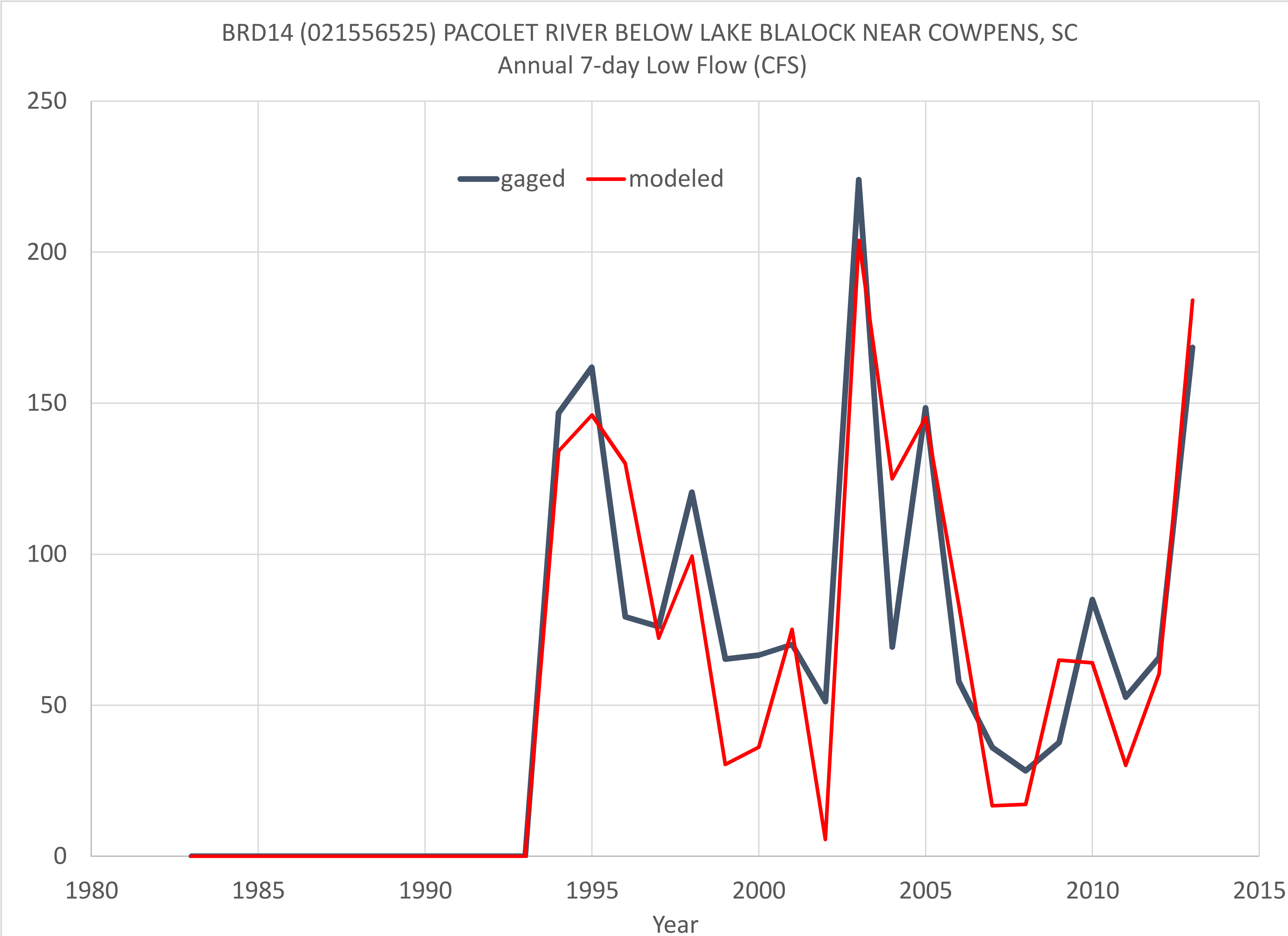

BRD12 (02155500) PACOLET RIVER NEAR FINGERVILLE, SC
Daily Flow Percentiles (CFS)
12,000
10,000
8,000
6,000
4,000
2,000
0
gaged
modeled
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

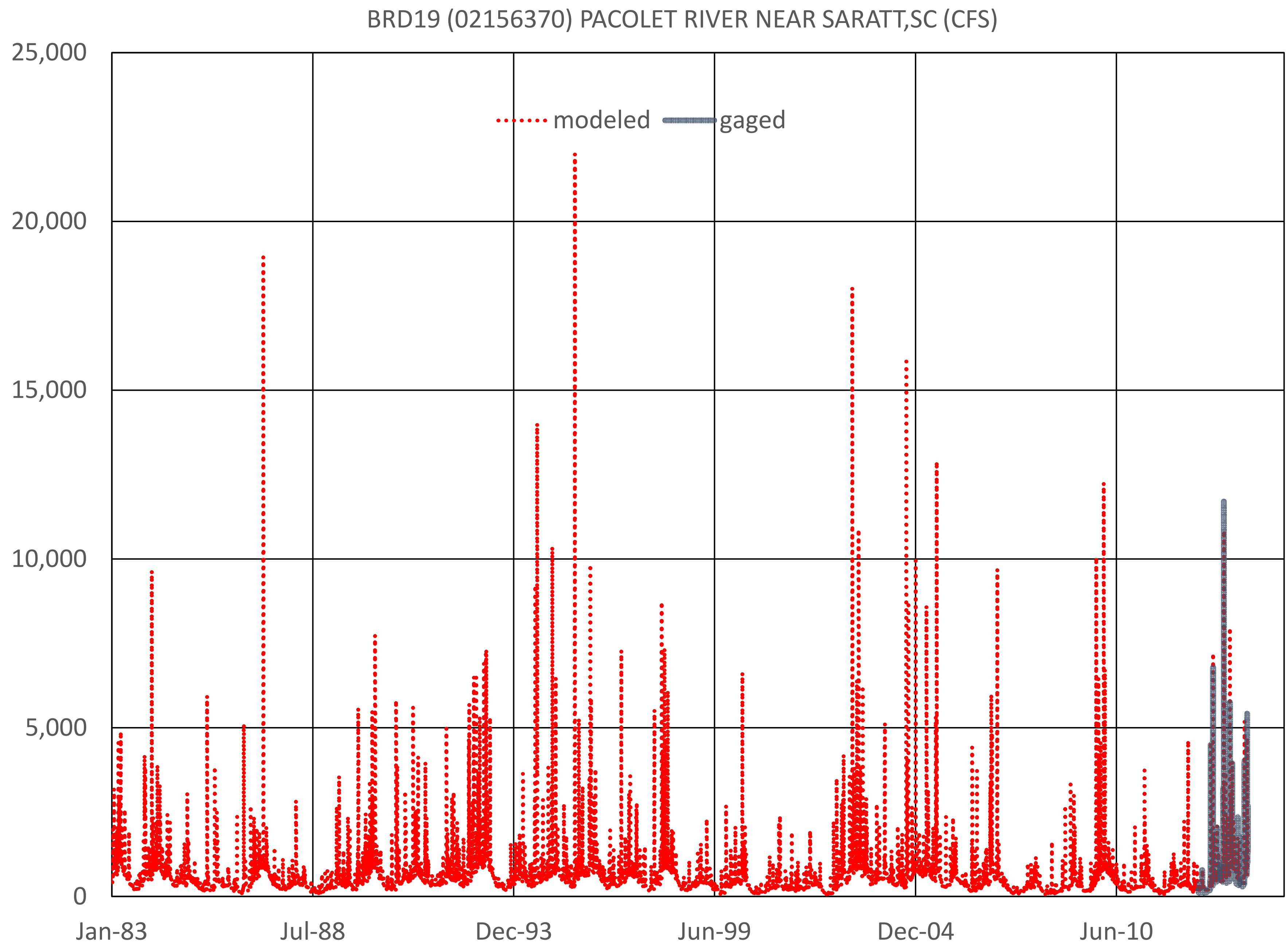

BRD12 (02155500) PACOLET RIVER NEAR FINGERVILLE, SC
Annual 7-day Low Flow (CFS)
gaged
modeled
200
180
160
140
120
100
80
60
40
20
0
1980
1985
1990
1995
2000
2005
2010
2015
Year

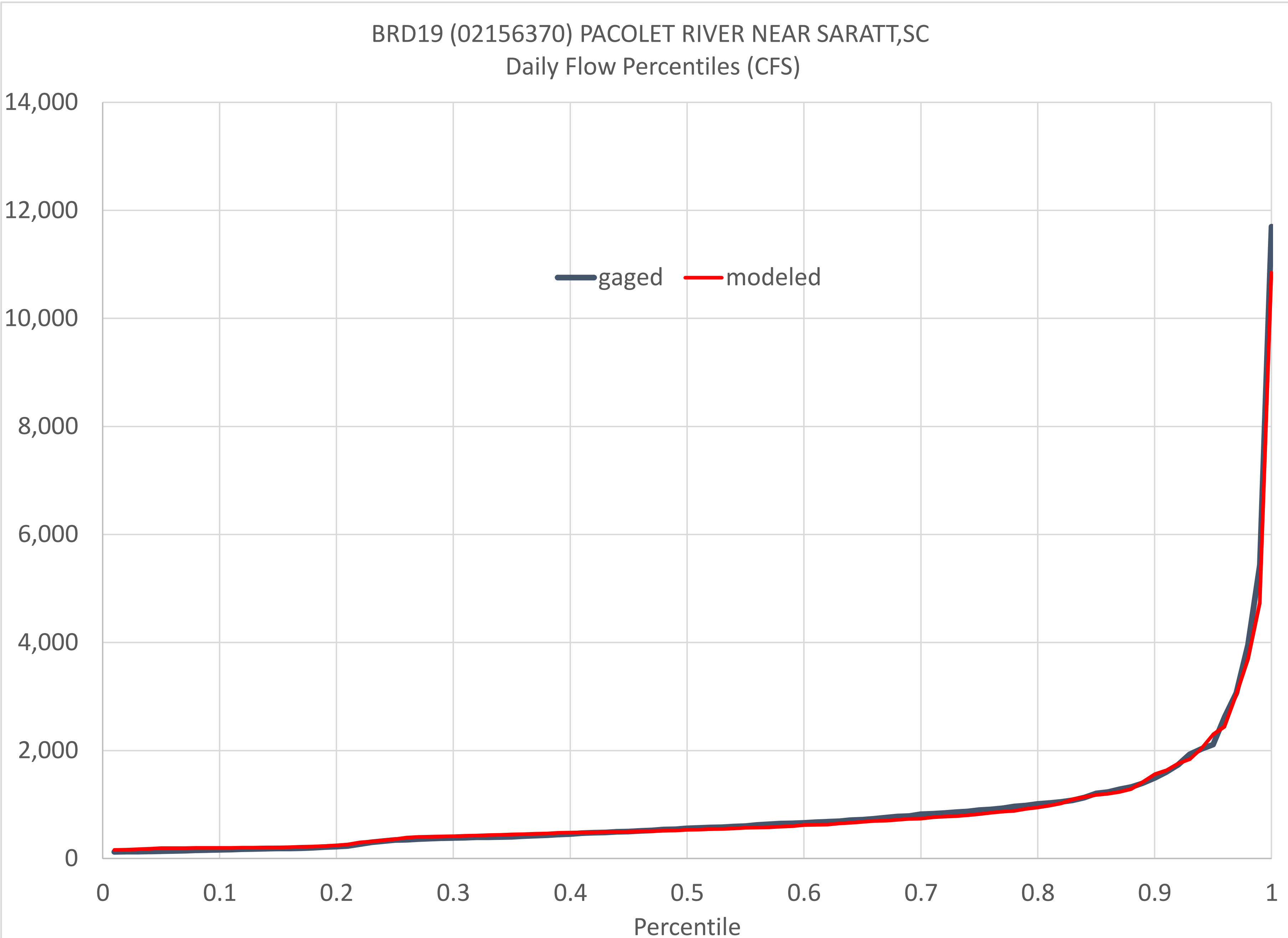


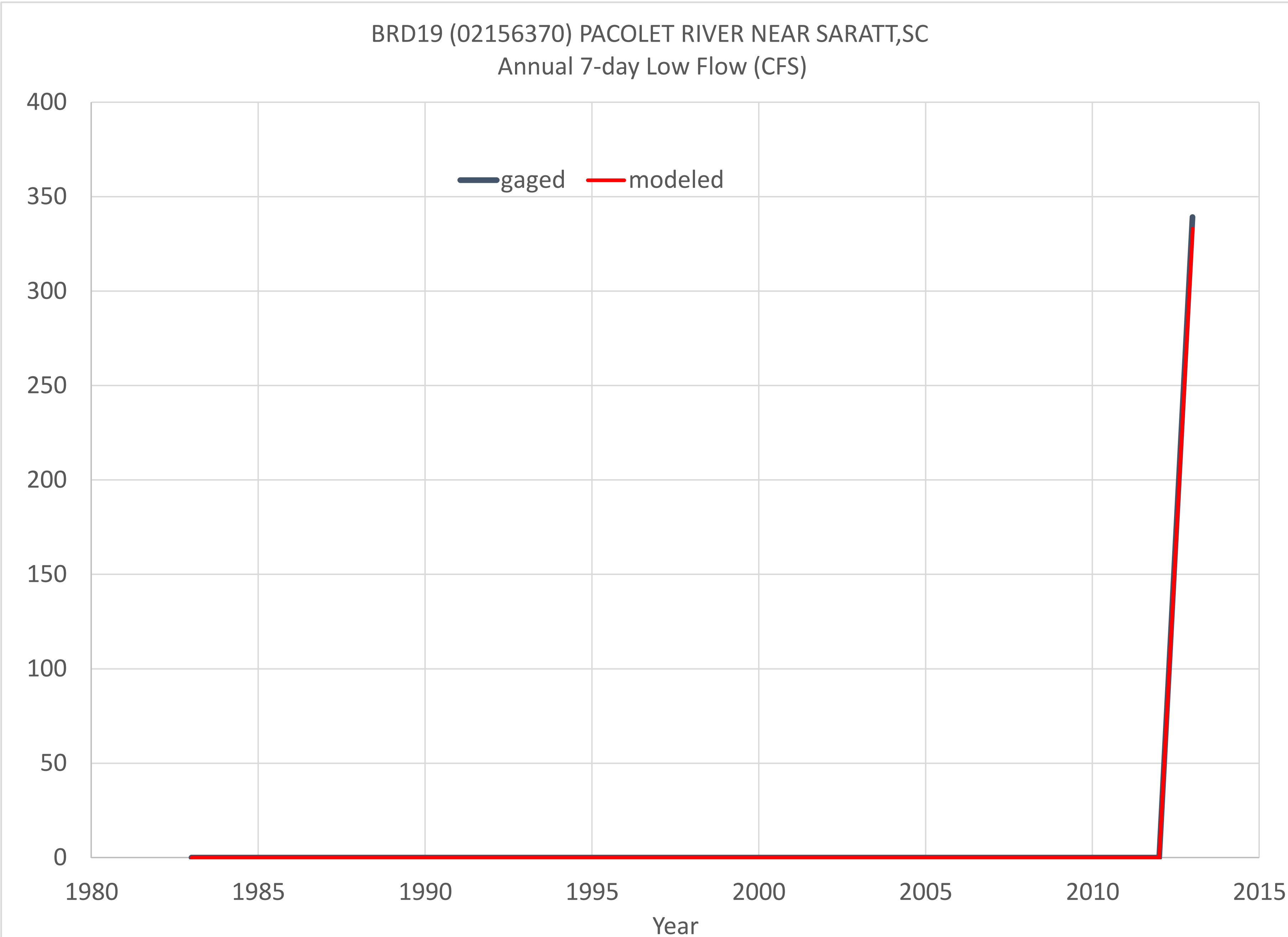
BRD14 (021556525)
PACOLET RIVER BELOW LAKE BLALOCK NEAR COWPENS, SC (CFS)
modeled
gaged
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10


BRD14 (021556525) PACOLET RIVER BELOW LAKE BLALOCK NEAR COWPENS, SC
Daily Flow Percentiles (CFS)
gaged
modeled
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

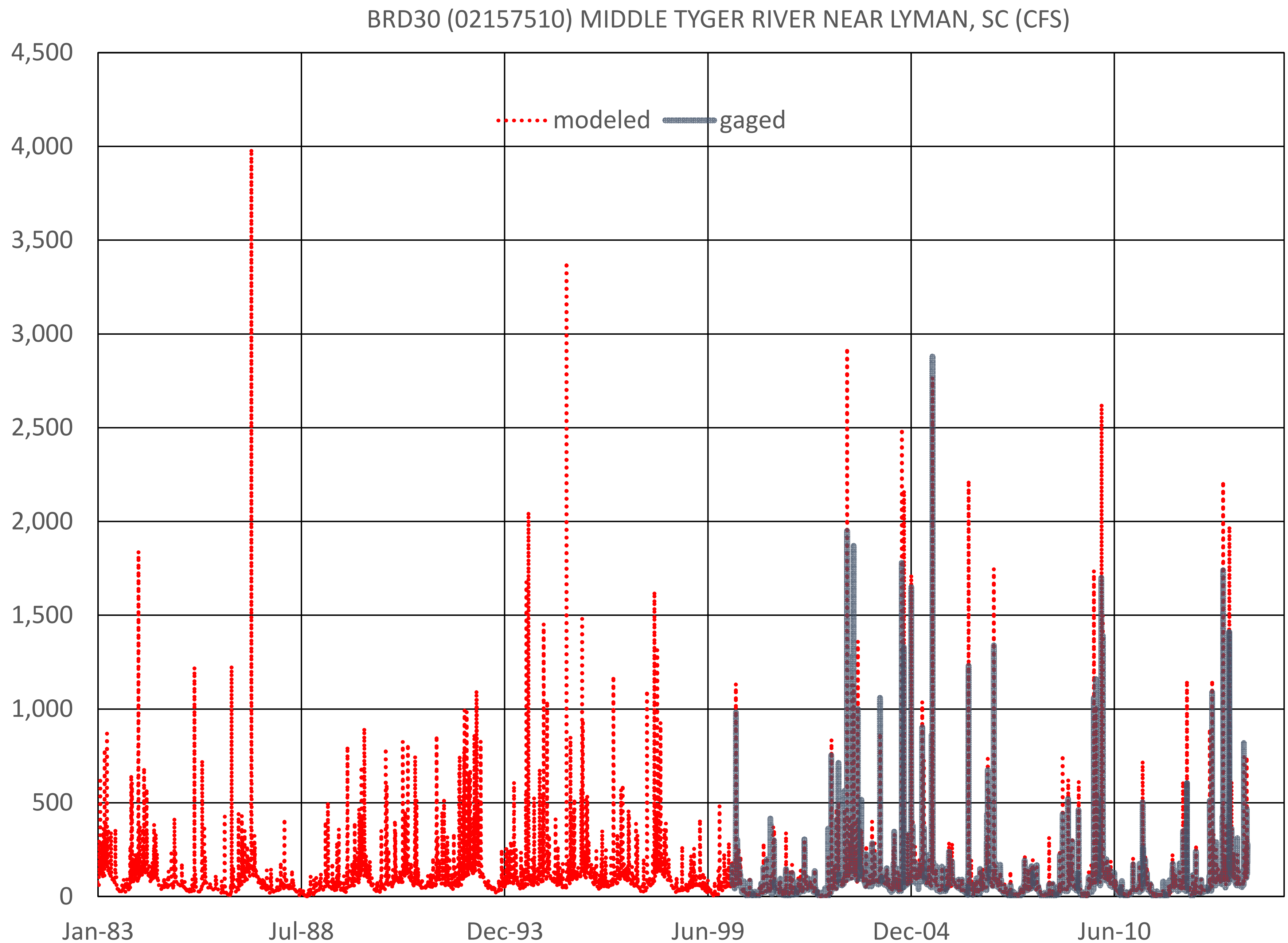

BRD14 (021556525) PACOLET RIVER BELOW LAKE BLALOCK NEAR COWPENS, SC
Annual 7-day Low Flow (CFS)
gaged
modeled
250
200
150
100
50
0
1980
1985
1990
1995
2000
2005
2010
2015
Year


BRD19 (02156370) PACOLET RIVER NEAR SARATT,SC (CFS)
modeled
gaged
25,000
20,000
15,000
10,000
5,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

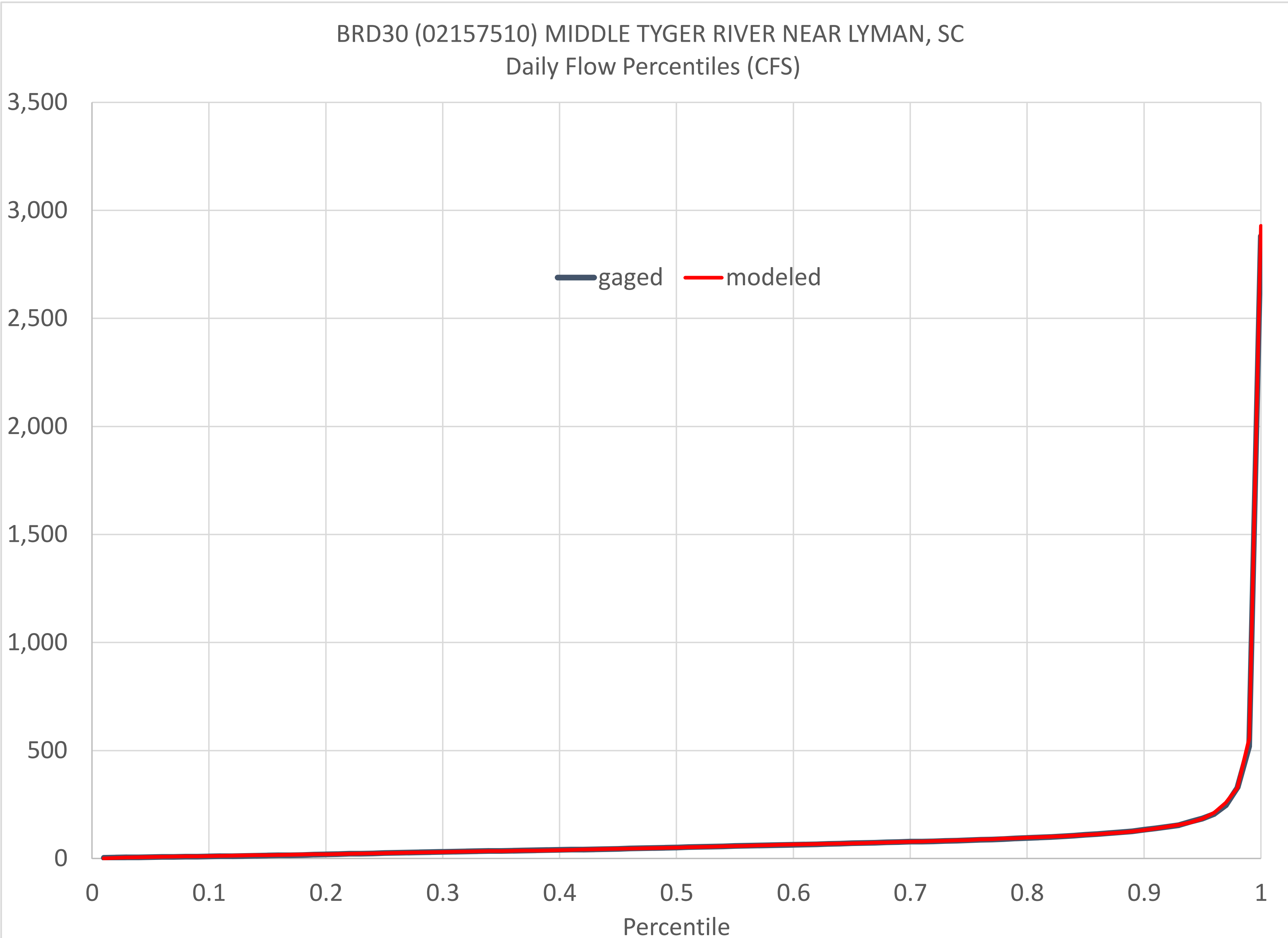

BRD19 (02156370) PACOLET RIVER NEAR SARATT,SC
Daily Flow Percentiles (CFS)
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
gaged
modeled
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

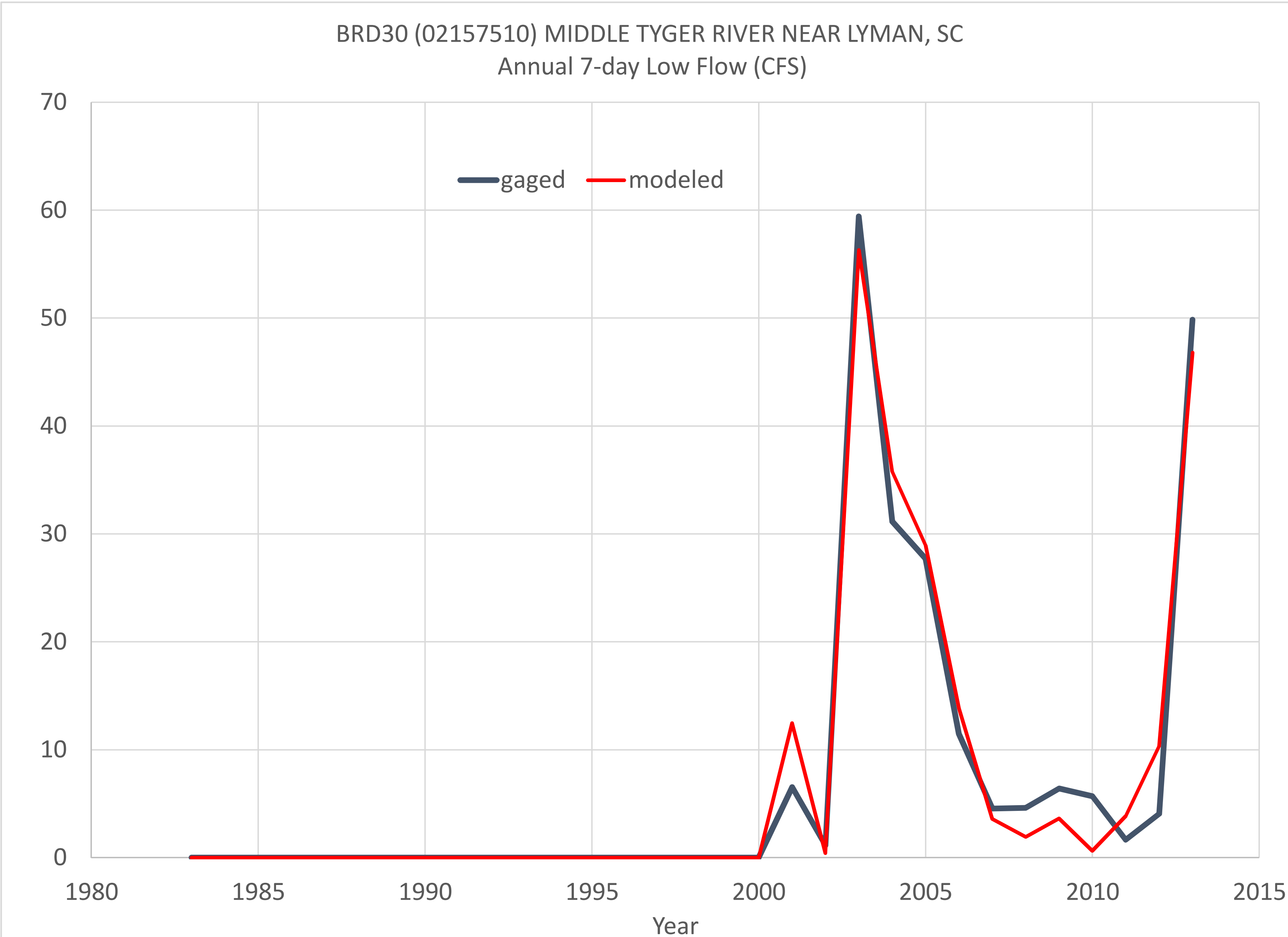


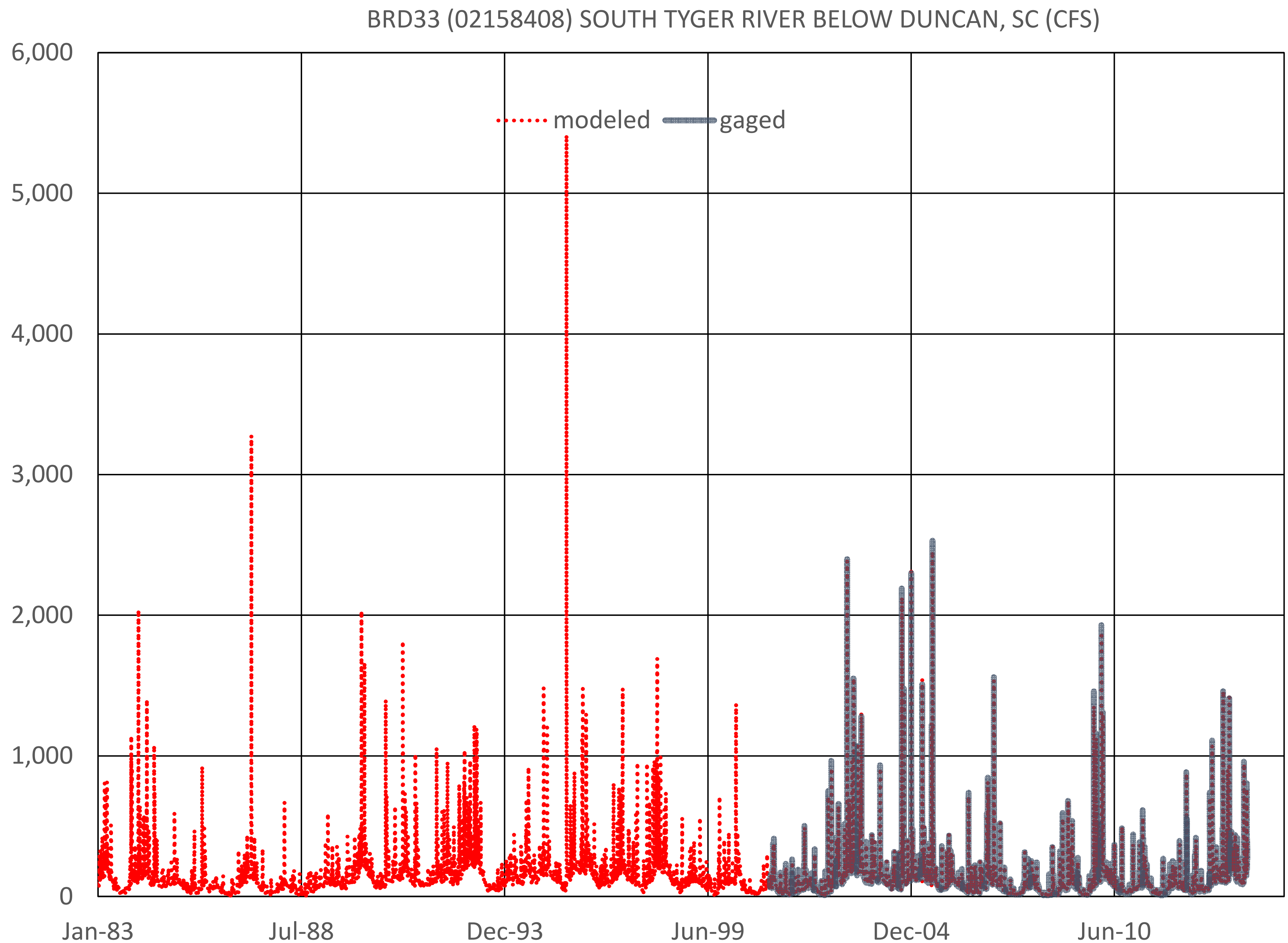
BRD19 (02156370) PACOLET RIVER NEAR SARATT,SC
Annual 7-day Low Flow (CFS)
gaged
modeled
400
350
300
250
200
150
100
50
0
1980
1985
1990
1995
2000
2005
2010
2015
Year



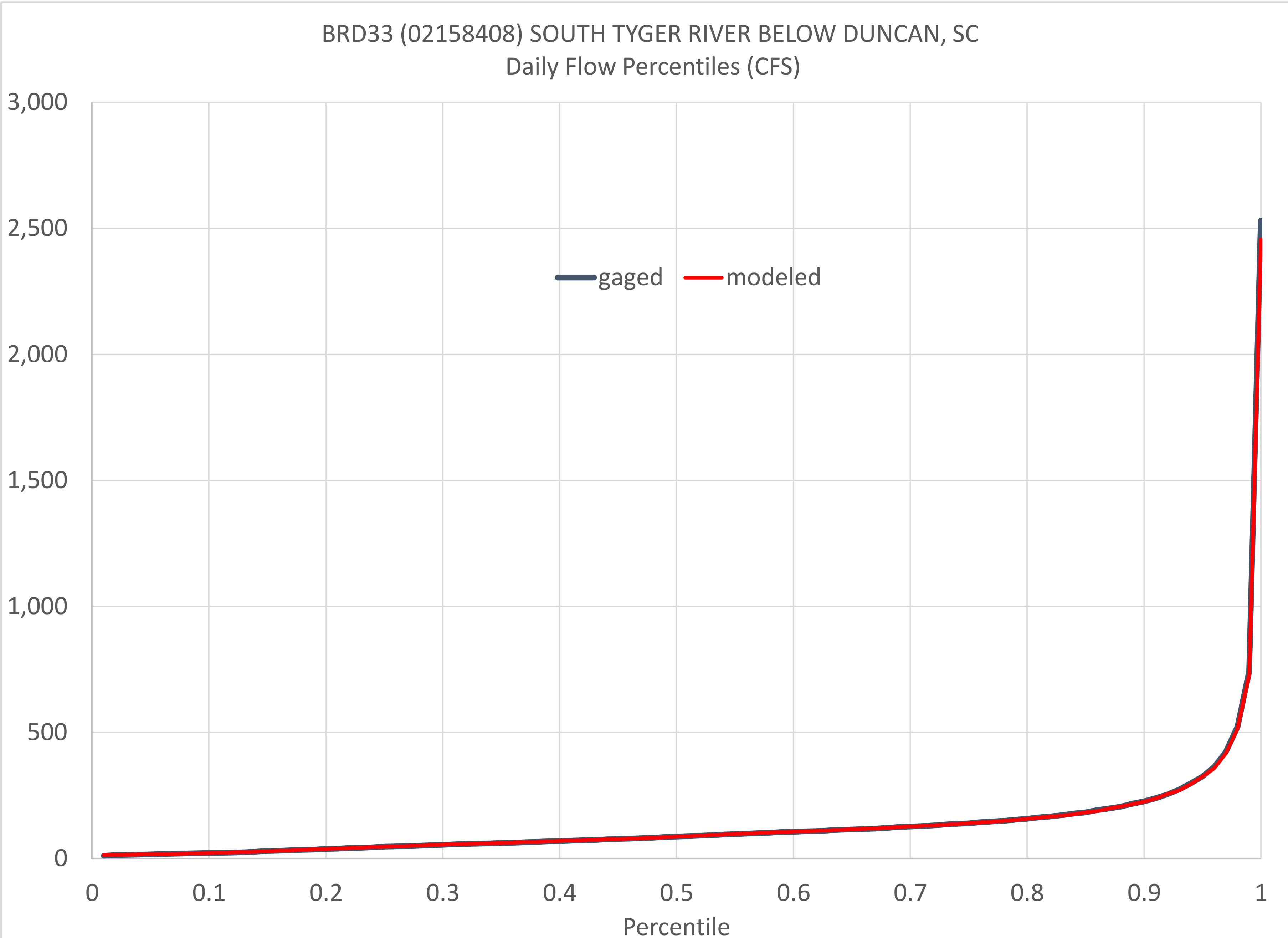
BRD30 (02157510) MIDDLE TYGER RIVER NEAR LYMAN, SC (CFS)
modeled
gaged
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10


BRD30 (02157510) MIDDLE TYGER RIVER NEAR LYMAN, SC
Daily Flow Percentiles (CFS)
gaged
modeled
3,500
3,000
2,500
2,000
1,500
1,000
500
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

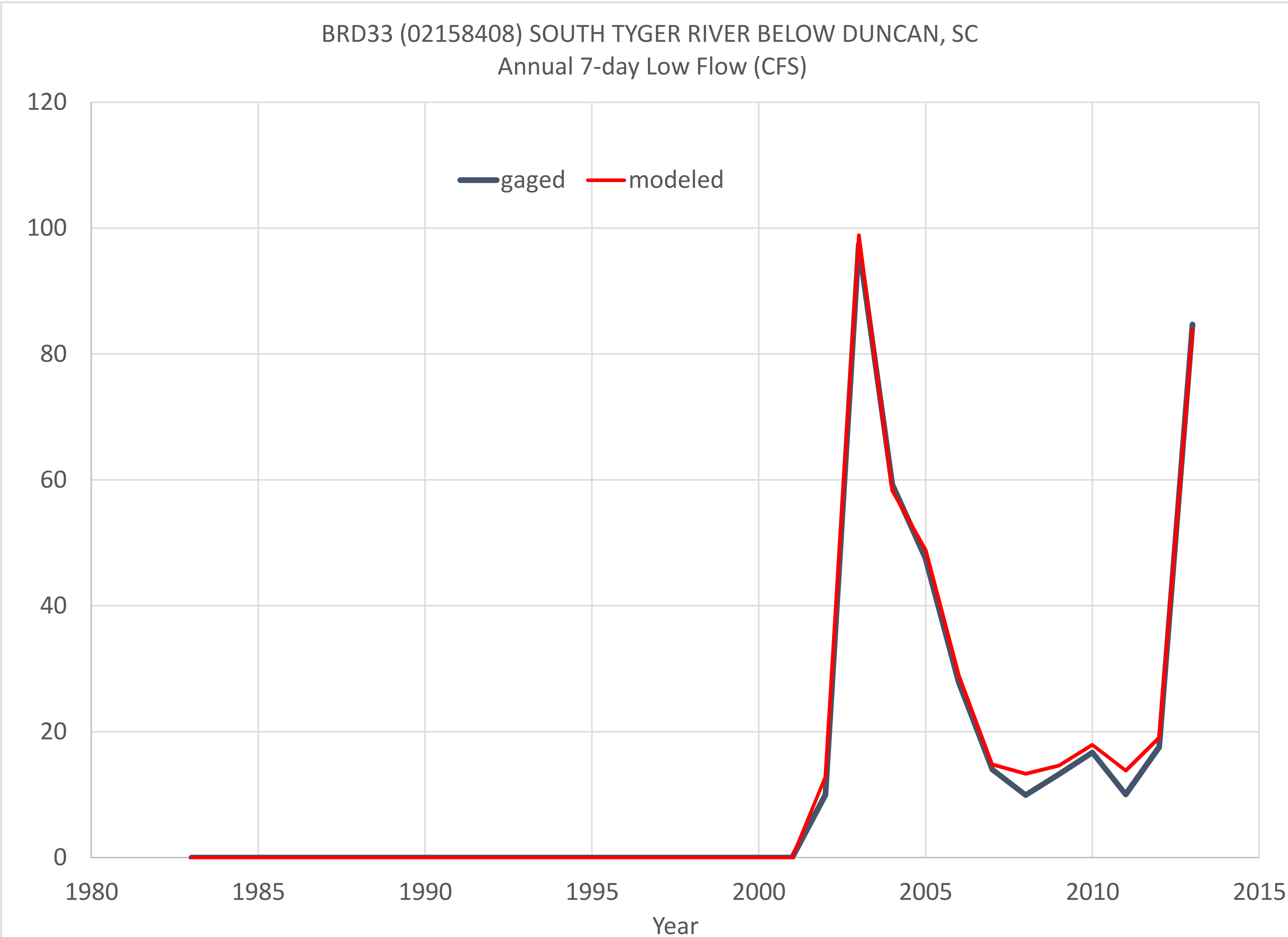

BRD30 (02157510) MIDDLE TYGER RIVER NEAR LYMAN, SC
Annual 7-day Low Flow (CFS)
gaged
modeled
70
60
50
40
30
20
10
0
1980
1985
1990
1995
2000
2005
2010
2015
Year

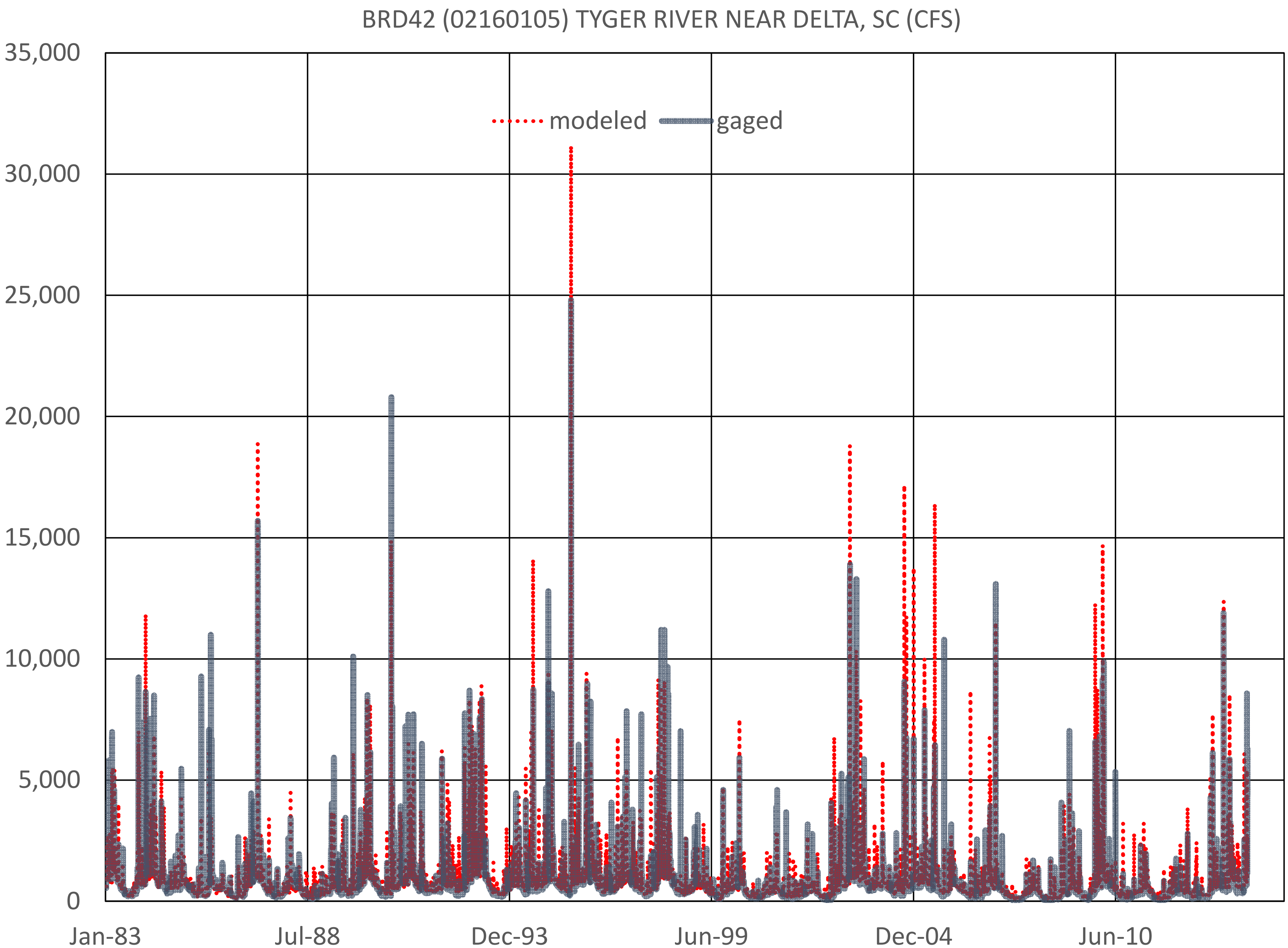


BRD33 (02158408) SOUTH TYGER RIVER BELOW DUNCAN, SC (CFS)
modeled
gaged
6,000
5,000
4,000
3,000
2,000
1,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

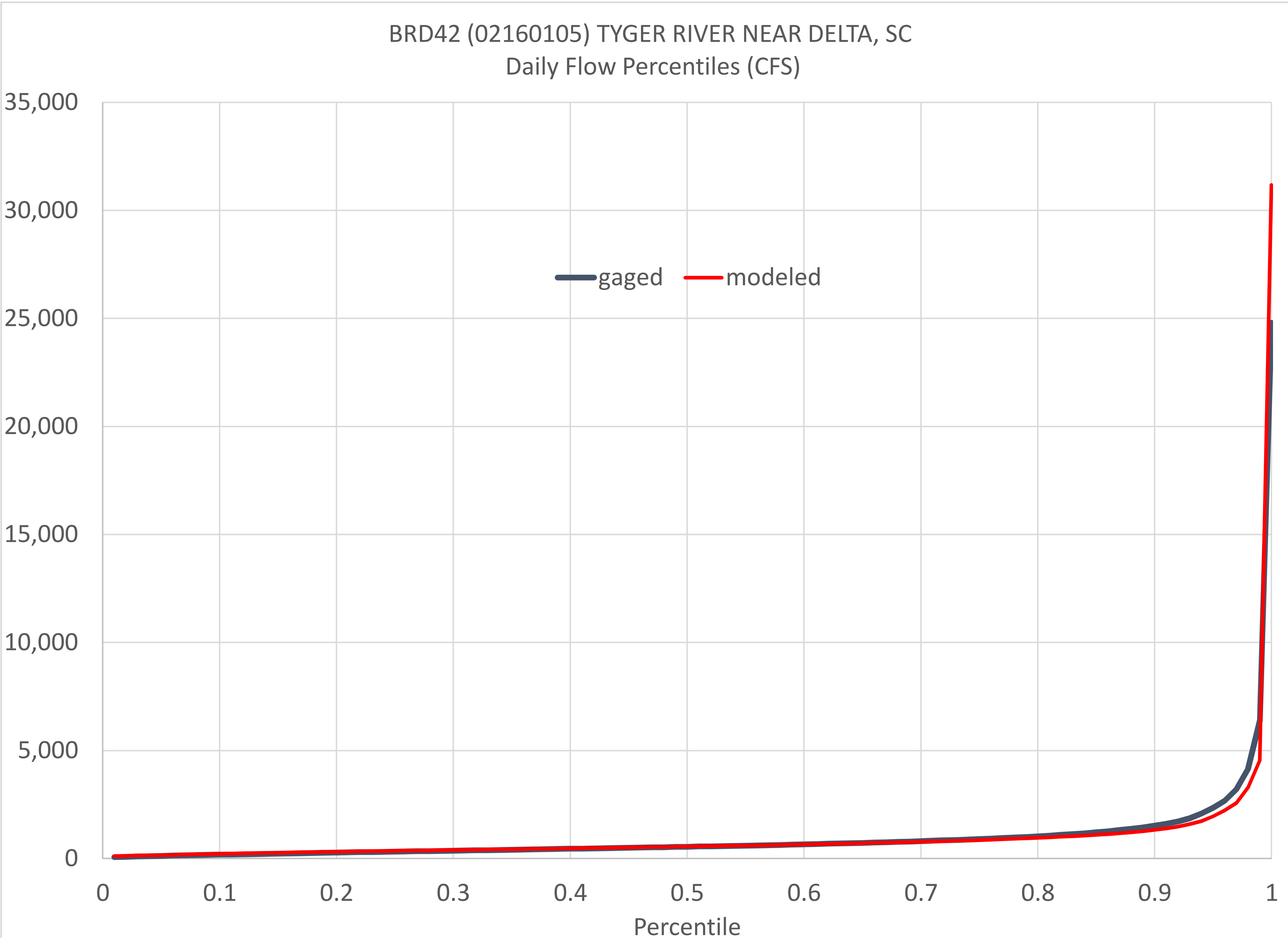


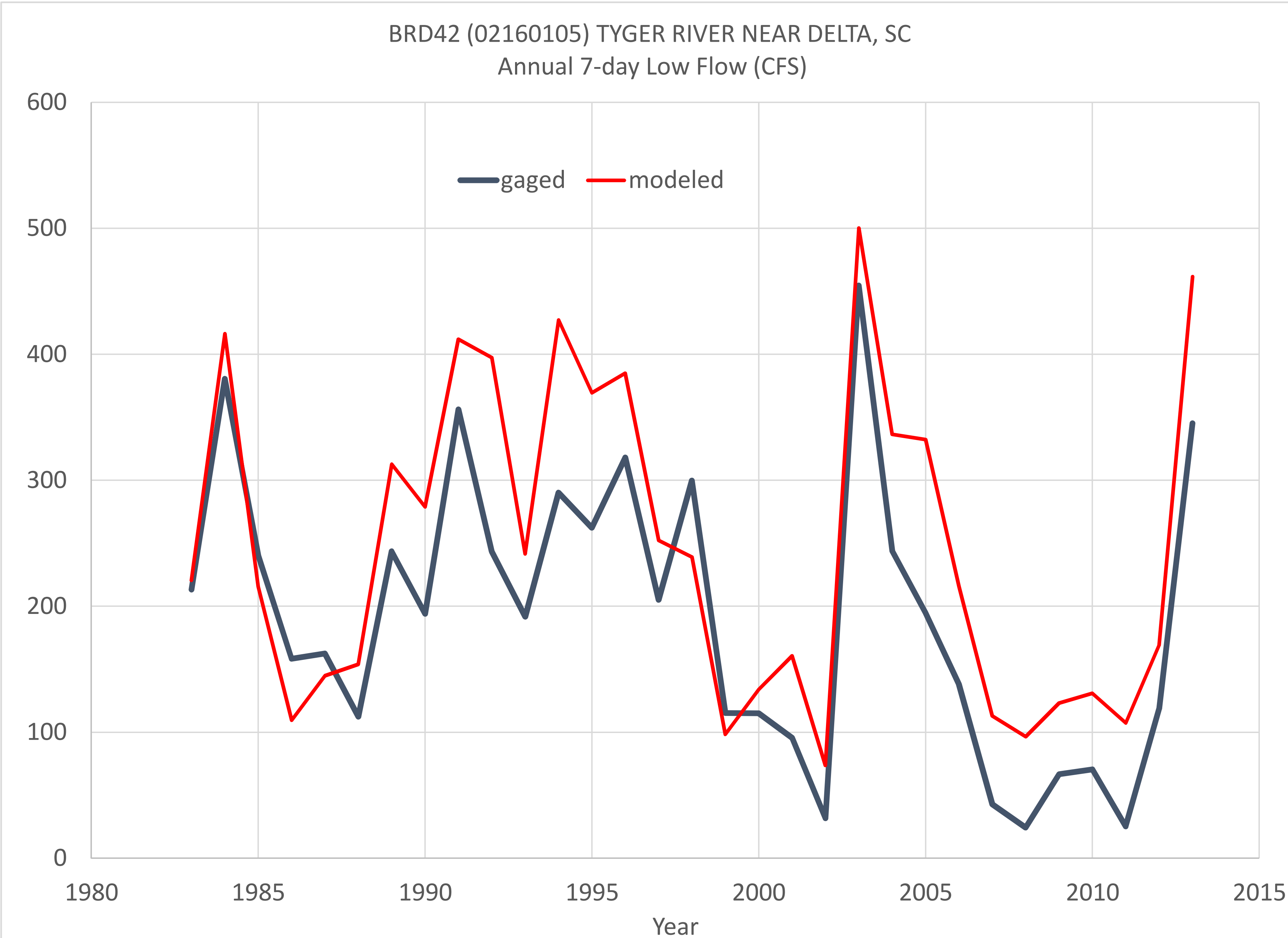
BRD33 (02158408) SOUTH TYGER RIVER BELOW DUNCAN, SC
Daily Flow Percentiles (CFS)
3,000
2,500
2,000
1,500
1,000
500
0
gaged
modeled
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile


BRD33 (02158408) SOUTH TYGER RIVER BELOW DUNCAN, SC
Annual 7-day Low Flow (CFS)
gaged
modeled
120
100
80
60
40
20
0
1980
1985
1990
1995
2000
2005
2010
2015
Year

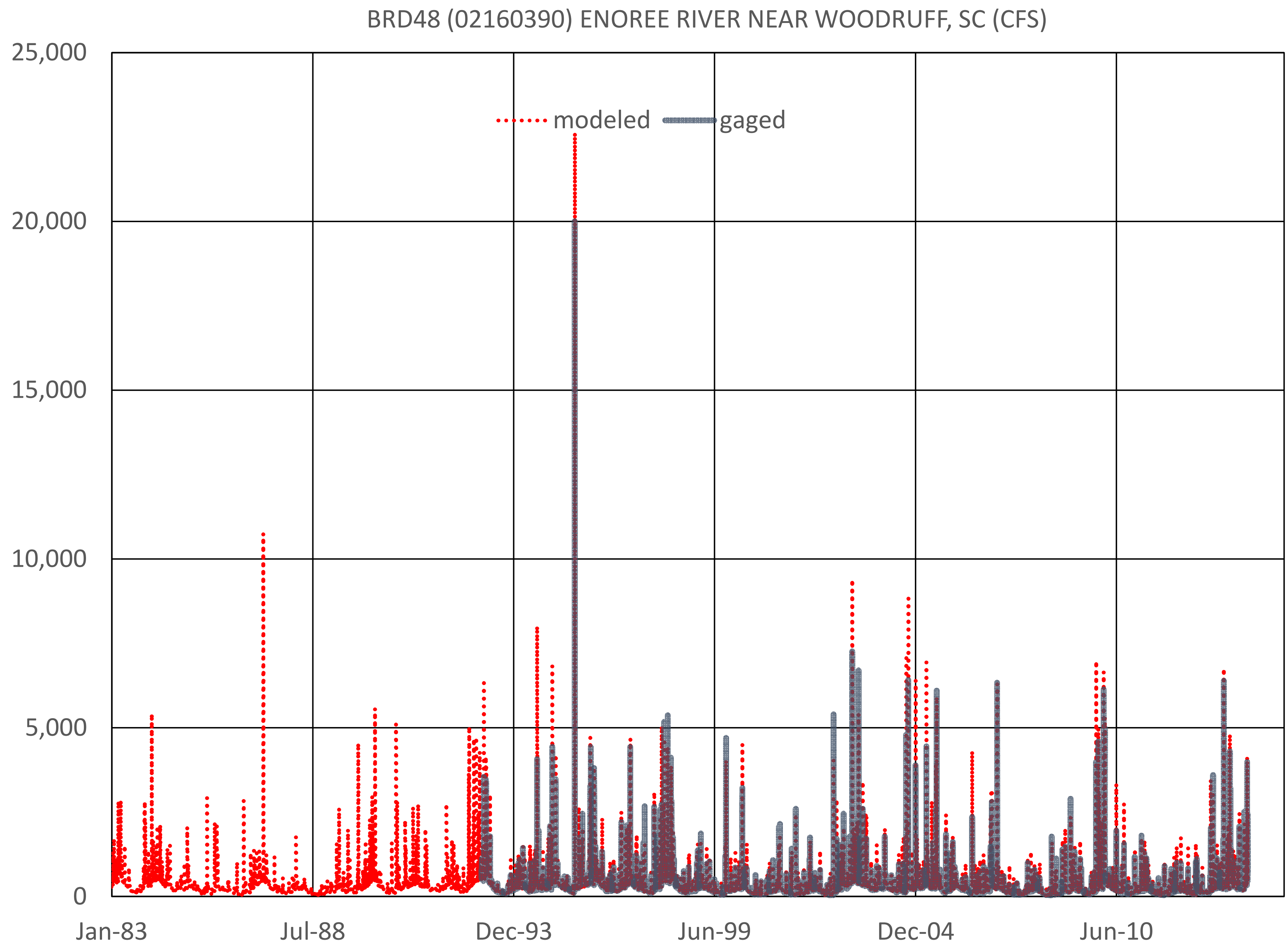


BRD42 (02160105) TYGER RIVER NEAR DELTA, SC (CFS)
modeled
gaged
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

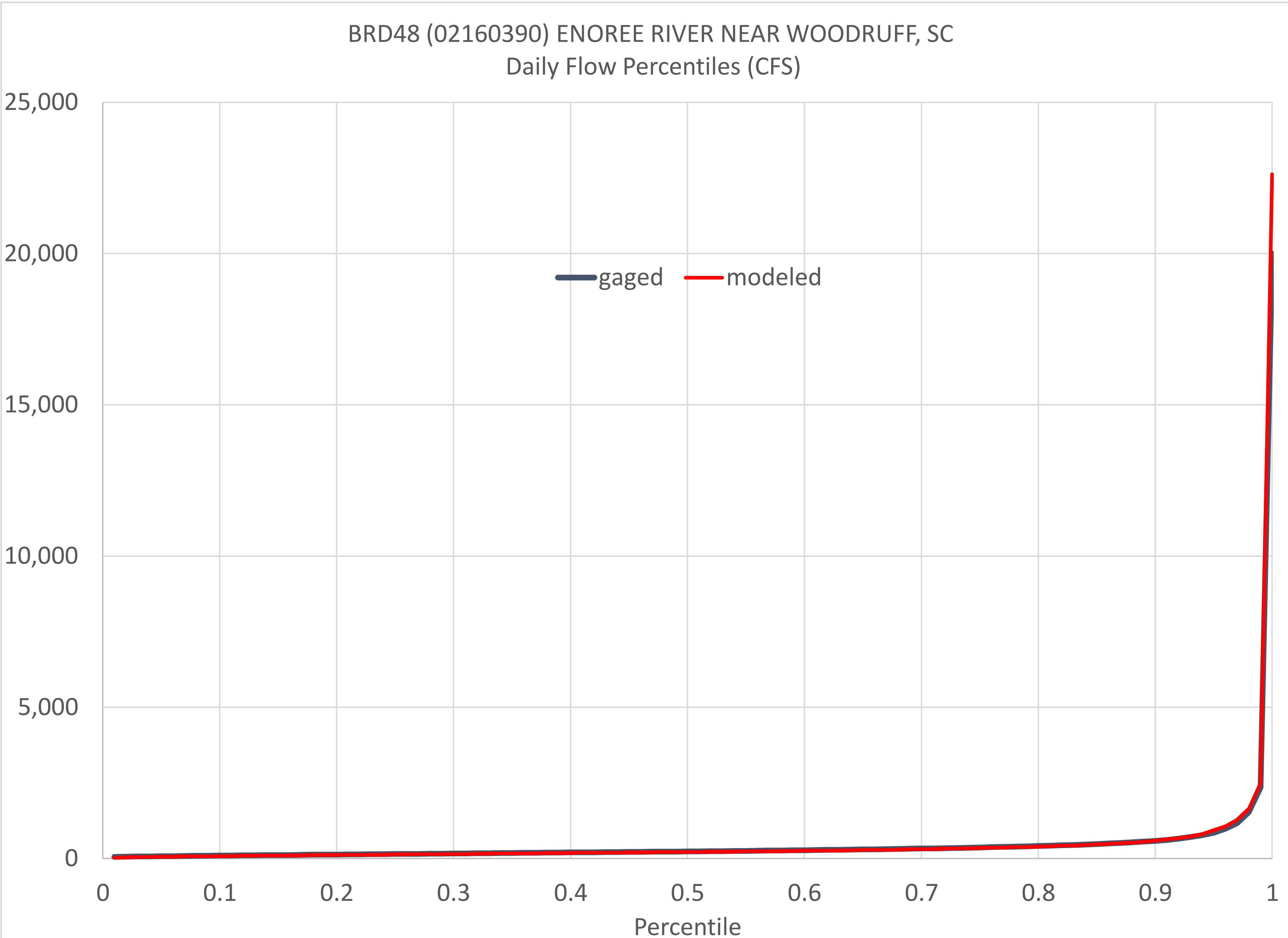

BRD42 (02160105) TYGER RIVER NEAR DELTA, SC
Daily Flow Percentiles (CFS)
gaged
modeled
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

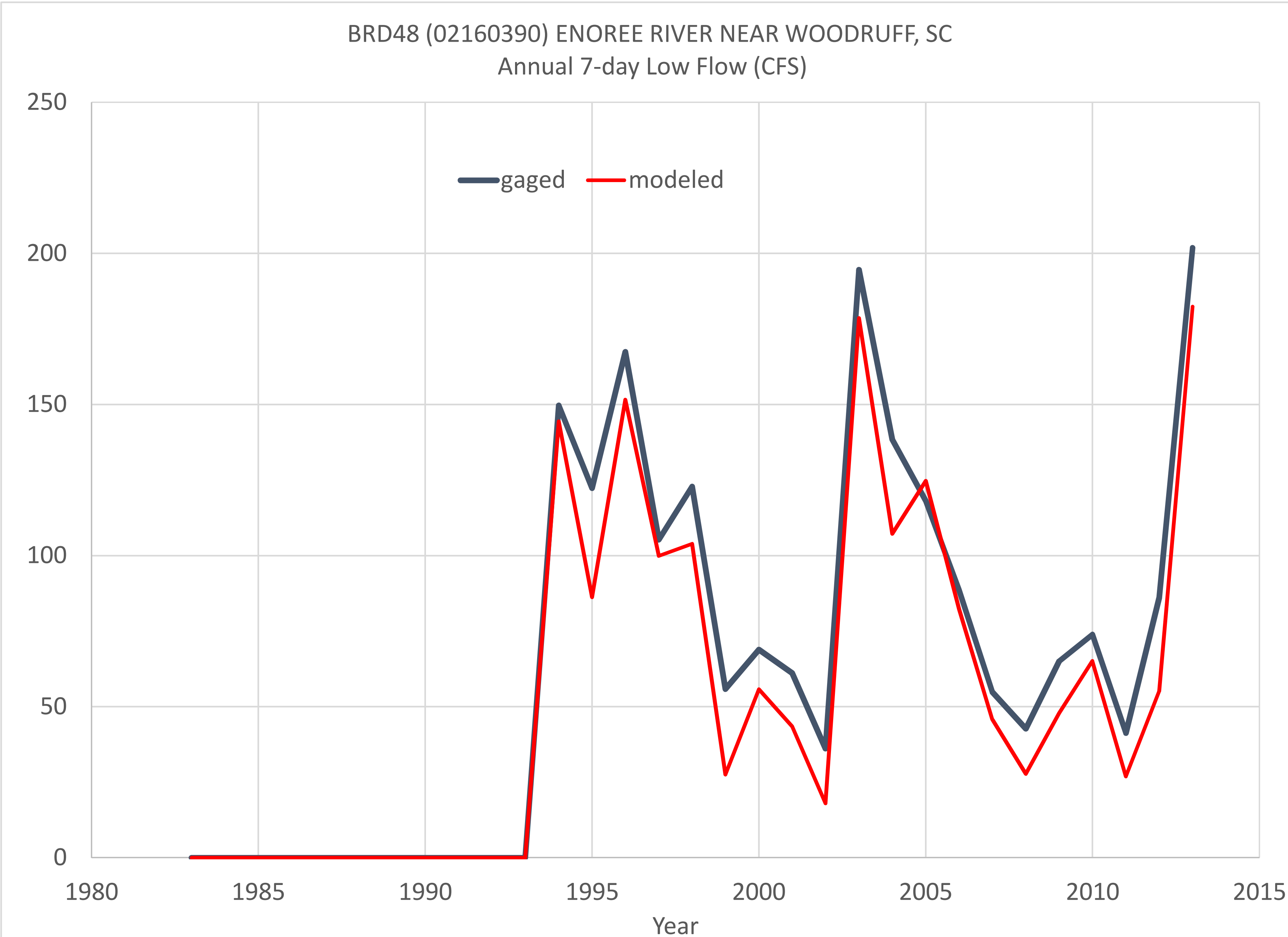


BRD42 (02160105) TYGER RIVER NEAR DELTA, SC
Annual 7-day Low Flow (CFS)
gaged
modeled
600
500
400
300
200
100
0
1980
1985
1990
1995
2000
2005
2010
2015
Year

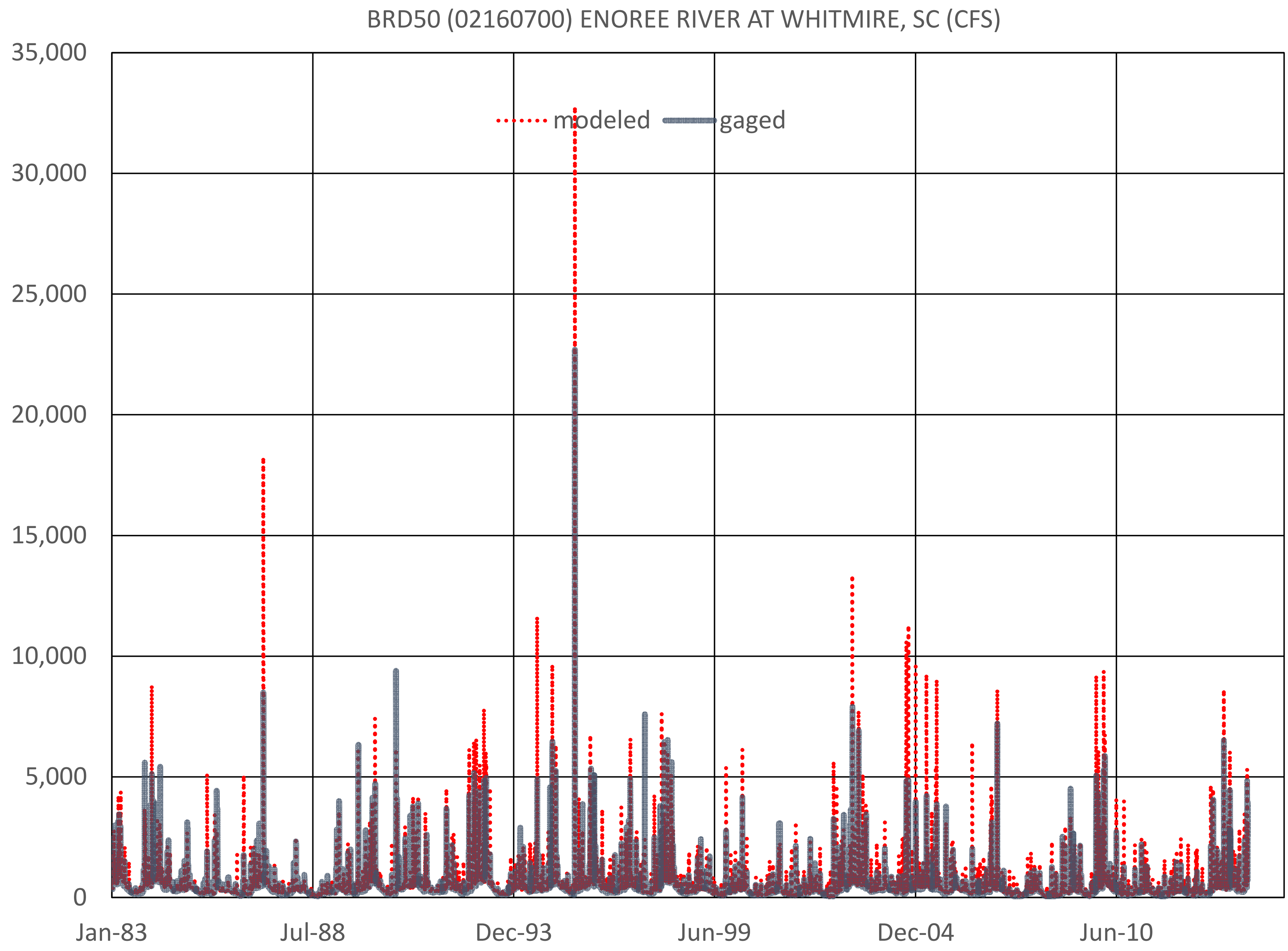


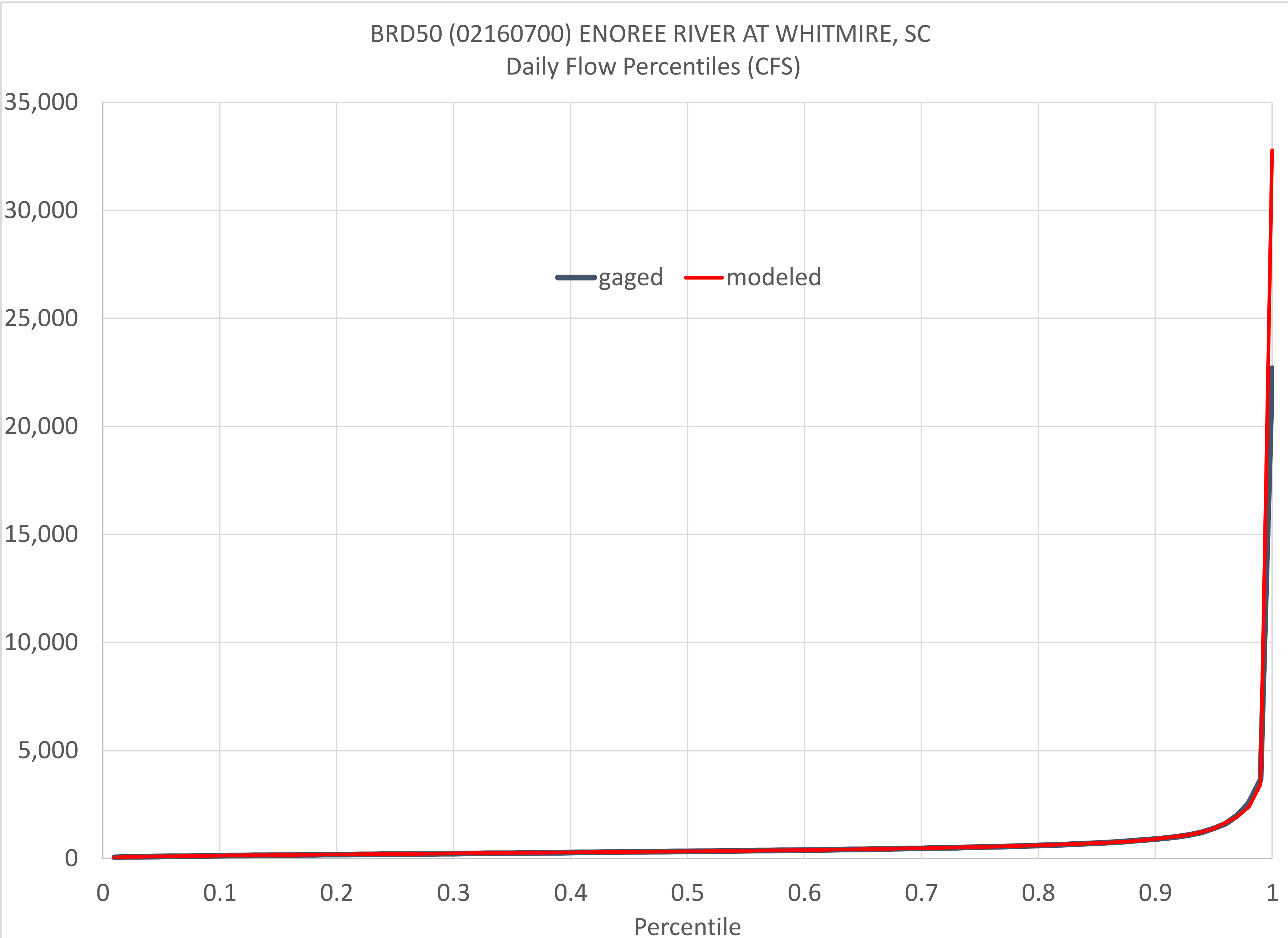
BRD48 (02160390) ENOREE RIVER NEAR WOODRUFF, SC (CFS)
modeled
gaged
25,000
20,000
15,000
10,000
5,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

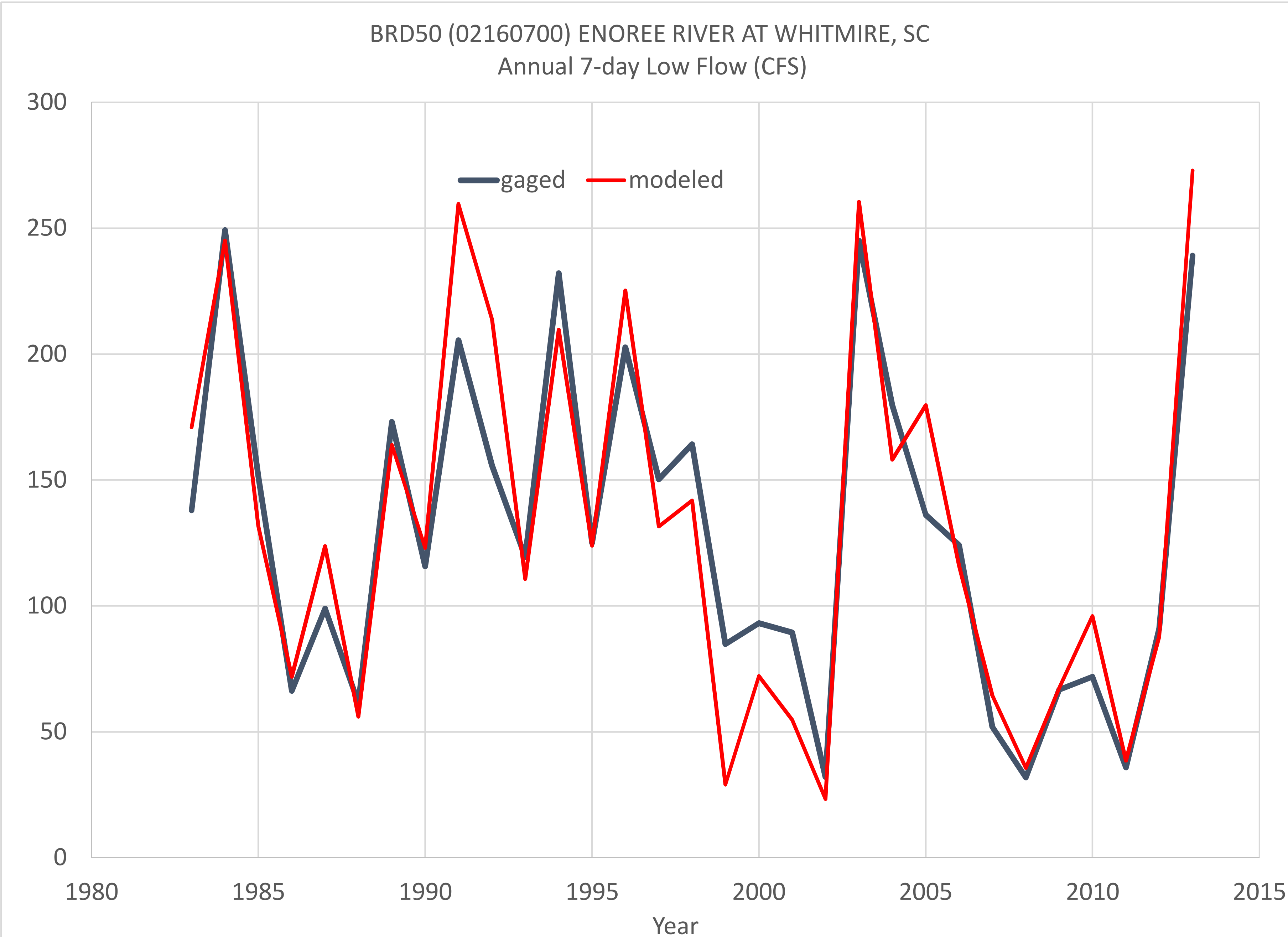

BRD48 (02160390) ENOREE RIVER NEAR WOODRUFF, SC
Daily Flow Percentiles (CFS)
gaged
modeled
25,000
20,000
15,000
10,000
5,000
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

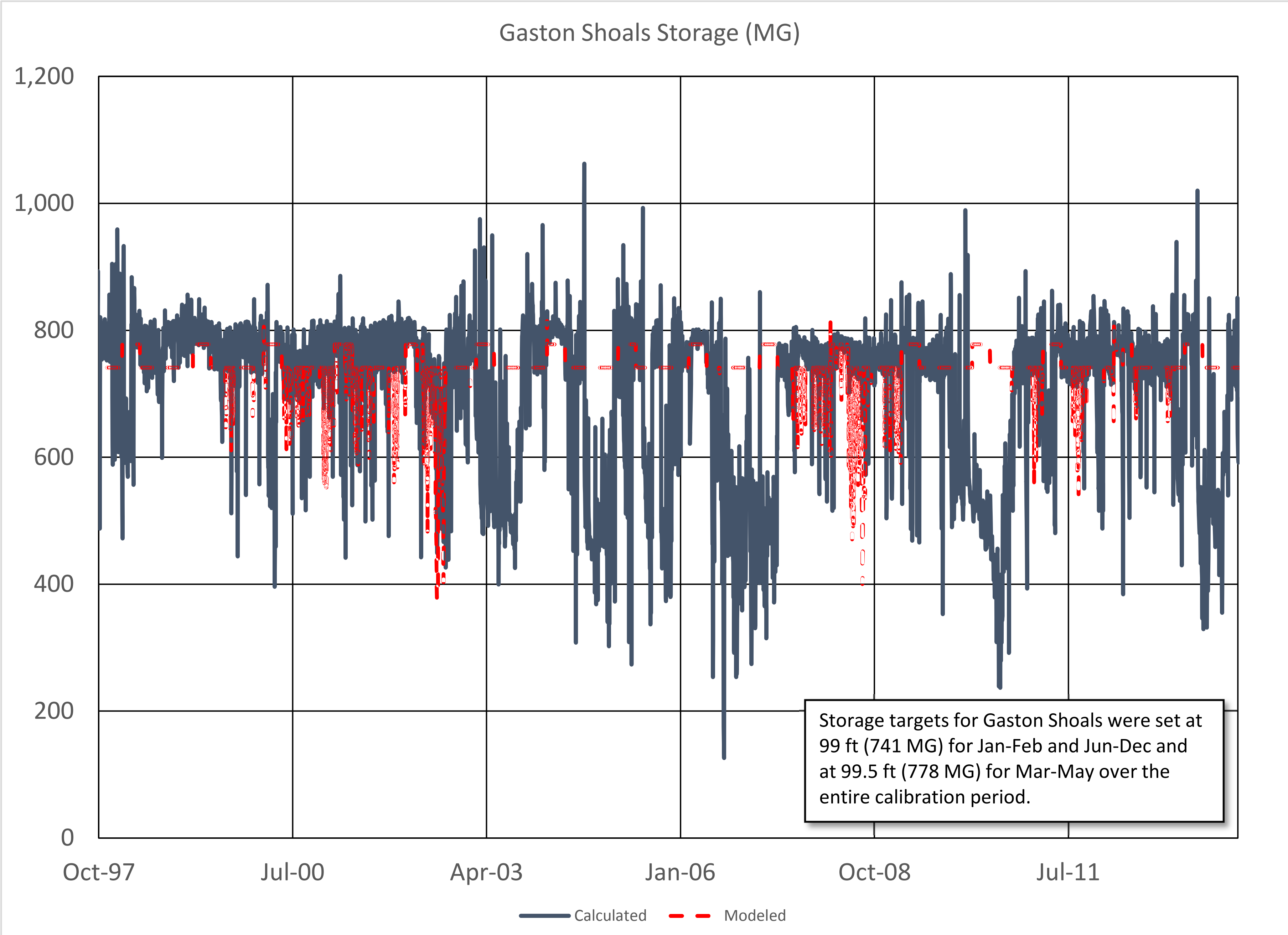


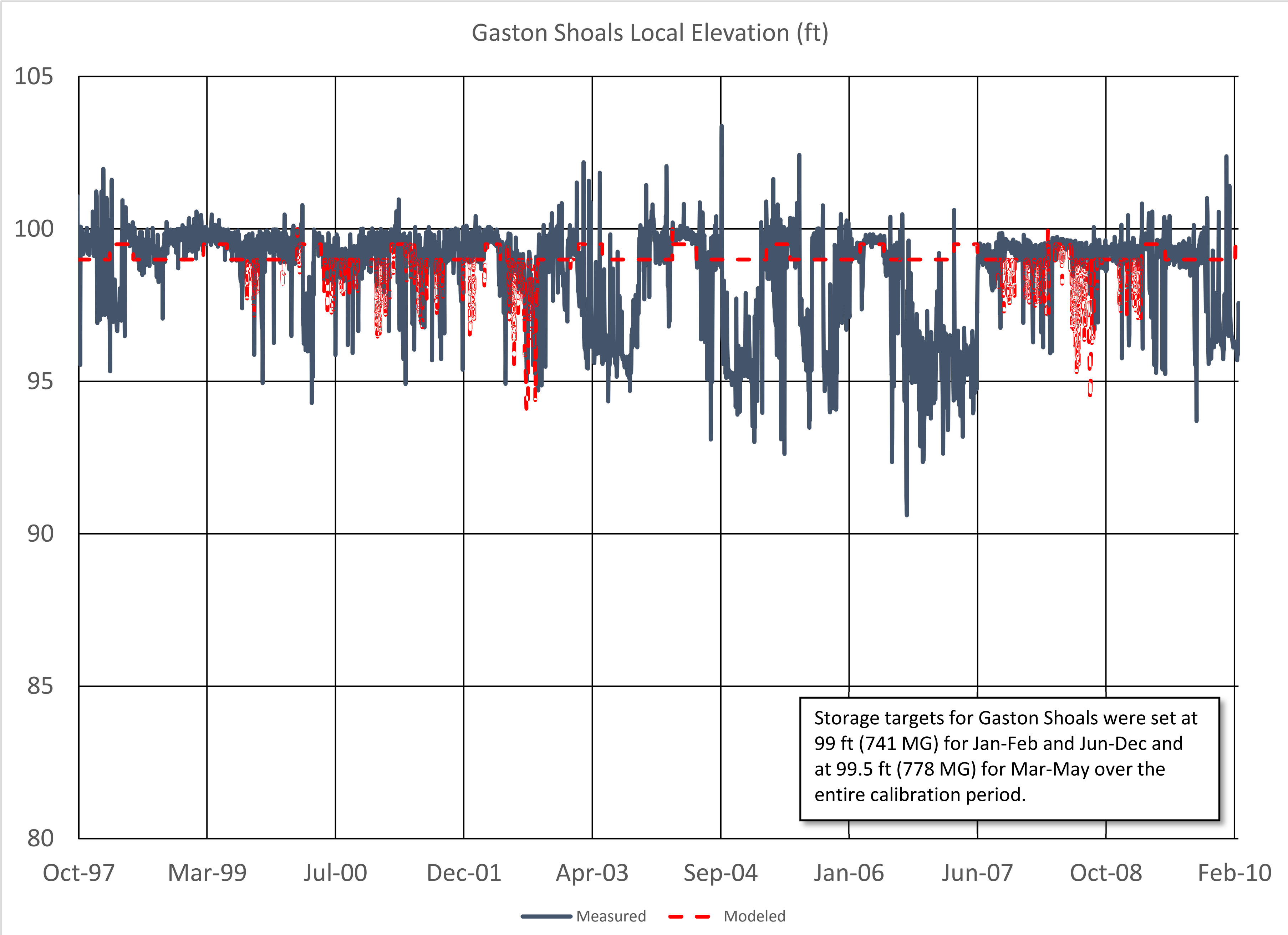
BRD48 (02160390) ENOREE RIVER NEAR WOODRUFF, SC
Annual 7-day Low Flow (CFS)
gaged
modeled
250
200
150
100
50
0
1980
1985
1990
1995
2000
2005
2010
2015
Year


BRD50 (02160700) ENOREE RIVER AT WHITMIRE, SC (CFS)
modeled
gaged
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

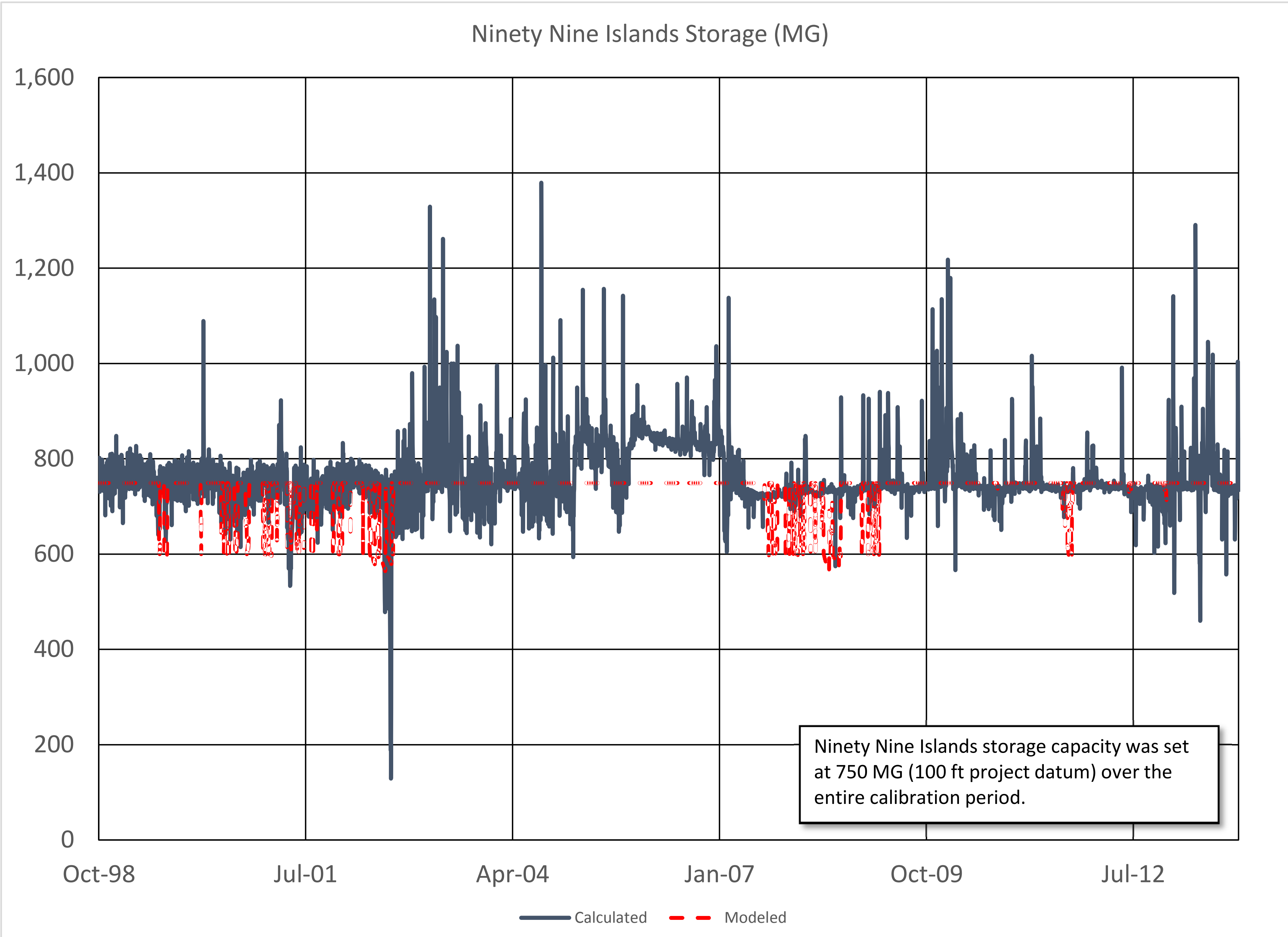

BRD50 (02160700) ENOREE RIVER AT WHITMIRE, SC
Daily Flow Percentiles (CFS)
gaged
modeled
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile


BRD50 (02160700) ENOREE RIVER AT WHITMIRE, SC
Annual 7-day Low Flow (CFS)
gaged
modeled
300
250
200
150
100
50
0
1980
1985
1990
1995
2000
2005
2010
2015
Year

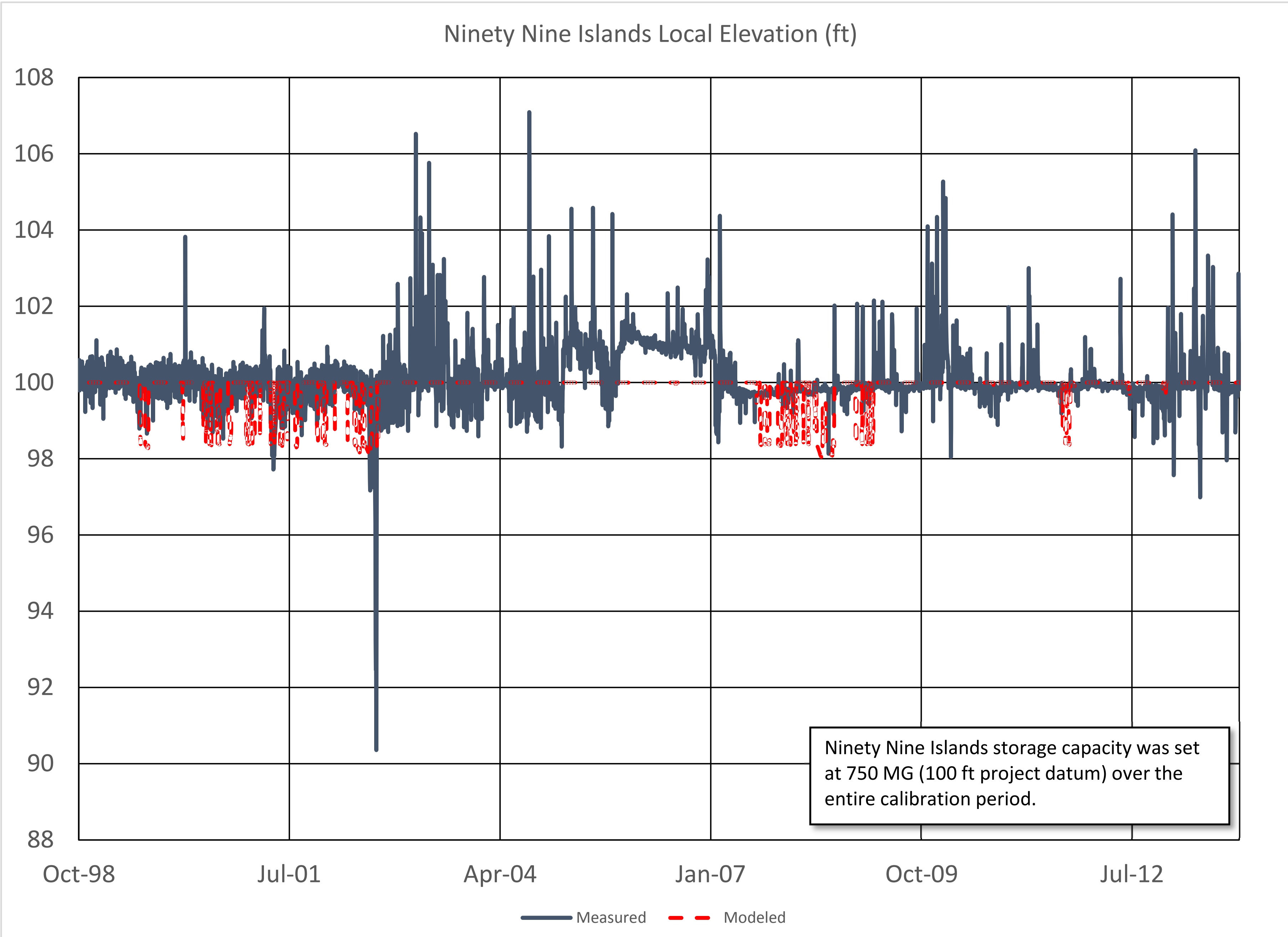

Gaston Shoals Storage (MG)
1,200
1,000
800
600
400
200
0
Oct-97
Jul-00
Apr-03
Jan-06
Oct-08
Jul-11
Calculated
Modeled
Storage targets for Gaston Shoals were set at 99 ft (741 MG) for Jan-Feb and Jun-Dec and at 99.5 ft (778 MG) for Mar-May over the entire calibration period.



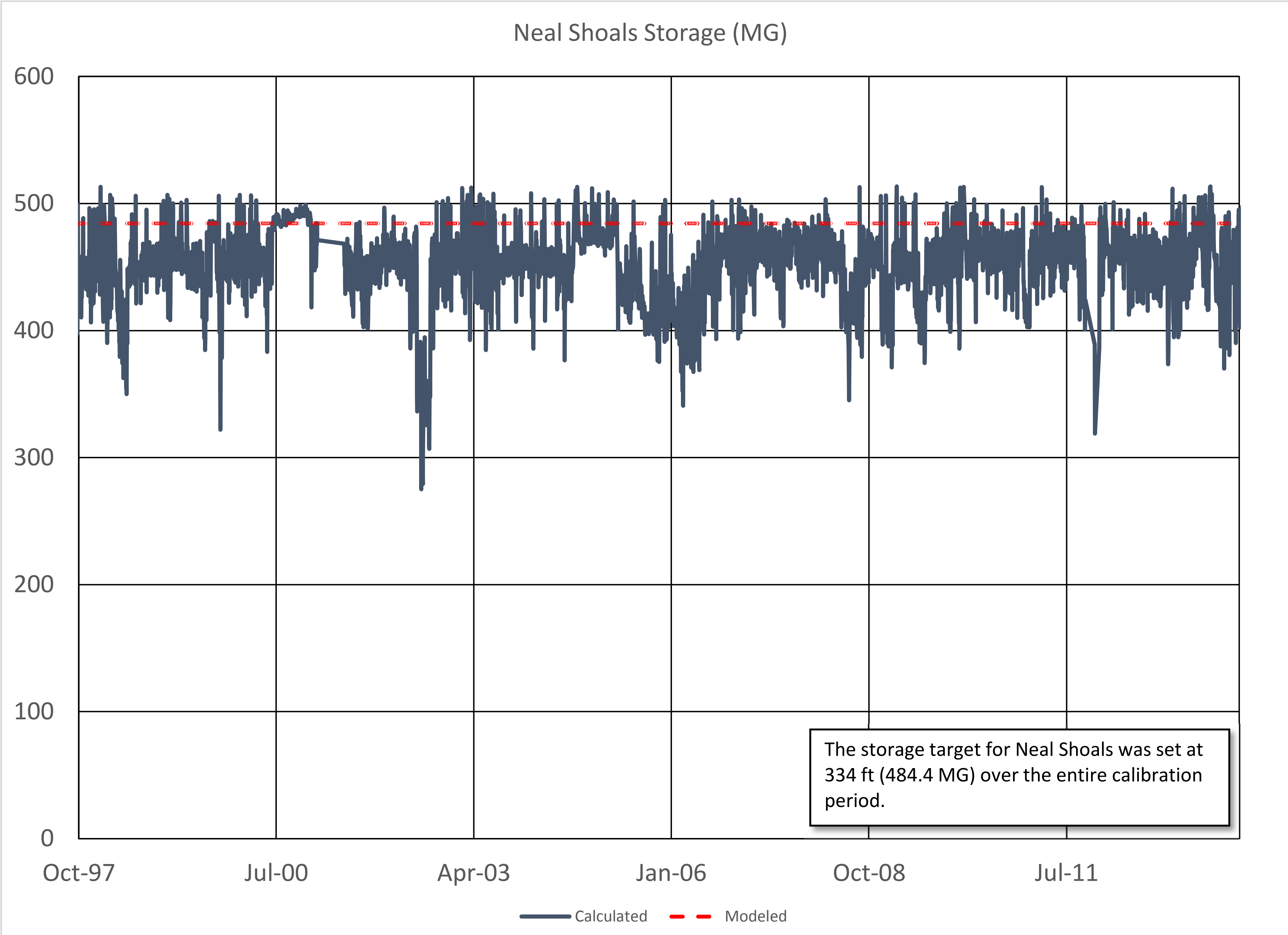
Gaston Shoals Local Elevation (ft)
105
100
95
90
85
80
Oct-97
Mar-99
Jul-00
Dec-01
Apr-03
Sep-04
Jan-06
Jun-07
Oct-08
Feb-10
Storage targets for Gaston Shoals were set at 99 ft (741 MG) for Jan-Feb and Jun-Dec and at 99.5 ft (778 MG) for Mar-May over the entire calibration period.
Measured
Modeled



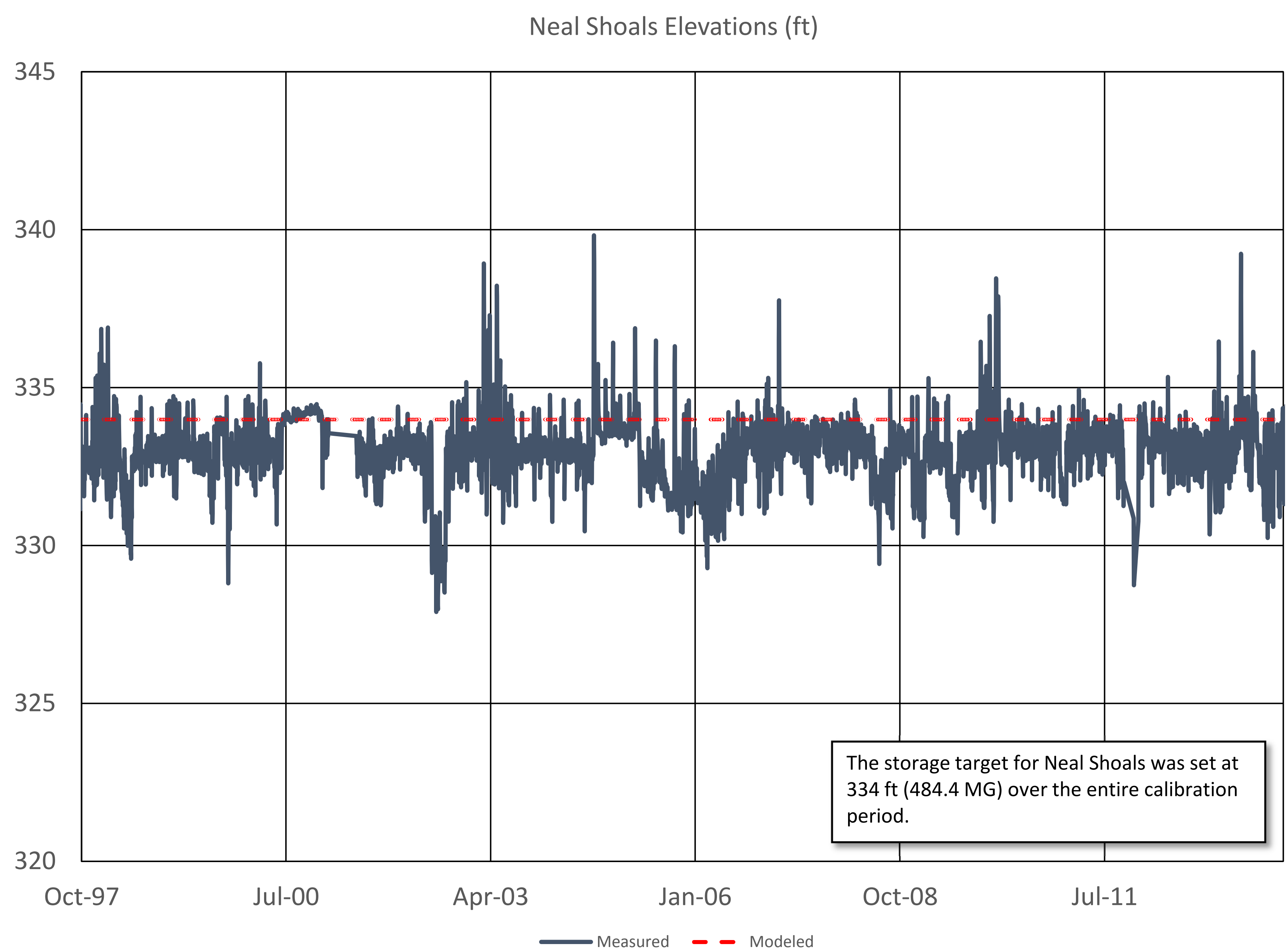
Ninety Nine Islands Storage (MG)
1,600
1,400
1,200
1,000
800
600
400
200
0
Oct-98
Jul-01
Apr-04
Jan-07
Oct-09
Jul-12
Ninety Nine Islands storage capacity was set at 750 MG (100 ft project datum) over the entire calibration period.
Calculated
Modeled



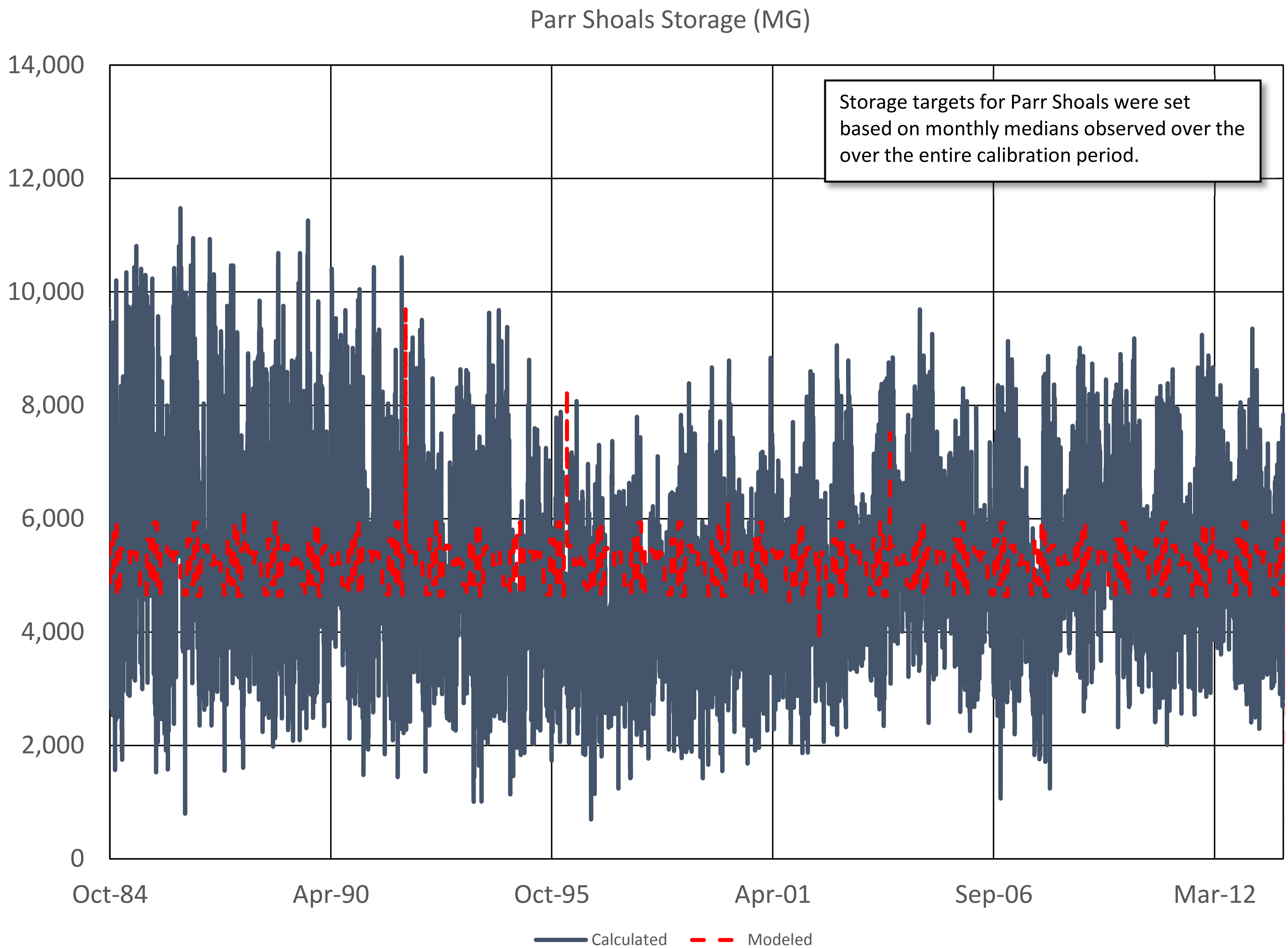
Ninety Nine Islands Local Elevation (ft)
108
106
104
102
100
98
96
94
92
90
88
Oct-98
Jul-01
Apr-04
Jan-07
Oct-09
Jul-12
Measured
Modeled
Ninety Nine Islands storage capacity was set at 750 MG (100 ft project datum) over the entire calibration period.

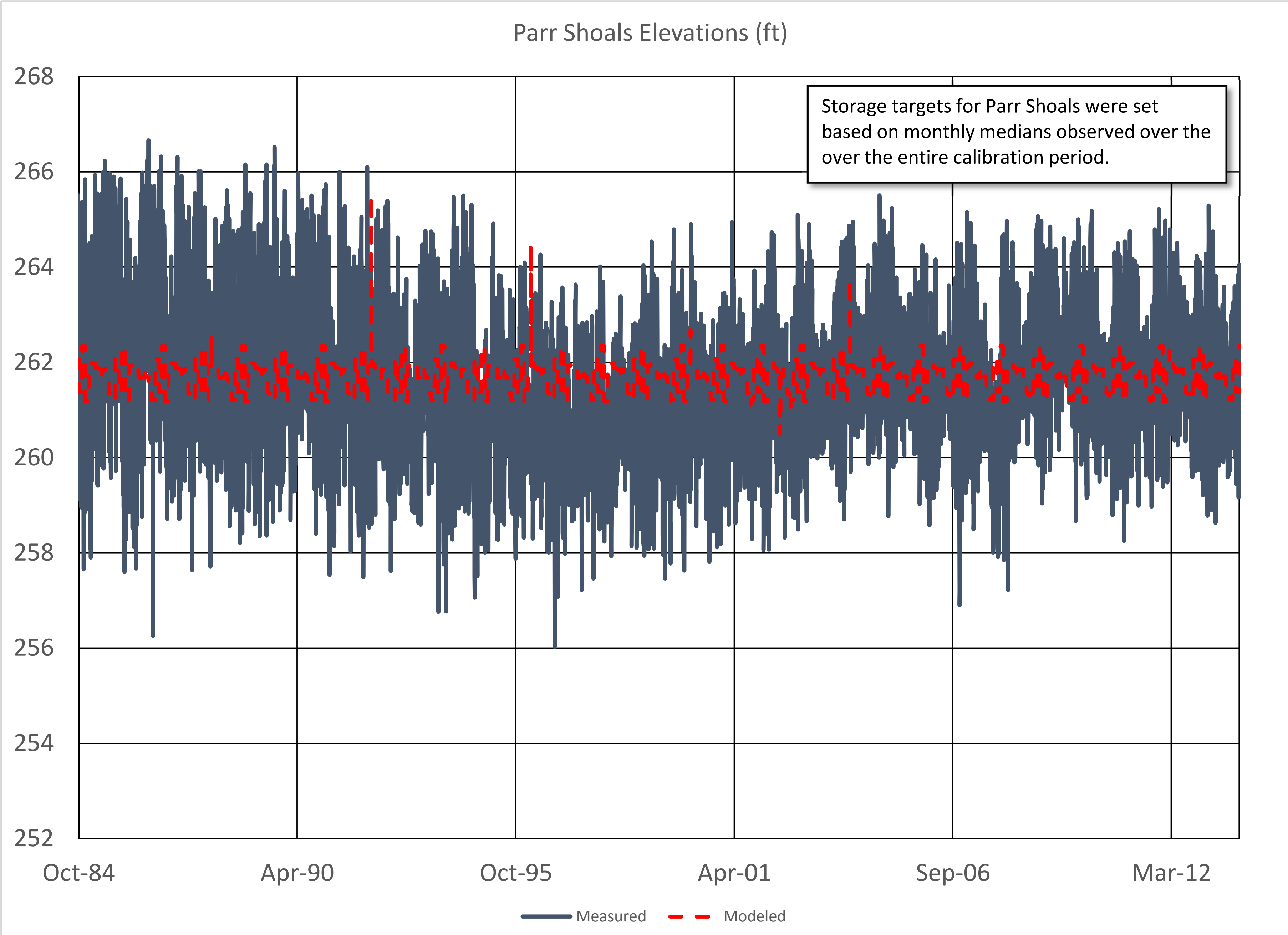


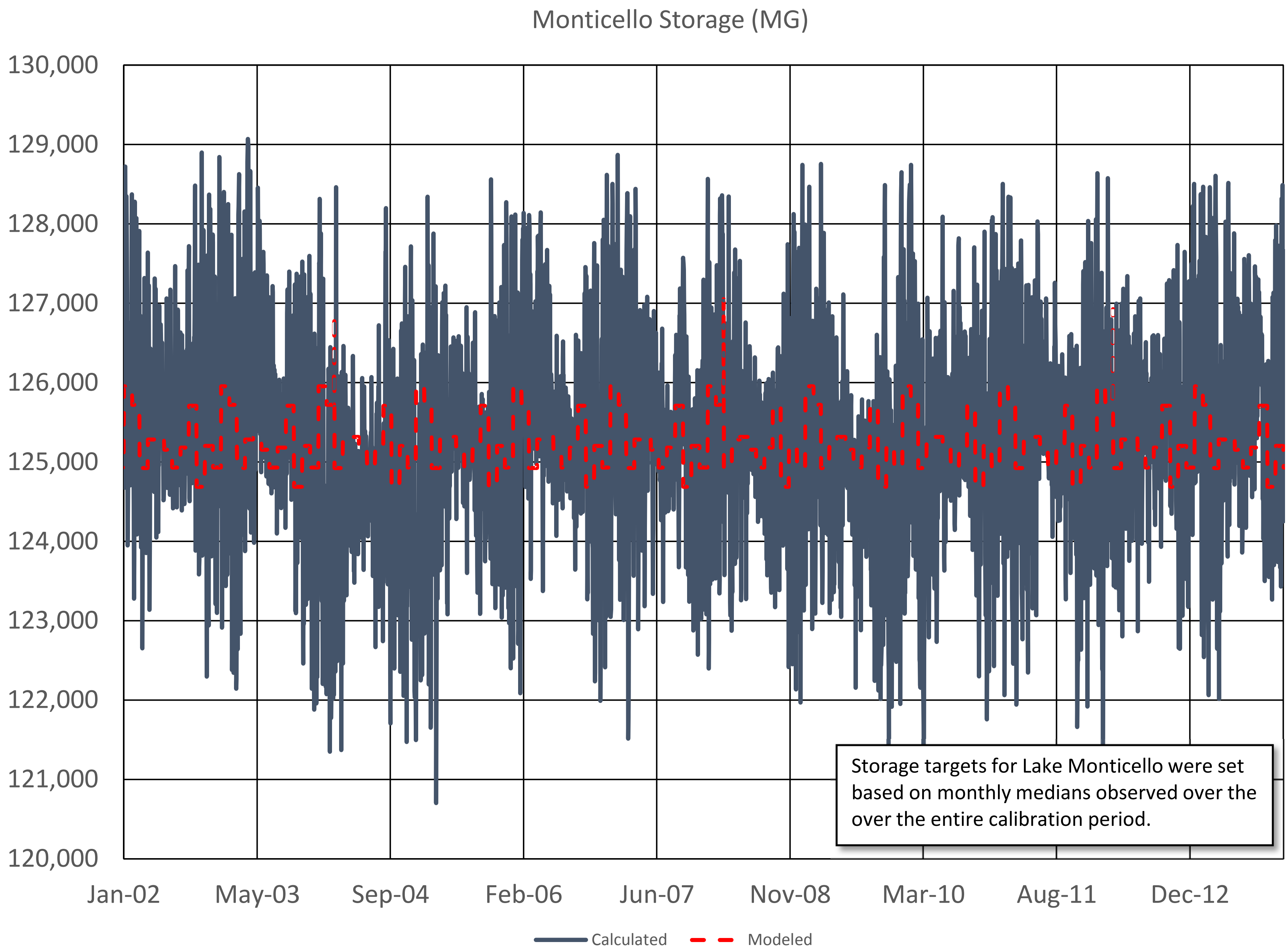
Neal Shoals Storage (MG)
600
500
400
300
200
100
0
Oct-97
Jul-00
Apr-03
Jan-06
Oct-08
Jul-11
Calculated
Modeled
The storage target for Neal Shoals was set at 334 ft (484.4 MG) over the entire calibration period.

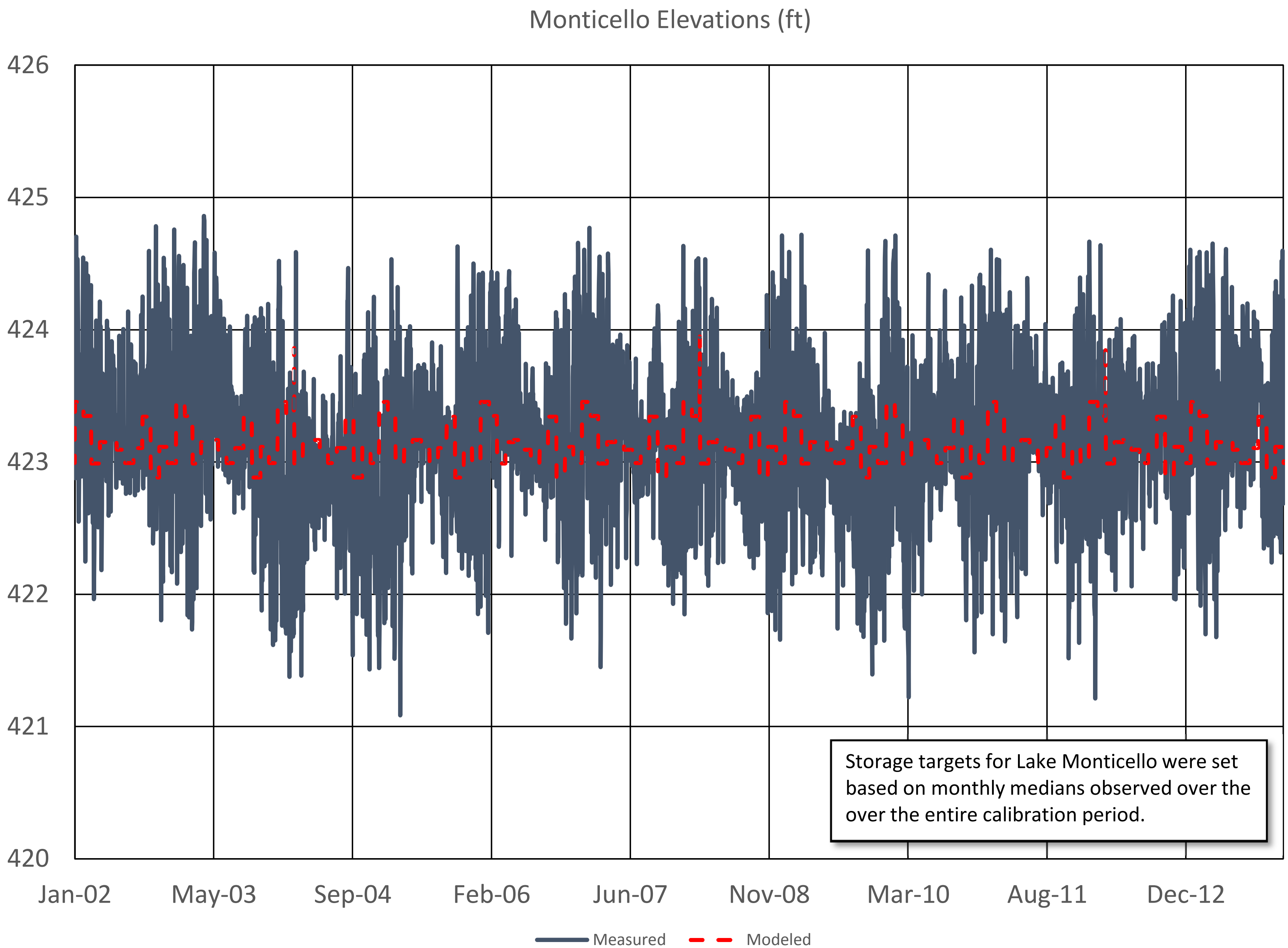


Neal Shoals Elevations (ft)
345
340
335
330
325
320
Oct-97
Jul-00
Apr-03
Jan-06
Oct-08
Jul-11
The storage target for Neal Shoals was set at 334 ft (484.4 MG) over the entire calibration period.
Measured
Modeled

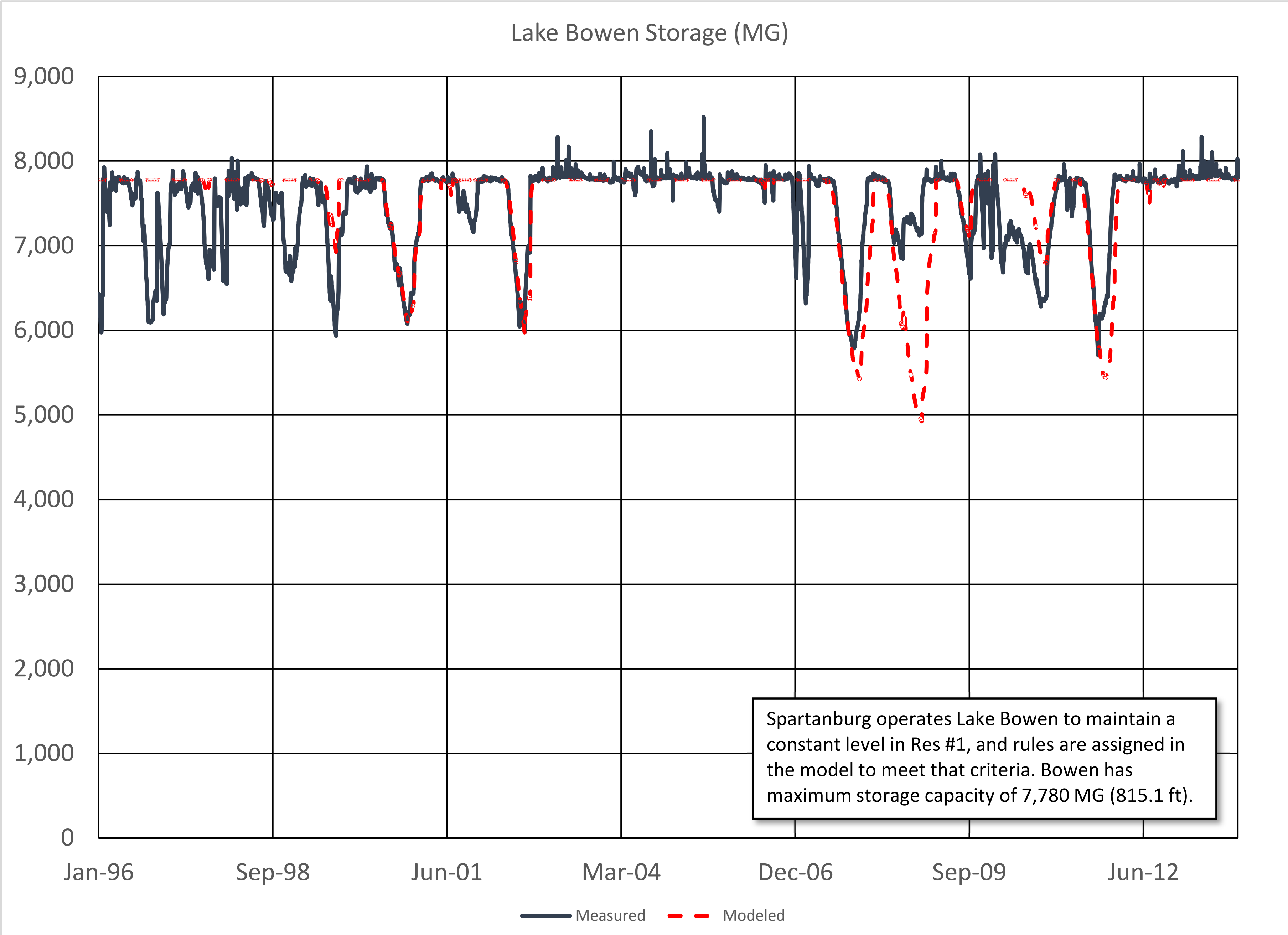

Parr Shoals Storage (MG)
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Oct-84
Apr-90
Oct-95
Apr-01
Sep-06
Mar-12
Storage targets for Parr Shoals were set based on monthly medians observed over the over the entire calibration period.
Calculated
Modeled

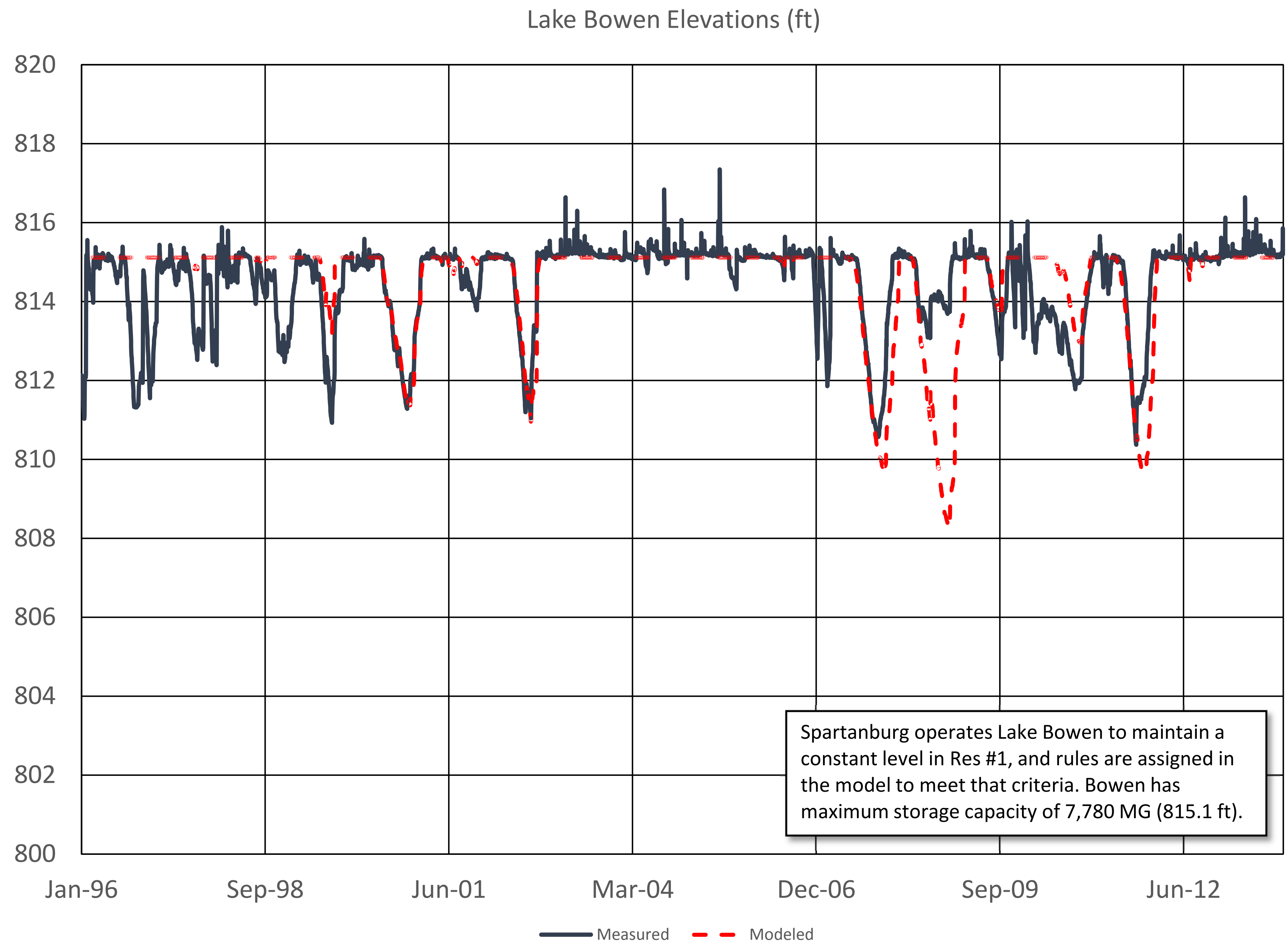

Parr Shoals Elevations (ft)
268
266
264
262
260
258
256
254
252
Oct-84
Apr-90
Oct-95
Apr-01
Sep-06
Mar-12
Storage targets for Parr Shoals were set based on monthly medians observed over the over the entire calibration period.
Measured
Modeled


Monticello Storage (MG)
130,000
129,000
128,000
127,000
126,000
125,000
124,000
123,000
122,000
121,000
120,000
Jan-02
May-03
Sep-04
Feb-06
Jun-07
Nov-08
Mar-10
Aug-11
Dec-12
Calculated
Modeled
Storage targets for Lake Monticello were set based on monthly medians observed over the over the entire calibration period.

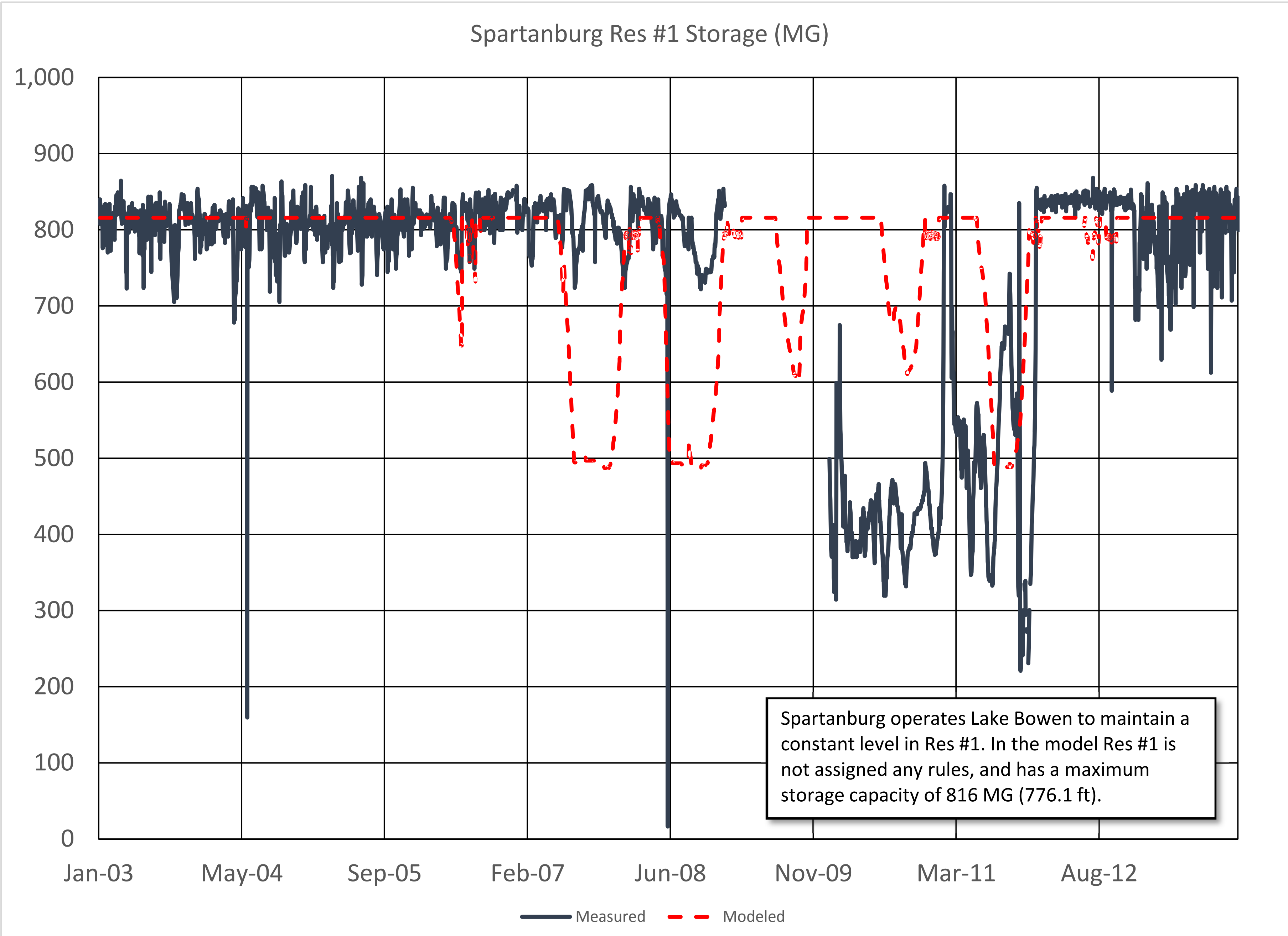


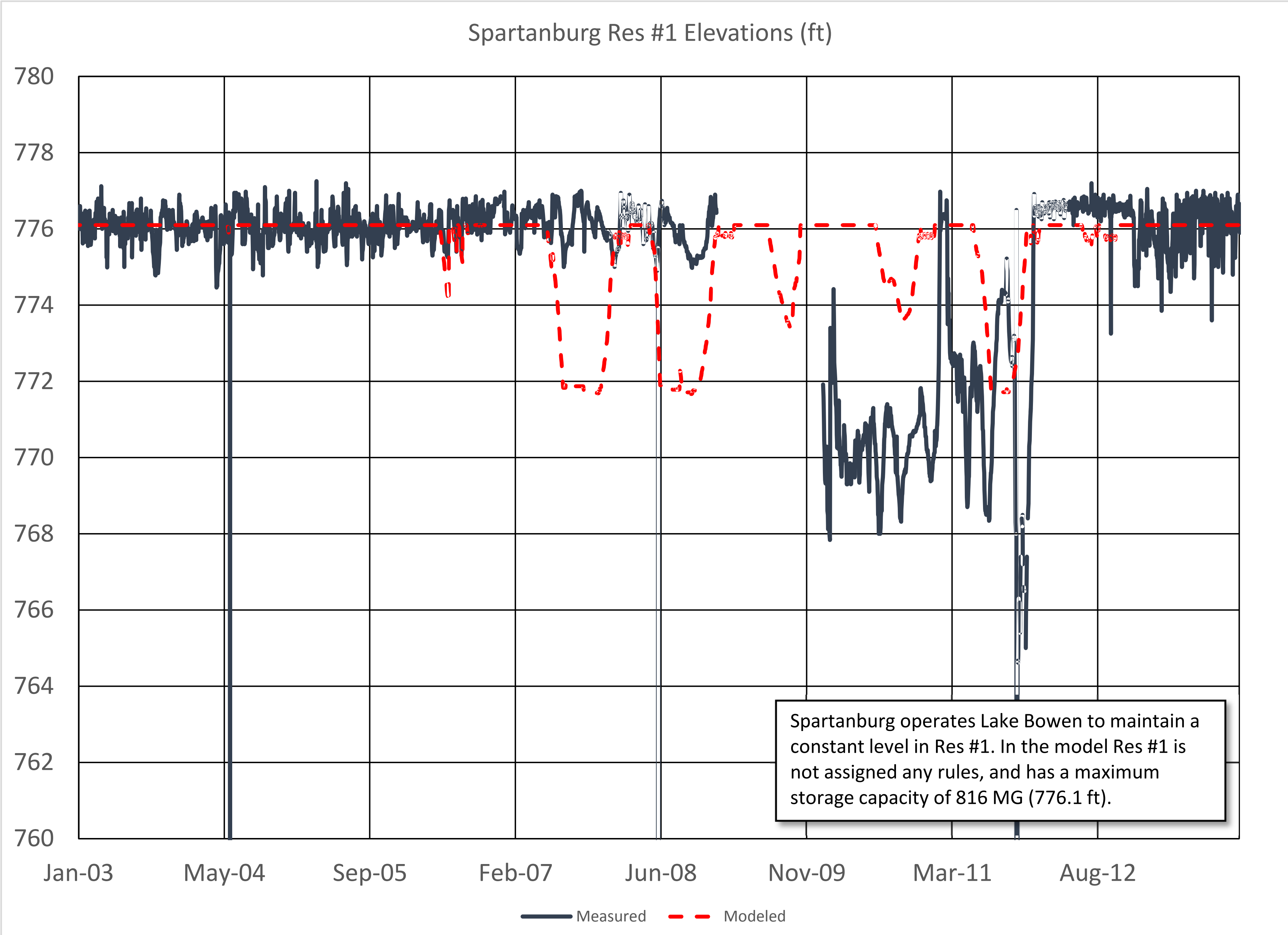
Monticello Elevations (ft)
426
425
424
423
422
421
420
Jan-02
May-03
Sep-04
Feb-06
Jun-07
Nov-08
Mar-10
Aug-11
Dec-12
Storage targets for Lake Monticello were set based on monthly medians observed over the over the entire calibration period.
Measured
Modeled


Lake Bowen Storage (MG)
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Jan-96
Sep-98
Jun-01
Mar-04
Dec-06
Sep-09
Jun-12
Spartanburg operates Lake Bowen to maintain a constant level in Res #1, and rules are assigned in the model to meet that criteria. Bowen has maximum storage capacity of 7,780 MG (815.1 ft).
Measured
Modeled



Lake Bowen Elevations (ft)
820
818
816
814
812
810
808
806
804
802
800
Jan-96
Sep-98
Jun-01
Mar-04
Dec-06
Sep-09
Jun-12
Spartanburg operates Lake Bowen to maintain a constant level in Res #1, and rules are assigned in the model to meet that criteria. Bowen has maximum storage capacity of 7,780 MG (815.1 ft).
Measured
Modeled


Spartanburg Res #1 Storage (MG)
1,000
900
800
700
600
500
400
300
200
100
0
Jan-03
May-04
Sep-05
Feb-07
Jun-08
Nov-09
Mar-11
Aug-12
Spartanburg operates Lake Bowen to maintain a constant level in Res #1. In the model Res #1 is not assigned any rules, and has a maximum storage capacity of 816 MG (776.1 ft).
Measured
Modeled


Spartanburg Res #1 Elevations (ft)
780
778
776
774
772
770
768
766
764
762
760
Jan-03
May-04
Sep-05
Feb-07
Jun-08
Nov-09
Mar-11
Aug-12
Measured
Modeled
Spartanburg operates Lake Bowen to maintain a constant level in Res #1. In the model Res #1 is not assigned any rules, and has a maximum storage capacity of 816 MG (776.1 ft).

Annual 7 day Low Flows: Modeled (Page 1)

Year	BROAD RIVER NEAR BLACKSBURG	BROAD RIVER NEAR GAFFNEY	BROAD RIVER BELOW NINETY NINE ISLAND RESERVOIR	BROAD R NR HICKORY GROVE	BROAD RIVER NEAR LOCKHART	BROAD RIVER BELOW NEAL SHOALS RES. NR CARLISLE	BROAD RIVER NEAR CARLISLE	BROAD RIVER AT BLAIR*	BROAD RIVER AT ALSTON	BROAD RIVER NEAR COLUMBIA*
ID->	**BRD01**	**BRD02**	**BRD03**	**BRD06**	**BRD21**	**BRD22**	**BRD24**	**BRD52**	**BRD54**	**BRD58**
1983							1024.2		1589.8	
1984							1764.7		2774.1	
1985							1048.2		1563.4	
1986							546.9		682.4	
1987		772.6					1012.3		1337.7	
1988		485.9					658.2		806.1	
1989		673.4					1066.1		1753.7	
1990							1293.4		1927.9	
1991							1619.7		2719.3	
1992							1594.3		2454.0	
1993							1084.4		1488.2	
1994							1509.9		2347.3	
1995							1759.1		2804.2	
1996							1544.4		2480.8	
1997					1131.3		1184.3		1684.8	
1998	730.9				1076.9		1117.2		1612.3	
1999	291.4		333.7				495.2		511.3	
2000	361.9		438.7				626.8		781.2	
2001	319.2		367.2				594.2		715.4	
2002	83.9		113.3	113.9			173.0		68.9	
2003	926.5		1067.9				1795.0		3319.9	
2004	971.4		1054.3				1526.0		2158.6	
2005	1015.0		1115.3				1619.7		2291.5	
2006	494.4		537.7				872.0		1271.2	
2007	341.6		418.6				536.7		691.1	
2008	152.1		186.2				254.0		215.7	
2009	565.9		620.6				862.2		1005.3	
2010	487.9		527.7				751.3		969.0	
2011	320.6	361.4	361.6				463.3	704.8	436.6	
2012	619.4	671.8	671.9				1003.1	1321.3	1103.7	1112.9
2013	1120.4	1212.3	1218.4			1688.3	1773.5		2531.7	2583.0

Annual 7 day Low Flows: Measured

Year	BROAD RIVER NEAR BLACKSBURG	BROAD RIVER NEAR GAFFNEY	BROAD RIVER BELOW NINETY NINE ISLAND RESERVOIR	BROAD R NR HICKORY GROVE	BROAD RIVER NEAR LOCKHART	BROAD RIVER BELOW NEAL SHOALS RES. NR CARLISLE	BROAD RIVER NEAR CARLISLE	BROAD RIVER AT BLAIR*	BROAD RIVER AT ALSTON	BROAD RIVER NEAR COLUMBIA*
ID->	**BRD01**	**BRD02**	**BRD03**	**BRD06**	**BRD21**	**BRD22**	**BRD24**	**BRD52**	**BRD54**	**BRD58**
1983							1304.3		1531.4	
1984							1717.1		1926.6	
1985							1104.3		1651.4	
1986							613.4		902.0	
1987		770.1					871.9		1127.1	
1988		566.6					565.1		797.0	
1989		933.6					1342.9		1364.3	
1990							1287.1		1418.6	
1991							1595.7		1847.1	
1992							1535.7		1762.9	
1993							1118.6		1365.7	
1994							1624.3		2161.4	
1995							1608.6		1880.0	
1996							1435.7		1921.4	
1997					1025.0		1110.6		1430.0	
1998	706.3				1117.0		1292.9		1552.9	
1999	269.4		325.7				457.0		733.6	
2000	269.0		375.1				484.7		686.3	
2001	329.7		387.3				472.1		531.6	
2002	90.3		168.0	175.3			220.0		199.9	
2003	1430.0		1153.1				2018.6		2591.4	
2004	909.9		989.9				1360.0		1586.6	
2005	743.4		815.4				1216.7		1602.9	
2006	469.3		655.4				765.6		957.7	
2007	257.7		261.1				301.7		320.6	
2008	158.9		182.7				206.4		264.4	
2009	495.6		496.9				727.4		912.4	
2010	384.3		372.3				500.1		702.7	
2011	259.4	270.9	284.0				386.3	133.6	435.1	
2012	505.4	533.0	489.4				710.0	534.7	896.4	891.3
2013	983.4	1075.9	961.0			1630.0	1617.1		2188.6	2151.4

Note: blank cells indicate years when sufficient gaged flows were not availalable for comparison.

Approximate 7Q10 Comparison - Modeled vs. Measured

Year	BROAD RIVER NEAR BLACKSBURG	BROAD RIVER NEAR GAFFNEY	BROAD RIVER BELOW NINETY NINE ISLAND RESERVOIR	BROAD R NR HICKORY GROVE	BROAD RIVER NEAR LOCKHART	BROAD RIVER BELOW NEAL SHOALS RES. NR CARLISLE	BROAD RIVER NEAR CARLISLE	BROAD RIVER AT BLAIR*	BROAD RIVER AT ALSTON	BROAD RIVER NEAR COLUMBIA*
ID->	**BRD01**	**BRD02**	**BRD03**	**BRD06**	**BRD21**	**BRD22**	**BRD24**	**BRD52**	**BRD54**	**BRD58**
Modeled	222	424	245	114	1082	1688	495	-	511	-
Measured	208	402	214	175	1034	1630	386	-	435	-
% Diff.	-6%	-5%	-15%	35%	-5%	-4%	-28%	-	-17%	-

** Gages were not used in calibration due to known backwater effects*

Annual 7 day Low Flows: Modeled (Page 2)

Year	NORTH PACOLET RIVER AT FINGERVILLE	LAWSONS FORK CREEK AT SPARTANBURG	LAWSON FORK CREEK @ TREATMENT PLANT @ SPARTANBURG	SOUTH PACOLET RIVER NR CAMPOBELLO	PACOLET RIVER NEAR FINGERVILLE	PACOLET RIVER BELOW LAKE BLALOCK NEAR COWPENS	PACOLET RIVER NEAR SARATT	TURKEY CREEK NEAR LOWRYS	MIDDLE TYGER RIVER NEAR GRAMLING	MIDDLE TYGER RIVER NEAR LYMAN
ID->	**BRD10**	**BRD17**	**BRD18**	**BRD11**	**BRD12**	**BRD14**	**BRD19**	**BRD20**	**BRD27**	**BRD30**
1983	80				92					
1984	99				128					
1985	60				69					
1986	37				46					
1987	66				76					
1988	31				40					
1989	69				79					
1990	82		25	26	93					
1991	102		49	50	144					
1992	106		48	46	139					
1993	76		39	29	86					
1994	98		50	44	111	134				
1995	106		38	44	121	146				
1996	93		46	40		130				
1997	67			28		72				
1998	73			31	84	99				
1999	33			14	42	30				
2000	37			16	46	36				
2001	50			23	60	75		1		12
2002	17			8	25	6				0
2003	125			54	172	204			35	56
2004	85			38	102	125			24	36
2005	96			45	119	145			22	29
2006	54			26		83			16	14
2007	29			12		17			6	4
2008	19			6	34	17			4	2
2009	41			20		65			6	4
2010	48			19		64			8	1
2011	31			6		30			4	4
2012	43			19	55	60			13	10
2013	99	54		48	152	184	333		24	47

Annual 7 day Low Flows: Measured

Year	NORTH PACOLET RIVER AT FINGERVILLE	LAWSONS FORK CREEK AT SPARTANBURG	LAWSON FORK CREEK @ TREATMENT PLANT @ SPARTANBURG	SOUTH PACOLET RIVER NR CAMPOBELLO	PACOLET RIVER NEAR FINGERVILLE	PACOLET RIVER BELOW LAKE BLALOCK NEAR COWPENS	PACOLET RIVER NEAR SARATT	TURKEY CREEK NEAR LOWRYS	MIDDLE TYGER RIVER NEAR GRAMLING	MIDDLE TYGER RIVER NEAR LYMAN
ID->	**BRD10**	**BRD17**	**BRD18**	**BRD11**	**BRD12**	**BRD14**	**BRD19**	**BRD20**	**BRD27**	**BRD30**
1983	80				91					
1984	99				143					
1985	60				72					
1986	38				41					
1987	66				91					
1988	32				50					
1989	71				97					
1990	83		49	26	105					
1991	104		55	50	122					
1992	106		51	46	131					
1993	77		39	29	94					
1994	99		48	44	116	147				
1995	107		53	44	114	162				
1996	93		56	40		79				
1997	67			28		76				
1998	73			31	83	121				
1999	33			14	50	65				
2000	37			16	41	67				
2001	50			23	57	70		1		7
2002	17			8	27	51				1
2003	125			54	166	224			35	59
2004	85			38	125	69			24	31
2005	96			45	109	148			22	28
2006	54			26		58			16	11
2007	29			12		36			6	5
2008	19			6	23	28			4	5
2009	41			20		38			6	6
2010	48			19		85			8	6
2011	31			6		53			4	2
2012	43			19	42	66			13	4
2013	99	52		48	148	168	339		24	50

Note: blank cells indicate years when sufficient gaged flows were not availalable for comparison.

Approximate 7Q10 Comparison - Modeled vs. Measured

Year	NORTH PACOLET RIVER AT FINGERVILLE	LAWSONS FORK CREEK AT SPARTANBURG	LAWSON FORK CREEK @ TREATMENT PLANT @ SPARTANBURG	SOUTH PACOLET RIVER NR CAMPOBELLO	PACOLET RIVER NEAR FINGERVILLE	PACOLET RIVER BELOW LAKE BLALOCK NEAR COWPENS	PACOLET RIVER NEAR SARATT	TURKEY CREEK NEAR LOWRYS	MIDDLE TYGER RIVER NEAR GRAMLING	MIDDLE TYGER RIVER NEAR LYMAN
ID->	**BRD10**	**BRD17**	**BRD18**	**BRD11**	**BRD12**	**BRD14**	**BRD19**	**BRD20**	**BRD27**	**BRD30**
Modeled	31	54	33	9.5	40	17	333	0.7	4.3	0.9
Measured	31	52	44	9.5	41	38	339	1.1	4.3	2.1
% Diff.	0%	-4%	26%	0%	2%	54%	2%	36%	0%	58%

** Gages were not used in calibration due to known backwater effects*

Annual 7 day Low Flows: Modeled (Page 3)

Year	SOUTH TYGER RIVER BELOW DUNCAN	FAIRFOREST CREEK BELOW SPARTANBURG	N. TYGER RIVER BELOW WELLFORD	TYGER RIVER NEAR DELTA	DURBIN CREEK ABOVE FOUNTAIN INN	ENOREE RIVER AT TAYLORS	ENOREE RIVER AT PELHAM	ENOREE RIVER NEAR WOODRUFF	ENOREE RIVER AT WHITMIRE
ID->	**BRD33**	**BRD40**	**BRD25**	**BRD42**	**BRD47**	**BRD43**	**BRD46**	**BRD48**	**BRD50**
1983				220					171
1984				416					245
1985				216					132
1986				110					72
1987				145					124
1988				154					56
1989		11		313					164
1990		8		279					123
1991		10		412					260
1992		9		397					214
1993		6		242					111
1994		13		427			63	144	210
1995		10		369	3		40	86	124
1996		12		385	5		70	152	225
1997		9		252	5		33	100	132
1998				239	5		39	104	142
1999				98	2	4	7	28	29
2000				134	2	11	19	56	72
2001				161	3	9	15	43	55
2002	13			74	0	6	10	18	23
2003	99			500	6	43	77	179	261
2004	58			336	3	28	50	107	158
2005	49			332	4	30	54	125	180
2006	29			216	3	19	35	82	116
2007	15			113			22	46	64
2008	13		3	97			13	28	36
2009	15		5	123			21	48	67
2010	18		7	131	1		30	65	96
2011	14		3	107	0		15	27	39
2012	19		5	169	1		30	55	88
2013	84			462	7		82	182	273

Annual 7 day Low Flows: Measured

Year	SOUTH TYGER RIVER BELOW DUNCAN	FAIRFOREST CREEK BELOW SPARTANBURG	N. TYGER RIVER BELOW WELLFORD	TYGER RIVER NEAR DELTA	DURBIN CREEK ABOVE FOUNTAIN INN	ENOREE RIVER AT TAYLORS	ENOREE RIVER AT PELHAM	ENOREE RIVER NEAR WOODRUFF	ENOREE RIVER AT WHITMIRE
ID->	**BRD33**	**BRD40**	**BRD25**	**BRD42**	**BRD47**	**BRD43**	**BRD46**	**BRD48**	**BRD50**
1983				213					138
1984				381					249
1985				240					152
1986				158					66
1987				163					99
1988				112					61
1989		11		244					173
1990		8		194					116
1991		10		356					206
1992		10		243					156
1993		7		192					119
1994		13		290			72	150	232
1995		10		262	3		50	122	125
1996		12		318	5		78	167	203
1997		9		205	5		44	105	150
1998				300	5		50	123	164
1999				115	2	9	19	56	85
2000				115	2	12	31	69	93
2001				96	3	7	27	61	89
2002	10			32	0	3	22	36	32
2003	97			455	6	46	86	195	245
2004	59			244	3	31	60	138	180
2005	48			195	4	37	63	118	136
2006	28			138	3	22	45	89	124
2007	14			43			32	55	52
2008	10		2	24			24	43	32
2009	13		2	67			32	65	67
2010	17		6	71	1		38	74	72
2011	10		2	25	0		26	41	36
2012	18		6	119	1		40	86	91
2013	85			345	7		93	202	239

Note: blank cells indicate years when sufficient gaged flows were not availalable for comparison.

Approximate 7Q10 Comparison - Modeled vs. Measured

Year	SOUTH TYGER RIVER BELOW DUNCAN	FAIRFOREST CREEK BELOW SPARTANBURG	N. TYGER RIVER BELOW WELLFORD	TYGER RIVER NEAR DELTA	DURBIN CREEK ABOVE FOUNTAIN INN	ENOREE RIVER AT TAYLORS	ENOREE RIVER AT PELHAM	ENOREE RIVER NEAR WOODRUFF	ENOREE RIVER AT WHITMIRE
ID->	**BRD33**	**BRD40**	**BRD25**	**BRD42**	**BRD47**	**BRD43**	**BRD46**	**BRD48**	**BRD50**
Modeled	13	7.7	3.1	107	0.5	5.0	13	27	39
Measured	10	7.8	1.6	43	0.5	5.5	24	43	52
% Diff.	-34%	1%	-89%	-150%	-2%	9%	47%	36%	26%

** Gages were not used in calibration due to known backwater effects*

Appendix C

Guidelines for Representing Multi-Basin Water Users in SWAM

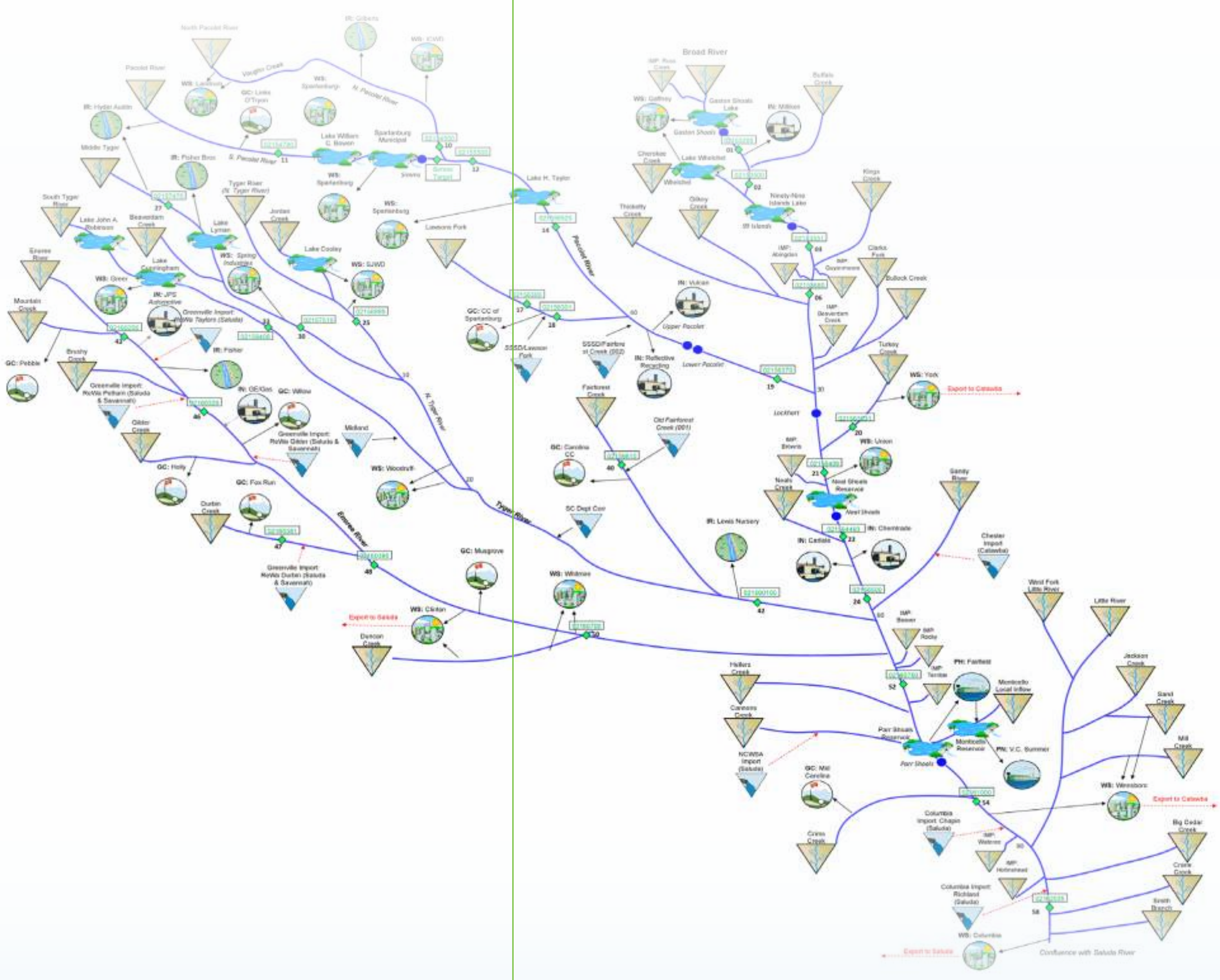
CDM Smith

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.



CDM Smith