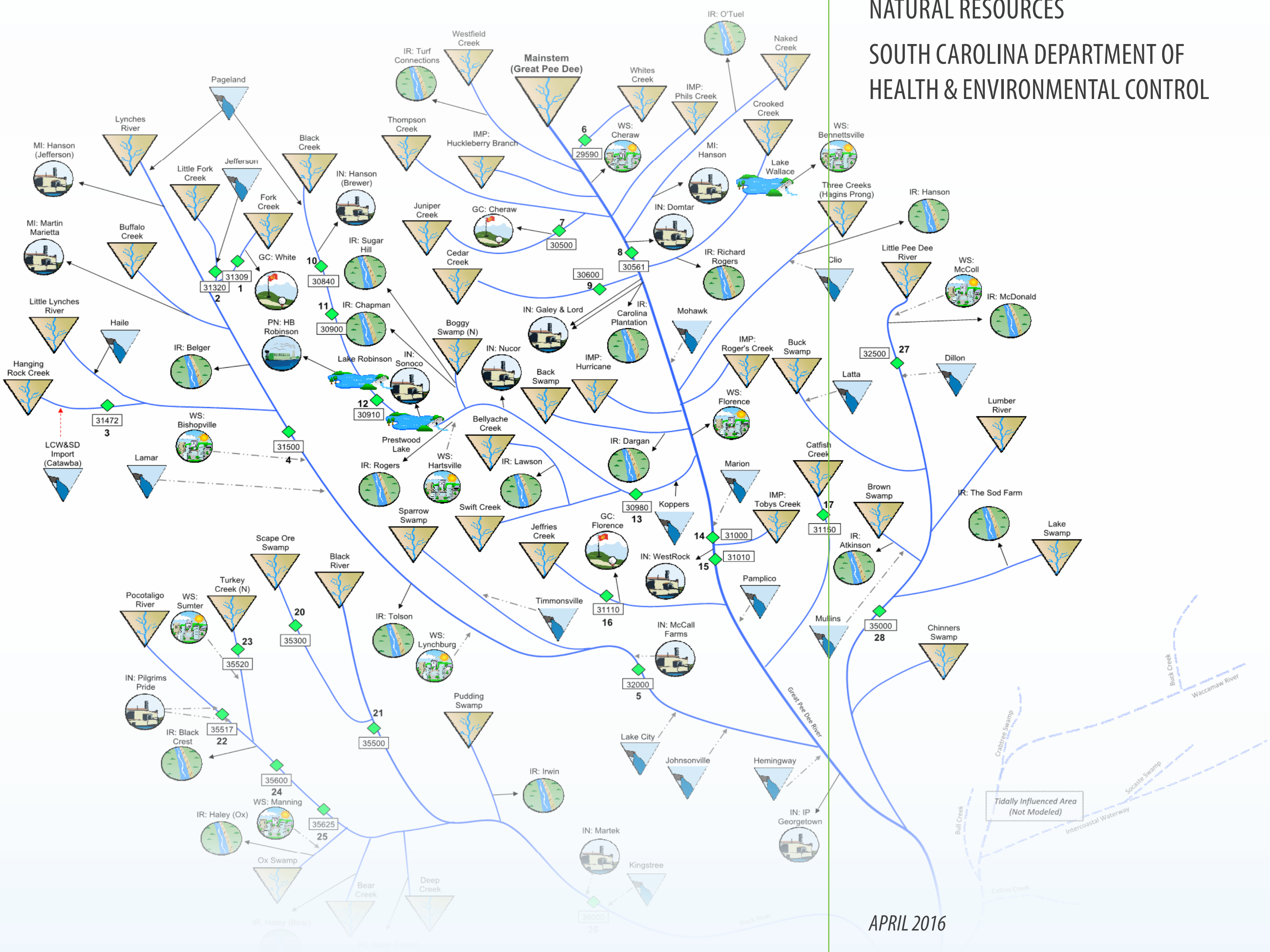
SOUTH CAROLINA
SURFACE WATER QUANTITY MODELS
PEE DEE RIVER BASIN MODEL

SUBMITTED TO:

SOUTH CAROLINA DEPARTMENT OF NATURAL RESOURCES

SOUTH CAROLINA DEPARTMENT OF HEALTH & ENVIRONMENTAL CONTROL



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Section 1

Purpose

This document, the Pee Dee 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 Pee Dee 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 Pee Dee 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 Pee Dee 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 Pee Dee 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 Pee Dee 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 Pee Dee 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 Pee Dee 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 Pee Dee River Basin – especially, with regard to model calibration and validation.

Section 4

Pee Dee Model Framework

The initial Pee Dee River Basin SWAM Model Framework was developed in collaboration with South Carolina DNR and DHEC, and was presented in the memorandum *Pee Dee Basin SWAM Model Framework* (CDM Smith, October 2015). The proposed framework was developed as a starting point for representing the Pee Dee Basin river network and its significant water withdrawals and discharges. The guiding principles in determining what elements of the Pee Dee 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 Pee Dee 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 Pee Dee, 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. One change to note is that water users and discharges in the tidally-influenced areas, including the Waccamaw River, the Atlantic Intercoastal Waterway, and the Sampit River have been excluded from the framework. Development of reliable unimpaired flows and calibration of the model is not possible in the tidally-influenced areas. Therefore, in order to simplify the model and avoid confusion, the water users and dischargers in these areas were removed.

4.1 Representation of Water Withdrawals

As noted above, significant withdrawals include those that have a permit or registration – which indicated that they may withdraw over 3 million gallons in any month. Withdraws may include both water used directly by that water user and water sold to other water users who may or may not be

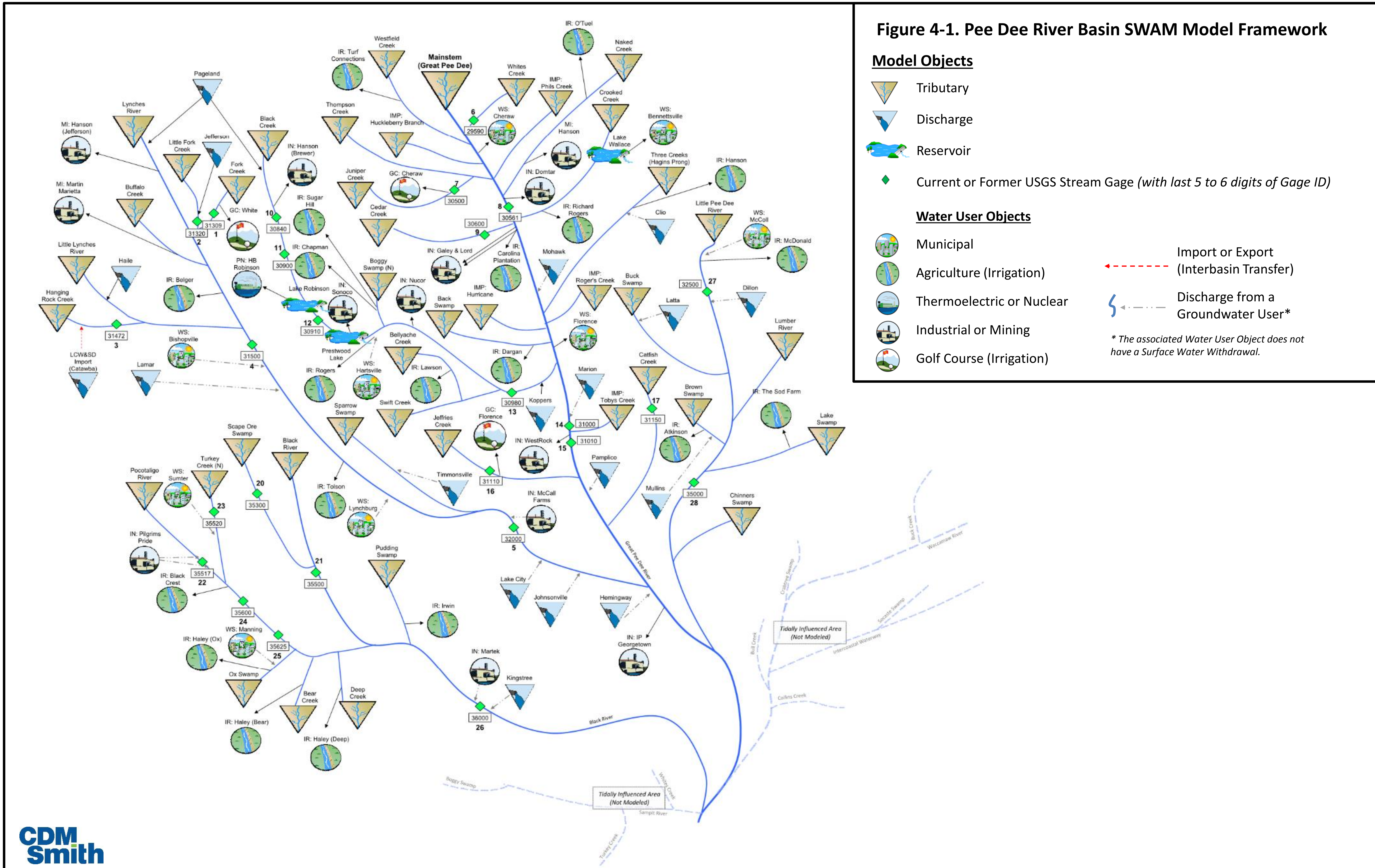


Figure 4-1. Pee Dee River Basin SWAM Model Framework

included as separate objects in the model. Since water withdrawals are associated with the permit holder rather than the ultimate water user, the Water User objects reflect the withdrawals associated with their permit.

4.2 Representation of Discharges

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

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

- Several municipal and industrial (M&I) discharges – Pageland, Jefferson, Haile, and Koppers were deemed significant enough to include in the model; however, the 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 the Lancaster County Water & Sewer District in the Catawba Basin, and then discharged in the Pee Dee Basin is represented by a Discharge object.

4.3 Groundwater Users and Associated Discharge

Although the Pee Dee 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 Pee Dee Basin, there are numerous, significant industrial and municipal groundwater withdrawals which have a corresponding, significant discharge to surface water. These include the following which are represented by municipal or industrial Water User objects:

- Manning
- Hartsville
- McCall Farms
- Bishopville

- Lynchburg
- McColl
- Pilgrims Pride
- Sumter
- Martek

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

- Clio
- Dillon
- Hemingway
- Johnsonville
- Kingstree
- Lake City
- Lamar
- Latta
- Marion
- Mohawk
- Mullins
- Timmonsville
- Pamplico

4.4 Implicit Tributaries

At certain locations along the main stem of the Pee Dee 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 Pee Dee 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 Pee Dee 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 summarizes the inputs used in both the calibration and baseline Pee Dee River Basin Models. As explained in Section 5, the calibration model incorporates historical water withdrawal and return data so that UIF flows and reach gains and losses can be calibrated to USGS gage flows. In contrast, the baseline model represents current demands and operations in the basin combined with an extended period of estimated hydrology. For future uses of the model, users can adjust the inputs, including demands, permit limits, and operational strategies, to perform “what if” simulations of basin water availability.

The following subsections describe the specific inputs to the Pee Dee 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).

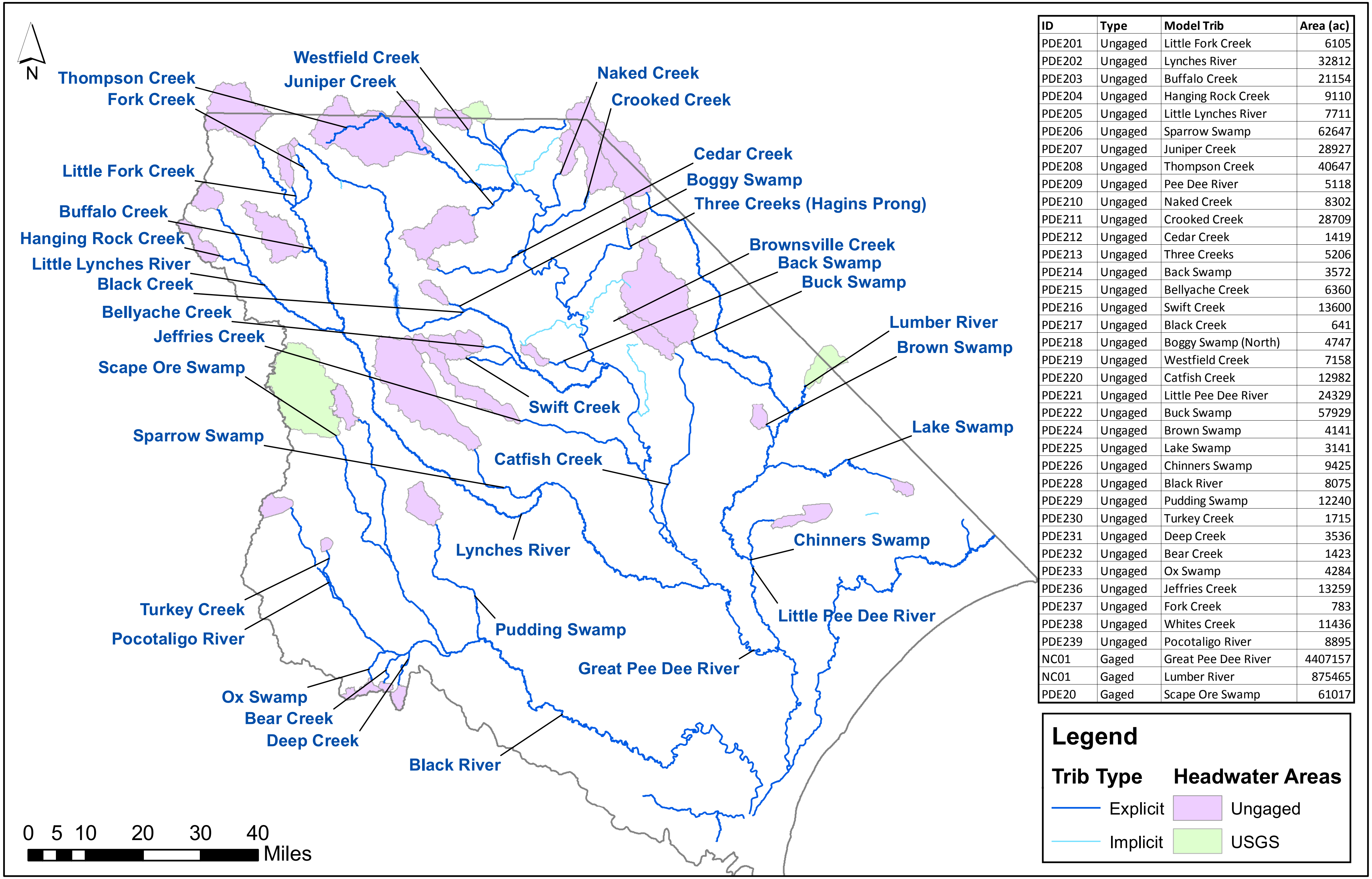
6.1.1 Explicit Tributary Objects: Headwater Flows

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, or area-prorated from calculated UIFs elsewhere in the basin. **Table 6-1** summarizes the gages, or in many instances, the reference gages used to develop headwater flows. **Figure 6-1** highlights the upstream drainage areas associated with the explicit tributary headwater flows. Green polygons correspond to unimpaired USGS gaged flow and purple polygons correspond to estimated ungaged flows. The inset table designates the project ID for each flow point, whether it was gaged or ungaged, the name of the tributary, and the corresponding drainage area in acres. Note that for the great Pee Dee River and Lumber River, only a small portion of the drainage area (the closest sub-basin) is shown; however, the corresponding drainage area, which includes the entire portion within North Carolina, is included in the table.

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

	Headwater Input			USGS Reference Gage (Unimpaired)		
Project ID	Type	USGS Number	SWAM Tributary	Project Gage ID	USGS Number	Stream
PDE201	Ungaged	-	Little Fork Creek	PDE02	02131320	Little Fork Creek
PDE202	Ungaged	-	Lynches River	PDE05	02132000	Lynches River
PDE203	Ungaged	-	Buffalo Creek	PDE03	02131472	Hanging Rock Creek
PDE204	Ungaged	-	Hanging Rock Creek	PDE03	02131472	Hanging Rock Creek
PDE205	Ungaged	-	Little Lynches River	PDE03	02131472	Hanging Rock Creek
PDE206	Ungaged	-	Sparrow Swamp	PDE05	02132000	Lynches River
PDE207	Ungaged	-	Juniper Creek	PDE07	02130500	Juniper Creek
PDE208	Ungaged	-	Thompson Creek	PDE07	02130500	Juniper Creek
PDE209	Ungaged	-	Pee Dee River	PDE06	02129590	Whites Creek
PDE210	Ungaged	-	Naked Creek	PDE06	02129590	Whites Creek
PDE211	Ungaged	-	Crooked Creek	PDE06	02129590	Whites Creek
PDE212	Ungaged	-	Cedar Creek	PDE09	02130600	Cedar Creek
PDE213	Ungaged	-	Three Creeks (Hagins Prong)	PDE06	02129590	Whites Creek
PDE214	Ungaged	-	Back Swamp	PDE09	02130600	Cedar Creek
PDE215	Ungaged	-	Bellyache Creek	PDE13	02130980	Black Creek
PDE216	Ungaged	-	Swift Creek	PDE13	02130980	Black Creek
PDE217	Ungaged	-	Black Creek	PDE11	02130900	Black Creek
PDE218	Ungaged	-	Boggy Swamp (North)	PDE12	02130910	Black Creek
PDE219	Ungaged	-	Westfield Creek	PDE06	02129590	Whites Creek
PDE220	Ungaged	-	Catfish Creek	PDE17	02131150	Catfish Creek
PDE221	Ungaged	-	Little Pee Dee River	PDE27	02132500	Little Pee Dee River
PDE222	Ungaged	-	Buck Swamp	PDE27	02132500	Little Pee Dee River
PDE224	Ungaged	-	Brown Swamp	PDE41	02135060	Chinners Swamp
PDE225	Ungaged	-	Lake Swamp	PDE41	02135060	Chinners Swamp
PDE226	Ungaged	-	Chinners Swamp	PDE41	02135060	Chinners Swamp
PDE228	Ungaged	-	Black River	PDE26	02136000	Black River
PDE229	Ungaged	-	Pudding Swamp	PDE26	02136000	Black River
PDE230	Ungaged	-	Turkey Creek	PDE24	02135600	Pocotaligo River
PDE231	Ungaged	-	Deep Creek	PDE26	02136000	Black River
PDE232	Ungaged	-	Bear Creek	PDE26	02136000	Black River
PDE233	Ungaged	-	Ox Swamp	PDE26	02136000	Black River
PDE236	Ungaged	-	Jeffries Creek	PDE16	02131110	Jeffries Creek
PDE237	Ungaged	-	Fork Creek	PDE01	02131309	Fork Creek
PDE238	Ungaged	-	Whites Creek	PDE06	02129590	Whites Creek
PDE239	Ungaged	-	Pocotaligo River	PDE22	02135517	Pocotaligo River
NC01	Gaged	02129000	Great Pee Dee River (Mainstem)	-	-	-
NC01	Gaged	02134500	Lumber River	-	-	-
PDE20	Gaged	02135300	Scape Ore Swamp	-	-	-



ID	Type	Model Trib	Area (ac)
PDE201	Ungaged	Little Fork Creek	6105
PDE202	Ungaged	Lynches River	32812
PDE203	Ungaged	Buffalo Creek	21154
PDE204	Ungaged	Hanging Rock Creek	9110
PDE205	Ungaged	Little Lynches River	7711
PDE206	Ungaged	Sparrow Swamp	62647
PDE207	Ungaged	Juniper Creek	28927
PDE208	Ungaged	Thompson Creek	40647
PDE209	Ungaged	Pee Dee River	5118
PDE210	Ungaged	Naked Creek	8302
PDE211	Ungaged	Crooked Creek	28709
PDE212	Ungaged	Cedar Creek	1419
PDE213	Ungaged	Three Creeks	5206
PDE214	Ungaged	Back Swamp	3572
PDE215	Ungaged	Bellyache Creek	6360
PDE216	Ungaged	Swift Creek	13600
PDE217	Ungaged	Black Creek	641
PDE218	Ungaged	Boggy Swamp (North)	4747
PDE219	Ungaged	Westfield Creek	7158
PDE220	Ungaged	Catfish Creek	12982
PDE221	Ungaged	Little Pee Dee River	24329
PDE222	Ungaged	Buck Swamp	57929
PDE224	Ungaged	Brown Swamp	4141
PDE225	Ungaged	Lake Swamp	3141
PDE226	Ungaged	Chinners Swamp	9425
PDE228	Ungaged	Black River	8075
PDE229	Ungaged	Pudding Swamp	12240
PDE230	Ungaged	Turkey Creek	1715
PDE231	Ungaged	Deep Creek	3536
PDE232	Ungaged	Bear Creek	1423
PDE233	Ungaged	Ox Swamp	4284
PDE236	Ungaged	Jeffries Creek	13259
PDE237	Ungaged	Fork Creek	783
PDE238	Ungaged	Whites Creek	11436
PDE239	Ungaged	Pocotaligo River	8895
NC01	Gaged	Great Pee Dee River	4407157
NC01	Gaged	Lumber River	875465
PDE20	Gaged	Scape Ore Swamp	61017

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

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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 five implicit tributaries.

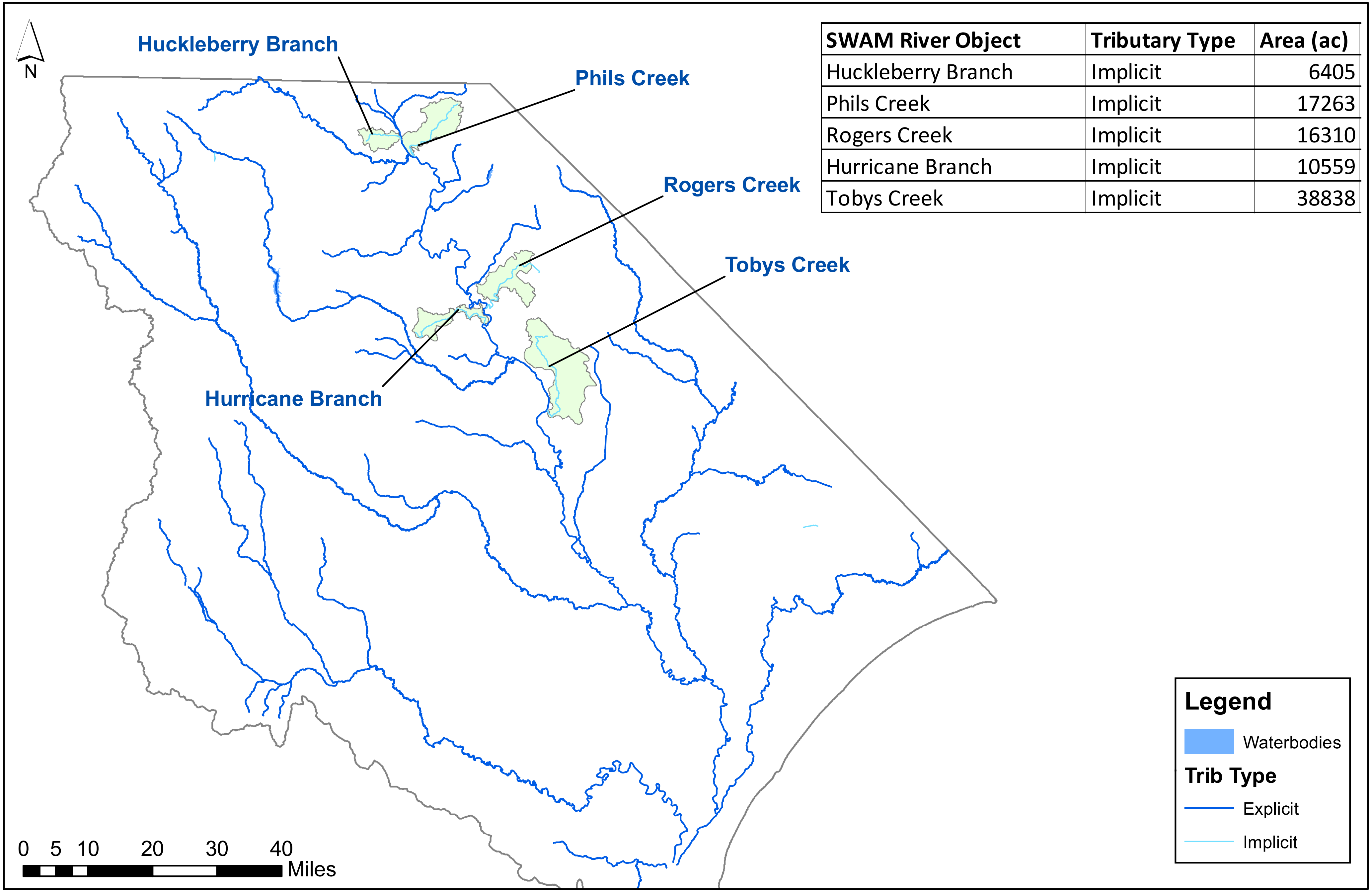
Table 6-2. Reference Gages Used for Headwater Flows on Implicit Tributaries

	Ungaged Basin	USGS Reference Gage (Unimpaired)		
Project ID	SWAM Tributary	Project Gage ID	USGS Number	Stream
PDE101	Huckleberry Branch	PDE06	02129590	Whites Creek
PDE102	Phils Creek	PDE06	02129590	Whites Creek
PDE103	Rogers Creek	PDE09	02130600	Cedar Creek
PDE104	Hurricane Branch	PDE09	02130600	Cedar Creek
PDE105	Tobys Creek	PDE17	02131150	Catfish Creek

6.1.3 Reach Gains and Losses

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

There are subtle differences in the way in which these gains and losses are characterized in the model inputs for non-mainstem tributary objects versus the mainstem tributary object, although they effectively achieve the same thing in the model calculations. For the mainstem, which represents the Great Pee Dee River in the model, gain/loss factors are specified on a per unit mile basis. For example, if the mainstem headwater flow is 10 cfs in a given timestep with a gain factor of 0.1 per mile specified for the entire mainstem reach, then the model applies a rate of gain of 1 cfs/mile throughout the length of the mainstem. At the end of a 5 mile reach with no other inflows or outflow, the flow would be 15 cfs. For all other tributary objects, sub-basin flow factors are specified as a total subbasin flow gain factor, used to calculate total natural (unimpaired) flow at the end of the designated reach. For example, if a tributary flow is 10 cfs in a given timestep, with a sub-basin flow factor of 5, then the end-of-reach flow (with no other inflows or outflows) is 50 cfs. The model linearly interpolates when calculating the unimpaired flow at intermediary points in the reach. The differences between mainstem vs. non-mainstem factors reflect physical differences between the two types of tributary objects as represented in SWAM. For non-mainstem tributaries, flow gains are usually dominated by easily-quantifiable increases in drainage area with distance downstream and therefore easily parameterized with drainage area-based sub-basin flow factors. For the mainstem, however, the bulk of the drainage area changes are already captured by the tributary objects and any additional changes in flow are more likely to be attributable to subsurface hydrologic interactions or very 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.



SWAM River Object	Tributary Type	Area (ac)
Huckleberry Branch	Implicit	6405
Phils Creek	Implicit	17263
Rogers Creek	Implicit	16310
Hurricane Branch	Implicit	10559
Tobys Creek	Implicit	38838

Figure 6-2. Implicit Tributaries in the Pee Dee River Basin

Tributary object gain/loss and sub-basin flow factors are the primary calibration parameters in the model, as discussed in Section 7. Recognizing the uncertainty in these parameters, factors are adjusted, as appropriate, to achieve a better match of modeled vs. measured downstream flows. As a starting point in the model, however, overall non-mainstem tributary sub-basin flow factors were prescribed in the model based only on drainage area ratios (headwater vs. confluence). Drainage areas are shown in Figures 6-1 and 6-2 and corresponding tributary and mainstem flow factors are summarized in **Table 6-3**.

6.2 Reservoirs

Three reservoirs are represented in the Pee Dee River Basin Model: Lake Robinson and Prestwood Lake on Black Creek and Lake Wallace on Crooked Creek. **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 pan-adjusted Hargreaves method estimates from daily temperature data and latitude. Temperature stations for were chosen based on proximity to pan evaporation sites. Temperature stations used in developing evaporative loss estimated are listed in Table 6-4.

6.2.2 Direct Precipitation

Because of their relatively small size, direct precipitation to the three reservoirs was considered insignificant, and not explicitly included in the model. However, precipitation rates were factored into the calculation of non-negative net evaporation rates for these smaller reservoirs. In other words, when evaporation was equal to or exceeded precipitation, precipitation was subtracted from the gross evaporation rate to calculate net rates. For timesteps where precipitation exceeded evaporation, net evaporation rates were set to zero.

6.2.3 Area-Capacity Relationships and Flood Control Outflow

No bathymetric or area-capacity information was available for the reservoirs; therefore, the area-capacity relationship is defined by estimated empty and full surface areas, and a very simplified linear relationship is assumed. As previously noted, these reservoirs are essentially run-of-river, and only minor elevation changes are expected. Therefore, the reservoirs' surface areas, which are used to the calculate evaporation, are expected to remain relatively unchanged. The reservoirs were not modeled as having a flood control pool, therefore no volume-to-flow relationship was identified for the flood control outflow.

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). The three reservoirs in the Pee Dee Basin are considered run-of-river and have no specific operating rules or release targets for inclusion in the model.

Table 6-3. Model Tributary Inputs

SWAM Tributary Object	Tributary Type	Confluence Stream	Confluence Location (mile)	Confluence Drainage Area (ac)	Headwater ID	End Mile	Drainage Area Ratio	Subbasin Flow Factor (unitless)
Mainstem	Explicit	none	none	5,200,000	NC01	12	*NA*	-0.0015*
						66		0.0025*
						70		-0.0020*
						500		0*
Back Swamp	Explicit	Mainstem	55	19,448	PDE214	6	5.4	5.4
Bear Creek	Explicit	Pocotaligo River	32	7,307	PDE232	6	5.1	5.1
Bellyache Creek	Explicit	Swift Creek	8	12,342	PDE215	5	1.9	1.9
Black Creek	Explicit	Mainstem	58	302,127	PDE217	15	51.9	51.9
						29	62.5	115.5
						39	57.1	170.0
						80	188.0	440.0
						91	38.2	38.2
Black River	Explicit	Mainstem	157	1,195,458	PDE228	23	12.3	12.3
						60	33.1	33.1
						157	57.5	57.5
Boggy Swamp (North)	Explicit	Black River	52	12,330	PDE218	52	2.6	2.6
Brown Swamp	Explicit	Little Pee Dee Rive	69	6,065	PDE224	2	1.5	1.5
Buck Swamp	Explicit	Little Pee Dee Rive	56	94,836	PDE222	15	1.6	1.6
Buffalo Creek	Explicit	Lynches River	24	22,827	PDE203	2	1.1	1.1
Catfish Creek	Explicit	Mainstem	96	113,238	PDE220	32	8.7	5.0
Cedar Creek	Explicit	Mainstem	19	43,796	PDE212	17	30.9	30.9
Chinners Swamp	Explicit	Little Pee Dee Rive	102	21,599	PDE226	102	2.3	2.3
Crooked Creek	Explicit	Mainstem	15	46,839	PDE211	10	1.6	1.6
Deep Creek	Explicit	Pocotaligo River	33	11,292	PDE231	21	3.2	3.2
Fork Creek	Explicit	Lynches River	14	26,674	PDE237	10	21.7	23.9
Hanging Rock Creek	Explicit	Little Lynches Rive	11	19,872	PDE204	5	2.2	3.7
Jeffries Creek	Explicit	Mainstem	80	125,628	PDE236	24	9.5	1.0
Juniper Creek	Explicit	Thompson Creek	19	40,997	PDE207	7	1.4	1.4
Lake Swamp	Explicit	Little Pee Dee Rive	75	108,875	PDE225	27	34.7	34.7
Little Fork Creek	Explicit	Fork Creek	10	9,657	PDE201	2	1.6	1.8
Little Lynches River	Explicit	Lynches River	46	124,875	PDE205	34	13.6	13.6
Little Pee Dee River	Explicit	Mainstem	133	565,718	PDE221	63	23.3	23.3
Lumber River	Explicit	Little Pee Dee Rive	63	1,123,354	PDE223	8	1.1	1.0
Lynches River	Explicit	Mainstem	105	906,056	PDE202	61	8.3	9.5
						118	7.7	10.2
						161	11.3	11.3
Naked Creek	Explicit	Mainstem	11	19,718	PDE210	9	2.4	2.4
Ox Swamp	Explicit	Pocotaligo River	30	17,496	PDE233	5	4.1	4.1
Pocotaligo River	Explicit	Black River	42	264,097	PDE239	12	10	9.0
						19	11	15.0
						39	14	14.2
Pudding Swamp	Explicit	Black River	48	115,753	PDE229	23	9.5	9.5
Scape Ore Swamp	Explicit	Black River	24	166,790	PDE20	24	2.7	2.7
Sparrow Swamp	Explicit	Lynches River	115	144,543	PDE206	16	2.3	2.3
Swift Creek	Explicit	Black River	71	42,996	PDE216	11	2.3	2.3
Thompson Creek	Explicit	Mainstem	4	167,338	PDE208	23	3.1	1.1
Three Creeks (Hagins Pro	Explicit	Mainstem	39	58,585	PDE213	9	11.3	11.3
Turkey Creek	Explicit	Pocotaligo River	12	11,948	PDE230	3	7.0	9.0
Westfield Creek	Explicit	Mainstem	0	20,538	PDE219	7	2.9	2.9
Whites Creek	Explicit	Pee Dee River	5	30,237	PDE238	10	2.6	1.7
Huckleberry Branch	Implicit	Mainstem	1	6,405	none	0	1	1
Hurricane Branch	Implicit	Mainstem	50	10,559	none	0	1	1
Phils Creek	Implicit	Mainstem	4	17,263	none	0	1	1
Rogers Creek	Implicit	Mainstem	46	16,310	none	0	1	1
Tobys Creek	Implicit	Mainstem	66	38,838	none	0	1	1

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

Table 6-4. Reservoir Inputs

Reservoir	Purpose	Receiving Stream	Temperature Station for Evaporation	Precipitation Station	Release Location (mi)	Storage Capacity (MG)	Initial Storage (MG)	Dead Pool (MG)	Area-Capacity Table	Operating Rules
Lake Robinson	Industry, power & recreation	Black Creek	Darlington USC00382260	Florence USC00383111	38.5	10,101	10,000	0	Simple	No minimum releases or storage targets
Prestwood Lake	Industry & recreation	Black Creek	Darlington USC00382260	Florence USC00383111	42.7	586	500	0	Simple	No minimum releases or storage targets
Lake Wallace	Water supply & recreation	Crooked Creek	Cheraw USC00381588	Florence USC00383111	2	541	500	0	Simple	No minimum releases or storage targets

6.3 Water Users and Dischargers

6.3.1 Sources of Supply

Table 6-5 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. Most notably, Duke Power's Lee Steam Station came off-line in late 2014, and therefore it is not included in the baseline model. One out-of-basin source is represented as a Discharge object (discussed below) and therefore does not appear in Table 6-5.

6.3.2 Demands

Table 6-6 presents the monthly surface water demand for Municipal (WS), Industrial (IN), Mining (MI), and nuclear power (PN) Water User objects in the baseline model. Monthly surface water irrigation demands for Golf Course (GC) and Agricultural (IR) Water User objects are presented in **Table 6-7**. The baseline model monthly demand assigned to each Water User object was calculated by averaging monthly demands (as reported to DHEC) over the ten-year period from 2004 through 2013. Demands for the calibration period (1983 through 2013) were input as a timeseries of monthly values based on monthly withdrawals reported to DHEC 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 Pee Dee River Basin Model, only one water user imports water from outside the basin. The Lancaster County Water and Sewer District is represented as a Discharge object (**LCW&SD Import**), as its water is sourced exclusively from the Catawba River Basin. A portion of its return flow discharges to the Pee Dee River Basin.

Table 6-5. Water User Objects and Sources of Supply Included in the Pee Dee River Basin Model

Model Object ID	Facility Name	Source of Supply	Intake ID	Diversion Location (mi)	Permit Limit (MGM)	Note
WS: Bennettsville	BENNETTSVILLE WTP	Crooked Creek (Lake Wallace)	34WS001S01	0.7	120.0	1
WS: Cheraw	TOWN OF CHERAW WTP	Great Pee Dee River	13WS001S01	1	357.0	1
WS: Florence	CITY OF FLORENCE PEE DEE SWTP	Great Pee Dee River	21WS002S01	55.8	930.0	1
MI: Hanson (Jefferson)	HANSON AGGREGATES - JEFFERSON FACILITY	Lynches River	13MI003S01	6.5	26.8	1
MI: Hanson (Marlboro)	HANSON AGGREGATES - MARLBORO FACILITY	Naked Creek	34MI001S03	7.2	133.9	1
MI: Martin Marietta	MARTIN MARIETTA MATERIALS PLANT	Buffalo Creek	28MI001S01	0.9	98.2	1
IN: Domtar	DOMTAR PAPER	Great Pee Dee River	34IN005S01	11.7	937.0	1
IN: Hanson (Brewer)	HANSON AGGREGATES - BREWER FACILITY	Black Creek	13IN002S01	6.8	205.3	2
IN: Galey & Lord	GALEY & LORD	Cedar Creek	16IN004S01	16.9	335.0	1
		Great Pee Dee River	16IN004S02	18.9	81.0	1
IN: IP (Georgetown)	INTERNATIONAL PAPER - GEORGETOWN MILL	Great Pee Dee River	22IN006S01	124.5	*NA*	1
IN: Nucor	NUCOR CORP	Black Creek	16IN006S01	60.2	31.0	1
IN: Sonoco	SONOCO PRODUCTS CO	Black Creek (Prestwood Lake)	16IN005S01	45.5	334.8	1
			16IN005S02	45.5	873.9	1
IN: WestRock	WESTROCK - FLORENCE MILL	Great Pee Dee River	21IN001S01	70.1	1249.9	1
PN: HB Robinson	H.B. ROBINSON NUCLEAR PLANT	Black Creek (Lake Robinson)	16PN001S01	38.4	22386.0	1
			16PN001S2	38.4	3884.0	1
GC: Cheraw	CHERAW STATE PARK	Juniper Creek	13GC001S01	4.5	46.8	1
GC: Florence	FLORENCE COUNTRY CLUB	Jeffries Creek	21GC001S01	2.7	49.1	1
GC: White Plains	WHITE PLAINS COUNTRY CLUB	Fork Creek	13GC003S01	0	49.0	1
IR: Atkinson	ATKINSON FARMS, LLC	Brown Swamp	33IR033S01	0	8.0	1,4
IR: Belger	BELGER FARMS	Lynches River	28IR011S03	31	91.3	1,4
IR: Black Crest	BLACK CREST FARMS MCLEOD W R FARMS	Pocotaligo River	43IR007S03	17.5	35.1	1,4
			43IR007S01	15.4	33.7	1,4
			43IR007S02	16.8	33.9	1,4
IR: Carolina Plantation	CAROLINA PLANTATION RICE	Black Creek	16IR080S01	61.6	60.0	1,4
IR: Chapman	CHAPMAN FARM	Boggy Swamp (N)	16IR030S01	1.8	8.0	1,4
			16IR030S02	1.8	2.4	1,4
IR: Dargan	DARGAN FARMS PARTNERSHIP	Back Swamp	16IR015S01	0.3	3.0	1,4
			16IR015S02	4.6	3.0	1,4
IR: Dunlap	DUNLAP FORESTY LLC	Great Pee Dee River	16IR006S01	24.5	*NA*	1,4
IR: Haley (Bear)	HALEY FARM	Bear Creek	14IR016S01	0	38.0	1,4
			14IR016S03	2.1	15.0	1,4
			14IR016S04	0.1	15.0	1,4
			14IR016S12	0.2	2.0	1,4
IR: Haley (Deep)	HALEY FARM	Deep Creek	14IR016S05	0	15.0	1,4
			14IR016S06	1	1.0	1,4
			14IR016S07	0.3	5.0	1,4
IR: Haley (Ox)	HALEY FARM	Ox Swamp	14IR016S02	0.3	15.0	1,4
			14IR016S13	0.7	10.0	1,4
IR: Hinson	HINSON FARM	Three Creeks (Hagins Prong)	34IR002S01	0.1	11.5	1,4
			34IR002S02	0	9.7	1,4
IR: Irwin	IRWIN MCINTOSH FARMS, INC.	Pudding Swamp	45IR002S01	21.8	4.8	1,4

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 Pee Dee Basin.
Note 4 indicates registered limit for irrigation

Table 6-5. Water User Objects and Sources of Supply Included in the Pee Dee River Basin Model (continued)

Model Object ID	Facility Name	Source of Supply	Intake ID	Diversion Location (mi)	Permit Limit (MGM)	Note
IR: Lawson Turf	LAWSON TURF FARMS	Bellyache Creek	16IR041S01	0.8	25.8	1,4
			16IR041S02	0.8	9.5	1,4
			16IR041S03	0.2	7.6	1,4
			16IR041S04	0.2	2.8	1,4
IR: McDonald	MCDONALD FARM	Little Pee Dee River	34IR007S01	5.4	9.2	1,4
IR: O'Tuel	O'TUEL FARM	Naked Creek	34IR004S01	0.2	69.0	1,4
IR: Richard Rogers	RICHARD ROGERS FARMS	Crooked Creek	34IR003S01	5.6	57.0	1,4
IR: Rogers	ROGER BROTHERS FARM	Black Creek	16IR016S01	49.6	11.5	1,4
			16IR016S02	49	*NA*	1,4
IR: The Sod Farm	SOD FARM THE	Lake Swamp	26IR025S01	1	2.1	1,4
IR: Sugar Hill	SUGAR HILL ACRES, LLC	Boggy Swamp (N)	16IR012S01	1.7	3.3	1,4
			16IR012S02	0.4	1.6	1,4
IR: Tolson	TOLSON FARMS	Lynches River	31IR008S01	81.2	7.0	1,4
IR: Turf Connections	TURF CONNECTIONS	Westfield Creek	13IR008S01	1.7	4.0	1,4
			13IR008S02	1.7	4.0	1,4

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 Pee Dee Basin.
Note 4 indicates registered limit for irrigation

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

	Baseline Model Average Monthly Demand (MGD)								
Month	IN: Domtar	IN: Galey & Lord	IN: Hanson (Jefferson)	IN: Sonoco	PN: HB Robinson	IN: WestRock	WS: Cheraw	WS: Florence	WS: Bennettsville
Permit Limit (MGD)-->	30.8	13.7	0.9	39.8	864.1	41.1	11.7	30.6	3.9
Jan	15.84	1.60	0.05	17.93	767.05	15.86	2.1	13.1	2.11
Feb	16.31	2.03	0.04	18.28	726.60	15.77	2.0	13.0	2.07
Mar	15.61	1.96	0.05	16.68	771.05	15.58	2.1	13.0	2.09
Apr	15.81	2.22	0.06	18.19	669.04	16.22	2.2	13.5	2.04
May	16.33	2.01	0.06	17.26	678.57	16.60	2.3	14.2	2.12
Jun	16.77	2.22	0.06	18.53	753.18	17.10	2.5	15.2	2.23
Jul	17.18	1.83	0.07	18.95	792.13	17.31	2.4	15.1	2.18
Aug	17.43	2.11	0.06	19.27	823.22	17.41	2.5	15.0	2.27
Sep	16.89	1.83	0.06	18.59	747.72	17.14	2.4	14.6	2.22
Oct	15.75	1.74	0.04	17.94	627.12	16.48	2.3	13.9	2.35
Nov	15.30	1.47	0.03	15.75	784.45	16.16	2.2	13.3	2.12
Dec	15.68	1.29	0.02	16.02	803.20	15.04	2.0	13.1	2.02

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

Table 6-7. Baseline Model Average Monthly Demand for GC and IR Water Users

	Baseline Model Average Monthly Demand (MGD)										
Month	**IR: Atkinson**	**IR: Belger**	**IR: Black Crest***	**IR: Carolina Plantation**	**IR: Chapman***	**IR: Dargan***	**IR: Haley (Bear)***	**IR: Haley (Deep)***	**IR: Haley (Ox)***	**IR: Hinson***	**IR: Irwin**
Limit (MGD)-->	**0.3**	**3.0**	**3.4**	**2.0**	**0.3**	**0.2**	**2.3**	**0.7**	**0.8**	**0.7**	**0.2**
Jan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Feb	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mar	0.03	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Apr	0.02	0.00	0.05	0.03	0.00	0.03	0.00	0.00	0.00	0.00	0.00
May	0.02	0.00	0.76	0.16	0.00	0.03	0.01	0.01	0.03	0.00	0.00
Jun	0.01	0.00	1.63	0.72	0.02	0.07	0.03	0.02	0.04	0.02	0.03
Jul	0.01	0.00	1.68	0.94	0.03	0.07	0.03	0.02	0.04	0.01	0.01
Aug	0.00	0.00	1.45	0.52	0.01	0.08	0.02	0.01	0.03	0.00	0.00
Sep	0.01	0.00	0.35	0.03	0.00	0.06	0.03	0.02	0.04	0.00	0.00
Oct	0.05	0.00	0.00	0.00	0.00	0.02	0.01	0.01	0.01	0.00	0.00
Nov	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.01
Dec	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01

	Baseline Model Average Monthly Demand (MGD)										
Month	**IR: Lawson Turf***	**IR: McDonald**	**IR: O'Tuel**	**IR: Richard Rogers**	**IR: Rogers**	**IR: The Sod Farm**	**IR: Sugar Hill***	**IR: Tolson**	**IR: Turf Connections***	**GC: White Plains**	**GC: Florence**
Limit (MGD)-->	**1.5**	**0.3**	**2.3**	**1.9**	**0.4**	**0.1**	**0.2**	**0.2**	**0.3**	**1.6**	**1.6**
Jan	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.22
Feb	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.29
Mar	0.01	0.00	0.07	0.04	0.00	0.00	0.00	0.00	0.03	1.08	1.28
Apr	0.12	0.00	0.21	0.07	0.00	0.01	0.00	0.01	0.07	2.85	2.58
May	0.39	0.00	0.42	0.47	0.05	0.01	0.00	0.00	0.09	3.25	2.71
Jun	0.45	0.03	0.54	0.82	0.07	0.01	0.02	0.10	0.13	3.61	3.54
Jul	0.53	0.05	0.54	0.54	0.18	0.01	0.03	0.10	0.09	3.89	3.13
Aug	0.56	0.03	0.45	0.20	0.07	0.01	0.00	0.06	0.17	3.83	3.44
Sep	0.36	0.03	0.13	0.09	0.03	0.01	0.00	0.01	0.15	3.57	3.24
Oct	0.28	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.13	2.12	1.57
Nov	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.66	0.87
Dec	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.21	0.20

Notes:

1. "Limit" shown is the total permit limit (for golf courses) or registered limit (for agricultural irrigators).

2. Limits are shown in MGD rather than MGM for comparative purposes. Actual permit/registration limits are in MGM.

** = Water users with multiple withdrawal locations. Withdrawal limits reflect the total permit or registration limit, accounting for all withdrawal locations.*

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 6-8** 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

Table 6-8. 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: Domtar	DOMTAR PAPER CO LLC/ MARLBORO MILL	SC0042188	-001	34IN005	Great Pee Dee River	11.9	100
IN: Galey & Lord	GALEY & LORD/SOCIETY HILL	SC0002704	-001	16IN004	Great Pee Dee River	18.9	100
IN: Hanson (Brewer)	HANSON AGGR SE/BREWER	SCG730286	-1AA	13IN002	Black Creek	6.8	100
IN: IP (Georgetown)	INTERNATIONAL PAPER/GEORGETOWN	SC0000868	-001	22IN006S01	Whites Creek		100
IN: Martek	MARTEK BIOSCIENCES KINGSTREE	SC0003123	-001,-002	45IN001G	Black River	61.2	100
IN: McCall Farms	MCCALL FARMS INC	SC0039284	-001,-01A	21IN008G	Lynches River	117.5	100
IN: Pilgrims Pride	PILGRIMS PRIDE POULTRY PROC. PLANT	SC0000795	-001,-002	43IN005G	Pocotaligo River	12.2	100
IN: Sonoco	SONOCO PRODUCTS/HARTSVILLE	SC0003042	-001,-002,-003,-004,-005,-006	16IN005	Black Creek	45.5	100
IN: Trebol	TREBOL USA LLC	SC0001619	-001	22IN007G	Boggy Swamp (S)	0.0	100
IN: WestRock	WESTROCK	SC0000876	-001	21IN001	Great Pee Dee River	75.0	100
MI: Hanson (Jefferson)	HANSON AGGR SE/JEFFERSON	SCG730062	-000	13MI003	Lynches River	6.5	100
PN: HB Robinson	PROGRESS ENERGY/ROBINSON	SC0002925	-001,-003,-006,-008,-009,-011,-013,-014	16PN001	Black Creek	38.4	100
WS: Bennettsville	BENNETTSVILLE WWTF	SC0025178	-001	34WS001	Crooked Creek	4.2	100
WS: Bishopville	BISHOPVILLE WWTF	SC0035378	-001	31WS001G	Lynches River	62.9	100
WS: Cheraw	CHERAW WWTF	SC0020249	-001	13WS001	Great Pee Dee River	2.2	100
WS: Florence	DARLINGTON/BLACK CREEK WWTF	SC0039624	-001	21WS002	Black Creek	66.6	100
WS: Florence	FLORENCE/PEE DEE RIVER PLANT	SC0045462	-001	21WS002	Great Pee Dee River	70.2	100
WS: Hartsville	HARTSVILLE WWTF	SC0021580	-001	16WS003G	Black Creek	49.9	100
WS: Lynchburg	LYNCHBURG WWTF	SC0042676	-001	31WS002G	Lynches River	85.5	100
WS: Manning	MANNING WWTF	SC0020419	-001	14WS001G	Ox Swamp	4.6	100
WS: McColl	MCCOLL WWTF	SC0041963	-001	34WS003G	Little Pee Dee River	0.0	100
WS: Sumter	SUMTER/POCOTALIGO RIV. PLANT	SC0027707	-001	43WS001G	Turkey Creek (N)	5.1	100
Transbasin Imports Represented by Discharge Objects							
LCW&SD Import (Catawba)	LANCASTER COUNTY WATER & SEWER DISTRICT	SC0025798	-001	29WS005	Hanging Rock Creek	0.3	-
In-basin Returns Represented by Individual Discharge Objects							
Clio	CLIO WWTF	SC0040606	-01C,01A	34WS050G	Three Creek (Hagins Prong)	5.8	-
Dillon	DILLON/LITTLE PEE DEE	SC0021776	-001,-002,-003,-004	17WS001G	Little Pee Dee River	32.7	-
Haile	HAILE GOLD MINE	SC0040479	-002	none	Little Lynches Creek	5.5	-
Hemingway	HEMINGWAY, TOWN OF	SC0039934	-001	45WS001G	Lynches River	160.5	-
Jefferson	JEFFERSON WWTF	SC0024767	-001	none	Little Fork Creek	1.9	-
Johnsonville	JOHNSONVILLE/EAST PLANT	SC0025933	-001	21IN002G	Lynches River	155.1	-
Kingstree	KINGSTREE, TOWN OF	SC0035971	-001	45WS002G	Black River	62.2	-
Koppers	KOPPERS INC	SC0003018	-001,-002	none	Black Creek	82.1	-
Lake City	LAKE CITY/LAKE SWAMP WW PLANT	SC0046311	-001	21WS005G	Lynches River	139.2	-
Lamar	LAMAR WWTF	SC0043702	-001	16WS005G	Lynches River	75.0	-
Latta	LATTA, TOWN OF	SC0025402	-001	17WS003G	Buck Swamp	0.6	-
Marion	MARION/S. MAIN ST. WWTF	SC0046230	-001	33WS001G	Great Pee Dee River	65.5	-
Mohawk	MOHAWK IND/OAK RIVER PLANT	SC0001996	-001,-002,-003	34IN003G	Great Pee Dee River	31.6	-
Mullins	MULLINS/WHITE OAK CREEK WWTF	SC0029408	-001	33WS002G	Brown Swamp	0.1	-
Pageland	PAGELAND/NORTHWEST WWTF	SC0021504	-001	none	Lynches River	0.1	-
Pageland	PAGELAND/SOUTHEAST WWTF	SC0021539	-001	none	Black Creek	1.9	-
Pamplico	PAMPLICO, TOWN OF	SC0021351	-002	21WS007G	Great Pee Dee River	88.7	-
Timmonsville	TIMMONSVILLE, TOWN OF	SC0025356	-001	21WS003G	Sparrow Swamp	0.3	-

on their close proximity to one another (e.g., The HB Robinson Nuclear Plant). No returns are assumed for golf course and agricultural irrigation (i.e., 100% consumptive use).

Table 6-9 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).

Table 6-9. Baseline Model Monthly Consumptive Use Percentage

	Monthly Consumptive Use (%)								
Month	IN: Domtar	IN: Galey & Lord	IN: Hanson (Jefferson)	IN: Sonoco	PN: HB Robinson	IN: WestRock	WS: Cheraw	WS: Florence	WS: Bennettsville
Jan	2.4	7.2	85.0	27.9	0.4	17.2	8.2	20.4	8.0
Feb	0.3	4.2	85.0	18.0	1.0	13.0	5.6	12.4	6.4
Mar	0.6	4.9	85.0	13.9	0.4	9.6	3.9	13.4	6.8
Apr	0.9	8.9	85.0	21.7	0.0	17.1	13.0	19.1	14.0
May	0.5	7.3	85.0	15.4	0.0	23.4	21.3	25.6	19.5
Jun	0.4	8.4	85.0	13.8	0.0	25.9	23.5	26.3	20.1
Jul	0.5	15.9	85.0	19.9	0.0	29.7	24.8	27.7	21.0
Aug	1.0	11.0	74.4	14.0	0.0	26.5	20.9	26.4	22.1
Sep	2.1	8.5	85.0	16.6	0.2	24.0	25.5	32.0	23.0
Oct	2.4	13.0	85.0	18.9	0.2	20.9	21.4	29.3	26.8
Nov	2.0	8.2	85.0	22.3	0.0	28.3	19.0	27.8	25.1
Dec	1.2	6.4	85.0	20.4	0.0	23.9	9.9	21.5	15.2

Table 6-10 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 Pee Dee 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 Pee Dee River Basin model, these calibration inputs only include reach hydrologic gain/loss factors and, to a very limited extent, reservoir operating rule targets.

Table 6-10. Baseline Model Monthly Return Flows for Discharge Objects

	Monthly Return Flow (MGD)								
Month	Clio	Dillon	Haile	Hemingway	Jefferson	Johnsonville	Kingstree	Koppers	Lake City
Jan	0.13	2.86	0.17	0.38	0.10	1.33	1.76	0.07	3.01
Feb	0.17	3.18	0.16	0.44	0.11	1.36	1.83	0.08	3.56
Mar	0.17	3.30	0.24	0.40	0.11	1.41	1.82	0.13	3.37
Apr	0.14	2.98	0.23	0.38	0.10	1.40	1.65	0.15	3.20
May	0.10	2.76	0.28	0.36	0.08	1.46	1.66	0.16	2.56
Jun	0.13	3.13	0.20	0.33	0.08	1.52	1.72	0.44	2.81
Jul	0.17	3.12	0.24	0.32	0.09	1.36	1.73	0.25	2.94
Aug	0.11	2.73	0.29	0.34	0.08	1.51	1.69	0.14	2.80
Sep	0.14	3.01	0.28	0.37	0.07	1.44	1.66	0.15	2.63
Oct	0.10	2.61	0.30	0.36	0.06	1.38	1.60	0.12	2.44
Nov	0.13	2.60	0.31	0.30	0.07	1.37	1.60	0.13	2.36
Dec	0.13	2.85	0.25	0.30	0.09	1.32	1.71	0.10	2.78

	Monthly Return Flow (MGD)								
Month	Lamar	Latta	Marion	Mohawk	Mullins	Pageland (NW)	Pageland (SE)	Pamplico	Timmonsville
Jan	0.36	0.54	1.62	0.34	1.26	0.16	0.36	0.24	0.77
Feb	0.35	0.61	2.02	0.36	1.59	0.16	0.36	0.32	0.93
Mar	0.34	0.65	1.97	0.35	1.44	0.16	0.38	0.30	1.17
Apr	0.33	0.55	1.64	0.36	1.23	0.14	0.35	0.24	1.05
May	0.32	0.43	1.48	0.36	1.14	0.13	0.30	0.16	0.83
Jun	0.32	0.46	1.73	0.35	1.36	0.12	0.29	0.21	0.73
Jul	0.26	0.44	1.68	0.35	1.20	0.13	0.30	0.18	0.75
Aug	0.26	0.47	1.75	0.37	1.14	0.12	0.28	0.21	0.71
Sep	0.25	0.44	1.84	0.38	1.15	0.11	0.32	0.26	0.71
Oct	0.25	0.38	1.38	0.37	0.95	0.09	0.27	0.16	0.75
Nov	0.32	0.35	1.40	0.37	1.07	0.10	0.29	0.21	0.67
Dec	0.27	0.51	1.66	0.34	1.25	0.13	0.32	0.21	0.70

Note: *The Pageland Discharge Object has two discharge locations (NW=Lynches River; SE=Black Creek)*

Section 7

Model Calibration/Verification

7.1 Philosophy and Objectives

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

The overriding objective of the SWAM calibration process is to verify that the model is generally accurately representing water availability in the basin; i.e. that ungaged flow estimates are roughly accurate, that flows are being combined correctly, and that basin operations and water use are well captured. More specifically, the objectives include:

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

In many ways, the exercise described here is more about model verification than true model calibration. The model parameterization is supported by a large set of known information and data – including tributary flows, drainage areas, water use and return data, and reservoir operating rules. These primary inputs are not changed during model calibration. In fact, only a small number of parameters are modified as part of this process. This is a key difference compared to hydrologic model calibration exercises, where a large number of parameters can be adjusted to achieve a desired modeled vs. measured fit. Because SWAM is a data-driven model and not a parametric reproduction of the physics that govern streamflow dynamics, care is taken so that observed data used to create model inputs are not altered. In calibrating SWAM, generally the primary parameters adjusted are sub-basin flow factors for select tributary objects and reach gain/loss factors for the mainstem. These factors capture ungaged flow gains associated with increasing drainage area with distance downstream. Flow gains through a sub-basin are initially assumed to be linearly proportional to drainage area, in line with common ungaged flow estimation techniques. However, there is significant uncertainty in this assumption and it is therefore appropriate to adjust these factors, within a small range, as part of the model calibration process. These are often the only parameters changed in the model during calibration, though adjustments can also be made if needed to reservoir operating rules, consumptive use rates, and flow estimates in ungaged headwater basins. 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 Pee Dee Basin model, as described in Sections 5 and 6, was used to simulate the 1983 through 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.

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 Pee Dee 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.

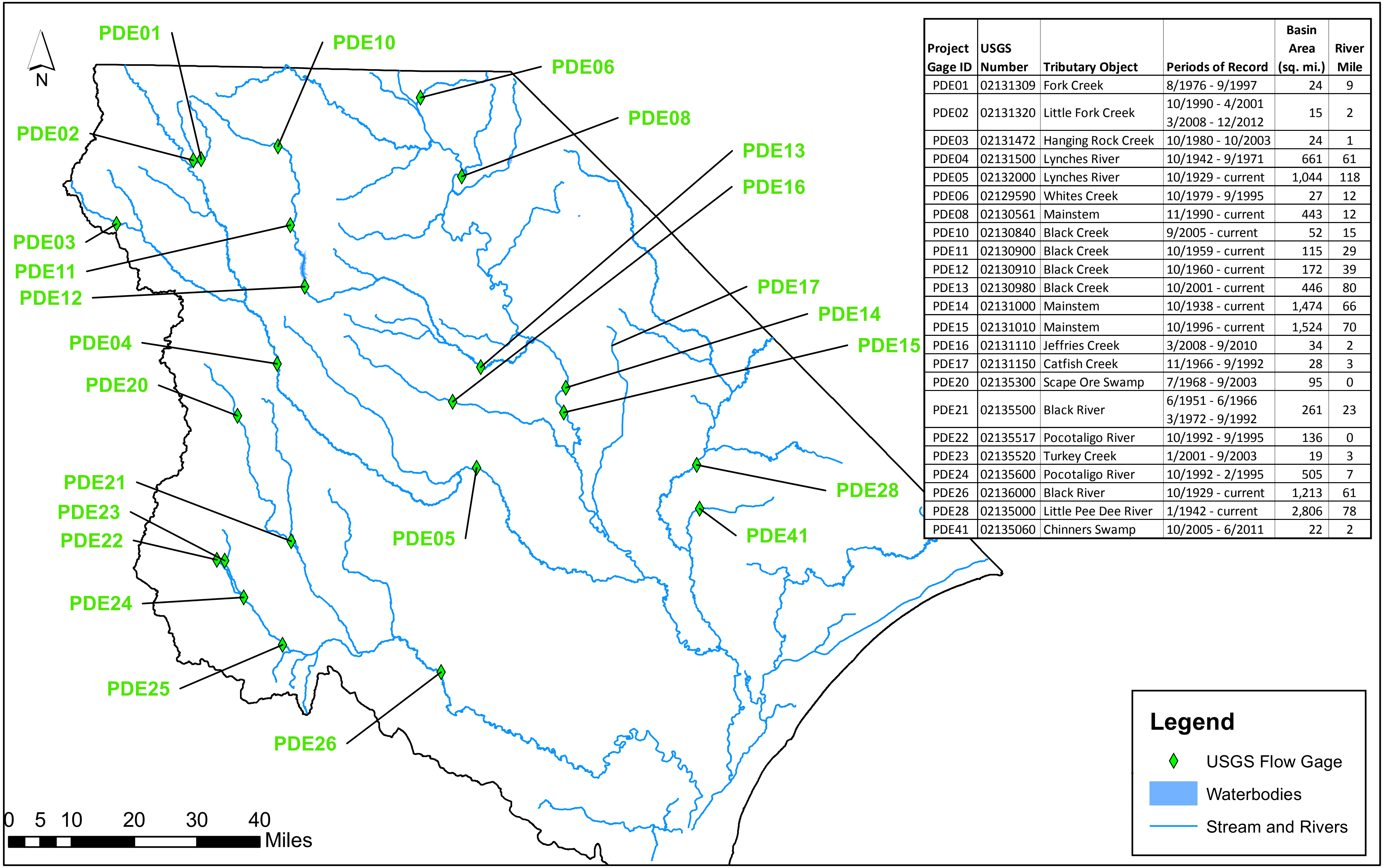
5. The representation of the three modeled reservoirs was reviewed based on the limited monthly reservoir level modeled vs. measured comparisons.

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

All USGS flow gages at non-tidally influenced downstream locations in the basin with reasonable records within the targeted calibration period were used to assess model performance and guide the model calibration steps described above. The gages used for calibration are shown in **Figure 7-1**. Note that in order to minimize the uncertainty in our calibration targets, only gaged (i.e. measured) flow records were used to assess model performance as part of this exercise. No ungaged flow estimates or record filling techniques were used to supplement this data set (although many of the input flows were developed through various record extensions techniques). Note also that all upstream basin water use and operations are implicitly represented in these gaged data, thereby providing an ideal target to which the combination of estimated UIFs and historic water uses could be compared. In addition to the flow gages, reported historical reservoir levels (available only for Lake Robinson) were also used as calibration/verification targets. Lastly, all water users in the model were checked to ensure that historical demands were being fully met in the model or, alternatively, if demands were not being met during certain periods, that there was a sensible explanation for the modeled shortfalls.

As indicated above, options for model calibration parameters (i.e. those that are adjusted to achieve better modeled vs. measured matches) are limited to a very small group of inputs with relatively high associated uncertainty. In general, and for future basin models, these might include any of the following: mainstem hydrologic gain/loss factors, tributary sub-basin flow factors, reservoir operational rules, assumed consumptive use percentages, and return flow locations and/or lag times associated with outdoor use. However, the primary calibration parameters in SWAM are the sub-basin flow factors and mainstem gain/loss factors. The final model sub-basin flow factors and mainstem gains/losses are presented in Section 6, Table 6-3. The use of alternative reference gages to estimate an ungaged headwater tributary flow is also considered during calibration. Similarly, the method used to extend a headwater UIF may also be re-evaluated, and an alternative extension method may be found to produce a better match of modeled vs. measured flows at a downstream gage. Adjustments to most other parameters are secondary and often not required.

A number of performance metrics were used to assess the model's ability to reproduce past basin hydrology and operations. These include: monthly and daily water user supply delivery and/or shortfalls; monthly and daily timeseries plots of both river flow and reservoir levels; cumulative flow



Project Gage ID	USGS Number	Tributary Object	Periods of Record	Basin Area (sq. mi.)	River Mile
PDE01	02131309	Fork Creek	8/1976 - 9/1997	24	9
PDE02	02131320	Little Fork Creek	10/1990 - 4/2001 3/2008 - 12/2012	15	2
PDE03	02131472	Hanging Rock Creek	10/1980 - 10/2003	24	1
PDE04	02131500	Lynches River	10/1942 - 9/1971	661	61
PDE05	02132000	Lynches River	10/1929 - current	1,044	118
PDE06	02129590	Whites Creek	10/1979 - 9/1995	27	12
PDE08	02130561	Mainstem	11/1990 - current	443	12
PDE10	02130840	Black Creek	9/2005 - current	52	15
PDE11	02130900	Black Creek	10/1959 - current	115	29
PDE12	02130910	Black Creek	10/1960 - current	172	39
PDE13	02130980	Black Creek	10/2001 - current	446	80
PDE14	02131000	Mainstem	10/1938 - current	1,474	66
PDE15	02131010	Mainstem	10/1996 - current	1,524	70
PDE16	02131110	Jeffries Creek	3/2008 - 9/2010	34	2
PDE17	02131150	Catfish Creek	11/1966 - 9/1992	28	3
PDE20	02135300	Scape Ore Swamp	7/1968 - 9/2003	95	0
PDE21	02135500	Black River	6/1951 - 6/1966 3/1972 - 9/1992	261	23
PDE22	02135517	Pocotaligo River	10/1992 - 9/1995	136	0
PDE23	02135520	Turkey Creek	1/2001 - 9/2003	19	3
PDE24	02135600	Pocotaligo River	10/1992 - 2/1995	505	7
PDE26	02136000	Black River	10/1929 - current	1,213	61
PDE28	02135000	Little Pee Dee River	1/1942 - current	2,806	78
PDE41	02135060	Chinners Swamp	10/2005 - 6/2011	22	2

Figure 7-1. USGS Streamflow Gages Used in Calibration

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

The reliability of past water supply to meet specific water user demands is an important consideration in the calibration process to ensure that water user demands and supply portfolios are properly represented in the model, as well as providing checks on supply availability at specific points of withdrawal. Timeseries plots, both monthly and daily, are used to assess the model's ability to simulate observed temporal variation and patterns in flow and storage data and to capture an appropriate range of high and low flow values. Cumulative flow plots are useful confirm that there is not an overall bias of too high or too low flows over an extended period. Percentile plots are useful for assessing the model's ability to reproduce the range of flows, including extreme events, observed in the past (and are particularly important when considering that the value of a long-term planning model like this is its ability to predict the frequency at which future flow thresholds might be exceeded, or the frequency that various amounts of water will be available). Monthly statistics provide valuable information on the model's ability to generally reproduce seasonal patterns, while annual totals and period of record mean flows help confirm the overall water balance represented in the model. Lastly, regulatory low flows (7Q10) are of specific interest as the model could be used to predict such low flows as a function of future impairment. However, the limitations of the daily model and supporting data should be properly considered in assessing model performance on this particular metric. Note that for the purposes of this exercise a simplified 7Q10 calculation was employed. Our approach used the Excel percentile function to estimate the 10 year recurrence interval (10th percentile) of modeled and measured 7 day low flows. This differs from the more standard methods often using specific fitted probability distributions (e.g. log-Pearson).

Assessment of performance and adequacy of calibration was primarily based on graphical comparisons (modeled vs. measured) of the metrics described above. It is our opinion that graphical results, in combination with sound engineering judgement, provide the most comprehensive view of model performance for this type of model. Reliance on specific statistical metrics can result in a skewed and/or shortsighted assessments of model performance. In addition to the graphical assessments, period of record flow averages and 7Q10 values were assessed based on tabular comparisons and percent differences. Ultimately, keeping in mind the philosophies and objectives described in Section 7.1, consideration was given as to whether the model calibration could be significantly improved with further parameter adjustments, given the limited calibration "knobs" available in the process. In actuality, a clear point of "diminishing returns" was reached whereby no significant improvements in performance could be achieved without either: a) adjusting parameters outside of their range of uncertainty or, b) constructing an overly prescriptive historical model that then becomes less useful for future predictive simulations. At this point, the calibration exercise was considered completed.

7.3 Results

Detailed monthly and daily model calibration results are provided in **Appendix A** and **B**, respectively. In general, a strong agreement between modeled and measured data is observed for 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 flow 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 measured flows, indicating that the model is not significantly over- or under-predicting flows. The one exception was PDE21 on the Black River, where the model is slightly over-predicting (cumulative modeled flow is 6.2% high).

For all sites, modeled mean flow values, averaged over the full period of record, were all within 10% of measured mean flows. The one exception is PDE41 (Chinners Swamp) which had six years of record for comparison and extremely low average flows (14 cfs). These results indicate that the overall water balance is very well simulated in the model and there are no obvious missing or excess sources of flow in the model.

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.

In terms of daily timestep simulations, daily flow fluctuations are generally well captured by the model. Modeled daily percentile plots exhibit excellent agreement with measured data for the mainstem (Great Pee Dee River) locations (PDE8, PDE14 and PDE15). At PDE14 and PDE15, the model tends to exaggerate the flashiness associated with short duration (single day) peaks that occur less than 3% of the time. These 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. The other metrics, including the monthly means, generally match well during the calibration period.

In both the daily and monthly timesteps, the model has the tendency to over-predict low flows and under-predict high flows at PDE10, the most upstream gage on Black Creek. PDE11, which was used as the reference gage for headwater input to Black Creek, is only 14 miles downstream of PDE10, but does not exhibit the same level of "flashiness" relative to PDE10. Given that PDE11, PDE12, and PDE13, which are all located on Black Creek, exhibit an excellent match of modeled and measured flows, no additional adjustments were made to improve the model results at PDE10.

Modeled regulatory low flow values (7Q10) are within 13% to 28% of measured values at mainstem gages PDE08, PDE14 and PDE15. At each gage, the model under-predicts the 7Q10. Modeled 7Q10 flows in Black Creek are within 3% to 15% of measured values at gages PDE11, PDE12 and PDE13. Modeled 7Q10 flows in the Lynches River are within 14% and 32% of measured values at gages PDE05 and PDE04, respectively. Note that PDE04 only had 11 years of flow records, compared to PDE05, which has 31 years (during the calibration period). A table comparing model and measured 7Q10 flows is provided at the end of Appendix B.

The model adequately hindcasts delivered water supply to the water users in the model. Simulated supply roughly equals simulated demand for all users, with no significant shortfalls. Limited exceptions to this include the irrigation withdrawals associated with the Haley and O'Toul farms and the Florence and White Plains golf courses. In each case, the shortfalls were limited to a few, or even as little as one month during the calibration period. Except for the Florence golf course, the withdrawals occur on ungaged tributaries, where flow uncertainty is relatively high. For the few shortages observed, it is possible that reported or estimated (hindcasted) surface water usage is inaccurate and irrigation was temporarily reduced due to supply limitations. There may also be small storage ponds or tanks in use that mitigate against shortages but are not represented in the model.

Section 8

Use Guidelines for the Baseline Model

The baseline Pee Dee 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 1925 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 Pee Dee Basin, it will be useful to examine flows with either managed or unimpaired Yadkin River and Lumber River flows coming across state lines 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

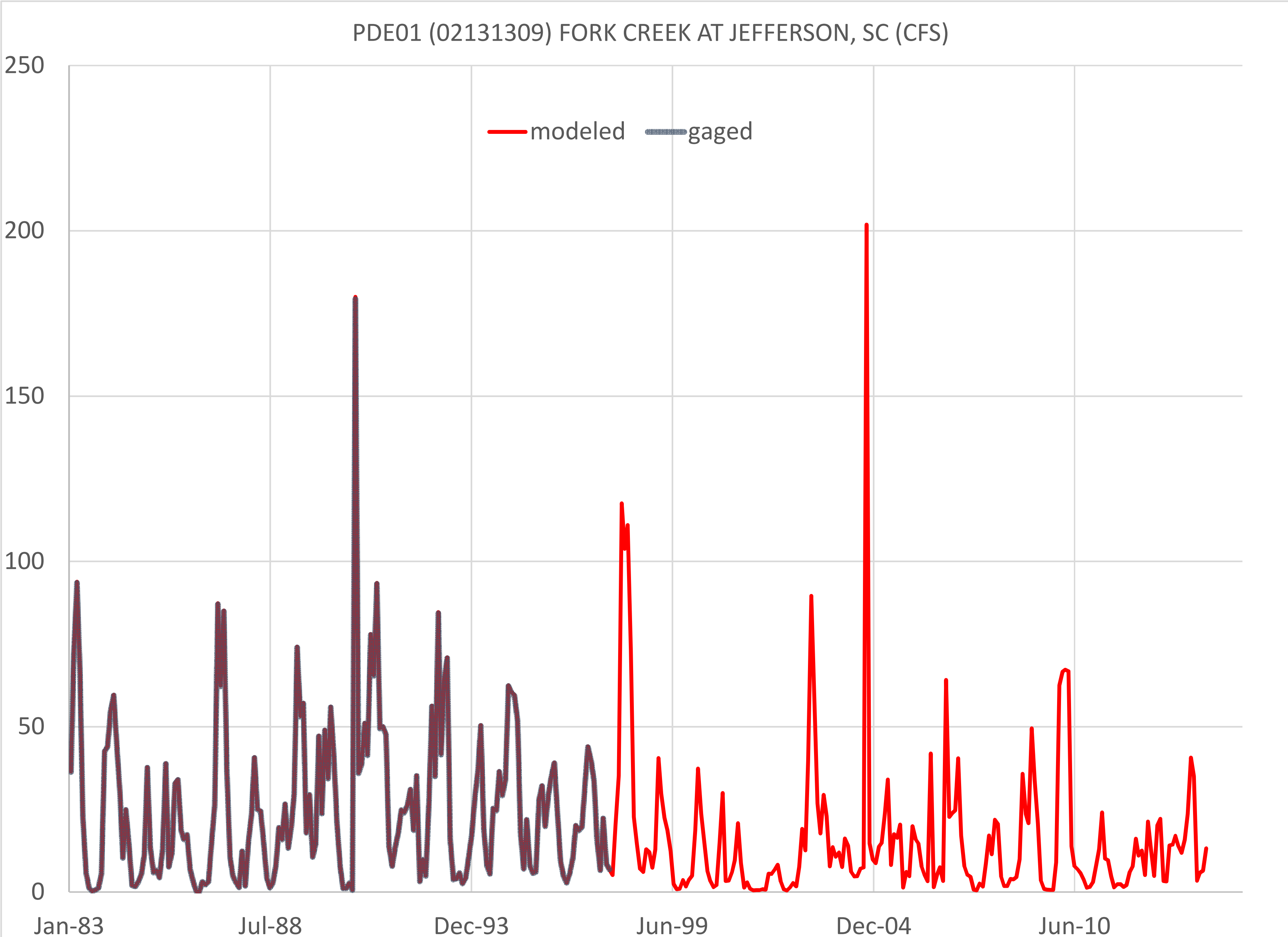
CDM Smith, October 2015. *Pee Dee Basin SWAM Model Framework*

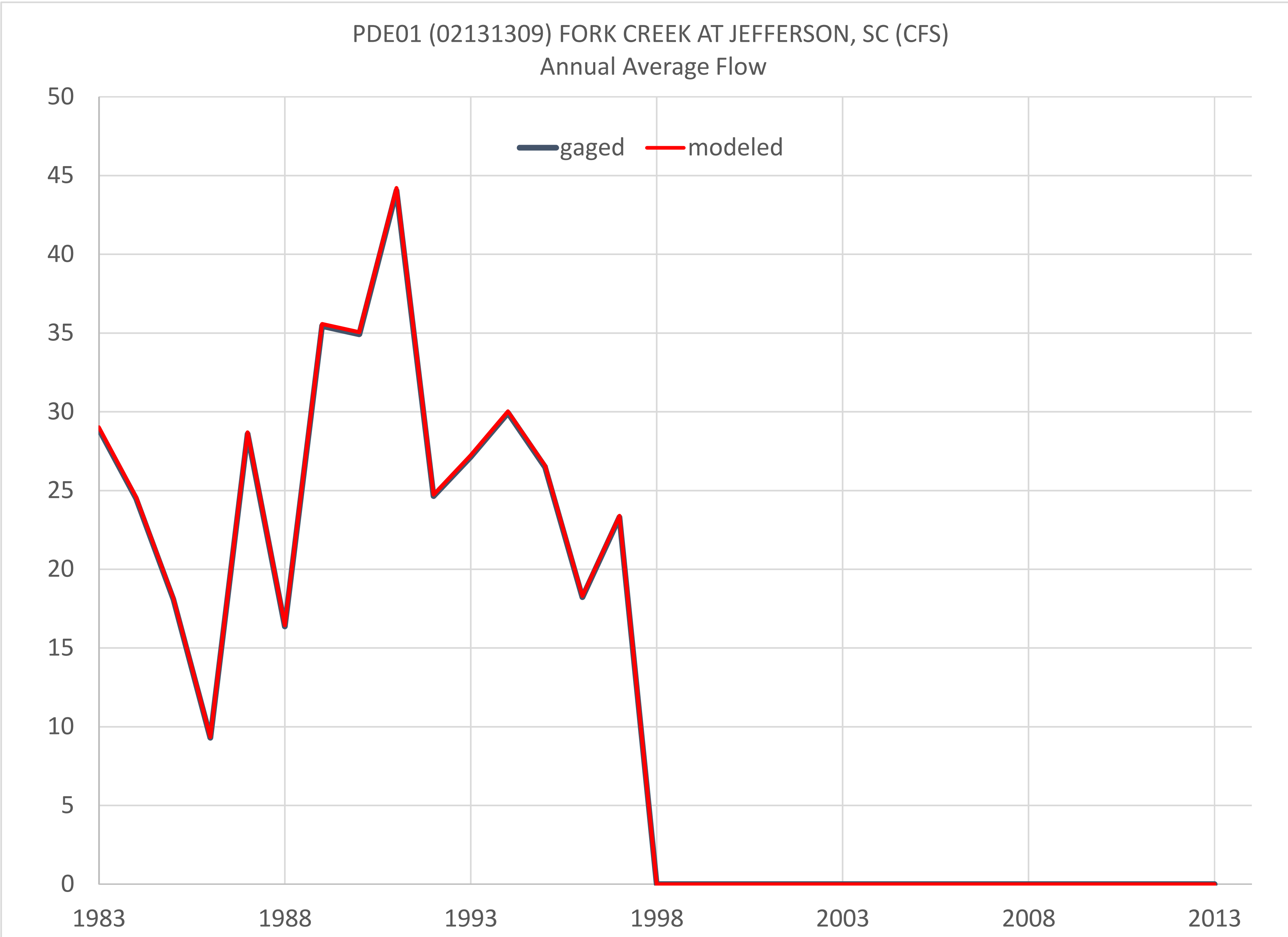
CDM Smith, 2016. *Simplified Water Allocation Model (SWAM) User's Manual, Version 4.0.*

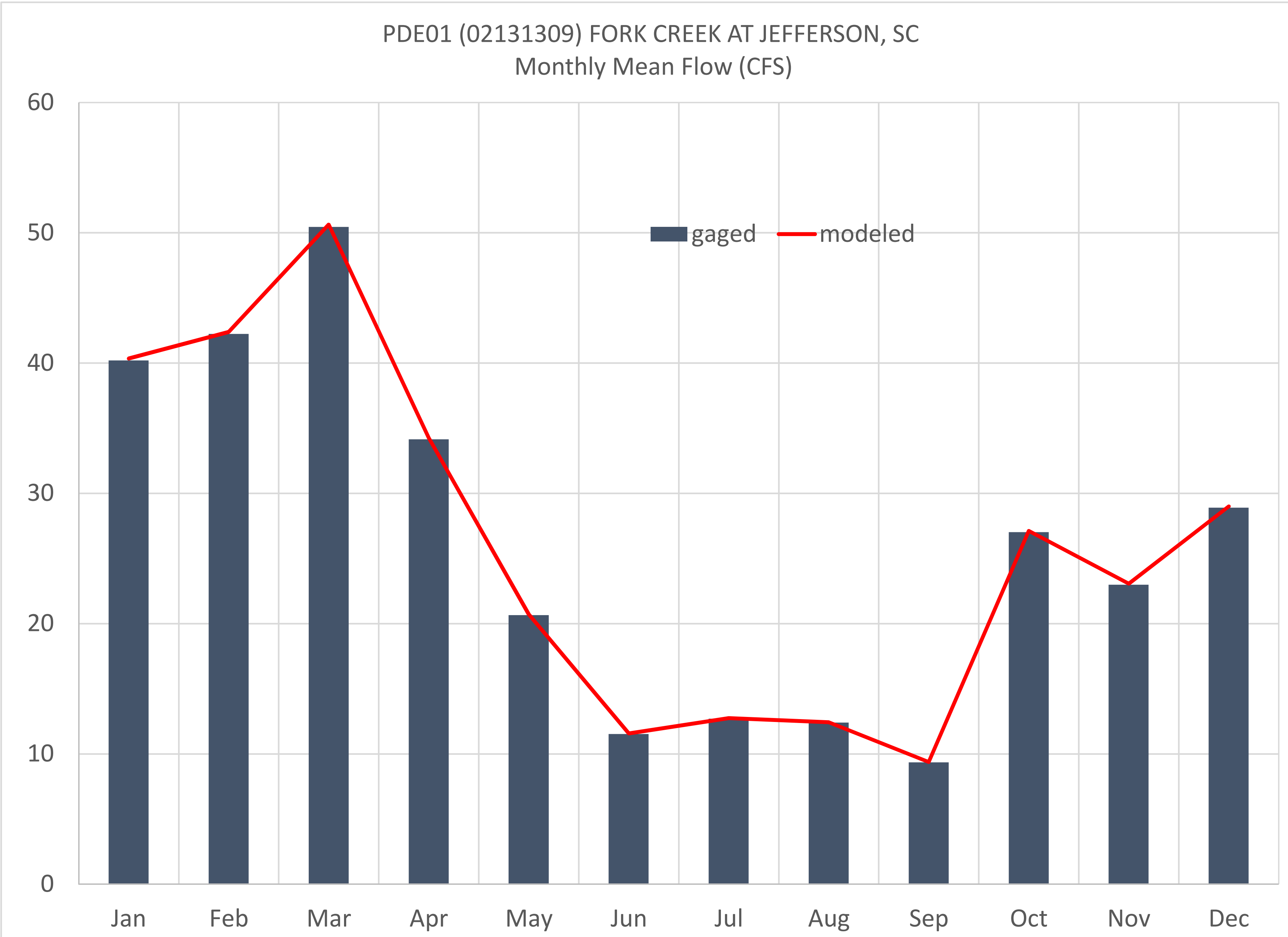
Appendix A

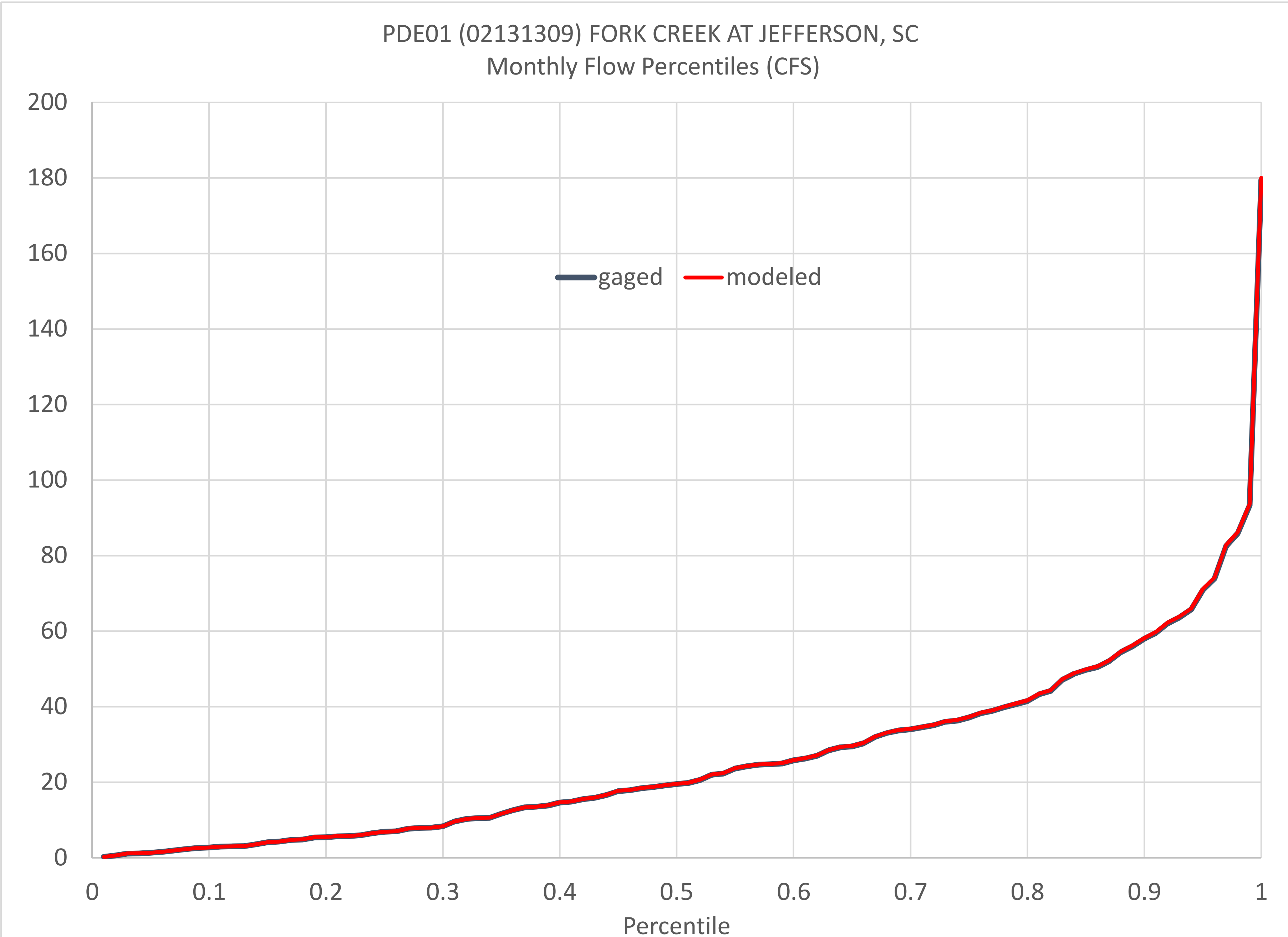
Pee Dee River Basin Model Monthly Calibration Results

CDM Smith

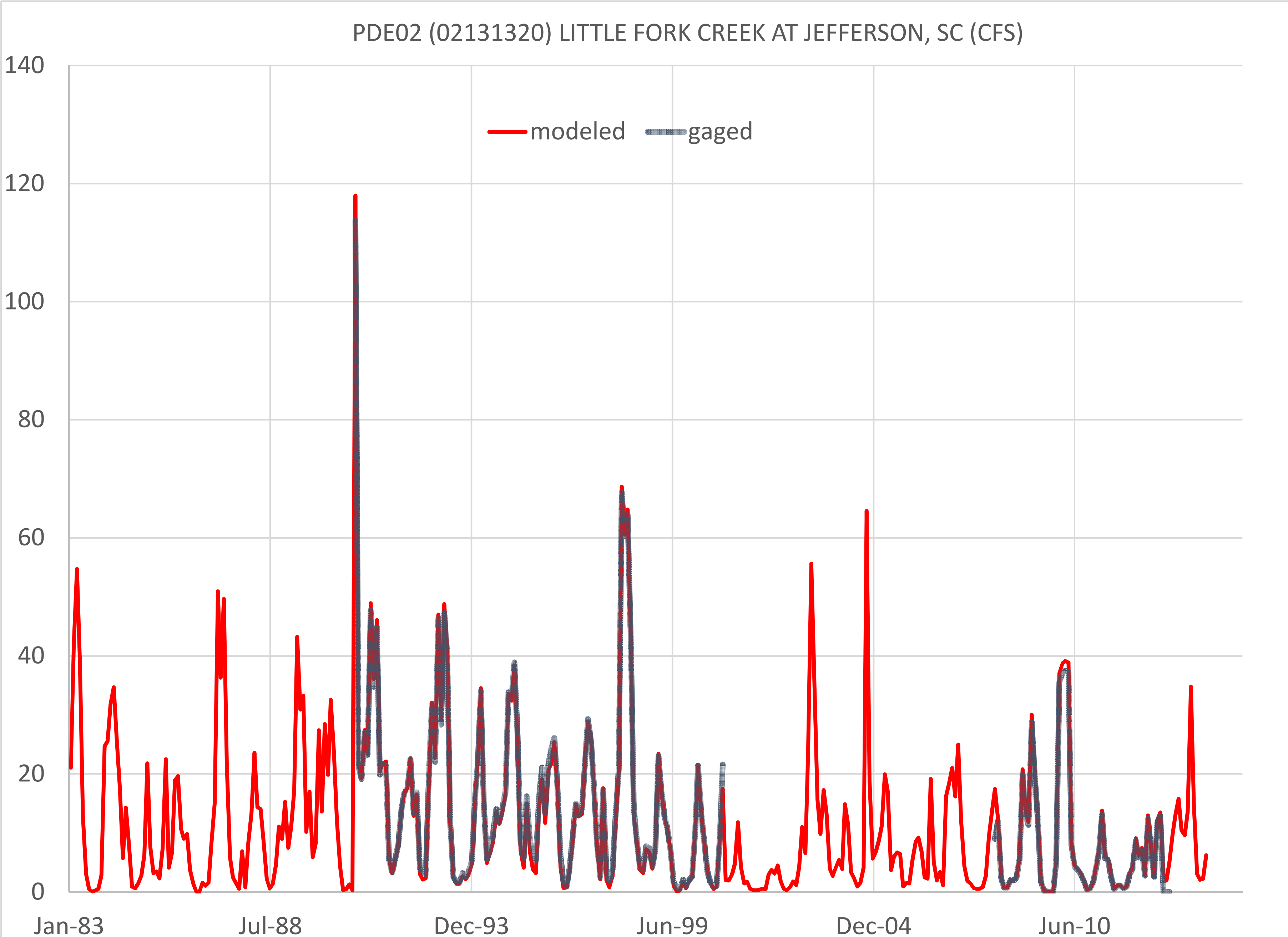

PDE01 (02131309) FORK CREEK AT JEFFERSON, SC (CFS)
modeled
gaged
250
200
150
100
50
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

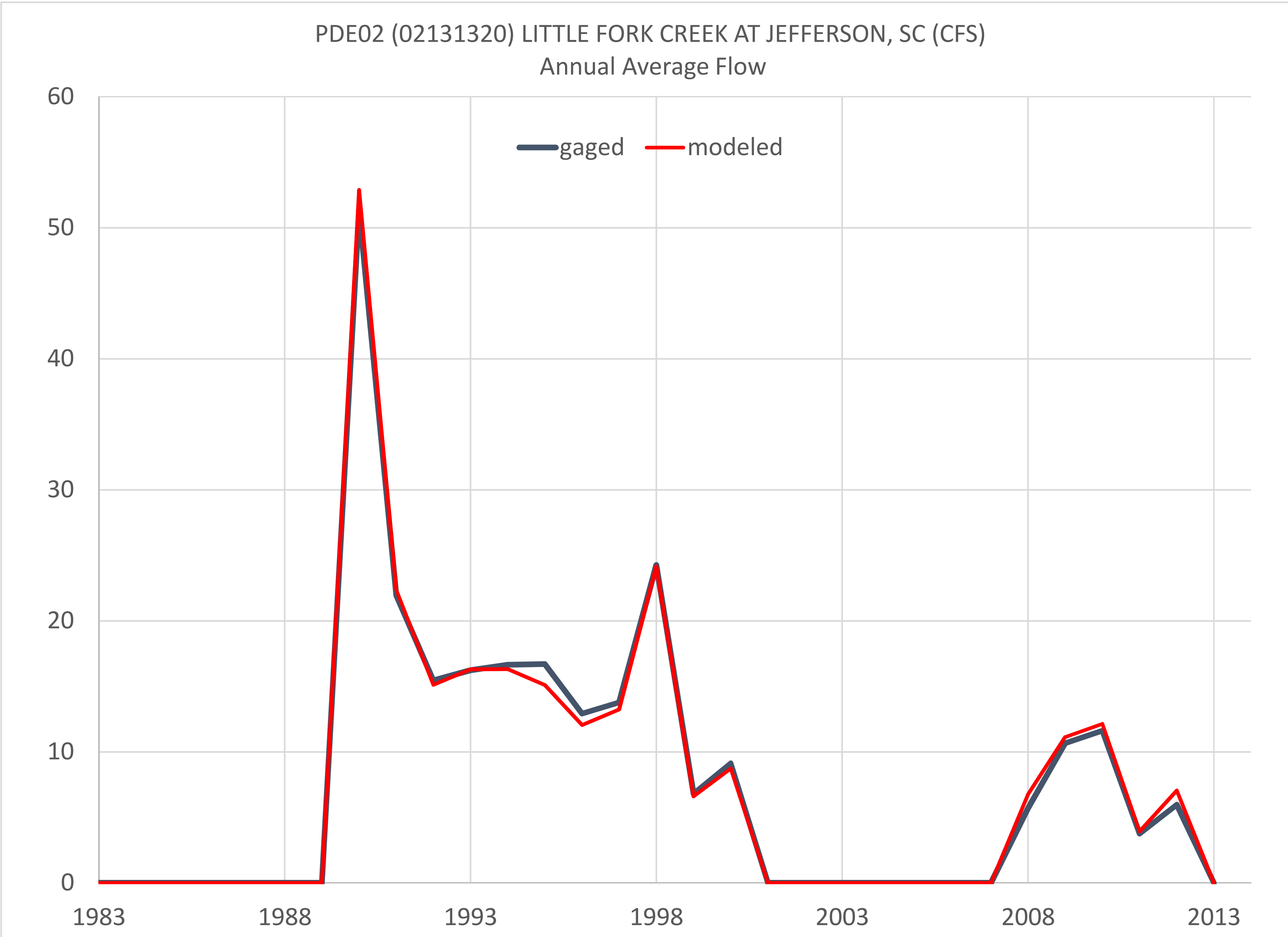

PDE01 (02131309) FORK CREEK AT JEFFERSON, SC (CFS)
Annual Average Flow
gaged
modeled
50
45
40
35
30
25
20
15
10
5
0
1983
1988
1993
1998
2003
2008
2013

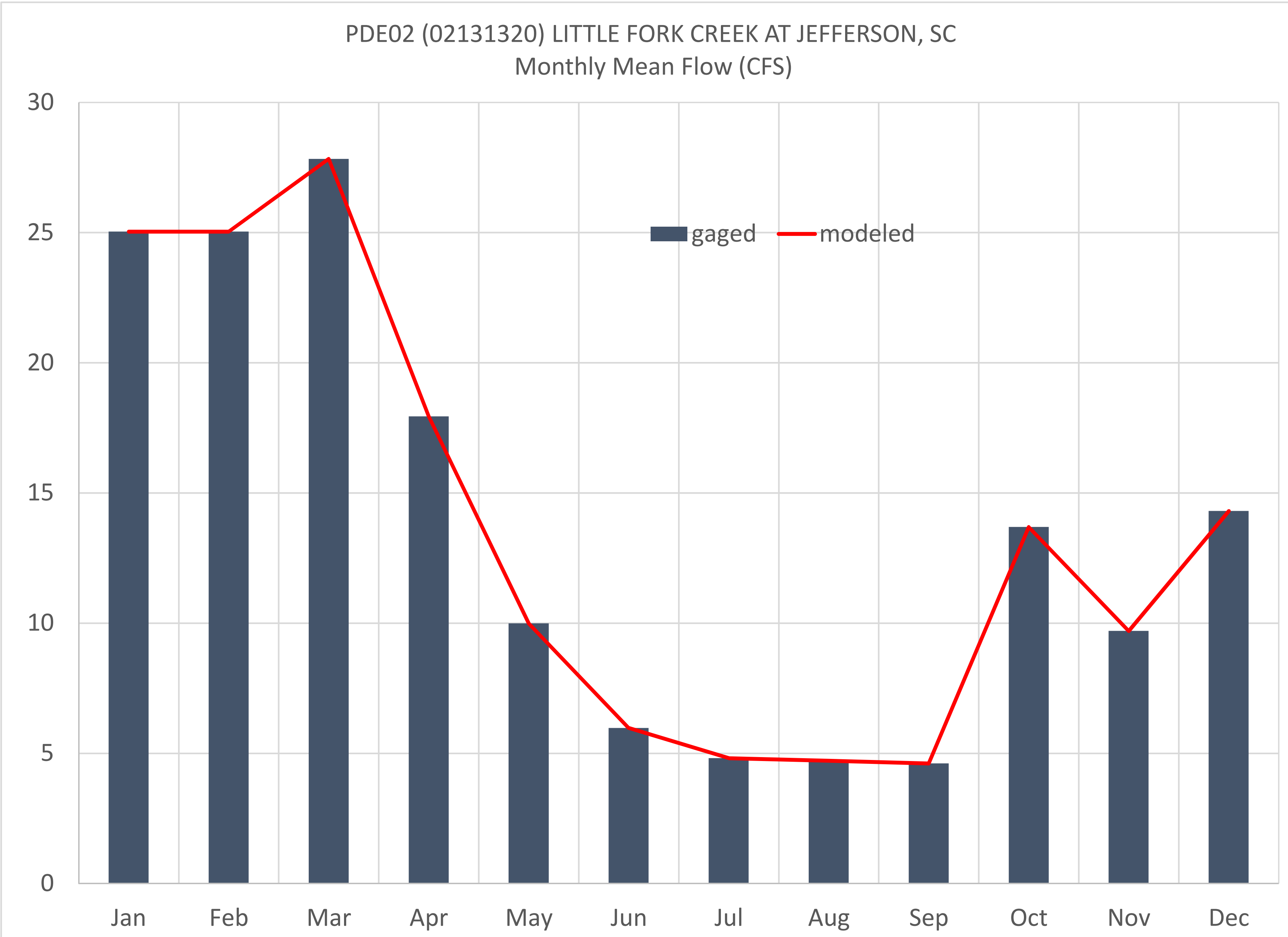

PDE01 (02131309) FORK CREEK AT JEFFERSON, SC
Monthly Mean Flow (CFS)
60
50
40
30
20
10
0
gaged
modeled
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec



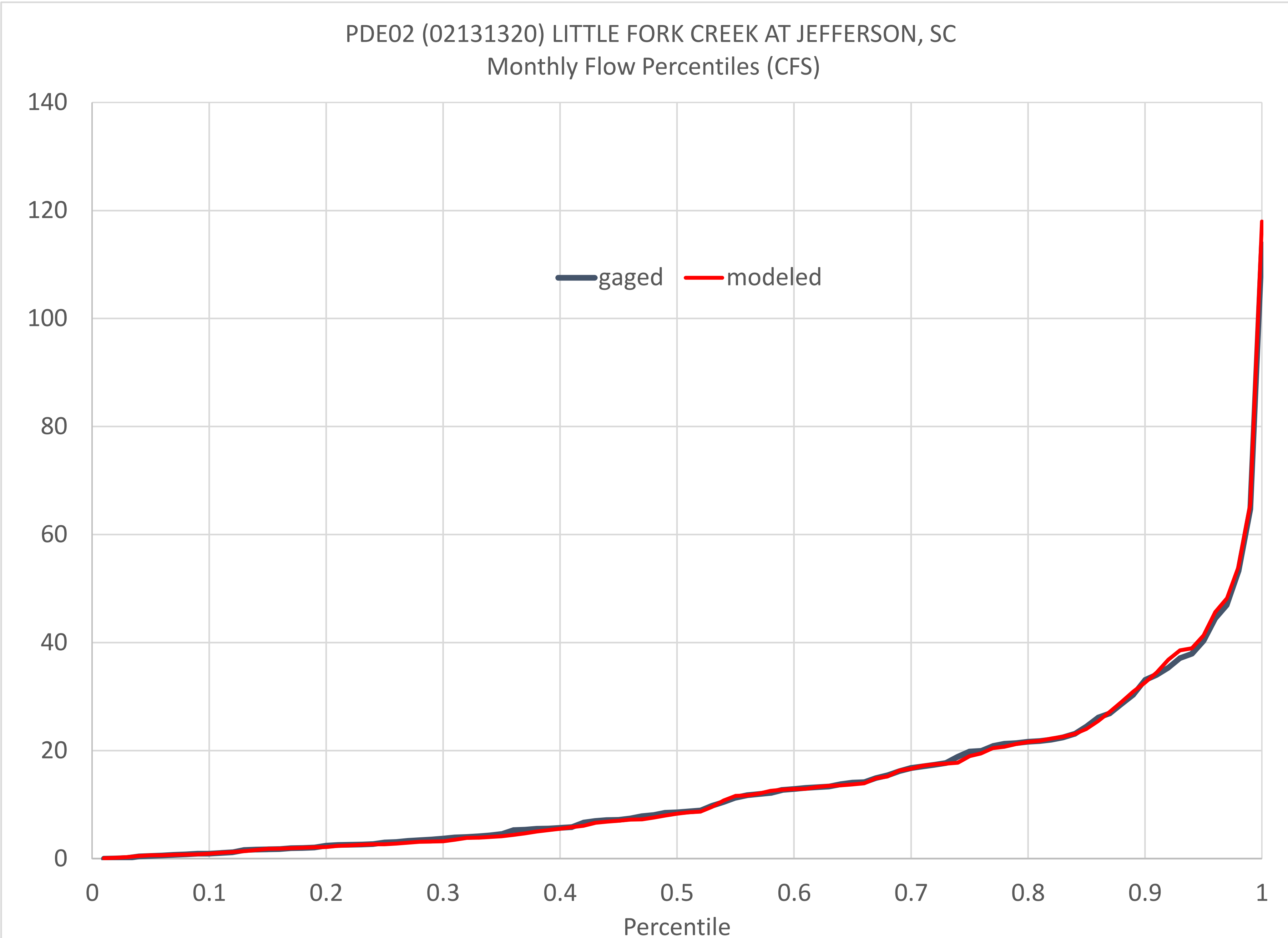
PDE01 (02131309) FORK CREEK AT JEFFERSON, SC
Monthly Flow Percentiles (CFS)
200
180
160
140
120
100
80
60
40
20
0
gaged
modeled
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

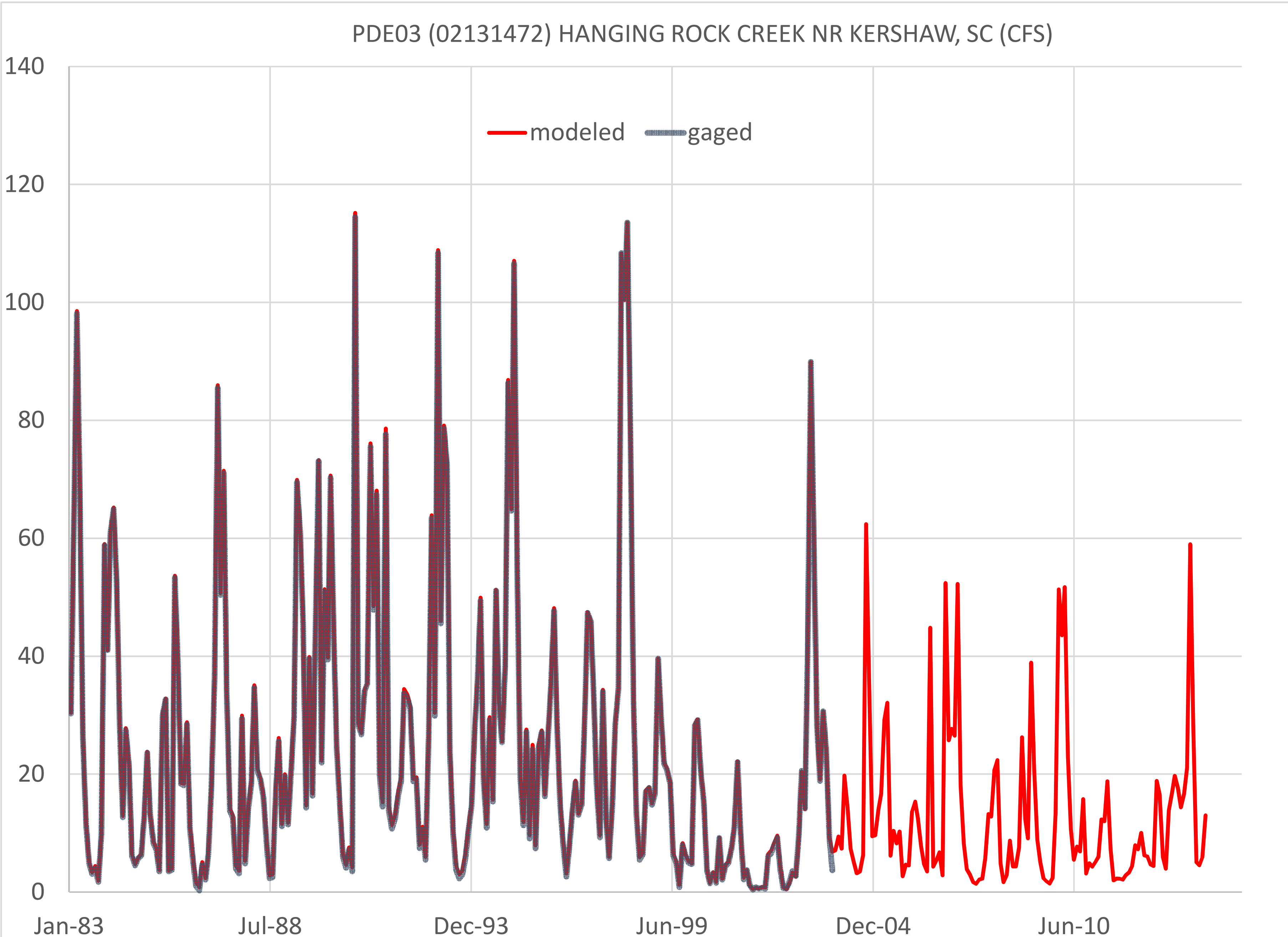

PDE02 (02131320) LITTLE FORK CREEK AT JEFFERSON, SC (CFS)
modeled
gaged
140
120
100
80
60
40
20
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

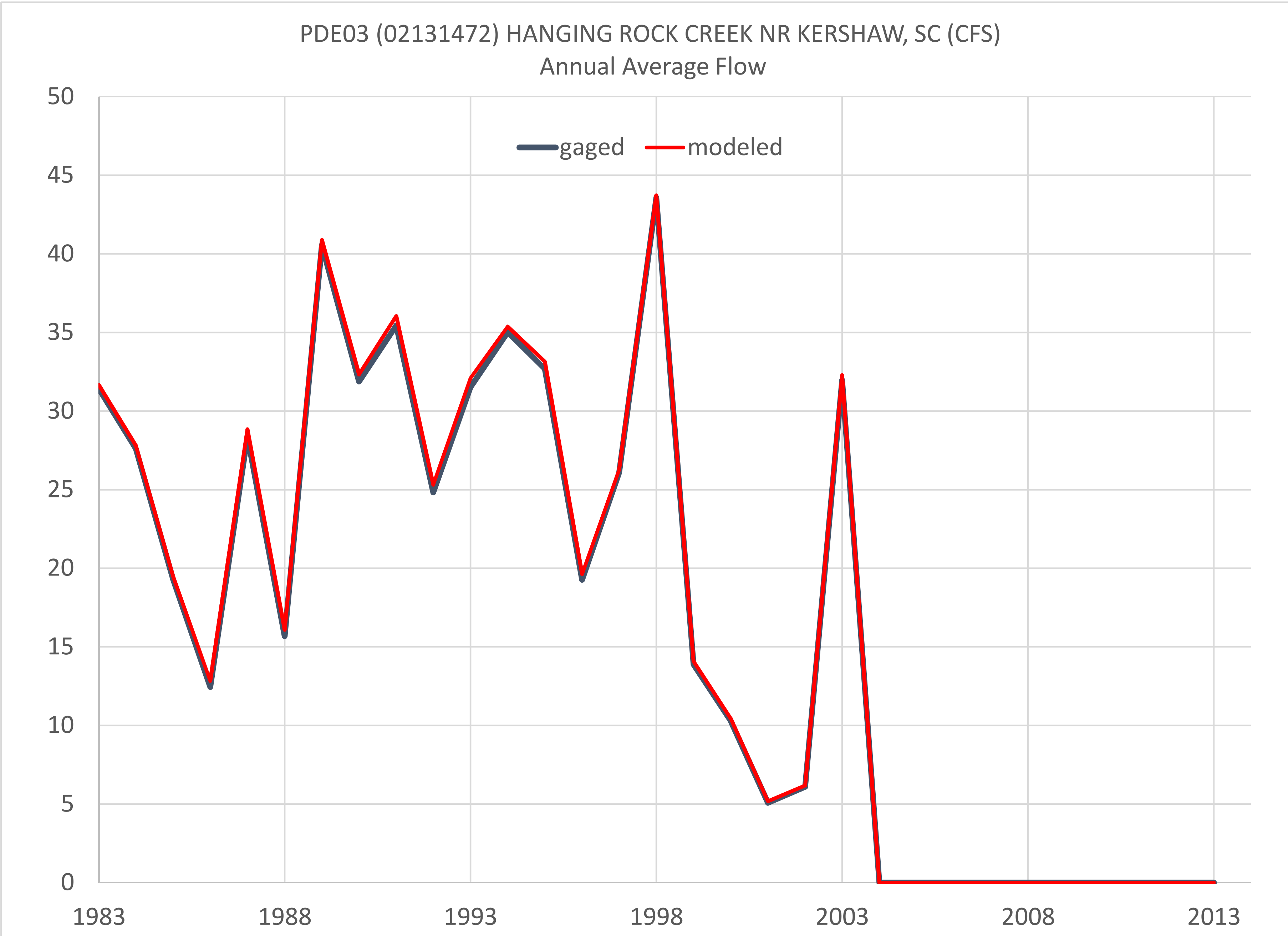

PDE02 (02131320) LITTLE FORK CREEK AT JEFFERSON, SC (CFS)
Annual Average Flow
gaged
modeled
0
10
20
30
40
50
60
1983
1988
1993
1998
2003
2008
2013

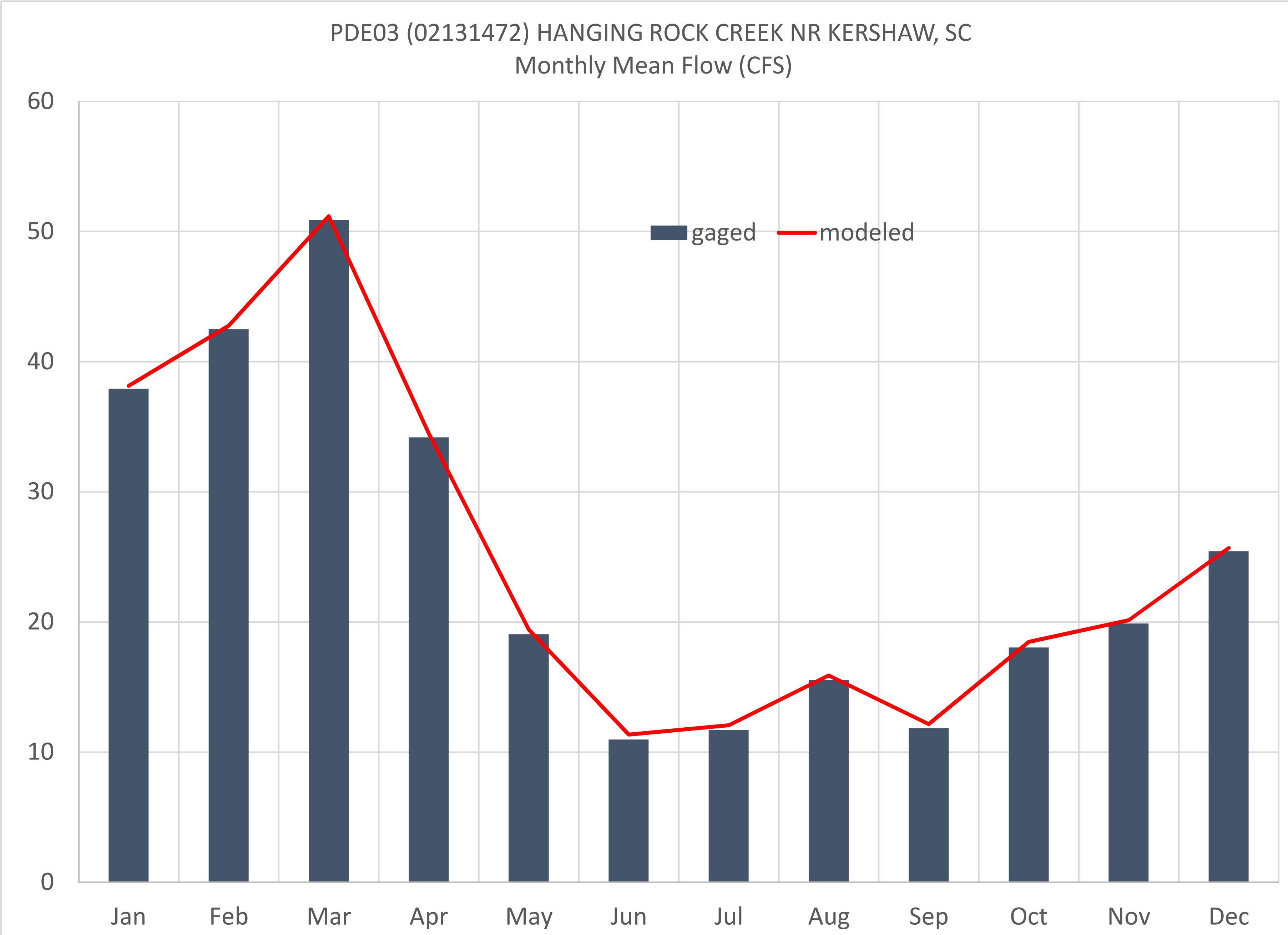


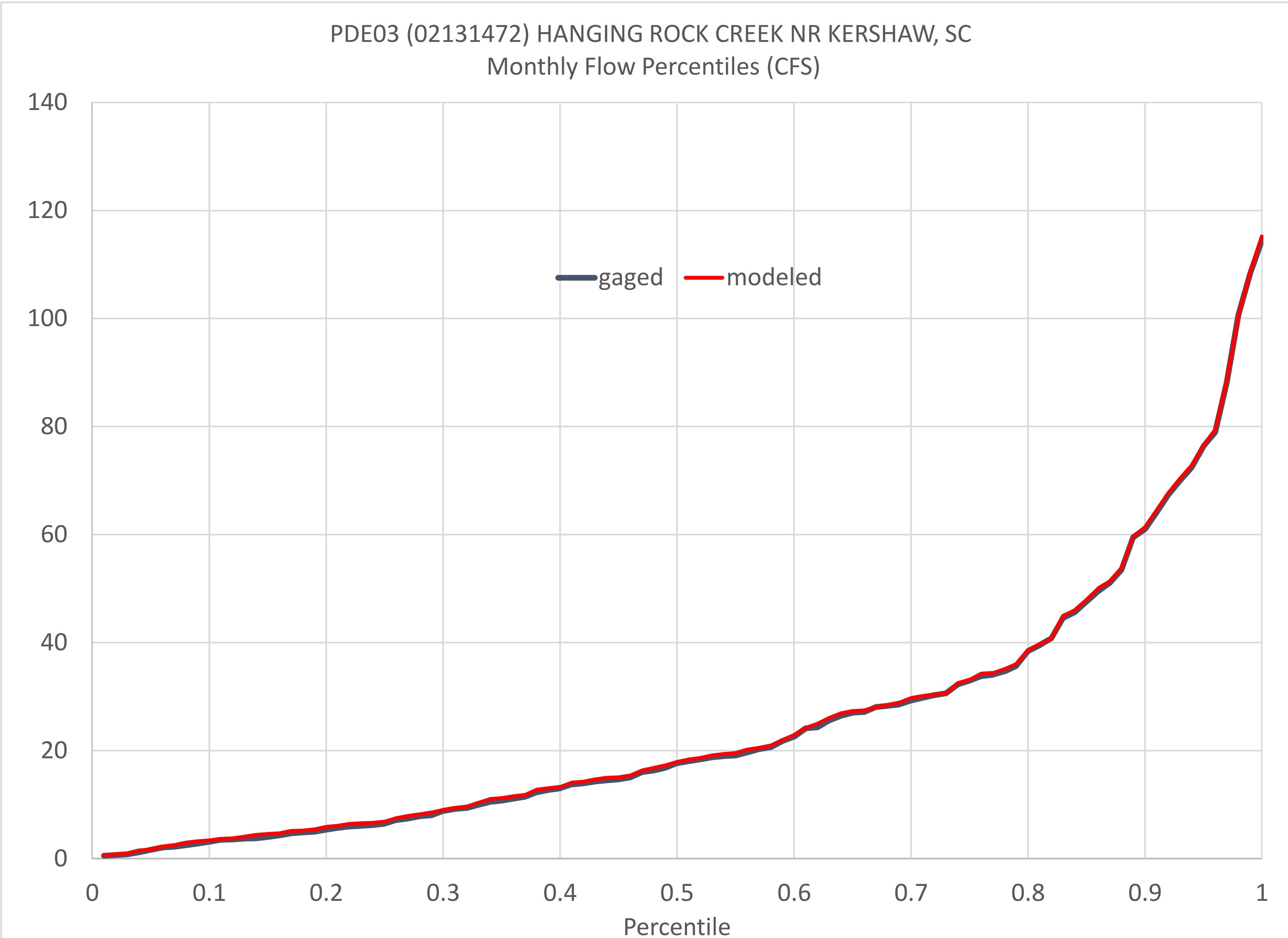
PDE02 (02131320) LITTLE FORK CREEK AT JEFFERSON, SC
Monthly Mean Flow (CFS)
gaged
modeled
30
25
20
15
10
5
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


PDE02 (02131320) LITTLE FORK CREEK AT JEFFERSON, SC
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

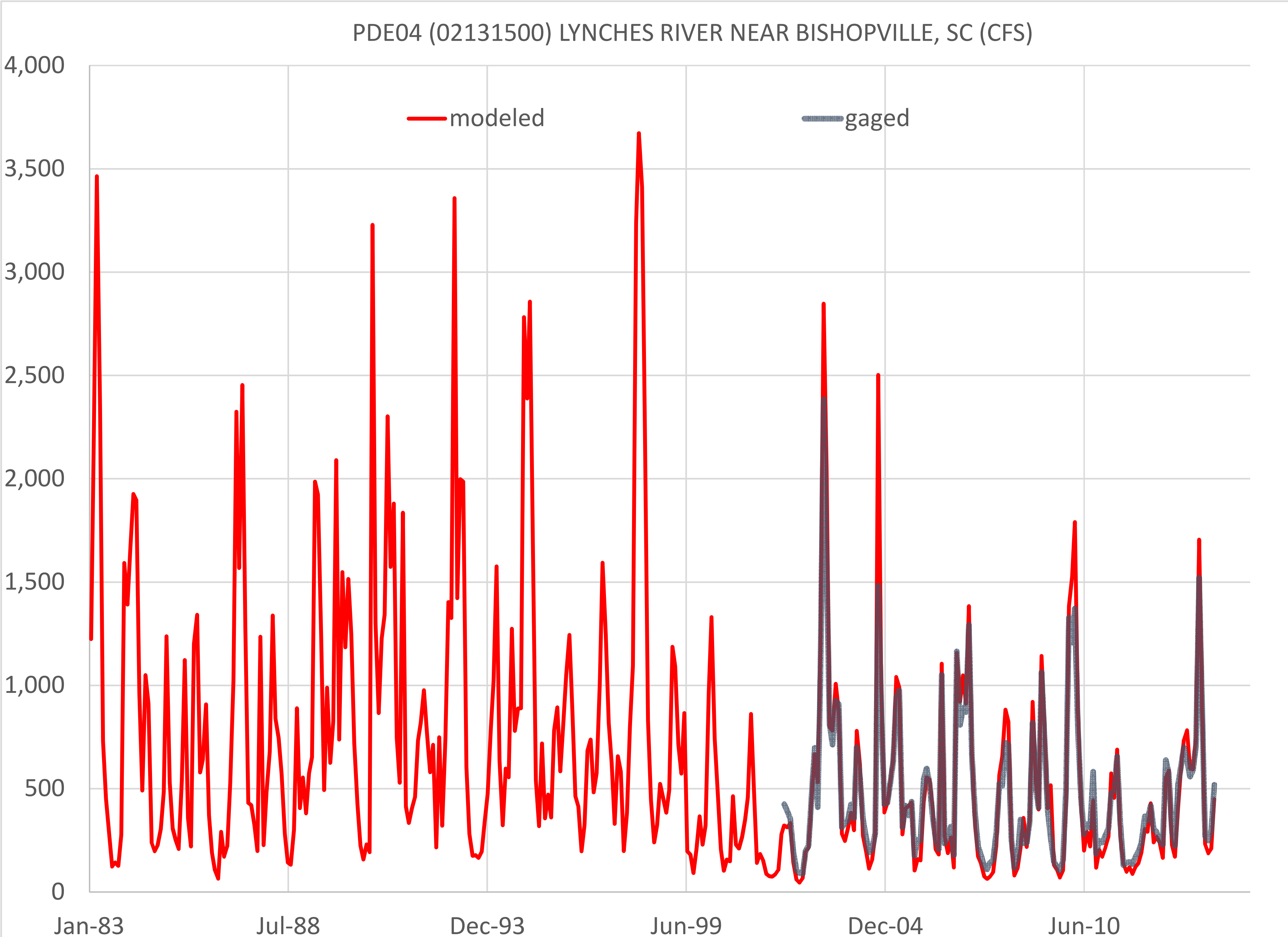

PDE03 (02131472) HANGING ROCK CREEK NR KERSHAW, SC (CFS)
modeled
gaged
140
120
100
80
60
40
20
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10


PDE03 (02131472) HANGING ROCK CREEK NR KERSHAW, SC (CFS)
Annual Average Flow
gaged
modeled
0
5
10
15
20
25
30
35
40
45
50
1983
1988
1993
1998
2003
2008
2013

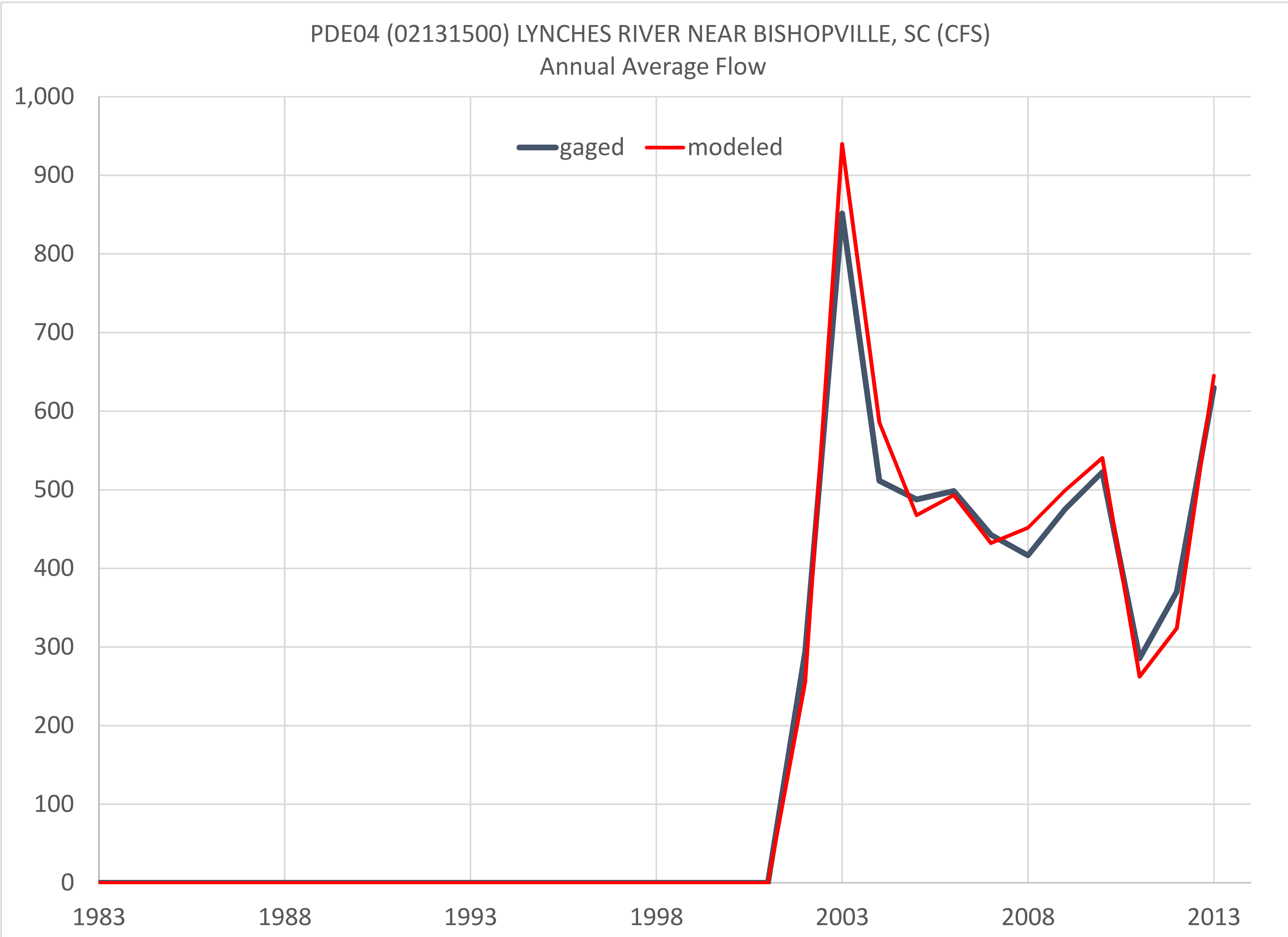

PDE03 (02131472) HANGING ROCK CREEK NR KERSHAW, SC
Monthly Mean Flow (CFS)
gaged
modeled
60
50
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

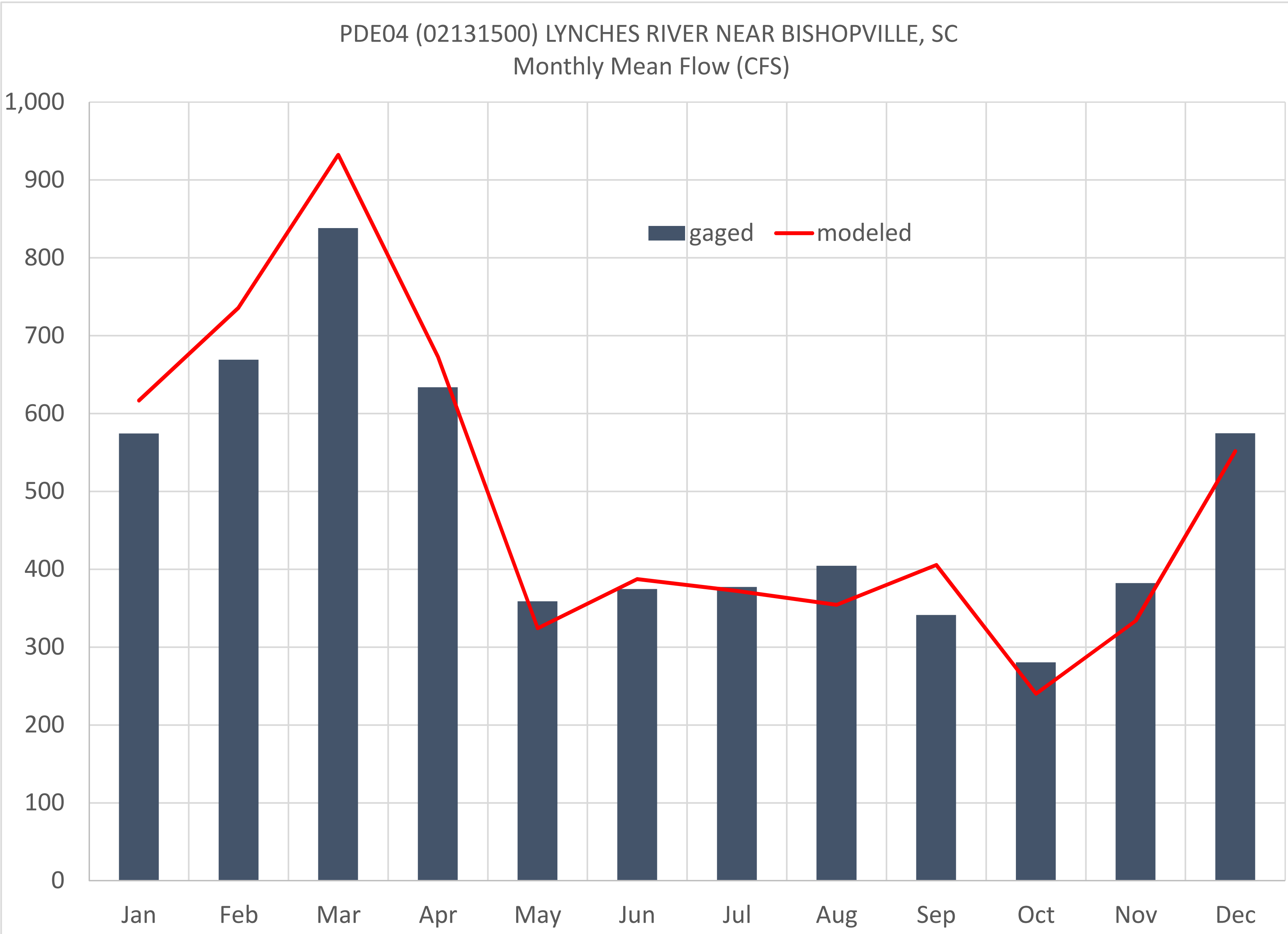


PDE03 (02131472) HANGING ROCK CREEK NR KERSHAW, SC
Monthly Flow Percentiles (CFS)
140
120
100
80
60
40
20
0
gaged
modeled
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

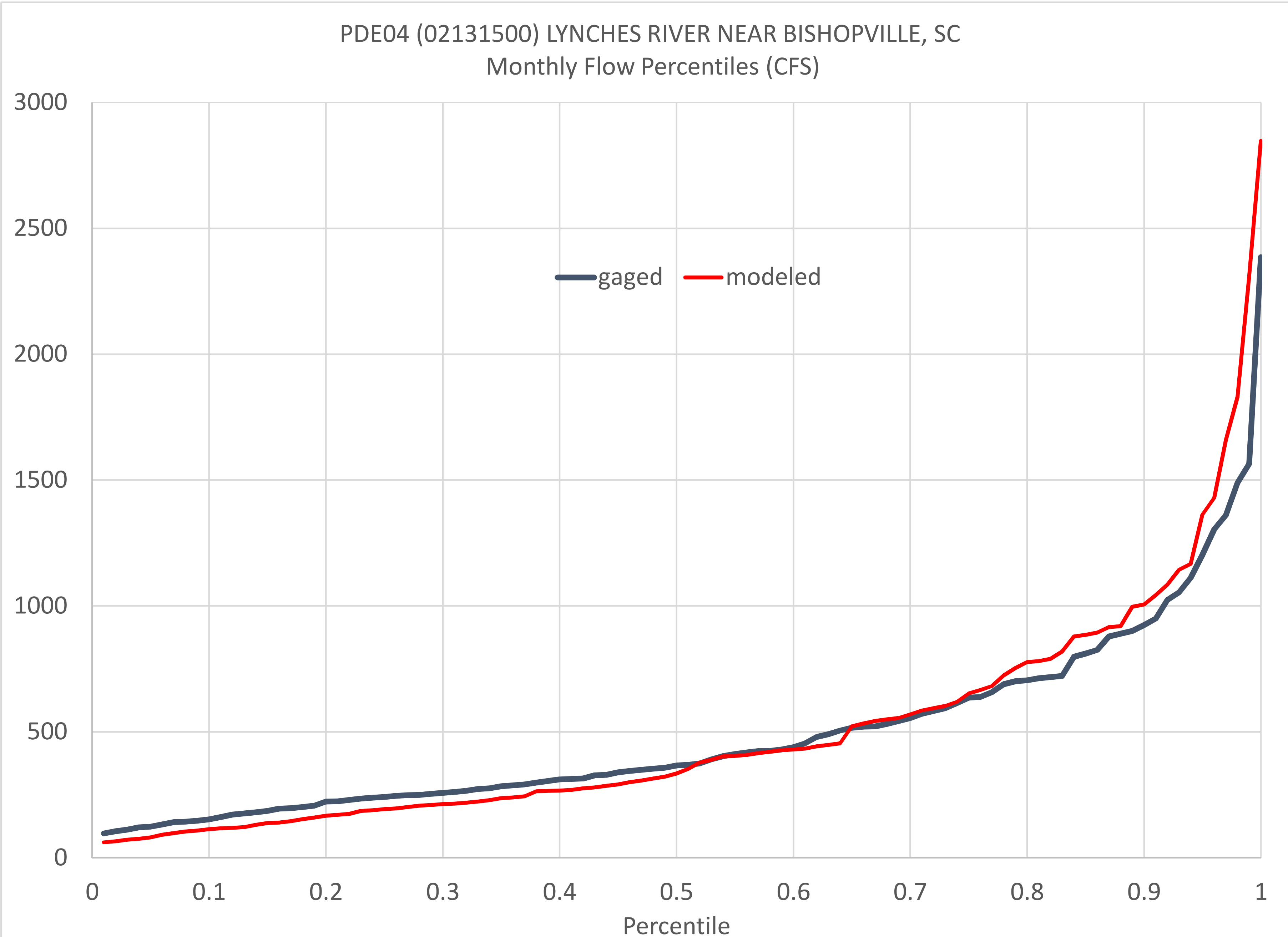


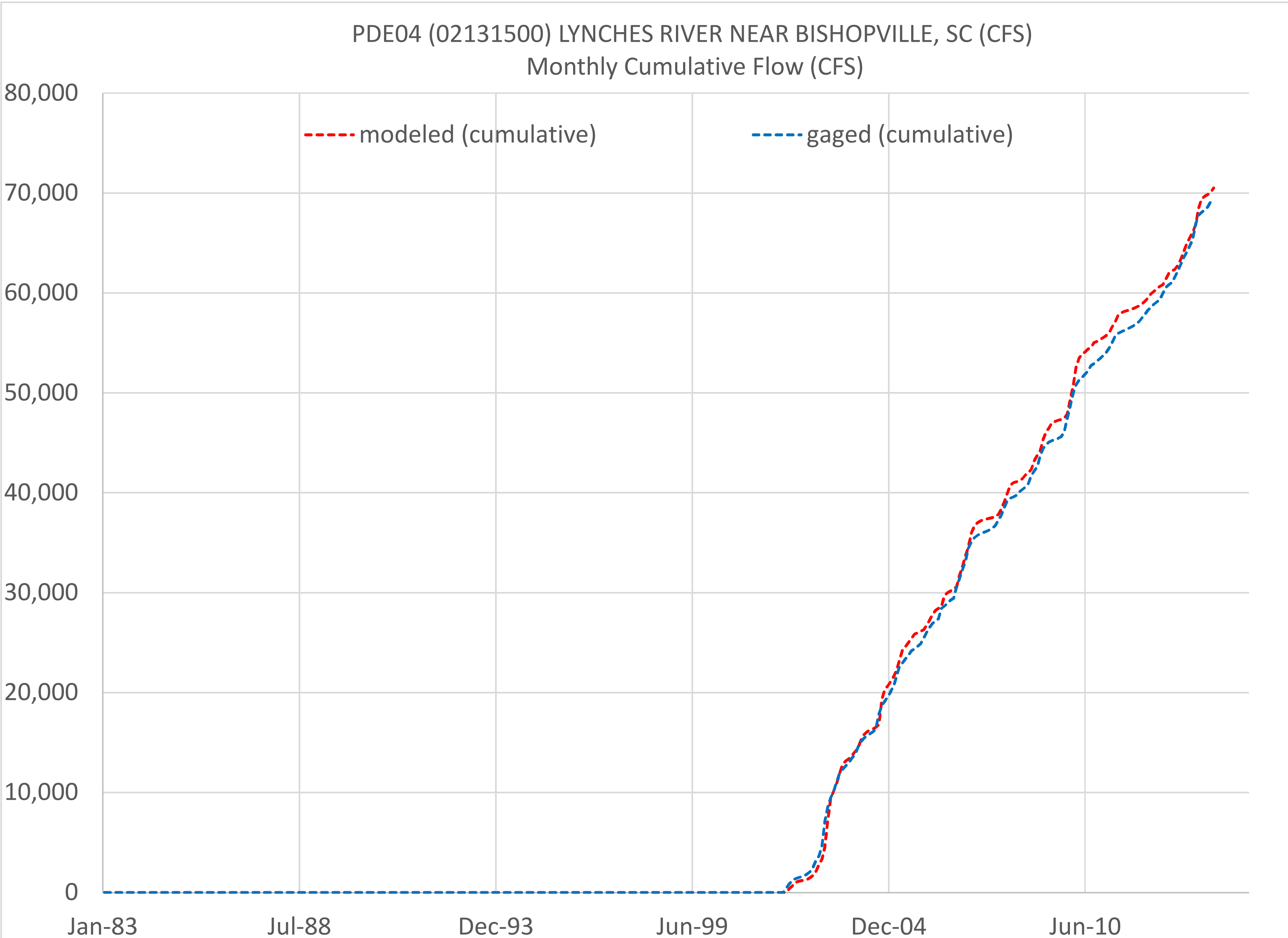
PDE04 (02131500) LYNCHES RIVER NEAR BISHOPVILLE, SC (CFS)
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
modeled
gaged
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

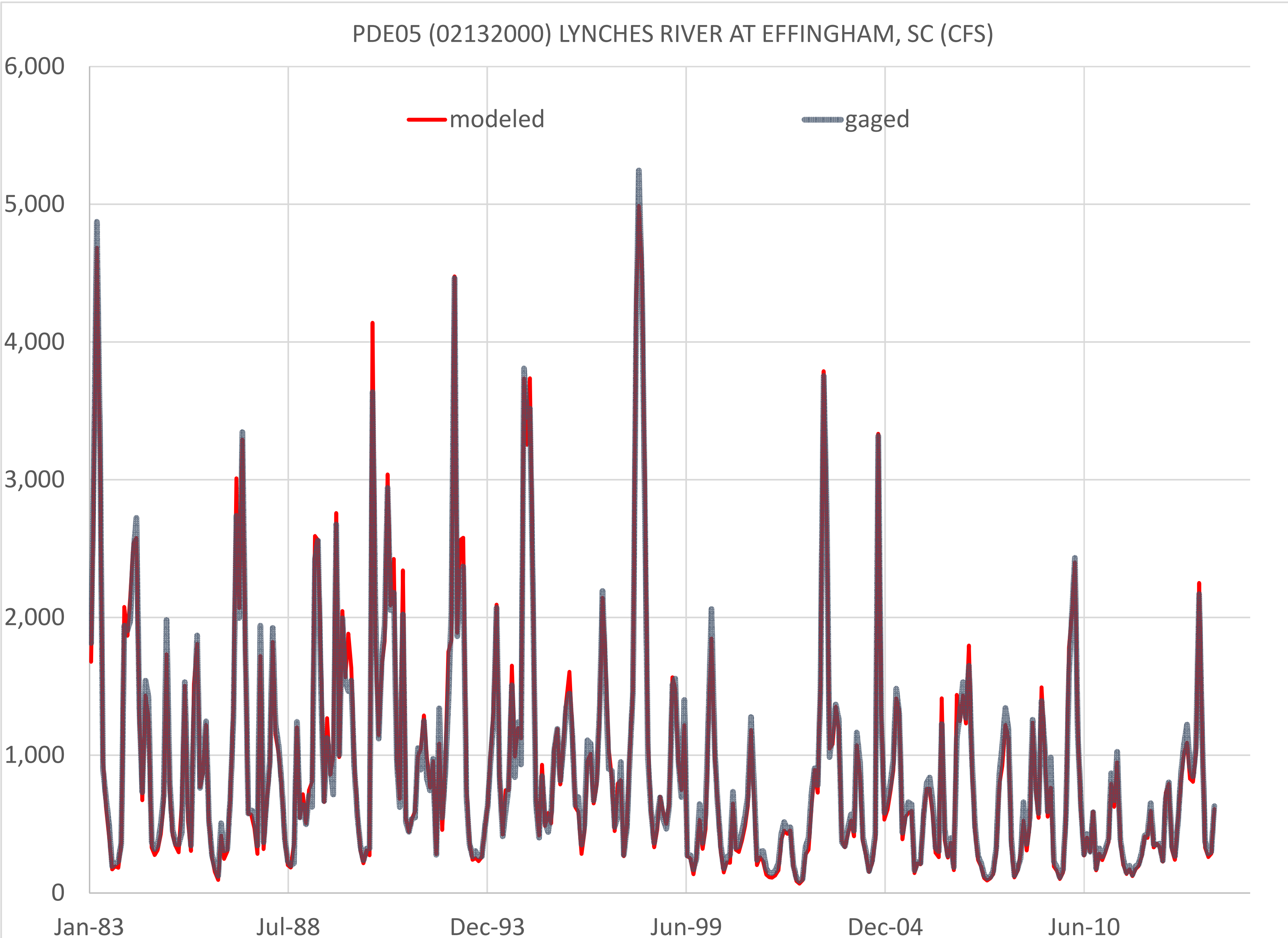

PDE04 (02131500) LYNCHES RIVER NEAR BISHOPVILLE, SC (CFS)
Annual Average Flow
gaged
modeled
1,000
900
800
700
600
500
400
300
200
100
0
1983
1988
1993
1998
2003
2008
2013

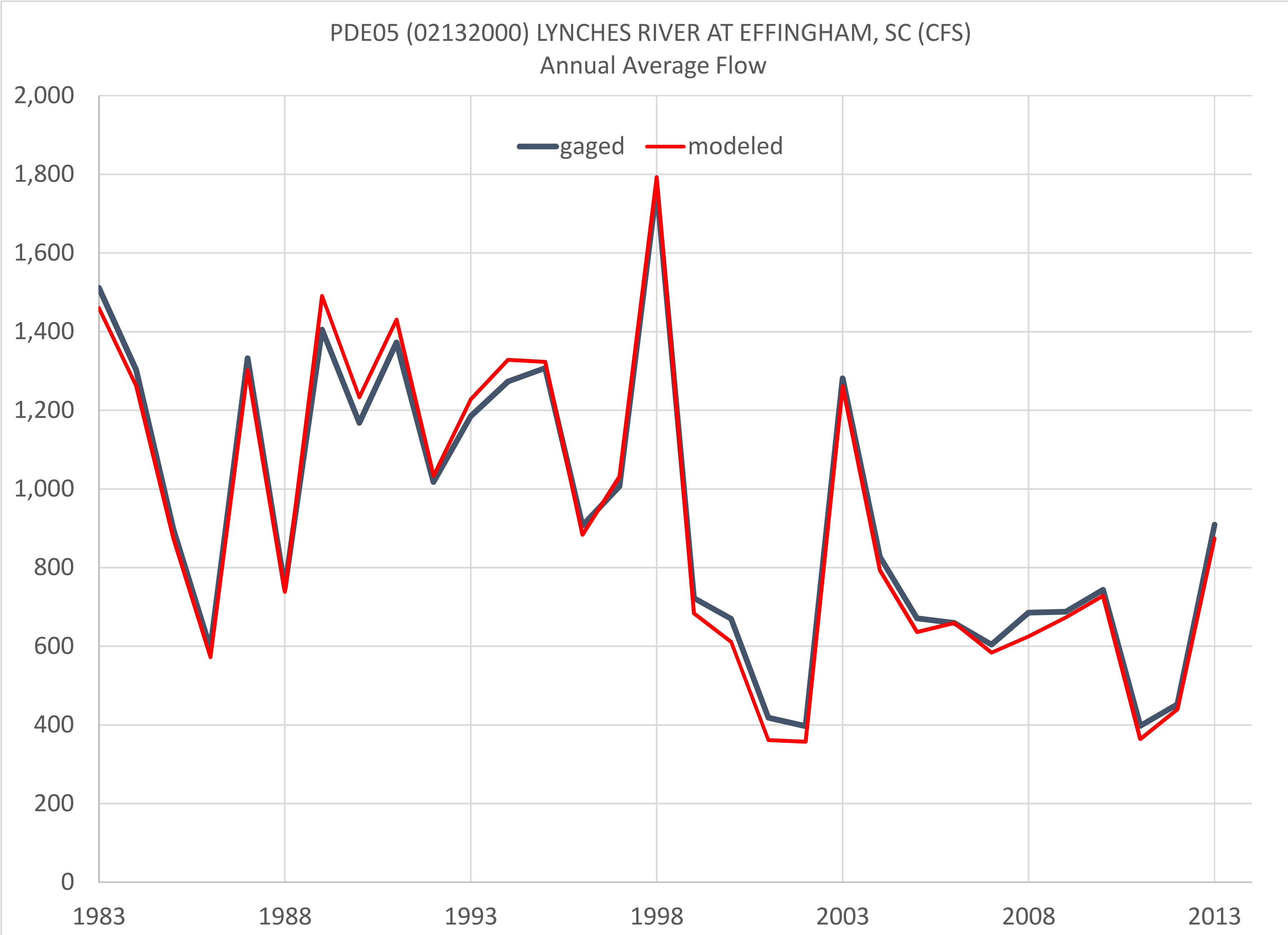


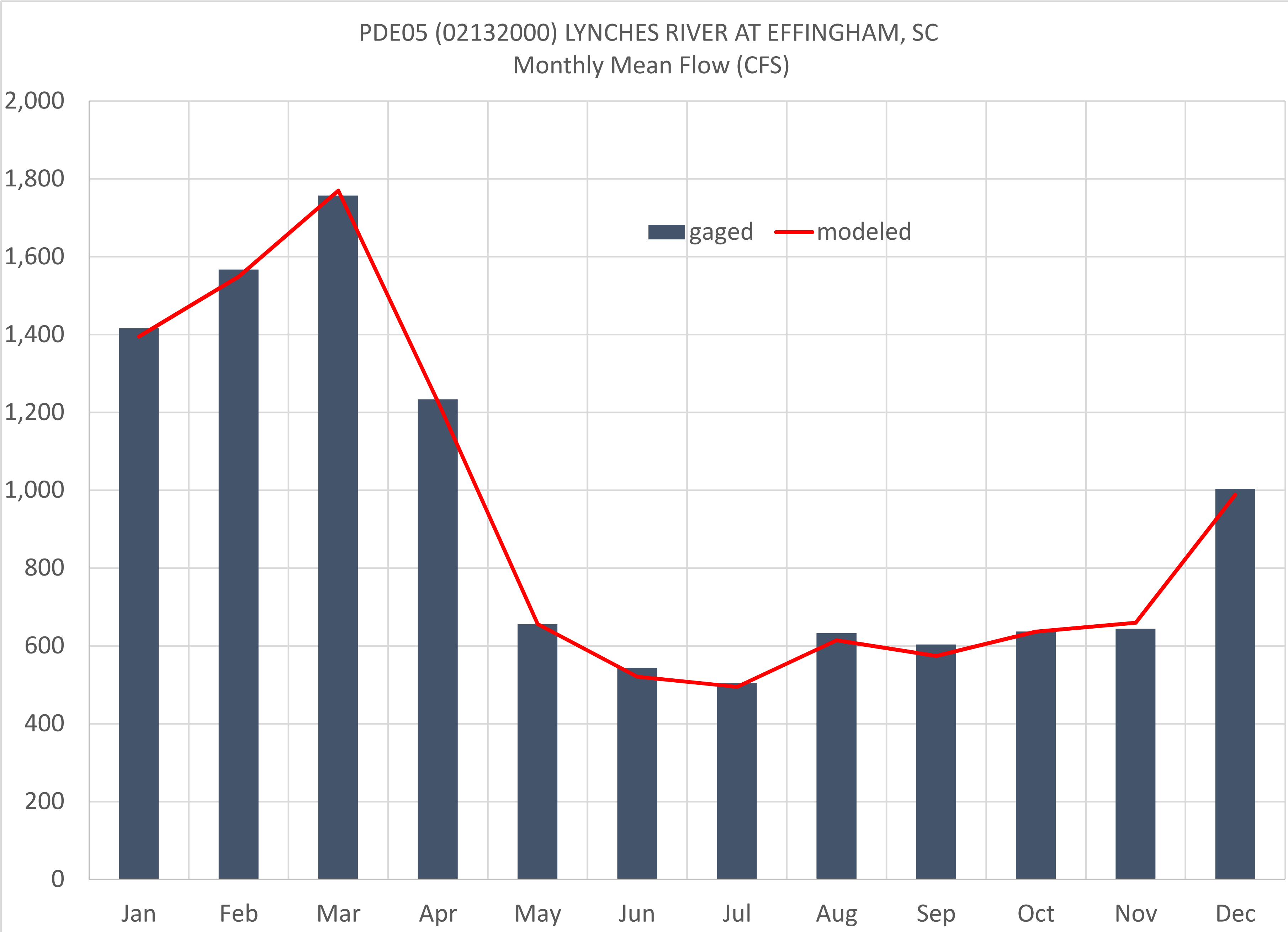
PDE04 (02131500) LYNCHES RIVER NEAR BISHOPVILLE, SC
Monthly Mean Flow (CFS)
gaged
modeled
1,000
900
800
700
600
500
400
300
200
100
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


PDE04 (02131500) LYNCHES RIVER NEAR BISHOPVILLE, SC
Monthly Flow Percentiles (CFS)
gaged
modeled
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

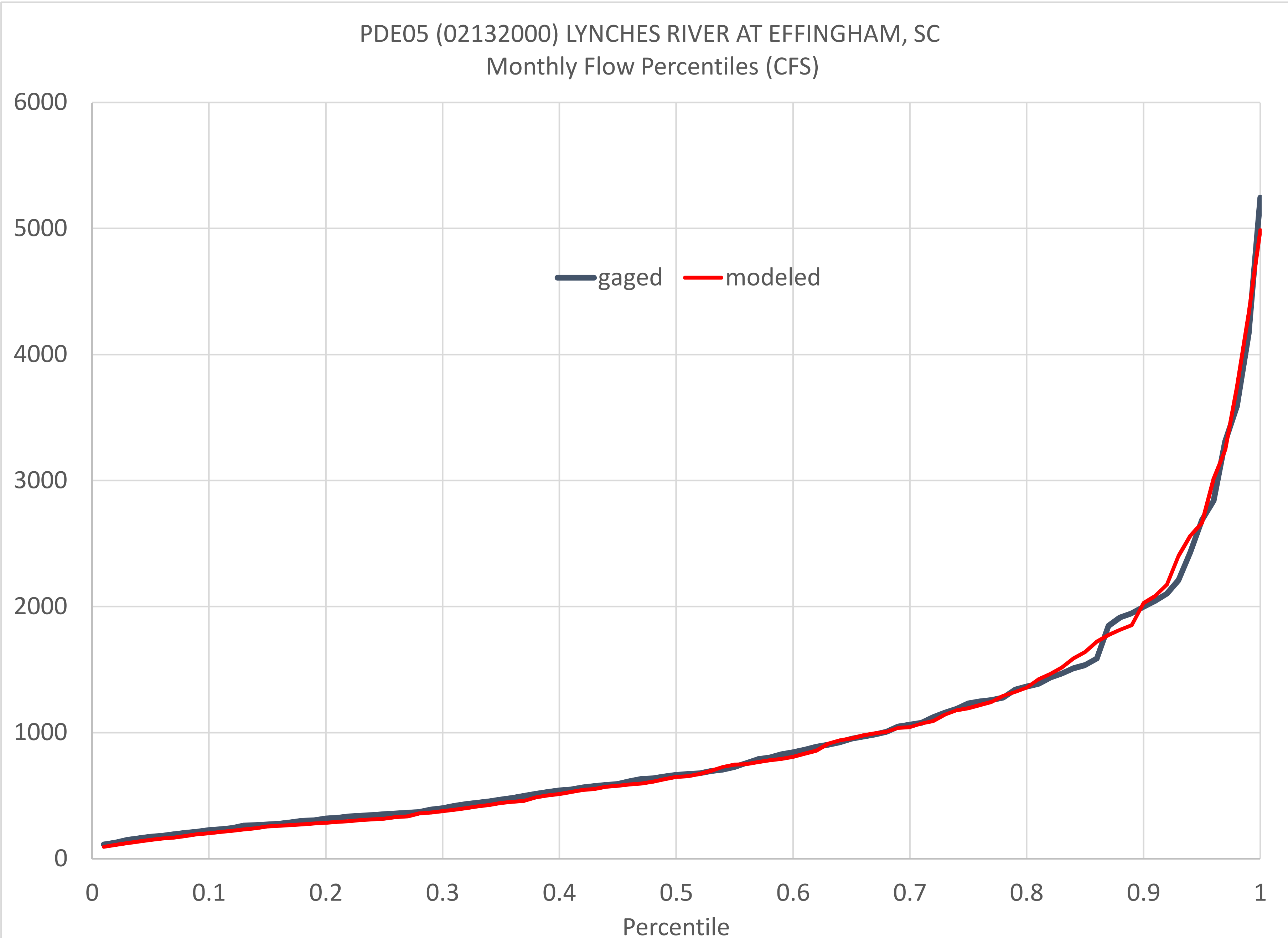

PDE04 (02131500) LYNCHES RIVER NEAR BISHOPVILLE, SC (CFS)
Monthly Cumulative Flow (CFS)
modeled (cumulative)
gaged (cumulative)
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

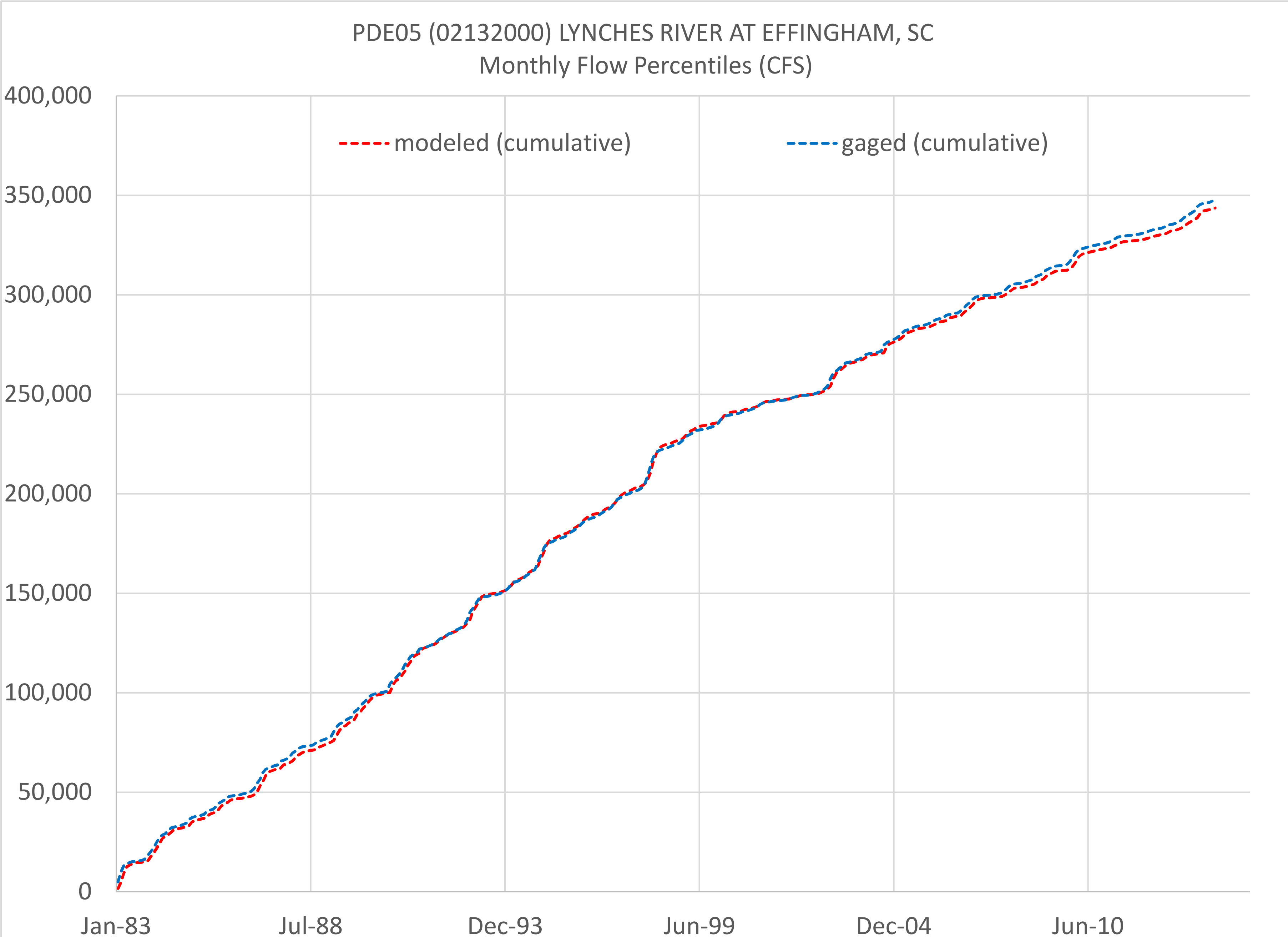

PDE05 (02132000) LYNCHES RIVER AT EFFINGHAM, SC (CFS)
modeled
gaged
6,000
5,000
4,000
3,000
2,000
1,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

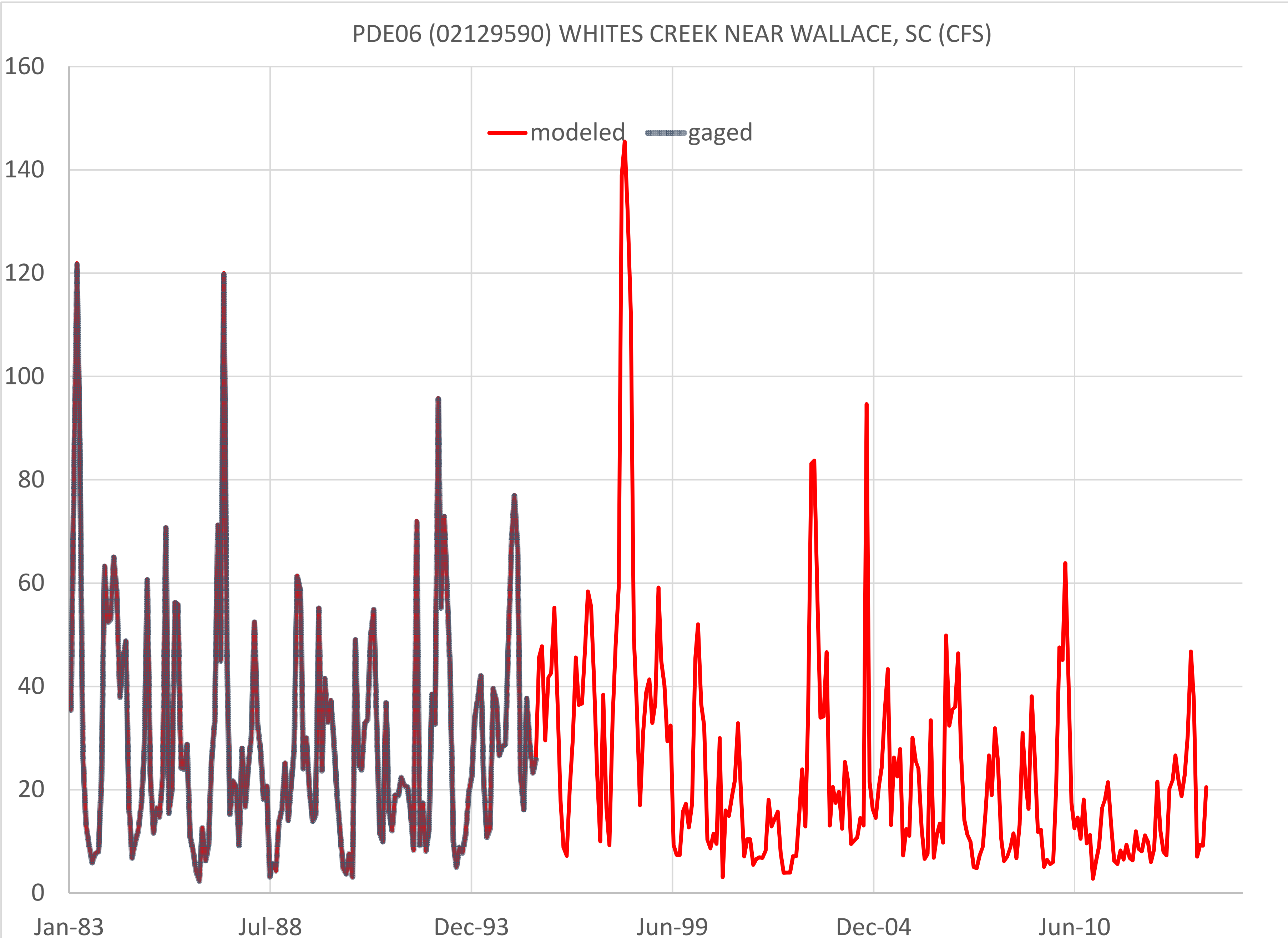

PDE05 (02132000) LYNCHES RIVER AT EFFINGHAM, SC (CFS)
Annual Average Flow
gaged
modeled
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
1983
1988
1993
1998
2003
2008
2013

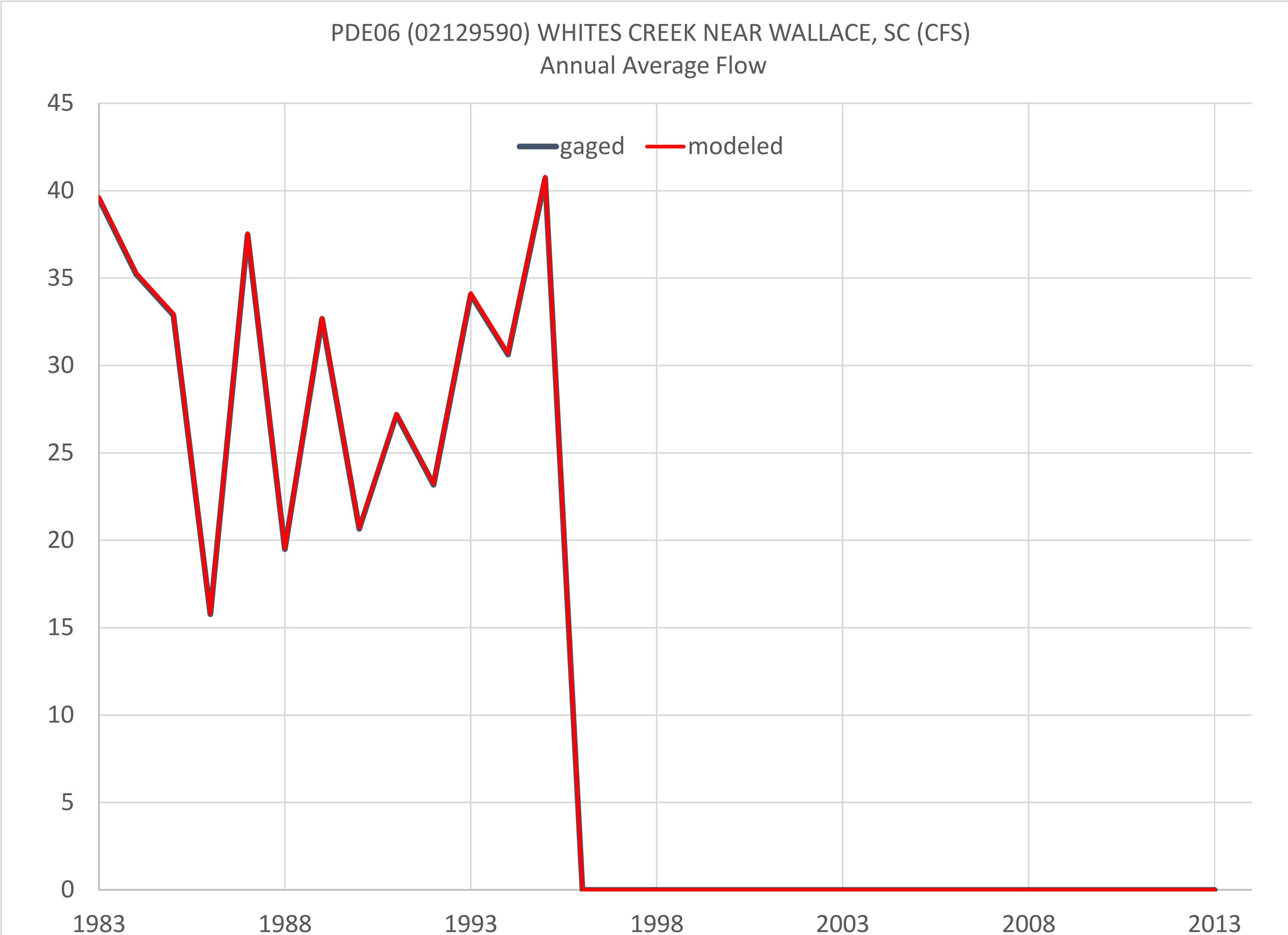


PDE05 (02132000) LYNCHES RIVER AT EFFINGHAM, SC
Monthly Mean Flow (CFS)
gaged
modeled
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

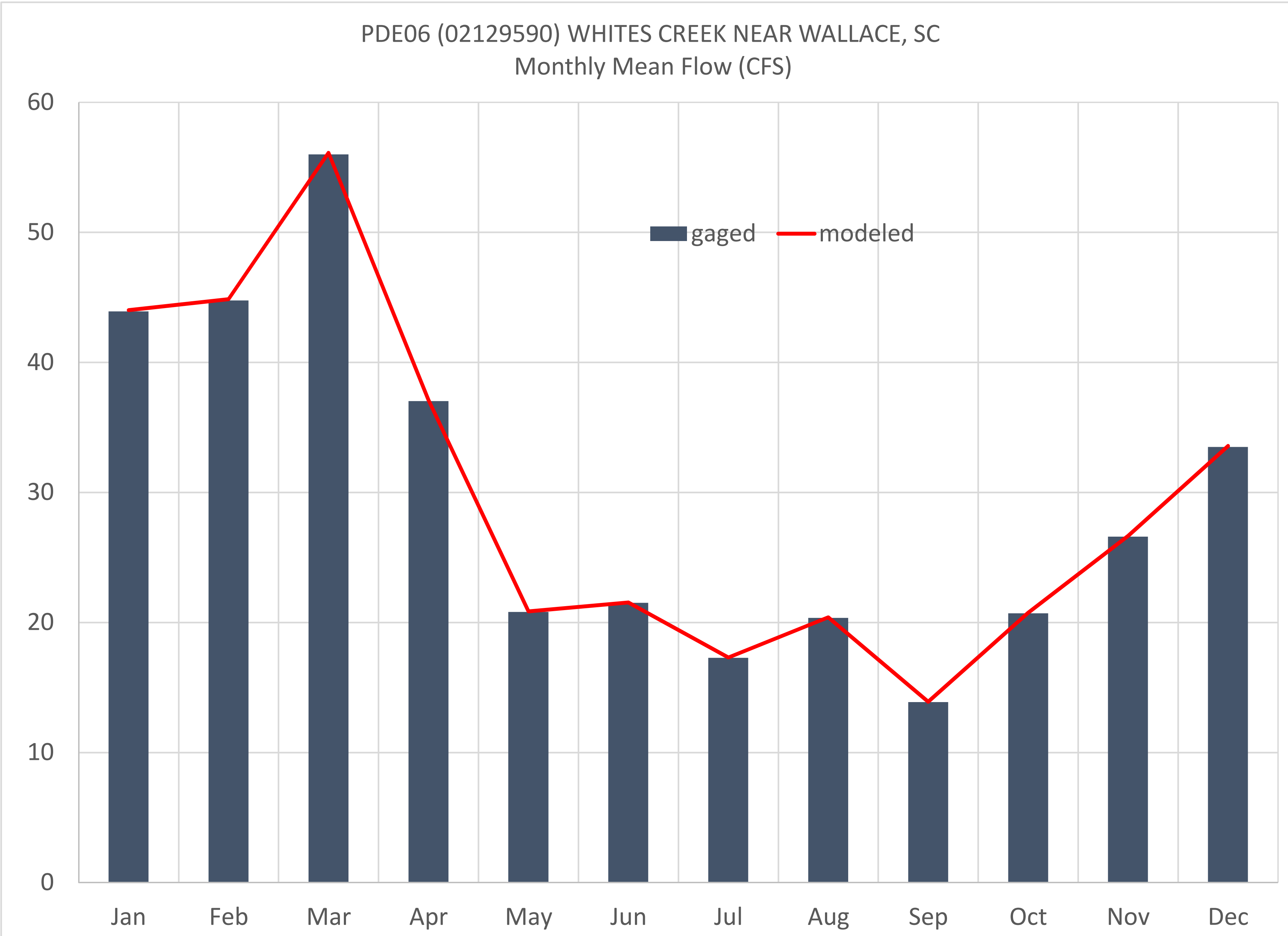

PDE05 (02132000) LYNCHES RIVER AT EFFINGHAM, SC
Monthly Flow Percentiles (CFS)
gaged
modeled
6000
5000
4000
3000
2000
1000
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

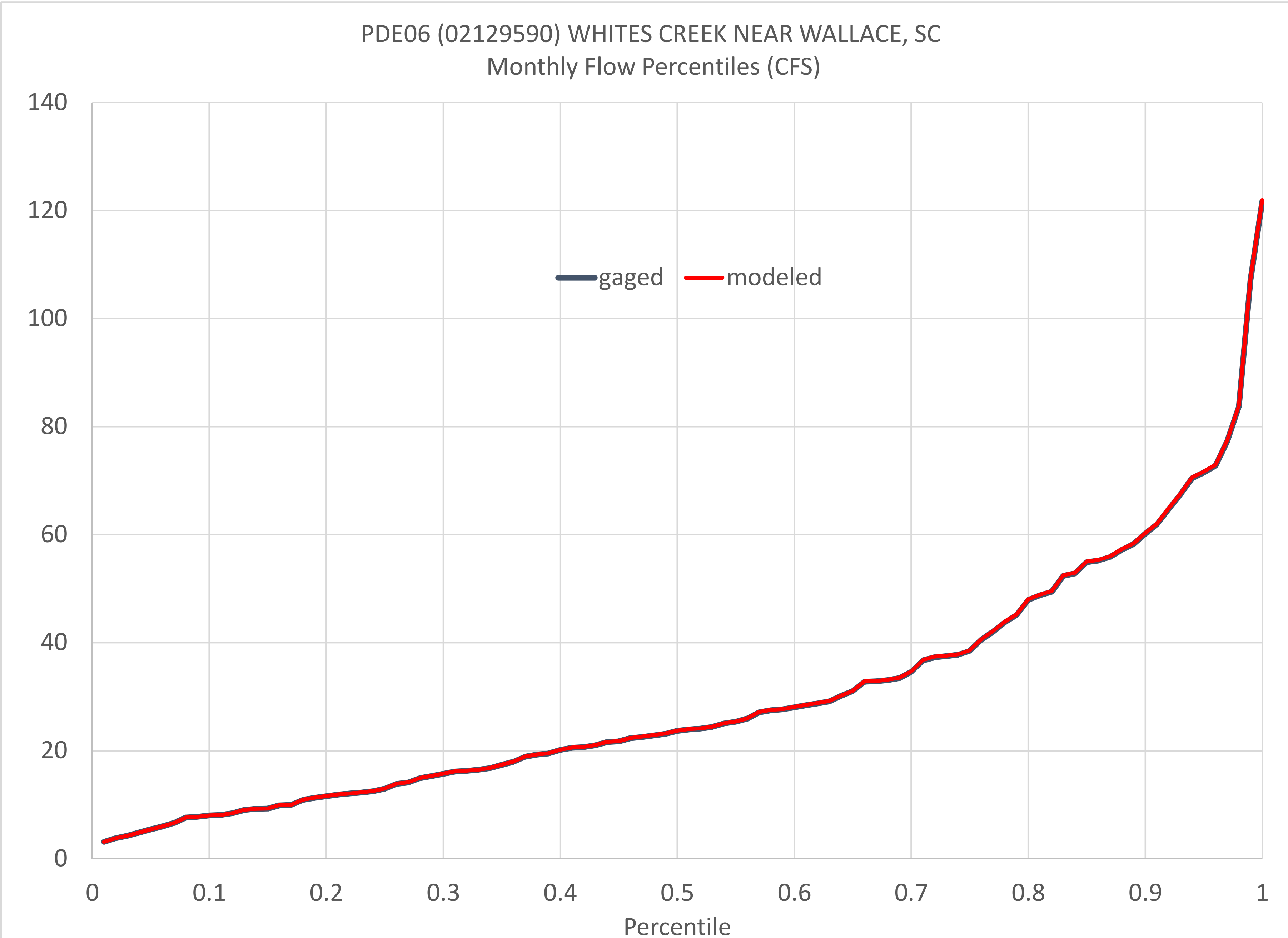

PDE05 (02132000) LYNCHES RIVER AT EFFINGHAM, SC
Monthly Flow Percentiles (CFS)
modeled (cumulative)
gaged (cumulative)
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

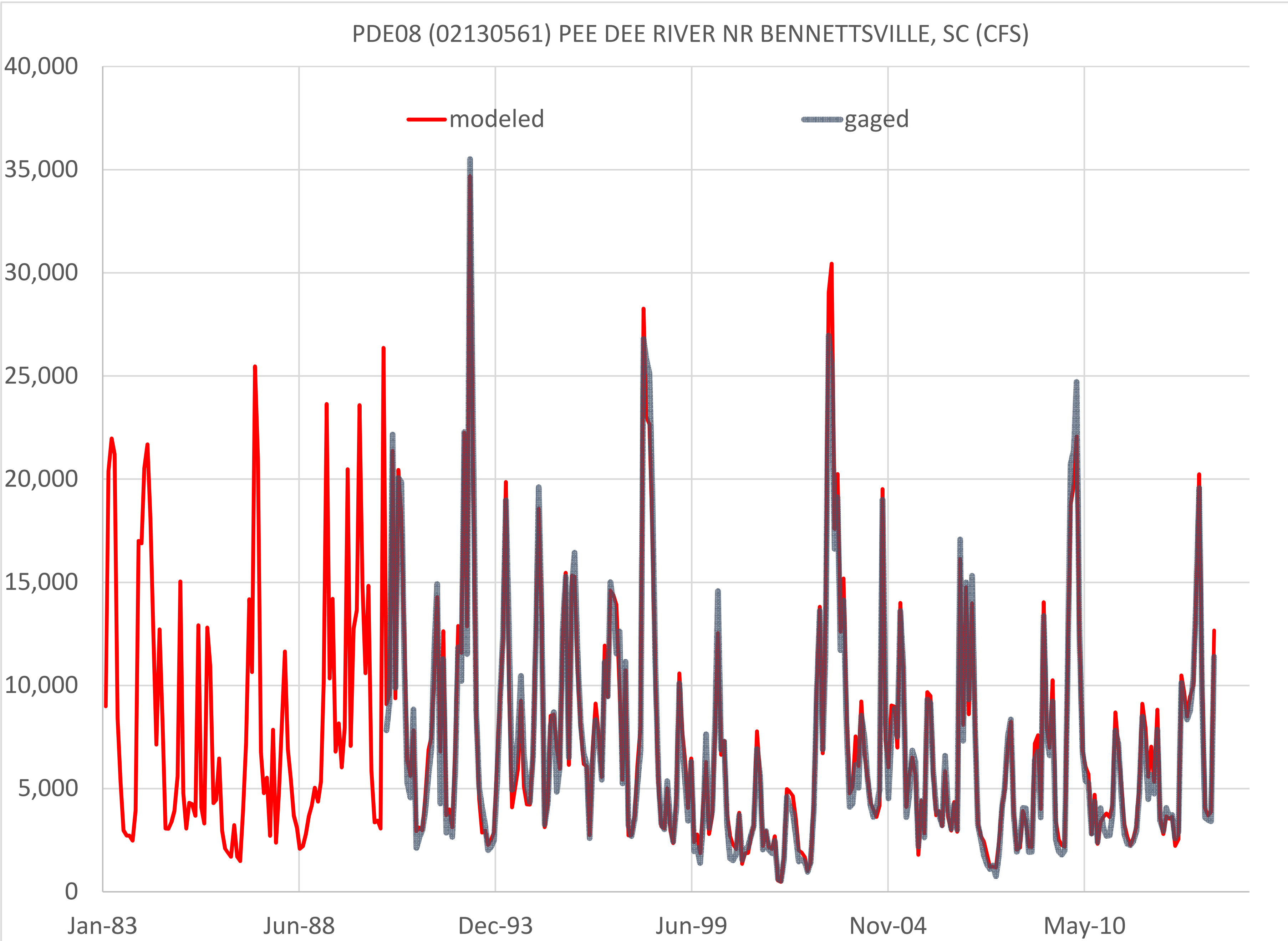

PDE06 (02129590) WHITES CREEK NEAR WALLACE, SC (CFS)
modeled
gaged
160
140
120
100
80
60
40
20
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10



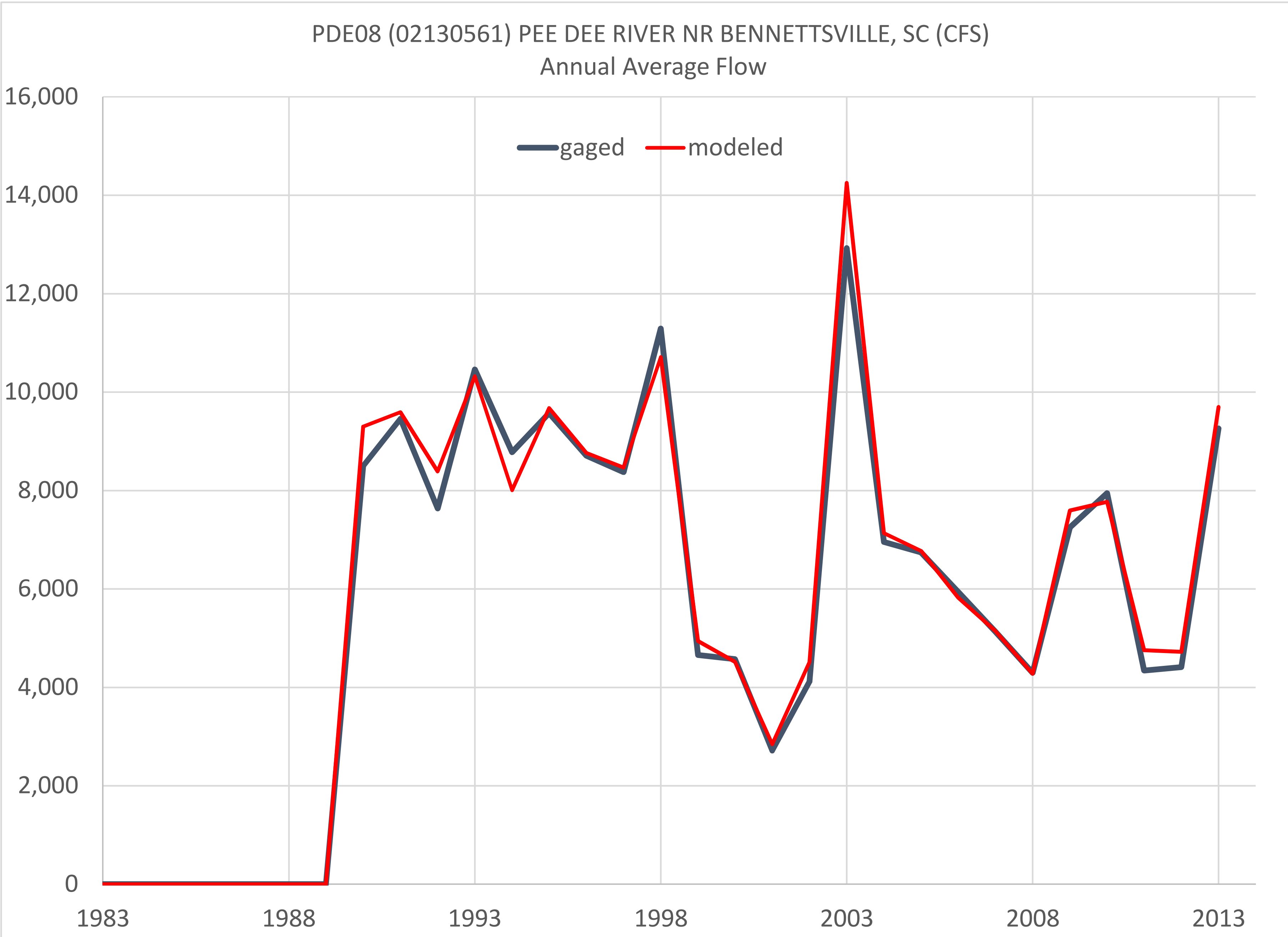
PDE06 (02129590) WHITES CREEK NEAR WALLACE, SC (CFS)
Annual Average Flow
gaged
modeled
45
40
35
30
25
20
15
10
5
0
1983
1988
1993
1998
2003
2008
2013

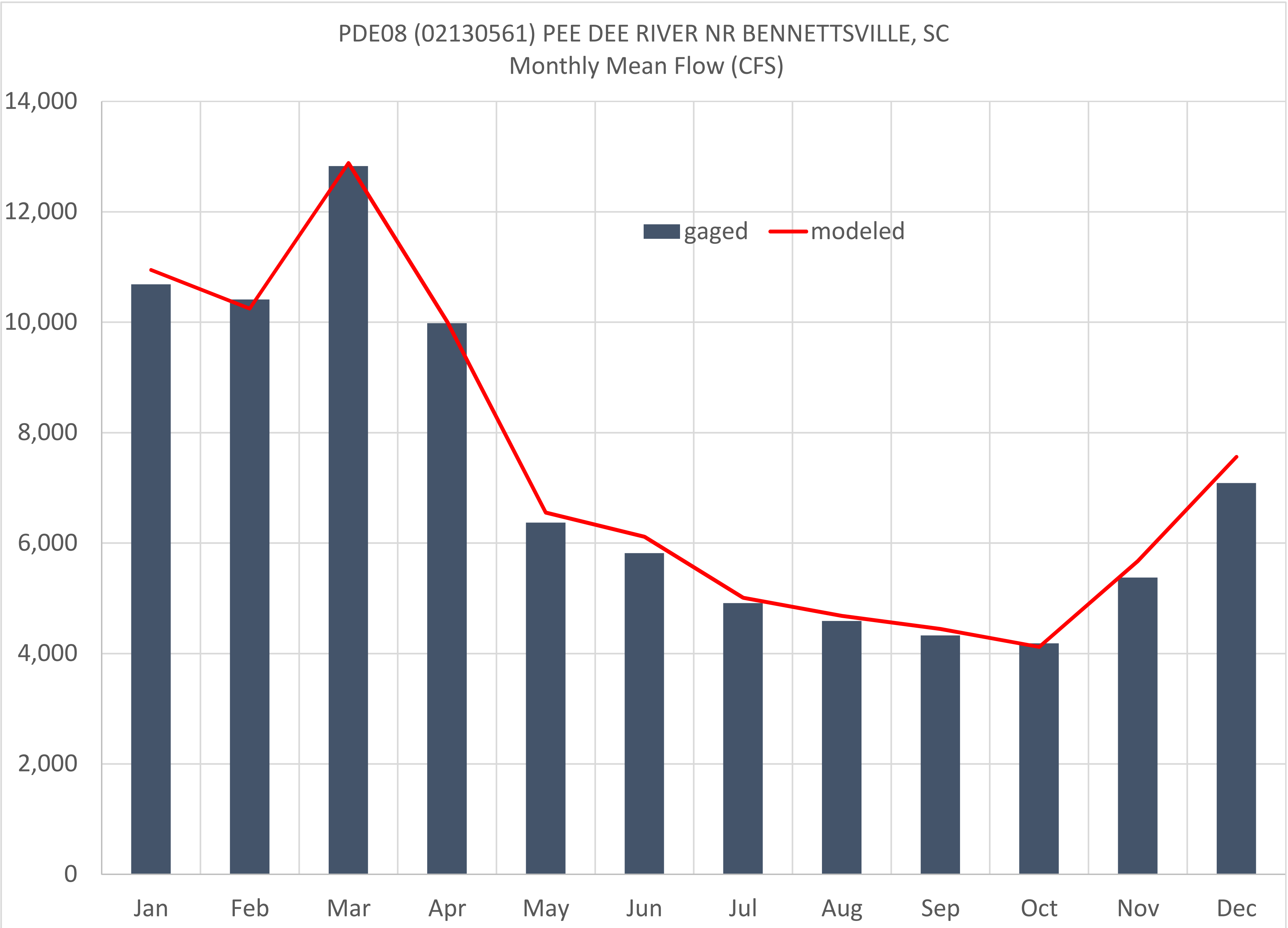

PDE06 (02129590) WHITES CREEK NEAR WALLACE, SC
Monthly Mean Flow (CFS)
gaged
modeled
0
10
20
30
40
50
60
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

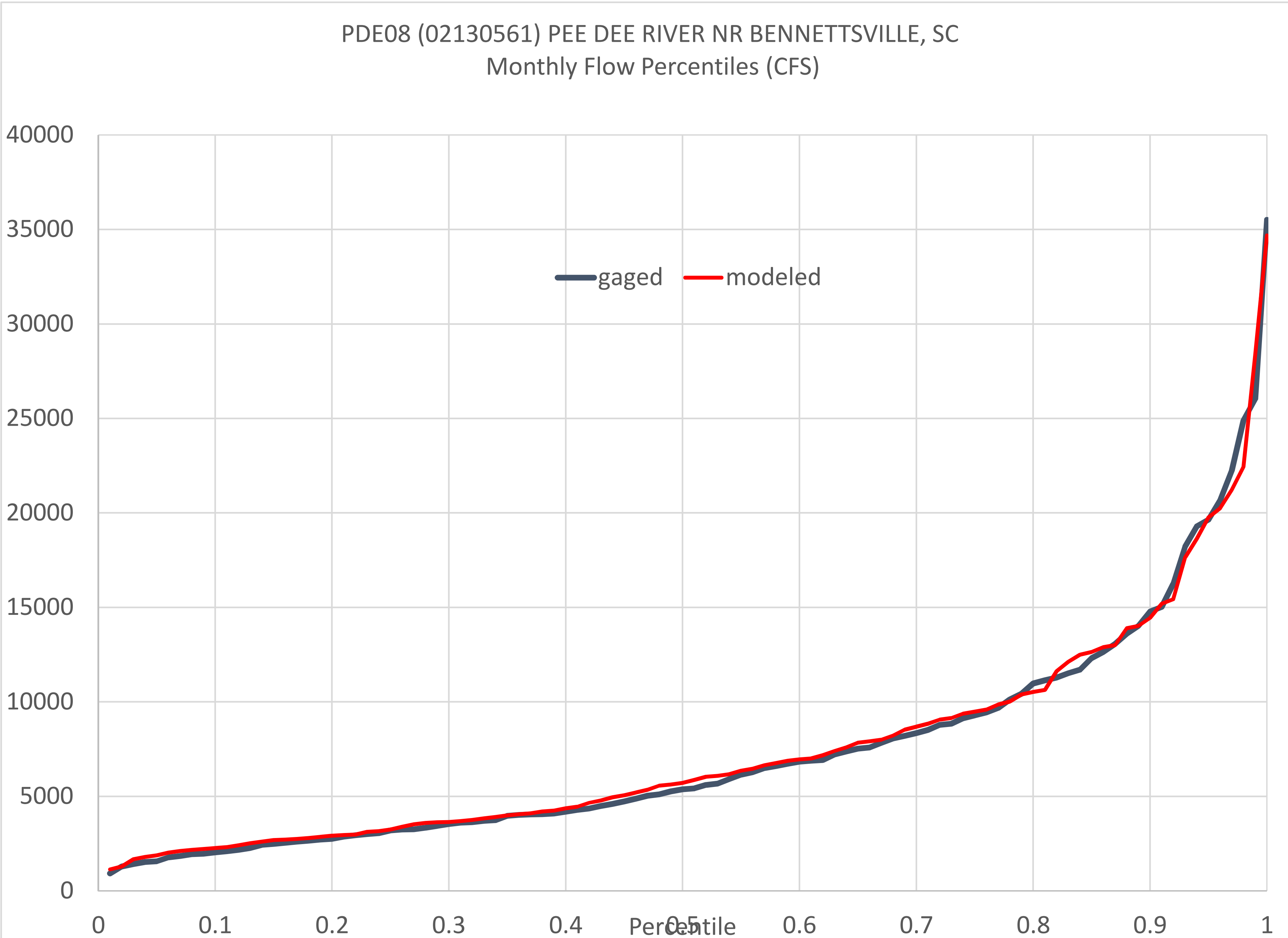

PDE06 (02129590) WHITES CREEK NEAR WALLACE, SC
Monthly Flow Percentiles (CFS)
140
120
100
80
60
40
20
0
gaged
modeled
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

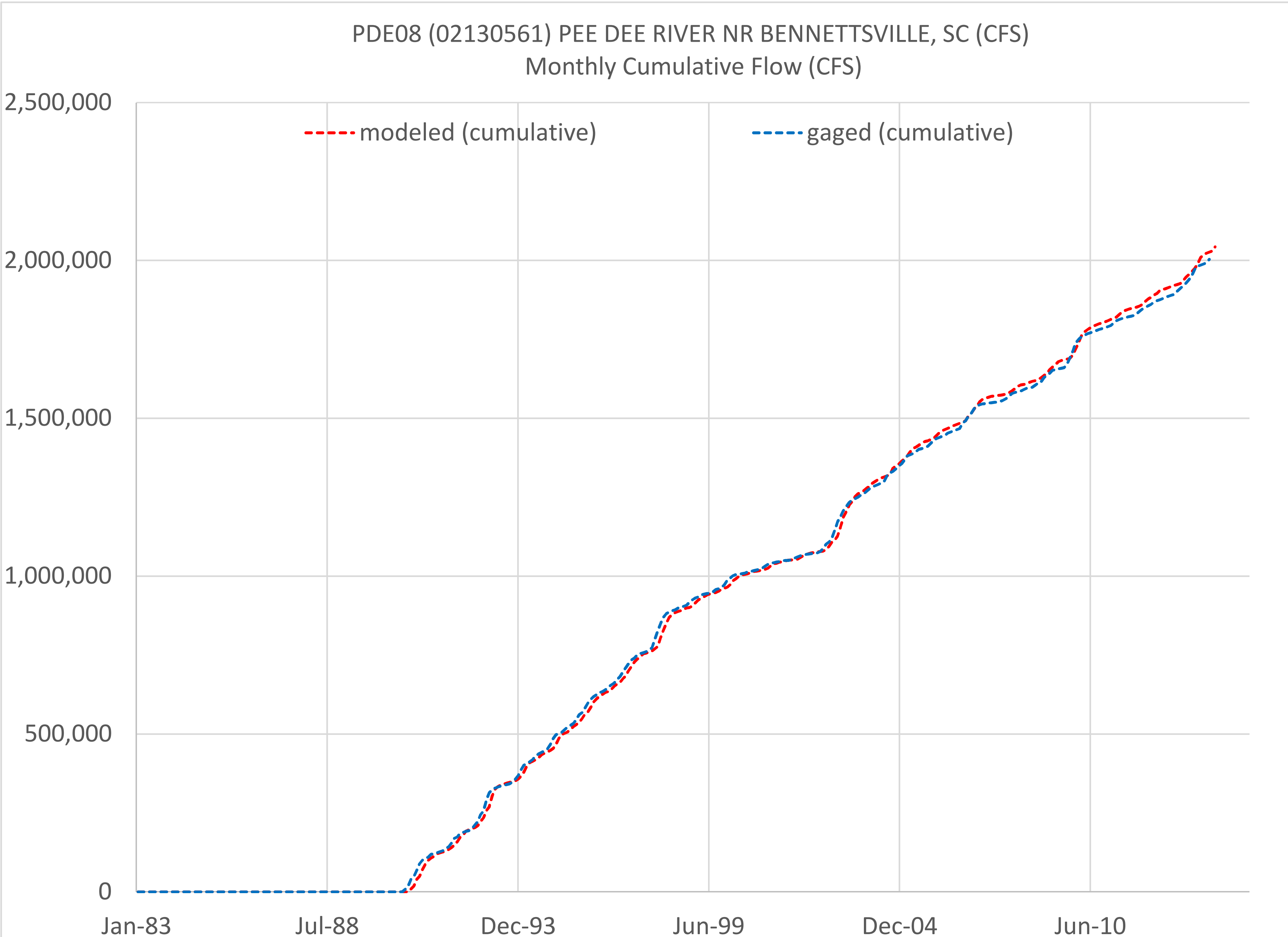


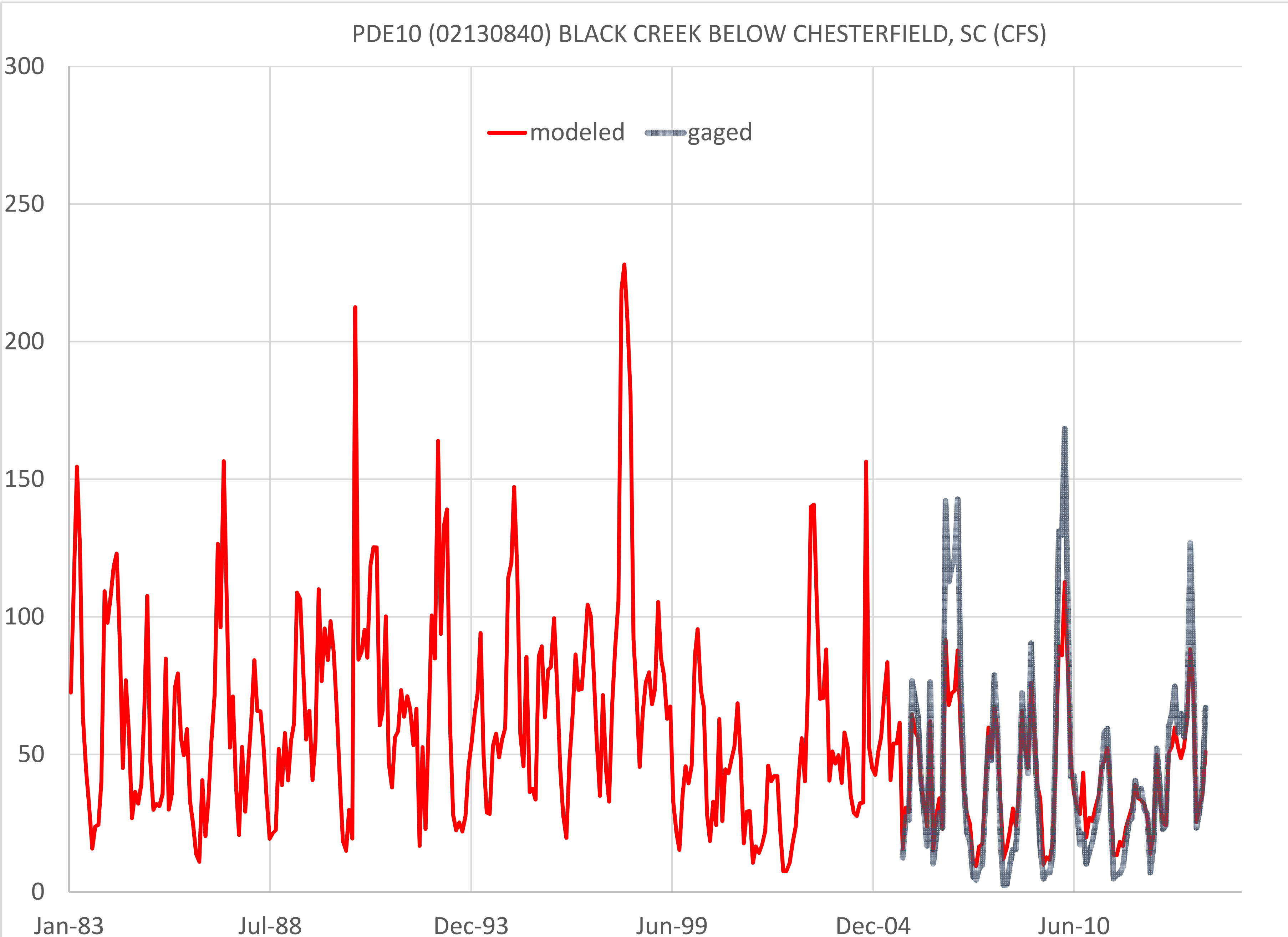
PDE08 (02130561) PEE DEE RIVER NR BENNETTSVILLE, SC (CFS)
modeled
gaged
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
Jan-83
Jun-88
Dec-93
Jun-99
Nov-04
May-10


PDE08 (02130561) PEE DEE RIVER NR BENNETTSVILLE, SC (CFS)
Annual Average Flow
gaged
modeled
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1983
1988
1993
1998
2003
2008
2013

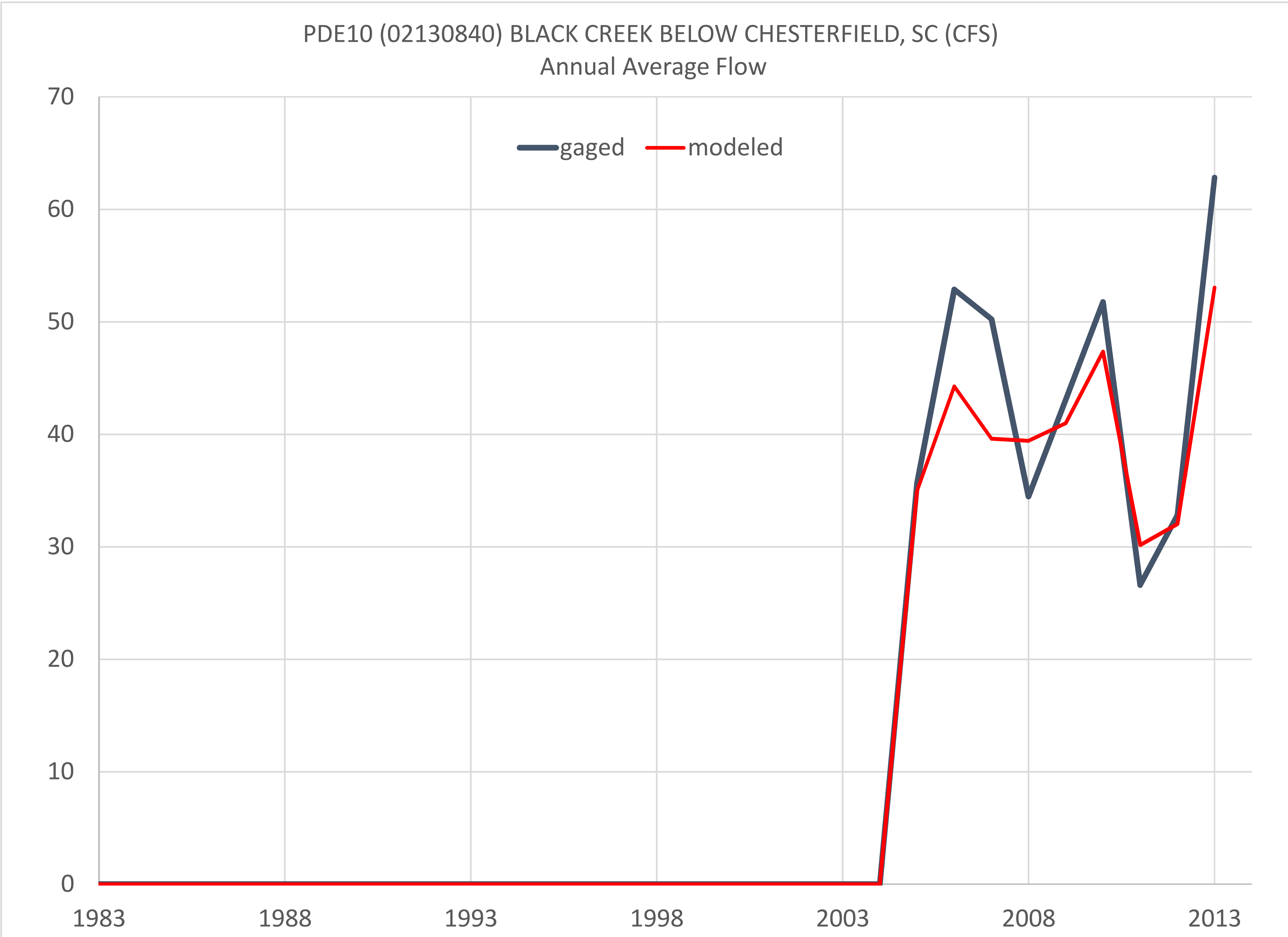

PDE08 (02130561) PEE DEE RIVER NR BENNETTSVILLE, SC
Monthly Mean Flow (CFS)
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
gaged
modeled
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

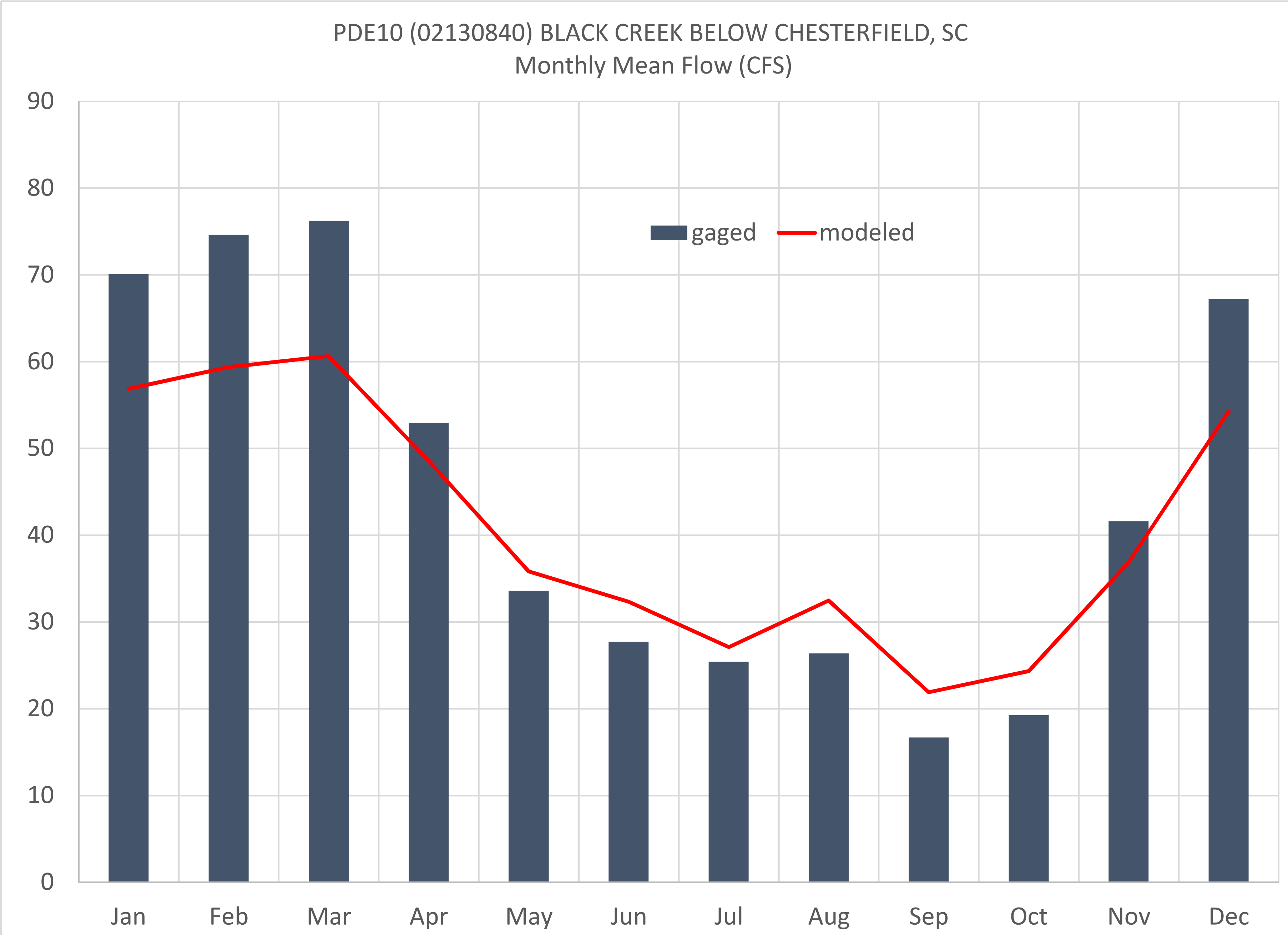

PDE08 (02130561) PEE DEE RIVER NR BENNETTSVILLE, SC
Monthly Flow Percentiles (CFS)
40000
35000
30000
25000
20000
15000
10000
5000
0
gaged
modeled
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

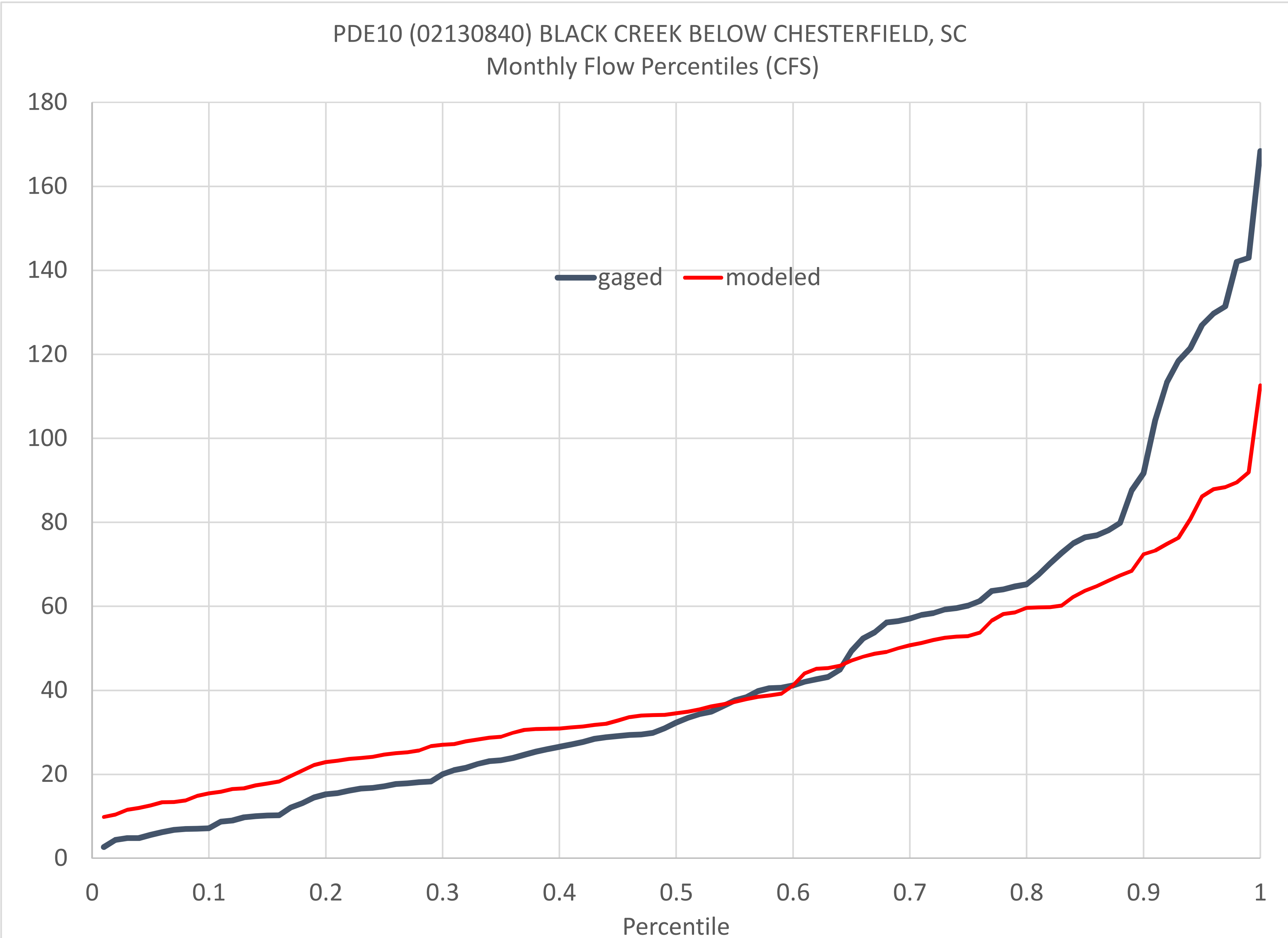

PDE08 (02130561) PEE DEE RIVER NR BENNETTSVILLE, SC (CFS)
Monthly Cumulative Flow (CFS)
modeled (cumulative)
gaged (cumulative)
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

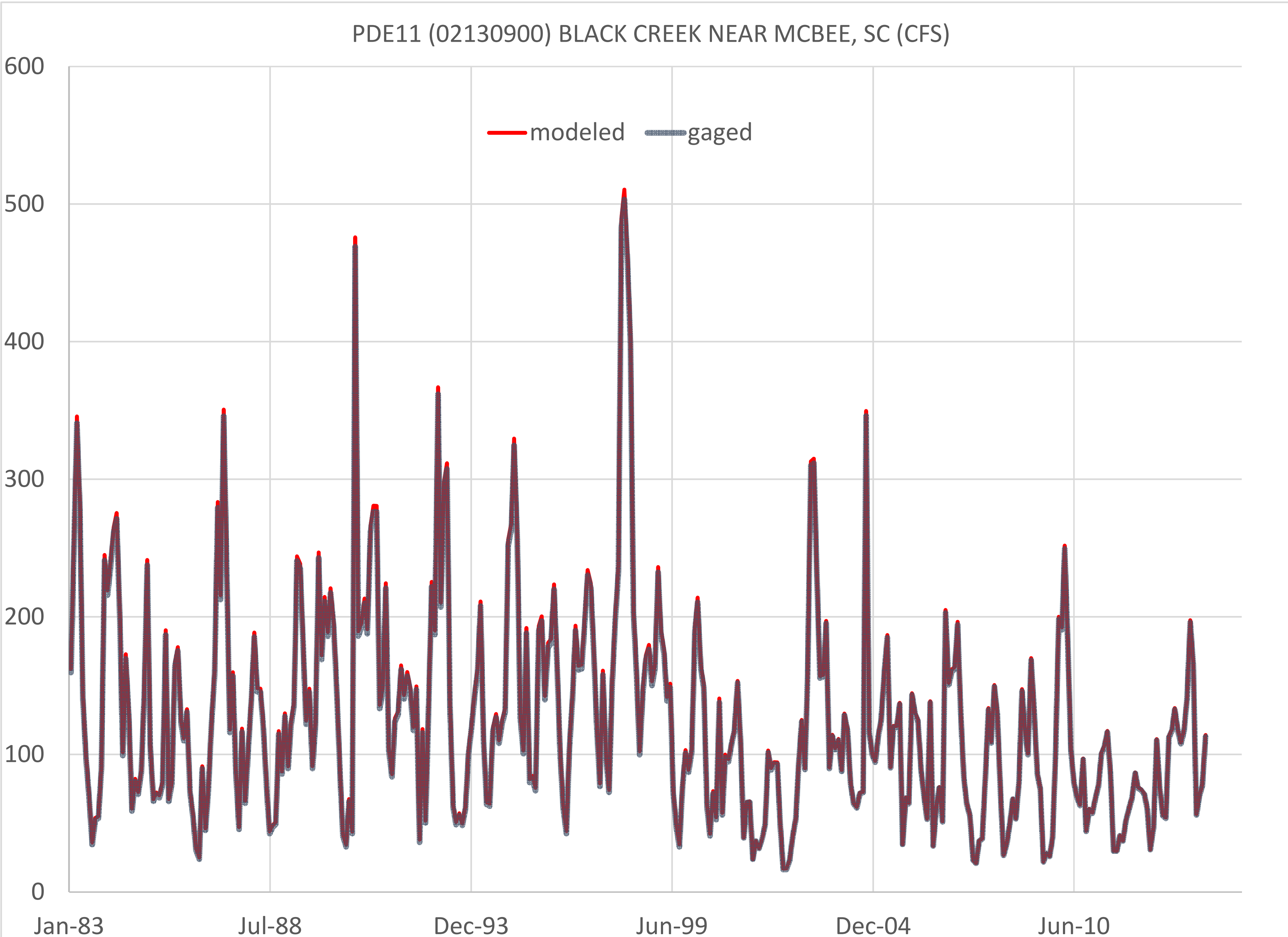


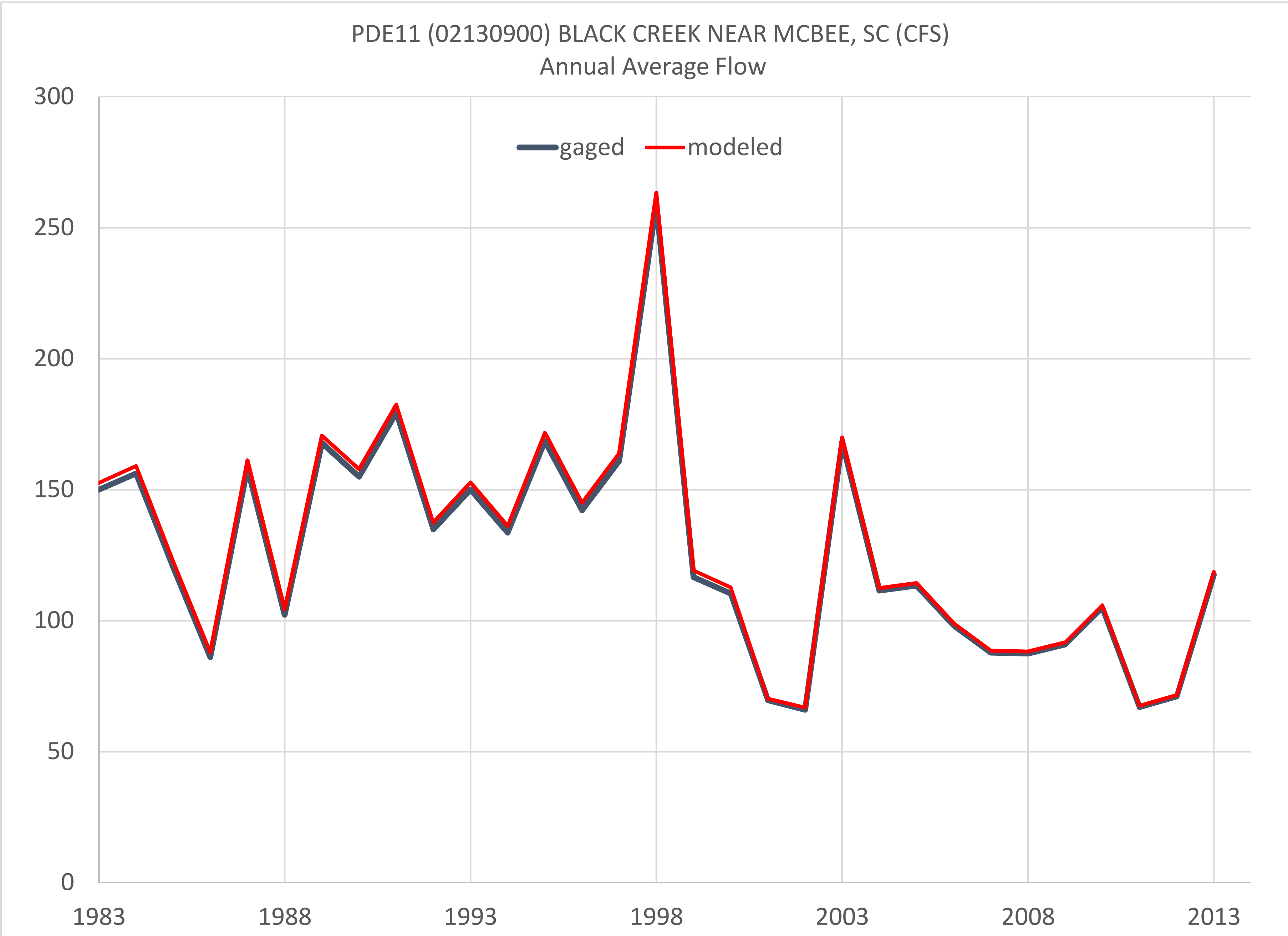
PDE10 (02130840) BLACK CREEK BELOW CHESTERFIELD, SC (CFS)
modeled
gaged
300
250
200
150
100
50
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

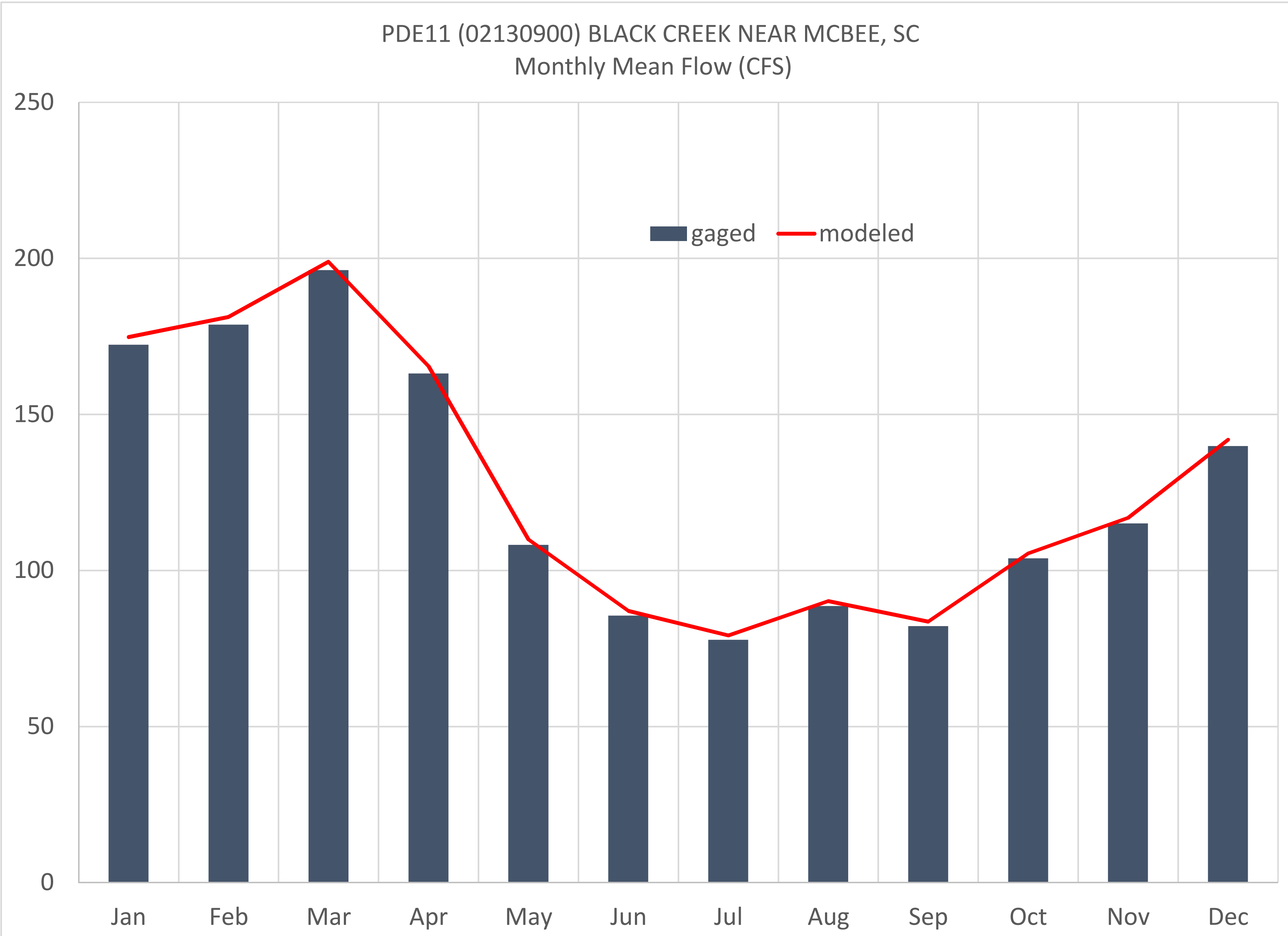

PDE10 (02130840) BLACK CREEK BELOW CHESTERFIELD, SC (CFS)
Annual Average Flow
gaged
modeled
70
60
50
40
30
20
10
0
1983
1988
1993
1998
2003
2008
2013

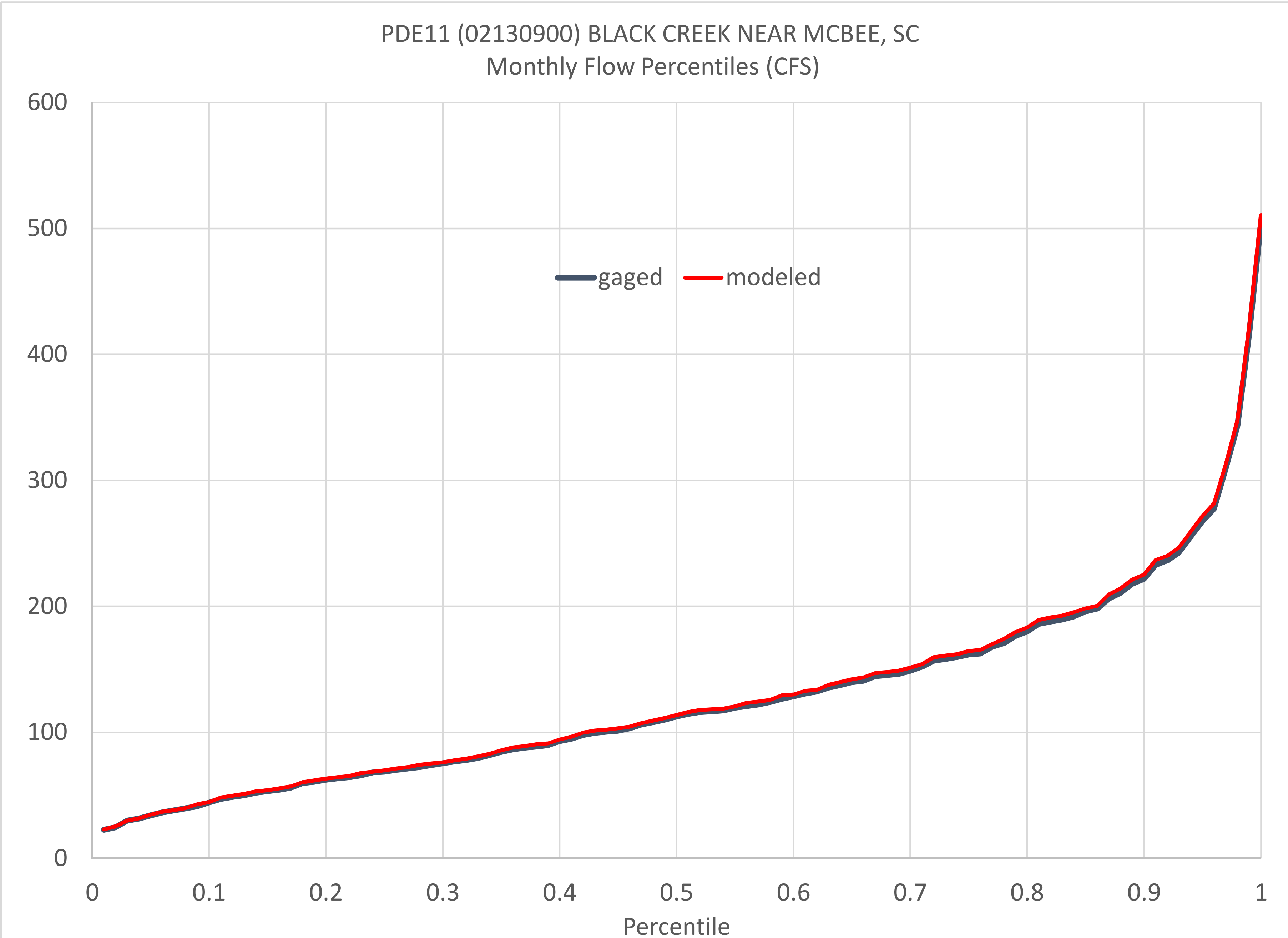

PDE10 (02130840) BLACK CREEK BELOW CHESTERFIELD, SC
Monthly Mean Flow (CFS)
90
80
70
60
50
40
30
20
10
0
gaged
modeled
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

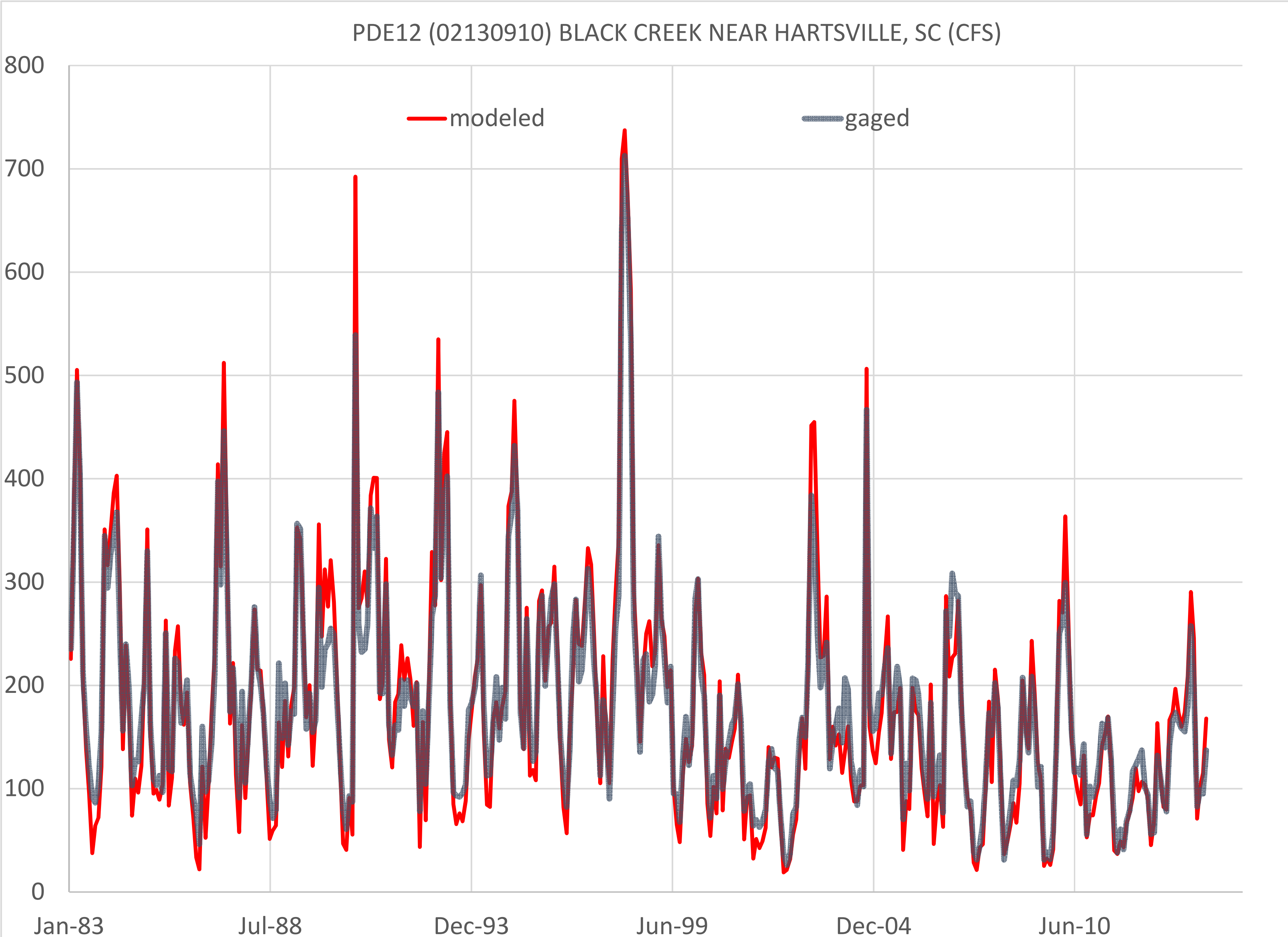

PDE10 (02130840) BLACK CREEK BELOW CHESTERFIELD, SC
Monthly Flow Percentiles (CFS)
180
160
140
120
100
80
60
40
20
0
gaged
modeled
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile


PDE11 (02130900) BLACK CREEK NEAR MCBEE, SC (CFS)
modeled
gaged
600
500
400
300
200
100
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

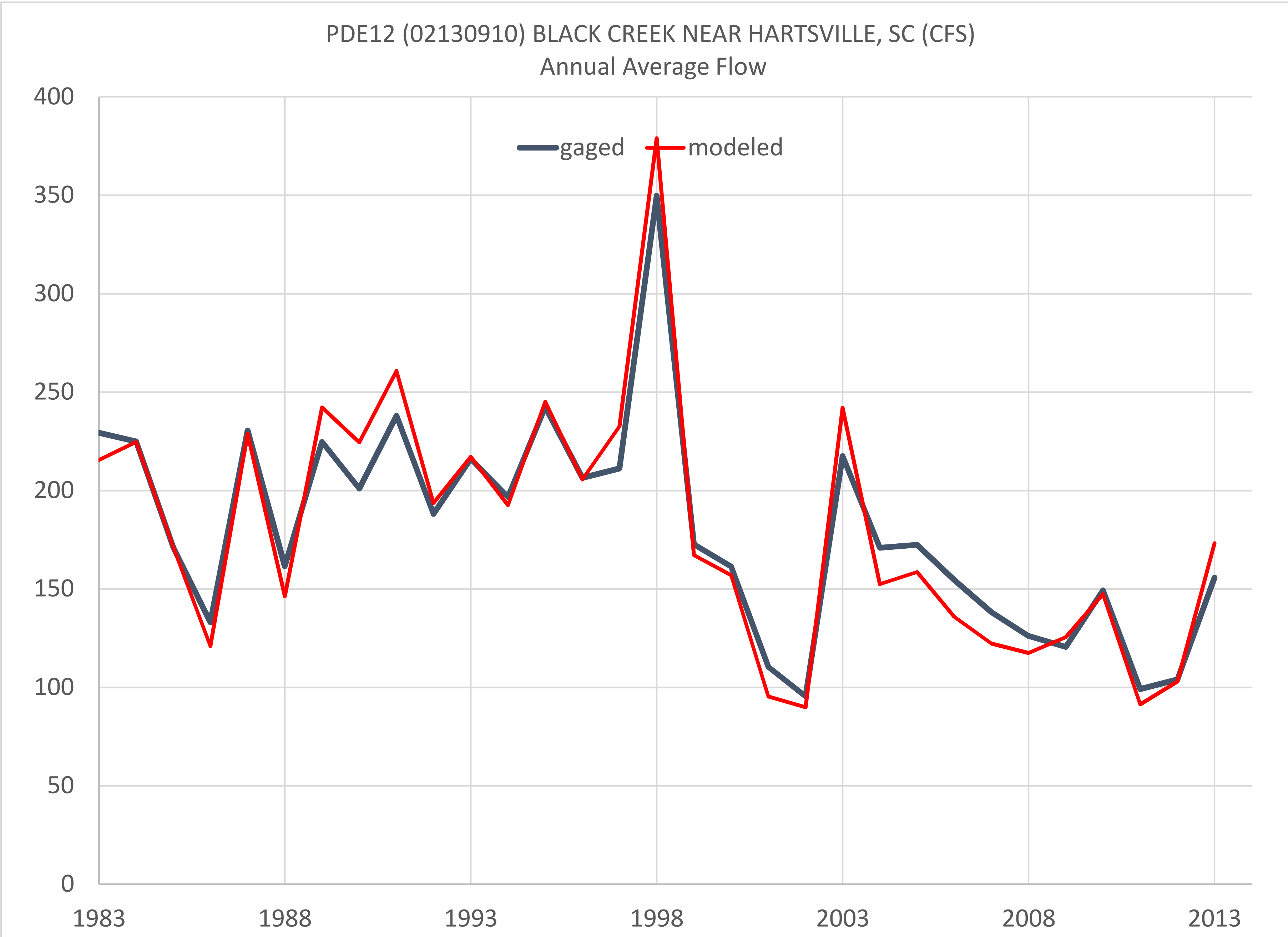

PDE11 (02130900) BLACK CREEK NEAR MCBEE, SC (CFS)
Annual Average Flow
gaged
modeled
300
250
200
150
100
50
0
1983
1988
1993
1998
2003
2008
2013


PDE11 (02130900) BLACK CREEK NEAR MCBEE, SC
Monthly Mean Flow (CFS)
gaged
modeled
250
200
150
100
50
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

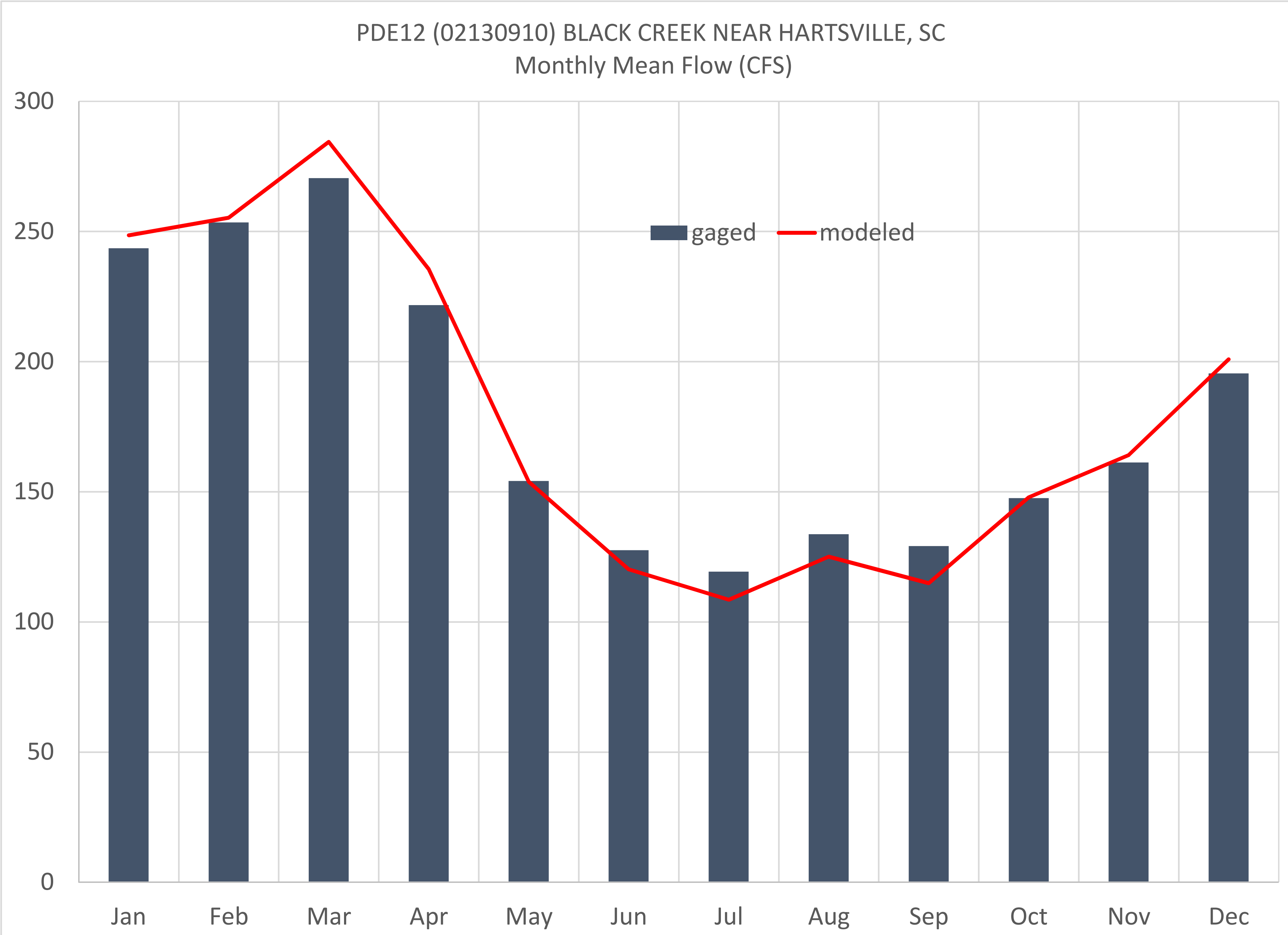

PDE11 (02130900) BLACK CREEK NEAR MCBEE, SC
Monthly Flow Percentiles (CFS)
gaged
modeled
600
500
400
300
200
100
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

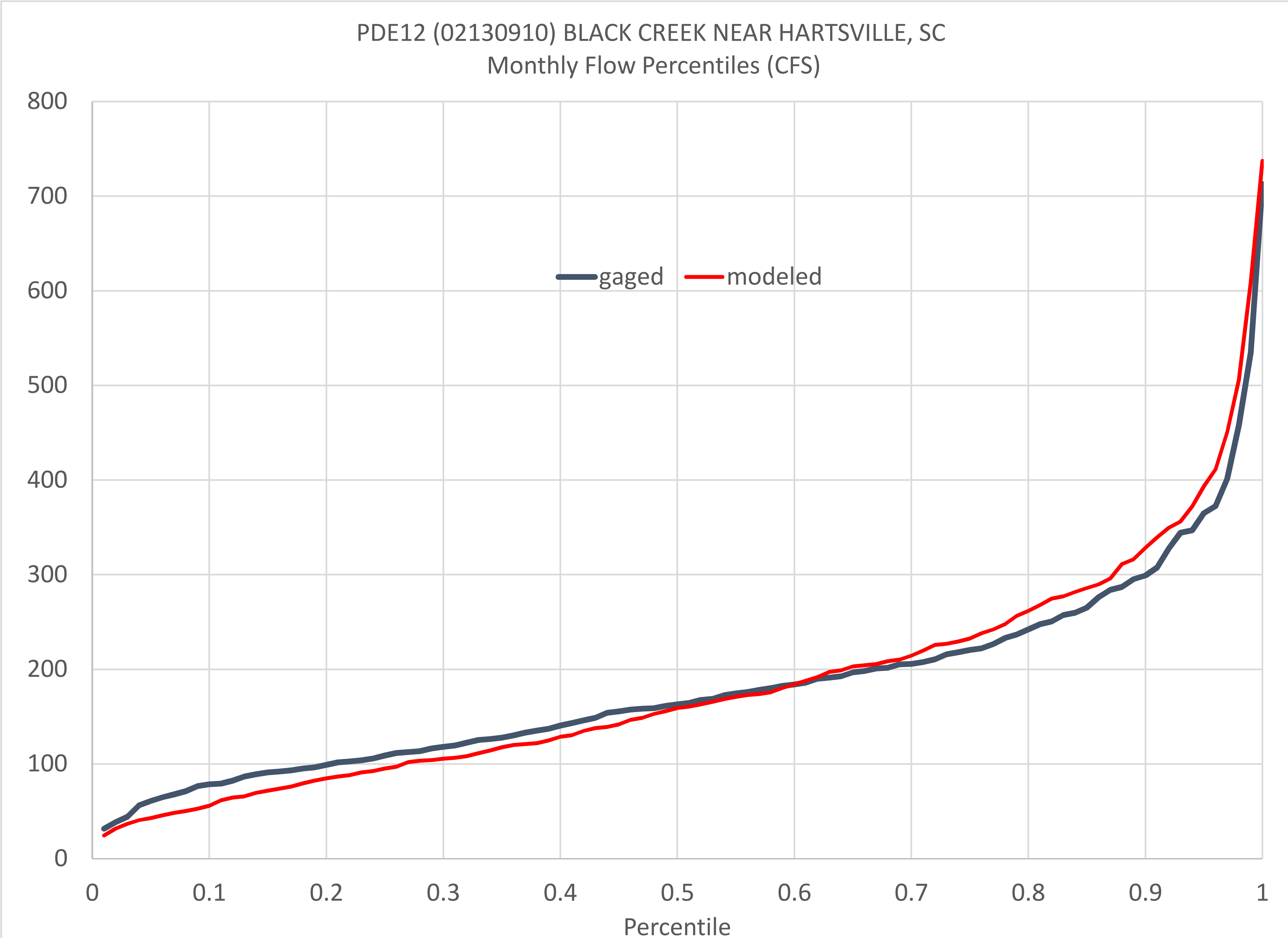


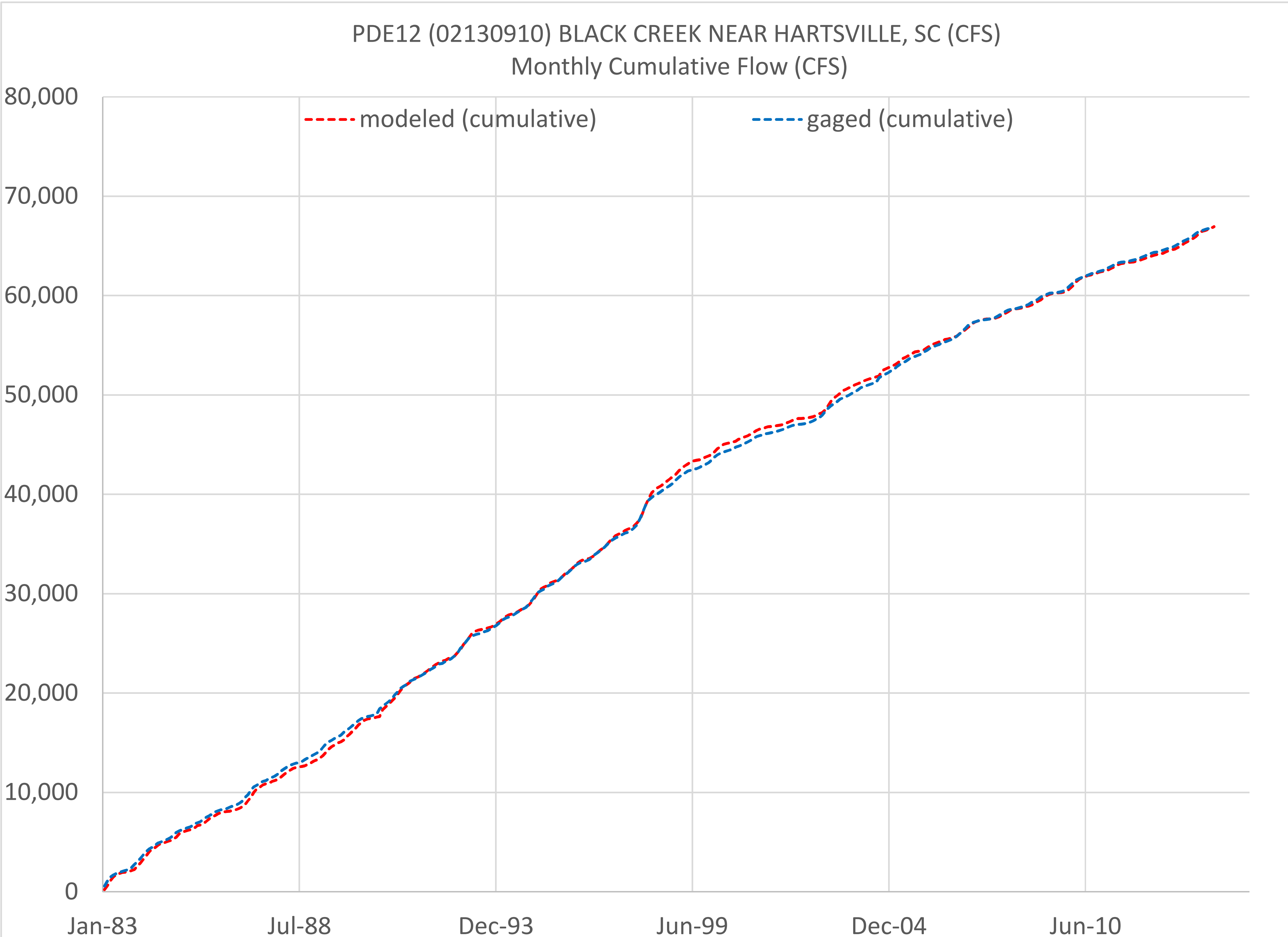
PDE12 (02130910) BLACK CREEK NEAR HARTSVILLE, SC (CFS)
modeled
gaged
800
700
600
500
400
300
200
100
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

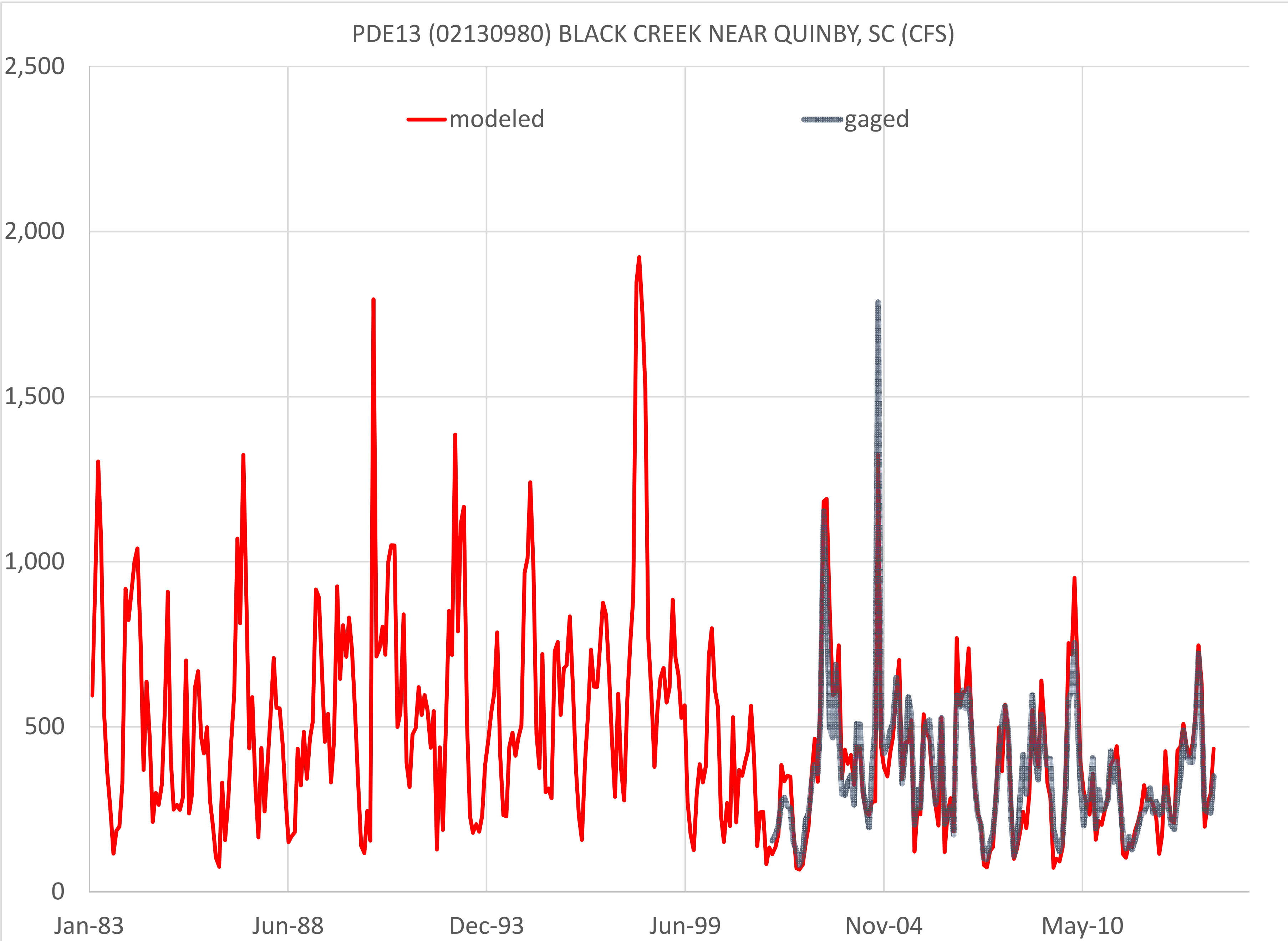


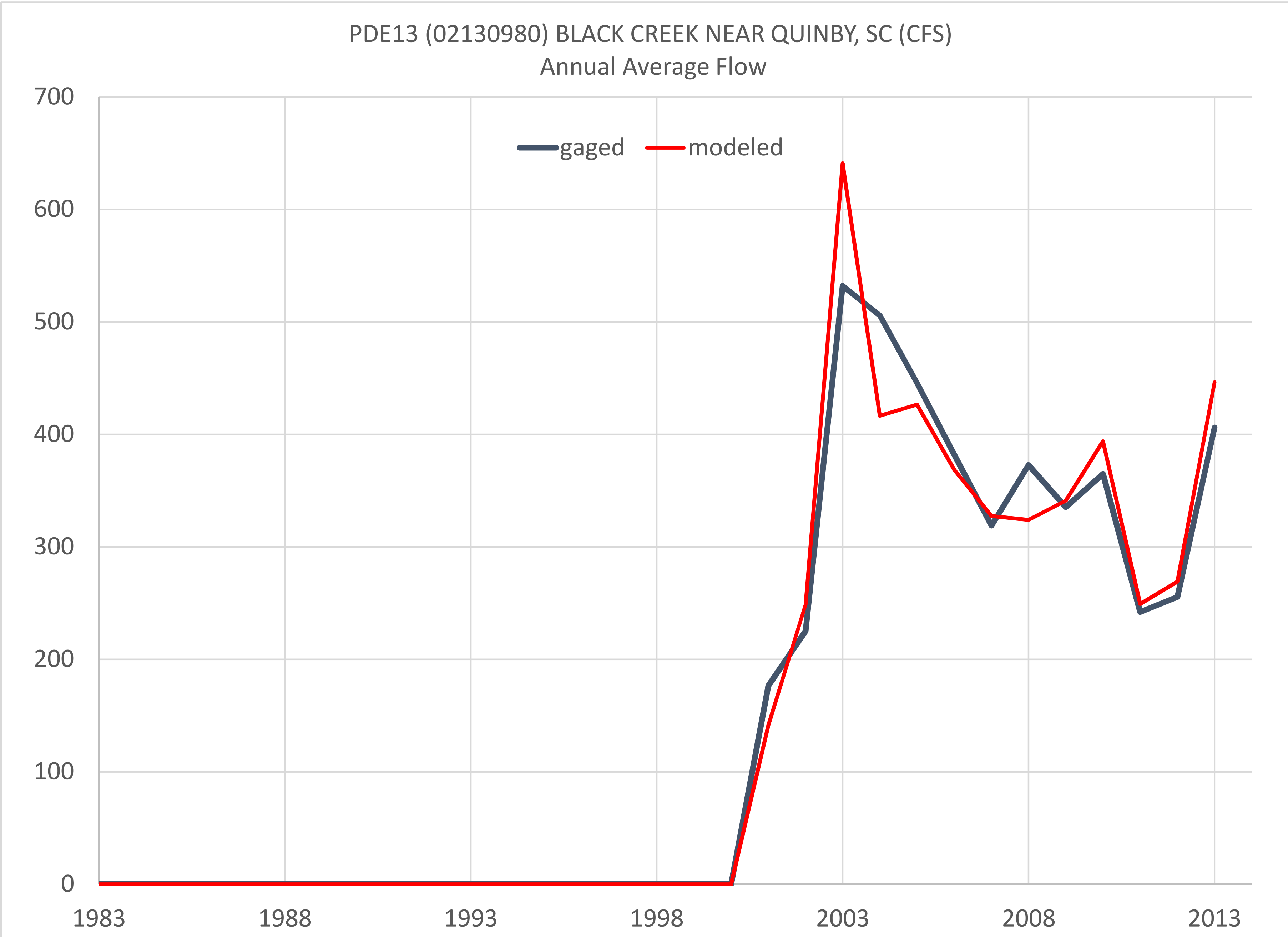
PDE12 (02130910) BLACK CREEK NEAR HARTSVILLE, SC (CFS)
Annual Average Flow
gaged
modeled
400
350
300
250
200
150
100
50
0
1983
1988
1993
1998
2003
2008
2013

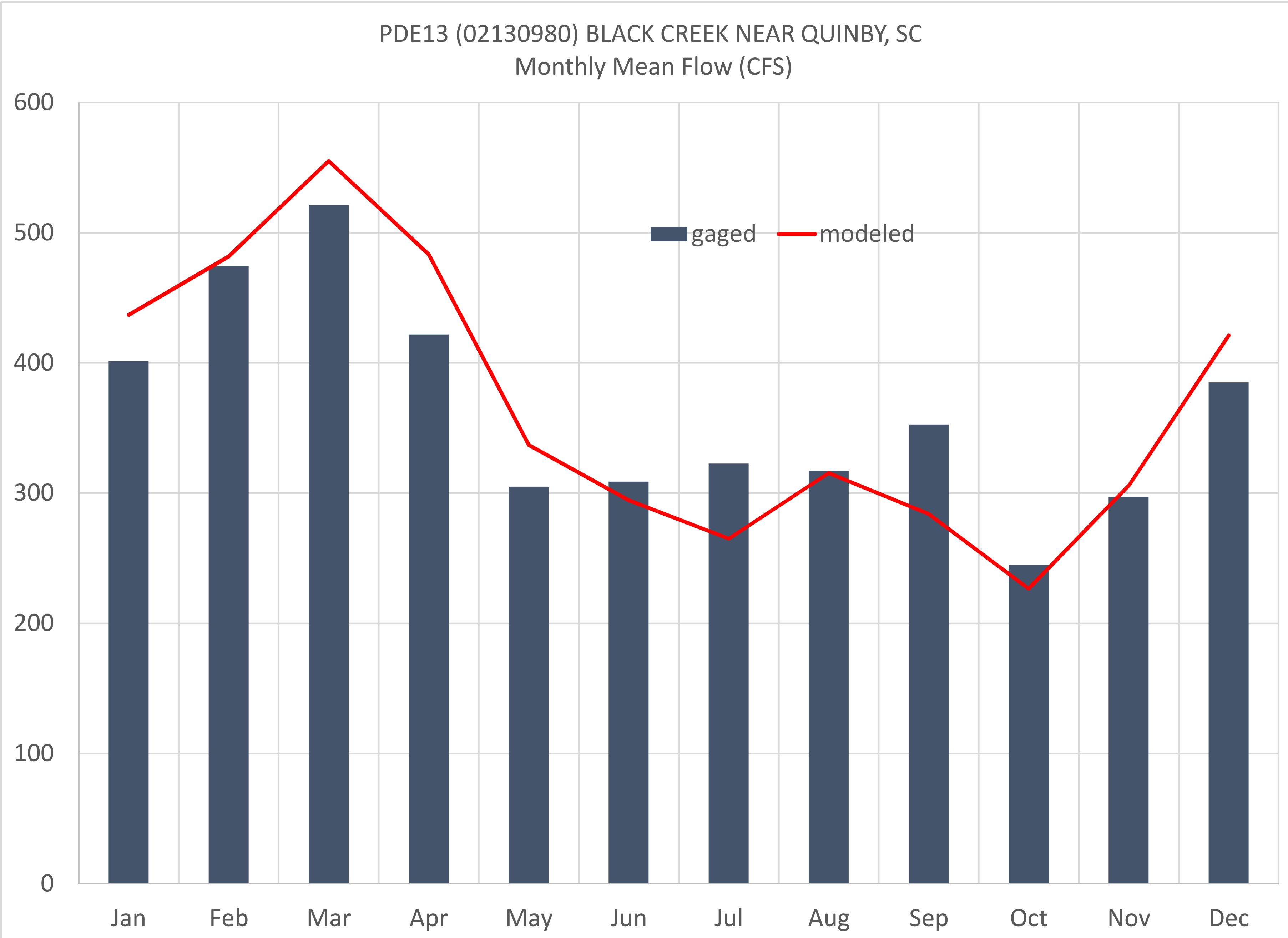

PDE12 (02130910) BLACK CREEK NEAR HARTSVILLE, SC
Monthly Mean Flow (CFS)
300
250
200
150
100
50
0
gaged
modeled
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

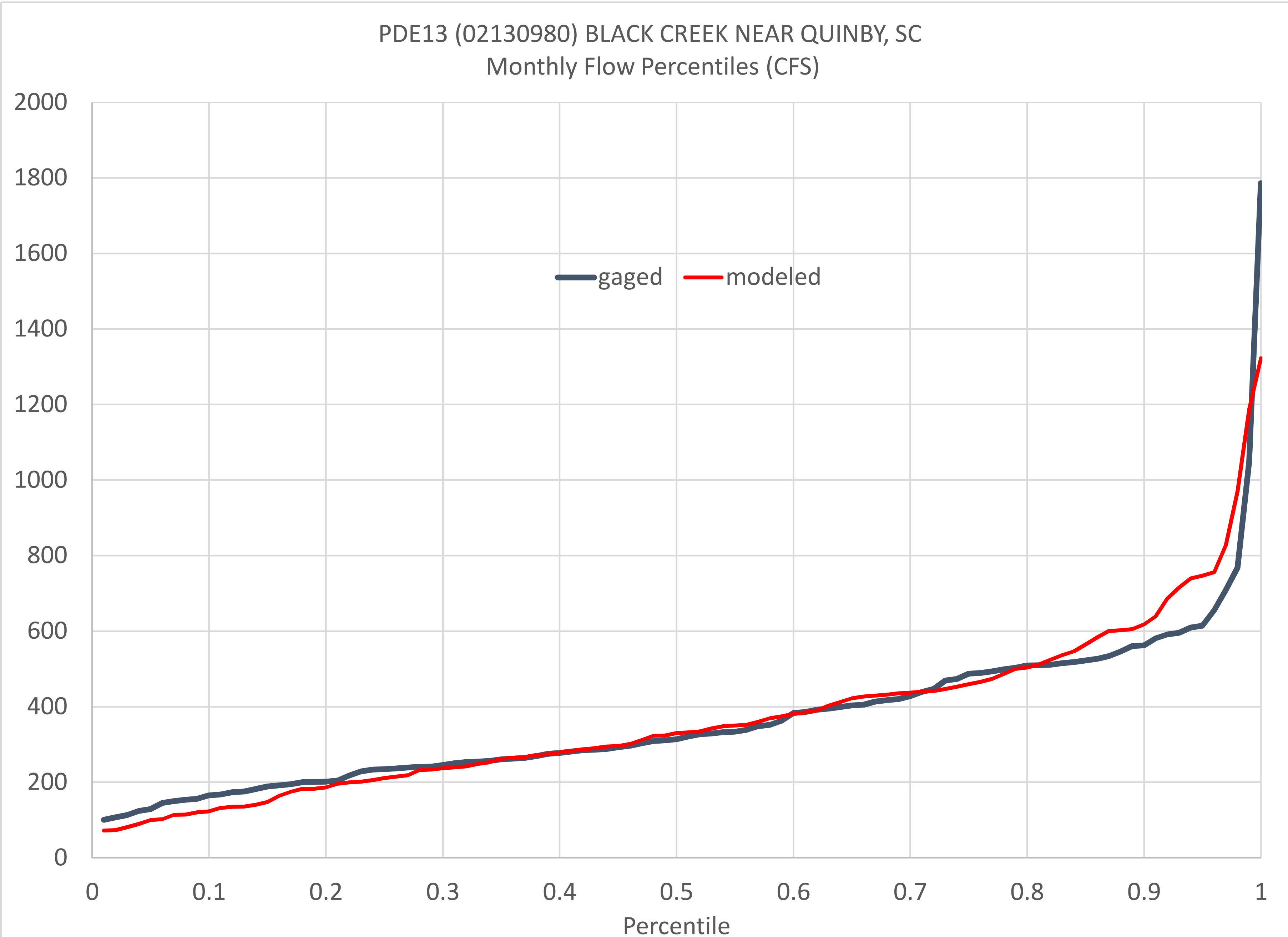

PDE12 (02130910) BLACK CREEK NEAR HARTSVILLE, SC
Monthly Flow Percentiles (CFS)
gaged
modeled
800
700
600
500
400
300
200
100
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

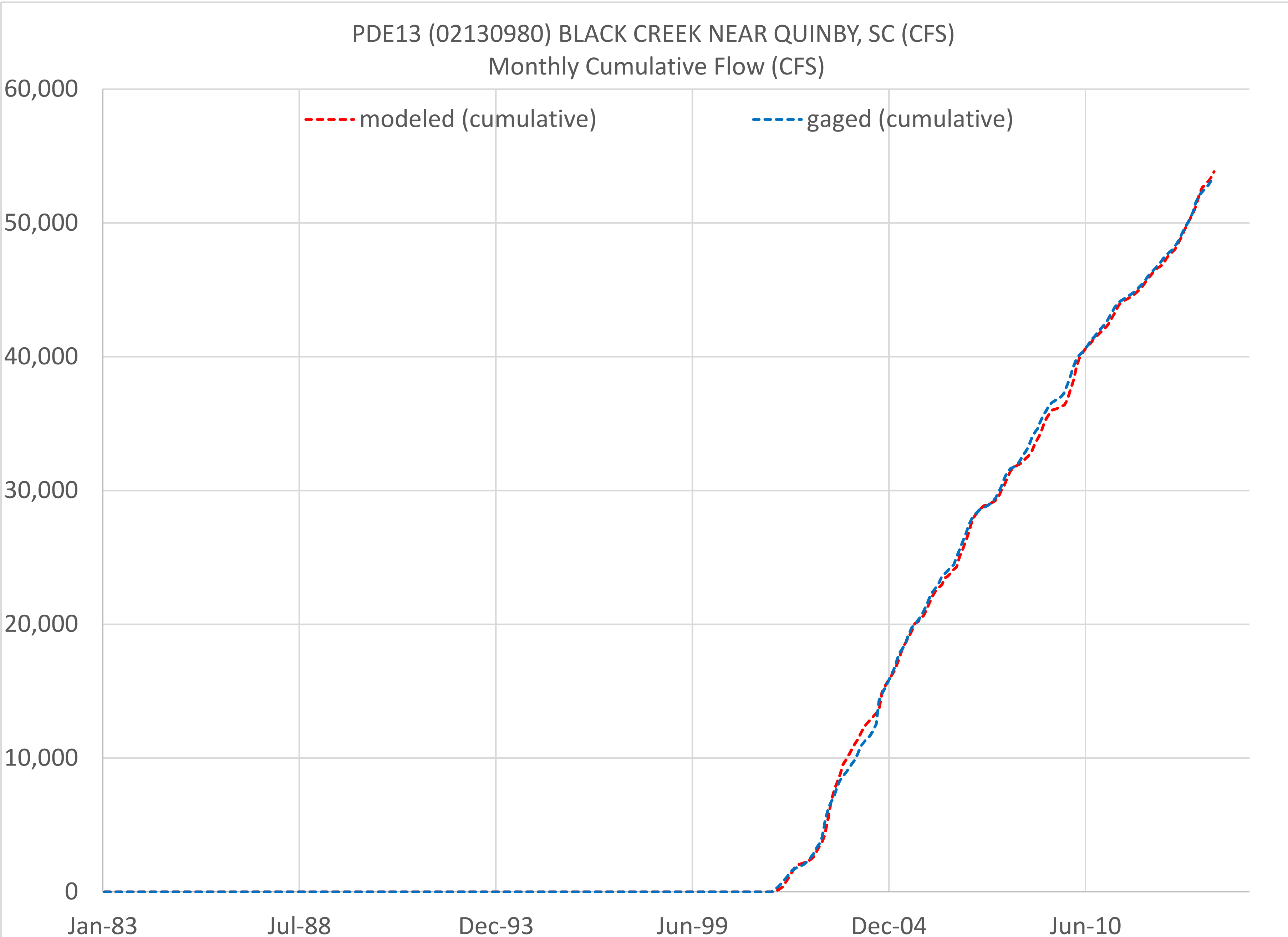

PDE12 (02130910) BLACK CREEK NEAR HARTSVILLE, SC (CFS)
Monthly Cumulative Flow (CFS)
modeled (cumulative)
gaged (cumulative)
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

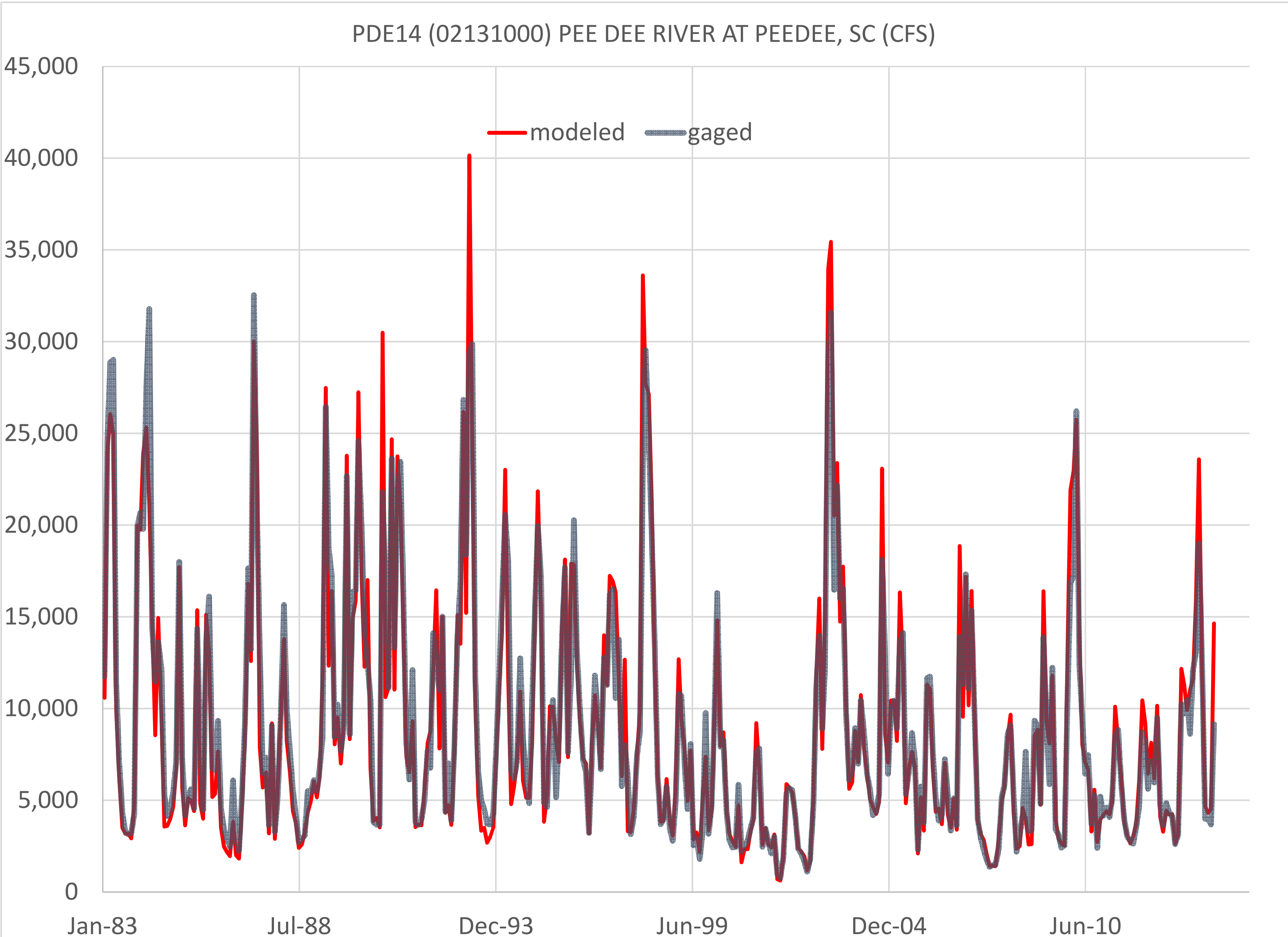

PDE13 (02130980) BLACK CREEK NEAR QUINBY, SC (CFS)
2,500
2,000
1,500
1,000
500
0
modeled
gaged
Jan-83
Jun-88
Dec-93
Jun-99
Nov-04
May-10

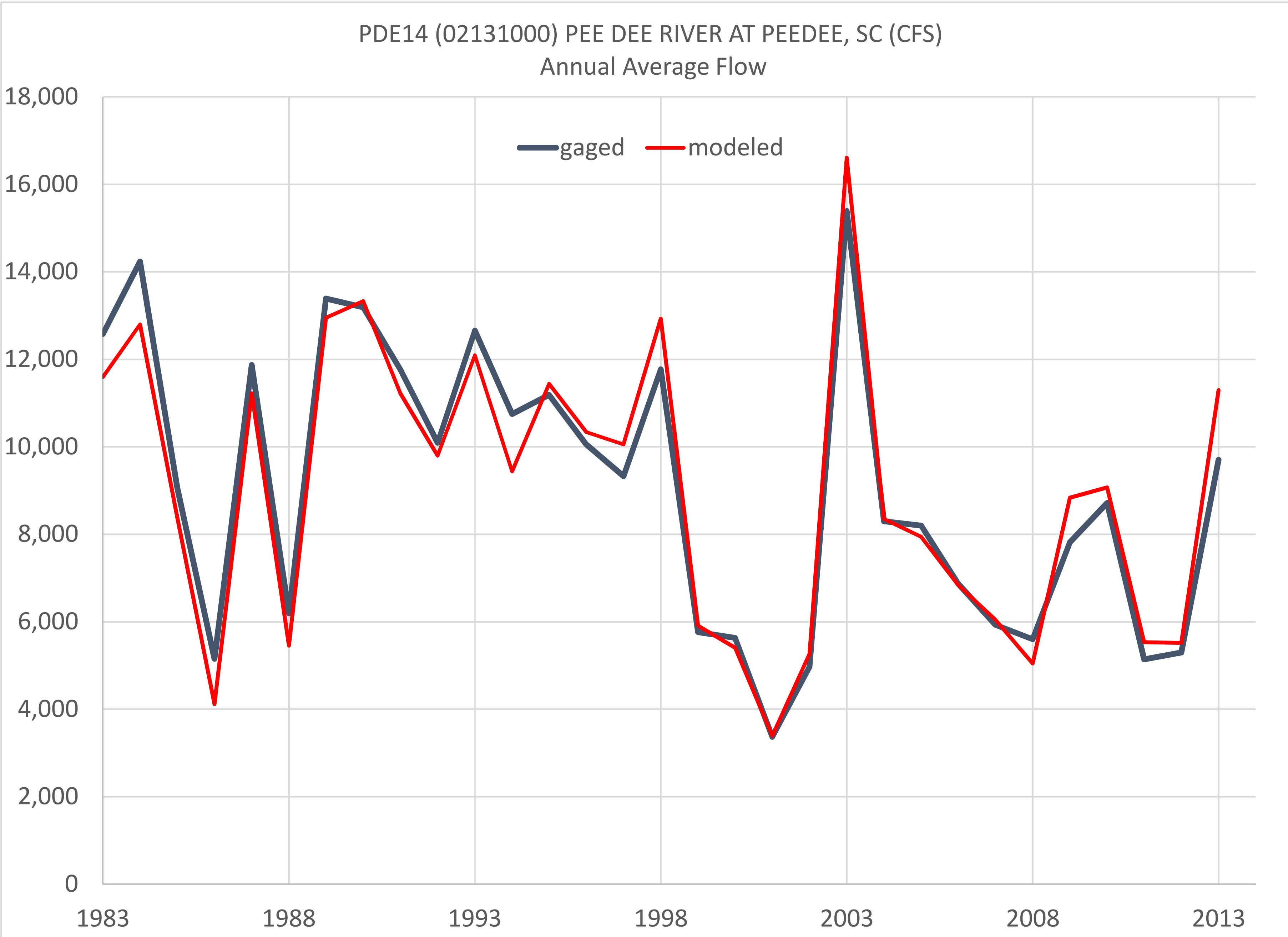

PDE13 (02130980) BLACK CREEK NEAR QUINBY, SC (CFS)
Annual Average Flow
gaged
modeled
700
600
500
400
300
200
100
0
1983
1988
1993
1998
2003
2008
2013

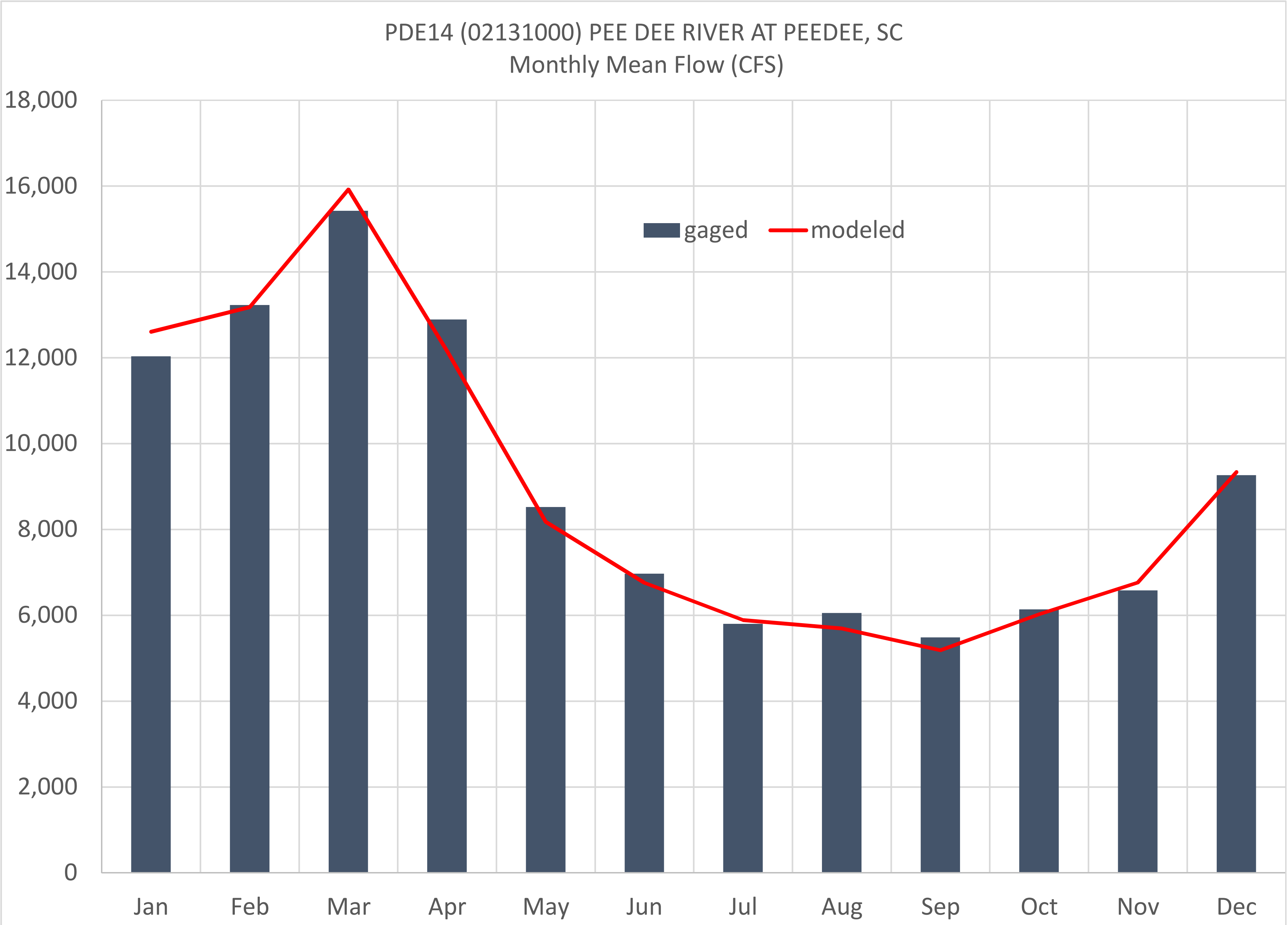

PDE13 (02130980) BLACK CREEK NEAR QUINBY, SC
Monthly Mean Flow (CFS)
gaged
modeled
600
500
400
300
200
100
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

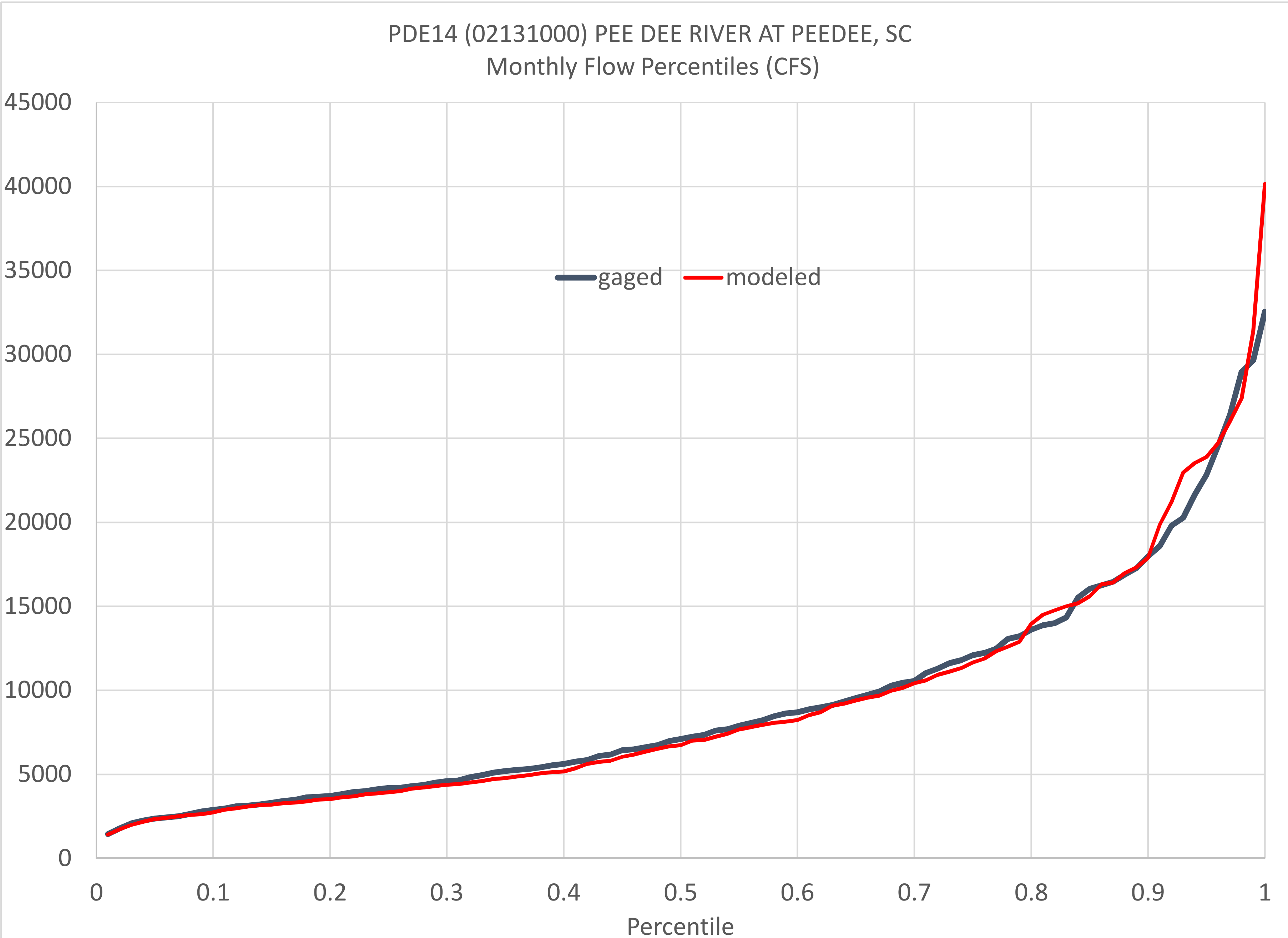

PDE13 (02130980) BLACK CREEK NEAR QUINBY, SC
Monthly Flow Percentiles (CFS)
gaged
modeled
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile


PDE13 (02130980) BLACK CREEK NEAR QUINBY, SC (CFS)
Monthly Cumulative Flow (CFS)
modeled (cumulative)
gaged (cumulative)
60,000
50,000
40,000
30,000
20,000
10,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

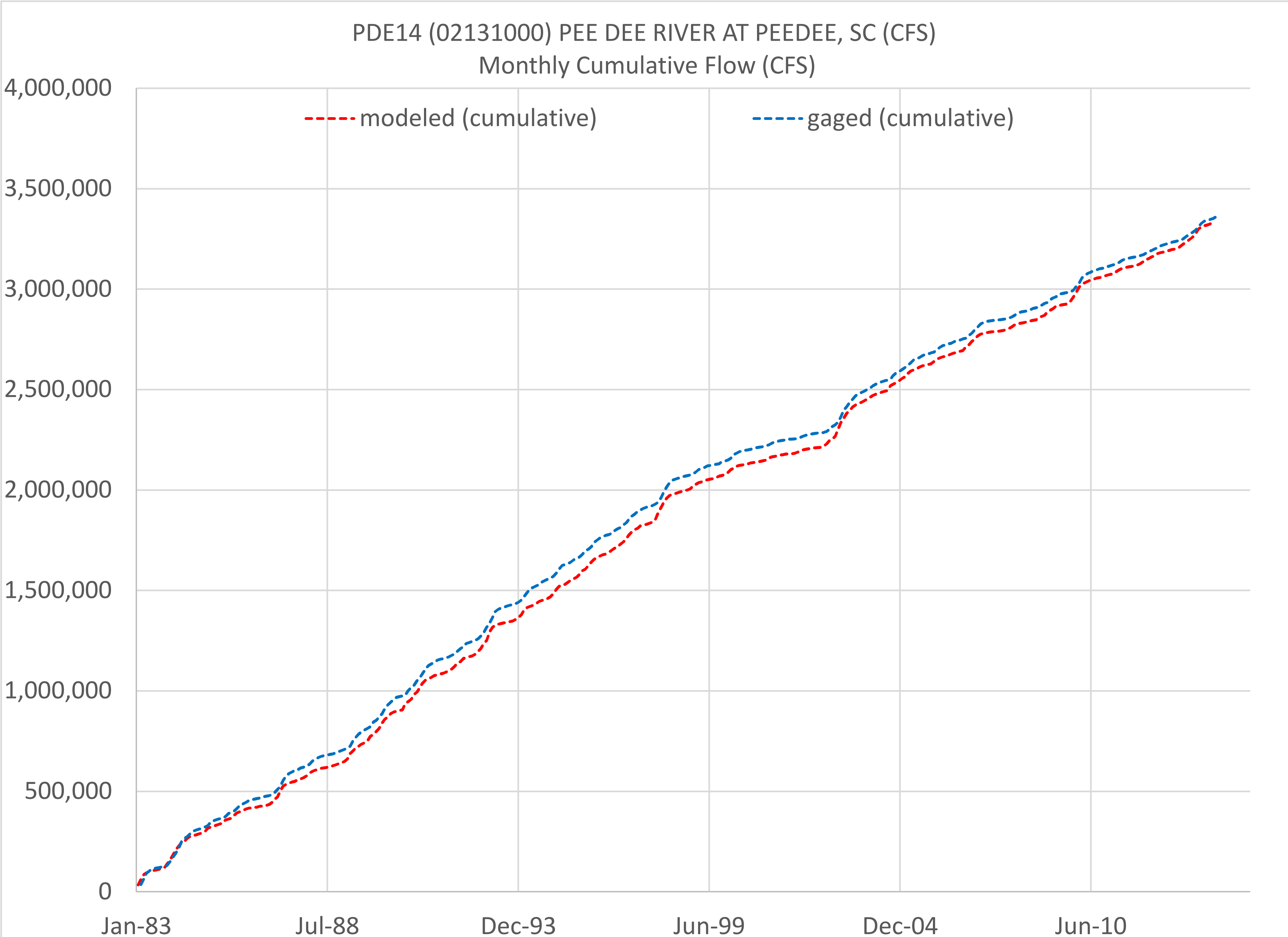

PDE14 (02131000) PEE DEE RIVER AT PEEDEE, SC (CFS)
modeled
gaged
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

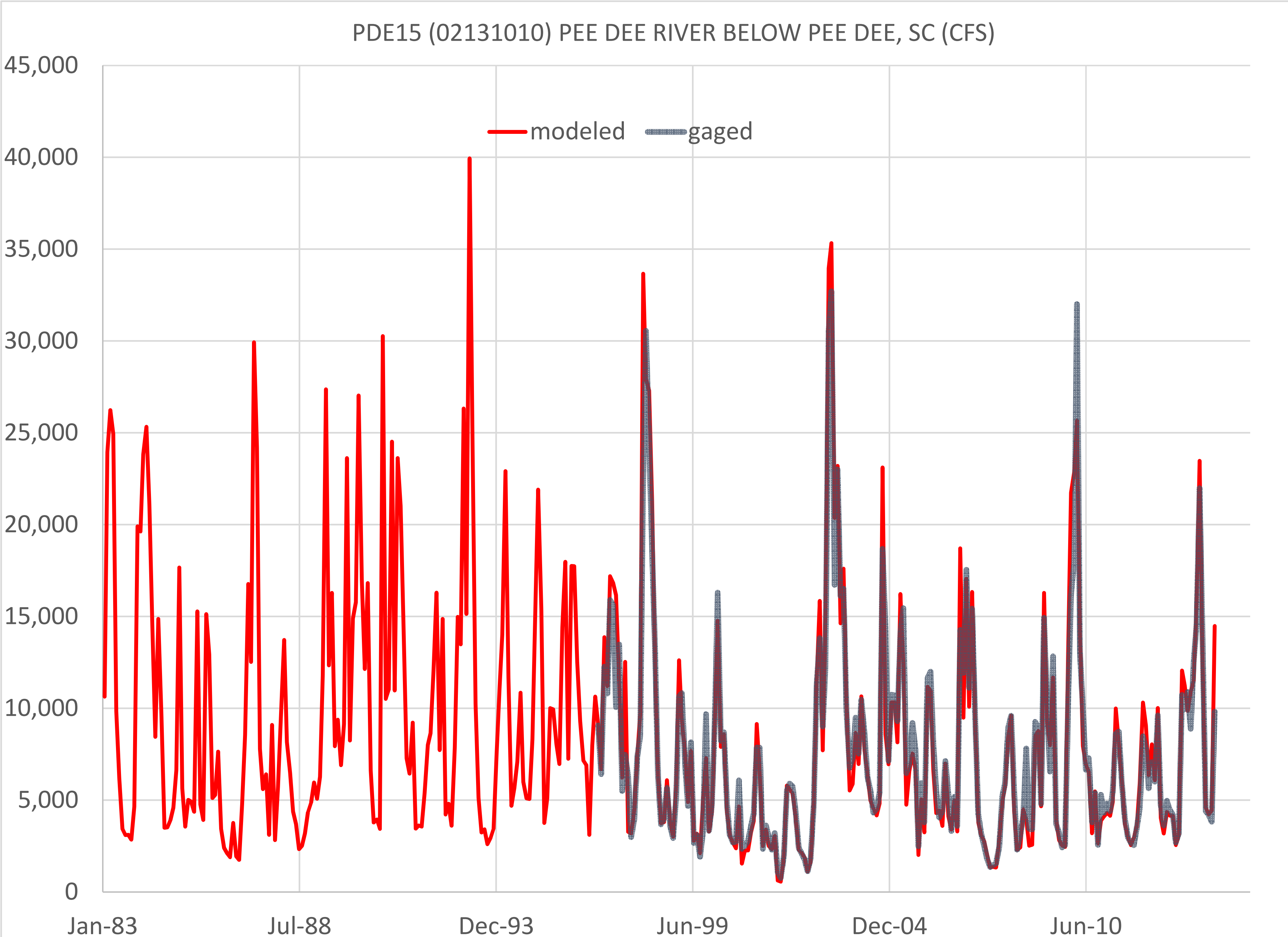

PDE14 (02131000) PEE DEE RIVER AT PEEDEE, SC (CFS)
Annual Average Flow
gaged
modeled
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1983
1988
1993
1998
2003
2008
2013


PDE14 (02131000) PEE DEE RIVER AT PEEDEE, SC
Monthly Mean Flow (CFS)
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
gaged
modeled
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

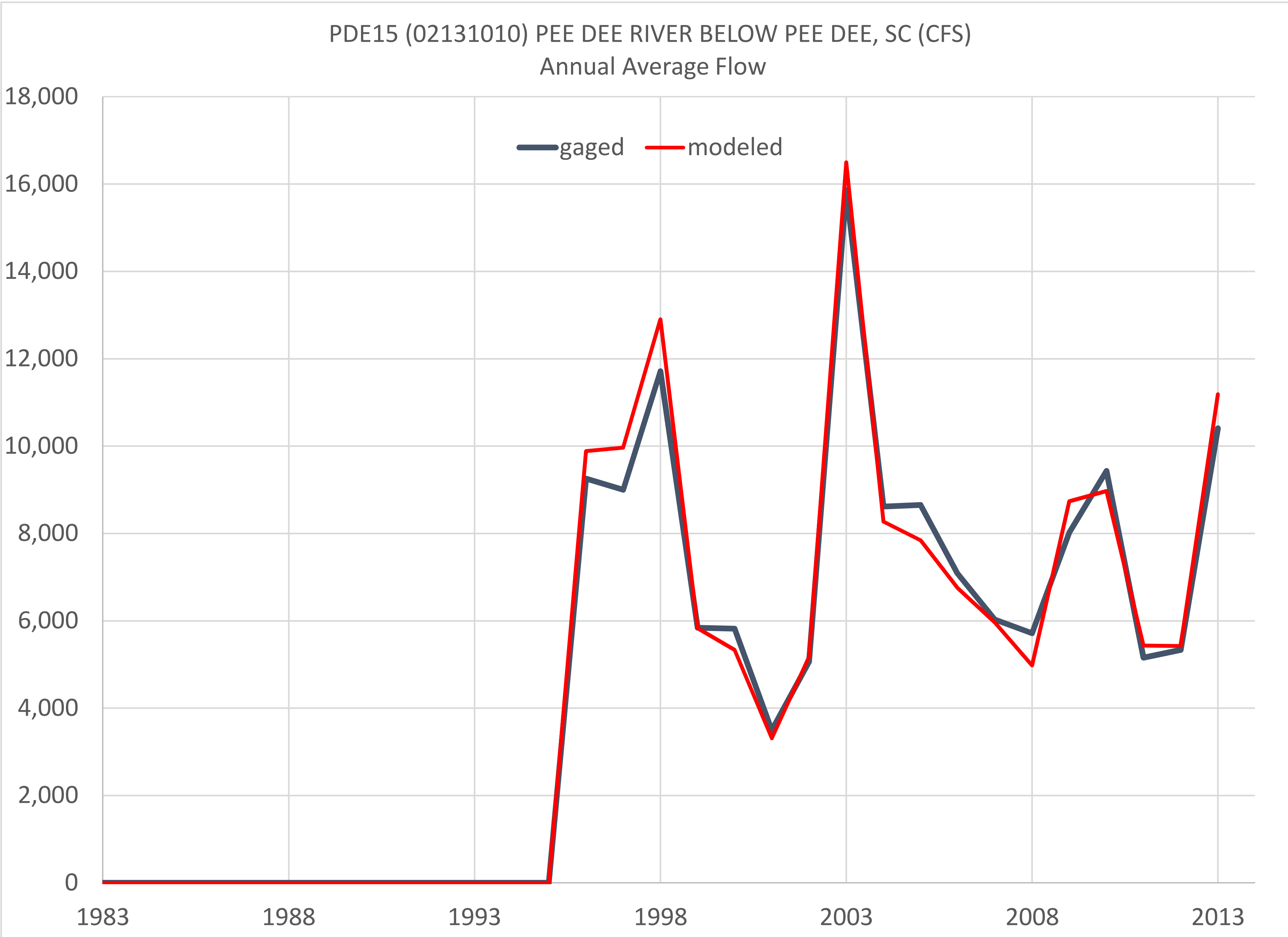


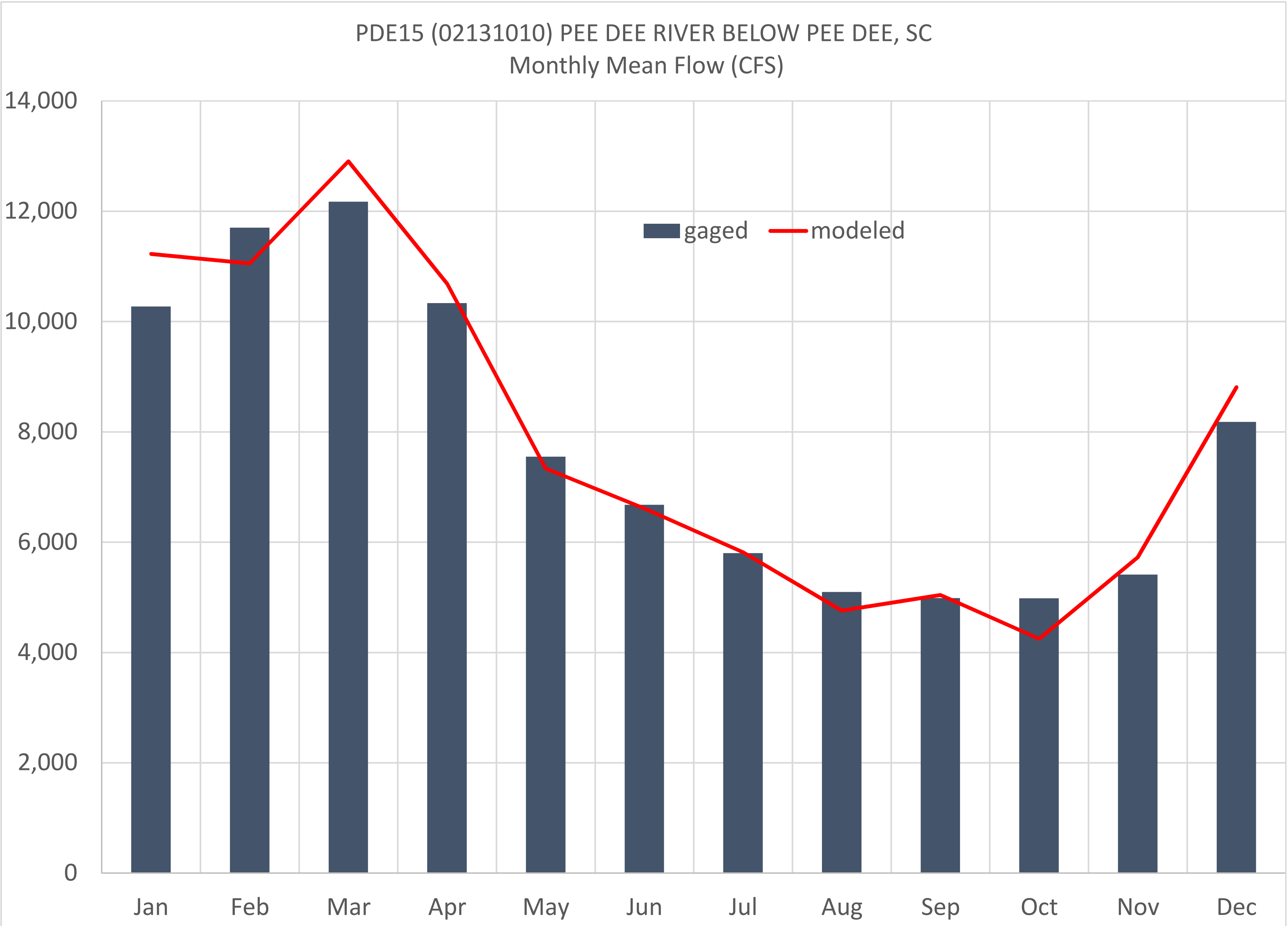
PDE14 (02131000) PEE DEE RIVER AT PEEDEE, SC
Monthly Flow Percentiles (CFS)
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
gaged
modeled
Percentile

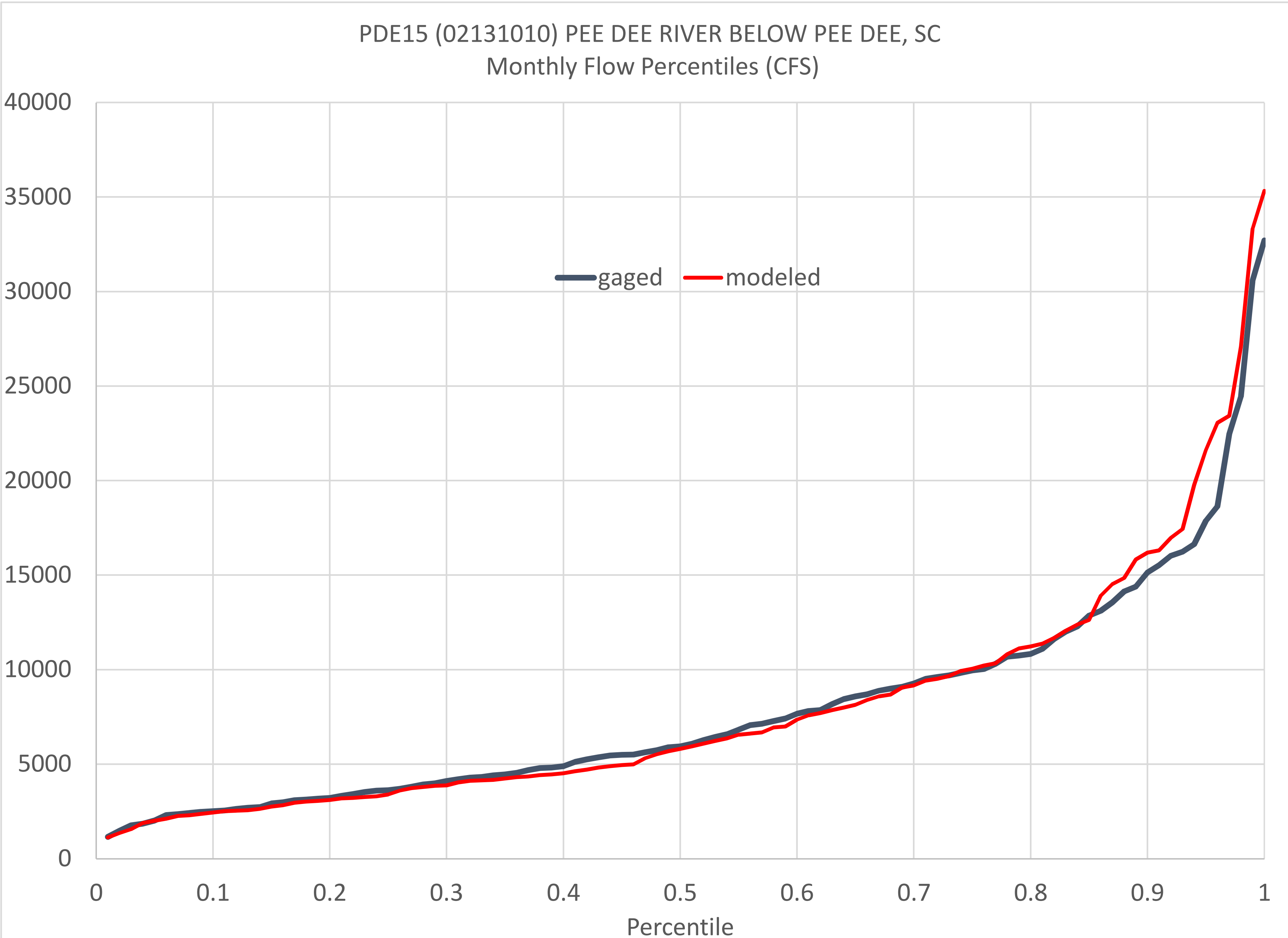

PDE14 (02131000) PEE DEE RIVER AT PEEDEE, SC (CFS)
Monthly Cumulative Flow (CFS)
modeled (cumulative)
gaged (cumulative)
4,000,000
3,500,000
3,000,000
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

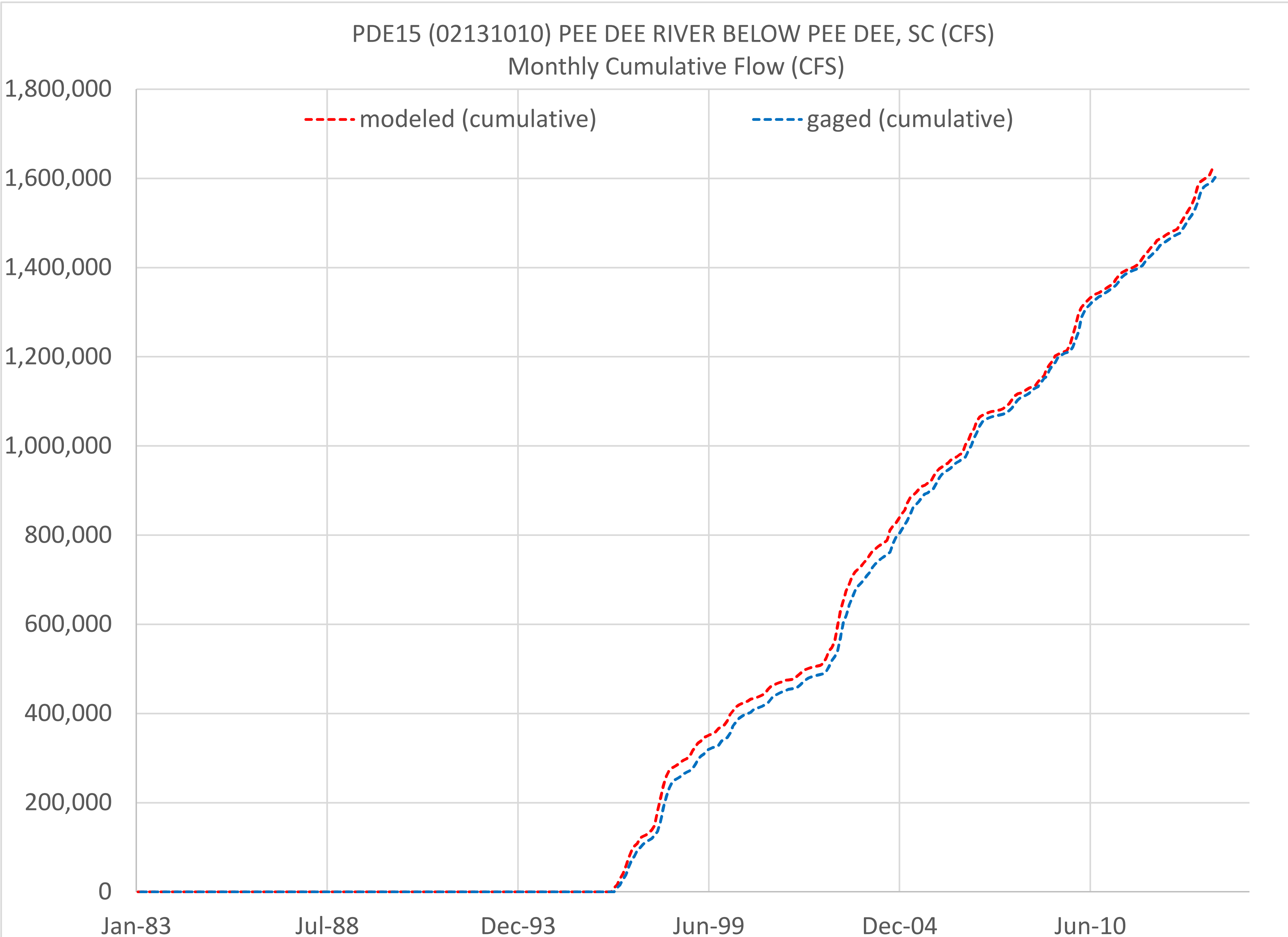


PDE15 (02131010) PEE DEE RIVER BELOW PEE DEE, SC (CFS)
modeled
gaged
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

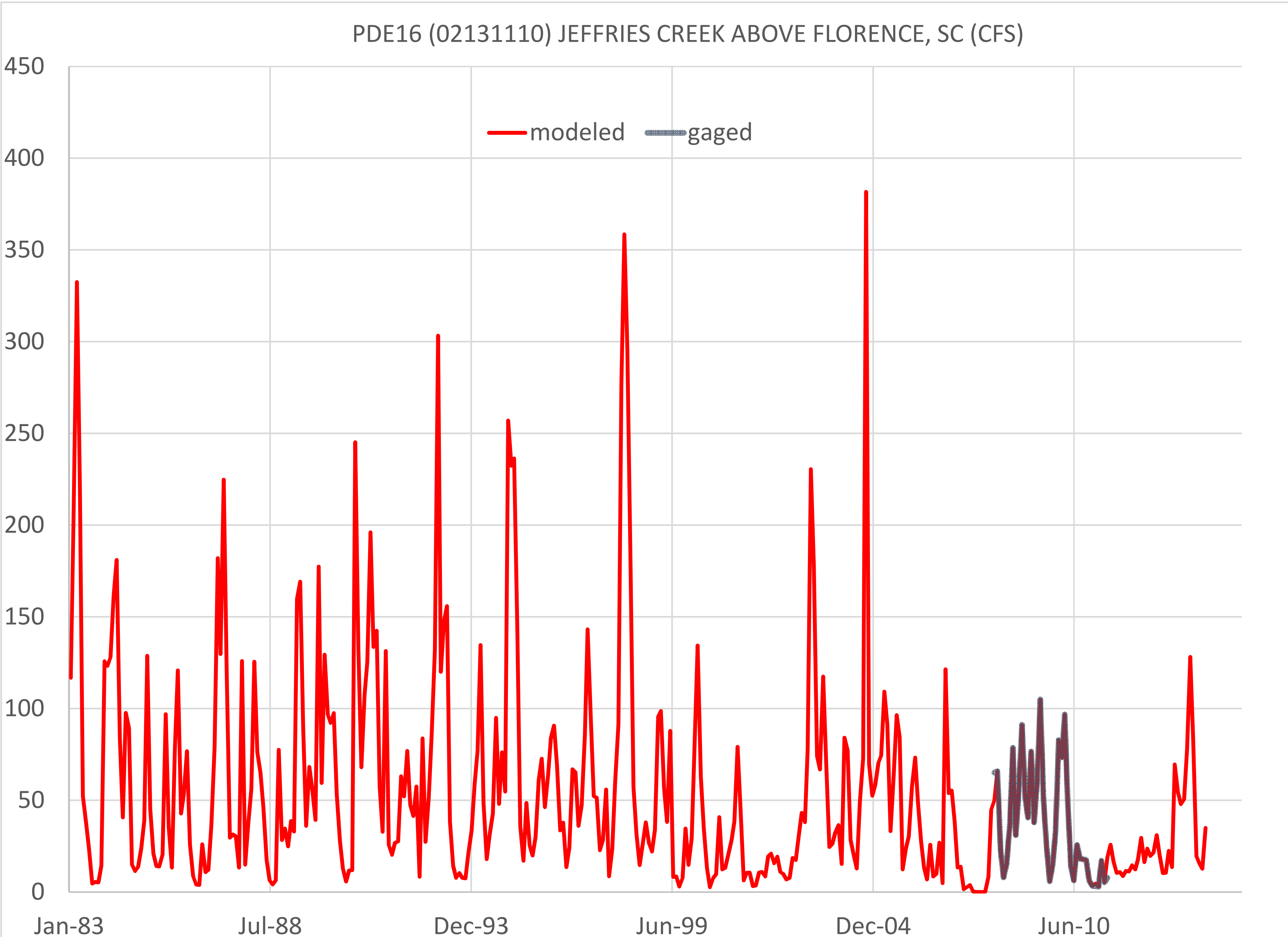

PDE15 (02131010) PEE DEE RIVER BELOW PEE DEE, SC (CFS)
Annual Average Flow
gaged
modeled
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1983
1988
1993
1998
2003
2008
2013

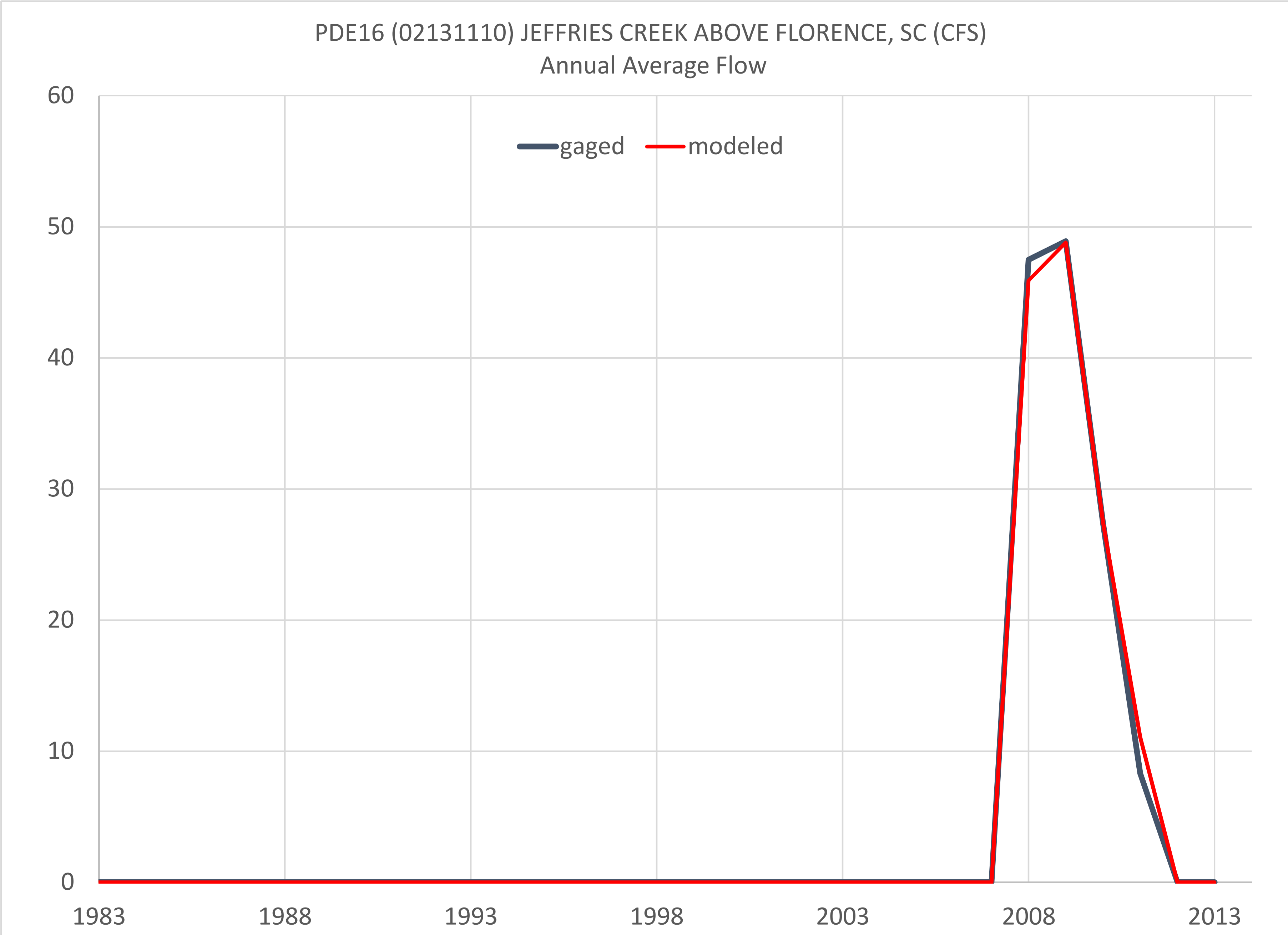

PDE15 (02131010) PEE DEE RIVER BELOW PEE DEE, SC
Monthly Mean Flow (CFS)
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
gaged
modeled
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


PDE15 (02131010) PEE DEE RIVER BELOW PEE DEE, SC
Monthly Flow Percentiles (CFS)
gaged
modeled
40000
35000
30000
25000
20000
15000
10000
5000
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

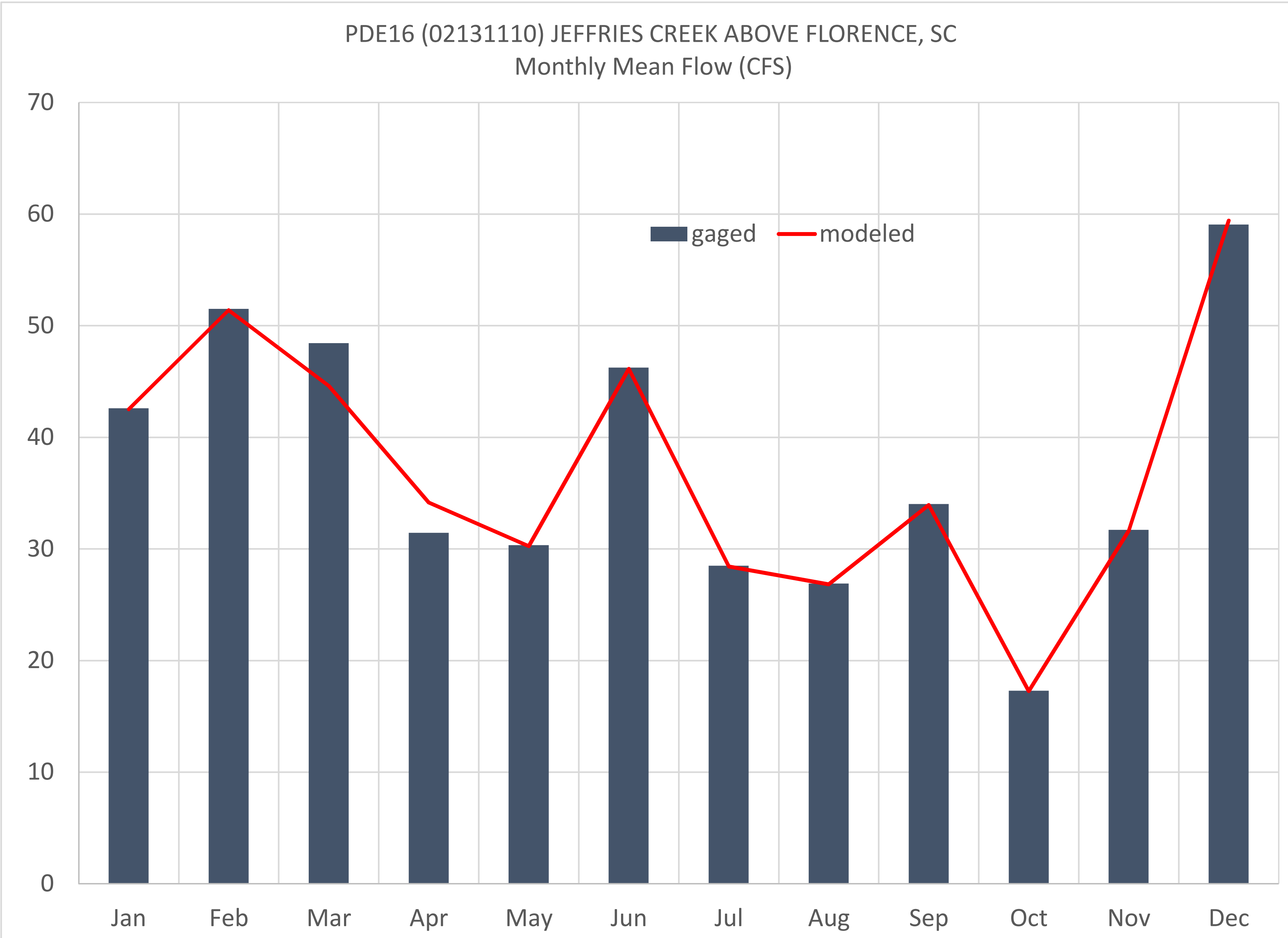


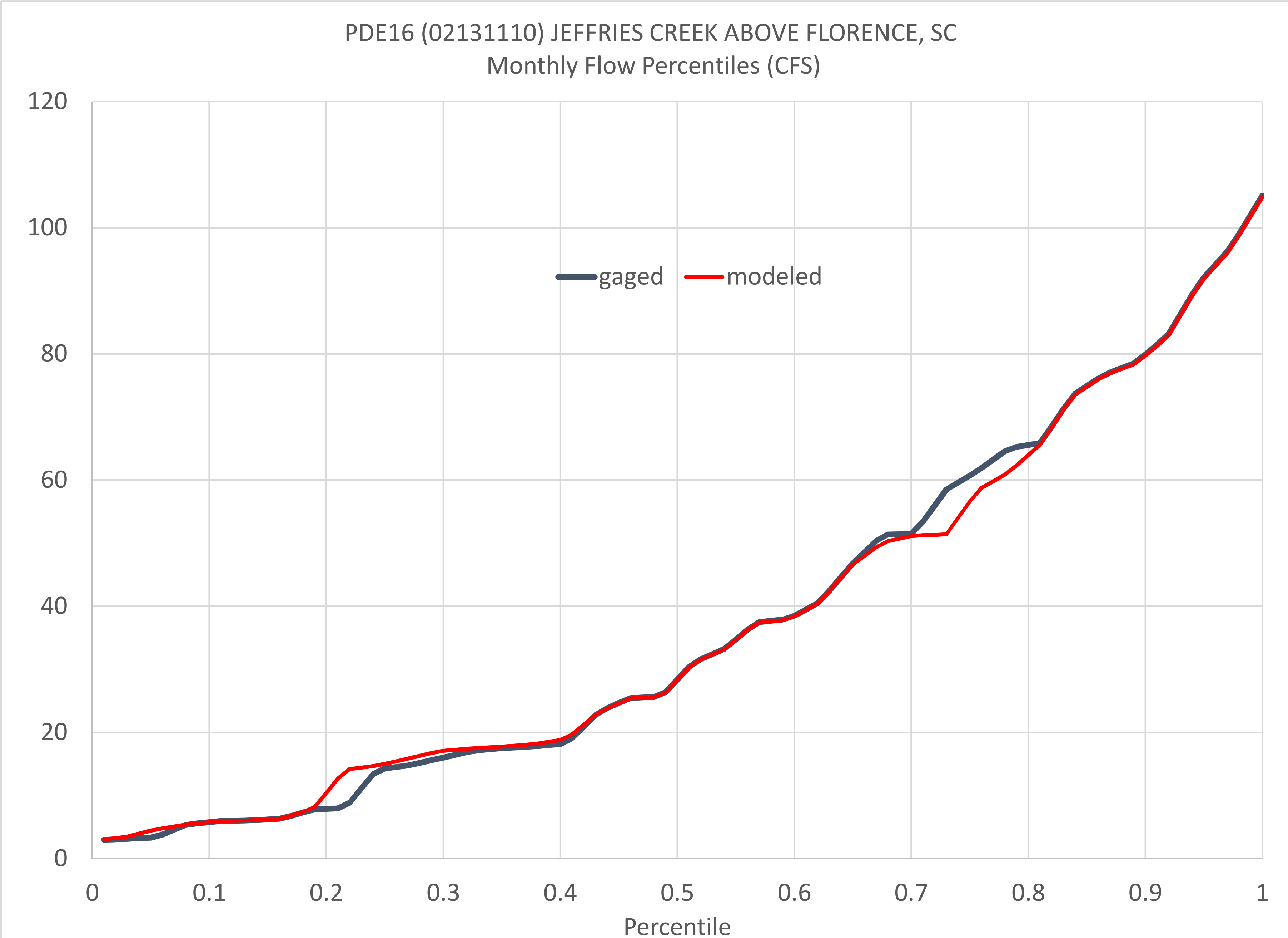
PDE15 (02131010) PEE DEE RIVER BELOW PEE DEE, SC (CFS)
Monthly Cumulative Flow (CFS)
modeled (cumulative)
gaged (cumulative)
1,800,000
1,600,000
1,400,000
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

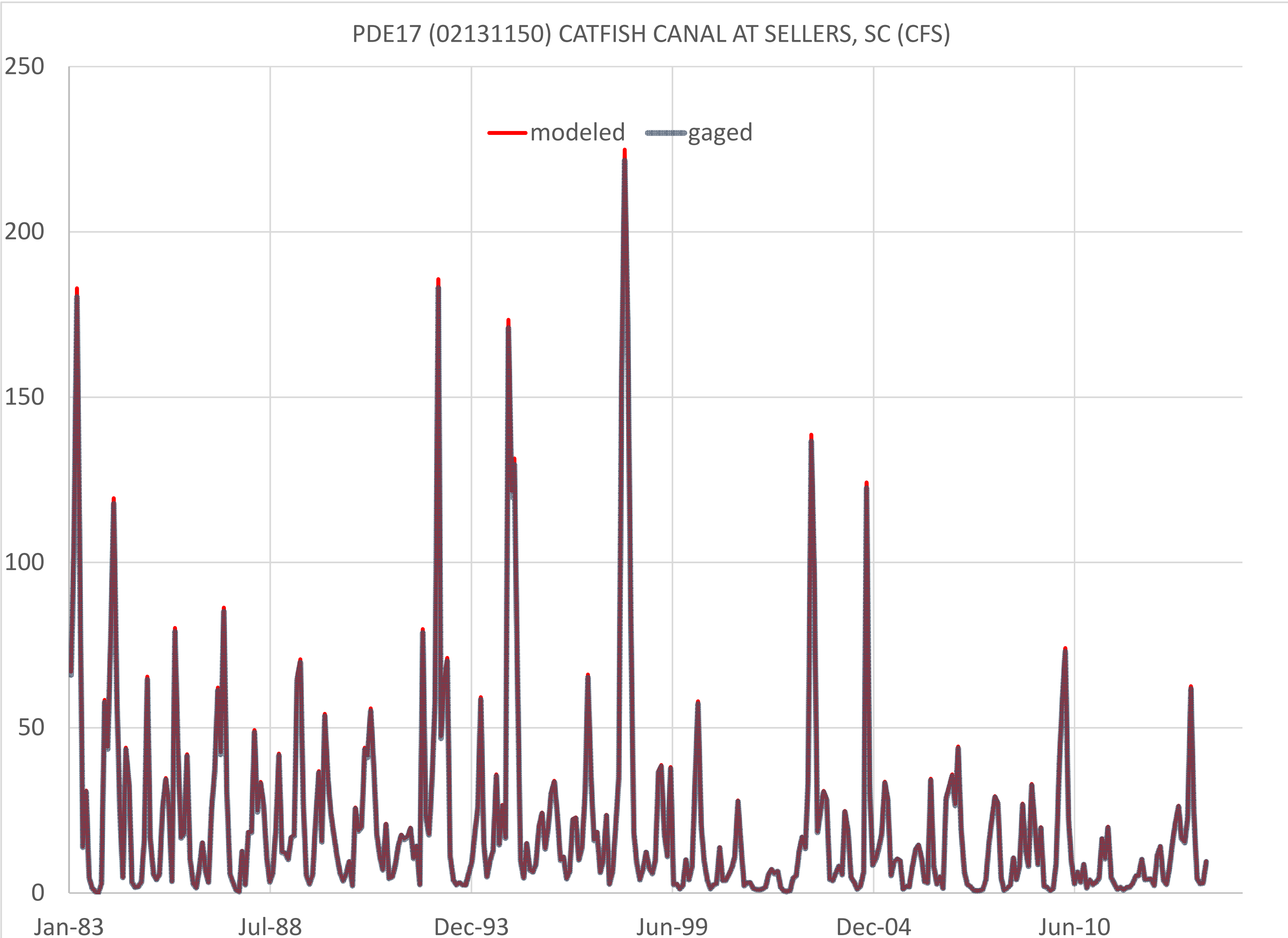

PDE16 (02131110) JEFFRIES CREEK ABOVE FLORENCE, SC (CFS)
modeled
gaged
450
400
350
300
250
200
150
100
50
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10



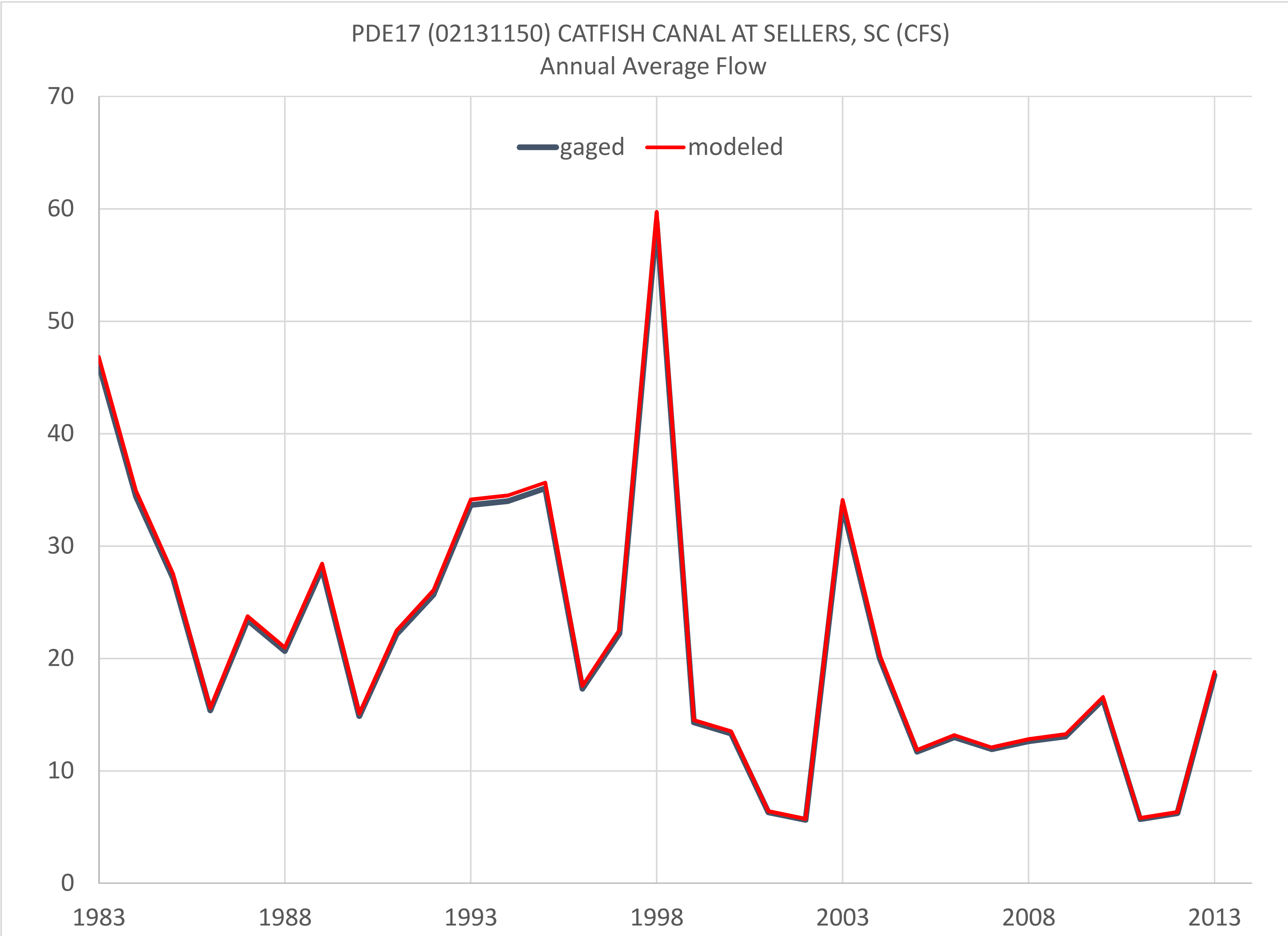
PDE16 (02131110) JEFFRIES CREEK ABOVE FLORENCE, SC (CFS)
Annual Average Flow
gaged
modeled
60
50
40
30
20
10
0
1983
1988
1993
1998
2003
2008
2013


PDE16 (02131110) JEFFRIES CREEK ABOVE FLORENCE, SC
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

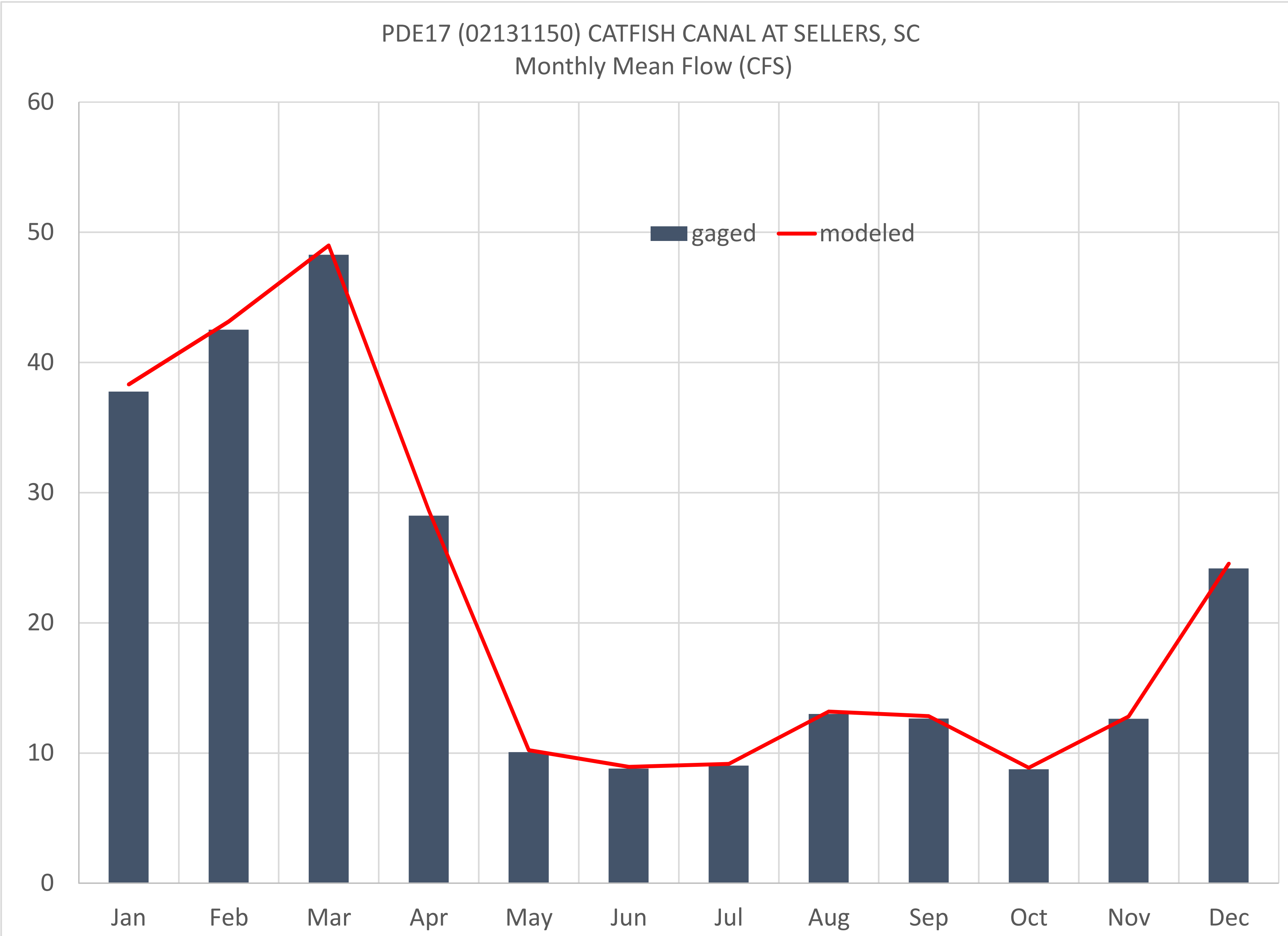

PDE16 (02131110) JEFFRIES CREEK ABOVE FLORENCE, SC
Monthly Flow Percentiles (CFS)
120
100
80
60
40
20
0
gaged
modeled
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile



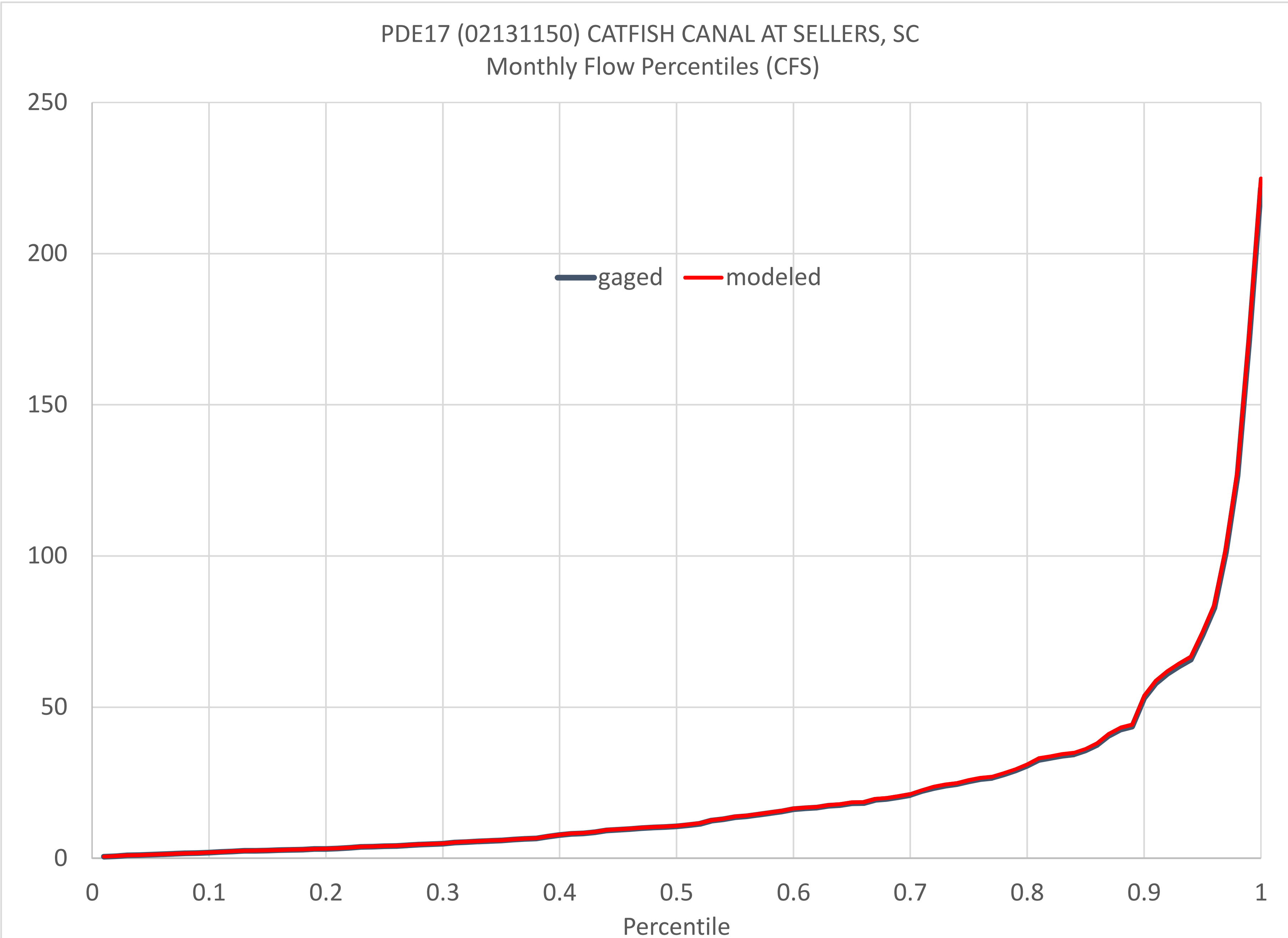
PDE17 (02131150) CATFISH CANAL AT SELLERS, SC (CFS)
modeled
gaged
250
200
150
100
50
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

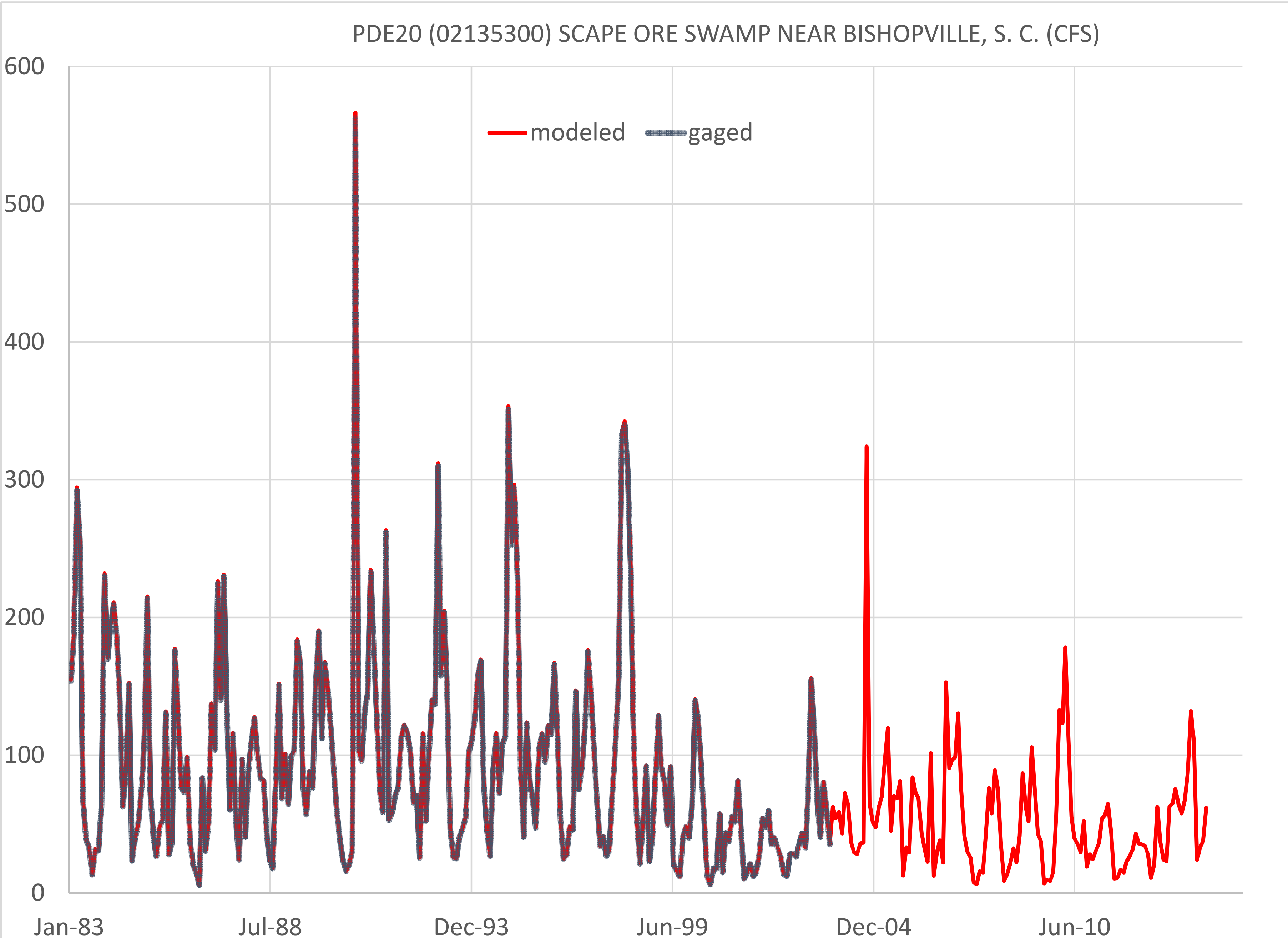


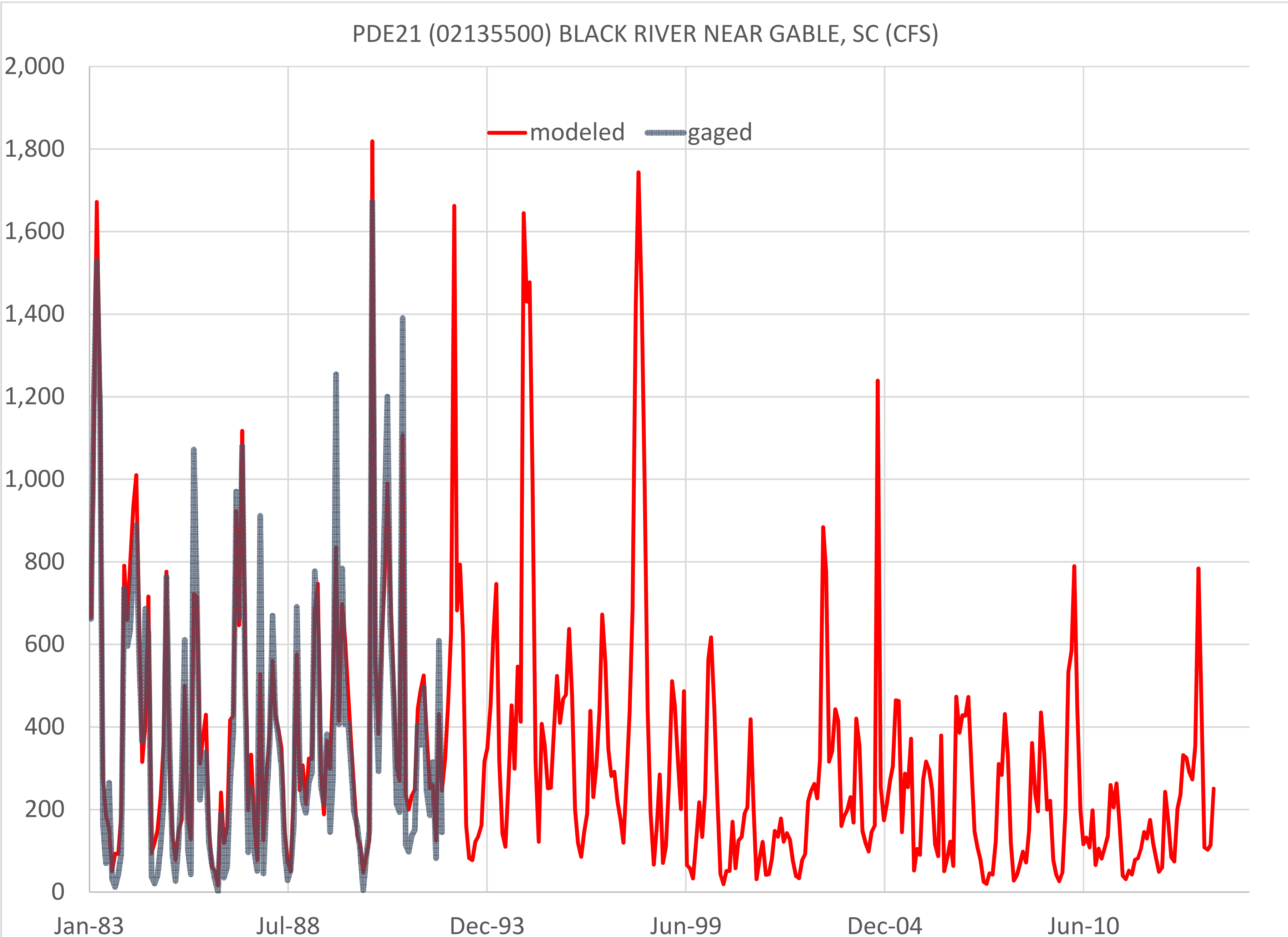
PDE17 (02131150) CATFISH CANAL AT SELLERS, SC (CFS)
Annual Average Flow
gaged
modeled
70
60
50
40
30
20
10
0
1983
1988
1993
1998
2003
2008
2013

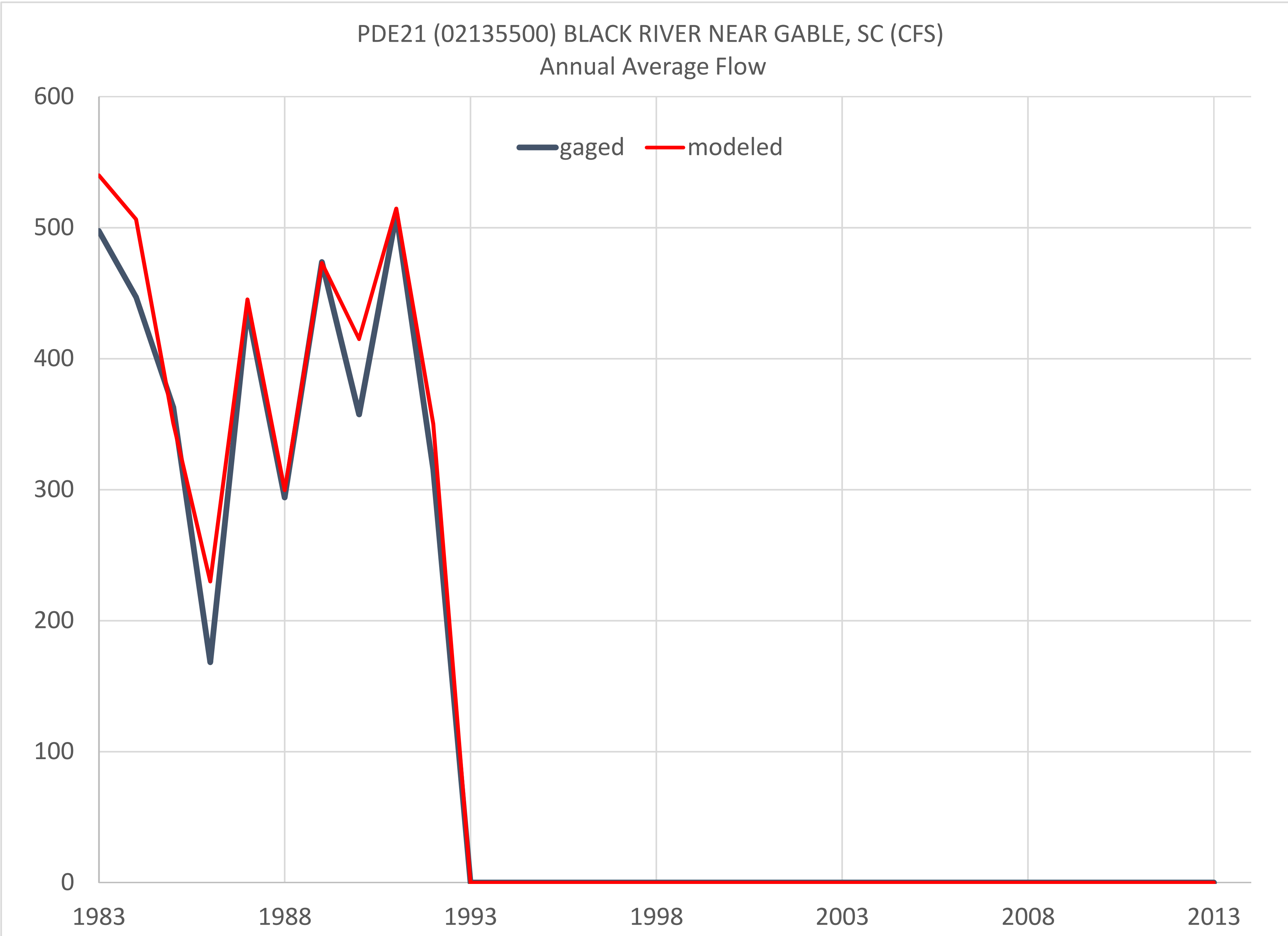


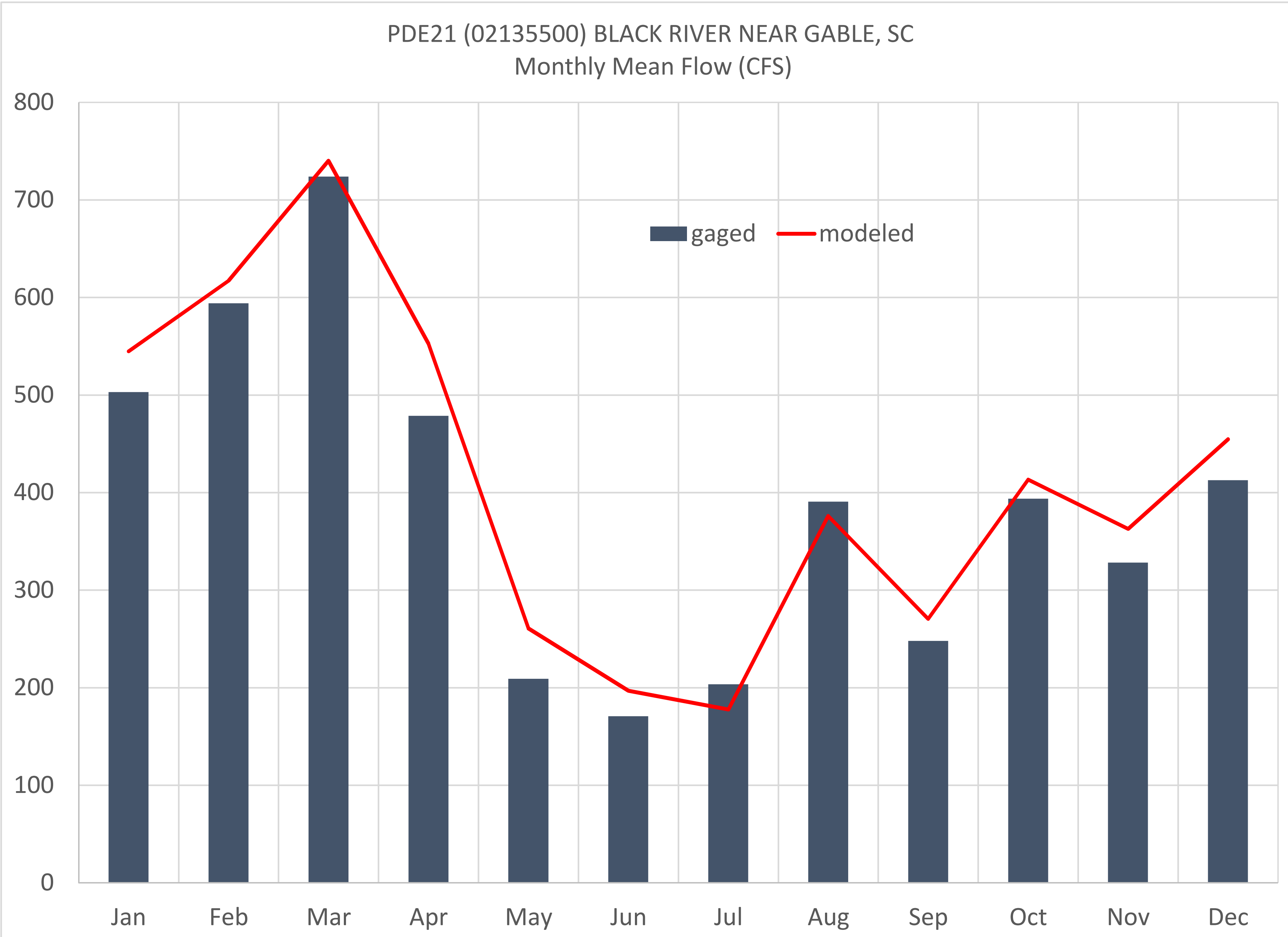
PDE17 (02131150) CATFISH CANAL AT SELLERS, SC
Monthly Mean Flow (CFS)
gaged
modeled
60
50
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

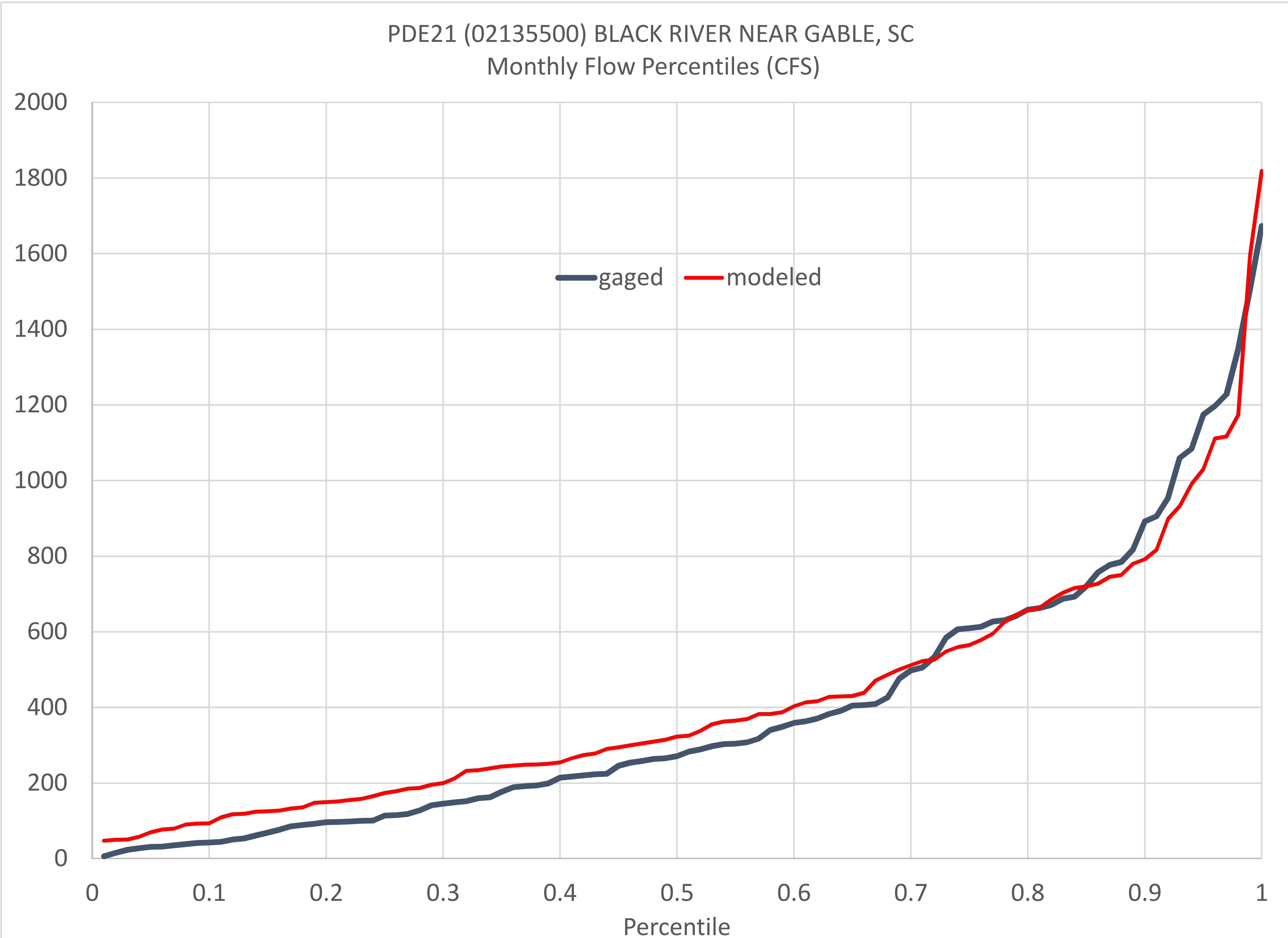

PDE17 (02131150) CATFISH CANAL AT SELLERS, SC
Monthly Flow Percentiles (CFS)
250
200
150
100
50
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile
gaged
modeled

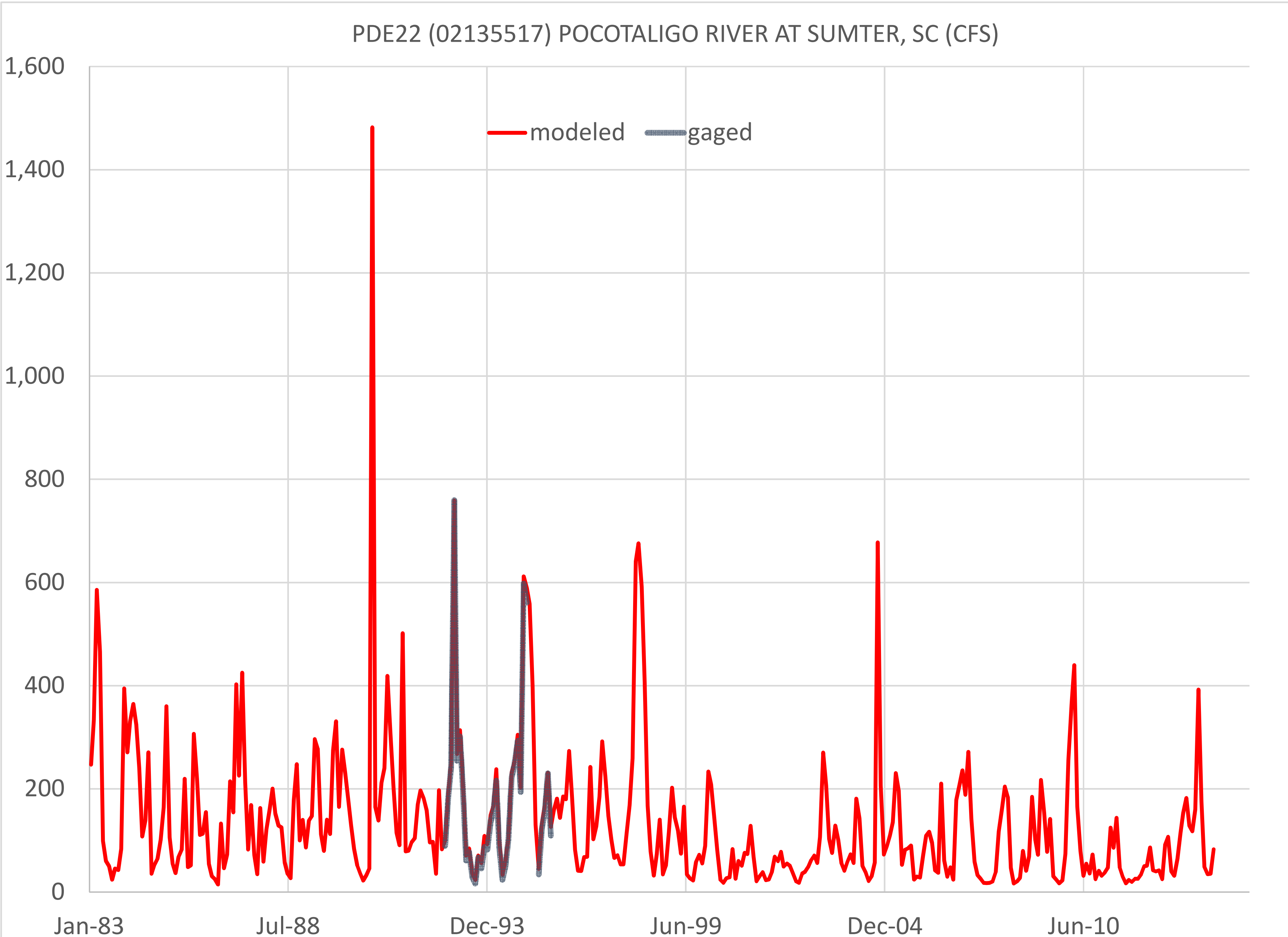

PDE20 (02135300) SCAPE ORE SWAMP NEAR BISHOPVILLE, S. C. (CFS)
modeled
gaged
600
500
400
300
200
100
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

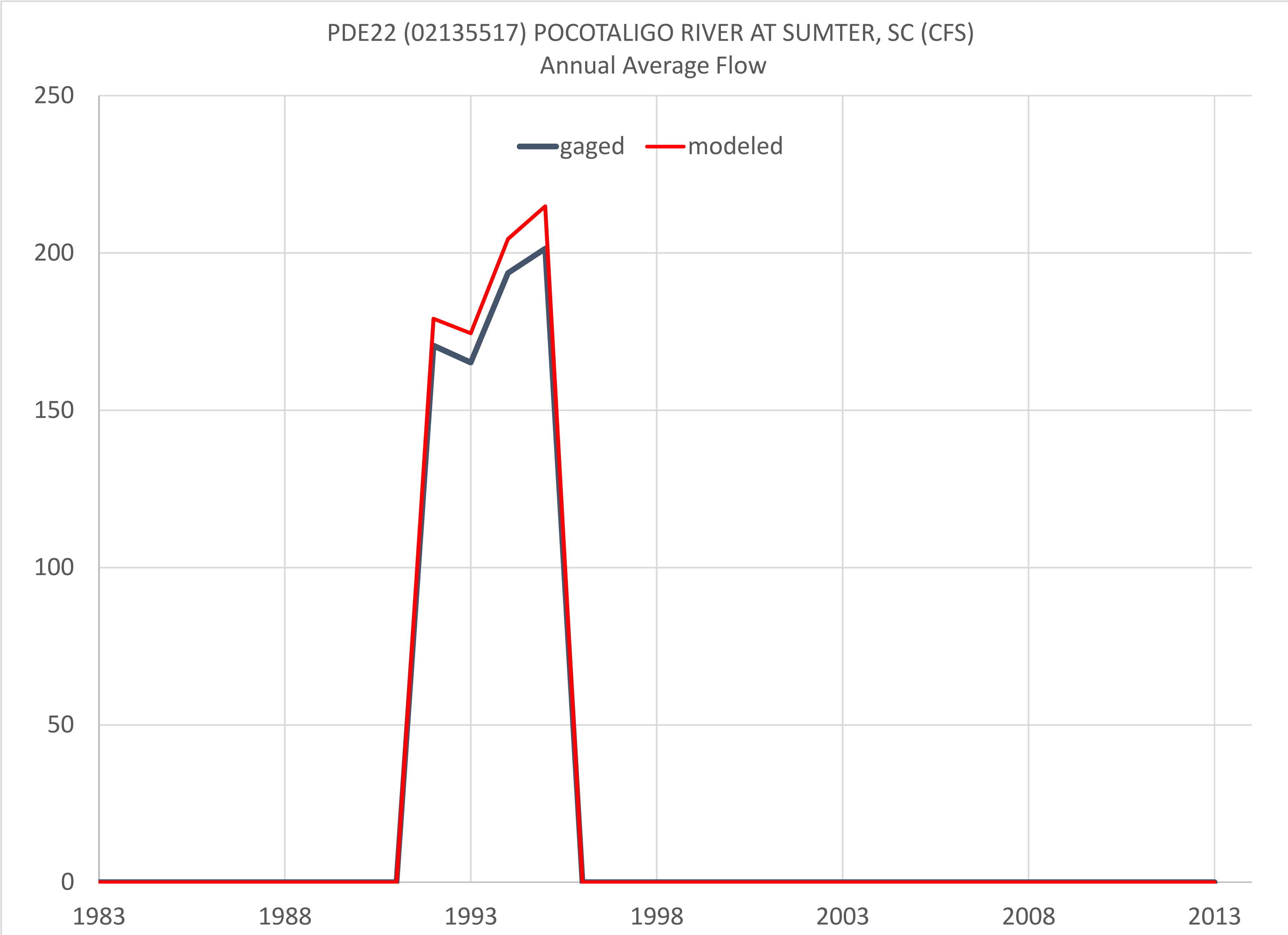

PDE21 (02135500) BLACK RIVER NEAR GABLE, SC (CFS)
modeled
gaged
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10


PDE21 (02135500) BLACK RIVER NEAR GABLE, SC (CFS)
Annual Average Flow
gaged
modeled
600
500
400
300
200
100
0
1983
1988
1993
1998
2003
2008
2013

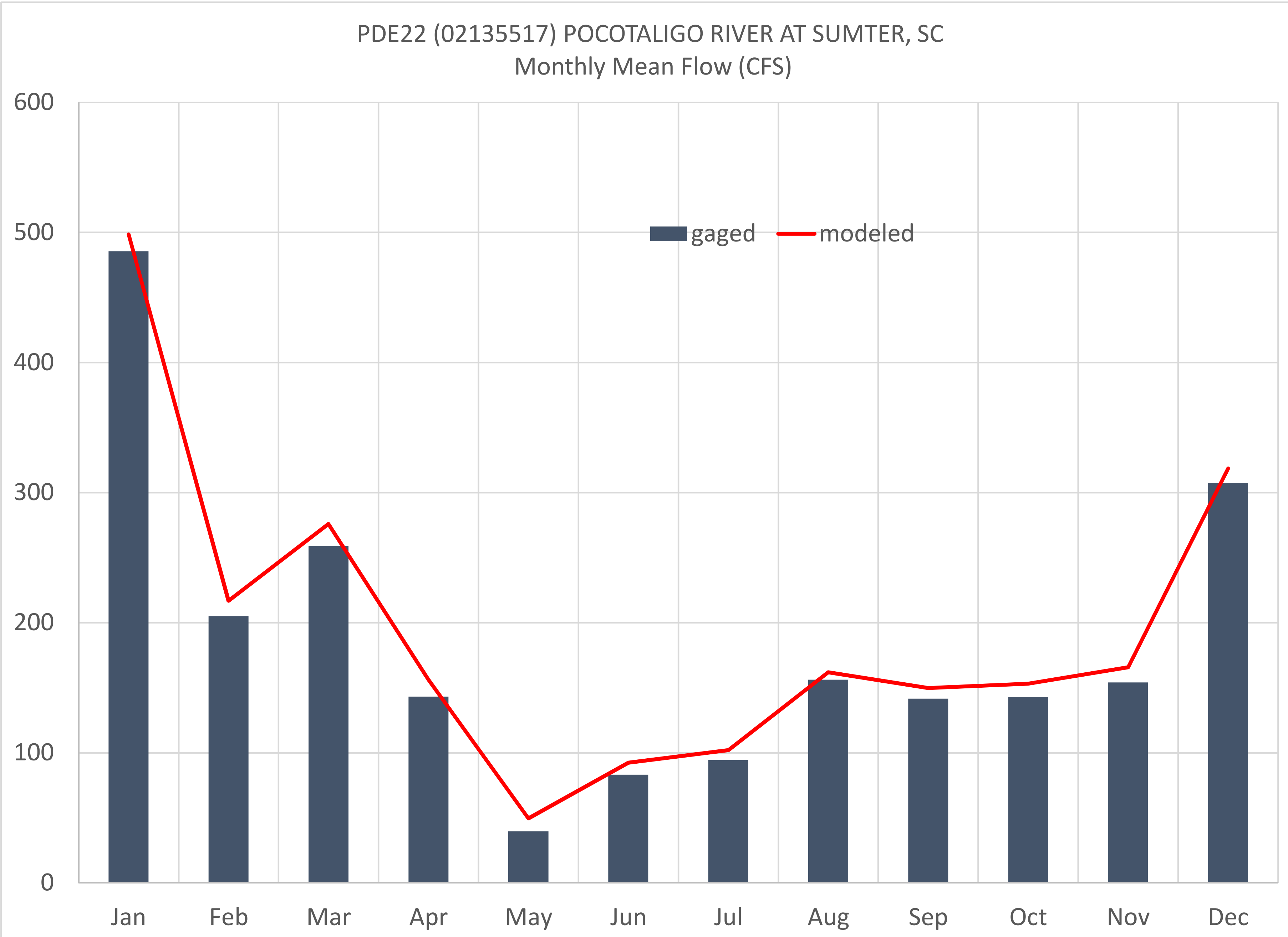

PDE21 (02135500) BLACK RIVER NEAR GABLE, SC
Monthly Mean Flow (CFS)
800
700
600
500
400
300
200
100
0
gaged
modeled
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

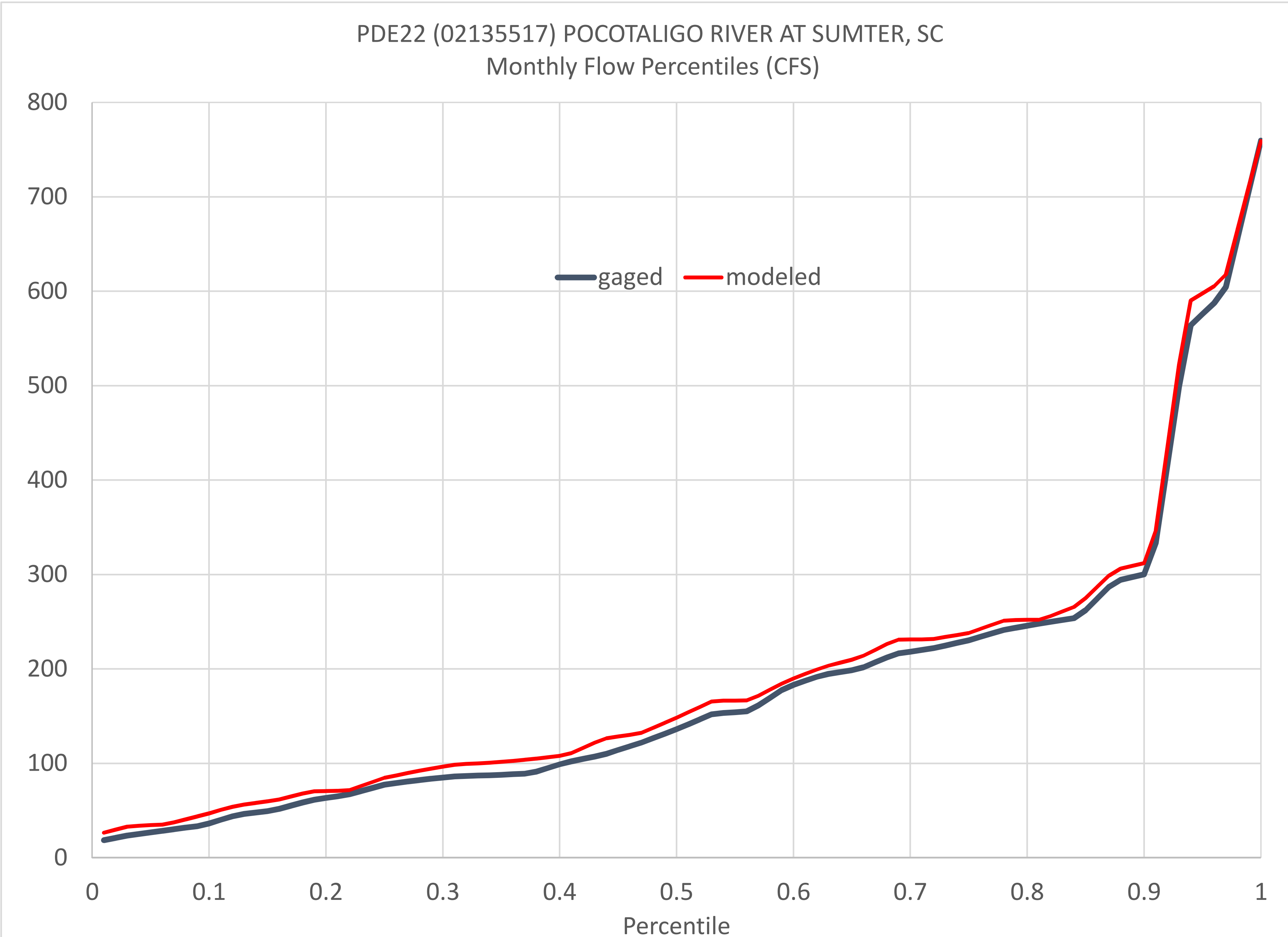

PDE21 (02135500) BLACK RIVER NEAR GABLE, SC
Monthly Flow Percentiles (CFS)
gaged
modeled
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

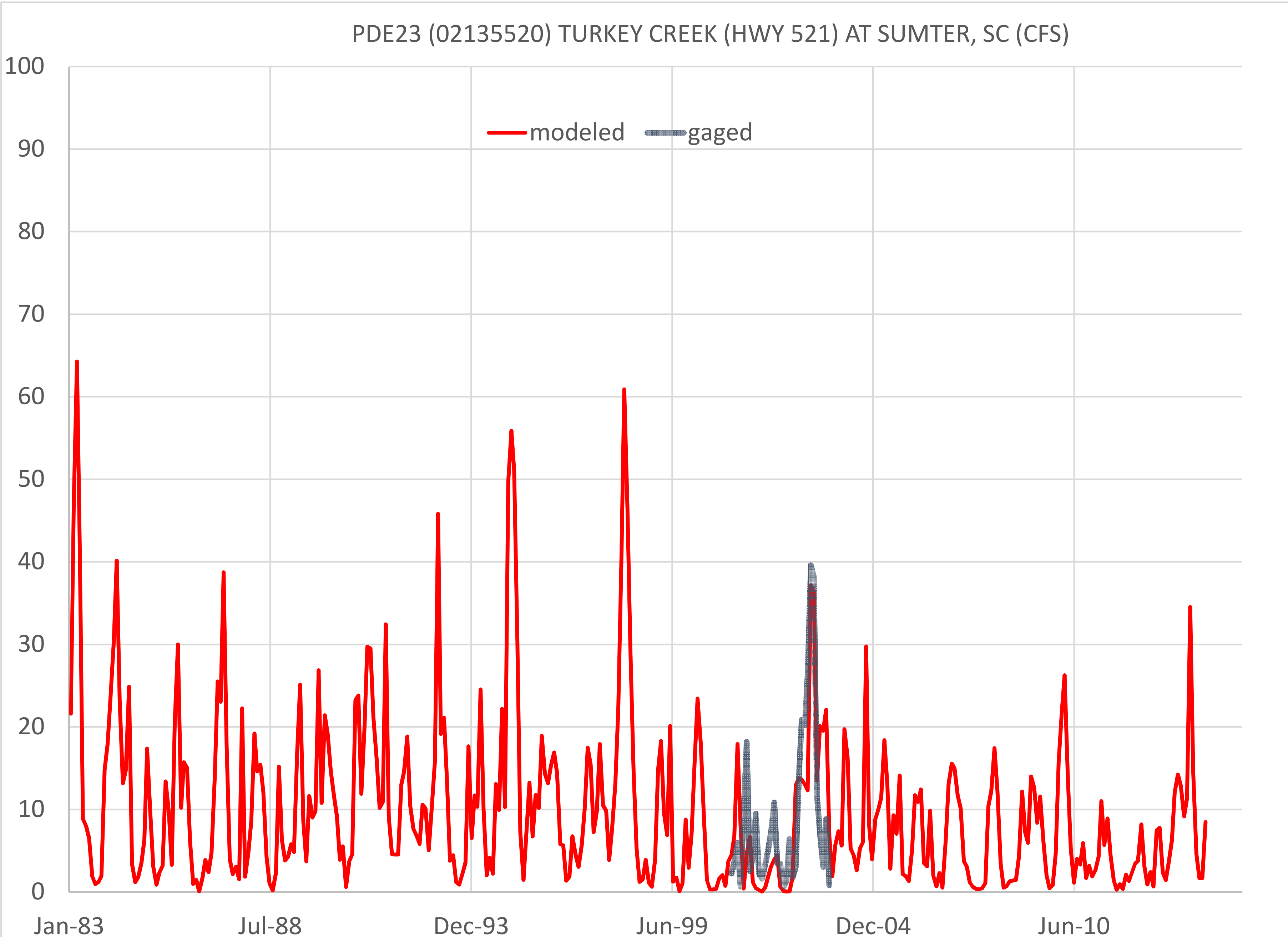

PDE22 (02135517) POCOTALIGO RIVER AT SUMTER, SC (CFS)
modeled
gaged
1,600
1,400
1,200
1,000
800
600
400
200
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

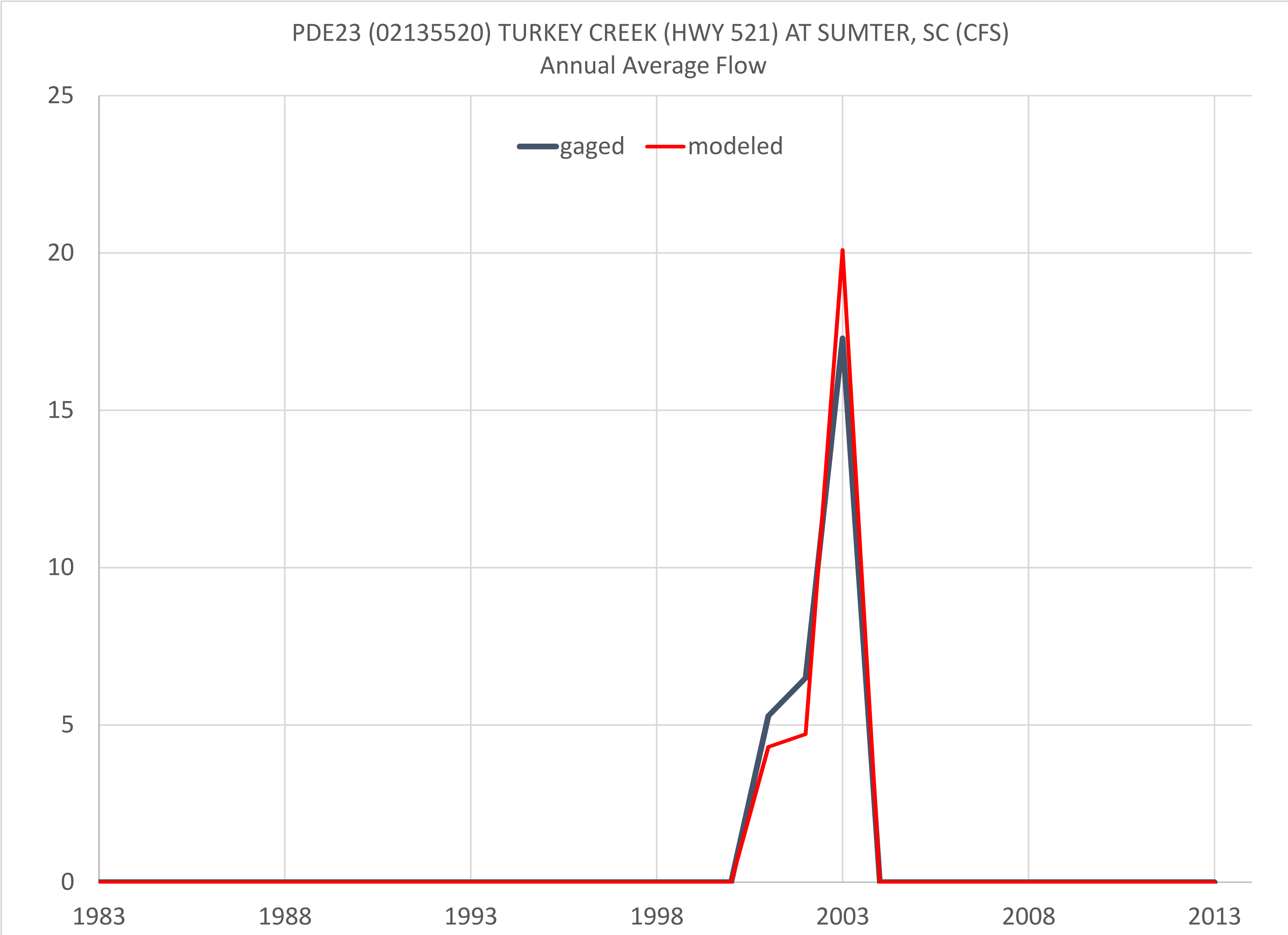


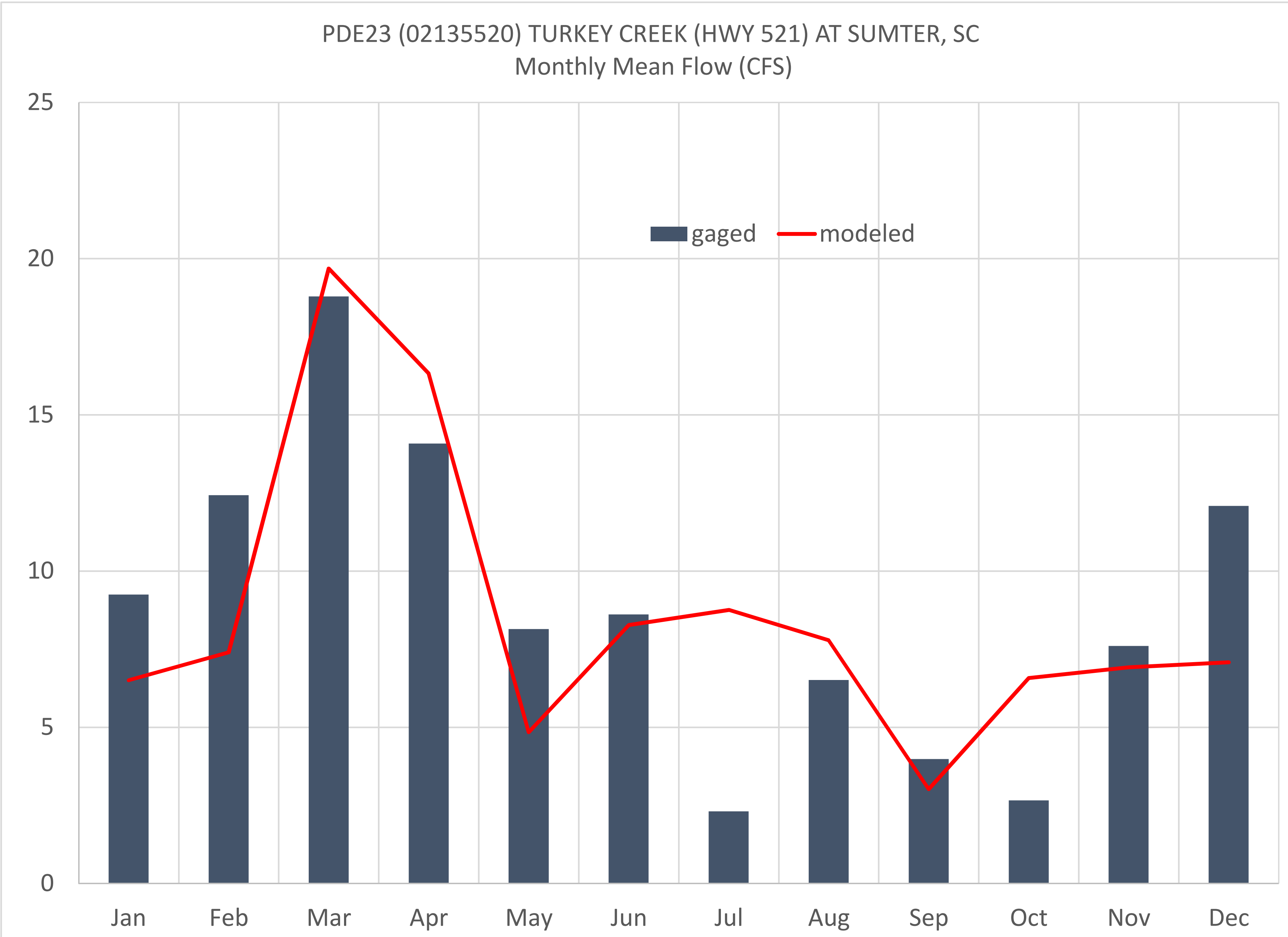
PDE22 (02135517) POCOTALIGO RIVER AT SUMTER, SC (CFS)
Annual Average Flow
gaged
modeled
250
200
150
100
50
0
1983
1988
1993
1998
2003
2008
2013

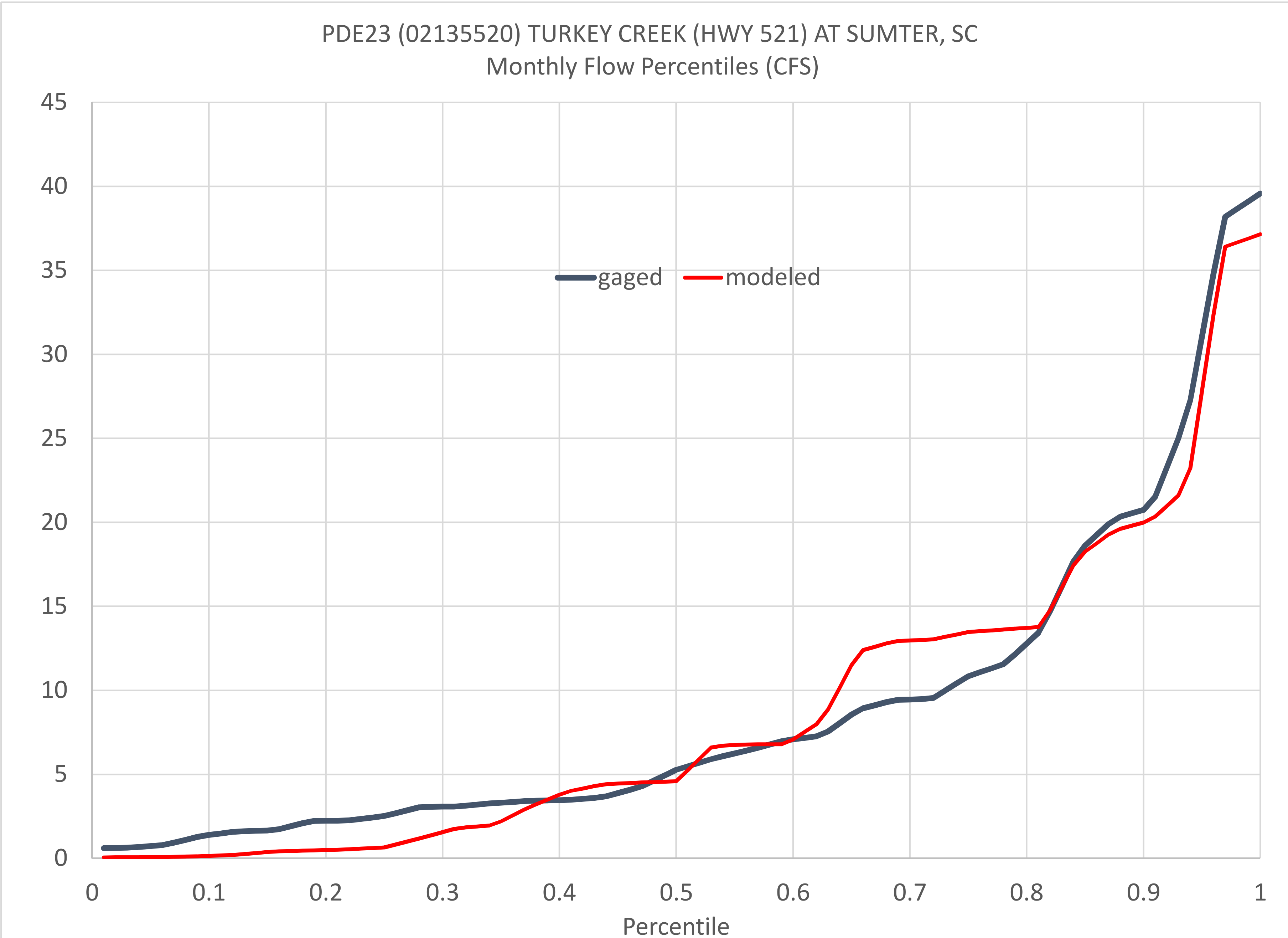

PDE22 (02135517) POCOTALIGO RIVER AT SUMTER, SC
Monthly Mean Flow (CFS)
gaged
modeled
0
100
200
300
400
500
600
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

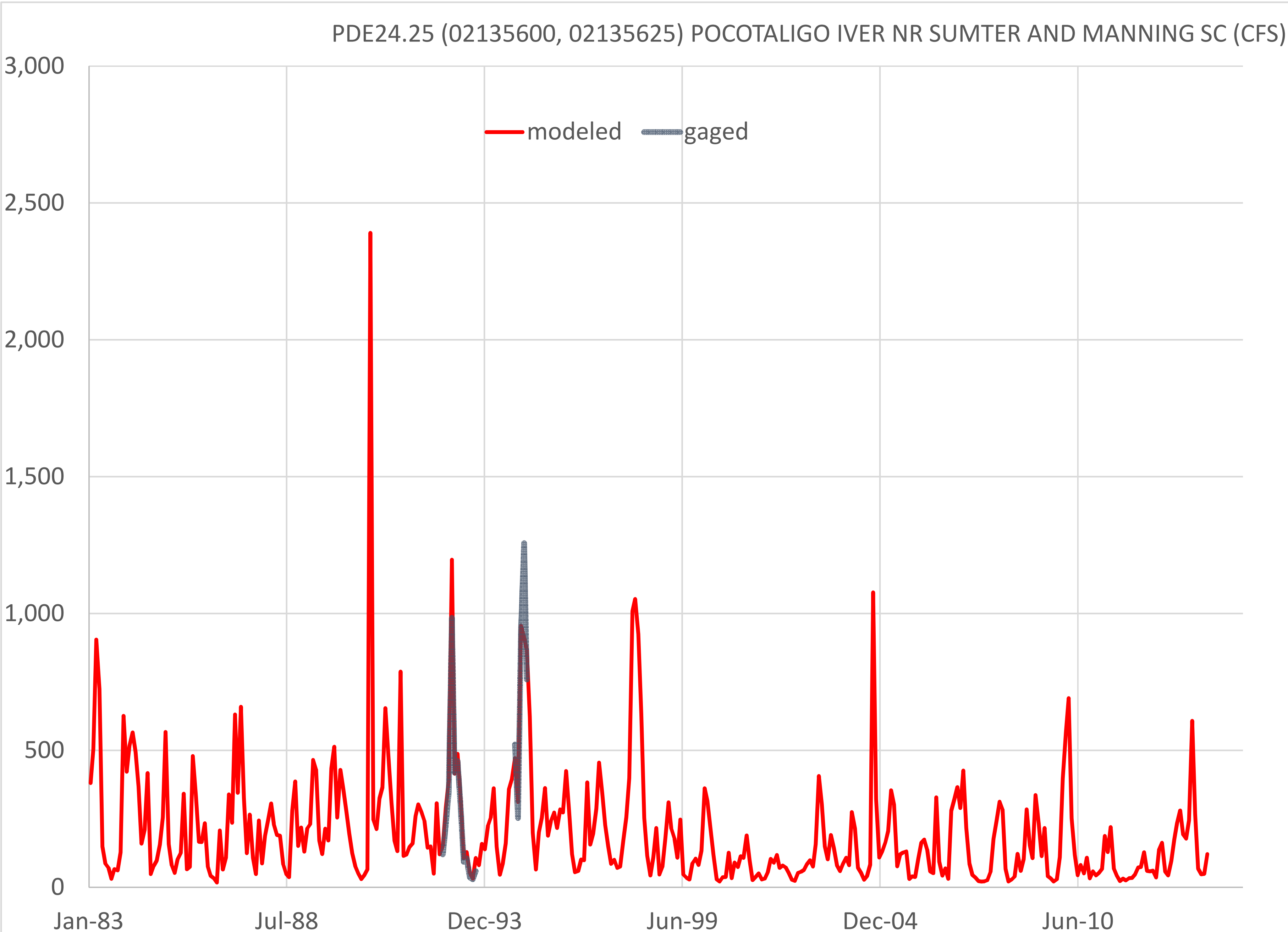

PDE22 (02135517) POCOTALIGO RIVER AT SUMTER, SC
Monthly Flow Percentiles (CFS)
gaged
modeled
0
100
200
300
400
500
600
700
800
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile


PDE23 (02135520) TURKEY CREEK (HWY 521) AT SUMTER, SC (CFS)
modeled
gaged
100
90
80
70
60
50
40
30
20
10
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

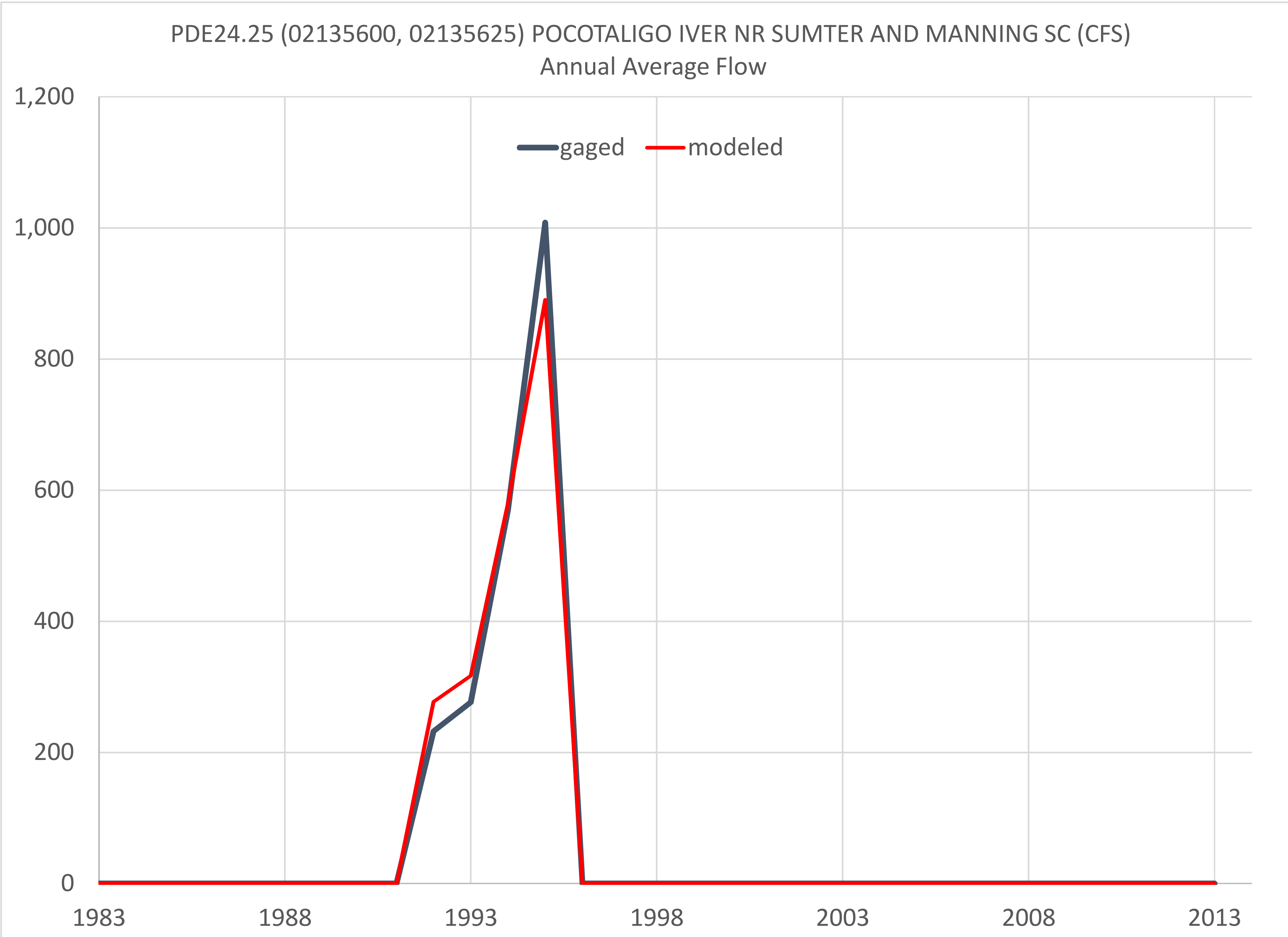

PDE23 (02135520) TURKEY CREEK (HWY 521) AT SUMTER, SC (CFS)
Annual Average Flow
gaged
modeled
25
20
15
10
5
0
1983
1988
1993
1998
2003
2008
2013


PDE23 (02135520) TURKEY CREEK (HWY 521) AT SUMTER, SC
Monthly Mean Flow (CFS)
25
20
15
10
5
0
gaged
modeled
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

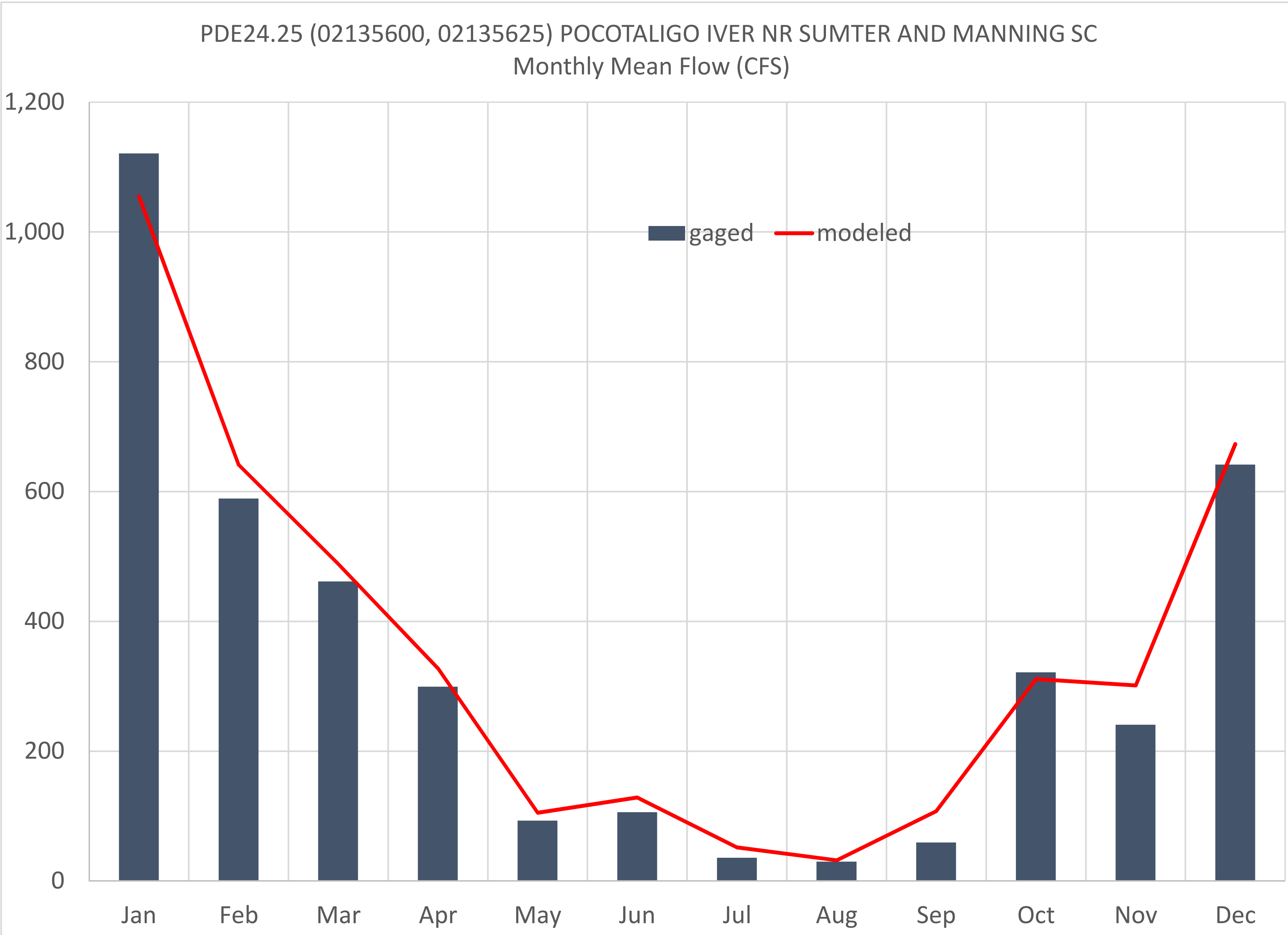

PDE23 (02135520) TURKEY CREEK (HWY 521) AT SUMTER, SC
Monthly Flow Percentiles (CFS)
gaged
modeled
45
40
35
30
25
20
15
10
5
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

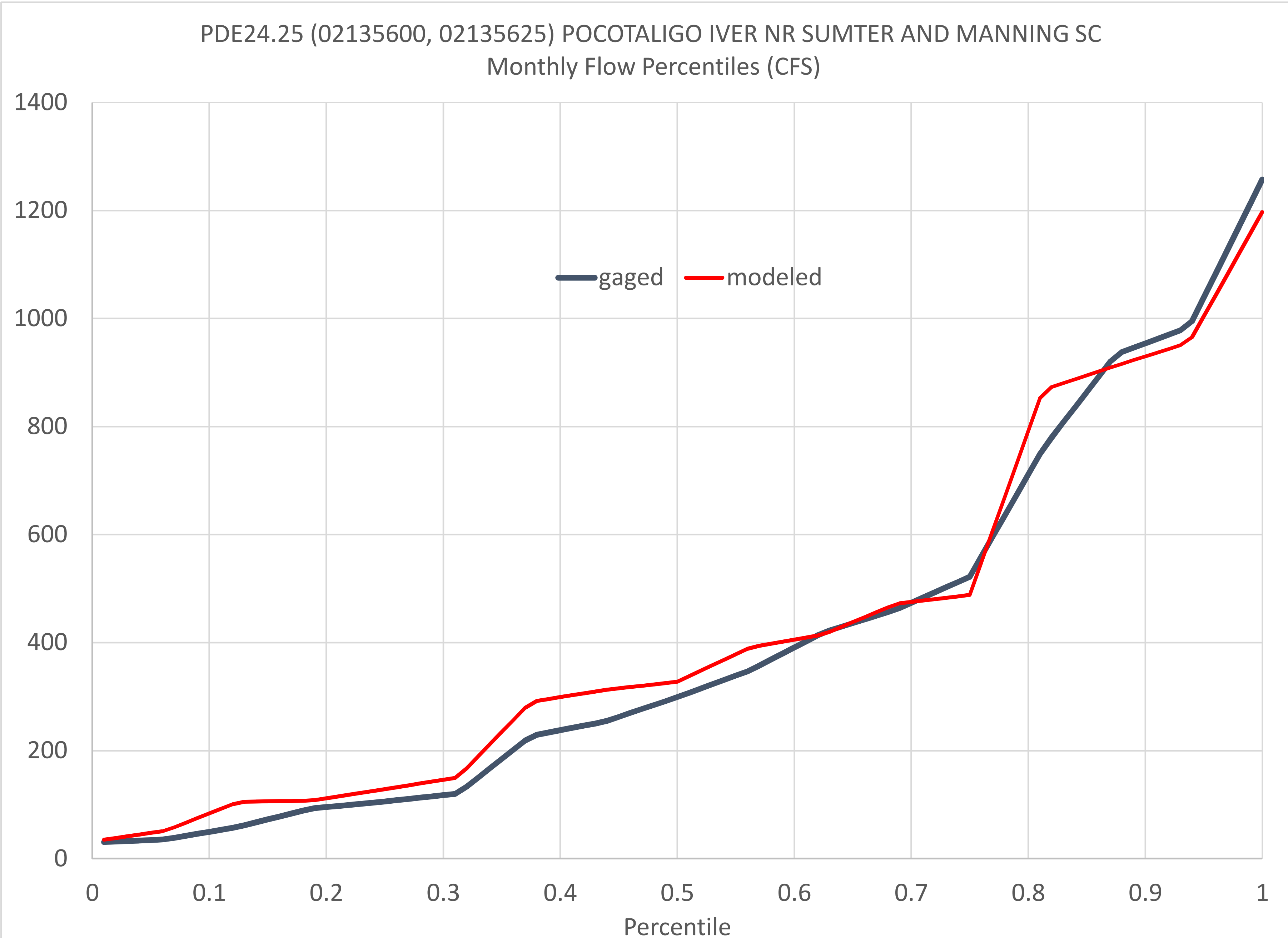


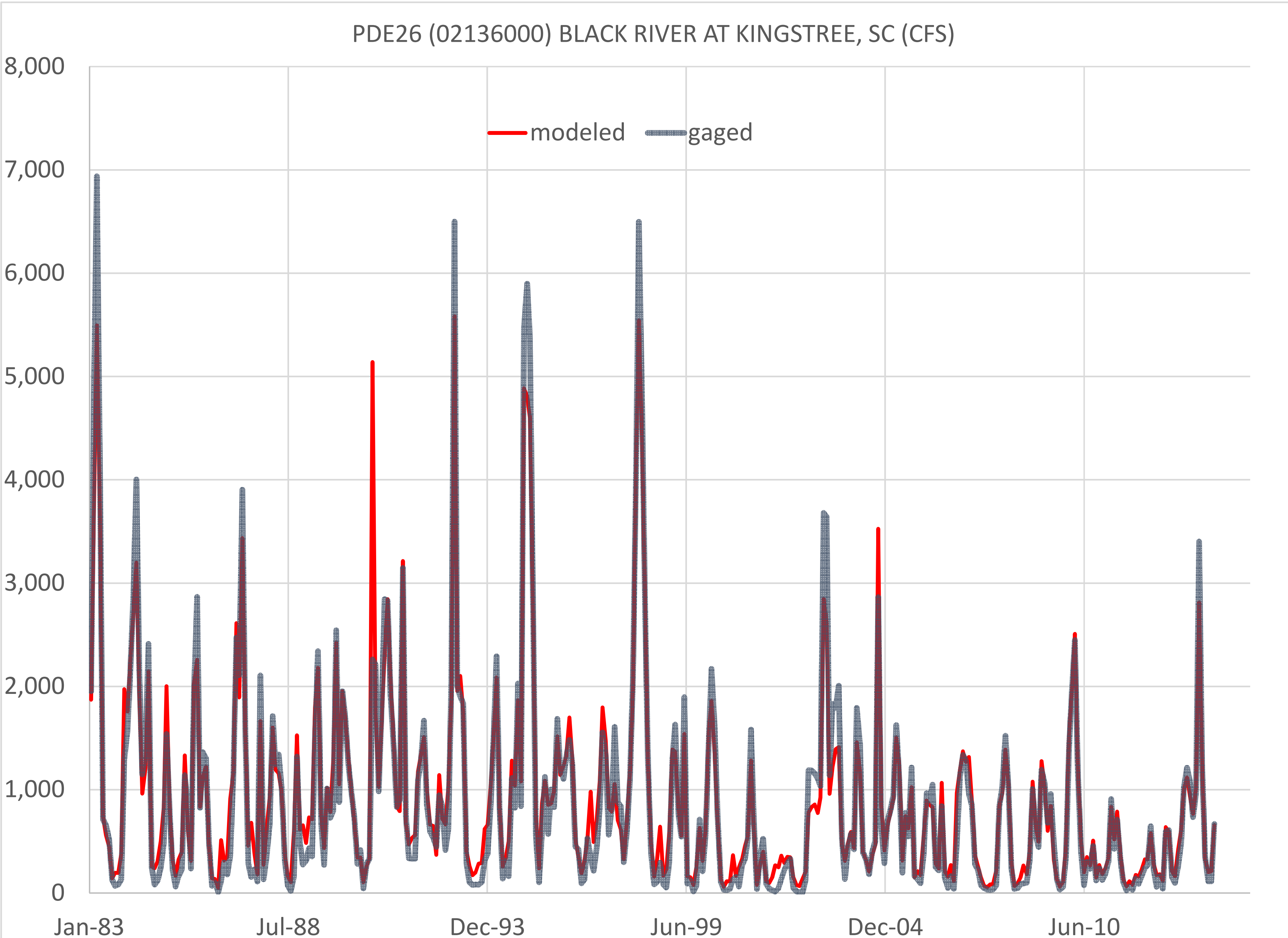
PDE24.25 (02135600, 02135625) POCOTALIGO IVER NR SUMTER AND MANNING SC (CFS)
modeled
gaged
3,000
2,500
2,000
1,500
1,000
500
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

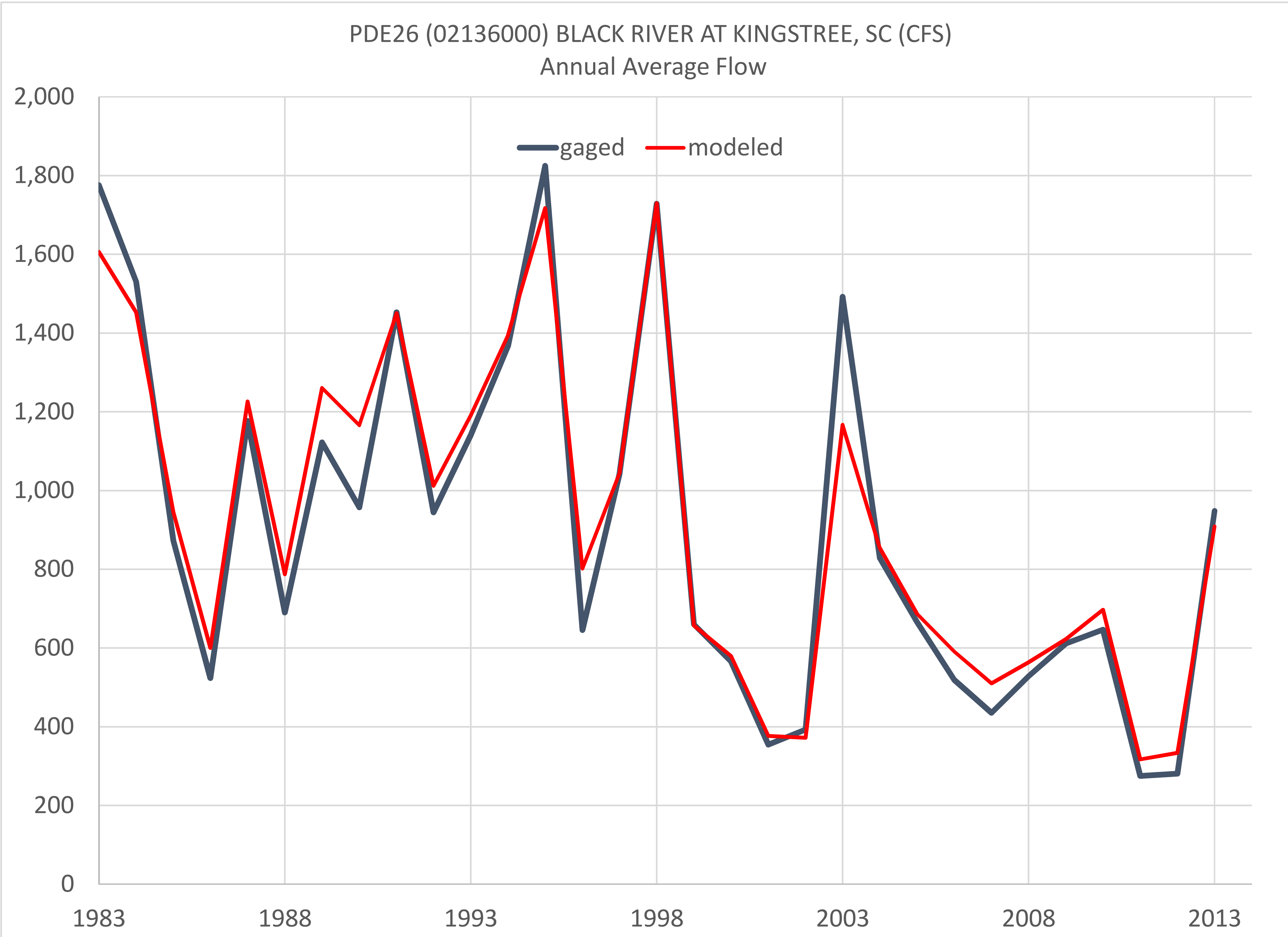


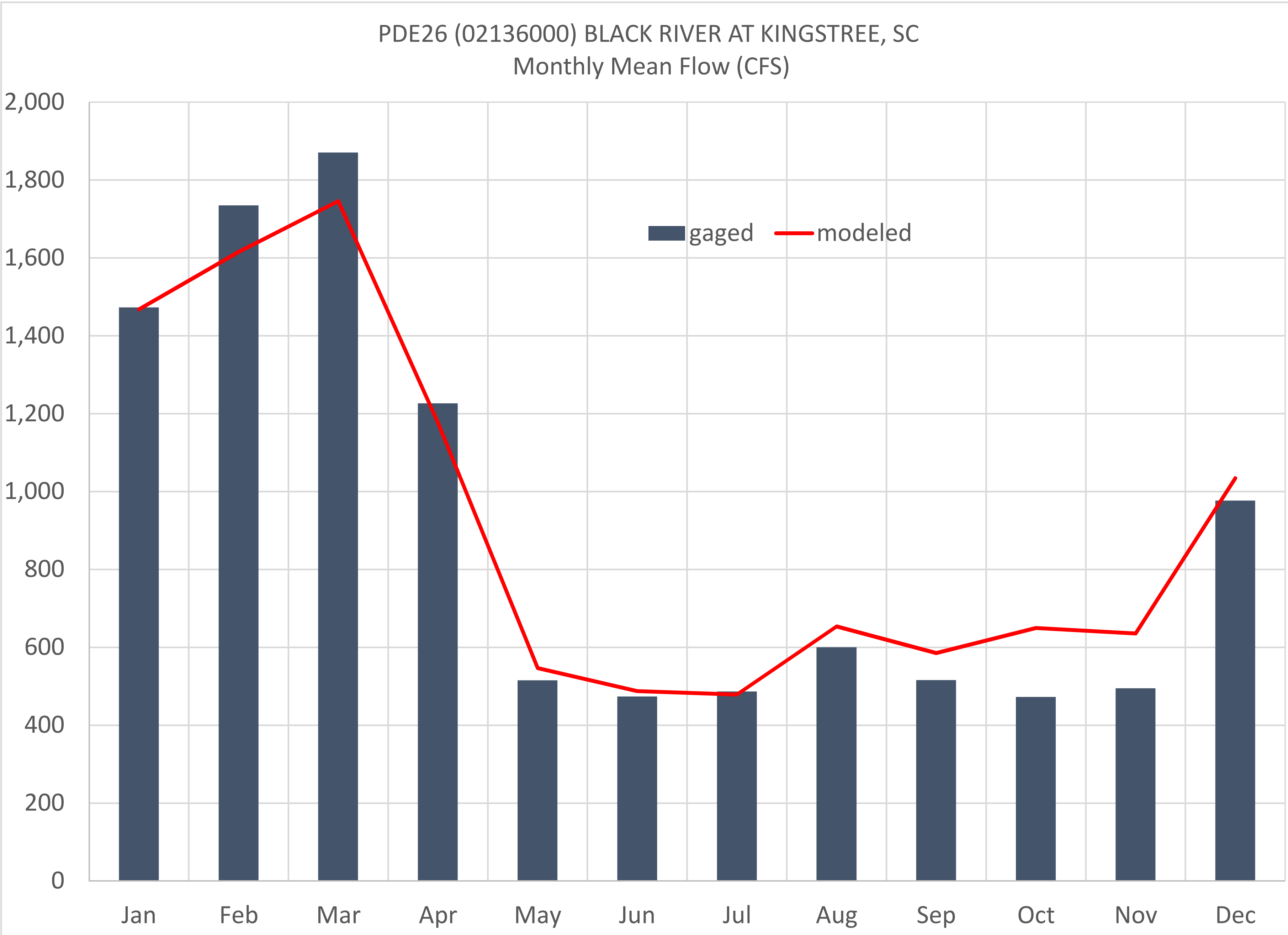
PDE24.25 (02135600, 02135625) POCOTALIGO IVER NR SUMTER AND MANNING SC (CFS)
Annual Average Flow
1,200
1,000
800
600
400
200
0
1983
1988
1993
1998
2003
2008
2013
gaged
modeled

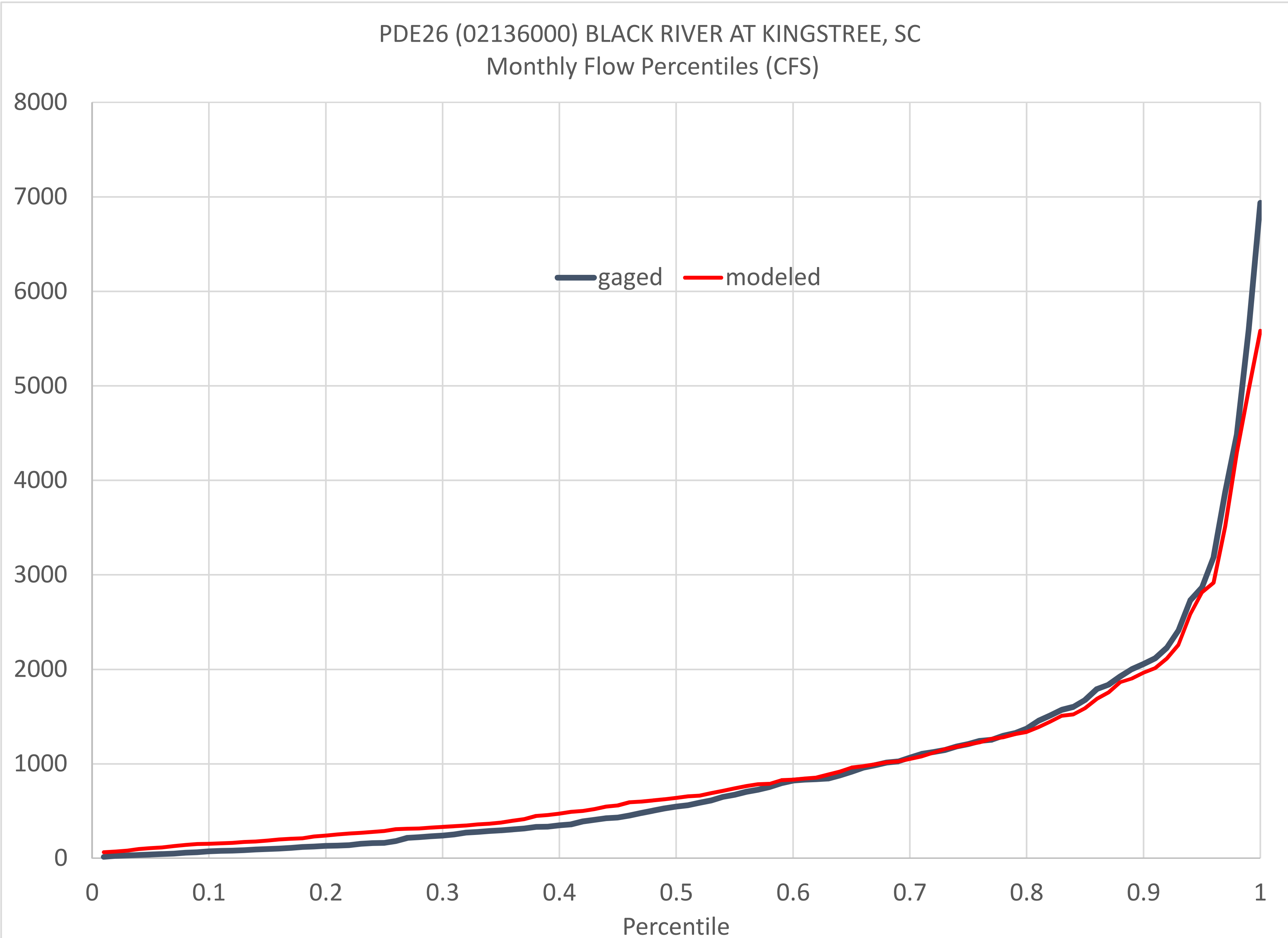

PDE24.25 (02135600, 02135625) POCOTALIGO IVER NR SUMTER AND MANNING SC
Monthly Mean Flow (CFS)
1,200
1,000
800
600
400
200
0
gaged
modeled
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

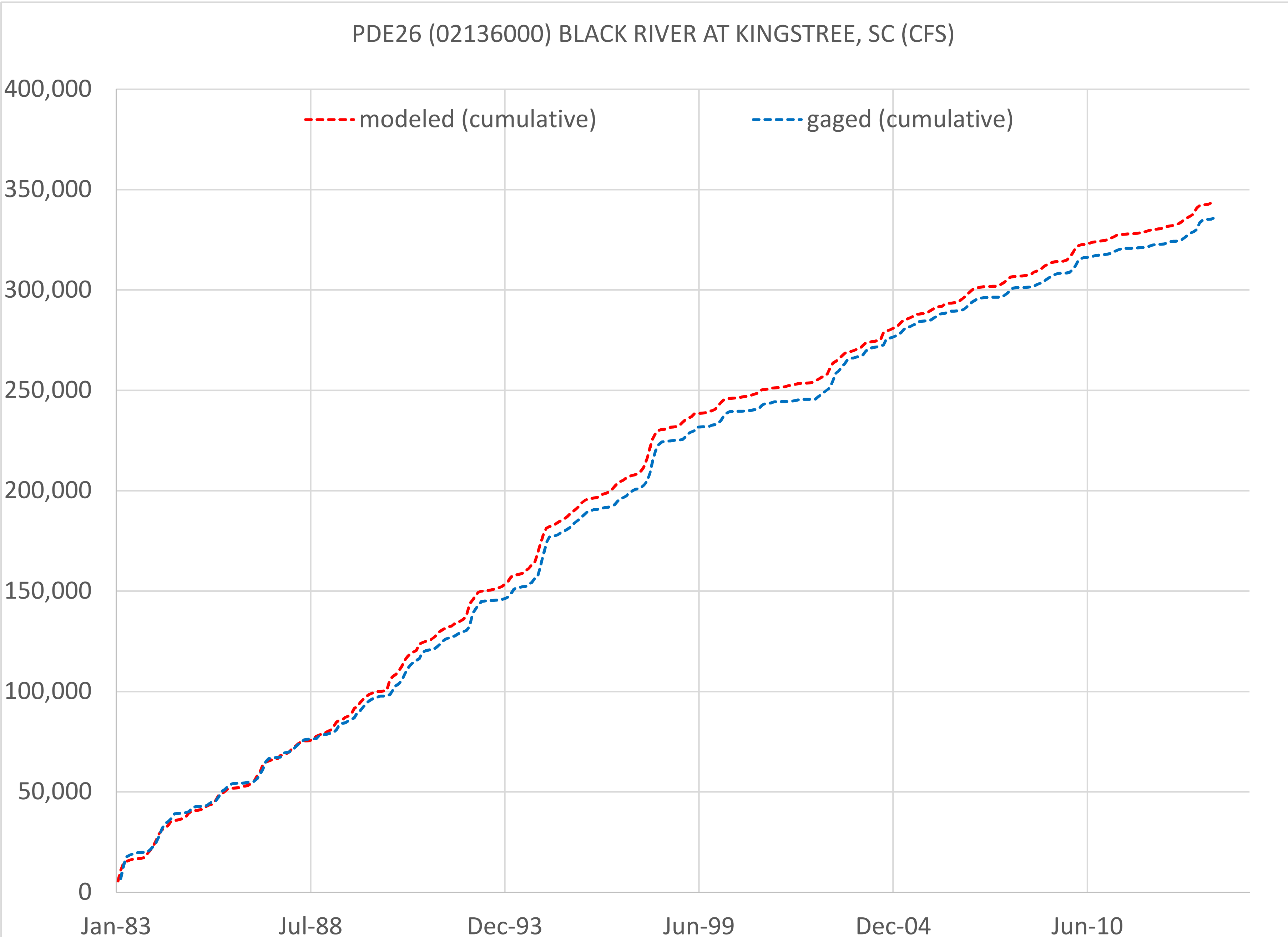

PDE24.25 (02135600, 02135625) POCOTALIGO IVER NR SUMTER AND MANNING SC
Monthly Flow Percentiles (CFS)
gaged
modeled
0
200
400
600
800
1000
1200
1400
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile


PDE26 (02136000) BLACK RIVER AT KINGSTREE, SC (CFS)
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
modeled
gaged
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

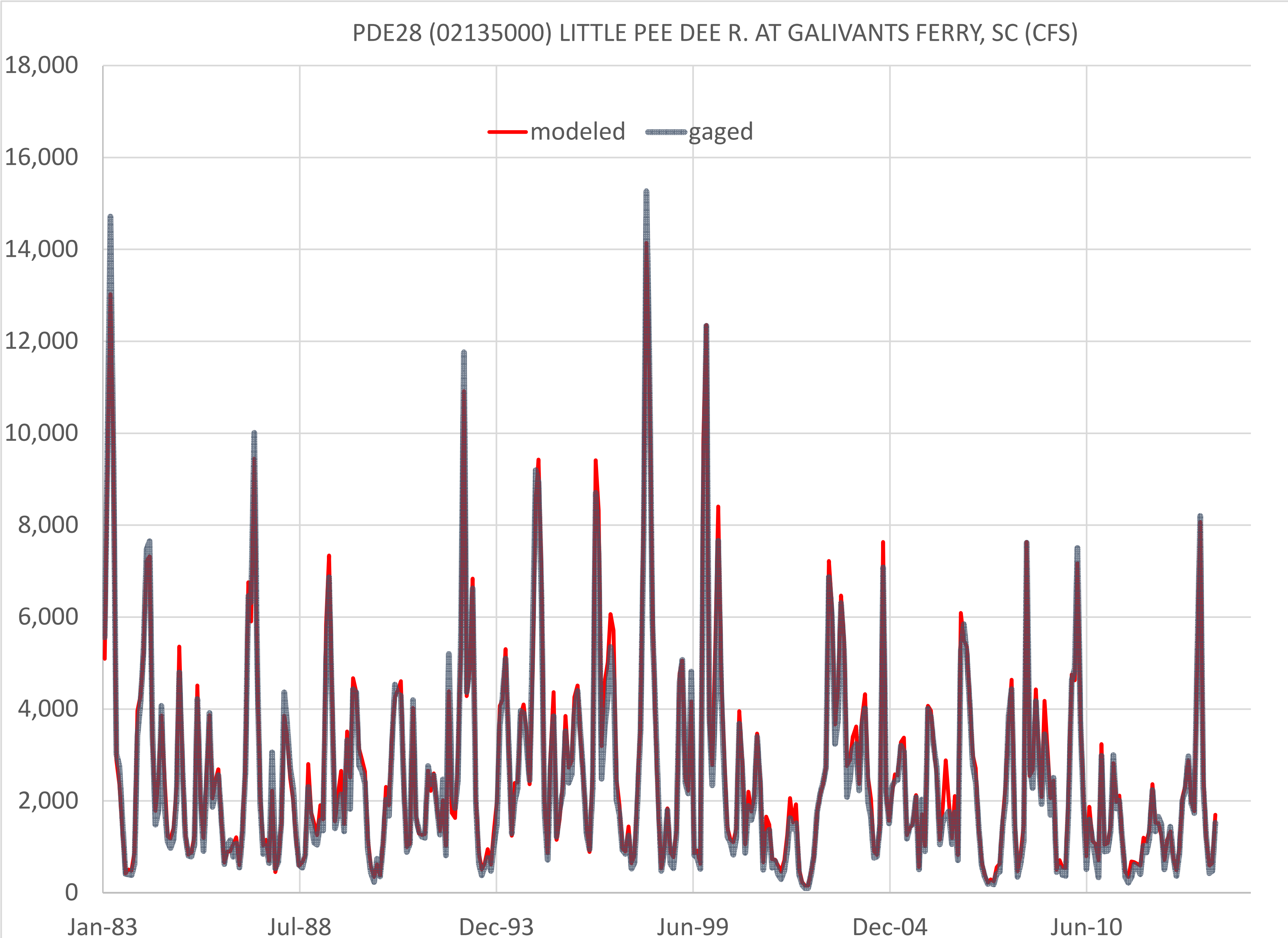

PDE26 (02136000) BLACK RIVER AT KINGSTREE, SC (CFS)
Annual Average Flow
gaged
modeled
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
1983
1988
1993
1998
2003
2008
2013


PDE26 (02136000) BLACK RIVER AT KINGSTREE, SC
Monthly Mean Flow (CFS)
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
gaged
modeled
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

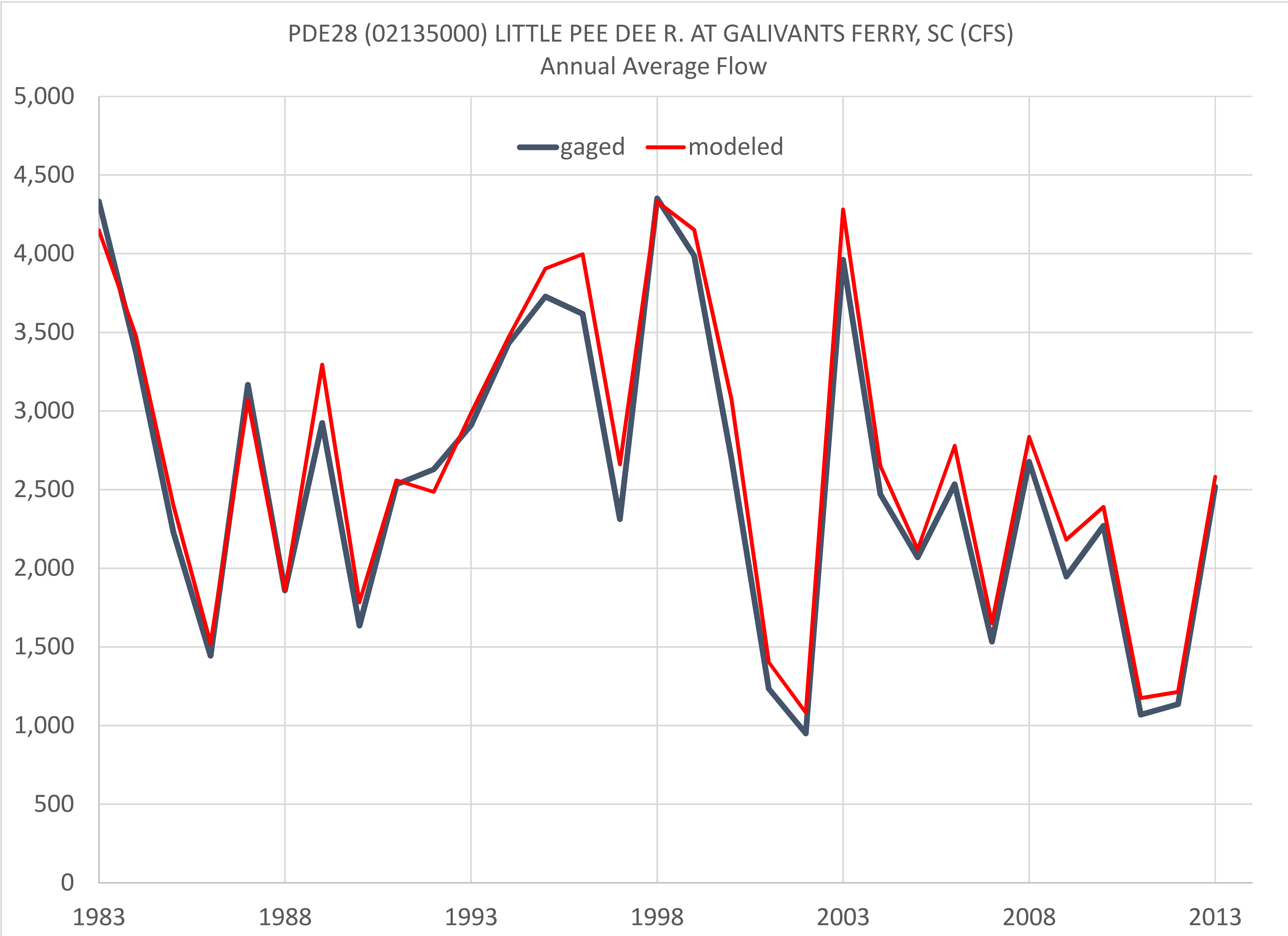

PDE26 (02136000) BLACK RIVER AT KINGSTREE, SC
Monthly Flow Percentiles (CFS)
gaged
modeled
8000
7000
6000
5000
4000
3000
2000
1000
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

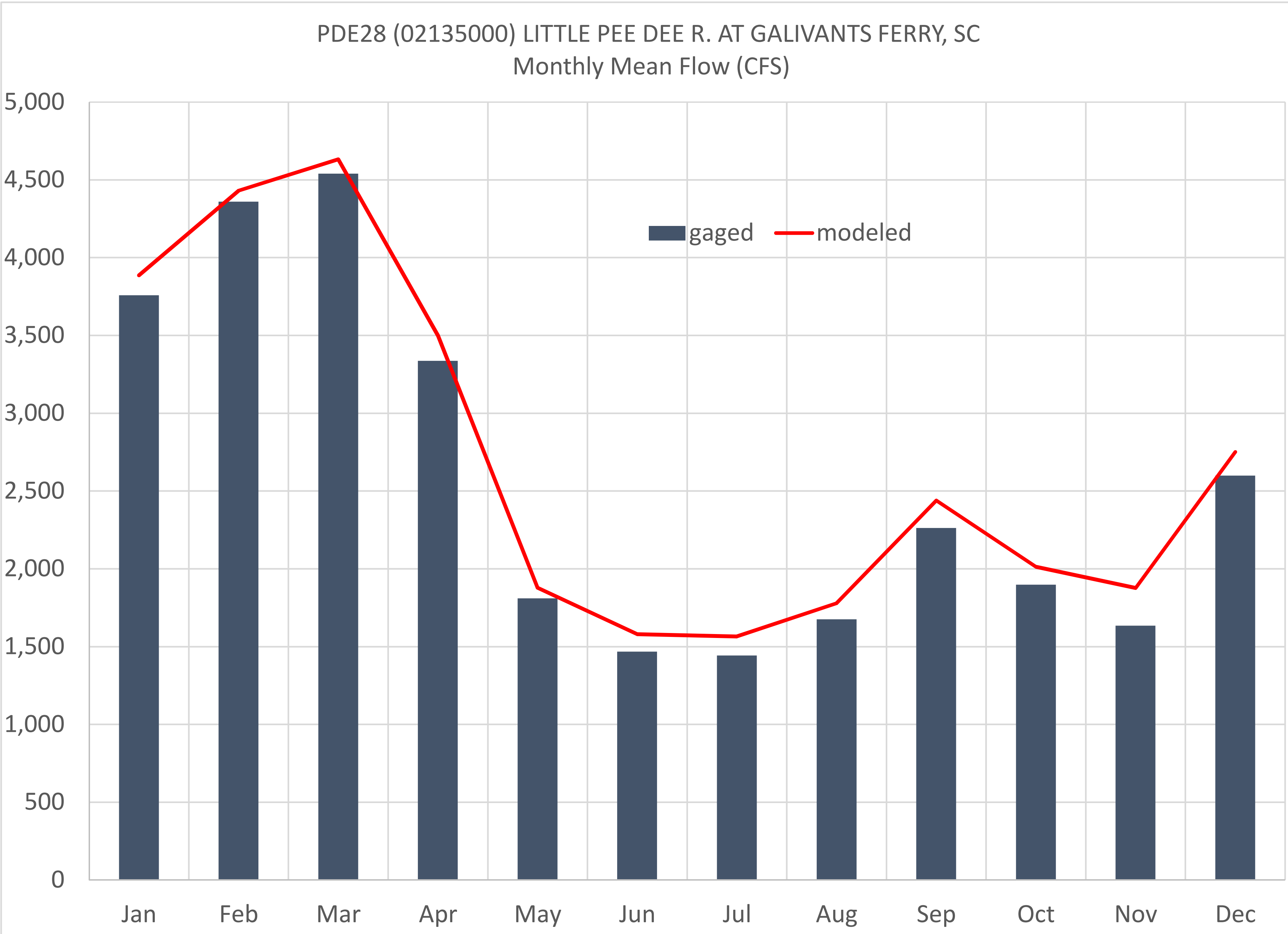


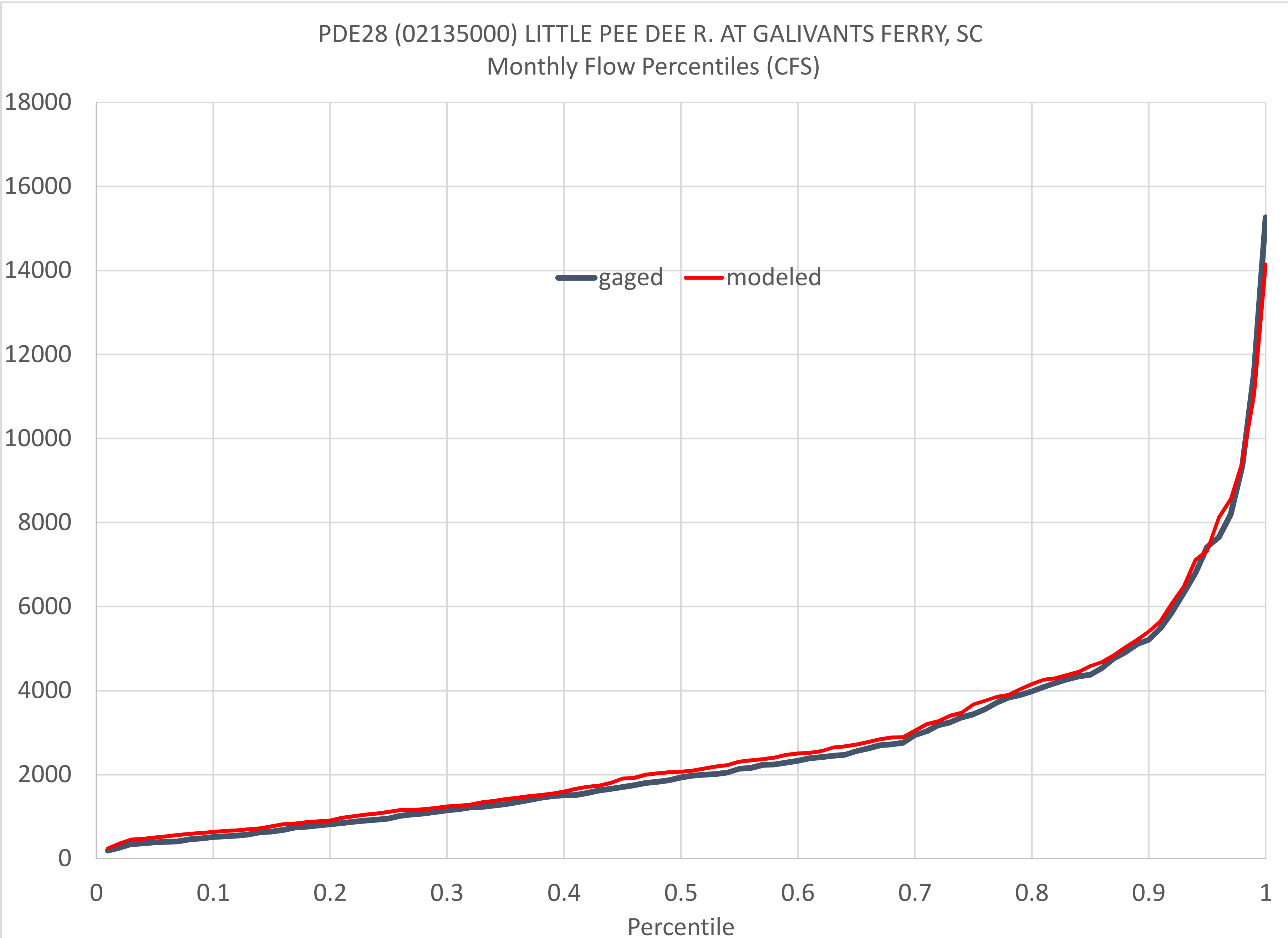
PDE26 (02136000) BLACK RIVER AT KINGSTREE, SC (CFS)
modeled (cumulative)
gaged (cumulative)
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

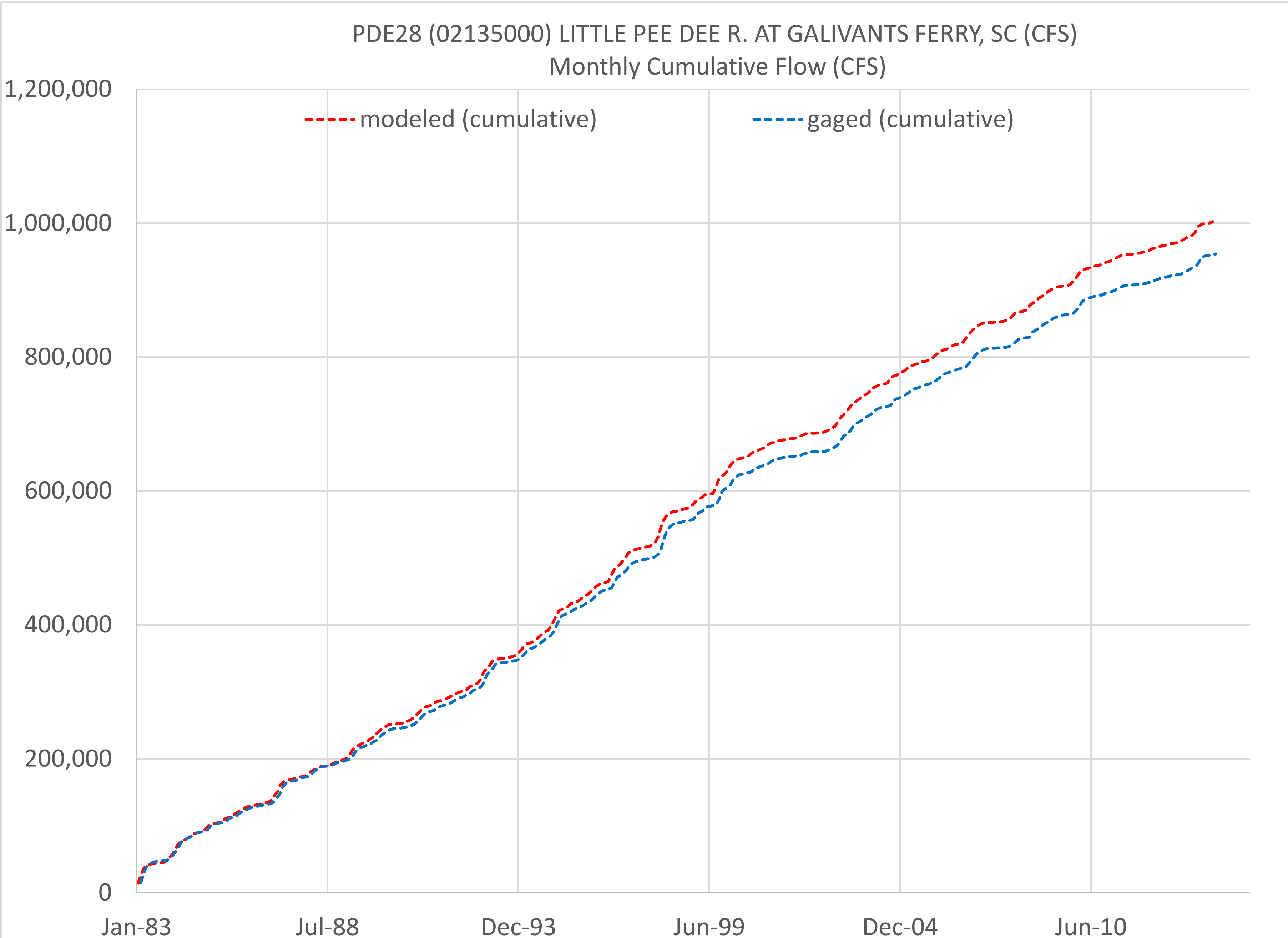


PDE28 (02135000) LITTLE PEE DEE R. AT GALIVANTS FERRY, SC (CFS)
modeled
gaged
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

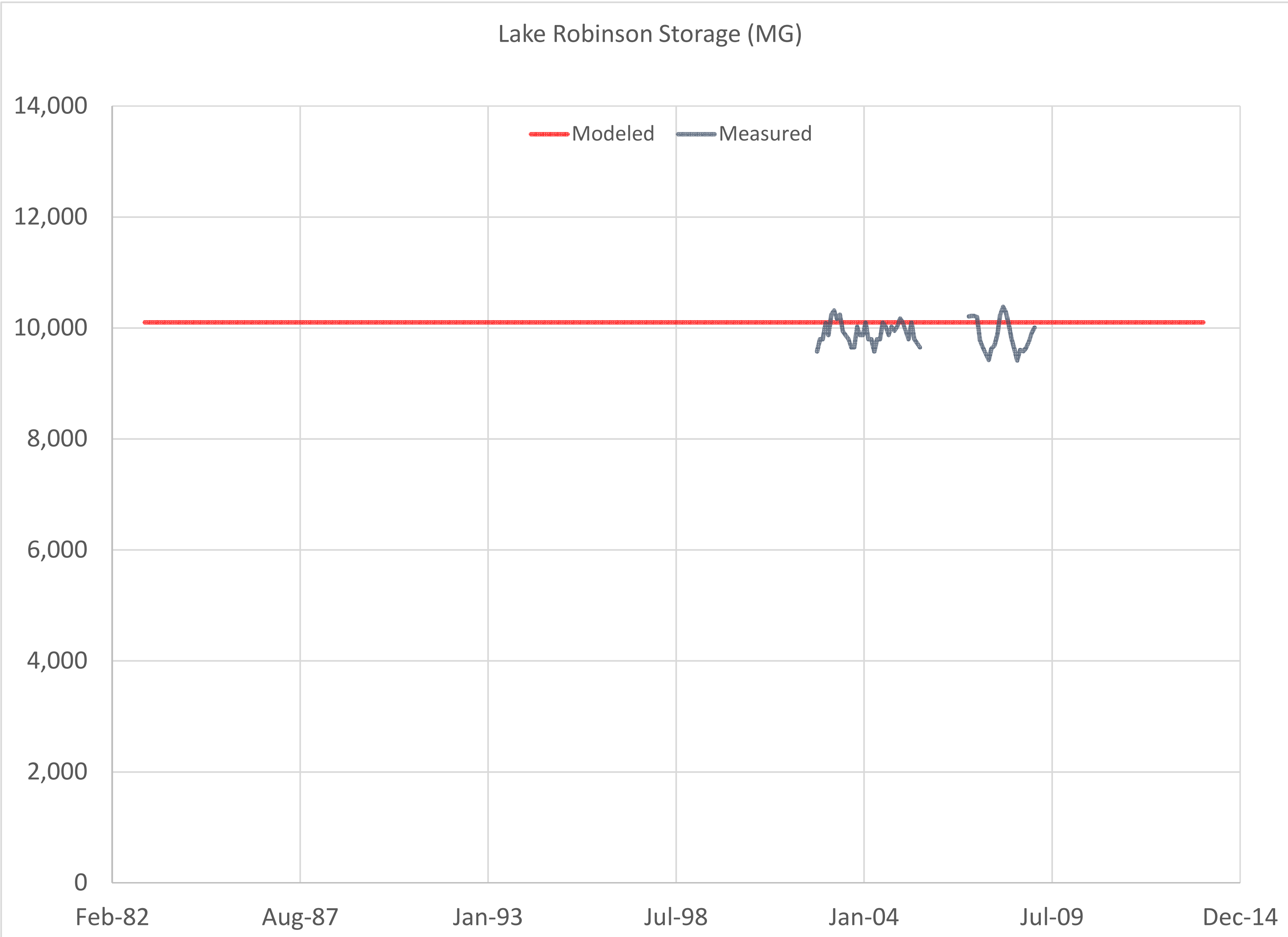

PDE28 (02135000) LITTLE PEE DEE R. AT GALIVANTS FERRY, SC (CFS)
Annual Average Flow
gaged
modeled
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
1983
1988
1993
1998
2003
2008
2013


PDE28 (02135000) LITTLE PEE DEE R. AT GALIVANTS FERRY, SC
Monthly Mean Flow (CFS)
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
gaged
modeled
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

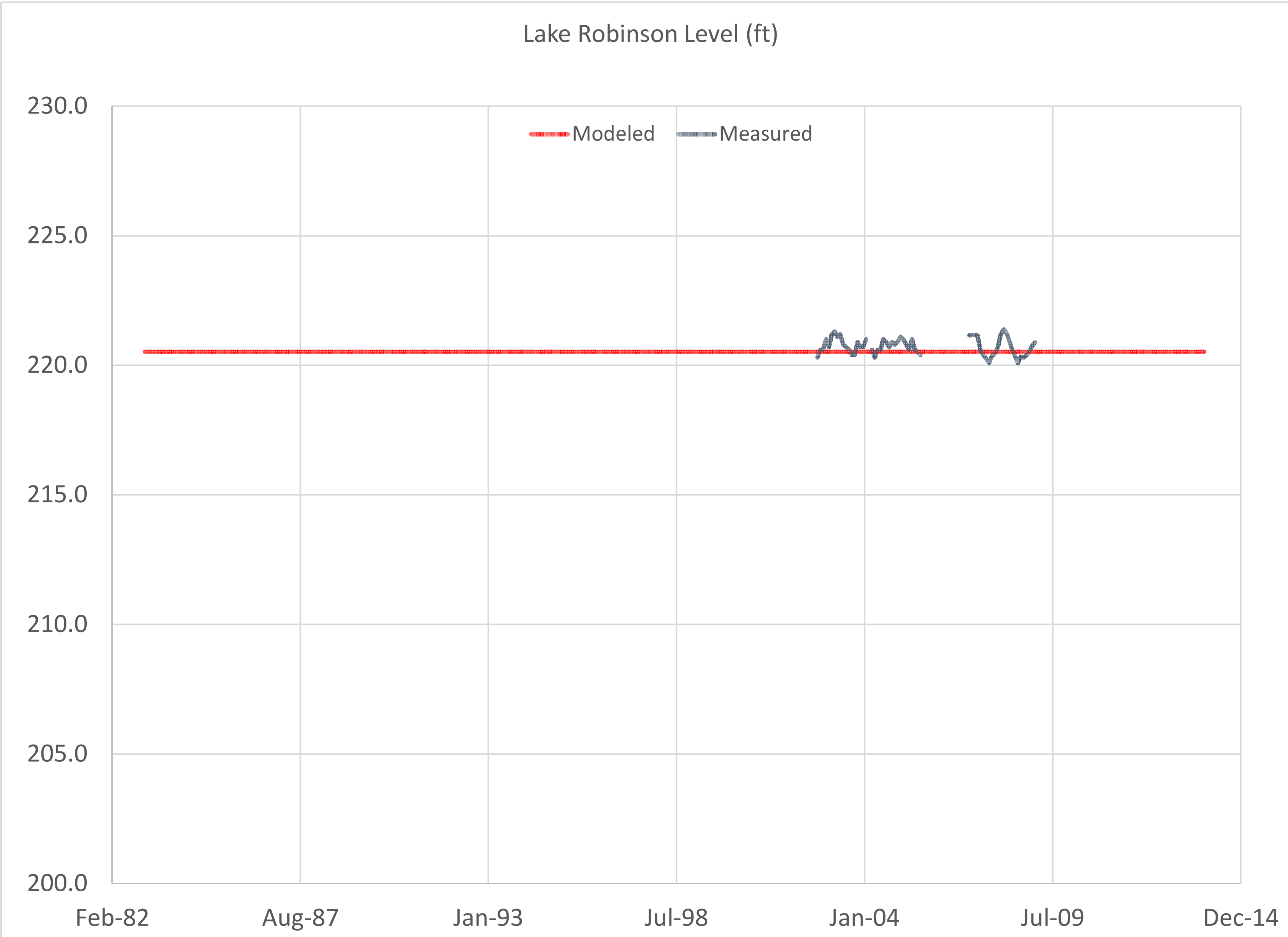

PDE28 (02135000) LITTLE PEE DEE R. AT GALIVANTS FERRY, SC
Monthly Flow Percentiles (CFS)
gaged
modeled
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile



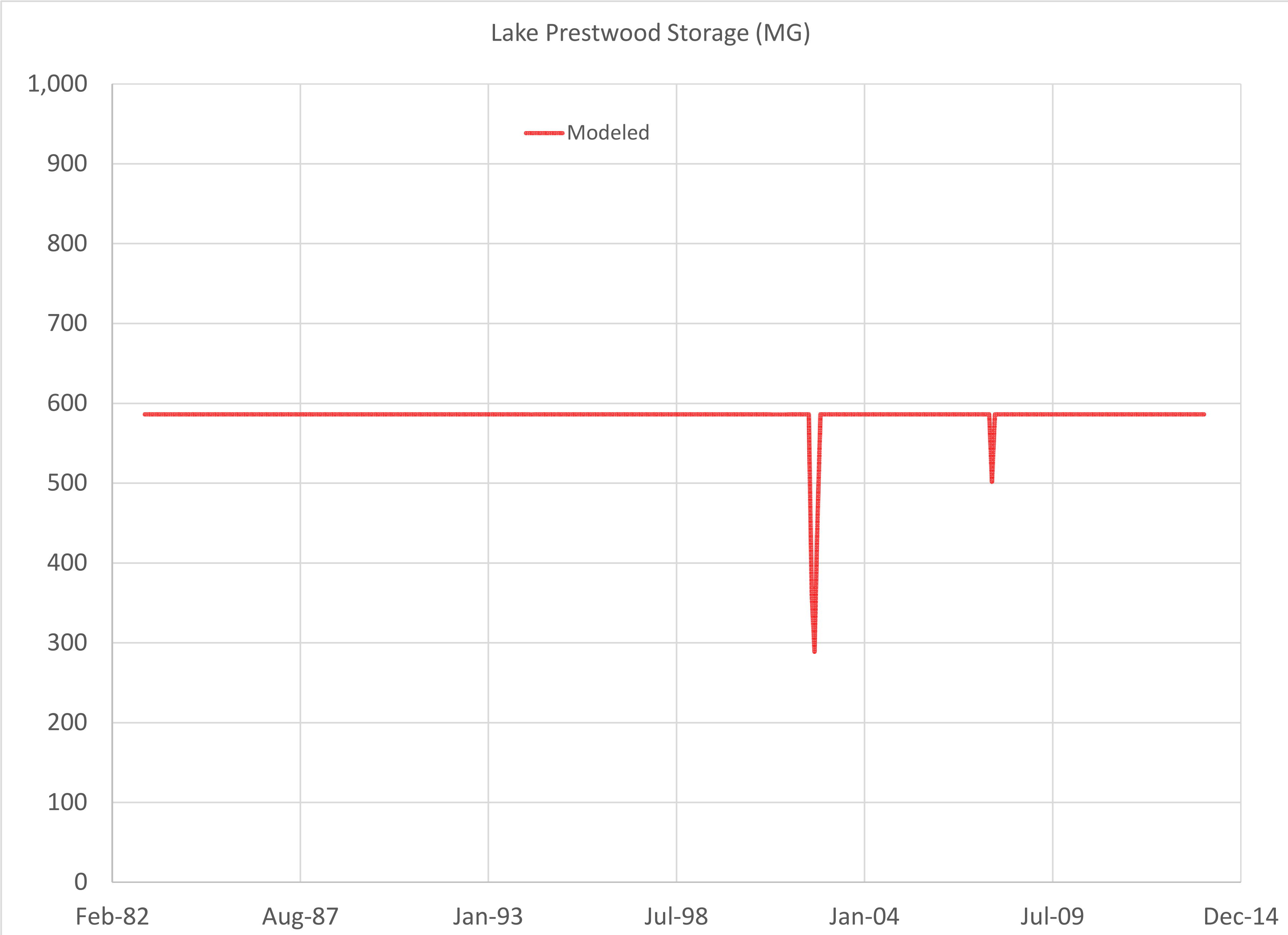
PDE28 (02135000) LITTLE PEE DEE R. AT GALIVANTS FERRY, SC (CFS)
Monthly Cumulative Flow (CFS)
modeled (cumulative)
gaged (cumulative)
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

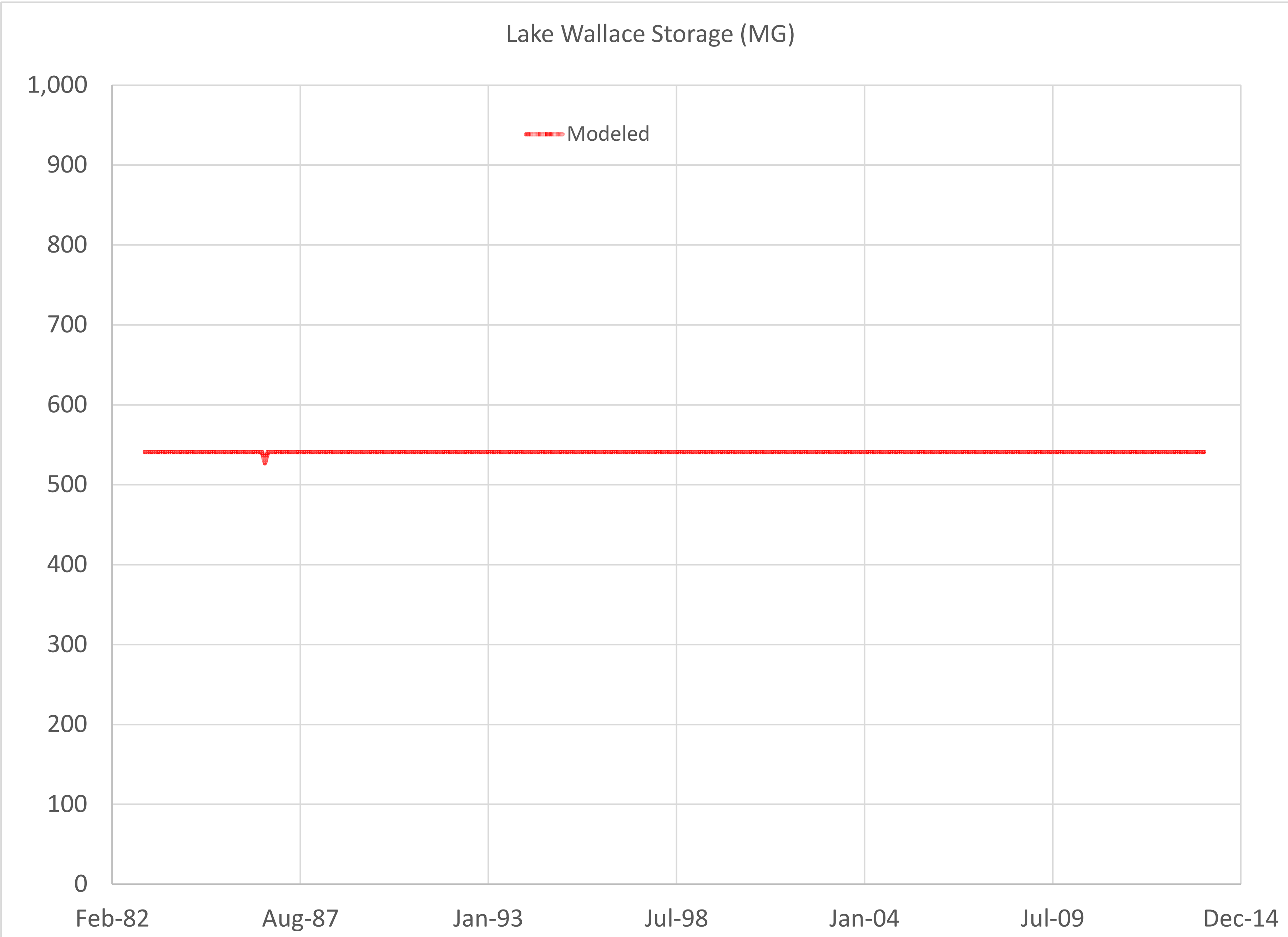


Lake Robinson Storage (MG)
Modeled
Measured
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Feb-82
Aug-87
Jan-93
Jul-98
Jan-04
Jul-09
Dec-14



Lake Robinson Level (ft)
Modeled
Measured
230.0
225.0
220.0
215.0
210.0
205.0
200.0
Feb-82
Aug-87
Jan-93
Jul-98
Jan-04
Jul-09
Dec-14


Lake Prestwood Storage (MG)
Modeled
1,000
900
800
700
600
500
400
300
200
100
0
Feb-82
Aug-87
Jan-93
Jul-98
Jan-04
Jul-09
Dec-14

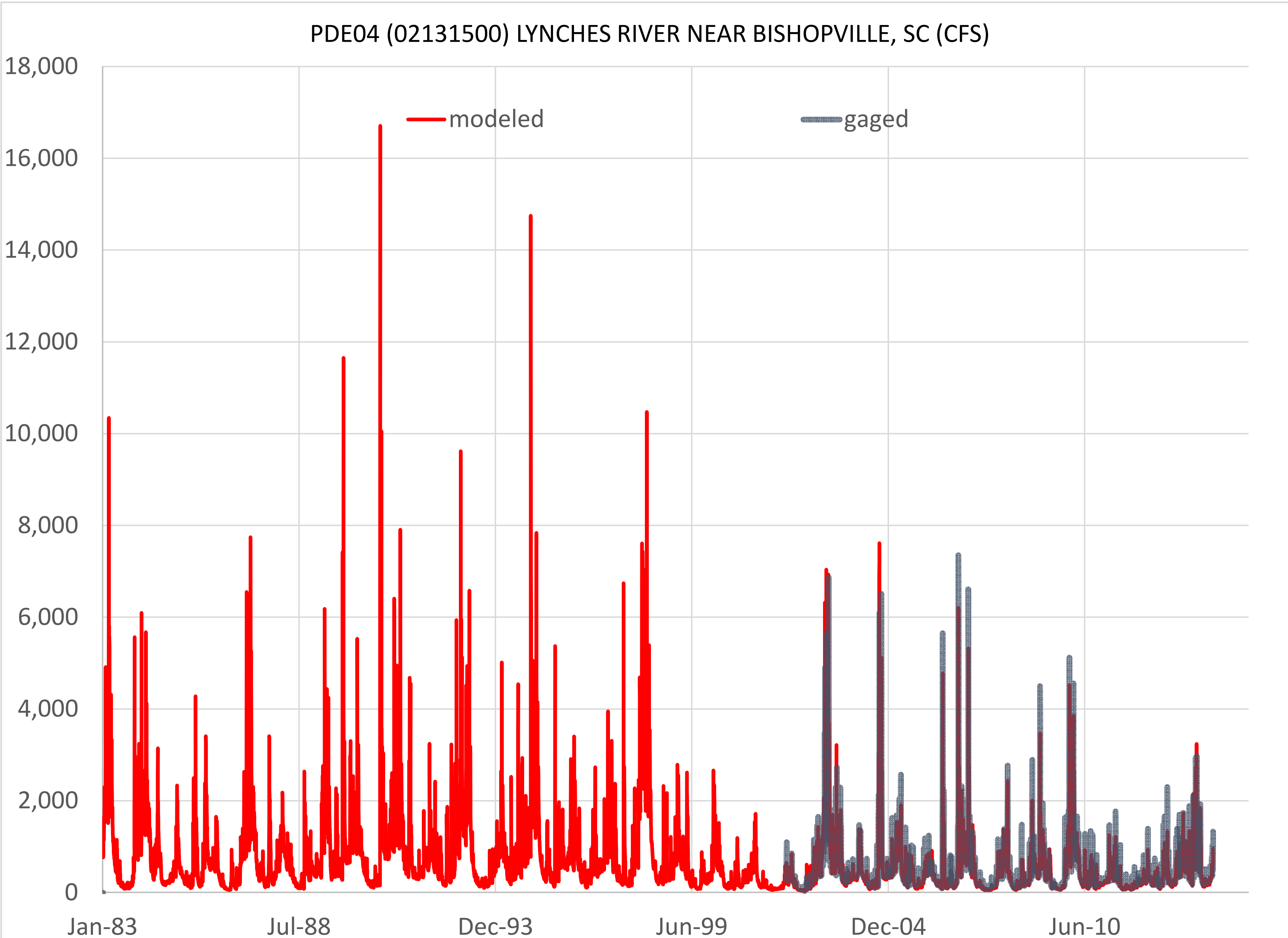

Lake Wallace Storage (MG)
Modeled
1,000
900
800
700
600
500
400
300
200
100
0
Feb-82
Aug-87
Jan-93
Jul-98
Jan-04
Jul-09
Dec-14

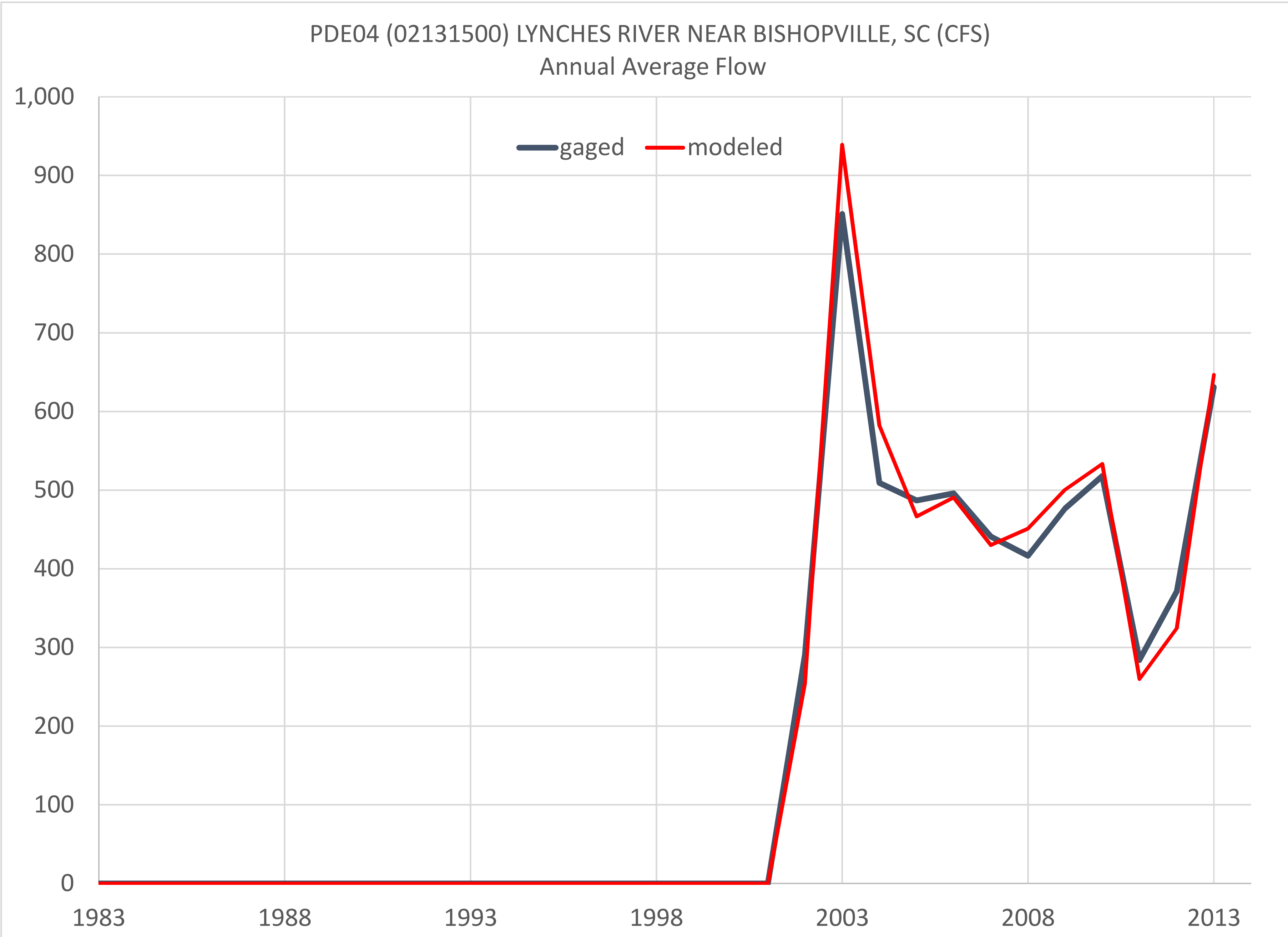
Appendix B

Pee Dee River Basin Model

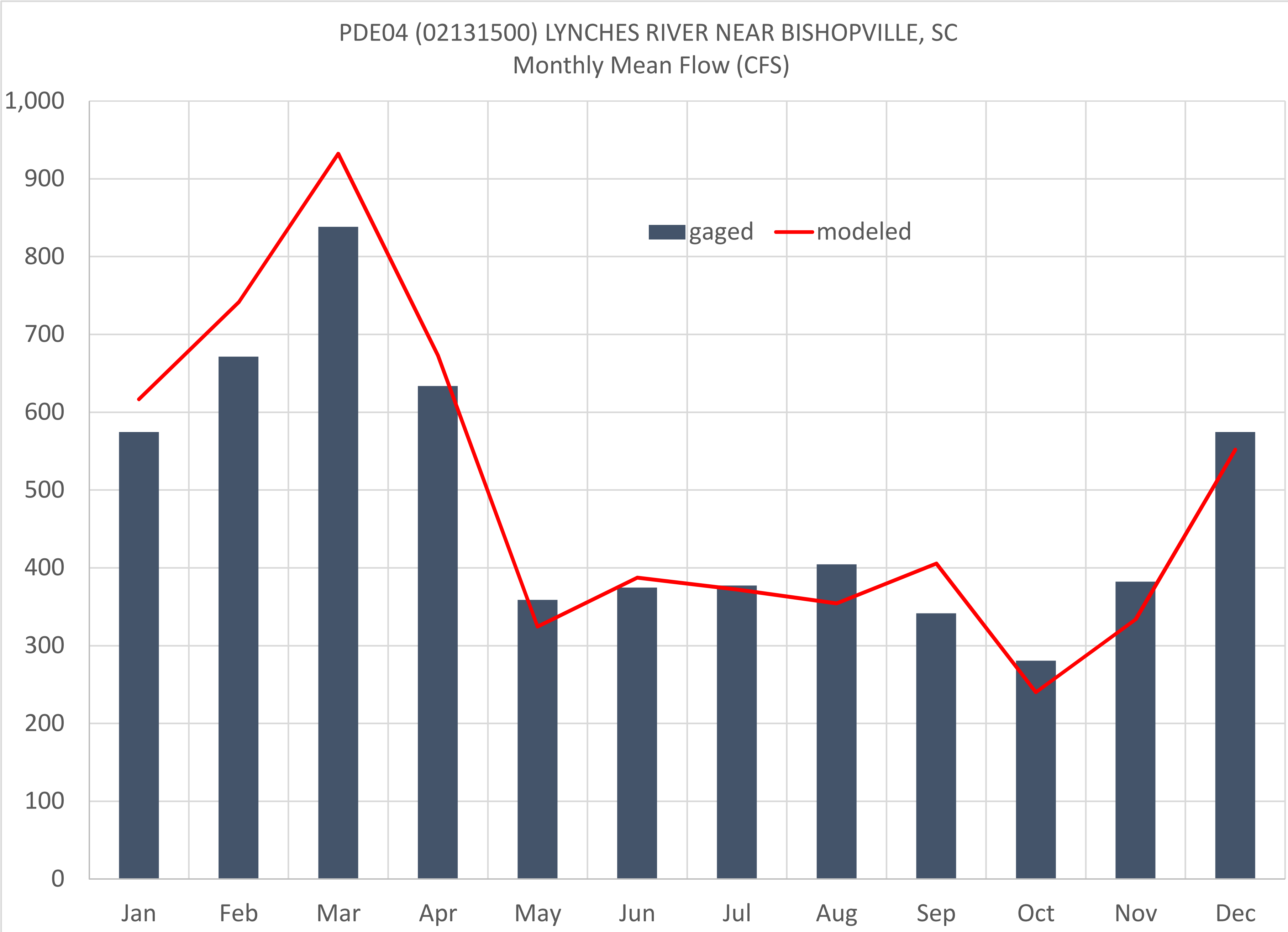
Daily Calibration Results

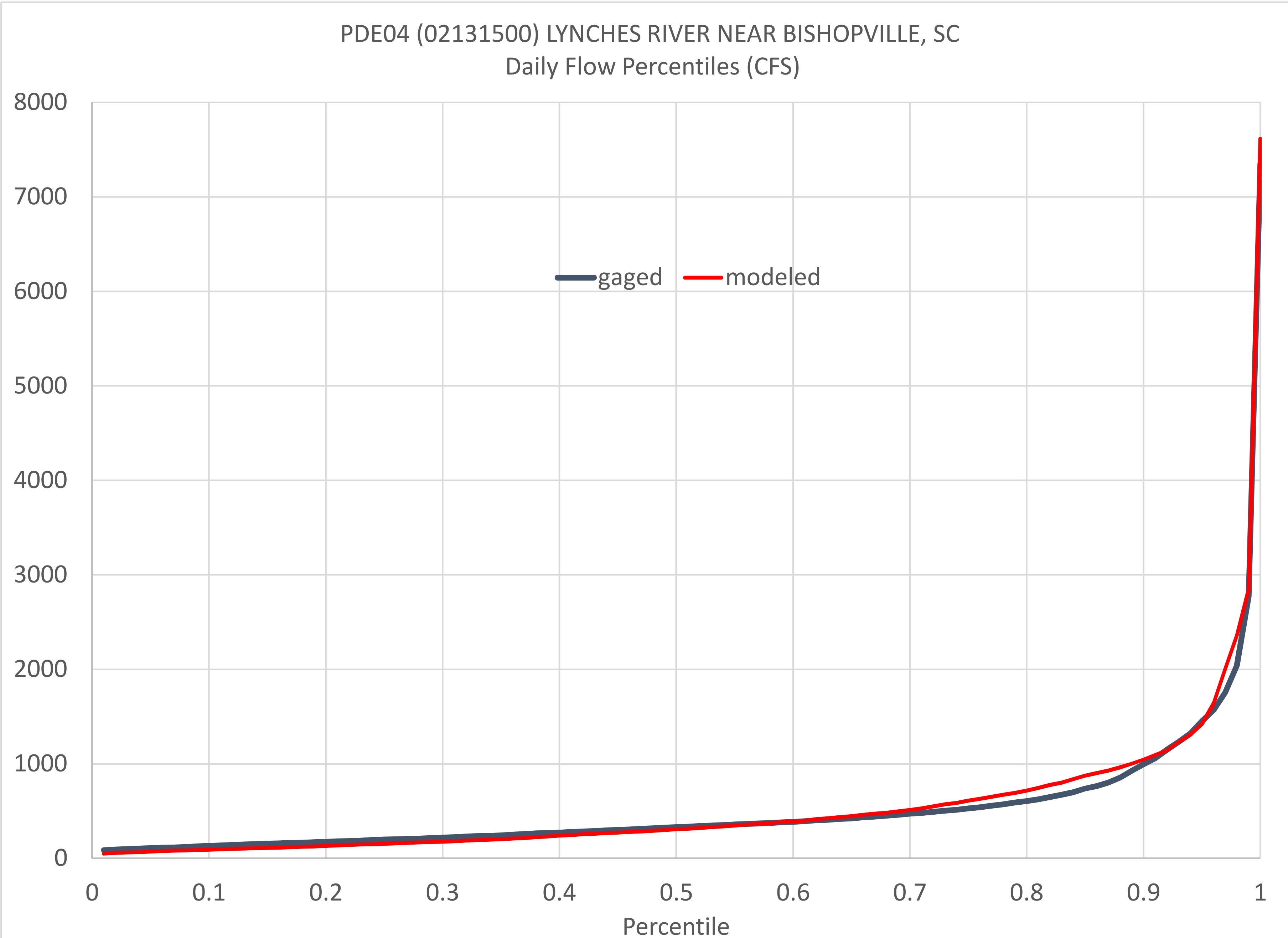
CDM Smith

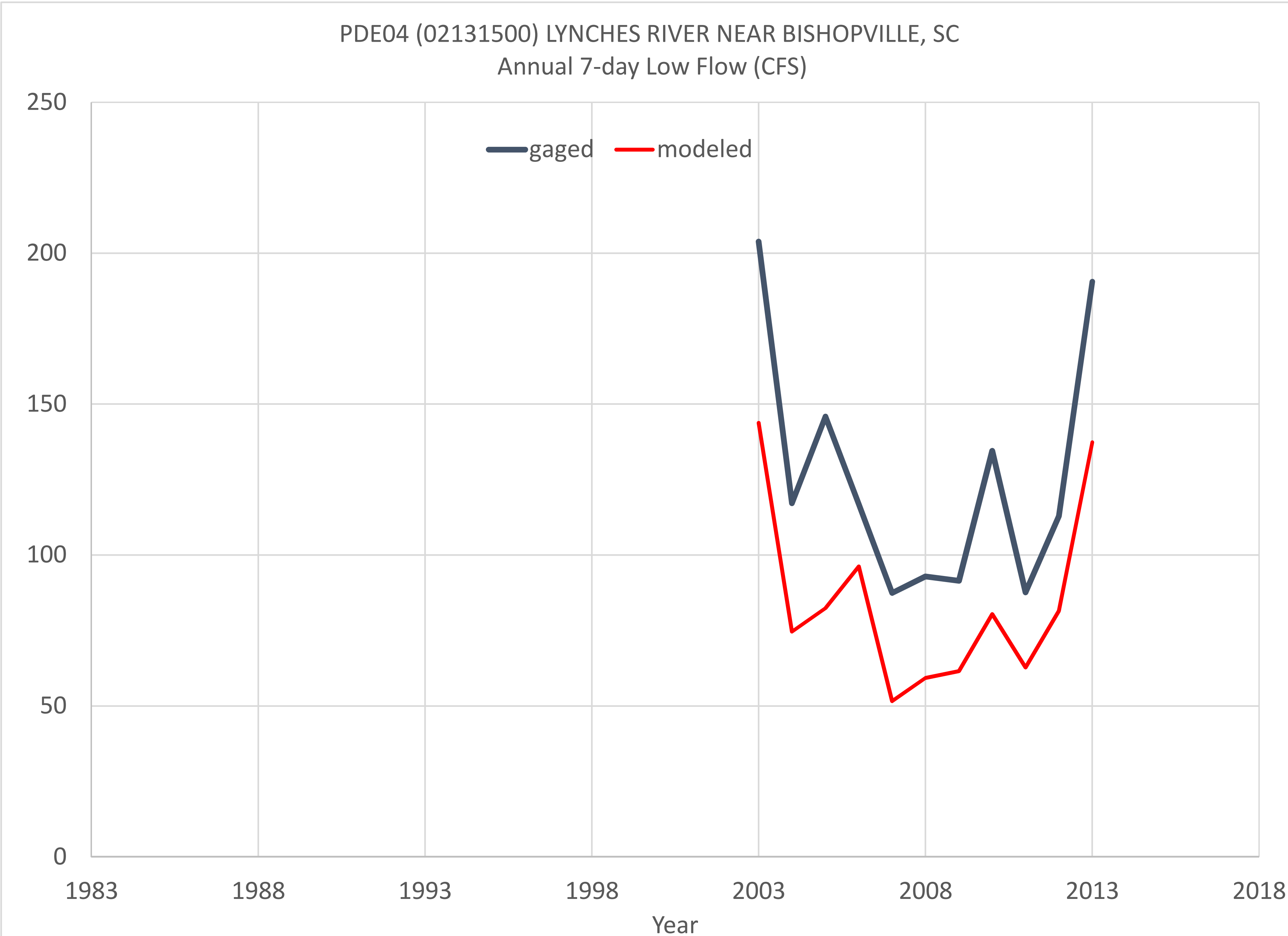

PDE04 (02131500) LYNCHES RIVER NEAR BISHOPVILLE, SC (CFS)
modeled
gaged
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

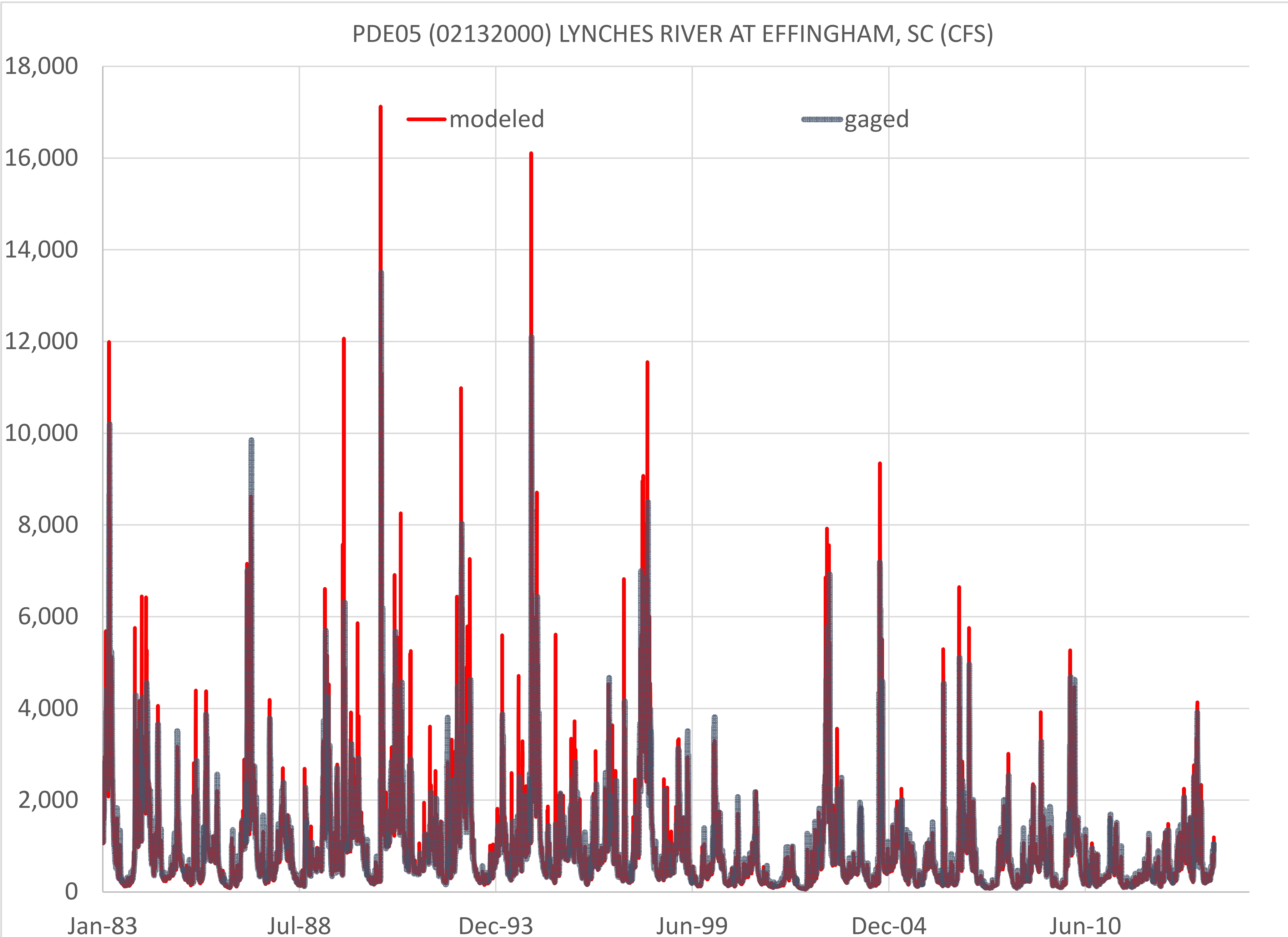


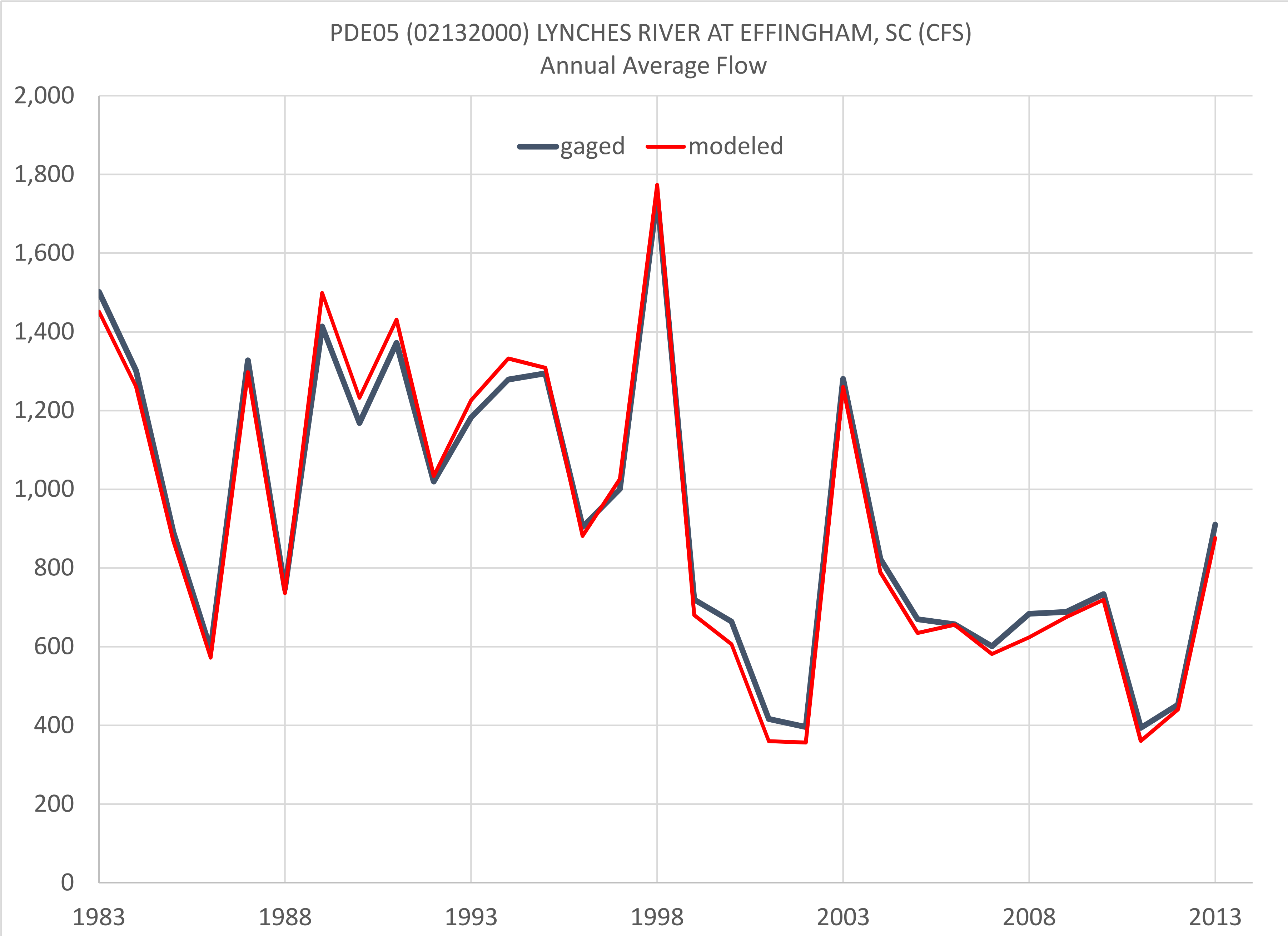
PDE04 (02131500) LYNCHES RIVER NEAR BISHOPVILLE, SC (CFS)
Annual Average Flow
gaged
modeled
1,000
900
800
700
600
500
400
300
200
100
0
1983
1988
1993
1998
2003
2008
2013


PDE04 (02131500) LYNCHES RIVER NEAR BISHOPVILLE, 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

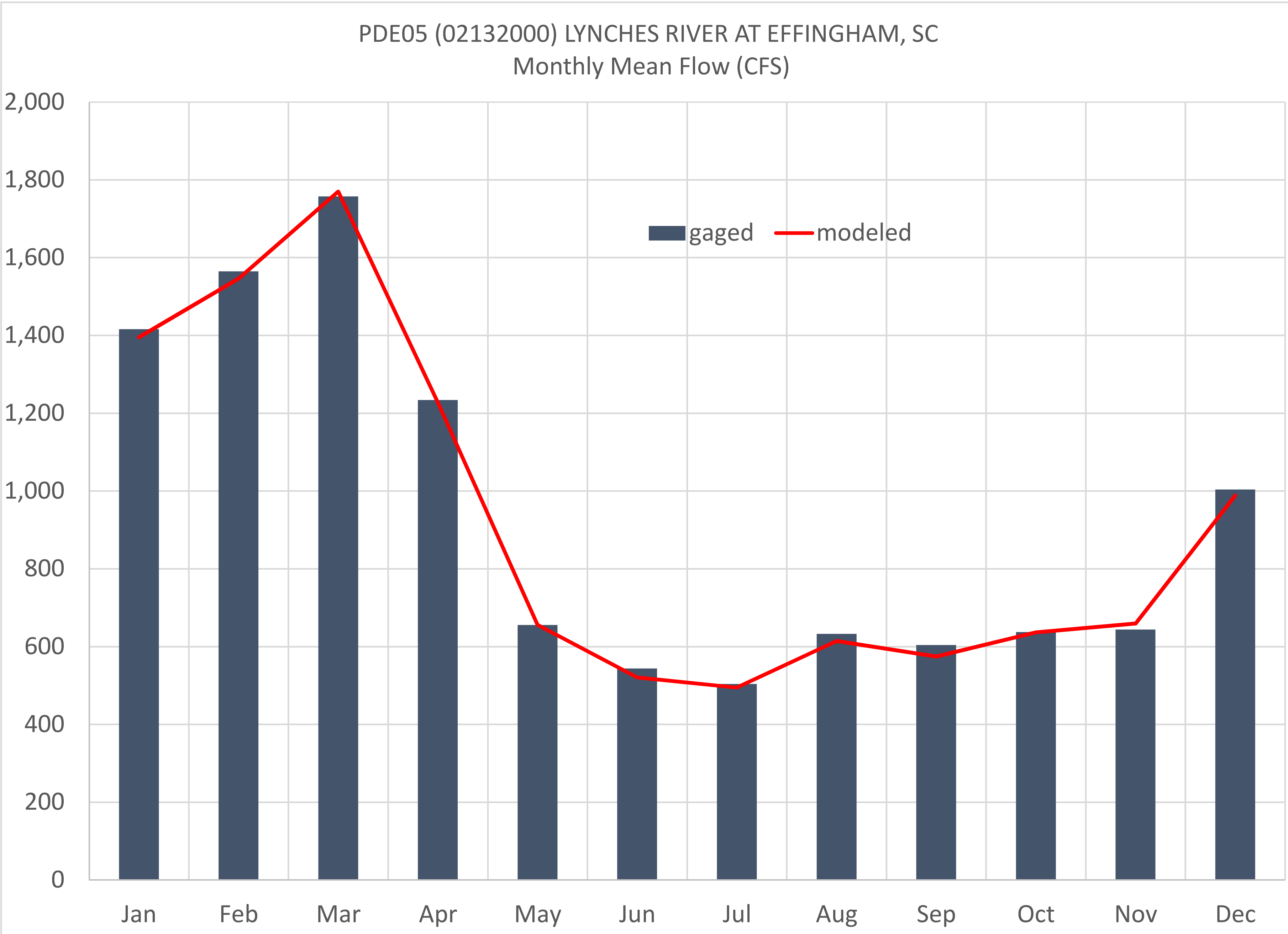

PDE04 (02131500) LYNCHES RIVER NEAR BISHOPVILLE, SC
Daily Flow Percentiles (CFS)
gaged
modeled
8000
7000
6000
5000
4000
3000
2000
1000
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile


PDE04 (02131500) LYNCHES RIVER NEAR BISHOPVILLE, SC
Annual 7-day Low Flow (CFS)
gaged
modeled
250
200
150
100
50
0
1983
1988
1993
1998
2003
2008
2013
2018
Year

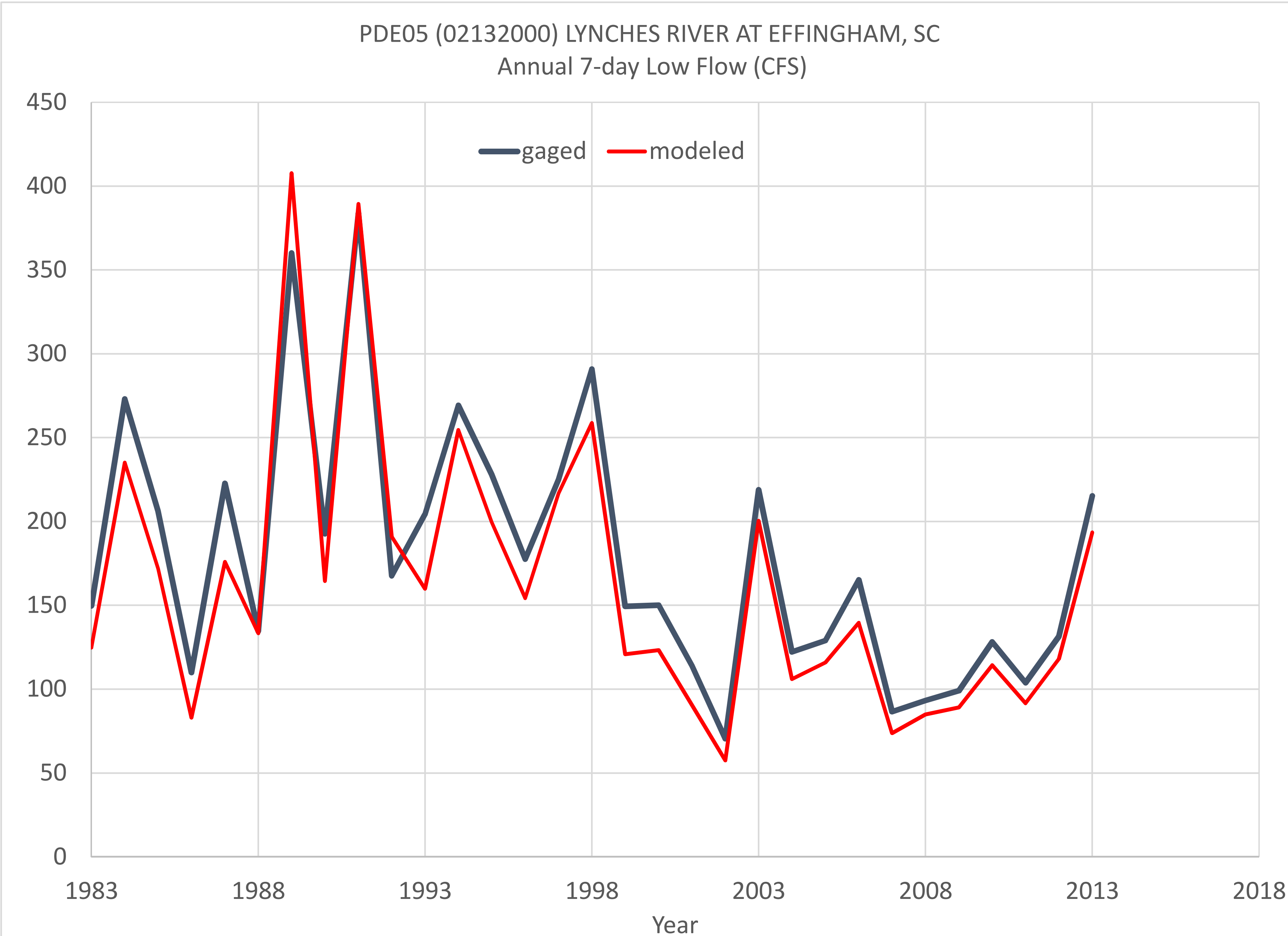

PDE05 (02132000) LYNCHES RIVER AT EFFINGHAM, SC (CFS)
modeled
gaged
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

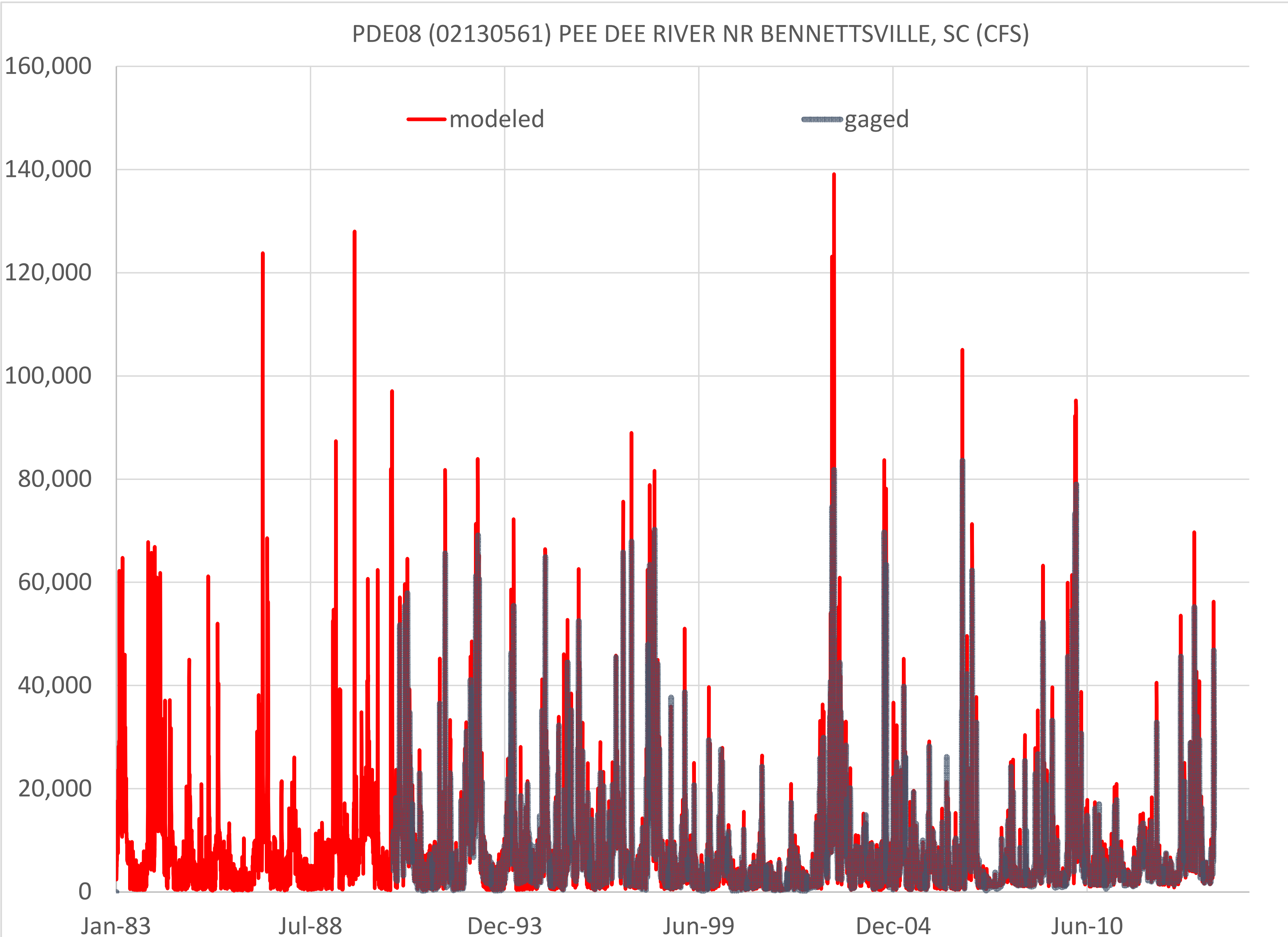


PDE05 (02132000) LYNCHES RIVER AT EFFINGHAM, SC (CFS)
Annual Average Flow
gaged
modeled
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
1983
1988
1993
1998
2003
2008
2013

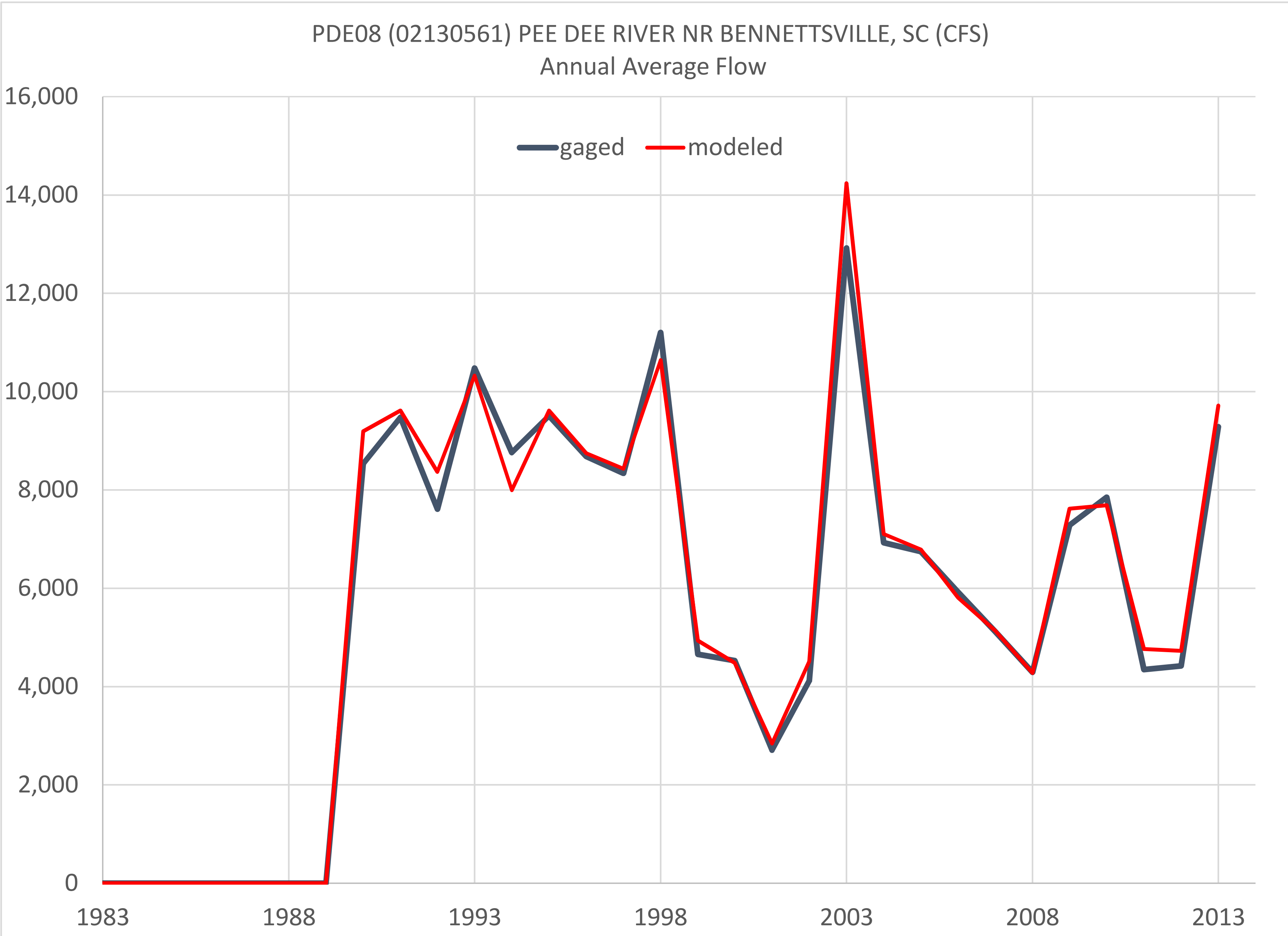

PDE05 (02132000) LYNCHES RIVER AT EFFINGHAM, SC
Monthly Mean Flow (CFS)
gaged
modeled
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

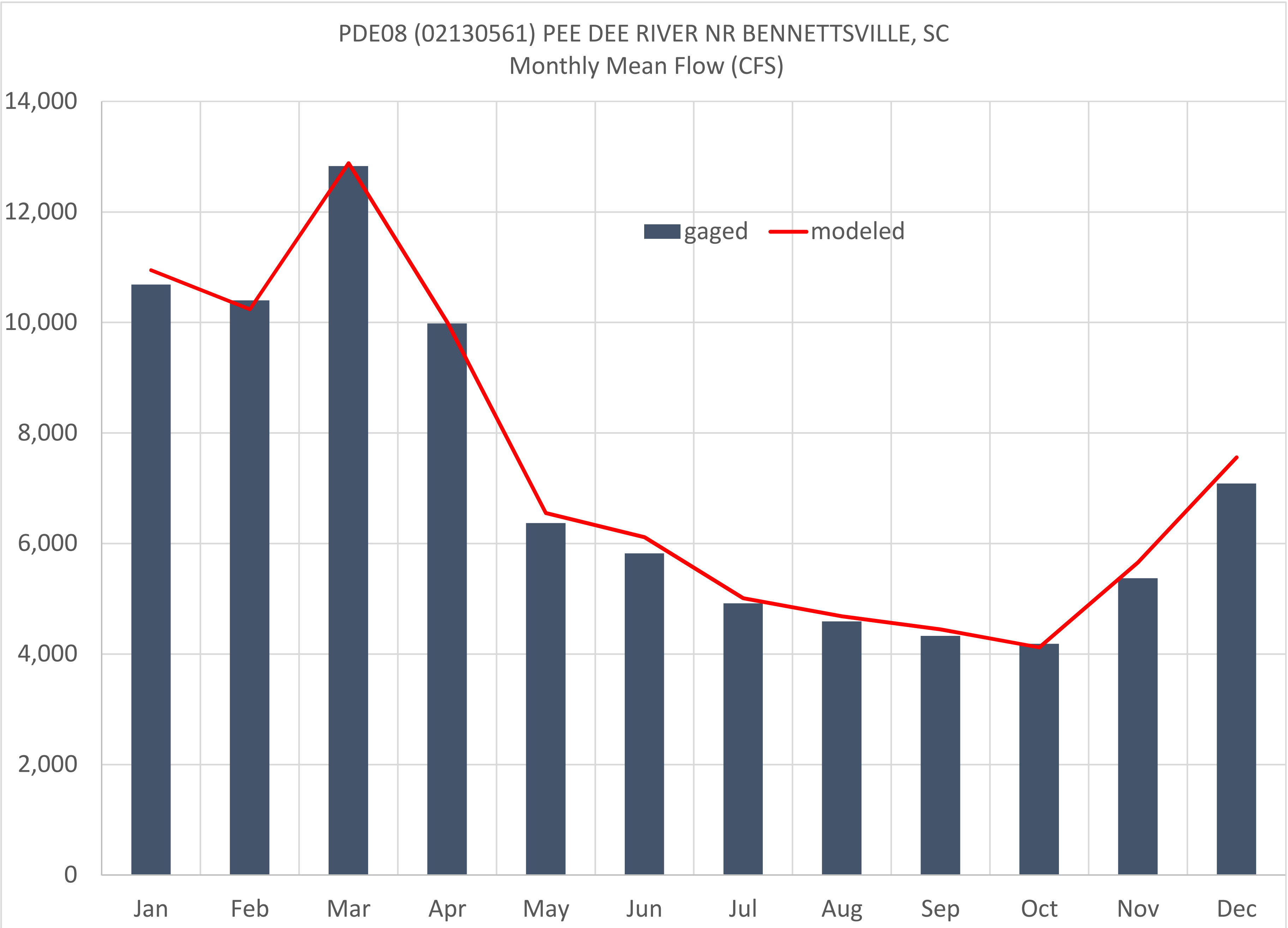

PDE05 (02132000) LYNCHES RIVER AT EFFINGHAM, SC
Daily Flow Percentiles (CFS)
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile
gaged
modeled


PDE05 (02132000) LYNCHES RIVER AT EFFINGHAM, SC
Annual 7-day Low Flow (CFS)
gaged
modeled
450
400
350
300
250
200
150
100
50
0
1983
1988
1993
1998
2003
2008
2013
2018
Year

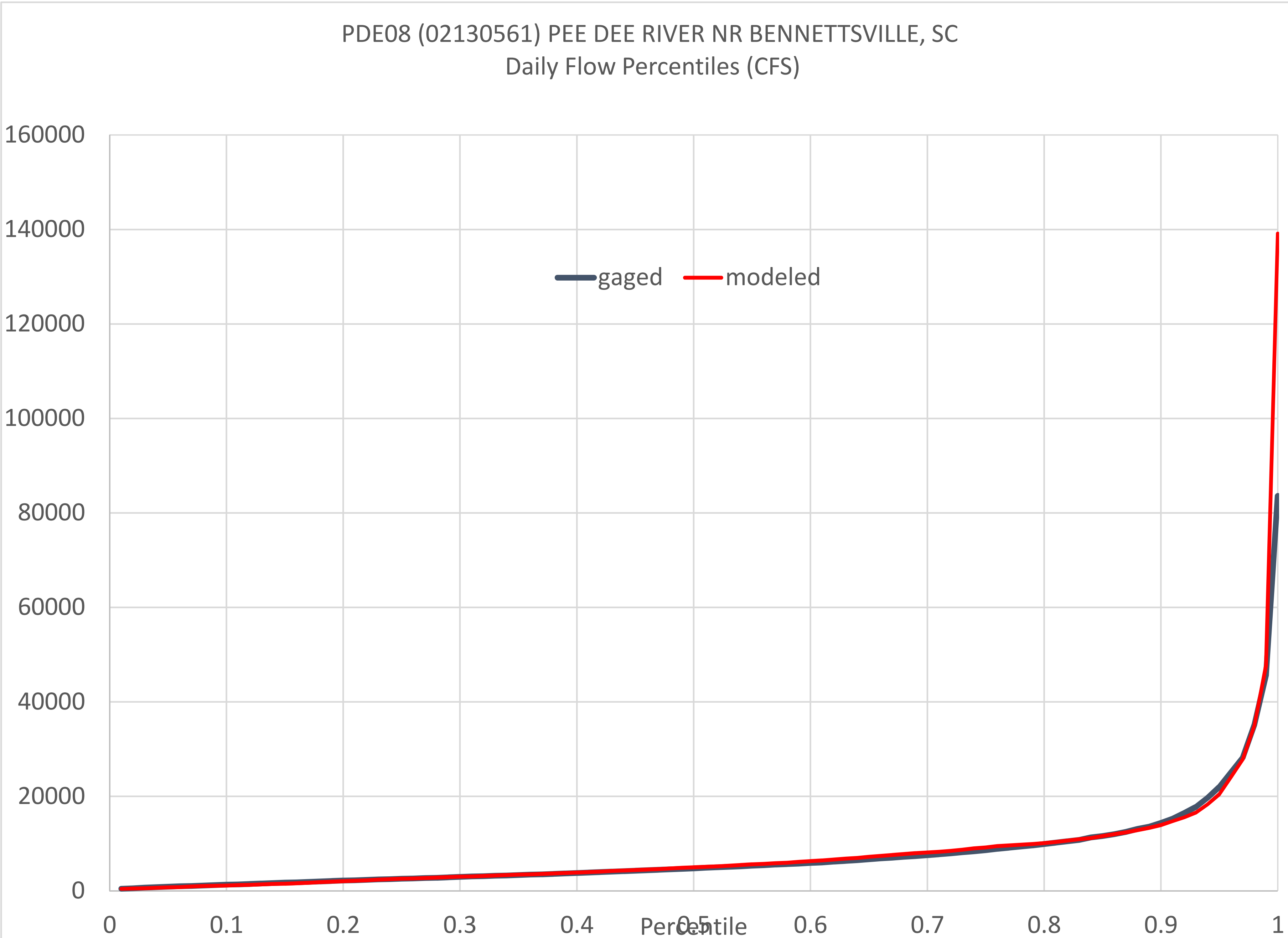


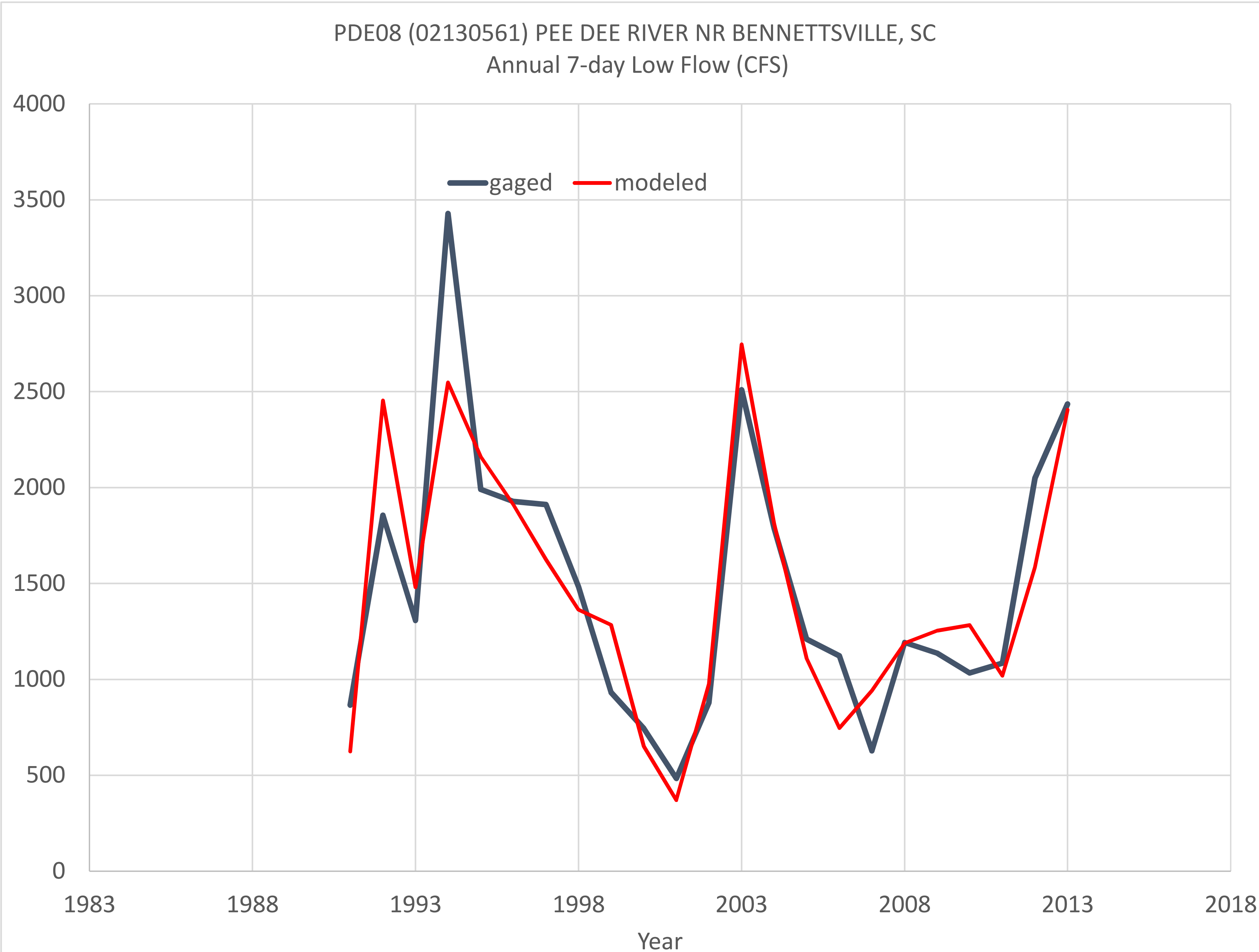
PDE08 (02130561) PEE DEE RIVER NR BENNETTSVILLE, SC (CFS)
modeled
gaged
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

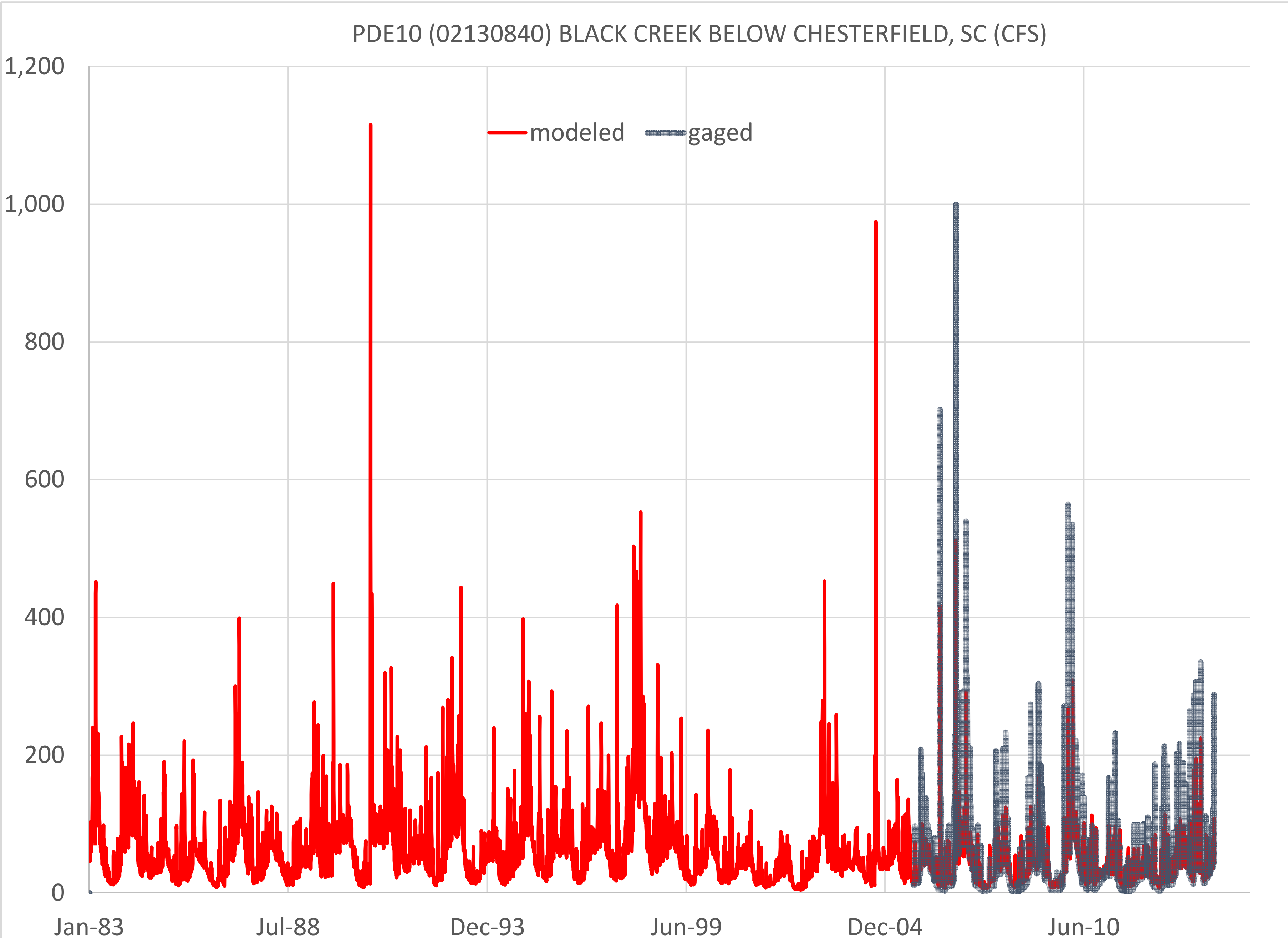

PDE08 (02130561) PEE DEE RIVER NR BENNETTSVILLE, SC (CFS)
Annual Average Flow
gaged
modeled
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1983
1988
1993
1998
2003
2008
2013



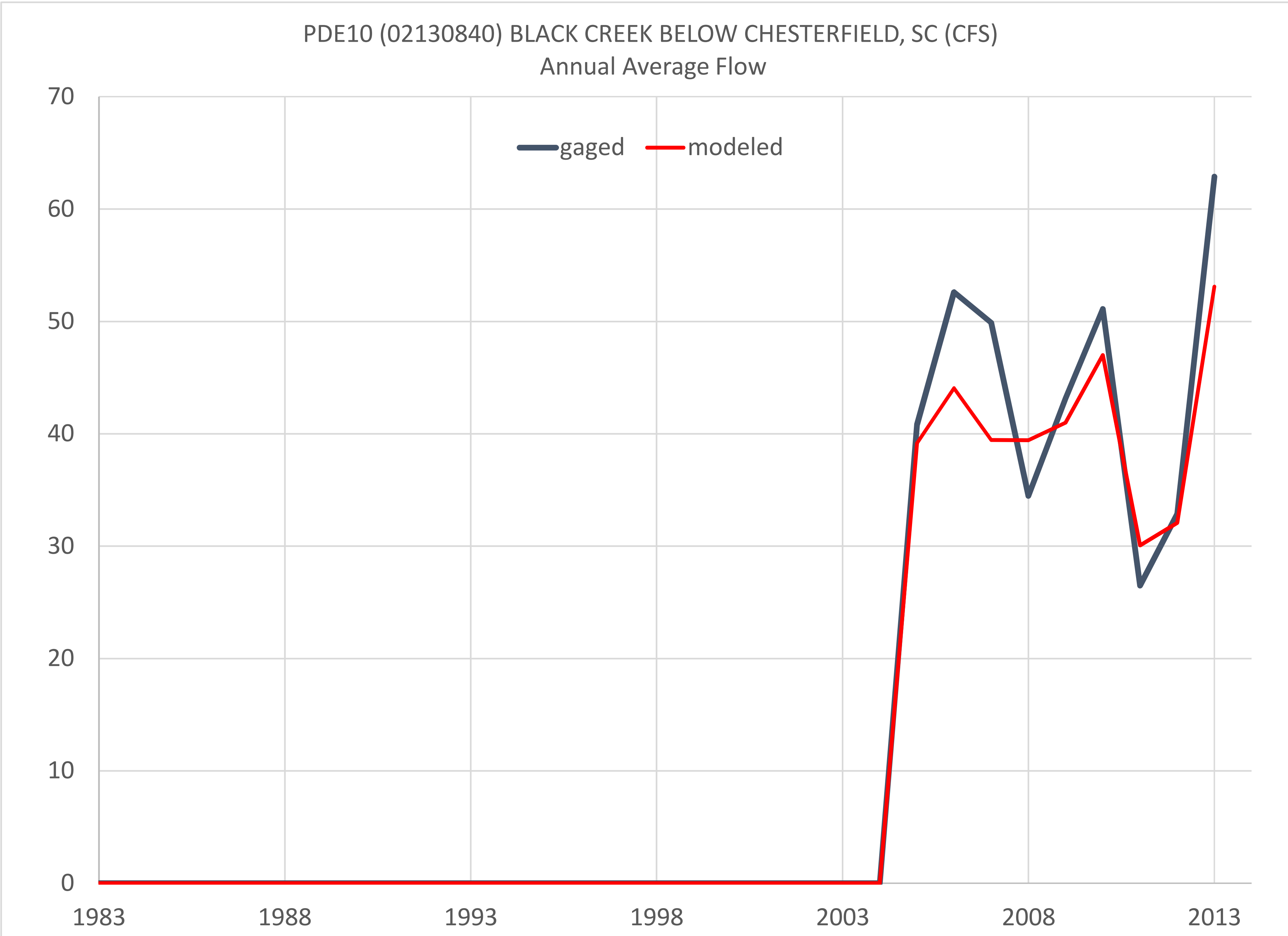
PDE08 (02130561) PEE DEE RIVER NR BENNETTSVILLE, SC
Monthly Mean Flow (CFS)
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
gaged
modeled
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


PDE08 (02130561) PEE DEE RIVER NR BENNETTSVILLE, SC
Daily Flow Percentiles (CFS)
gaged
modeled
160000
140000
120000
100000
80000
60000
40000
20000
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

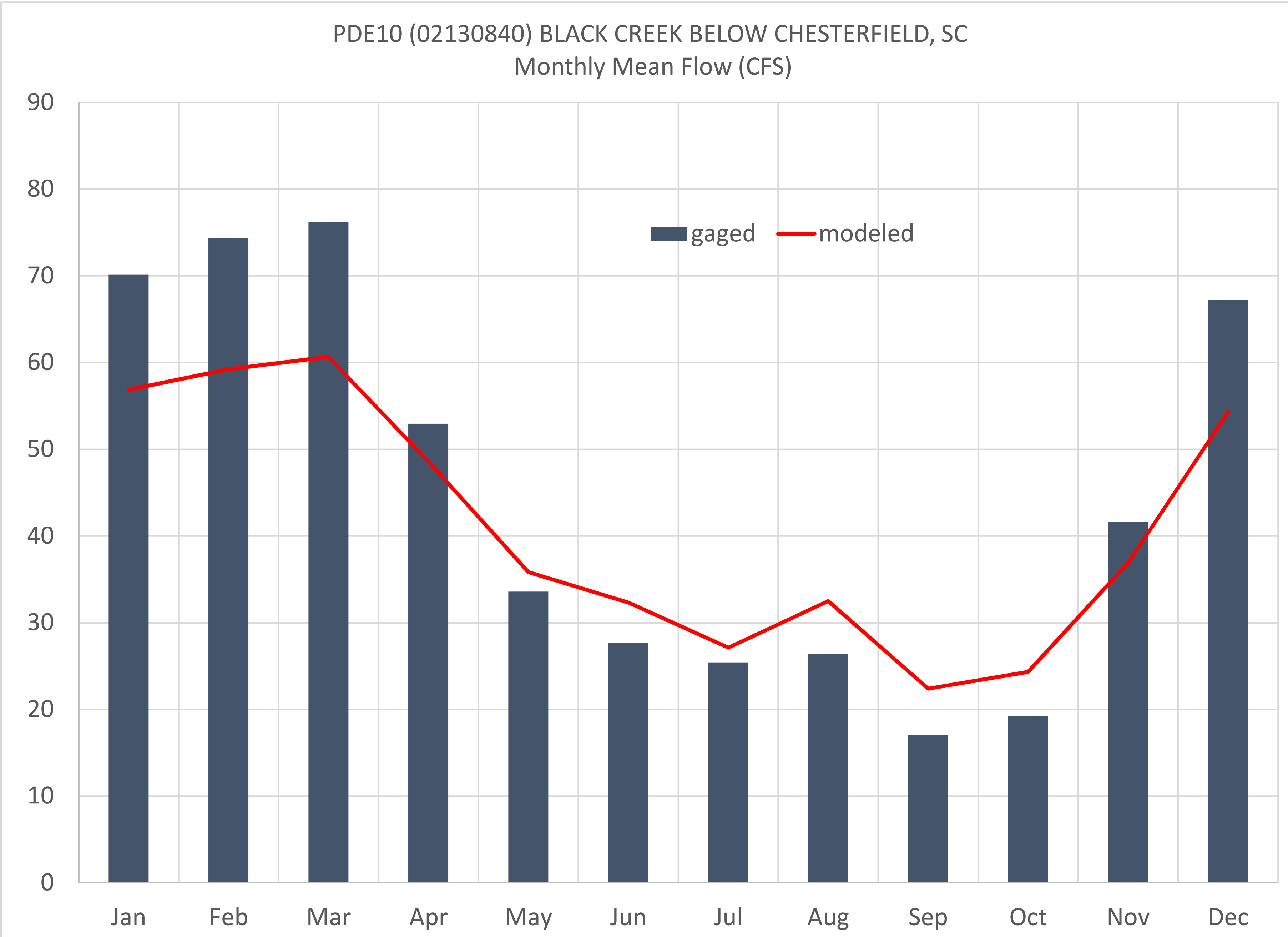

PDE08 (02130561) PEE DEE RIVER NR BENNETTSVILLE, SC
Annual 7-day Low Flow (CFS)
gaged
modeled
4000
3500
3000
2500
2000
1500
1000
500
0
1983
1988
1993
1998
2003
2008
2013
2018
Year

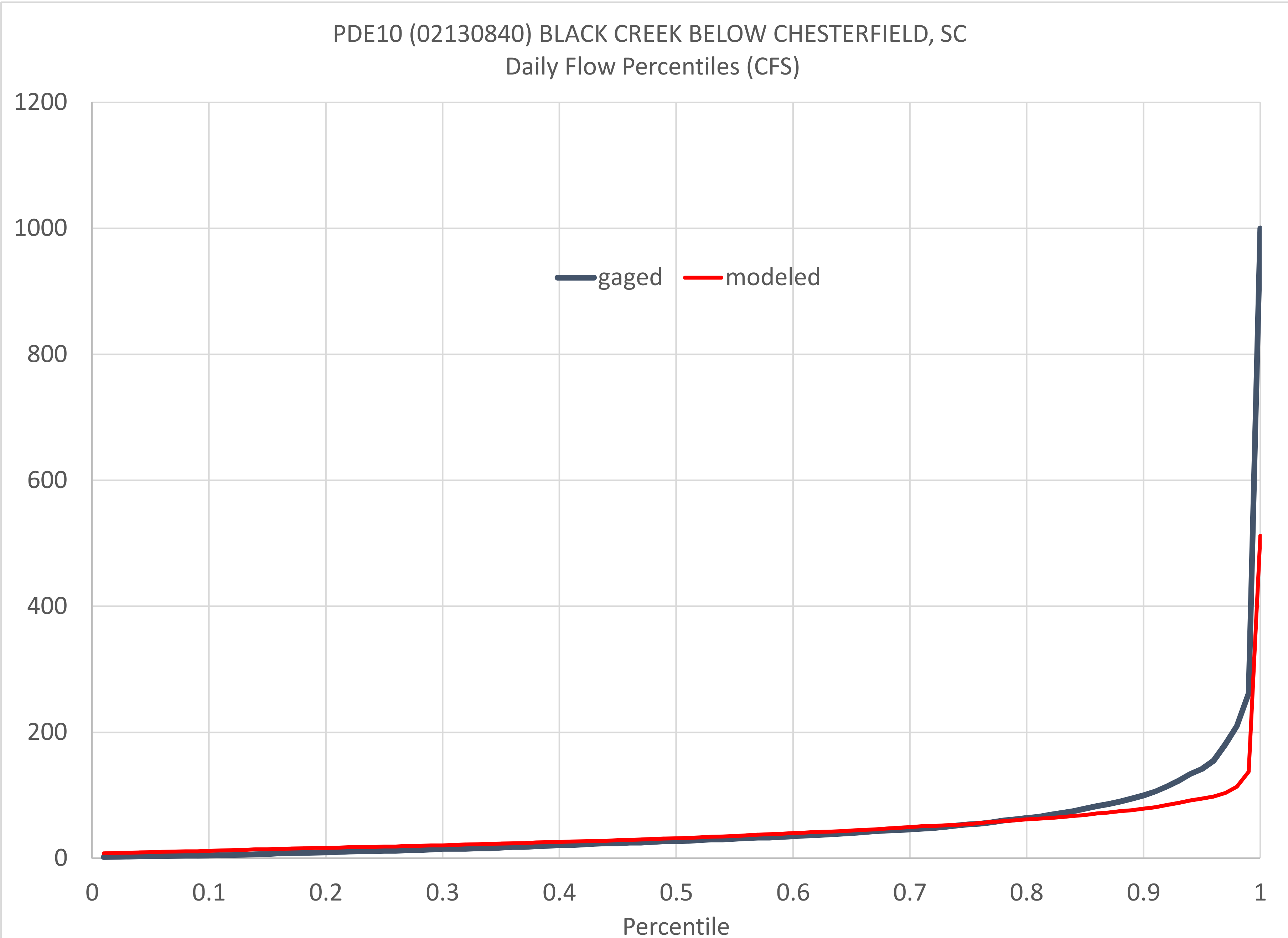


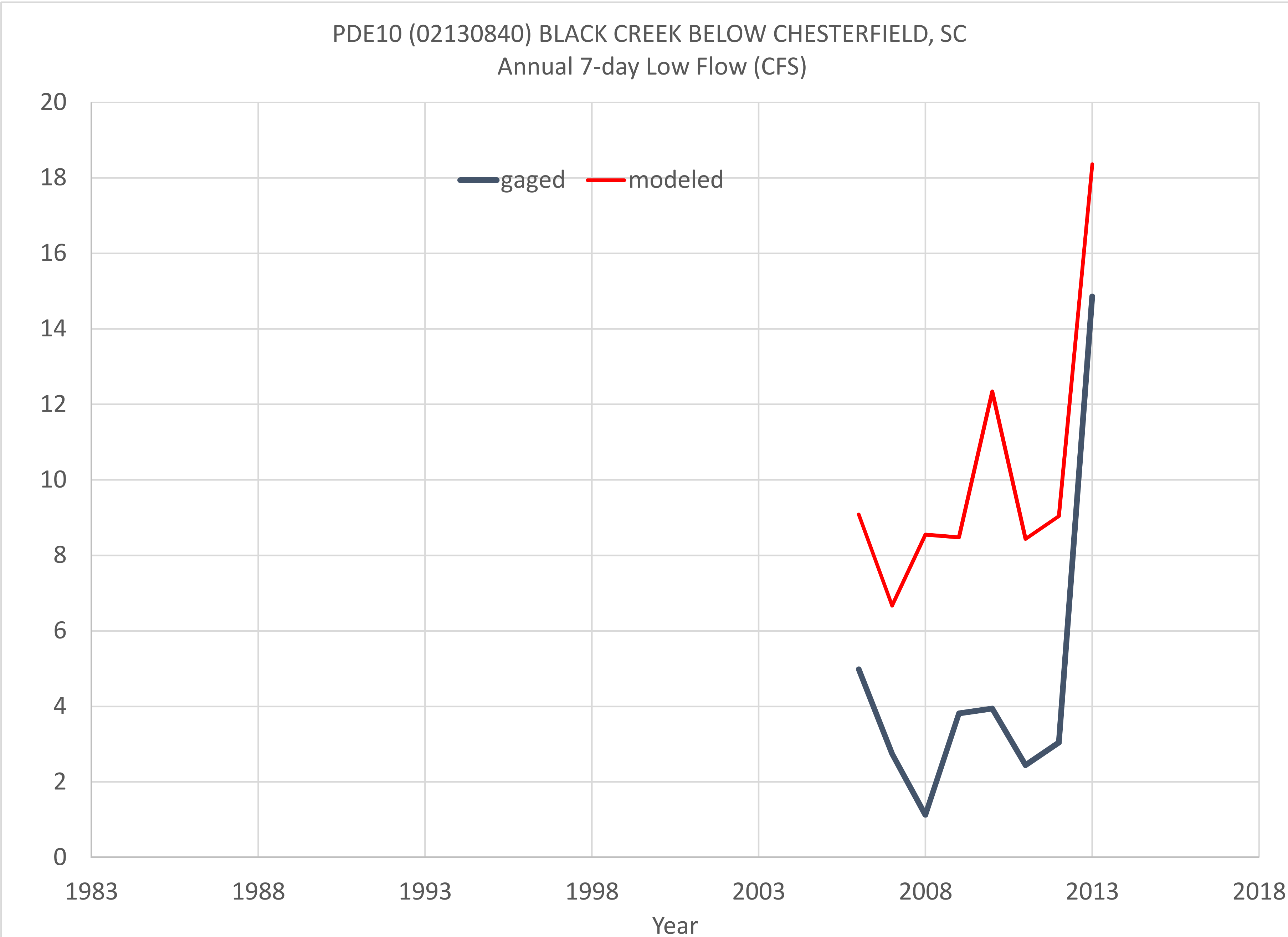
PDE10 (02130840) BLACK CREEK BELOW CHESTERFIELD, SC (CFS)
modeled
gaged
1,200
1,000
800
600
400
200
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

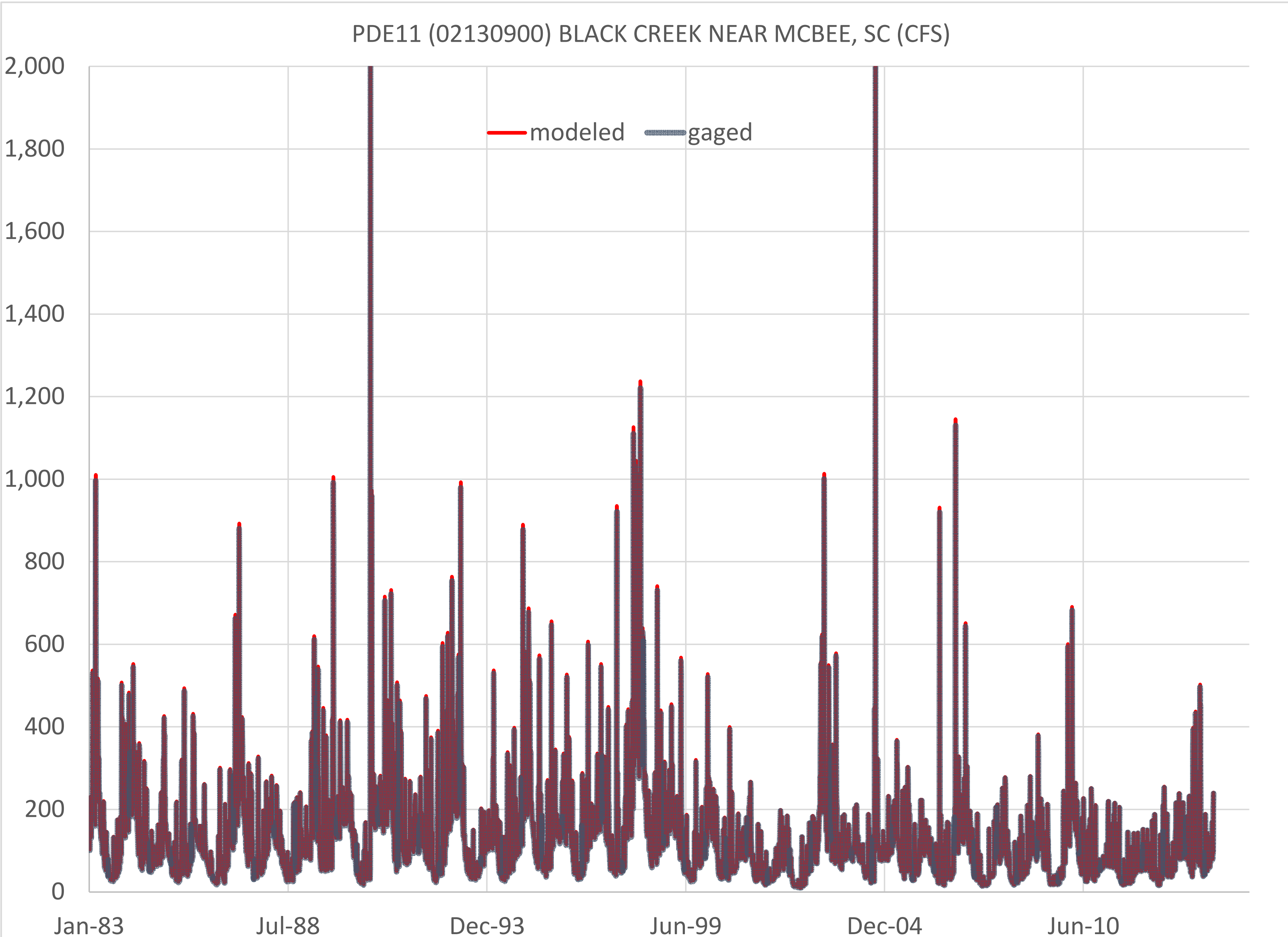


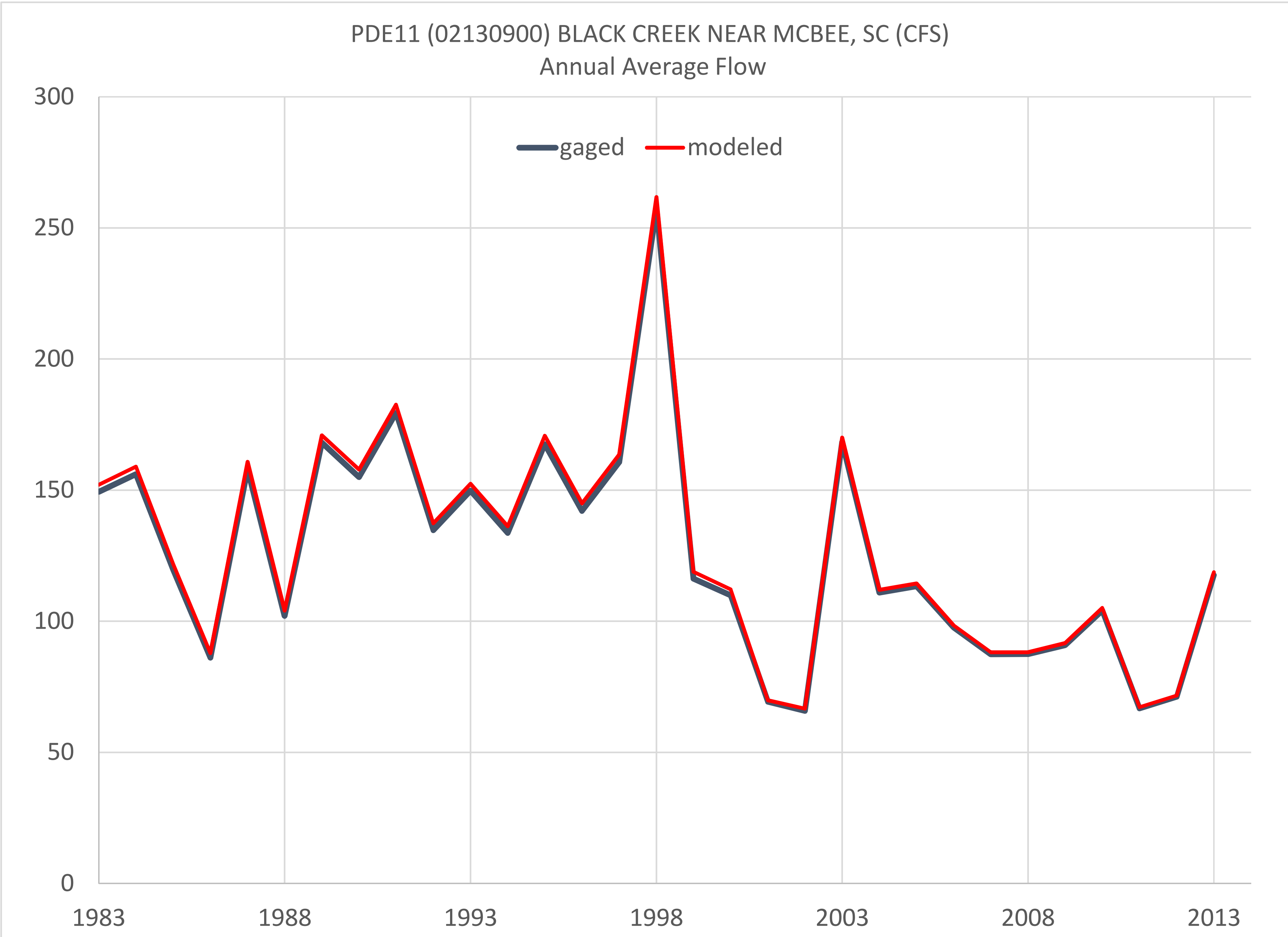
PDE10 (02130840) BLACK CREEK BELOW CHESTERFIELD, SC (CFS)
Annual Average Flow
gaged
modeled
0
10
20
30
40
50
60
70
1983
1988
1993
1998
2003
2008
2013

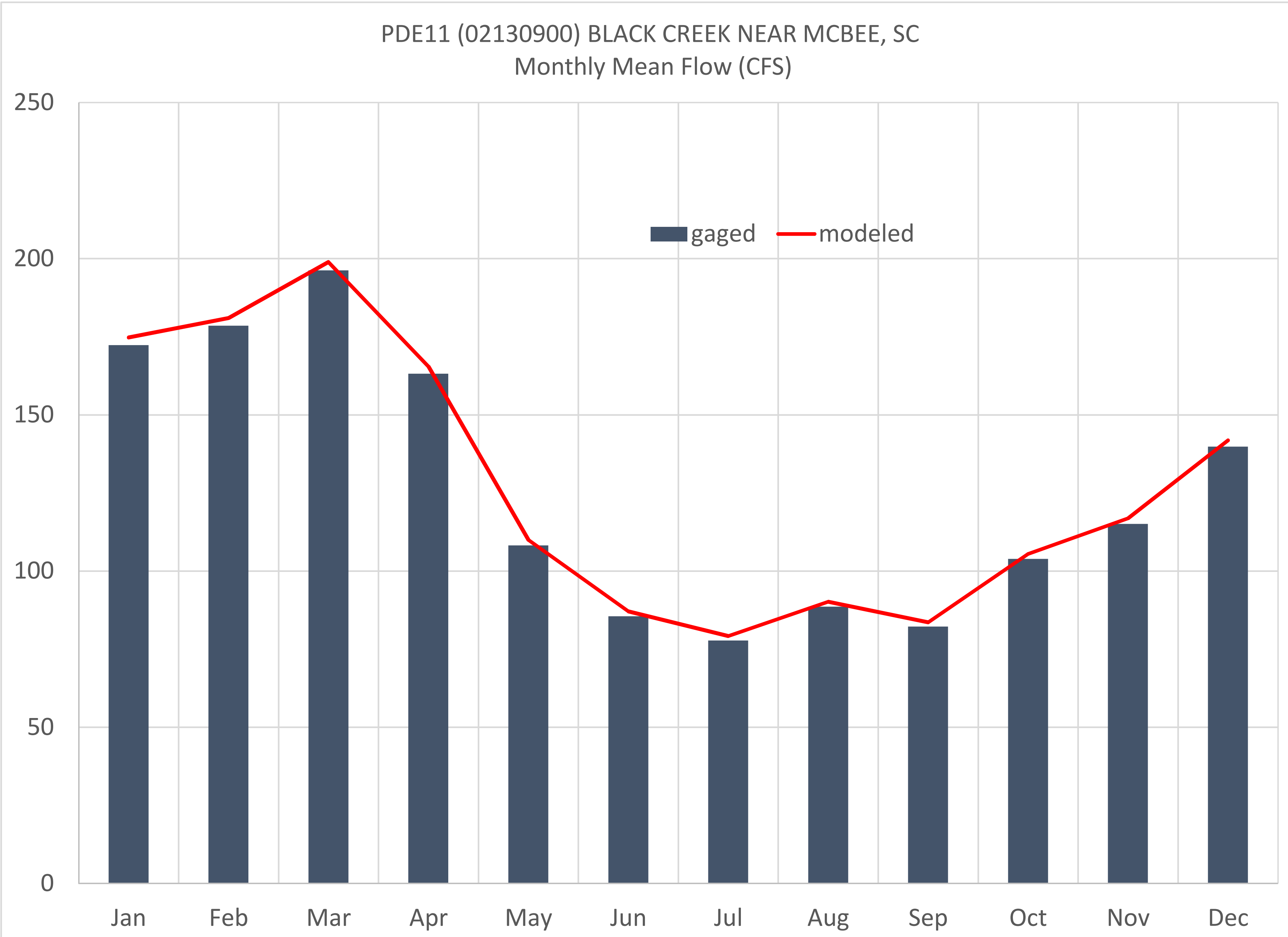

PDE10 (02130840) BLACK CREEK BELOW CHESTERFIELD, SC
Monthly Mean Flow (CFS)
90
80
70
60
50
40
30
20
10
0
gaged
modeled
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


PDE10 (02130840) BLACK CREEK BELOW CHESTERFIELD, SC
Daily Flow Percentiles (CFS)
gaged
modeled
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

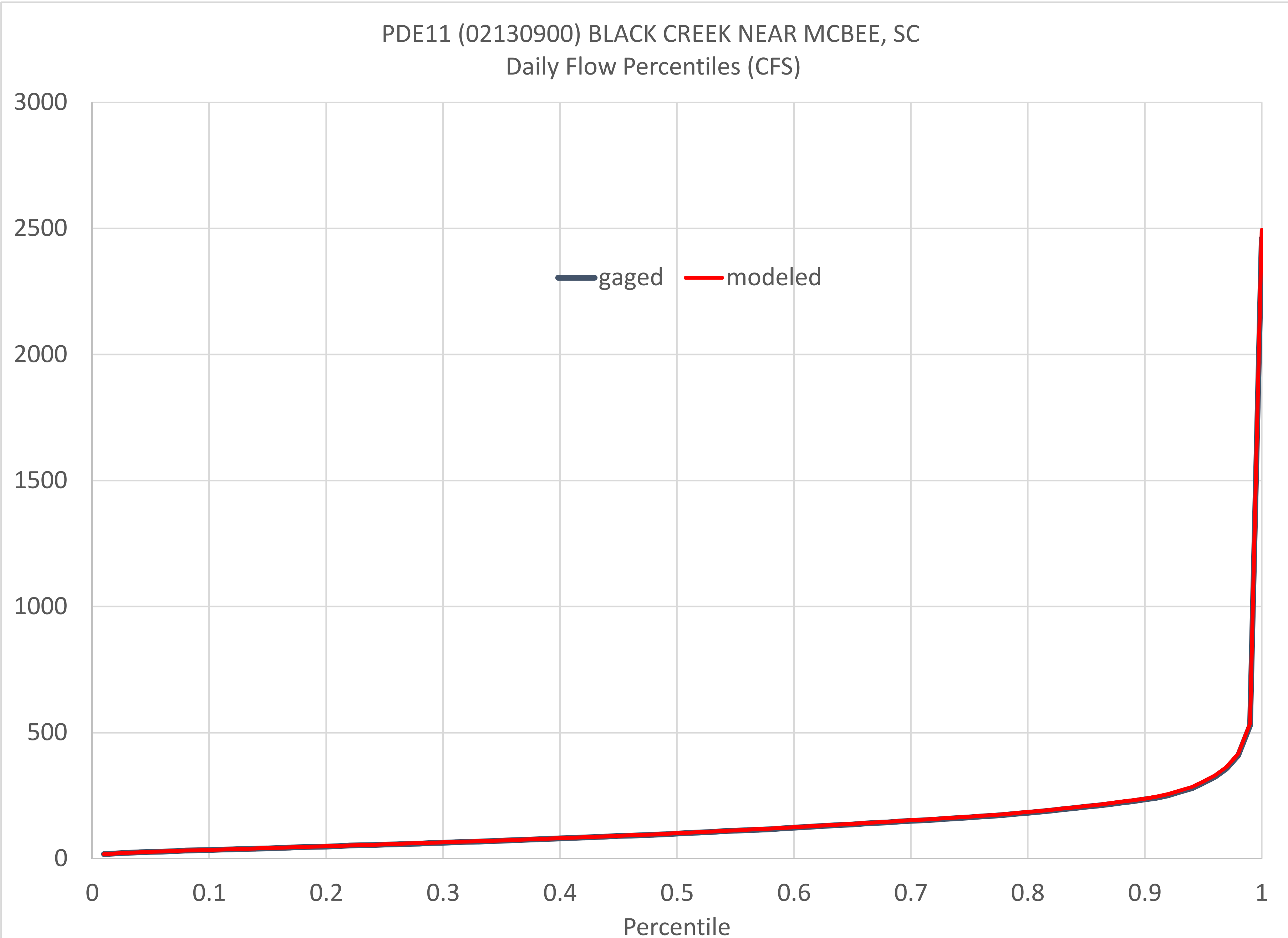

PDE10 (02130840) BLACK CREEK BELOW CHESTERFIELD, SC
Annual 7-day Low Flow (CFS)
gaged
modeled
20
18
16
14
12
10
8
6
4
2
0
1983
1988
1993
1998
2003
2008
2013
2018
Year

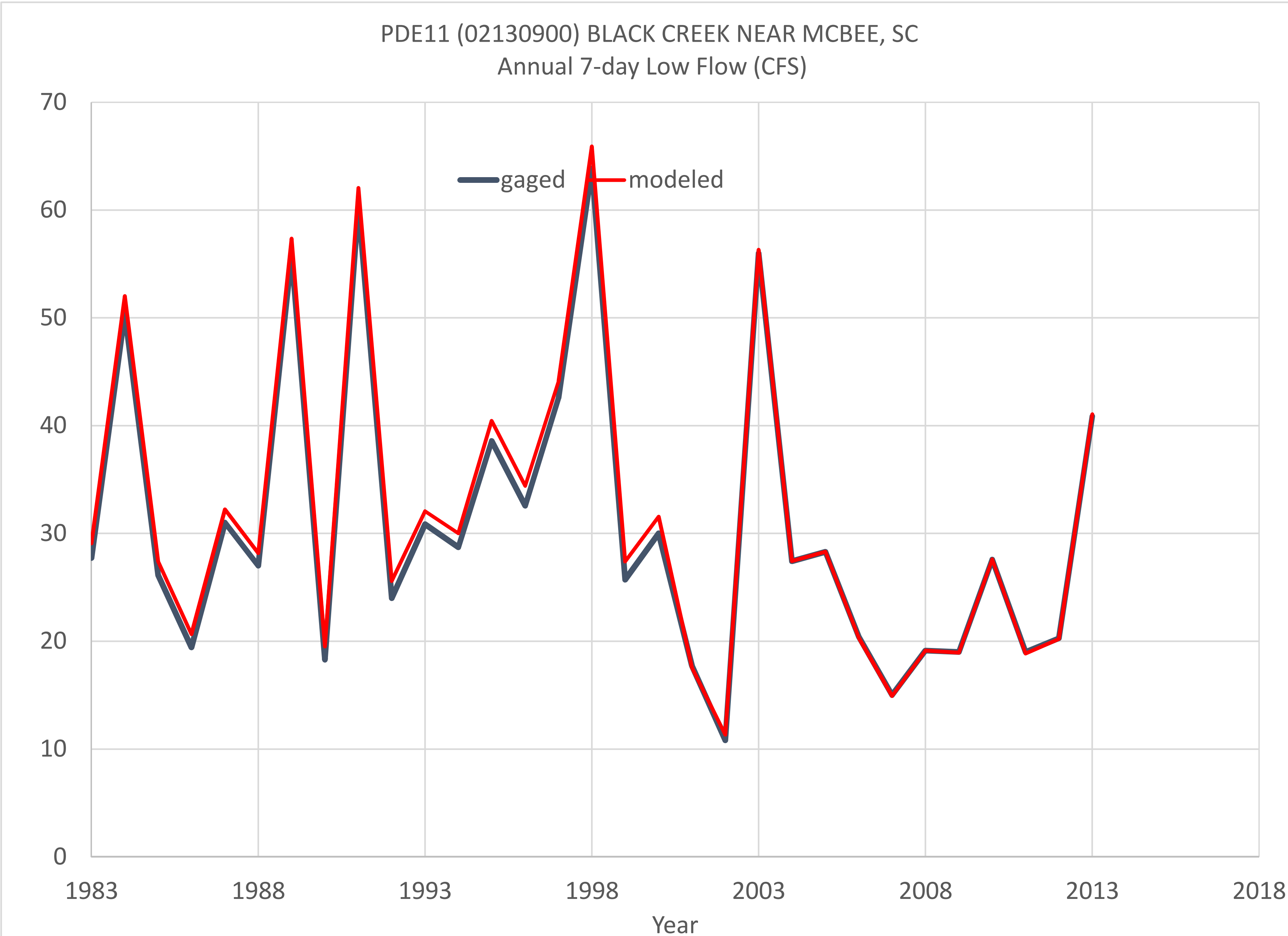

PDE11 (02130900) BLACK CREEK NEAR MCBEE, SC (CFS)
modeled
gaged
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

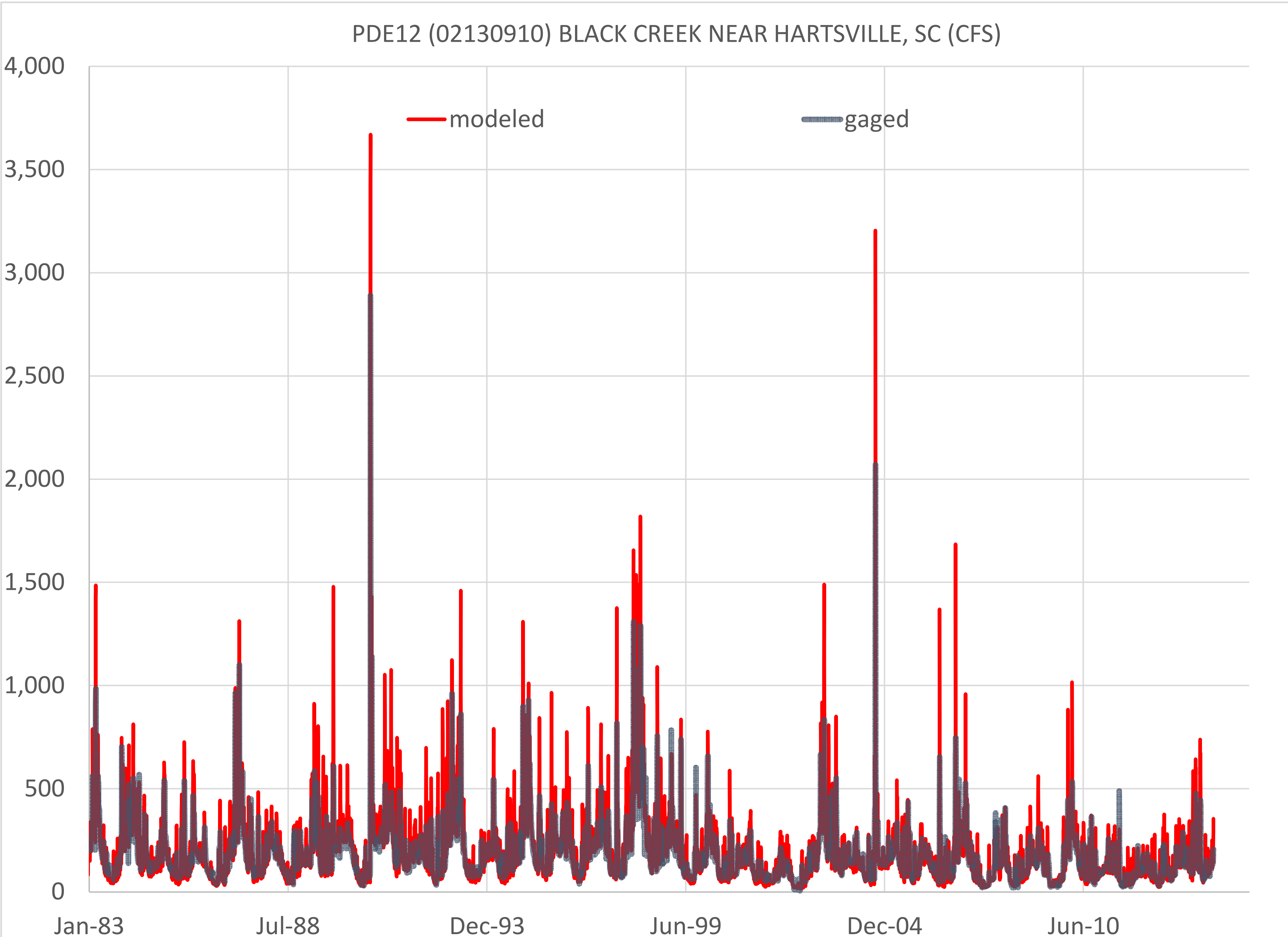

PDE11 (02130900) BLACK CREEK NEAR MCBEE, SC (CFS)
Annual Average Flow
gaged
modeled
300
250
200
150
100
50
0
1983
1988
1993
1998
2003
2008
2013

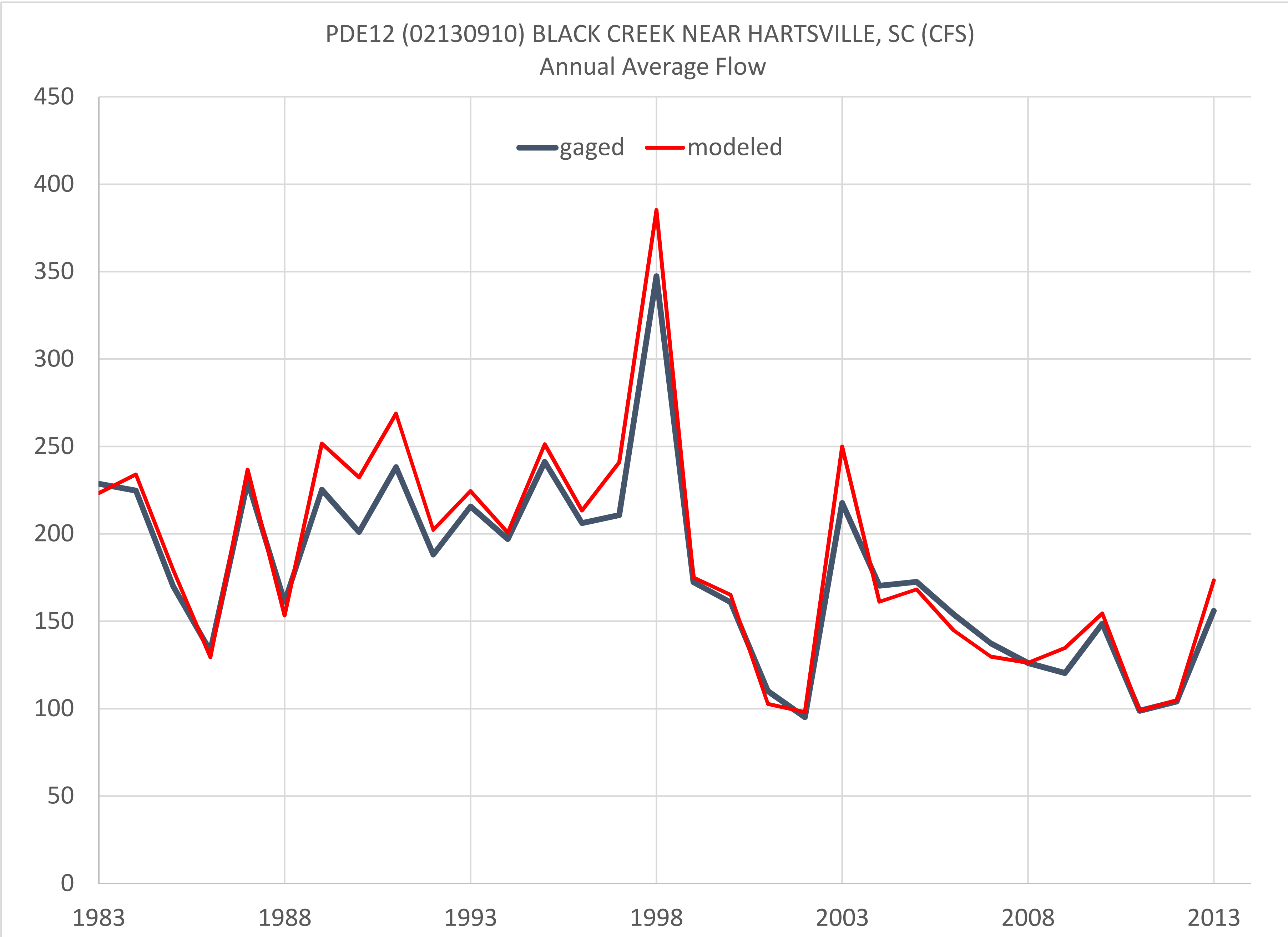


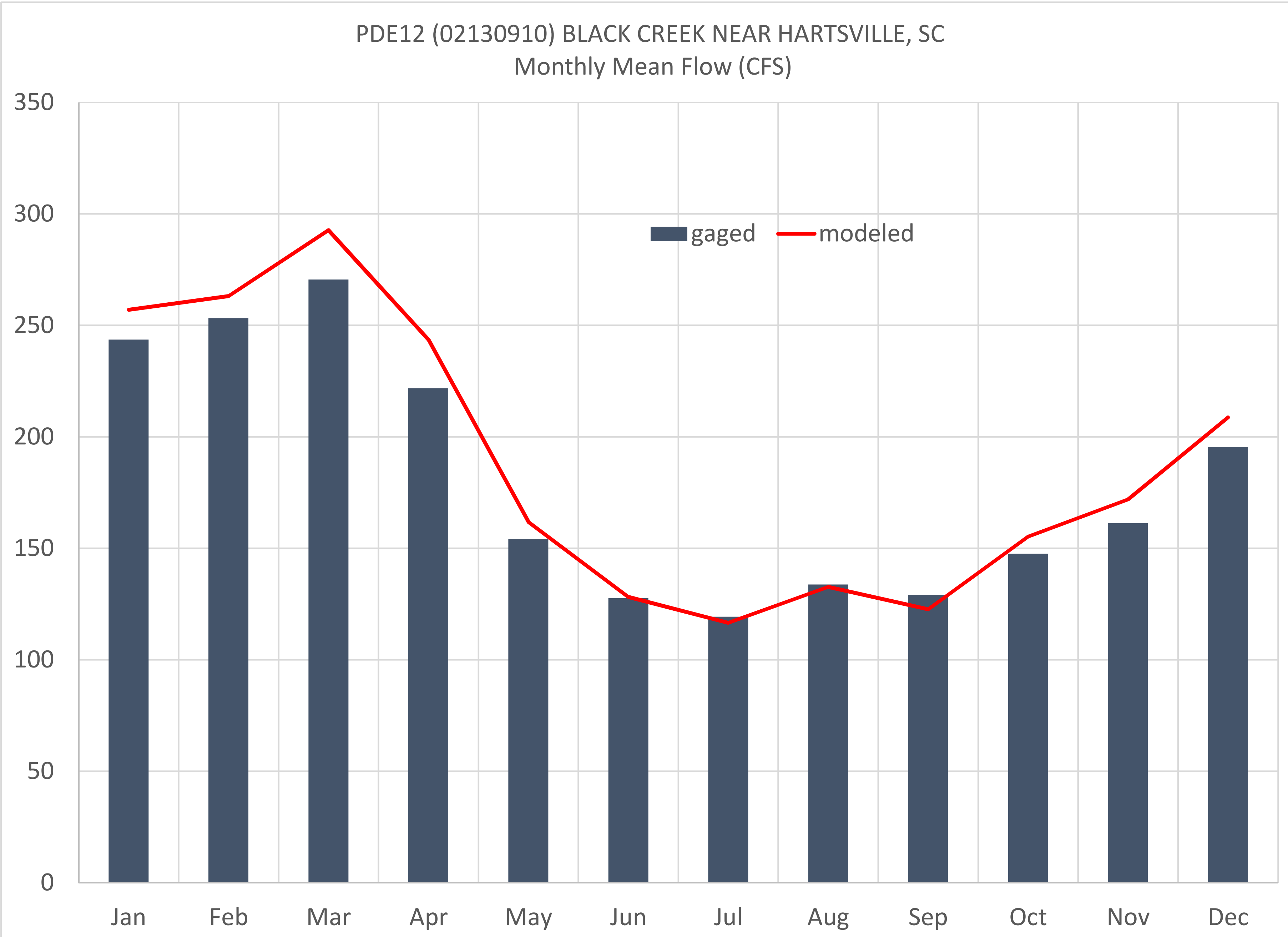
PDE11 (02130900) BLACK CREEK NEAR MCBEE, SC
Monthly Mean Flow (CFS)
gaged
modeled
250
200
150
100
50
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


PDE11 (02130900) BLACK CREEK NEAR MCBEE, SC
Daily Flow Percentiles (CFS)
gaged
modeled
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

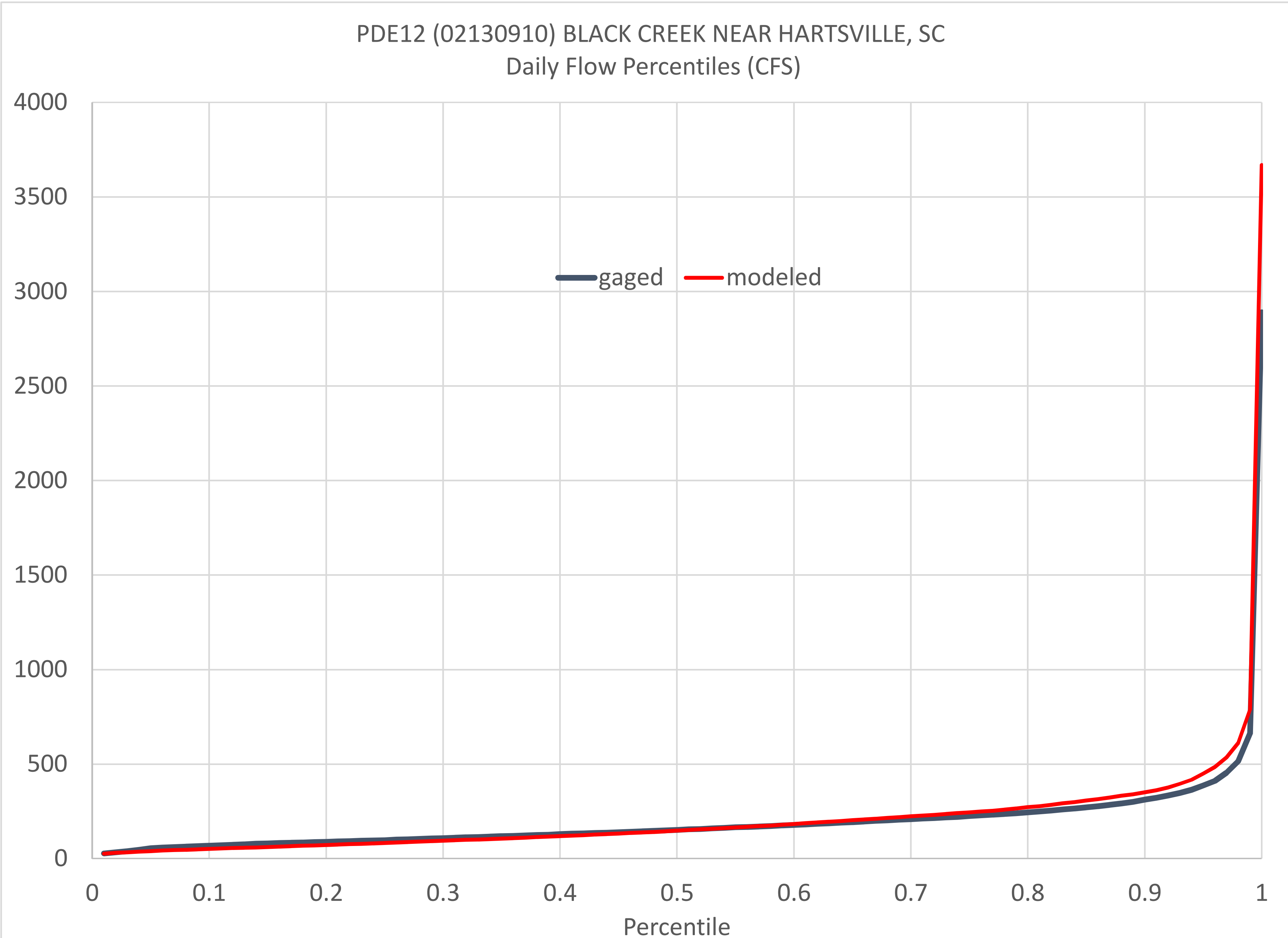

PDE11 (02130900) BLACK CREEK NEAR MCBEE, SC
Annual 7-day Low Flow (CFS)
gaged
modeled
0
10
20
30
40
50
60
70
1983
1988
1993
1998
2003
2008
2013
2018
Year

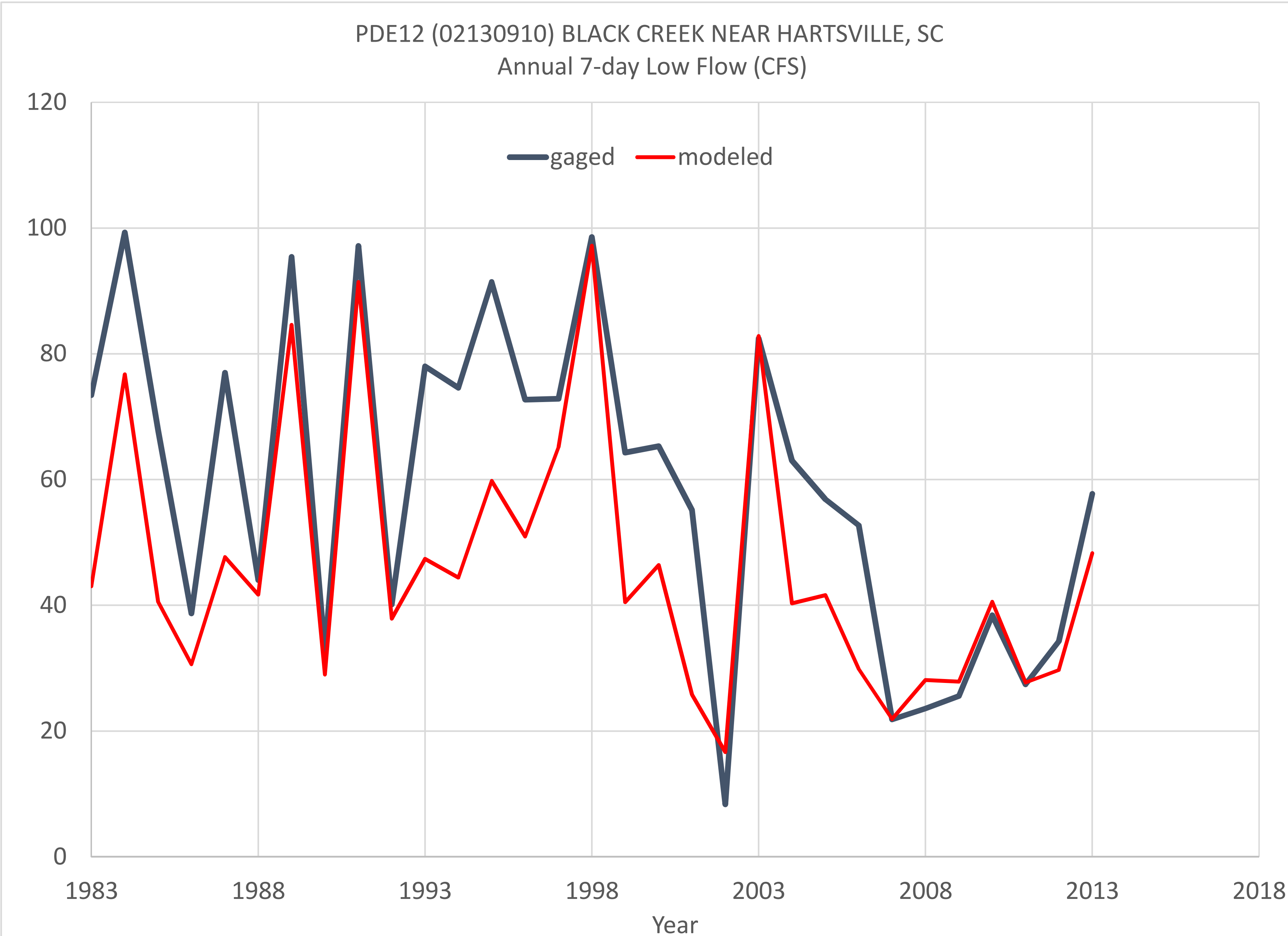

PDE12 (02130910) BLACK CREEK NEAR HARTSVILLE, SC (CFS)
modeled
gaged
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

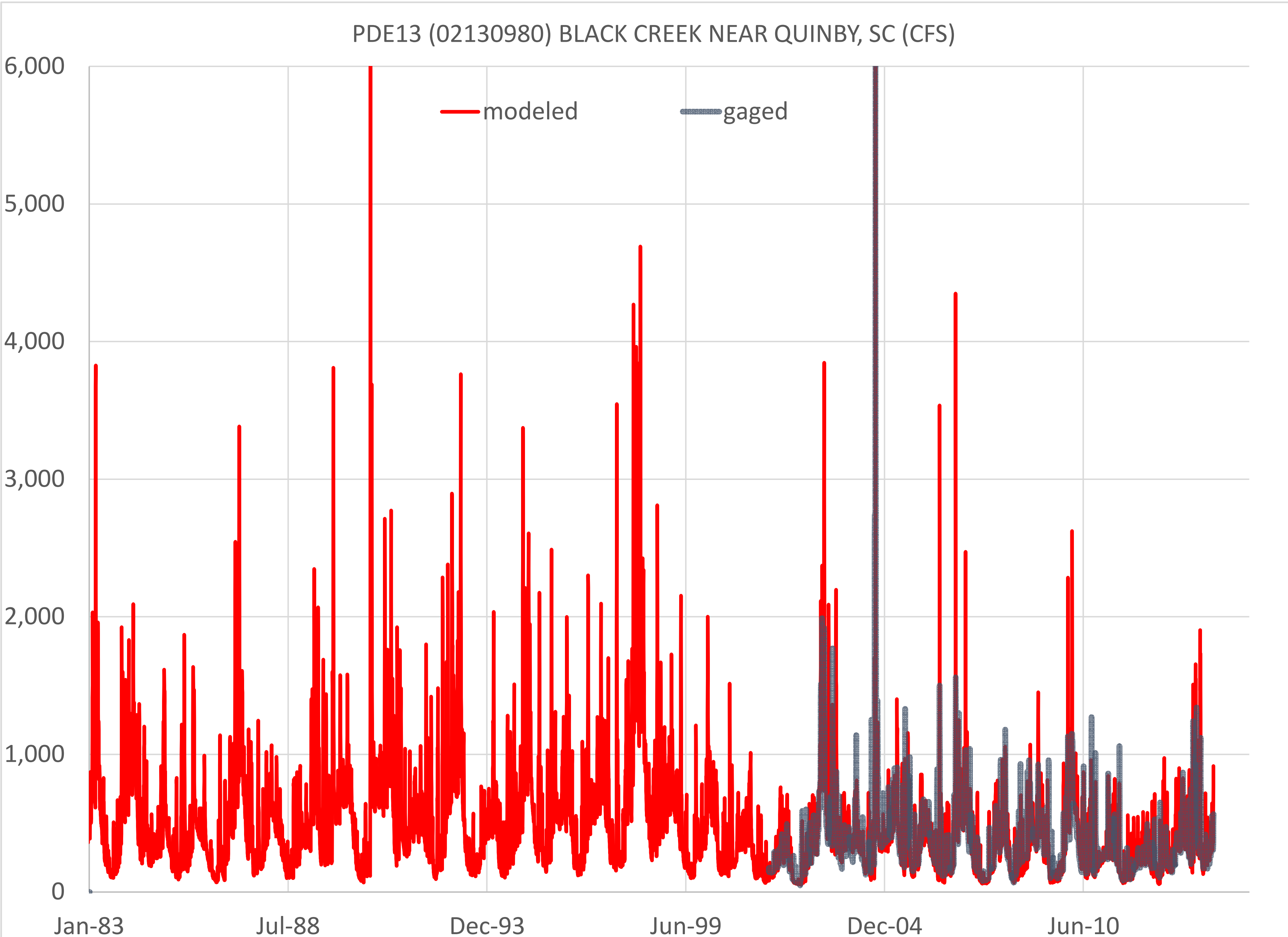

PDE12 (02130910) BLACK CREEK NEAR HARTSVILLE, SC (CFS)
Annual Average Flow
gaged
modeled
450
400
350
300
250
200
150
100
50
0
1983
1988
1993
1998
2003
2008
2013



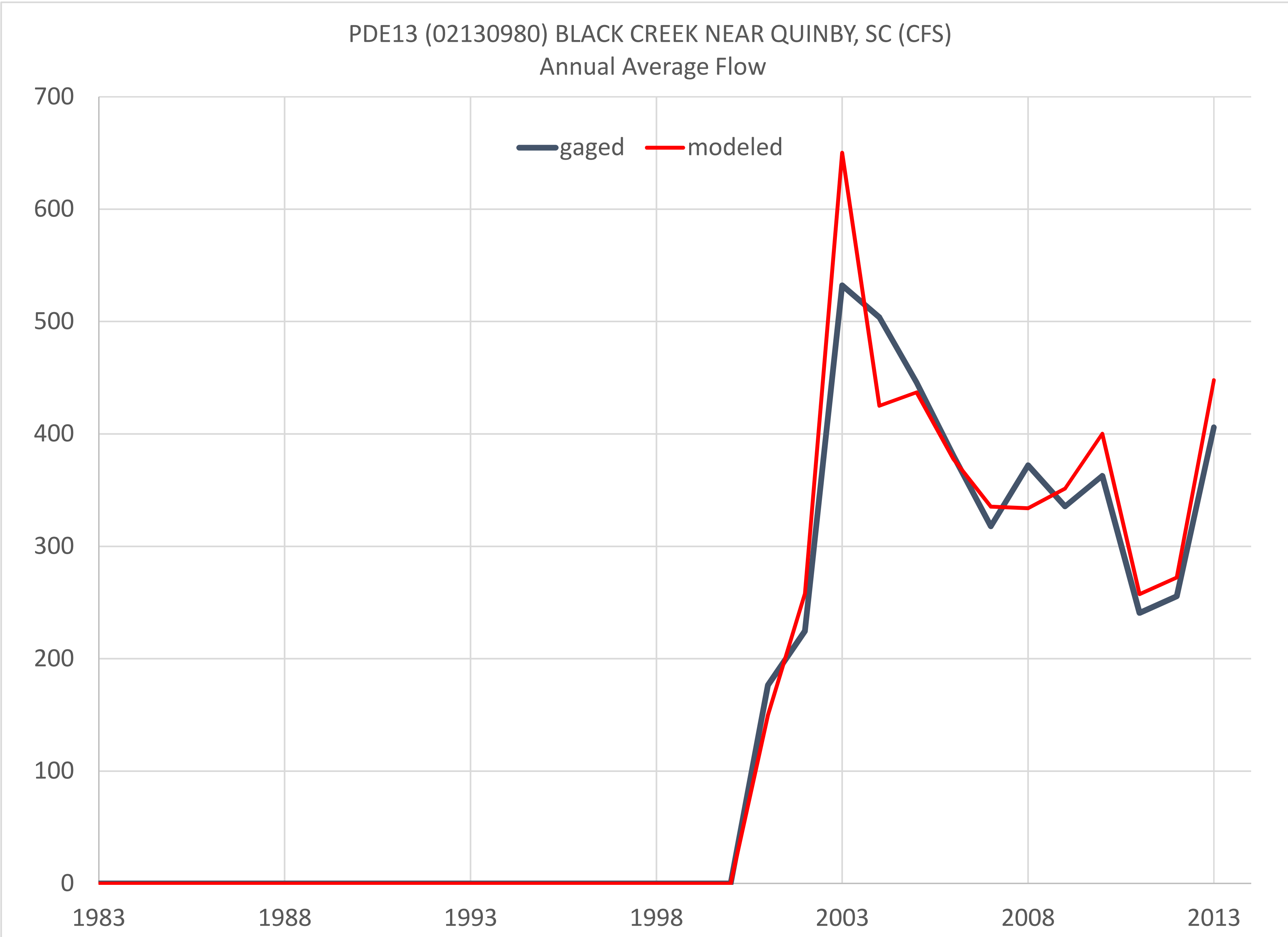
PDE12 (02130910) BLACK CREEK NEAR HARTSVILLE, SC
Monthly Mean Flow (CFS)
350
300
250
200
150
100
50
0
gaged
modeled
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


PDE12 (02130910) BLACK CREEK NEAR HARTSVILLE, SC
Daily Flow Percentiles (CFS)
4000
3500
3000
2500
2000
1500
1000
500
0
gaged
modeled
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

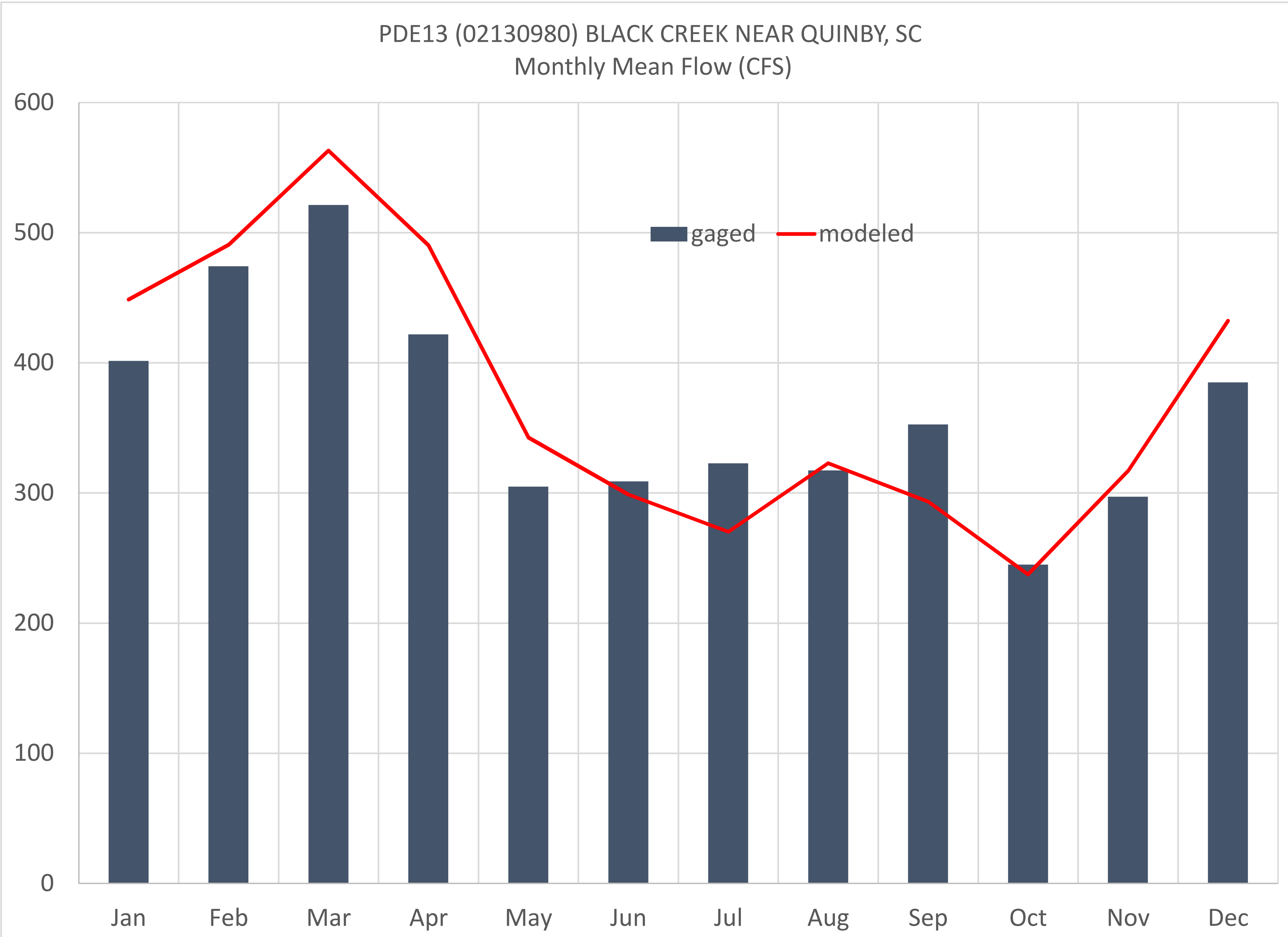

PDE12 (02130910) BLACK CREEK NEAR HARTSVILLE, SC
Annual 7-day Low Flow (CFS)
gaged
modeled
120
100
80
60
40
20
0
1983
1988
1993
1998
2003
2008
2013
2018
Year

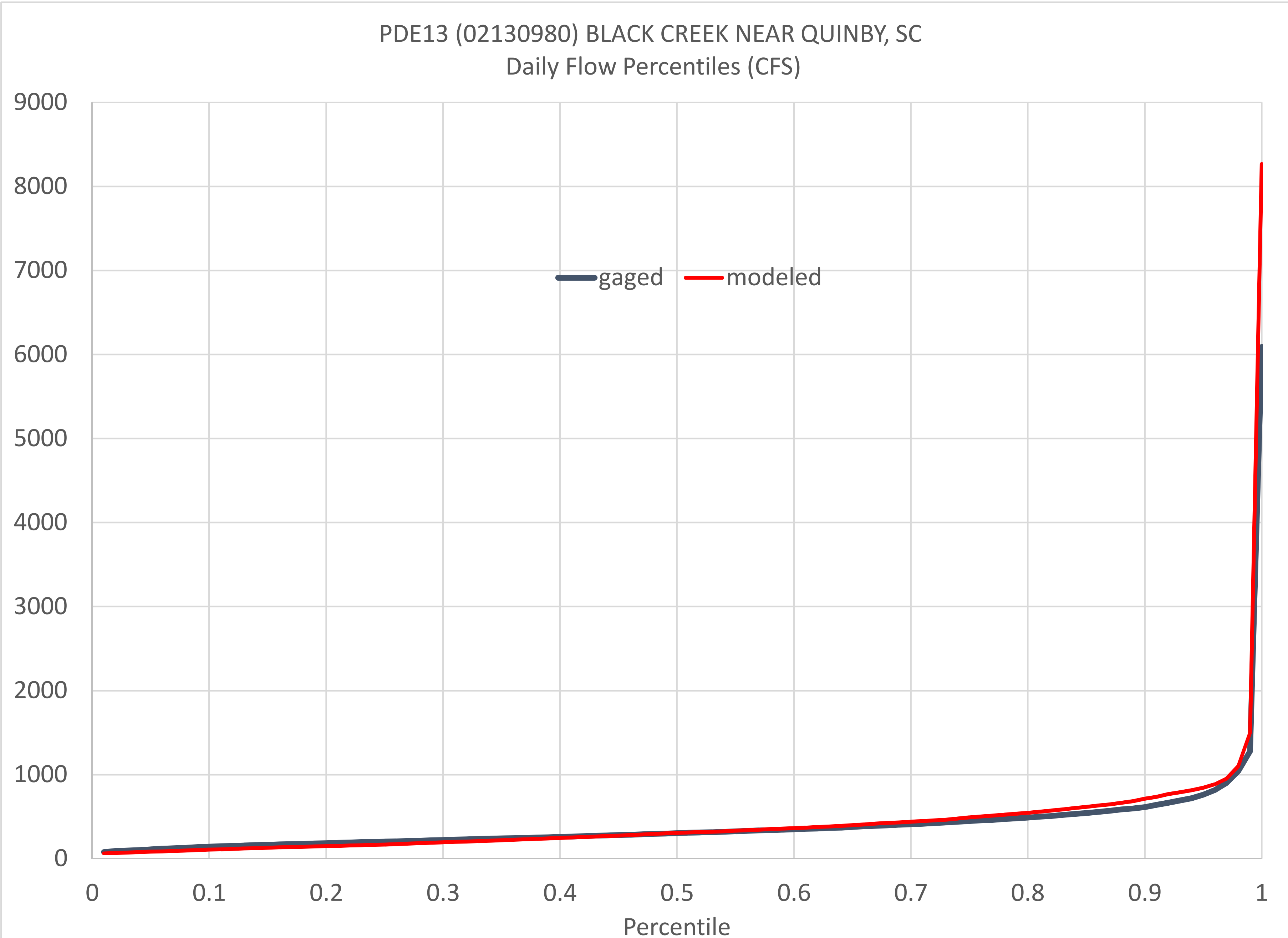


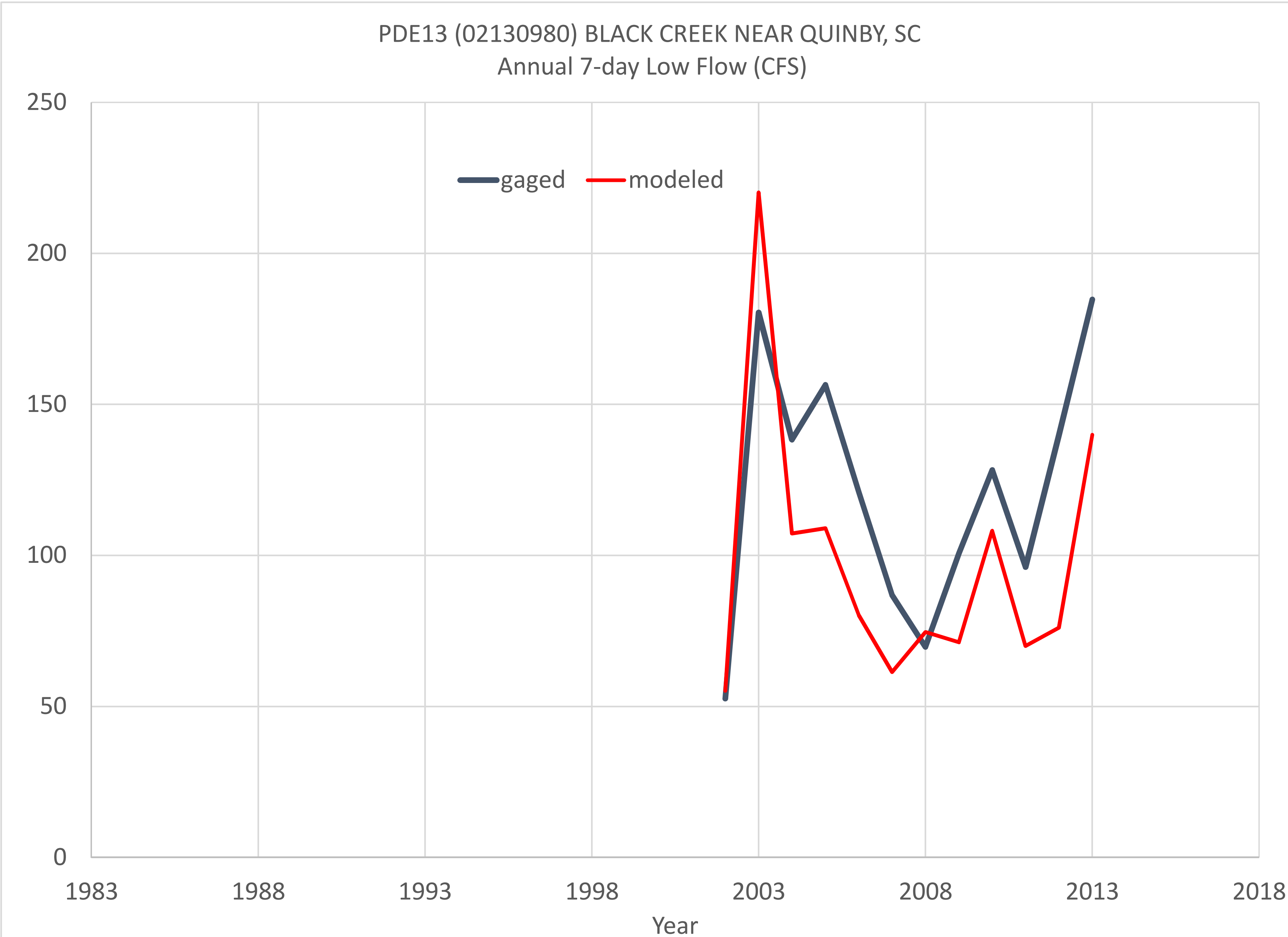
PDE13 (02130980) BLACK CREEK NEAR QUINBY, SC (CFS)
modeled
gaged
6,000
5,000
4,000
3,000
2,000
1,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

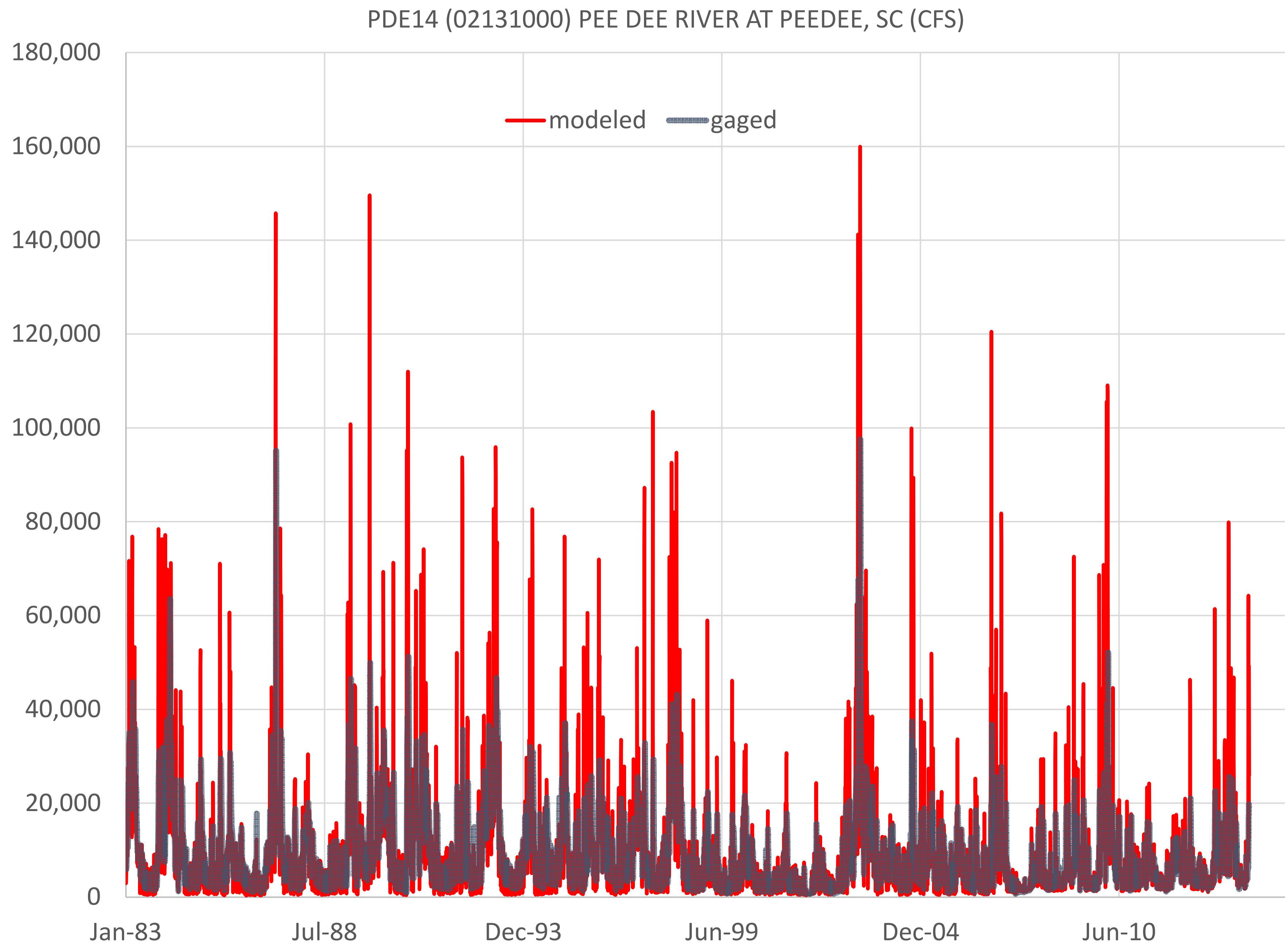


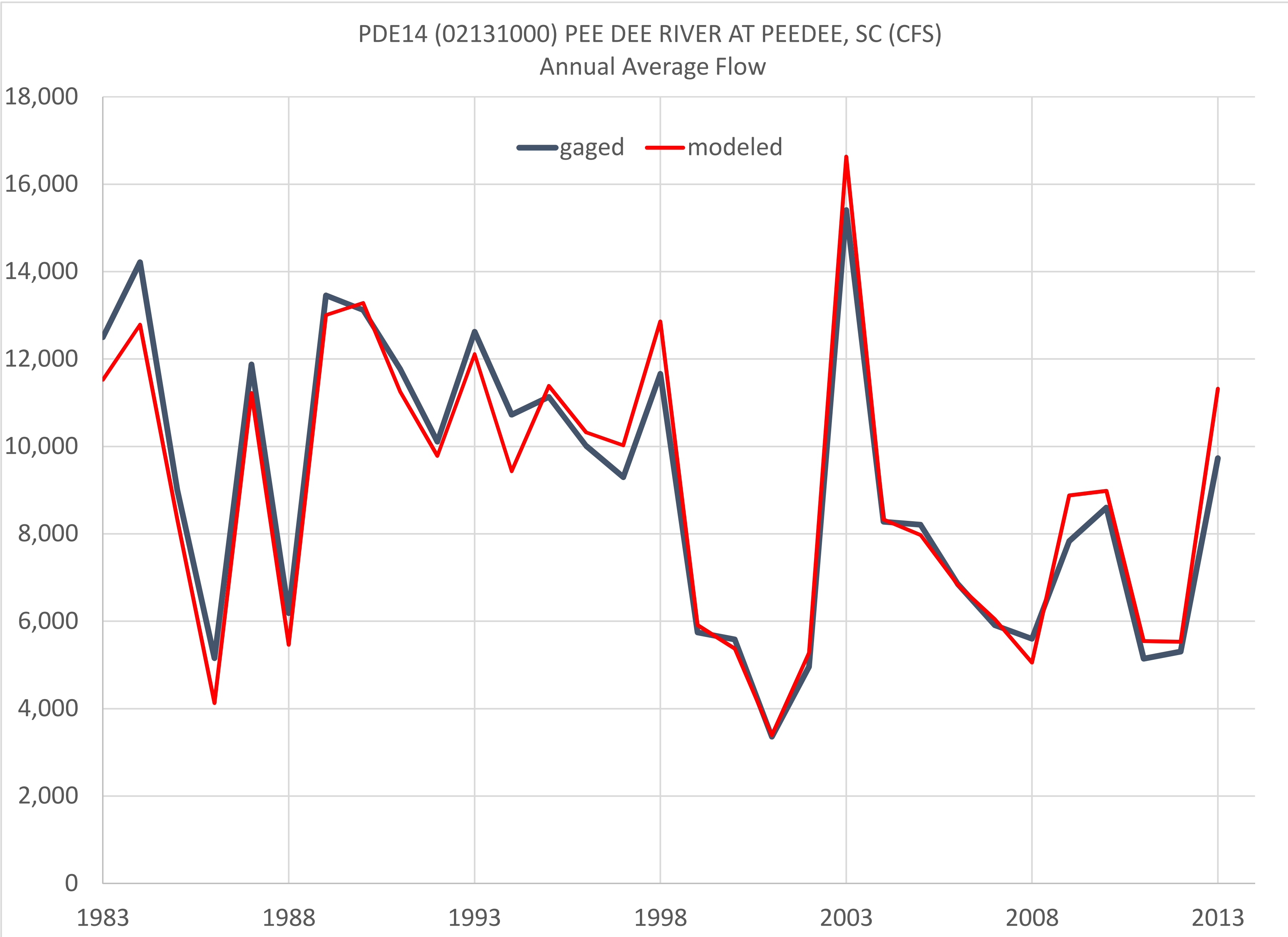
PDE13 (02130980) BLACK CREEK NEAR QUINBY, SC (CFS)
Annual Average Flow
gaged
modeled
700
600
500
400
300
200
100
0
1983
1988
1993
1998
2003
2008
2013

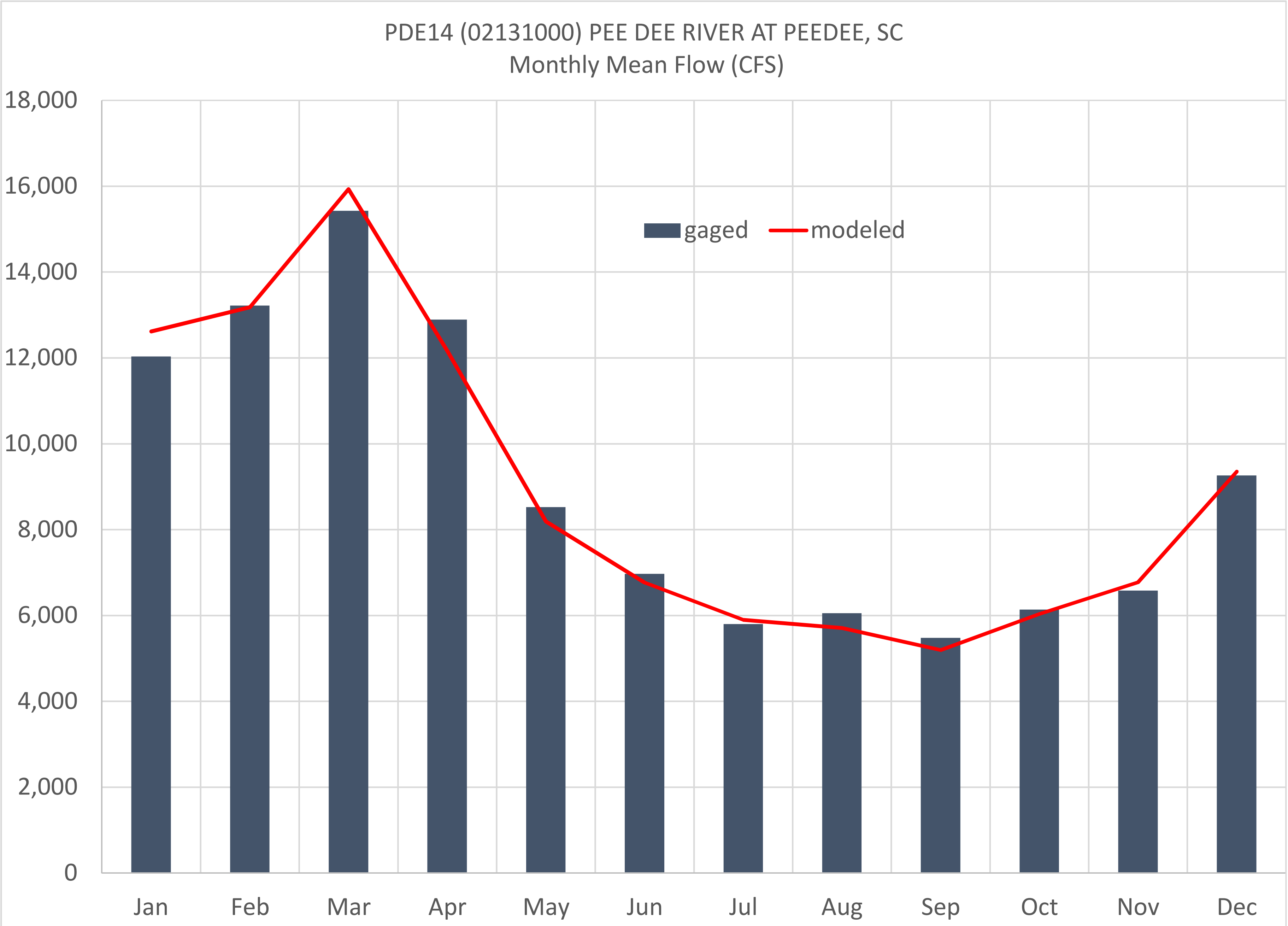

PDE13 (02130980) BLACK CREEK NEAR QUINBY, SC
Monthly Mean Flow (CFS)
gaged
modeled
600
500
400
300
200
100
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

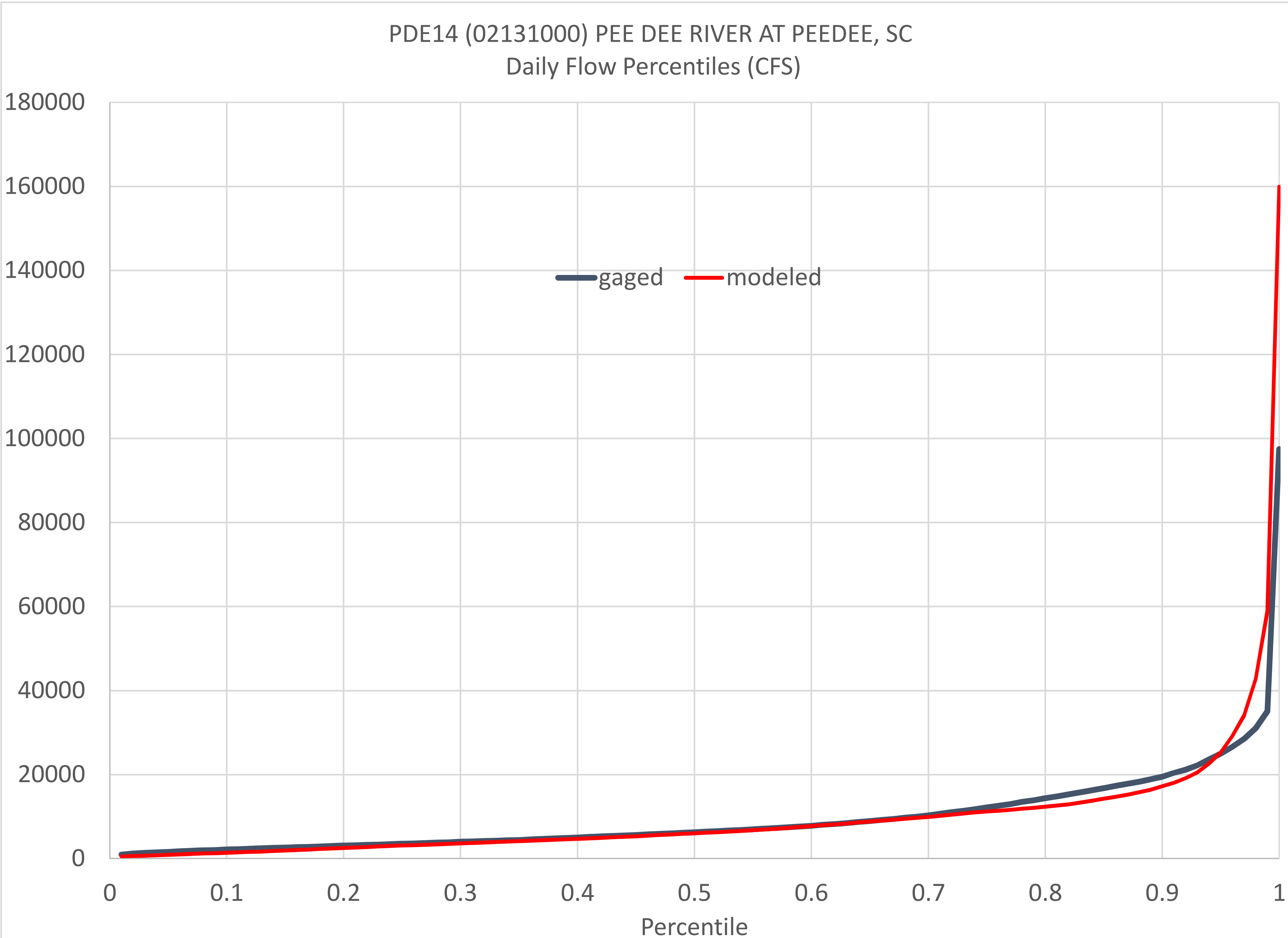

PDE13 (02130980) BLACK CREEK NEAR QUINBY, SC
Daily Flow Percentiles (CFS)
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
gaged
modeled
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

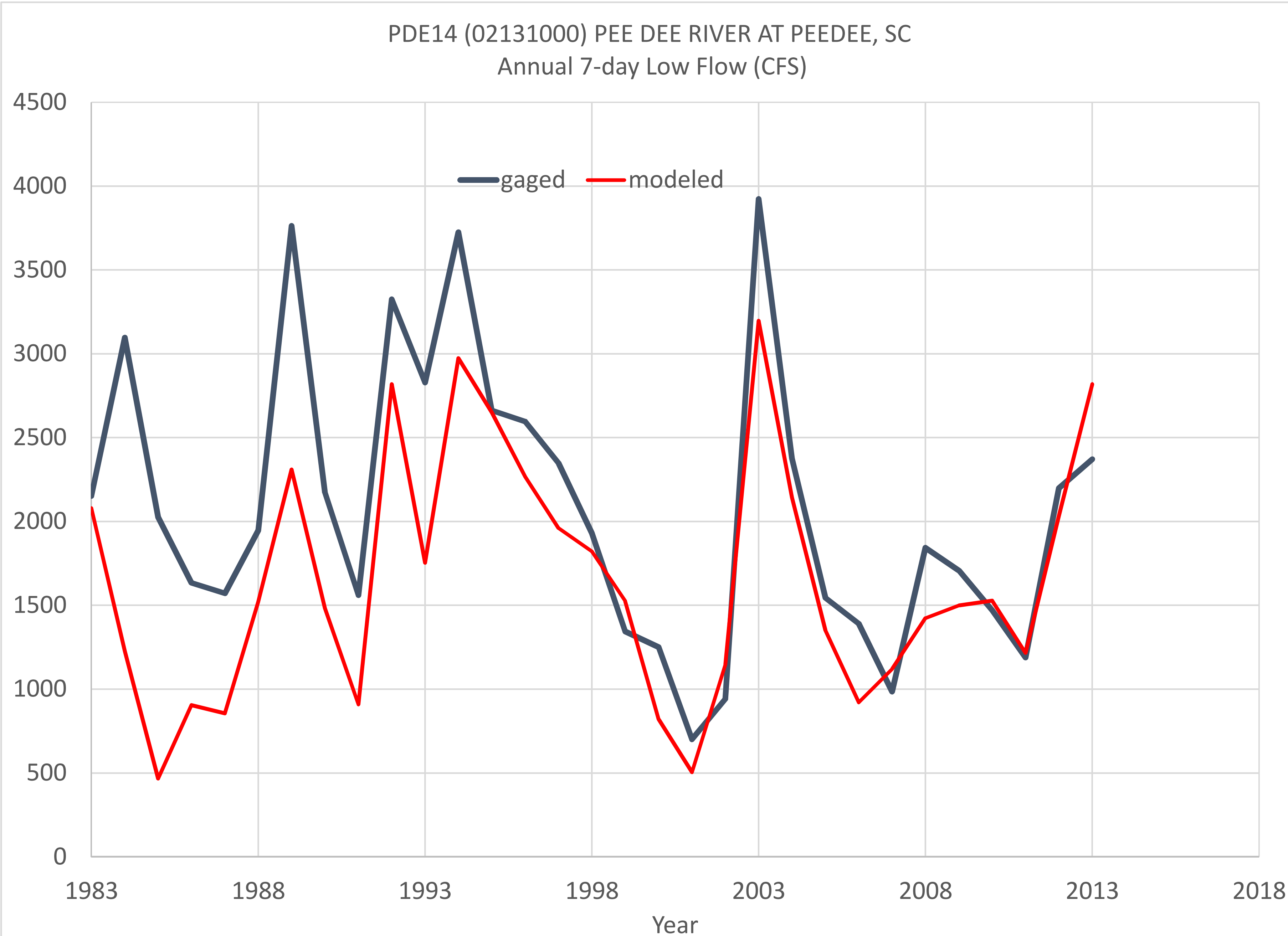

PDE13 (02130980) BLACK CREEK NEAR QUINBY, SC
Annual 7-day Low Flow (CFS)
gaged
modeled
250
200
150
100
50
0
1983
1988
1993
1998
2003
2008
2013
2018
Year

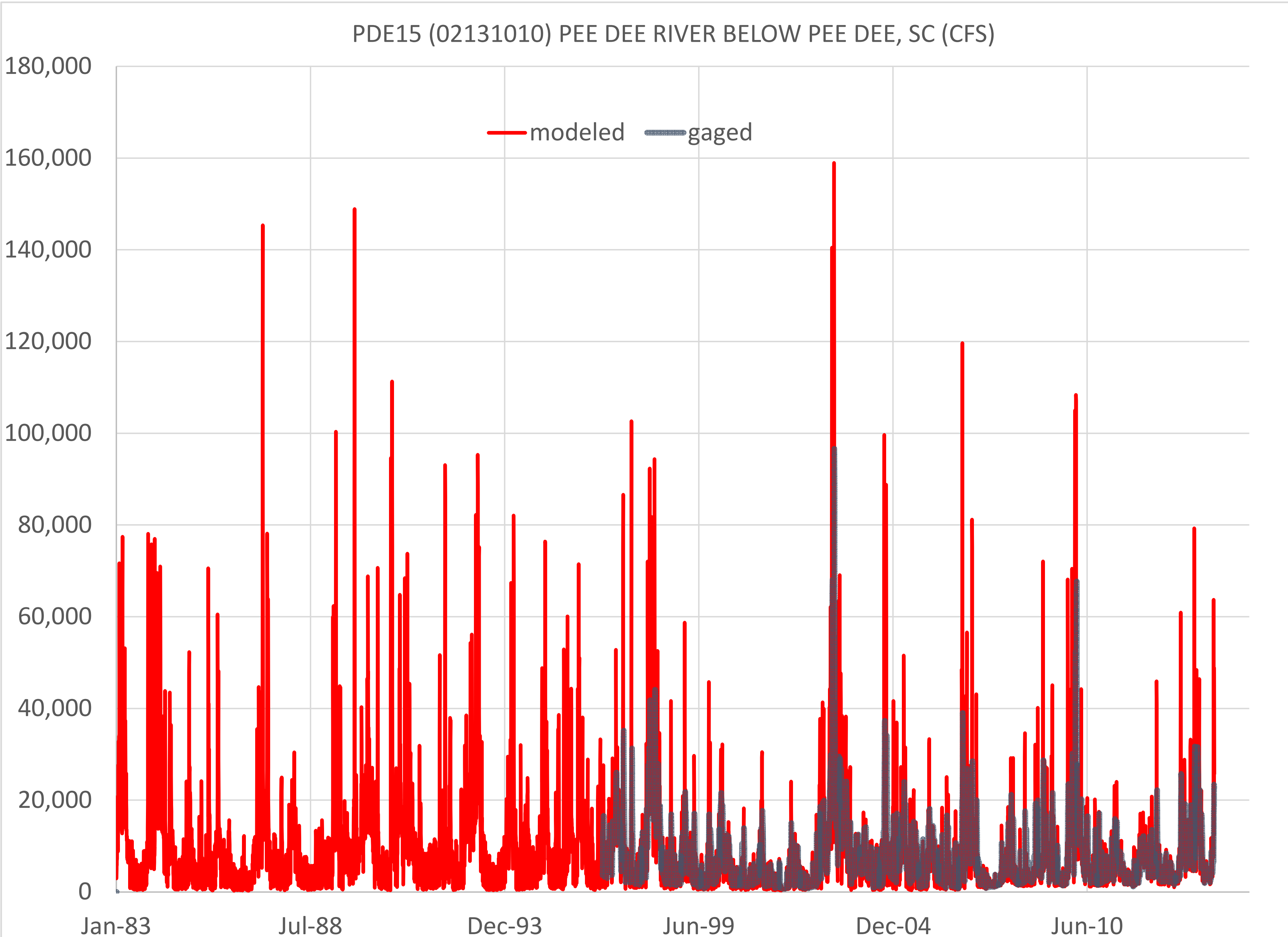

PDE14 (02131000) PEE DEE RIVER AT PEEDEE, SC (CFS)
modeled
gaged
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10


PDE14 (02131000) PEE DEE RIVER AT PEEDEE, SC (CFS)
Annual Average Flow
gaged
modeled
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1983
1988
1993
1998
2003
2008
2013

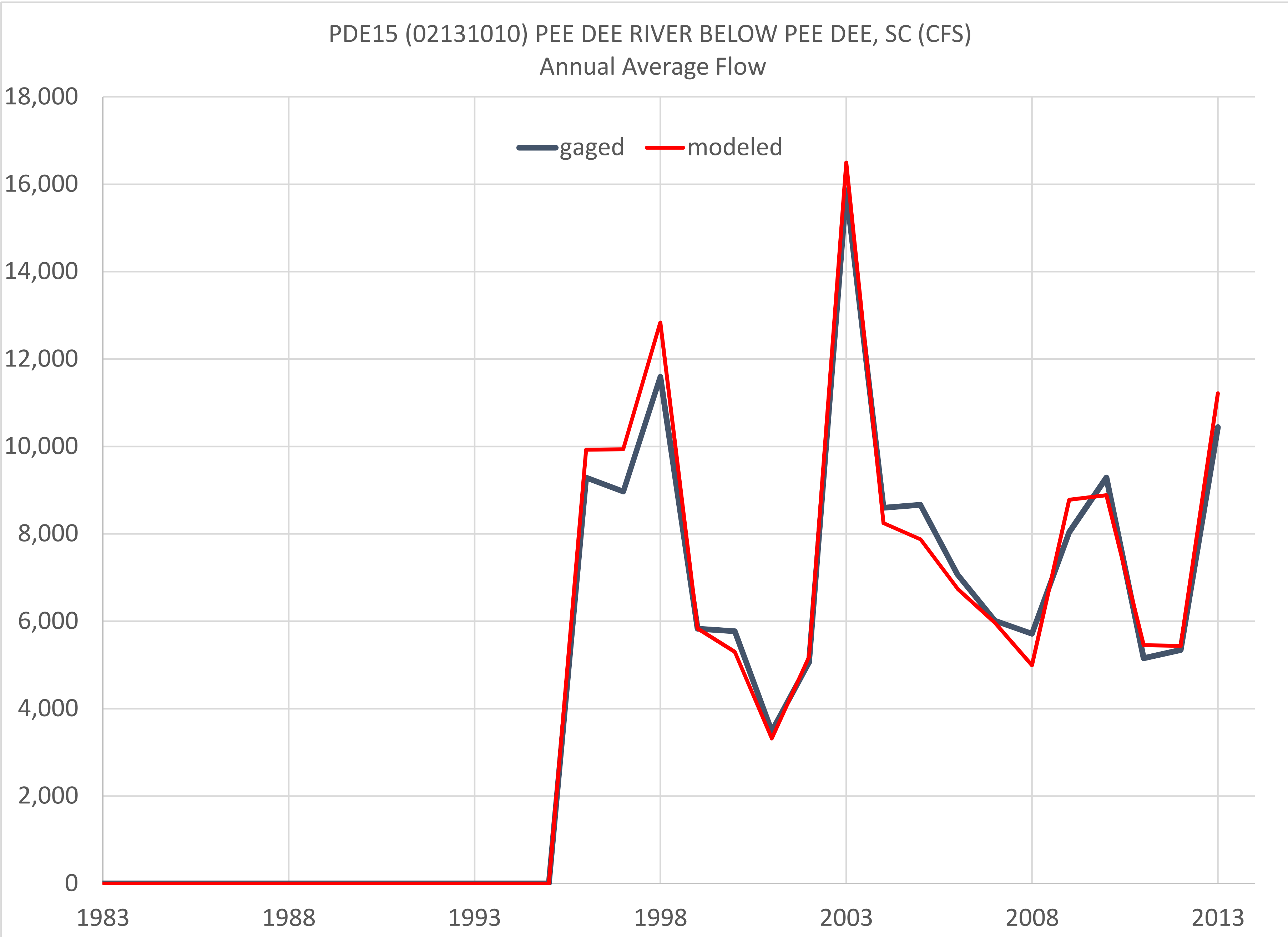

PDE14 (02131000) PEE DEE RIVER AT PEEDEE, SC
Monthly Mean Flow (CFS)
gaged
modeled
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


PDE14 (02131000) PEE DEE RIVER AT PEEDEE, SC
Daily Flow Percentiles (CFS)
gaged
modeled
180000
160000
140000
120000
100000
80000
60000
40000
20000
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

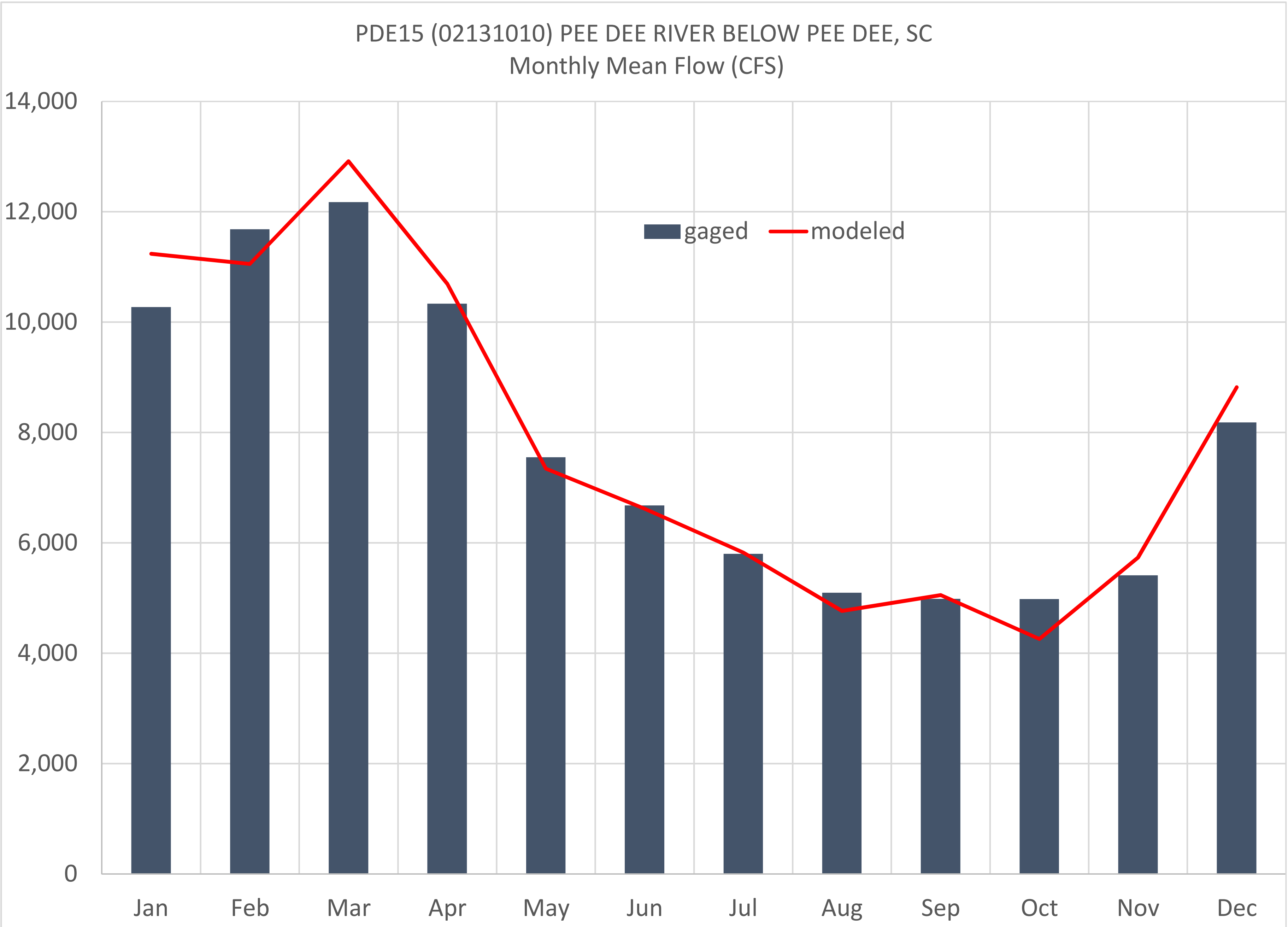

PDE14 (02131000) PEE DEE RIVER AT PEEDEE, SC
Annual 7-day Low Flow (CFS)
gaged
modeled
4500
4000
3500
3000
2500
2000
1500
1000
500
0
1983
1988
1993
1998
2003
2008
2013
2018
Year



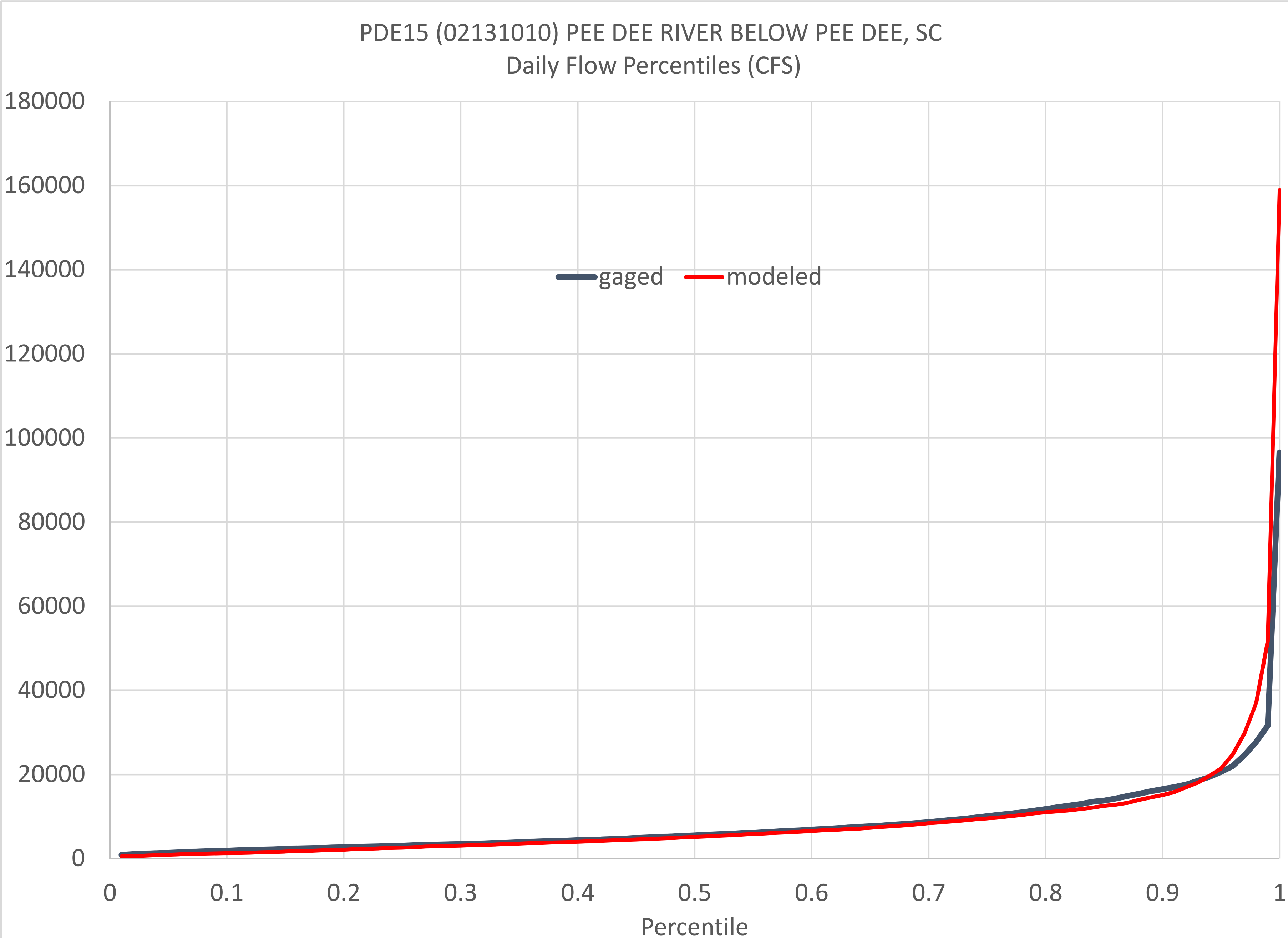
PDE15 (02131010) PEE DEE RIVER BELOW PEE DEE, SC (CFS)
modeled
gaged
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

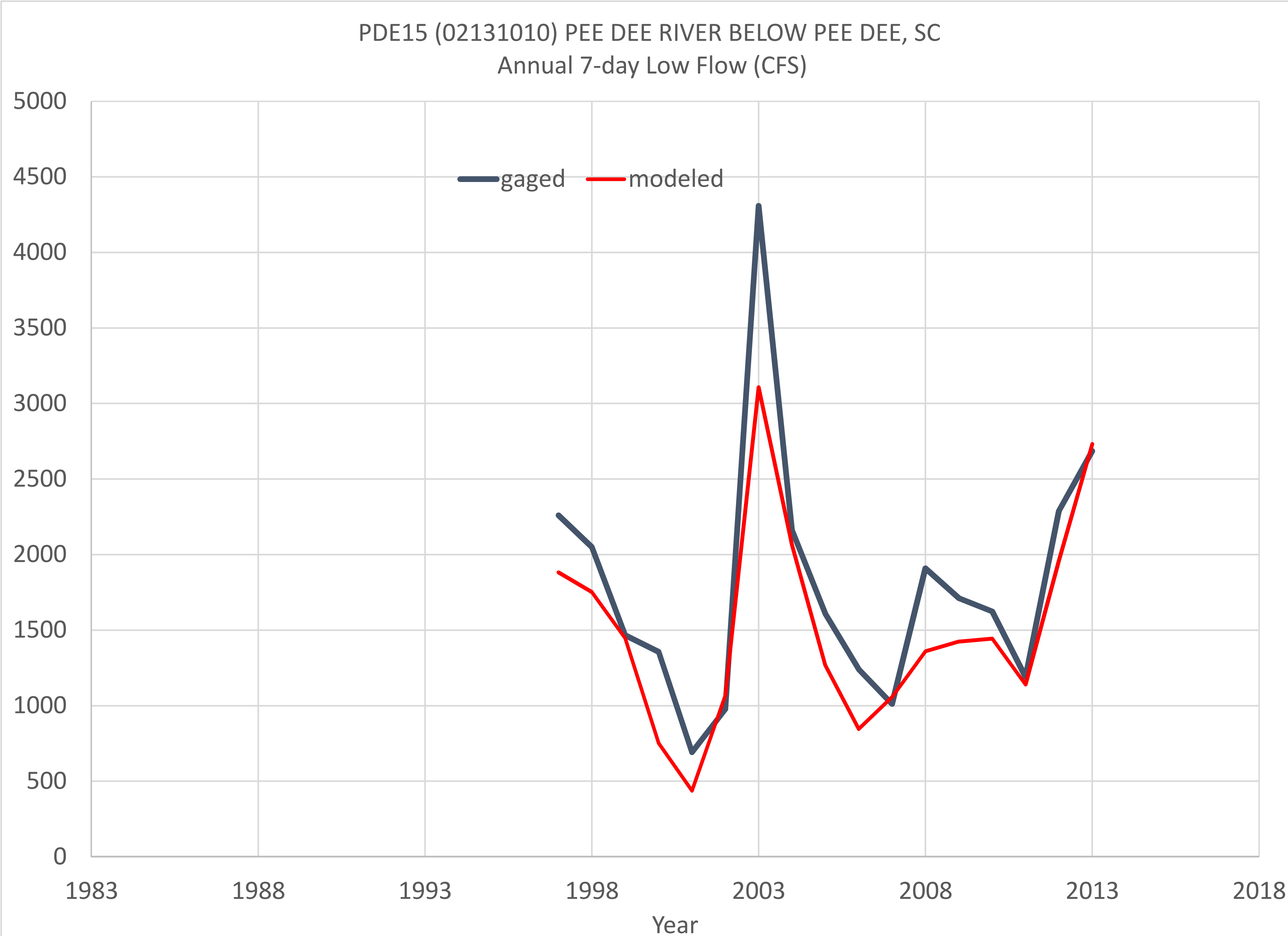


PDE15 (02131010) PEE DEE RIVER BELOW PEE DEE, SC (CFS)
Annual Average Flow
gaged
modeled
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1983
1988
1993
1998
2003
2008
2013

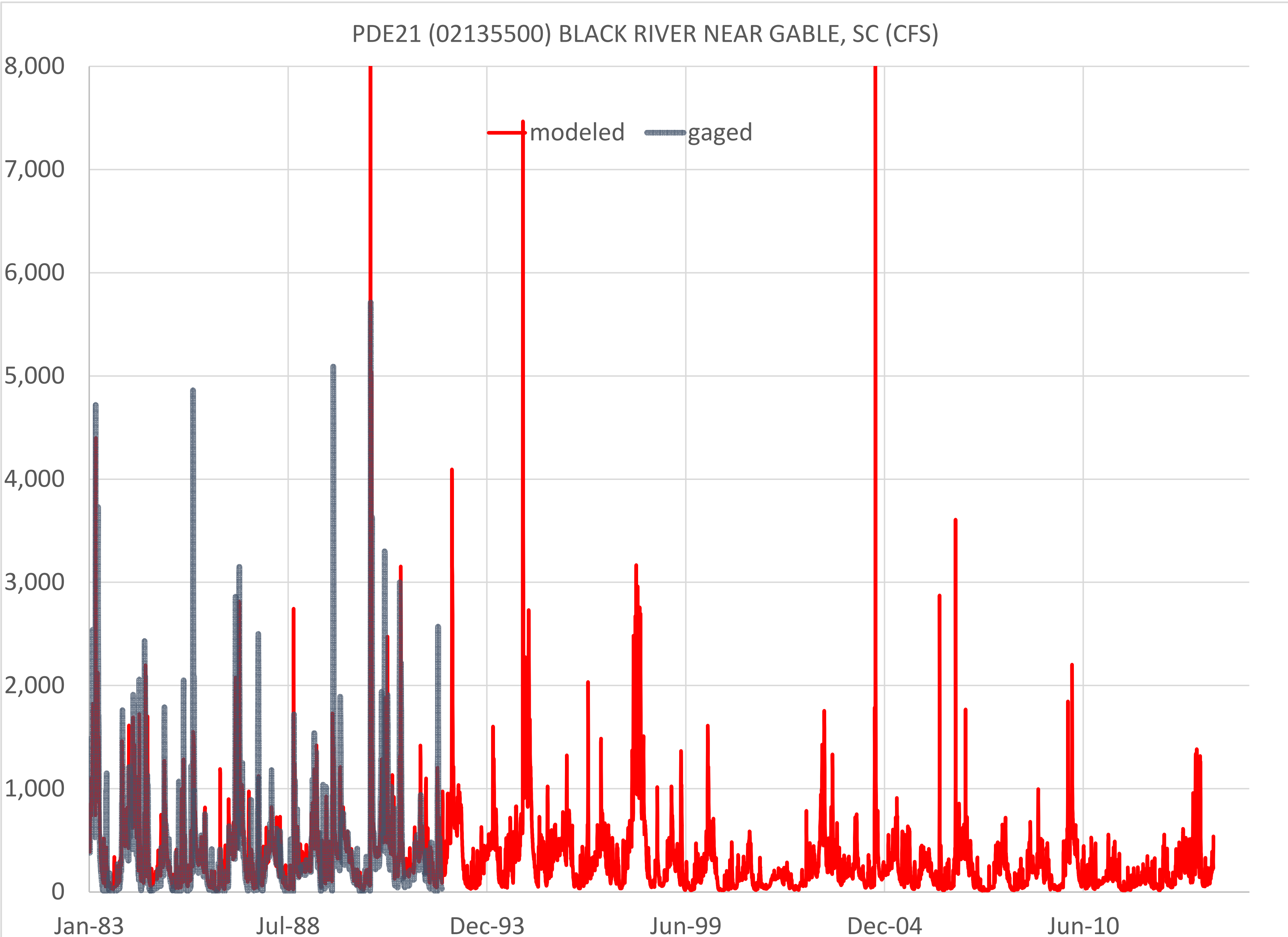


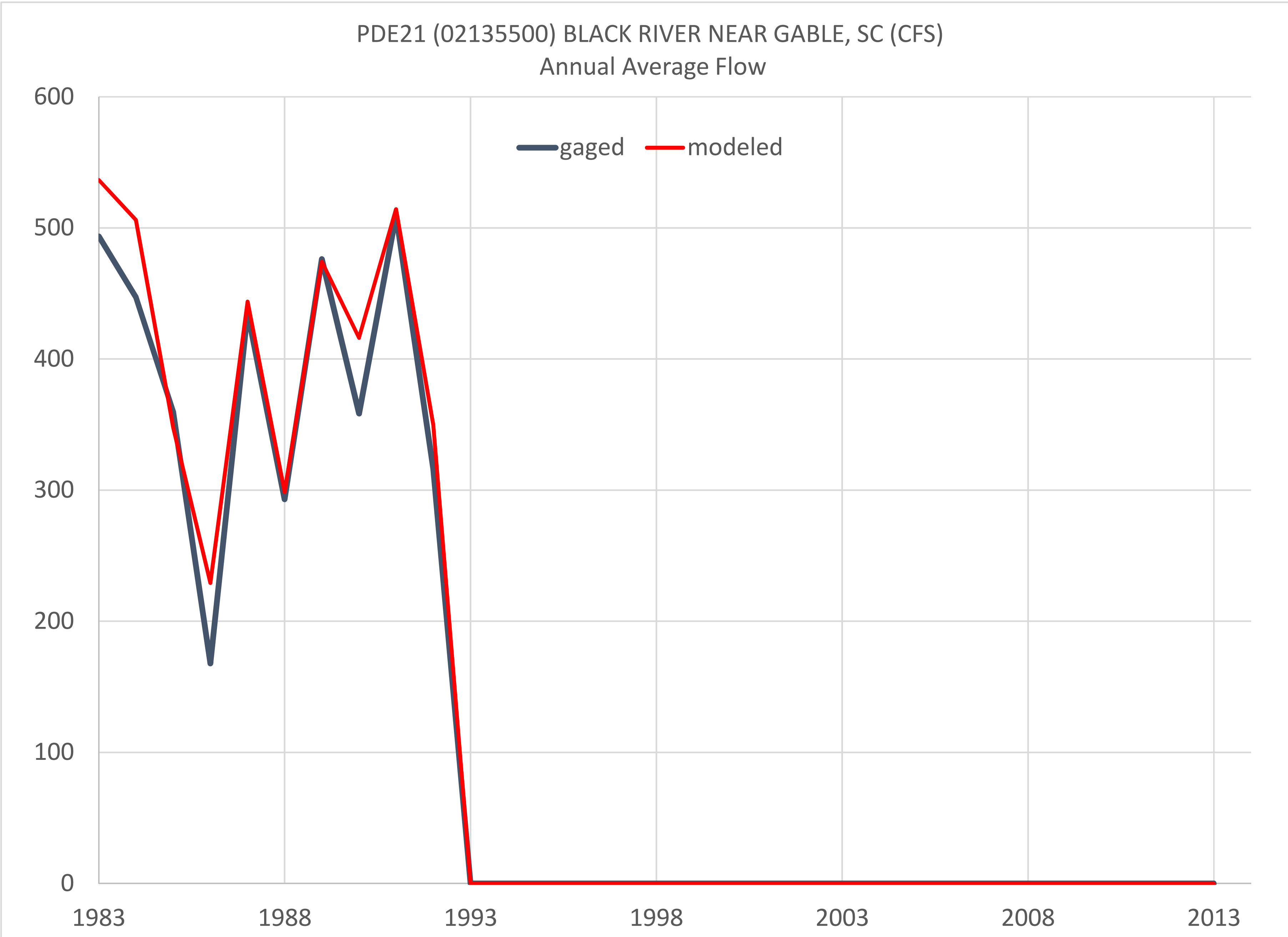
PDE15 (02131010) PEE DEE RIVER BELOW PEE DEE, SC
Monthly Mean Flow (CFS)
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
gaged
modeled
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


PDE15 (02131010) PEE DEE RIVER BELOW PEE DEE, SC
Daily Flow Percentiles (CFS)
180000
160000
140000
120000
100000
80000
60000
40000
20000
0
gaged
modeled
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

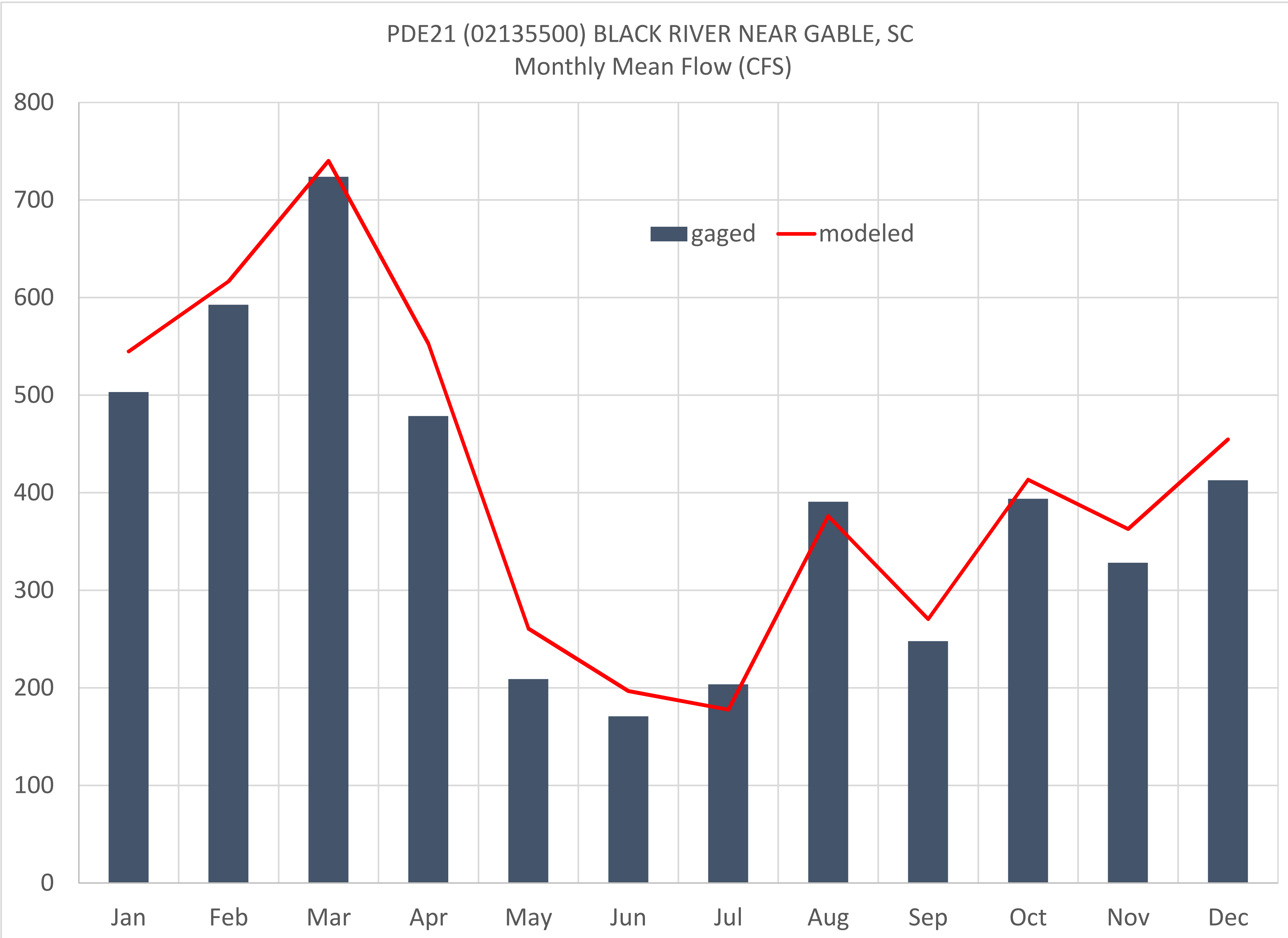


PDE15 (02131010) PEE DEE RIVER BELOW PEE DEE, SC
Annual 7-day Low Flow (CFS)
gaged
modeled
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
1983
1988
1993
1998
2003
2008
2013
2018
Year

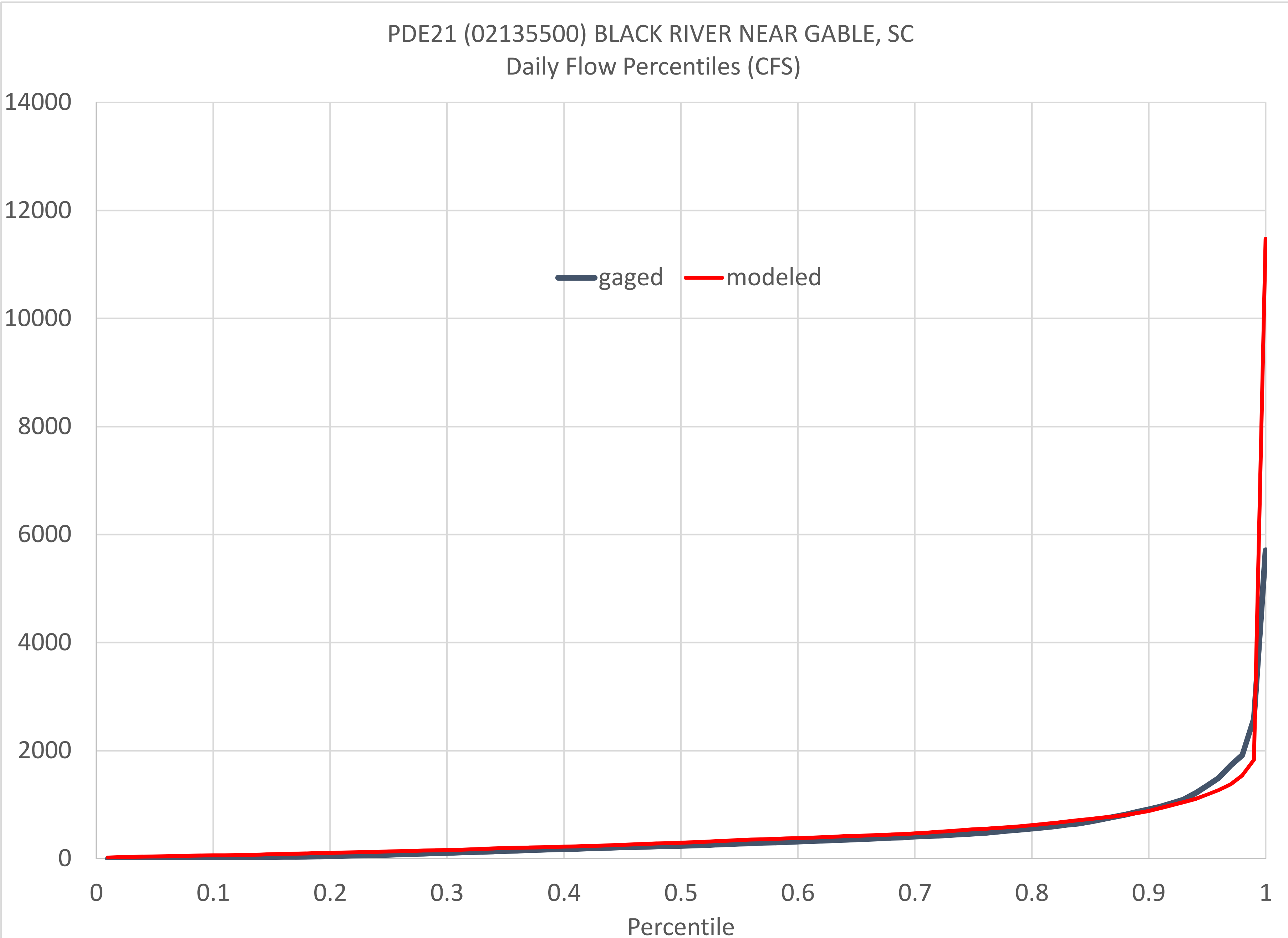

PDE21 (02135500) BLACK RIVER NEAR GABLE, SC (CFS)
modeled
gaged
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

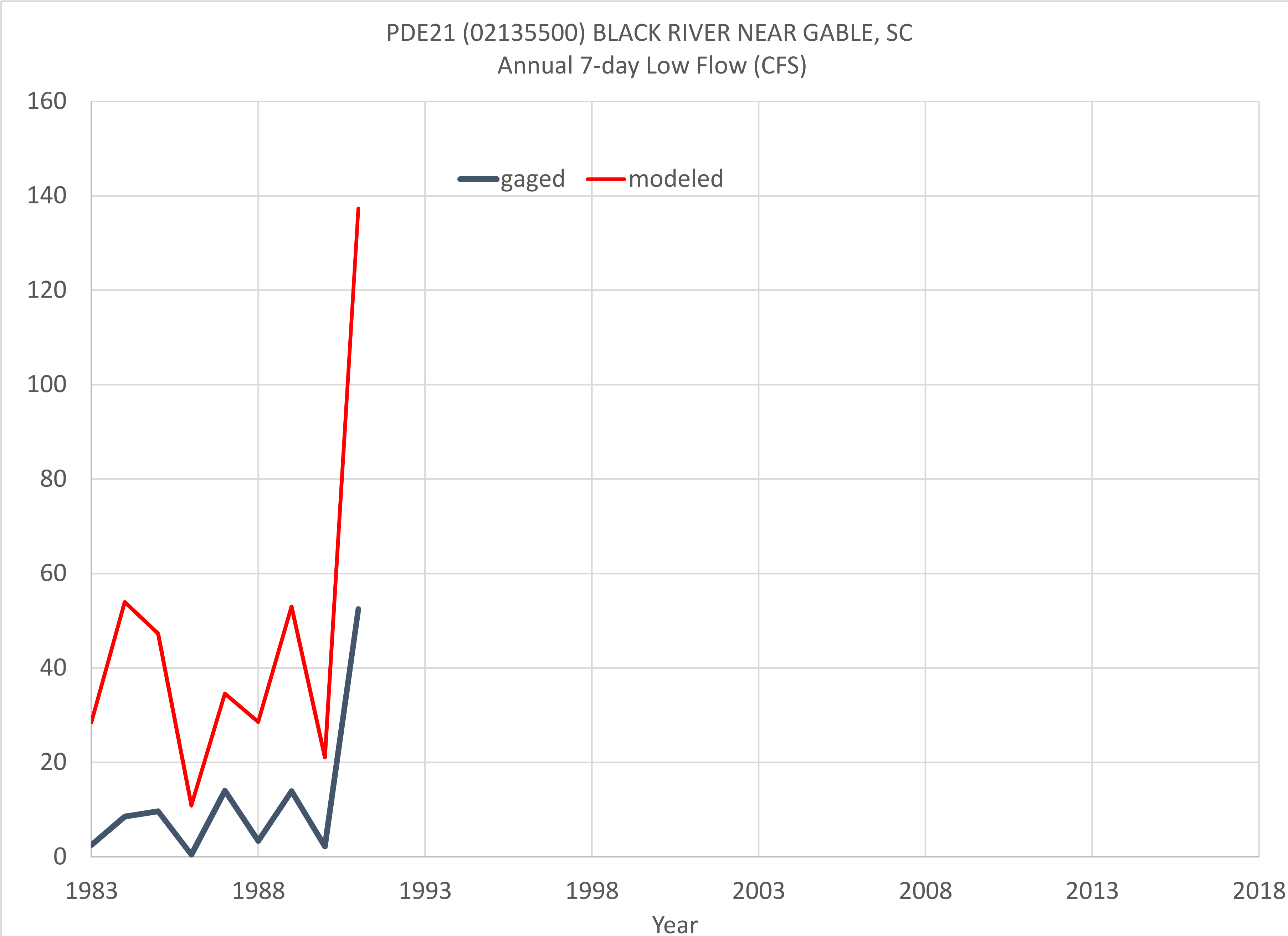


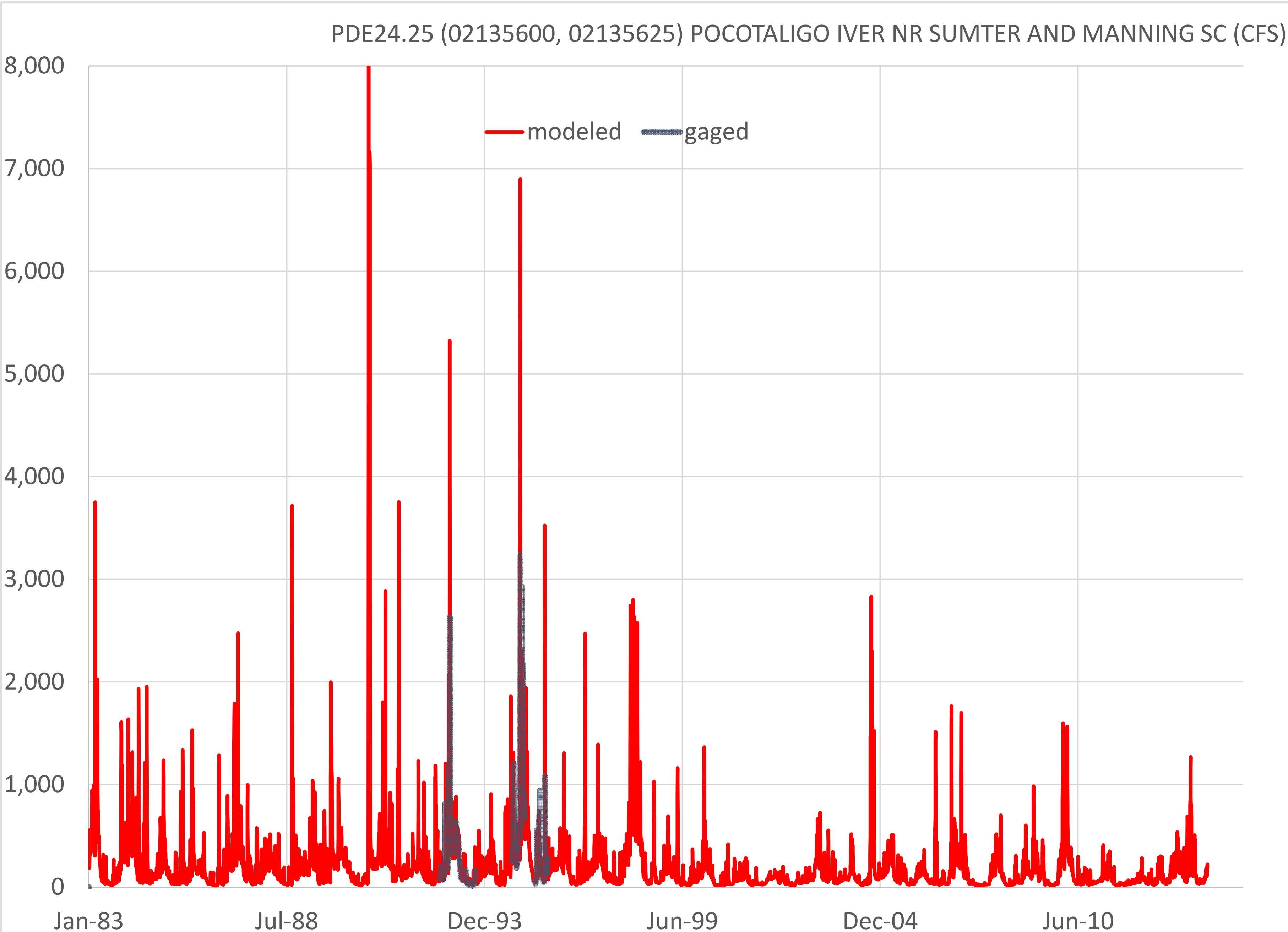
PDE21 (02135500) BLACK RIVER NEAR GABLE, SC (CFS)
Annual Average Flow
gaged
modeled
600
500
400
300
200
100
0
1983
1988
1993
1998
2003
2008
2013



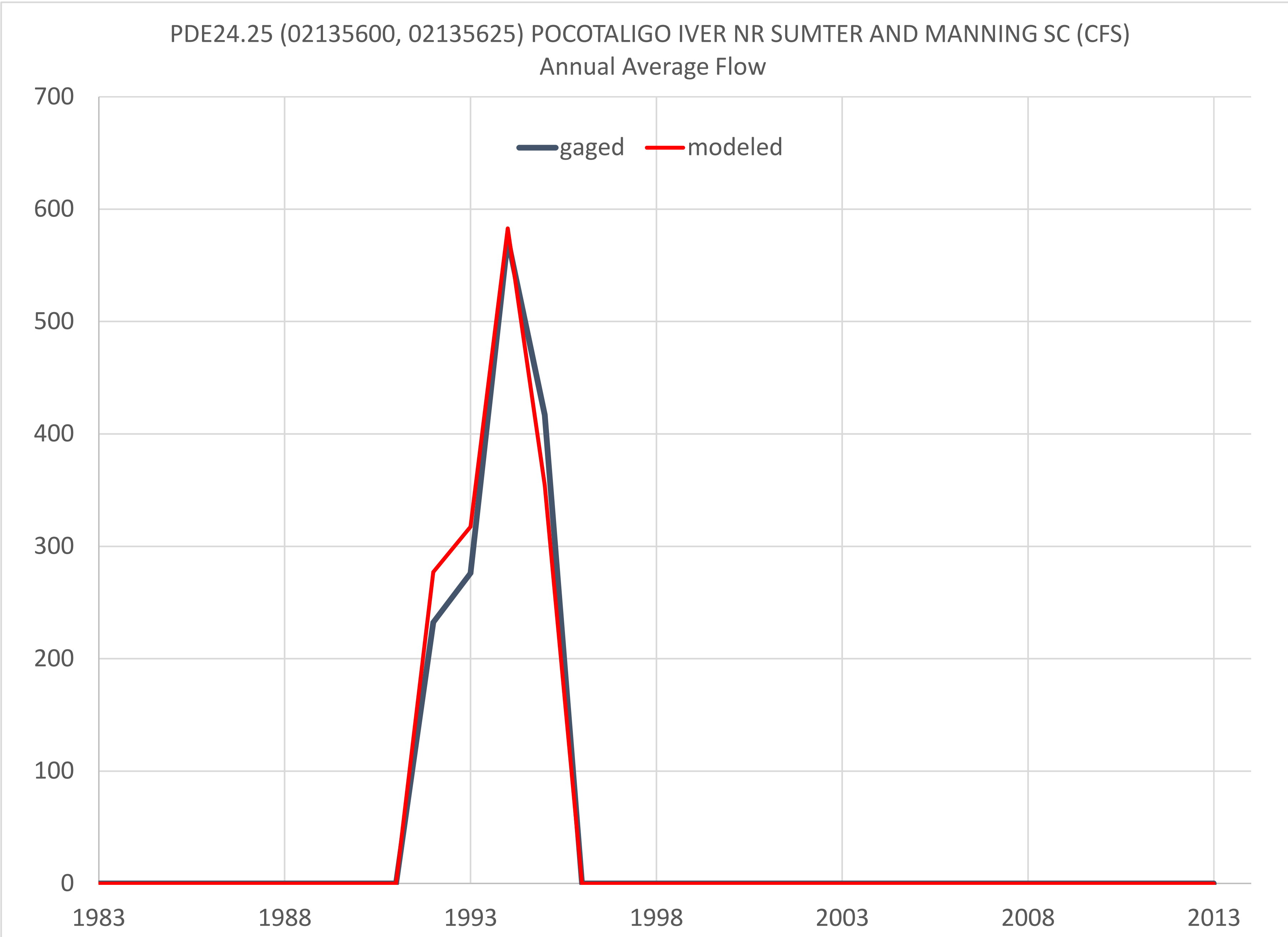
PDE21 (02135500) BLACK RIVER NEAR GABLE, SC
Monthly Mean Flow (CFS)
800
700
600
500
400
300
200
100
0
gaged
modeled
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

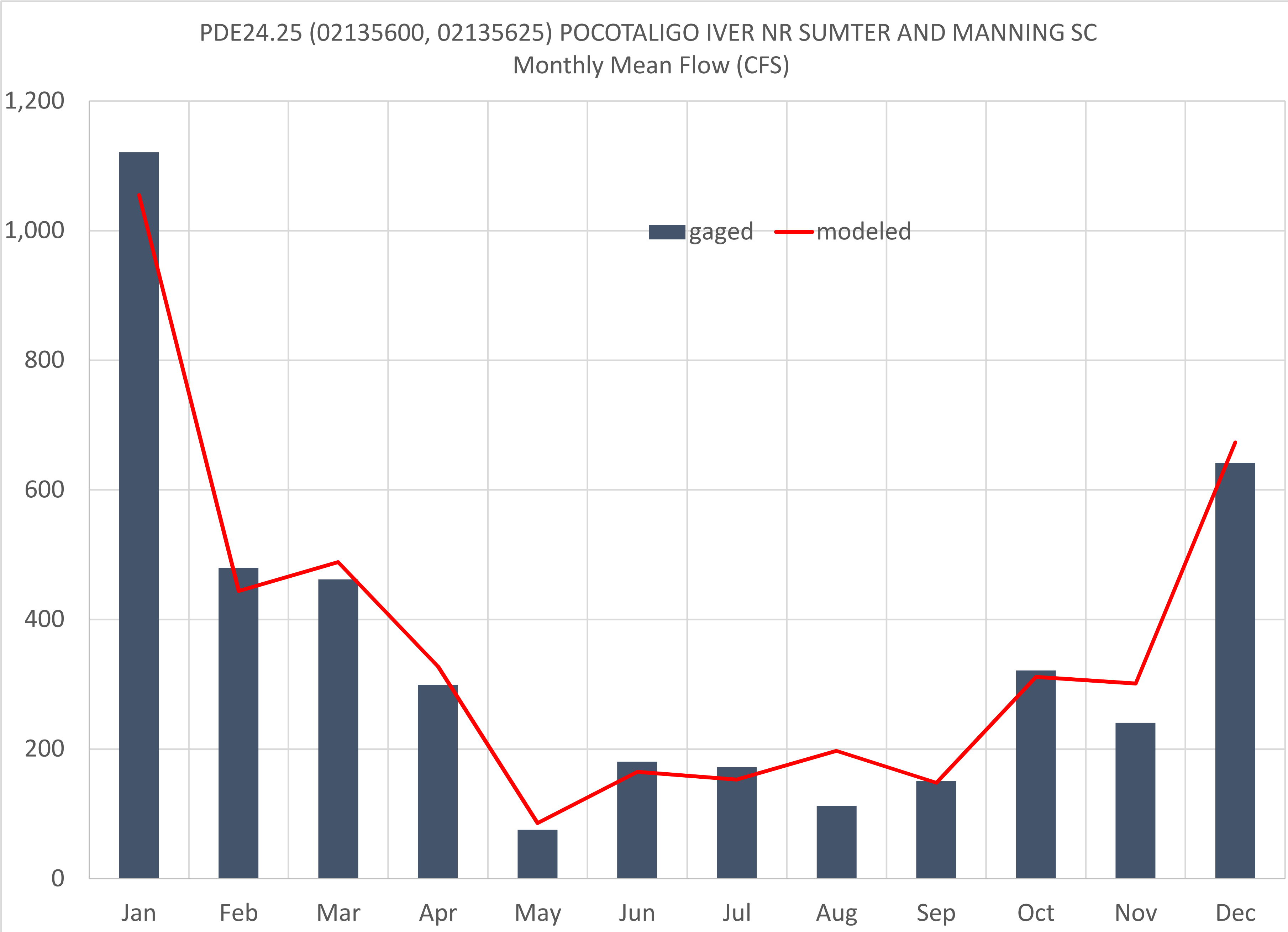

PDE21 (02135500) BLACK RIVER NEAR GABLE, SC
Daily Flow Percentiles (CFS)
14000
12000
10000
8000
6000
4000
2000
0
gaged
modeled
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile


PDE21 (02135500) BLACK RIVER NEAR GABLE, SC
Annual 7-day Low Flow (CFS)
gaged
modeled
160
140
120
100
80
60
40
20
0
1983
1988
1993
1998
2003
2008
2013
2018
Year

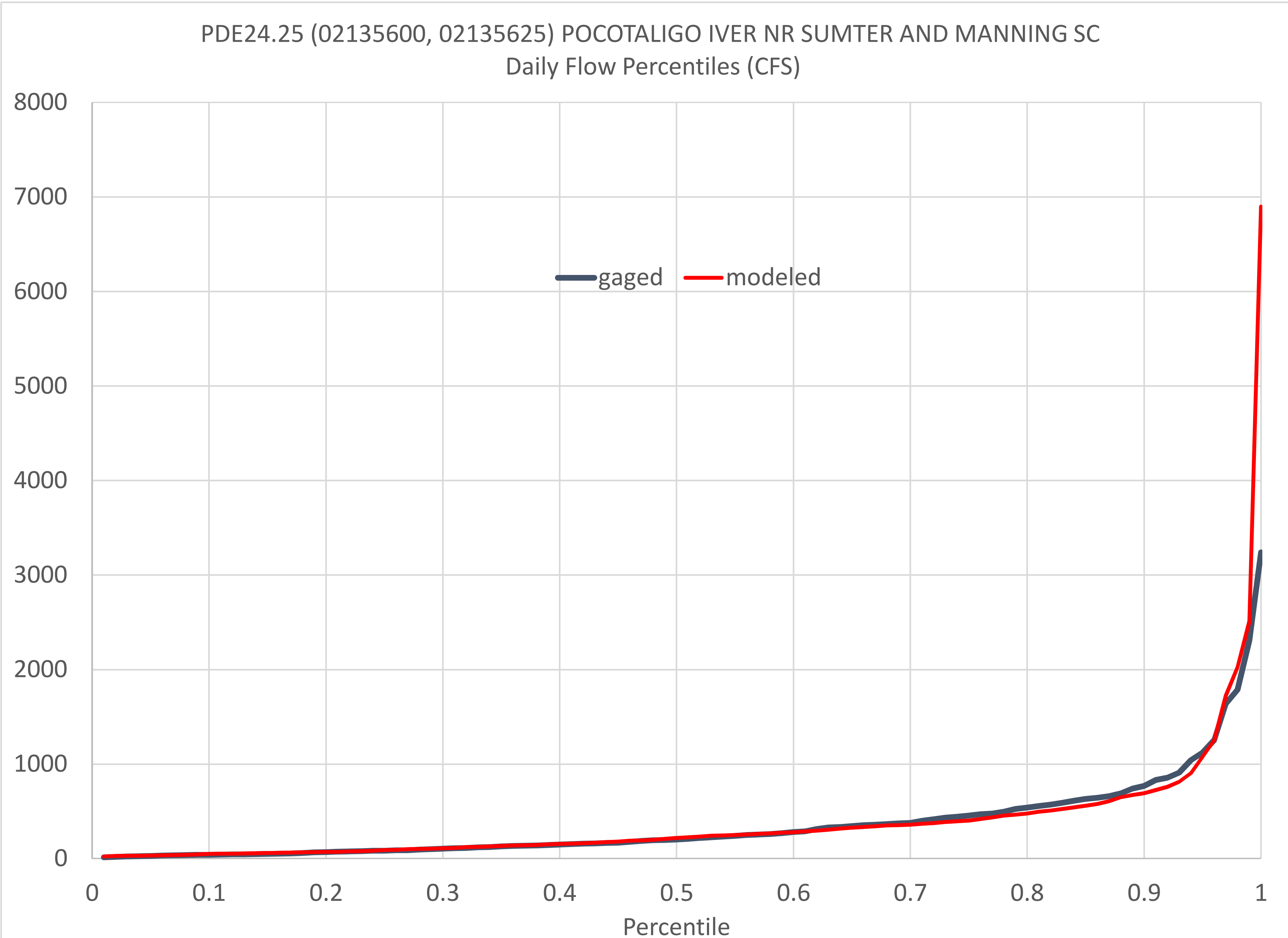


PDE24.25 (02135600, 02135625) POCOTALIGO IVER NR SUMTER AND MANNING SC (CFS)
modeled
gaged
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

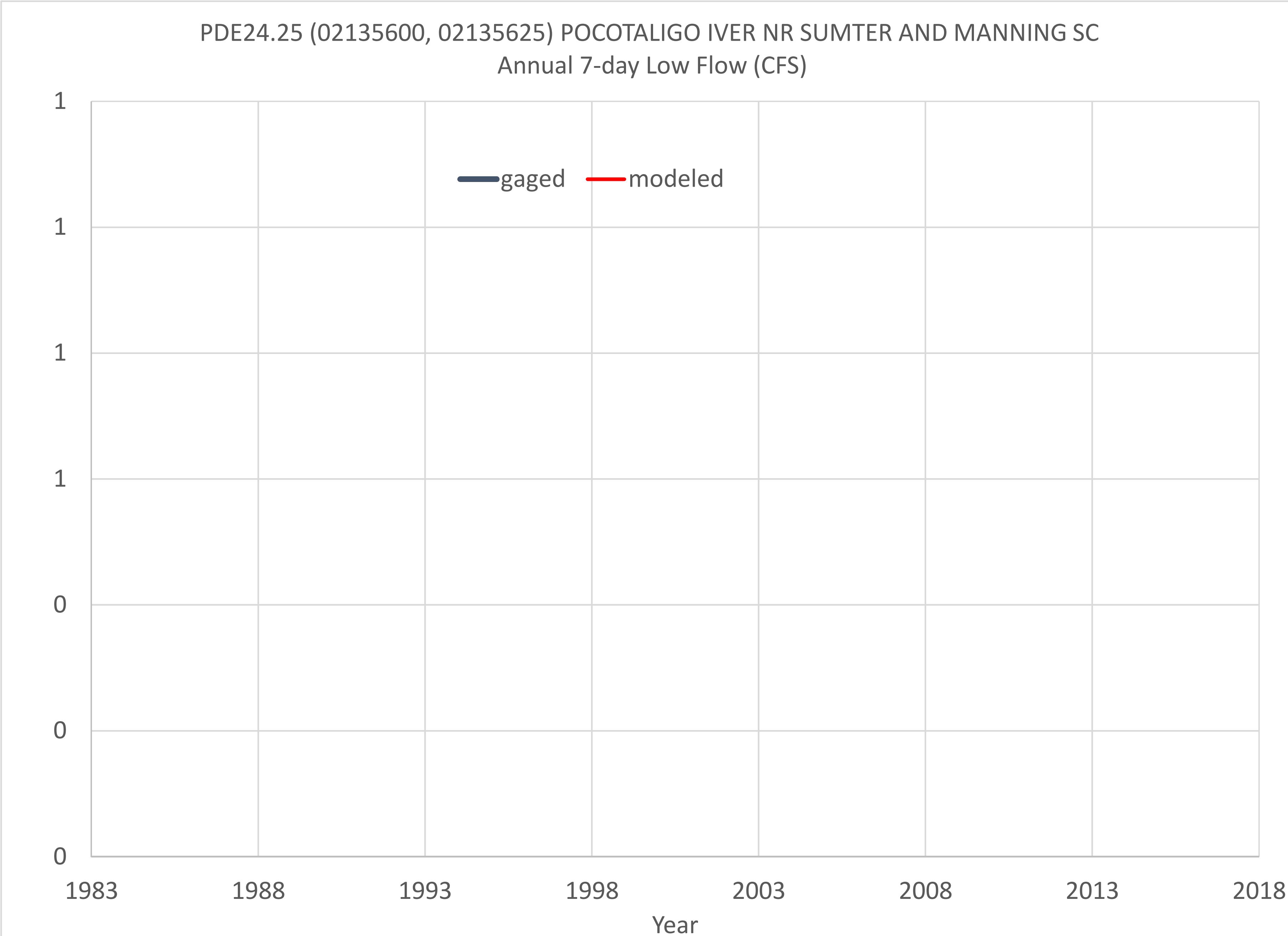

PDE24.25 (02135600, 02135625) POCOTALIGO IVER NR SUMTER AND MANNING SC (CFS)
Annual Average Flow
gaged
modeled
700
600
500
400
300
200
100
0
1983
1988
1993
1998
2003
2008
2013

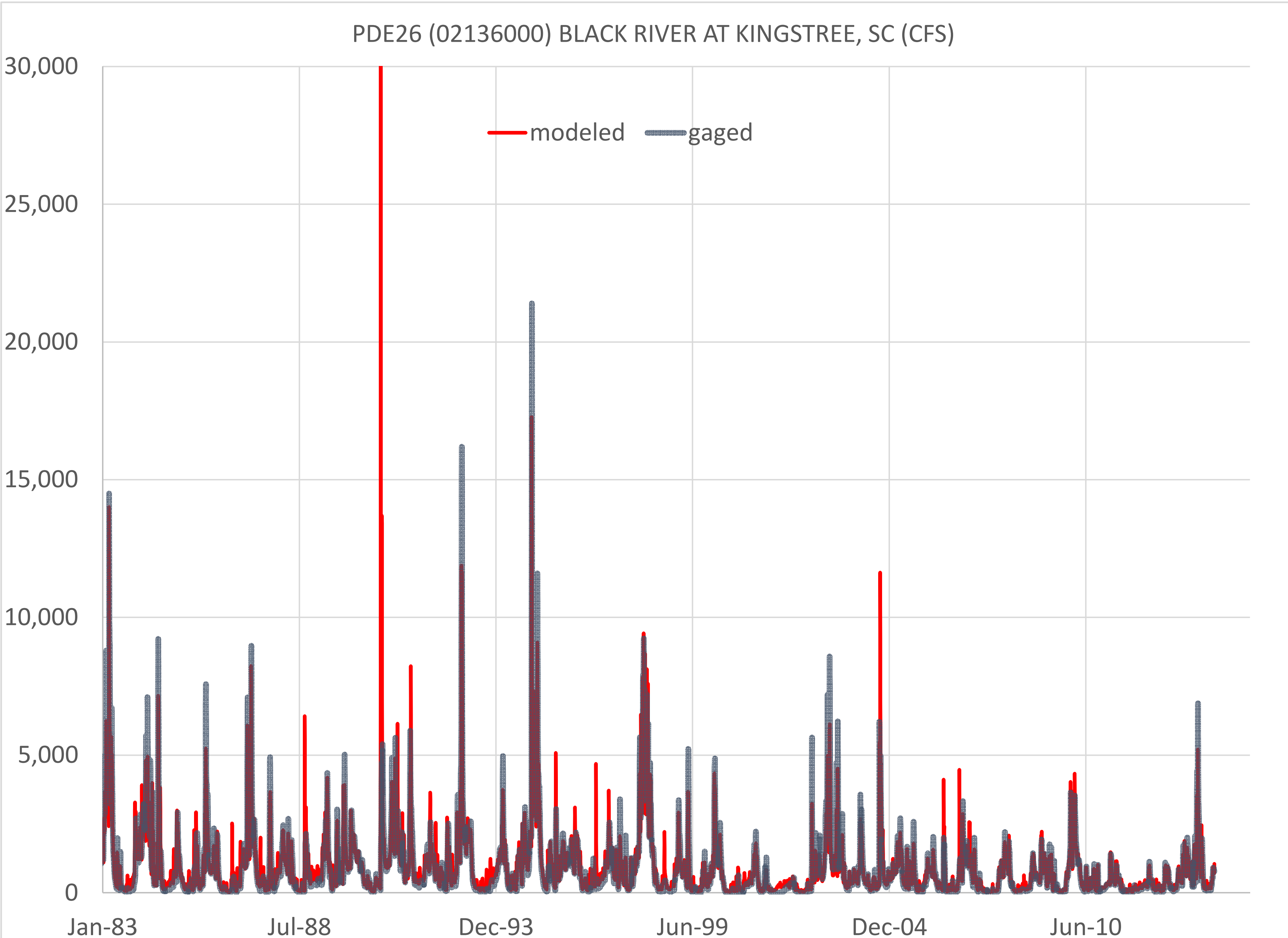


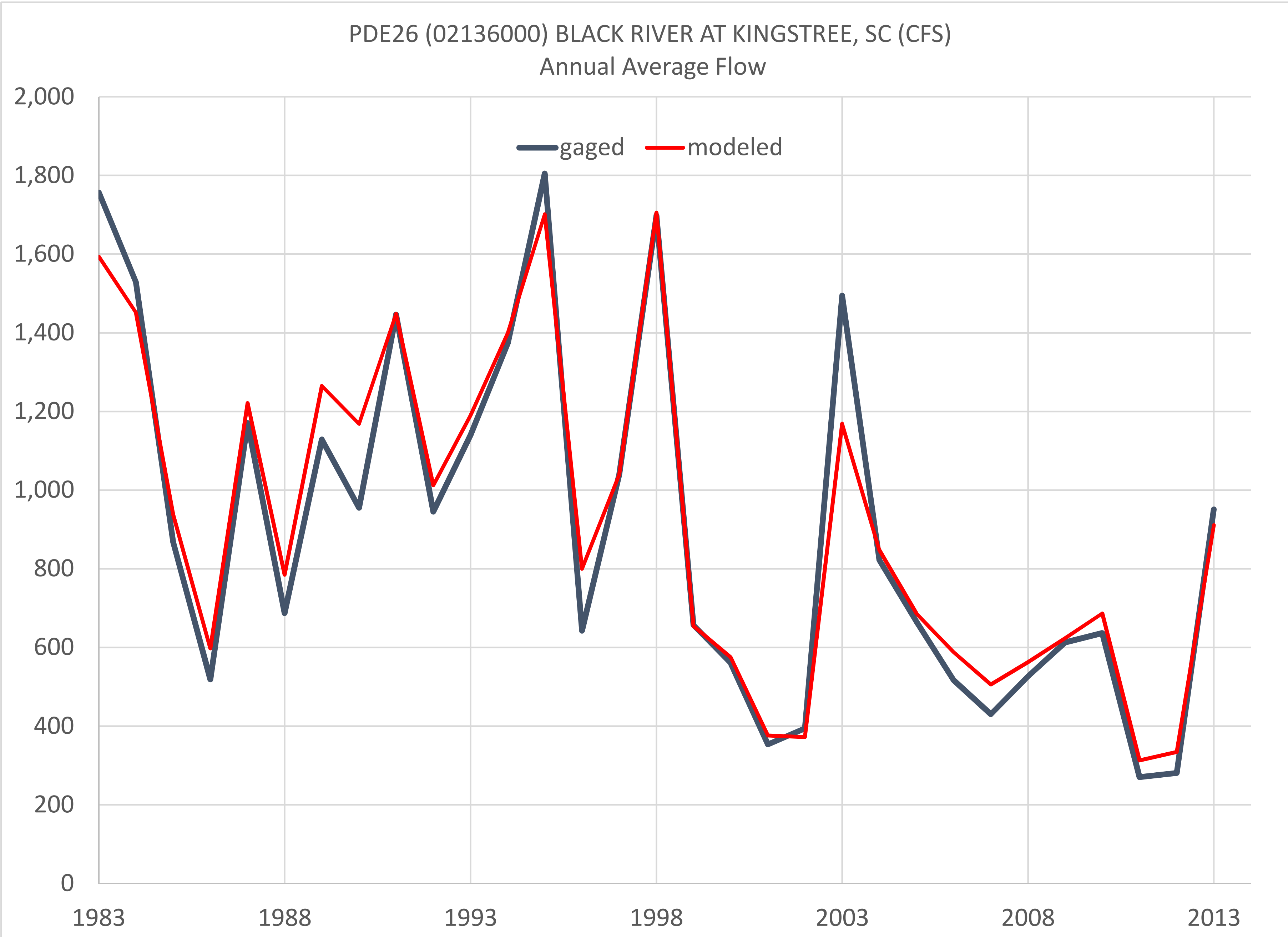
PDE24.25 (02135600, 02135625) POCOTALIGO IVER NR SUMTER AND MANNING SC
Monthly Mean Flow (CFS)
gaged
modeled
1,200
1,000
800
600
400
200
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec



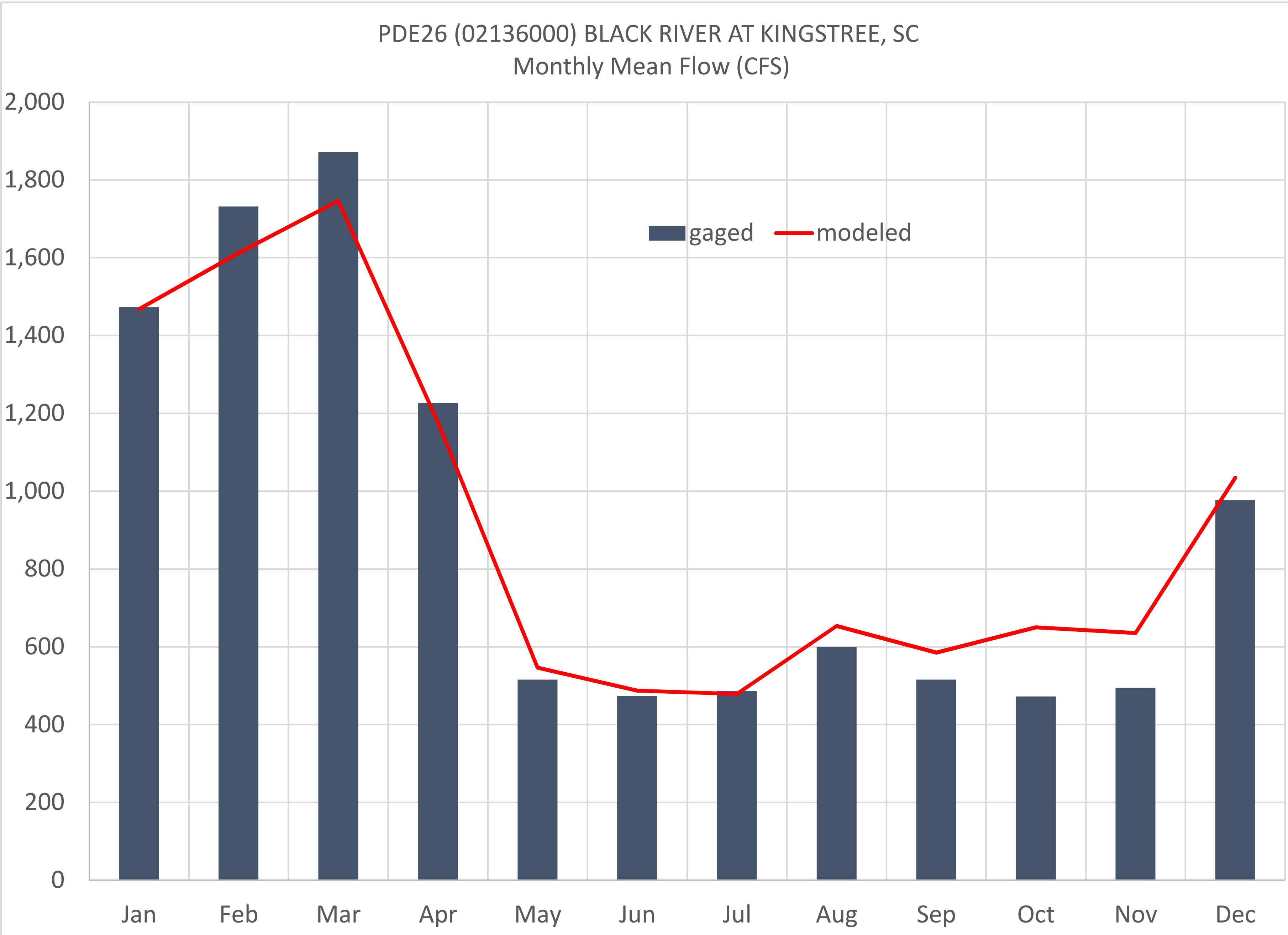
PDE24.25 (02135600, 02135625) POCOTALIGO IVER NR SUMTER AND MANNING SC
Daily Flow Percentiles (CFS)
8000
7000
6000
5000
4000
3000
2000
1000
0
gaged
modeled
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile


PDE24.25 (02135600, 02135625) POCOTALIGO IVER NR SUMTER AND MANNING SC
Annual 7-day Low Flow (CFS)
gaged
modeled
1
1
1
1
0
0
0
1983
1988
1993
1998
2003
2008
2013
2018
Year

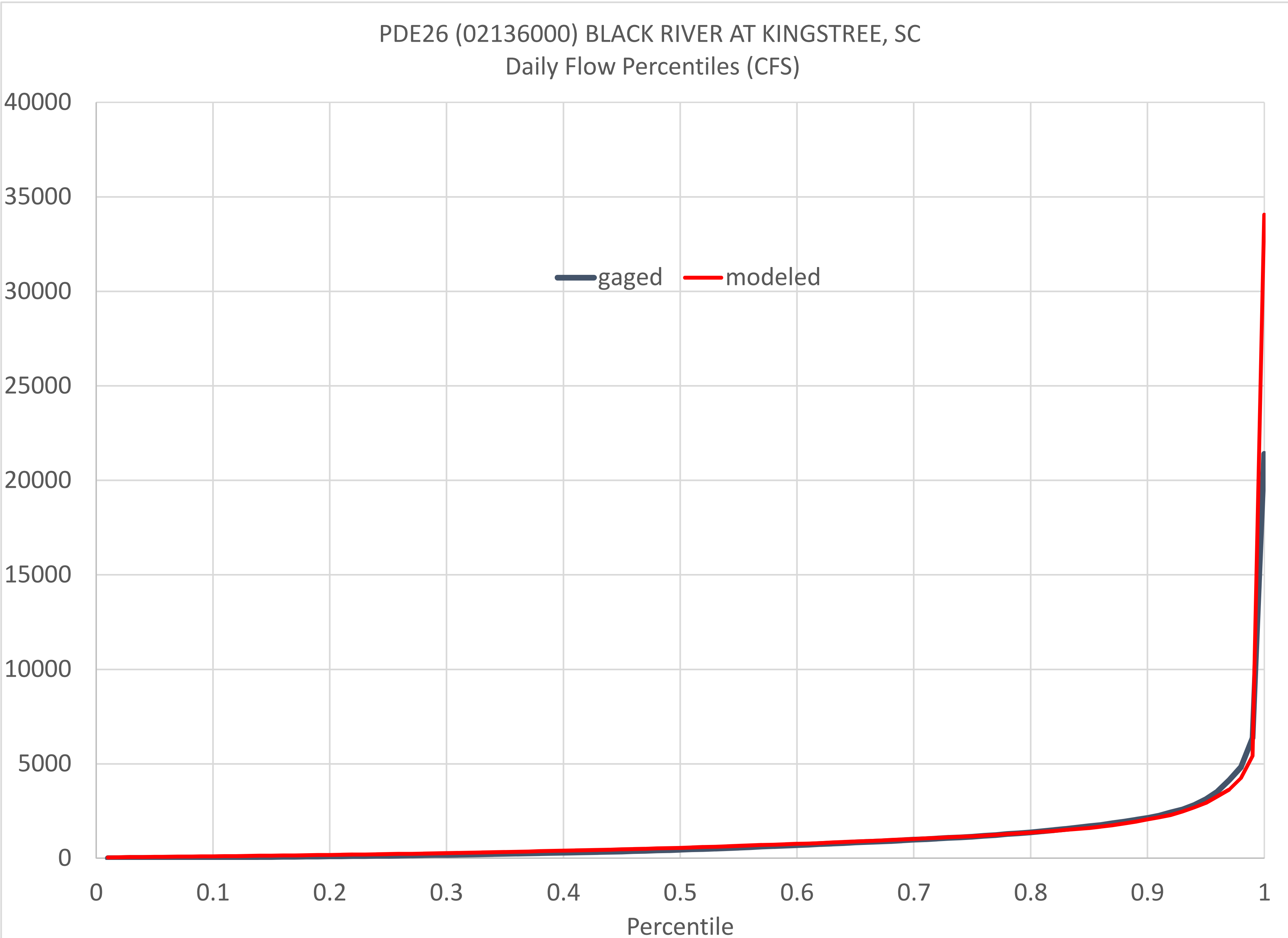

PDE26 (02136000) BLACK RIVER AT KINGSTREE, SC (CFS)
modeled
gaged
30,000
25,000
20,000
15,000
10,000
5,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

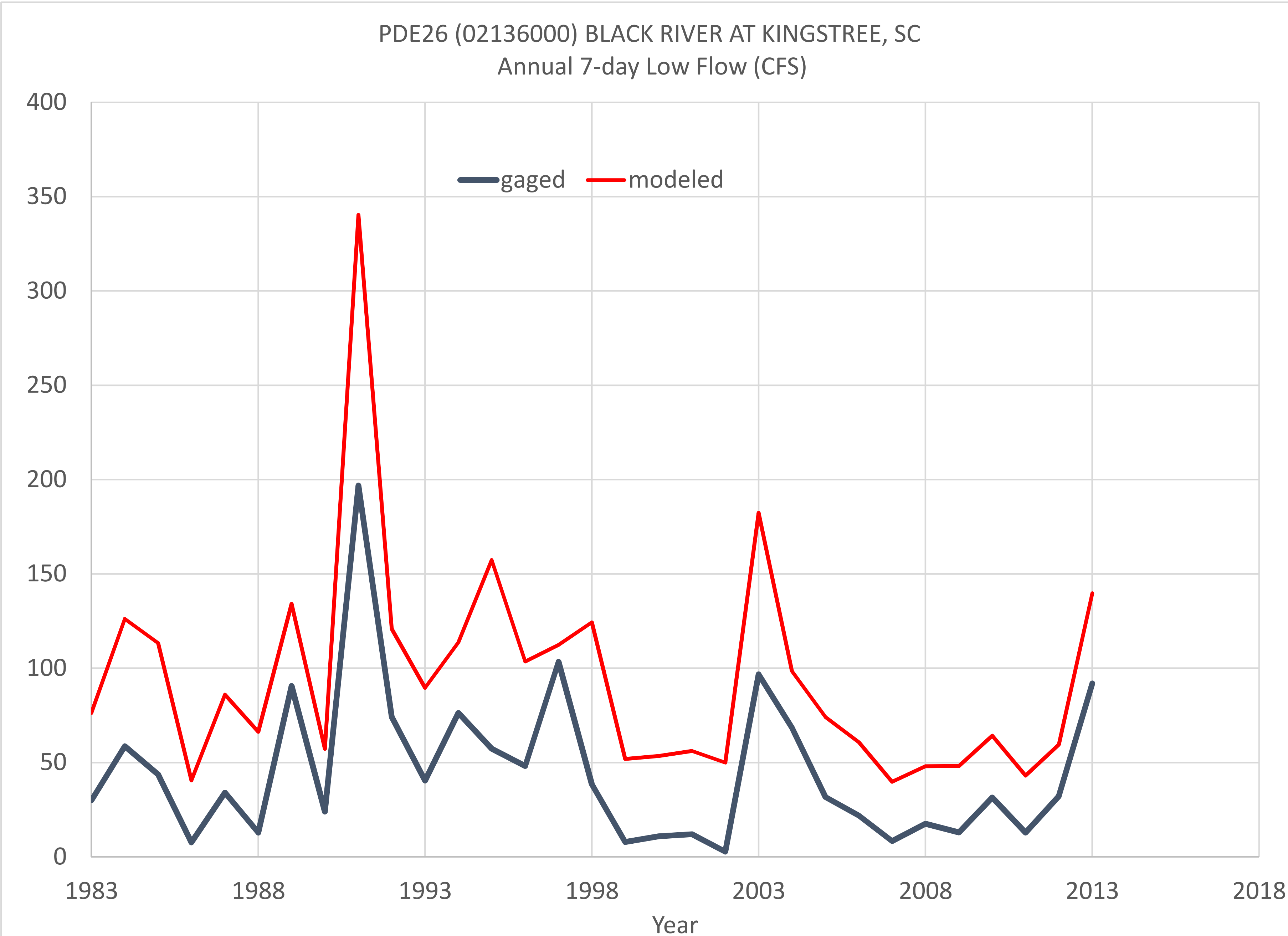


PDE26 (02136000) BLACK RIVER AT KINGSTREE, SC (CFS)
Annual Average Flow
gaged
modeled
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
1983
1988
1993
1998
2003
2008
2013

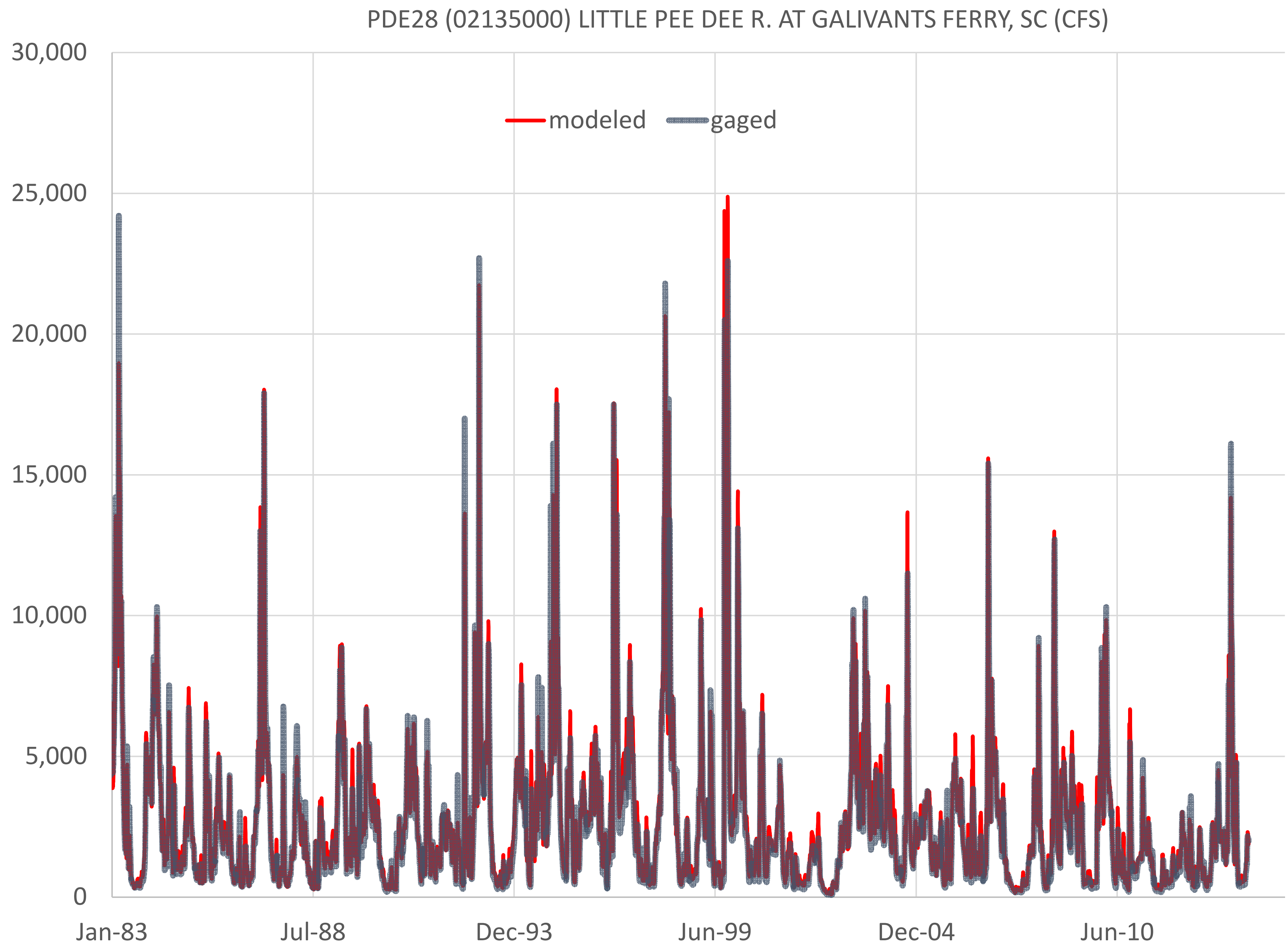


PDE26 (02136000) BLACK RIVER AT KINGSTREE, SC
Monthly Mean Flow (CFS)
gaged
modeled
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

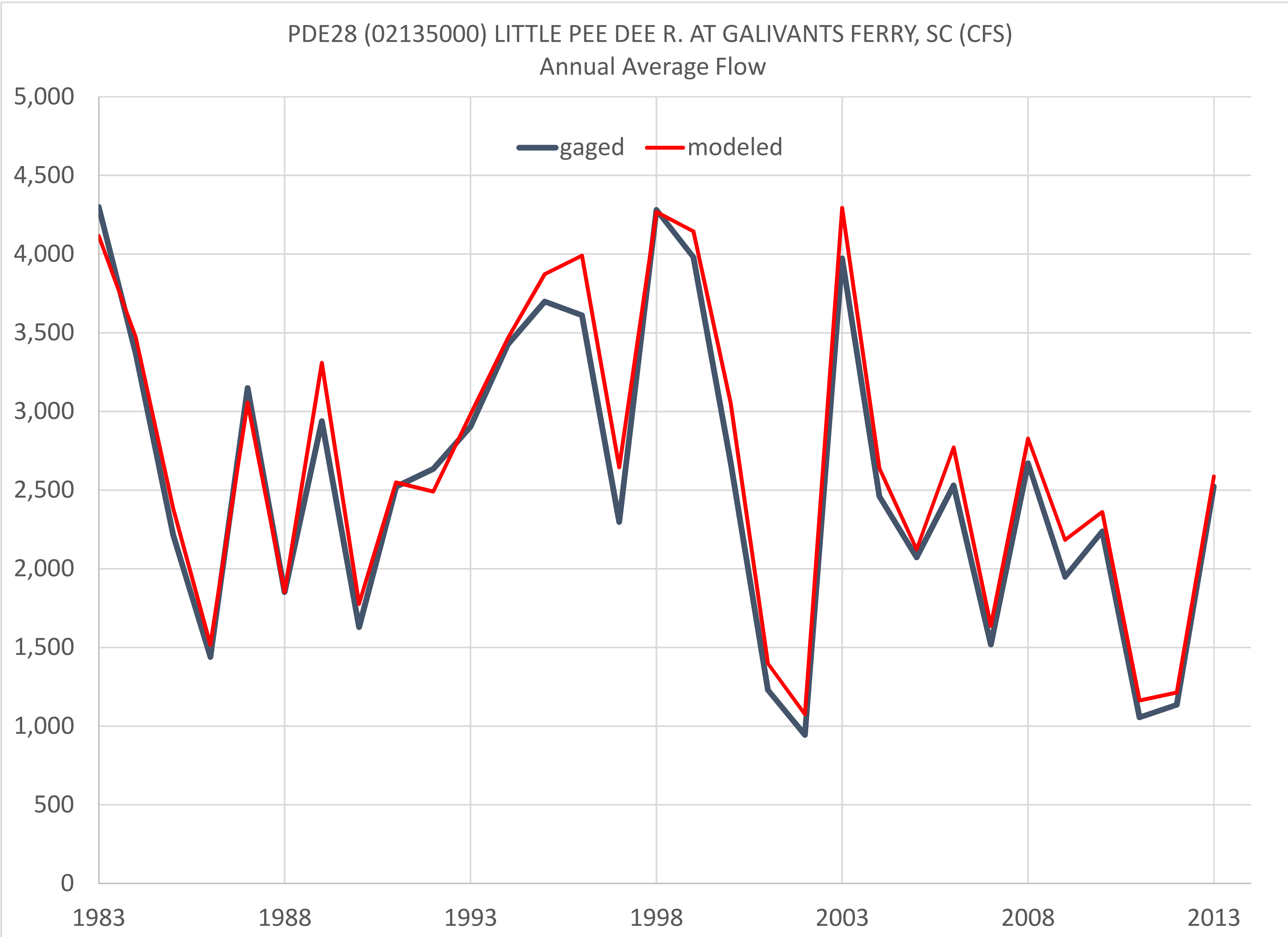

PDE26 (02136000) BLACK RIVER AT KINGSTREE, SC
Daily Flow Percentiles (CFS)
40000
35000
30000
25000
20000
15000
10000
5000
0
gaged
modeled
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile



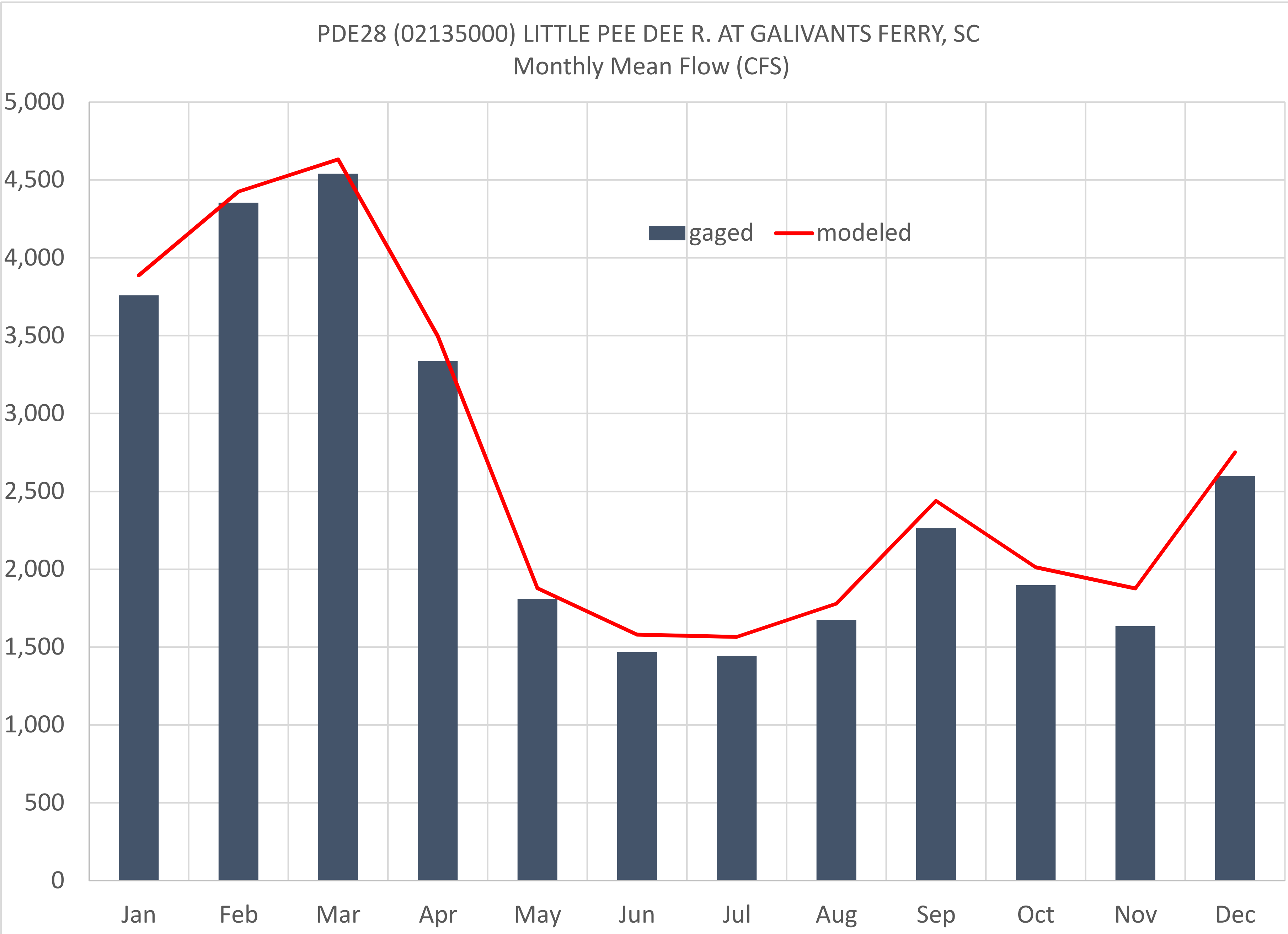
PDE26 (02136000) BLACK RIVER AT KINGSTREE, SC
Annual 7-day Low Flow (CFS)
gaged
modeled
400
350
300
250
200
150
100
50
0
1983
1988
1993
1998
2003
2008
2013
2018
Year

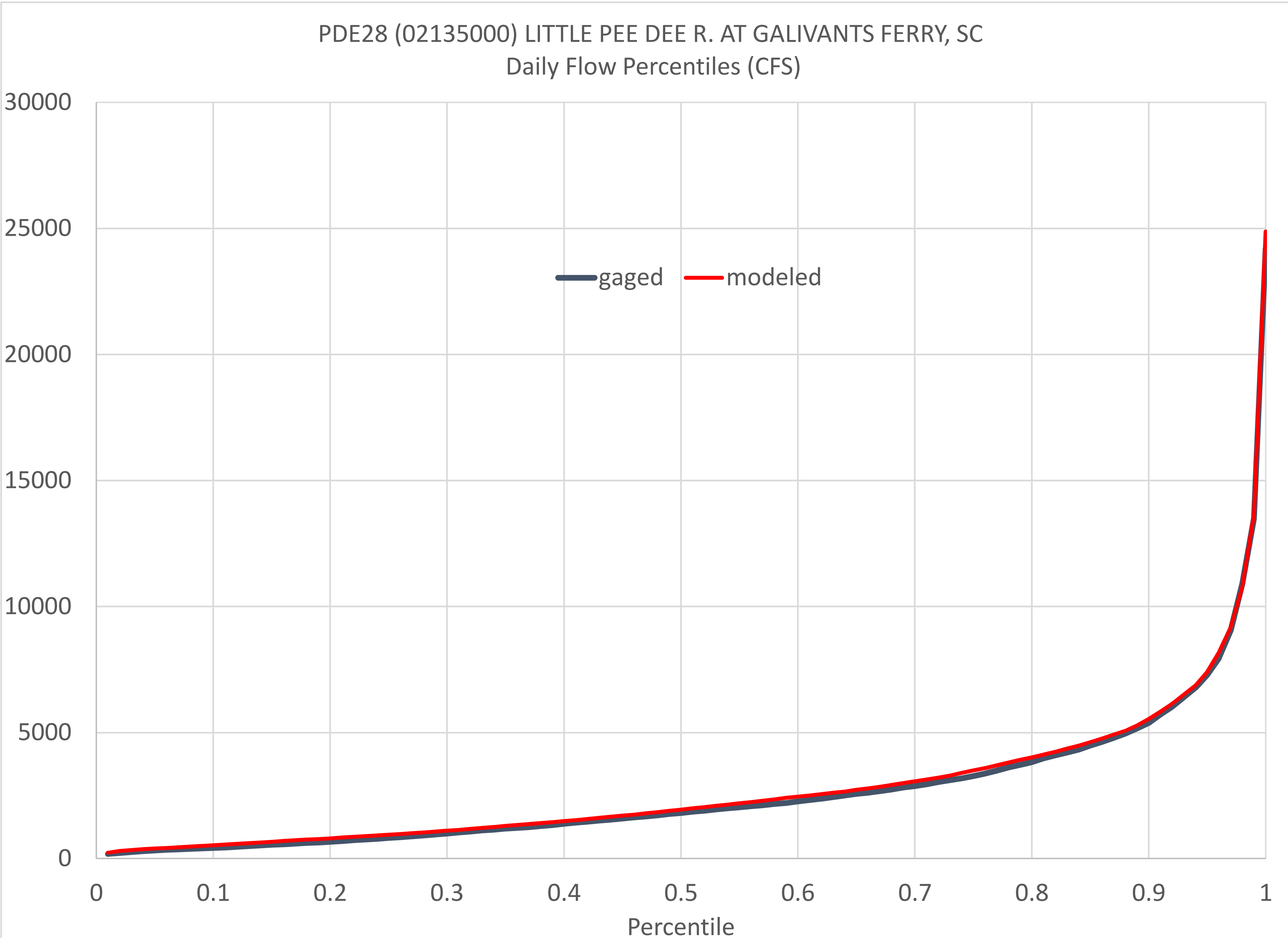


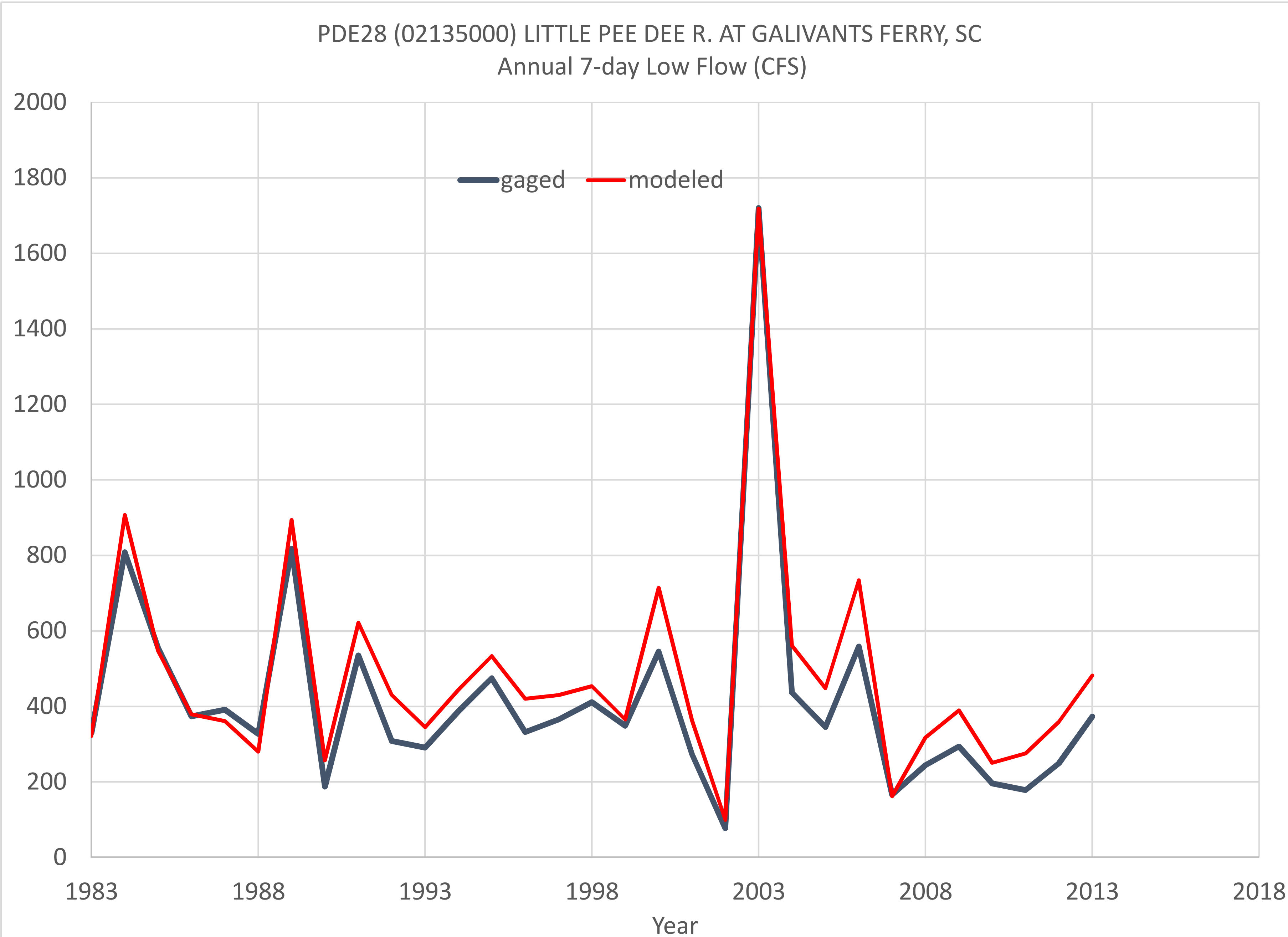
PDE28 (02135000) LITTLE PEE DEE R. AT GALIVANTS FERRY, SC (CFS)
modeled
gaged
30,000
25,000
20,000
15,000
10,000
5,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

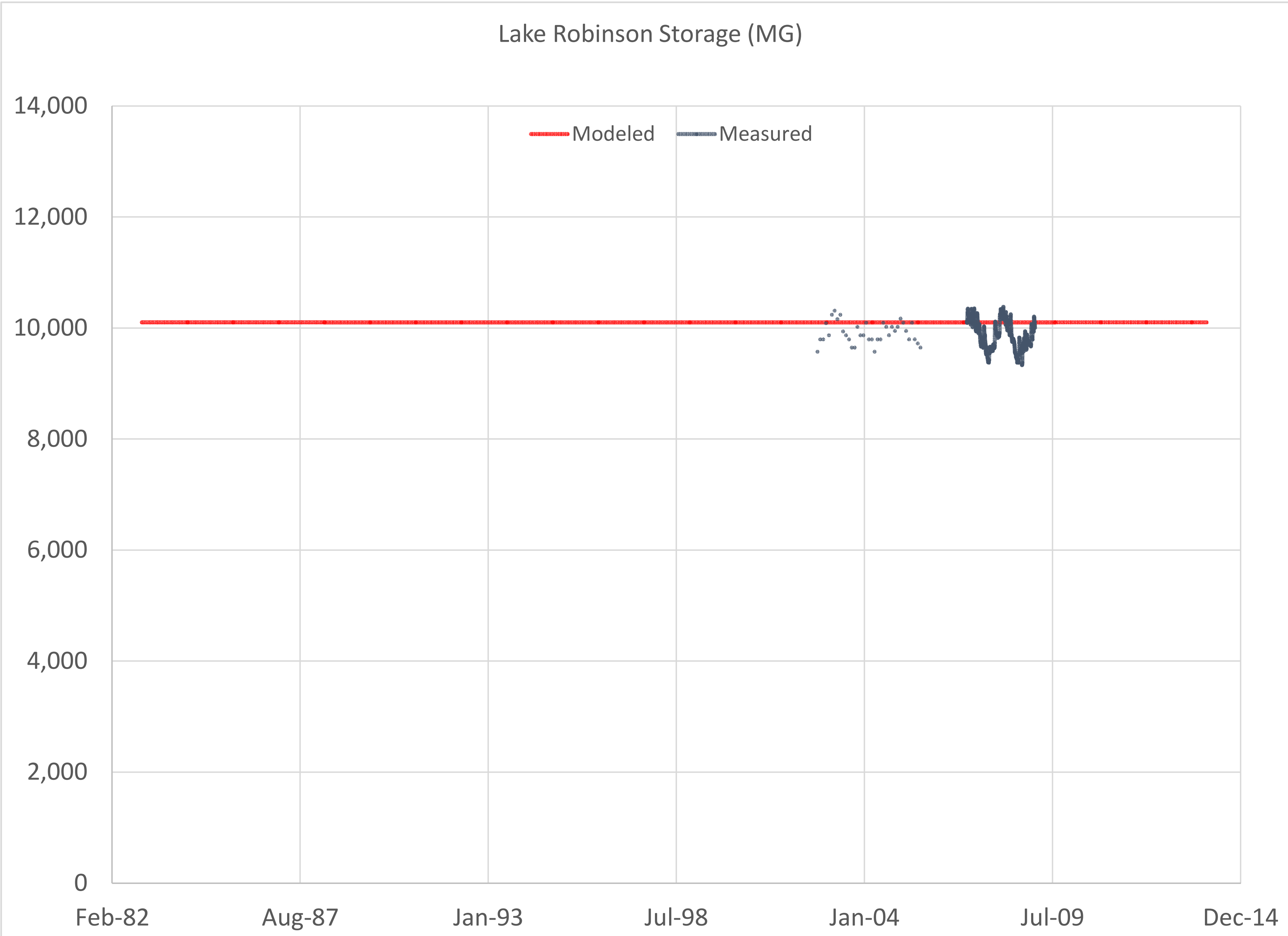


PDE28 (02135000) LITTLE PEE DEE R. AT GALIVANTS FERRY, SC (CFS)
Annual Average Flow
gaged
modeled
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
1983
1988
1993
1998
2003
2008
2013

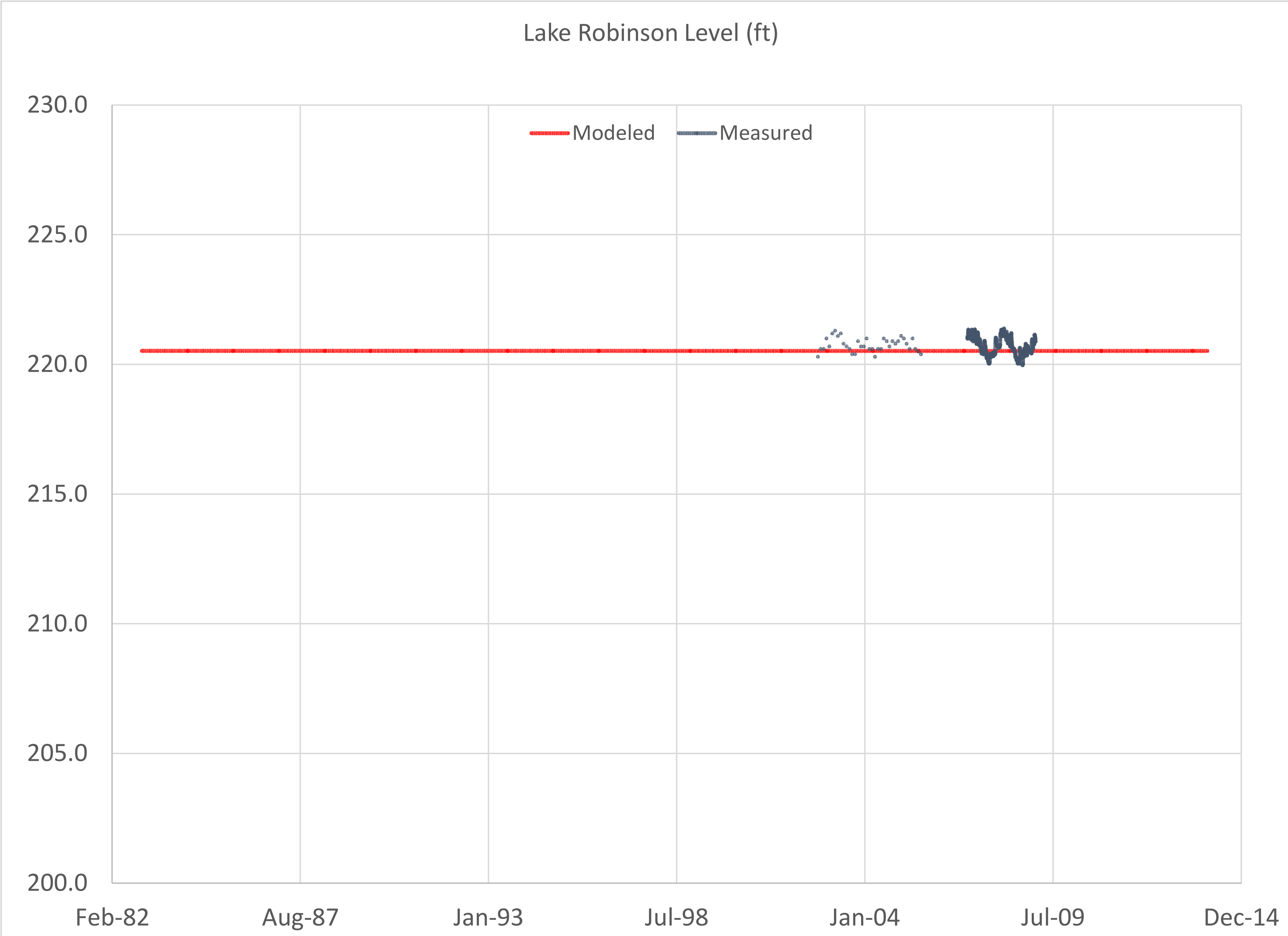

PDE28 (02135000) LITTLE PEE DEE R. AT GALIVANTS FERRY, SC
Monthly Mean Flow (CFS)
gaged
modeled
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


PDE28 (02135000) LITTLE PEE DEE R. AT GALIVANTS FERRY, SC
Daily Flow Percentiles (CFS)
30000
25000
20000
15000
10000
5000
0
gaged
modeled
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

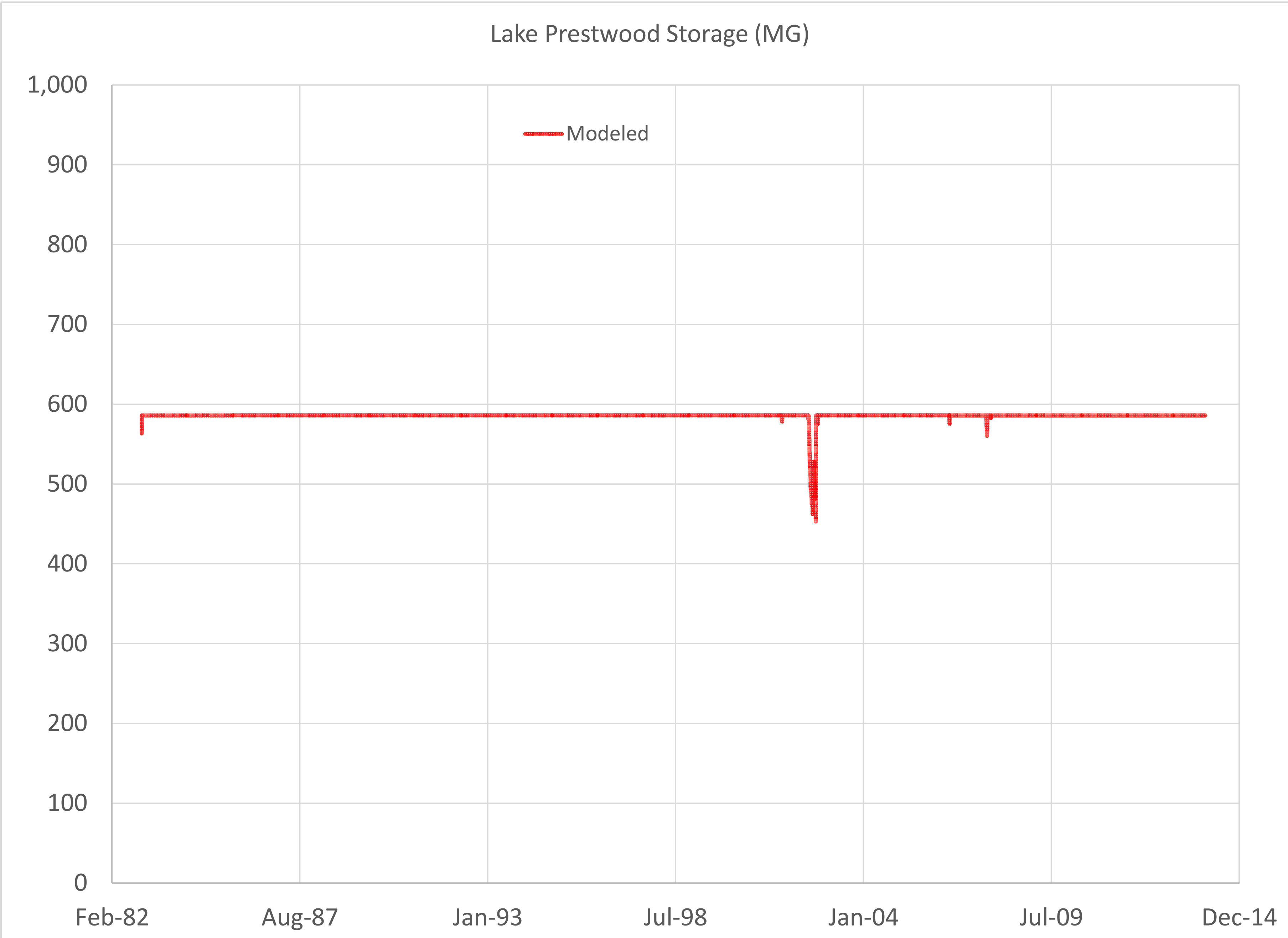

PDE28 (02135000) LITTLE PEE DEE R. AT GALIVANTS FERRY, SC
Annual 7-day Low Flow (CFS)
gaged
modeled
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1983
1988
1993
1998
2003
2008
2013
2018
Year



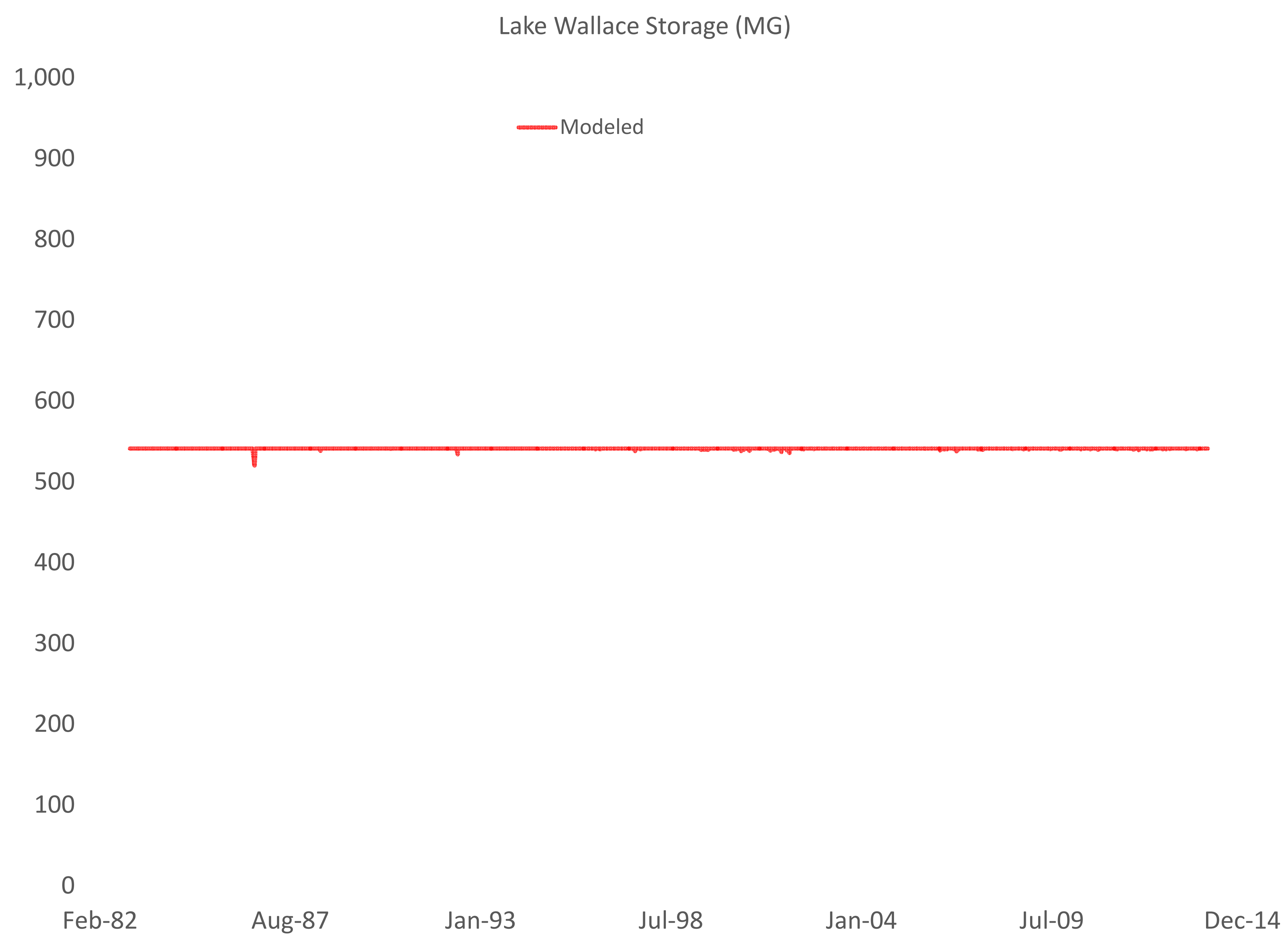
Lake Robinson Storage (MG)
Modeled
Measured
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Feb-82
Aug-87
Jan-93
Jul-98
Jan-04
Jul-09
Dec-14



Lake Robinson Level (ft)
Modeled
Measured
230.0
225.0
220.0
215.0
210.0
205.0
200.0
Feb-82
Aug-87
Jan-93
Jul-98
Jan-04
Jul-09
Dec-14



Lake Prestwood Storage (MG)
Modeled
1,000
900
800
700
600
500
400
300
200
100
0
Feb-82
Aug-87
Jan-93
Jul-98
Jan-04
Jul-09
Dec-14


Lake Wallace Storage (MG)
Modeled
1,000
900
800
700
600
500
400
300
200
100
0
Feb-82
Aug-87
Jan-93
Jul-98
Jan-04
Jul-09
Dec-14

Annual 7 day Low Flows: Modeled (Page 1)

Year	FORK CREEK AT JEFFERSON	LITTLE FORK CREEK AT JEFFERSON	HANGING ROCK CREEK NR KERSHAW	LYNCHES RIVER NR BISHOPVILLE	LYNCHES RIVER AT EFFINGHAM	WHITES CREEK NR WALLACE	PEE DEE RIVER NR BENNETTS-VILLE	BLACK CREEK BELOW CHESTER-FIELD	BLACK CREEK NR MCBEE	BLACK CREEK NR HARTSVILLE	BLACK CREEK NR QUINBY
ID->	**PDE01**	**PDE02**	**PDE03**	**PDE04**	**PDE05**	**PDE06**	**PDE08**	**PDE10**	**PDE11**	**PDE12**	**PDE13**
1983	0.0		0.9		125	0.5			29	43	
1984	0.6		3.1		235	6.6			52	77	
1985	0.3		1.0		172	3.8			27	41	
1986	0.0		0.6		83	0.3			21	31	
1987	0.1		1.3		176	3.2			32	48	
1988	0.0		1.3		133	0.5			28	42	
1989	4.0		9.0		408	5.1			57	85	
1990	0.0		1.6		164	0.0			20	29	
1991	4.5	2.4	8.9		389	3.1	624		62	91	
1992	0.7	0.9	4.5		191	0.3	2453		26	38	
1993	0.4	0.4	1.3		160	2.6	1481		32	47	
1994	0.5	1.3	5.8		255	4.5	2548		30	44	
1995	2.9	0.7	2.4		200		2161		40	60	
1996	2.1	0.1	2.0		154		1911		34	51	
1997		0.1	2.9		217		1624		44	65	
1998		0.8	3.4		259		1363		66	97	
1999		0.0	0.8		121		1284		27	40	
2000			0.7		123		651		32	46	
2001			0.2		91		370		18	26	
2002			0.2		57		974		11	17	55
2003				144	200		2746		56	83	220
2004				75	106		1812		27	40	107
2005				82	116		1108		28	42	109
2006				96	140		746	9	20	30	80
2007				52	74		941	7	15	22	61
2008				59	85		1189	9	19	28	75
2009		0.0		62	89		1254	8	19	28	71
2010		0.1		80	114		1283	12	28	41	108
2011		0.3		63	92		1020	8	19	28	70
2012				82	118		1584	9	20	30	76
2013				137	194		2405	18	41	48	140

Annual 7 day Low Flows: Measured

Year	FORK CREEK AT JEFFERSON	LITTLE FORK CREEK AT JEFFERSON	HANGING ROCK CREEK NR KERSHAW	LYNCHES RIVER NR BISHOPVILLE	LYNCHES RIVER AT EFFINGHAM	WHITES CREEK NR WALLACE	PEE DEE RIVER NR BENNETTS-VILLE	BLACK CREEK BELOW CHESTER-FIELD	BLACK CREEK NR MCBEE	BLACK CREEK NR HARTSVILLE	BLACK CREEK NR QUINBY
ID->	**PDE01**	**PDE02**	**PDE03**	**PDE04**	**PDE05**	**PDE06**	**PDE08**	**PDE10**	**PDE11**	**PDE12**	**PDE13**
1983	0.0		0.7		150	0.5			28	73	
1984	0.6		2.9		273	6.6			50	99	
1985	0.3		0.8		206	3.8			26	68	
1986	0.0		0.2		110	0.3			19	39	
1987	0.1		0.9		223	3.2			31	77	
1988	0.0		0.8		135	0.5			27	44	
1989	4.0		8.7		360	5.1			56	95	
1990	0.0		1.3		193	0.0			18	33	
1991	4.5	2.7	8.4		384	3.1	866		60	97	
1992	0.7	2.4	4.1		168	0.3	1855		24	40	
1993	0.4	0.7	0.6		204	2.6	1307		31	78	
1994	0.5	2.2	5.4		269	4.4	3429		29	75	
1995	2.8	3.6	1.8		228		1990		39	91	
1996	2.1	0.8	1.5		178		1928		33	73	
1997		0.9	2.7		225		1912		43	73	
1998		1.6	3.1		291		1482		64	99	
1999		0.3	0.4		149		932		26	64	
2000			0.7		150		744		30	65	
2001			0.3		114		484		18	55	
2002			0.4		70		877		11	8	53
2003				204	219		2510		56	82	180
2004				117	122		1789		27	63	138
2005				146	129		1210		28	57	156
2006				117	165		1123	5	20	53	121
2007				87	87		628	3	15	22	87
2008				93	93		1192	1	19	24	70
2009		0.0		91	99		1137	4	19	26	101
2010		0.1		135	128		1033	4	28	38	128
2011		0.3		88	104		1084	2	19	27	96
2012				113	131		2050	3	20	34	140
2013				191	215		2436	15	41	58	185

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

Approximate 7Q10 Comparison - Modeled vs. Measured

Year	FORK CREEK AT JEFFERSON	LITTLE FORK CREEK AT JEFFERSON	HANGING ROCK CREEK NR KERSHAW	LYNCHES RIVER NR BISHOPVILLE	LYNCHES RIVER AT EFFINGHAM	WHITES CREEK NR WALLACE	PEE DEE RIVER NR BENNETTS-VILLE	BLACK CREEK BELOW CHESTER-FIELD	BLACK CREEK NR MCBEE	BLACK CREEK NR HARTSVILLE	BLACK CREEK NR QUINBY
ID->	**PDE01**	**PDE02**	**PDE03**	**PDE04**	**PDE05**	**PDE06**	**PDE08**	**PDE10**	**PDE11**	**PDE12**	**PDE13**
Modeled	0.0	0.0	0.6	59	85	0.3	670	8	19	28	62
Measured	0.0	0.1	0.3	88	99	0.3	768	2	18	26	71
% Diff.				32%	14%		13%		-3%	-8%	13%

Note: Percent difference shown for 7Q10 flows > 25 cfs

Annual 7 day Low Flows: Modeled (Page 2)

Year	PEE DEE RIVER AT PEEDEE	PEE DEE RIVER BELOW PEE DEE	JEFFRIES CREEK ABOVE FLORENCE	CATFISH CANAL AT SELLERS	SCAPE ORE SWAMP NR BISHOPVILLE	BLACK RIVER NR GABLE	POCOTALIGO RIVER AT SUMTER	TURKEY CREEK (HWY 521) AT SUMTER	POCOTALIGO RIVER NR SUMTER & MANNING	BLACK RIVER AT KINGSTREE	LITTLE PEE DEE AT GALIVANT S FERRY	CHINNERS SWAMP NR AYNOR
ID->	**PDE14**	**PDE15**	**PDE16**	**PDE17**	**PDE20**	**PDE21**	**PDE22**	**PDE23**	**PDE24.25**	**PDE26**	**PDE28**	**PDE41**
1983	2079			0.0	9	29				76	322	
1984	1227			1.2	17	54				126	907	
1985	467			1.4	12	47				113	546	
1986	904			1.0	4	11				41	379	
1987	856			0.2	12	35				86	361	
1988	1520			1.1	9	29				66	280	
1989	2310			1.0	15	53				134	894	
1990	1483			0.6	7	21				57	257	
1991	909			2.7	27	137				340	622	
1992	2818				15					121	430	
1993	1754				11		17			90	345	
1994	2973				13		17			114	444	
1995	2651				19					157	534	
1996	2267				10					104	420	
1997	1961	1882			9					112	430	
1998	1821	1752			15					124	453	
1999	1527	1446			6					52	366	
2000	821	752			6					53	714	
2001	504	437			7					56	363	
2002	1146	1068			8			0.1		50	99	
2003	3197	3108								182	1719	
2004	2145	2065								98	561	
2005	1349	1266								74	448	
2006	921	845								61	734	
2007	1119	1057								40	162	0.0
2008	1423	1359								48	317	1.1
2009	1499	1424	3.2							48	389	1.0
2010	1528	1444	0.5							64	250	
2011	1217	1140								43	275	
2012	2032	1960								60	359	
2013	2819	2732								140	482	

Annual 7 day Low Flows: Measured

Year	PEE DEE RIVER AT PEEDEE	PEE DEE RIVER BELOW PEE DEE	JEFFRIES CREEK ABOVE FLORENCE	CATFISH CANAL AT SELLERS	SCAPE ORE SWAMP NR BISHOPVILLE	BLACK RIVER NR GABLE	POCOTALIGO RIVER AT SUMTER	TURKEY CREEK (HWY 521) AT SUMTER	POCOTALIGO RIVER NR SUMTER & MANNING	BLACK RIVER AT KINGSTREE	LITTLE PEE DEE AT GALIVANT S FERRY	CHINNERS SWAMP NR AYNOR
ID->	**PDE14**	**PDE15**	**PDE16**	**PDE17**	**PDE20**	**PDE21**	**PDE22**	**PDE23**	**PDE24.25**	**PDE26**	**PDE28**	**PDE41**
1983	2153			0.0	9	2				30	330	
1984	3096			1.2	17	9				59	809	
1985	2026			1.3	12	10				44	555	
1986	1634			1.0	4	0				8	374	
1987	1571			0.2	12	14				34	391	
1988	1947			1.1	9	3				13	327	
1989	3763			1.0	15	14				91	817	
1990	2174			0.6	7	2				24	187	
1991	1560			2.7	27	52				197	535	
1992	3324				15					74	309	
1993	2829				11		10			40	291	
1994	3724				13		7			76	387	
1995	2663				19					57	475	
1996	2596				10					48	332	
1997	2349	2260			9					103	365	
1998	1930	2050			15					38	411	
1999	1344	1466			6					8	349	
2000	1250	1356			6					11	546	
2001	701	692			7					12	274	
2002	941	977			8			0.0		3	77	
2003	3923	4309								97	1720	
2004	2377	2163								68	436	
2005	1545	1607								32	345	
2006	1391	1241								22	559	
2007	986	1012								8	167	0.0
2008	1843	1909								18	245	1.6
2009	1707	1711	3.2							13	294	1.4
2010	1470	1623	0.5							31	196	
2011	1189	1190								13	179	
2012	2199	2289								32	249	
2013	2371	2686								92	373	

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

Approximate 7Q10 Comparison - Modeled vs. Measured

Year	PEE DEE RIVER AT PEEDEE	PEE DEE RIVER BELOW PEE DEE	JEFFRIES CREEK ABOVE FLORENCE	CATFISH CANAL AT SELLERS	SCAPE ORE SWAMP NR BISHOPVILLE	BLACK RIVER NR GABLE	POCOTALIGO RIVER AT SUMTER	TURKEY CREEK (HWY 521) AT SUMTER	POCOTALIGO RIVER NR SUMTER & MANNING	BLACK RIVER AT KINGSTREE	LITTLE PEE DEE AT GALIVANT S FERRY	CHINNERS SWAMP NR AYNOR
ID->	**PDE14**	**PDE15**	**PDE16**	**PDE17**	**PDE20**	**PDE21**	**PDE22**	**PDE23**	**PDE24.25**	**PDE26**	**PDE28**	**PDE41**
Modeled	856	808	0.8	0.2	5.8	19	17	0.1		48	257	0.2
Measured	1189	998	0.8	0.2	5.8	1.8	7	0.0		8	187	0.3
% Diff.	28%	19%									-37%	

Note: Percent difference shown for 7Q10 flows > 25 cfs

Appendix C

Guidelines for Representing Multi-Basin Water Users in SWAM

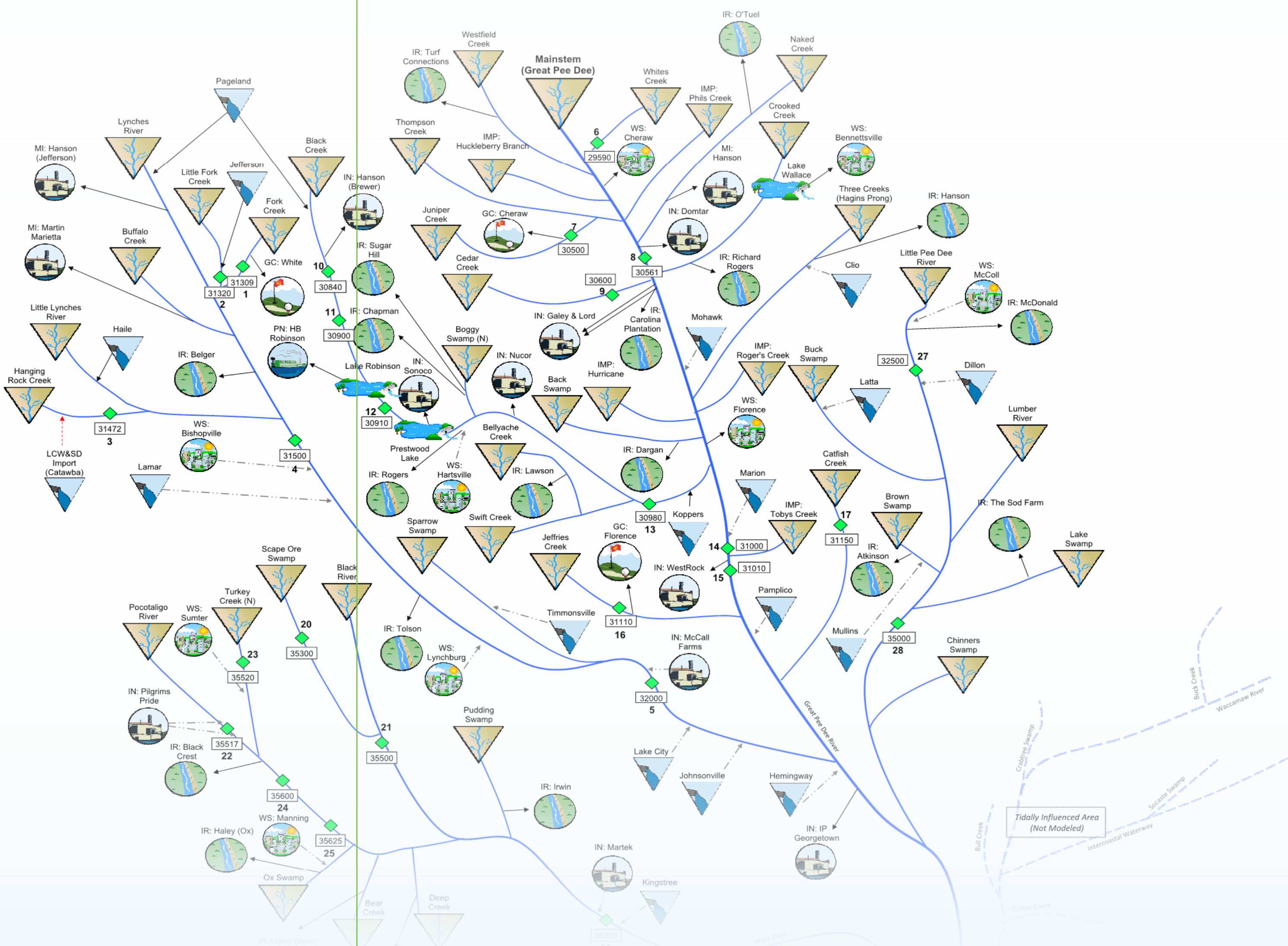
CDM Smith

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.



Mainstem (Great Pee Dee)
Westfield Creek
IR: Turf Connections
IR: O'Tuel
Naked Creek
Whites Creek
IMP: Phils Creek
Crooked Creek
Thompson Creek
IMP: Huckleberry Branch
WS: Cheraw
6
29590
MI: Hanson
Lake Wallace
WS: Bennettsville
Pageland
Lynches River
MI: Hanson (Jefferson)
Jefferson
Little Fork Creek
Black Creek
IN: Hanson (Brewer)
Fork Creek
GC: White
31309
1
31320
2
MI: Martin Marietta
Buffalo Creek
IR: Sugar Hill
10
30840
Juniper Creek
GC: Cheraw
7
30500
IN: Domtar
Three Creeks (Hagins Prong)
IR: Hanson
8
30561
IR: Richard Rogers
Cedar Creek
30600
9
Clio
Little Pee Dee River
WS: McColl
IR: McDonald
Little Lynches River
Haile
11
IR: Chapman
30900
PN: HB Robinson
Boggy Swamp (N)
IN: Galey & Lord
IR: Carolina Plantation
Mohawk
IR: Belger
Lake Robinson
IN: Sonoco
IN: Nucor
IMP: Hurricane
IMP: Roger's Creek
Buck Swamp
32500
27
Dillon
Hanging Rock Creek
31472
3
12
30910
Back Swamp
Latta
WS: Florence
Lumber River
LCW&SD Import (Catawba)
WS: Bishopville
31500
4
Prestwood Lake
Bellyache Creek
WS: Hartsville
IR: Rogers
IR: Lawson
IR: Dargan
Catfish Creek
Lamar
30980
13
Koppers
Marion
IMP: Tobys Creek
Brown Swamp
IR: The Sod Farm
Sparrow Swamp
Swift Creek
17
31150
Lake Swamp
Jeffries Creek
GC: Florence
14
31000
IR: Atkinson
IN: WestRock
15
31010
Scape Ore Swamp
Black River
Pamplico
Turkey Creek (N)
Pocotaligo River
WS: Sumter
23
20
35300
Timmonsville
31110
16
Mullins
35000
28
Chinners Swamp
IR: Tolson
35520
WS: Lynchburg
IN: McCall Farms
32000
5
IN: Pilgrims Pride
35517
22
IR: Black Crest
21
35500
Pudding Swamp
Great Pee Dee River
Lake City
Johnsonville
Hemingway
35600
24
IR: Irwin
WS: Manning
35625
25
IR: Haley (Ox)
IN: IP Georgetown
IN: Martek
Kingstree
Ox Swamp
Bear Creek
Deep Creek
Tidally Influenced Area (Not Modeled)
Waccamaw River
Buck Creek
Intercoastal Waterway