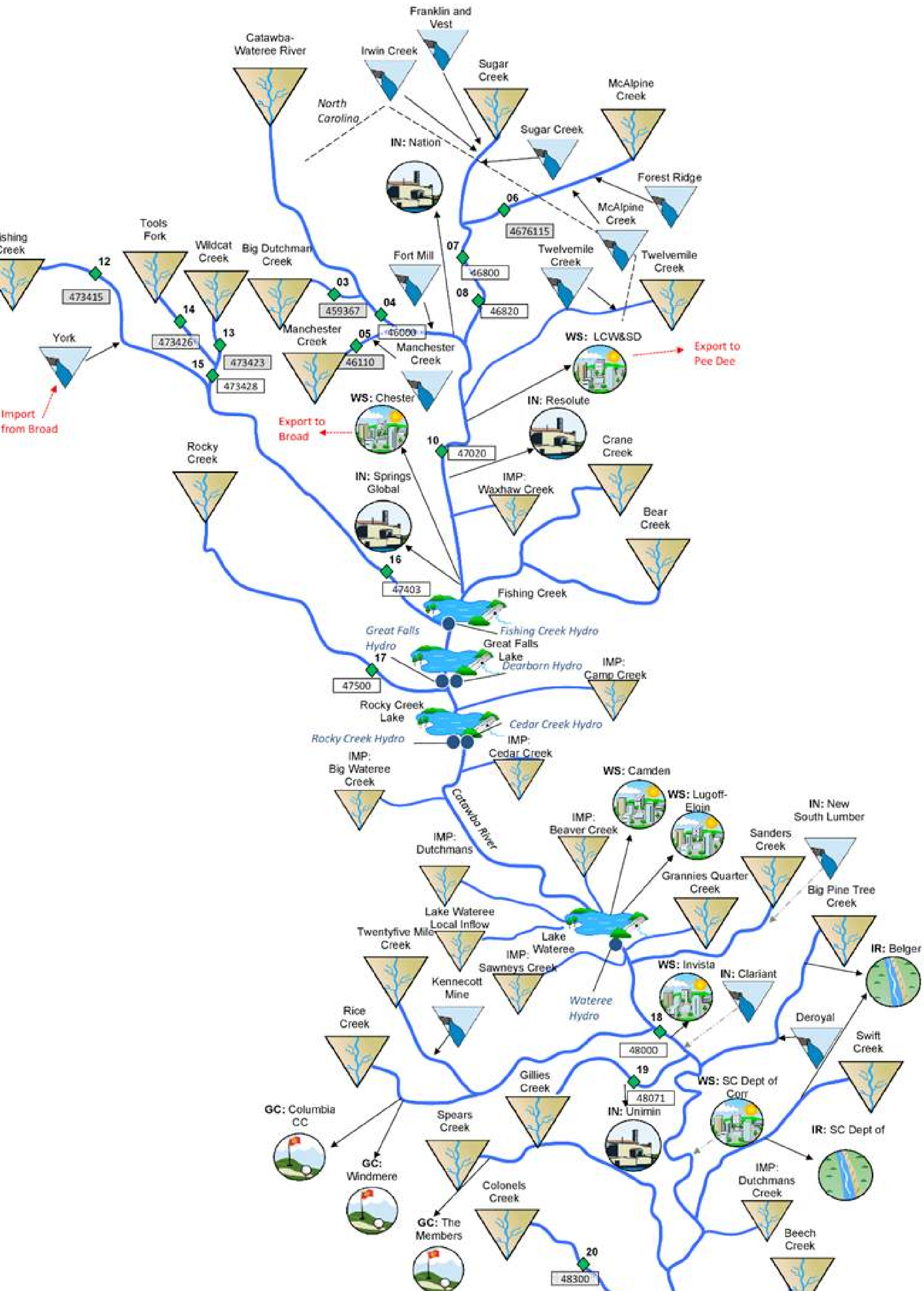
SOUTH CAROLINA
SURFACE WATER QUANTITY MODELS
CATAWBA-WATEREE RIVER BASIN MODEL

Healthy People. Healthy Communities.



SUBMITTED TO:

SOUTH CAROLINA DEPARTMENT OF NATURAL RESOURCES

SOUTH CAROLINA DEPARTMENT OF HEALTH & ENVIRONMENTAL CONTROL

March 2017

PREPARED BY:

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Section 1

Purpose

This document, the Catawba-Wateree 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 Catawba-Wateree 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 Catawba-Wateree River Basin Model is provided in the *Simplified Water Allocation Model (SWAM) User's Manual Version 4.0* (CDM Smith, 2016).

Additionally, this document is intended to help disseminate the information about how the model represents the South Carolina portion of the Catawba-Wateree 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 Catawba-Wateree River Basin Model in SWAM has been developed for multiple purposes, but it is primarily intended to support future permitting, policy, and planning efforts in the South Carolina portion of the basin. Fundamentally, the model will simulate the natural hydrology through the network of the Catawba and Wateree rivers below Lake Wylie, including their major tributaries, and the impacts to the river flows from human intervention: withdrawals, discharges, impoundment, and interbasin transfers.

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

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

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

Lastly, the model is intended to support a large user base, including staff at DNR and DHEC along with stakeholders throughout the South Carolina portion of the Catawba-Wateree 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 Catawba-Wateree River Basin Model. Where appropriate, additional discussion has been included in this report, to elaborate on specific aspects covered in the Modeling Plan. In certain instances, the procedures and guidelines detailed in the plan were modified and/or enhanced during development of the pilot model developed for the Saluda River Basin and the subsequent models developed for the Broad, Edisto, Pee Dee and Salkehatchie river basins. The enhanced procedures and guidelines, and the "lessons learned" were applied to the Catawba-Wateree River Basin – especially, with regard to model calibration and validation.

Section 4

Catawba-Wateree Model Framework

The initial Catawba-Wateree River Basin SWAM Model Framework was developed in collaboration with South Carolina DNR and DHEC, and was presented in the memorandum *Catawba-Wateree Basin SWAM Model Framework* (CDM Smith, October 2015). The proposed framework was developed as a starting point for representing the South Carolina portion of the Catawba-Wateree Basin river network and its significant water withdrawals and discharges. The guiding principles in determining what elements of the Catawba-Wateree River Basin to simulate explicitly were:

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

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

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

4. Generally, tributaries that are unused are not included explicitly, but the hydrologic contributions from these tributaries are embedded in the unimpaired flows (or reach gains) in downstream locations. As unimpaired flows (UIFs) are developed throughout the Catawba-Wateree, 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 the initial boundary conditions of the model were adjusted, to more easily work with output from the existing Catawba-Wateree CHEOPS model previously developed by HDR Engineering under contract to Duke Energy Carolinas, LLC, as reported in the *Catawba-Wateree Hydroelectric Project Operations Model – Model Logic and Verification Report* (HDR, 2014). The SWAM model's mainstem boundary was moved to the outlet of Lake Wylie, and Lake Wylie was omitted from the model. Output flows from the Catawba-Wateree CHEOPS model are easily obtained from this single location, for use as input to the SWAM model. If the boundary were set above Lake Wylie, output flows from multiple CHEOPS model nodes would be needed, given that there are several tributaries to Lake Wylie which originate in North Carolina. Furthermore, it eliminates the need to account for North Carolina withdrawals from, and discharges to, Lake Wylie, or the tributaries to it. These are already accounted for in the CHEOPS model.

4.1 Representation of Water Withdrawals

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

4.2 Representation of Discharges

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

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

- Several industrial discharges – Deroyal, USAF/Shaw AFB, Kennecott Mine, and Finnchem, were deemed significant enough to include in the model; however, the industry either purchases water from another permit holder or withdraws (or supplements) using groundwater. They do not have their own surface water withdrawal permit.
- Water withdrawn by the City of York in the Broad River Basin, and then discharged in the Catawba-Wateree Basin to Fishing Creek is represented by a Discharge object.
- Water withdrawn by multiple municipalities, including Charlotte, in the North Carolina-portion of the Catawba-Wateree River Basin is discharged into tributaries and affect South Carolina flows. These are represented by Discharge objects.

4.3 Representation of Hydropower Facilities

All hydropower facilities below Lake Wylie are explicitly included in the model as all at least have a rule curve and minor operating requirements. Rules for these facilities are discussed further in Section 6.

The following hydropower facilities are *essentially* operated as run-of-river, but have a storage target and required minimum flows. The storage target and minimum flows for these facilities are specified within the Reservoir objects associated with the hydropower facility.

- Dearborn and Great Falls pair on Great Falls Lake (Catawba River)

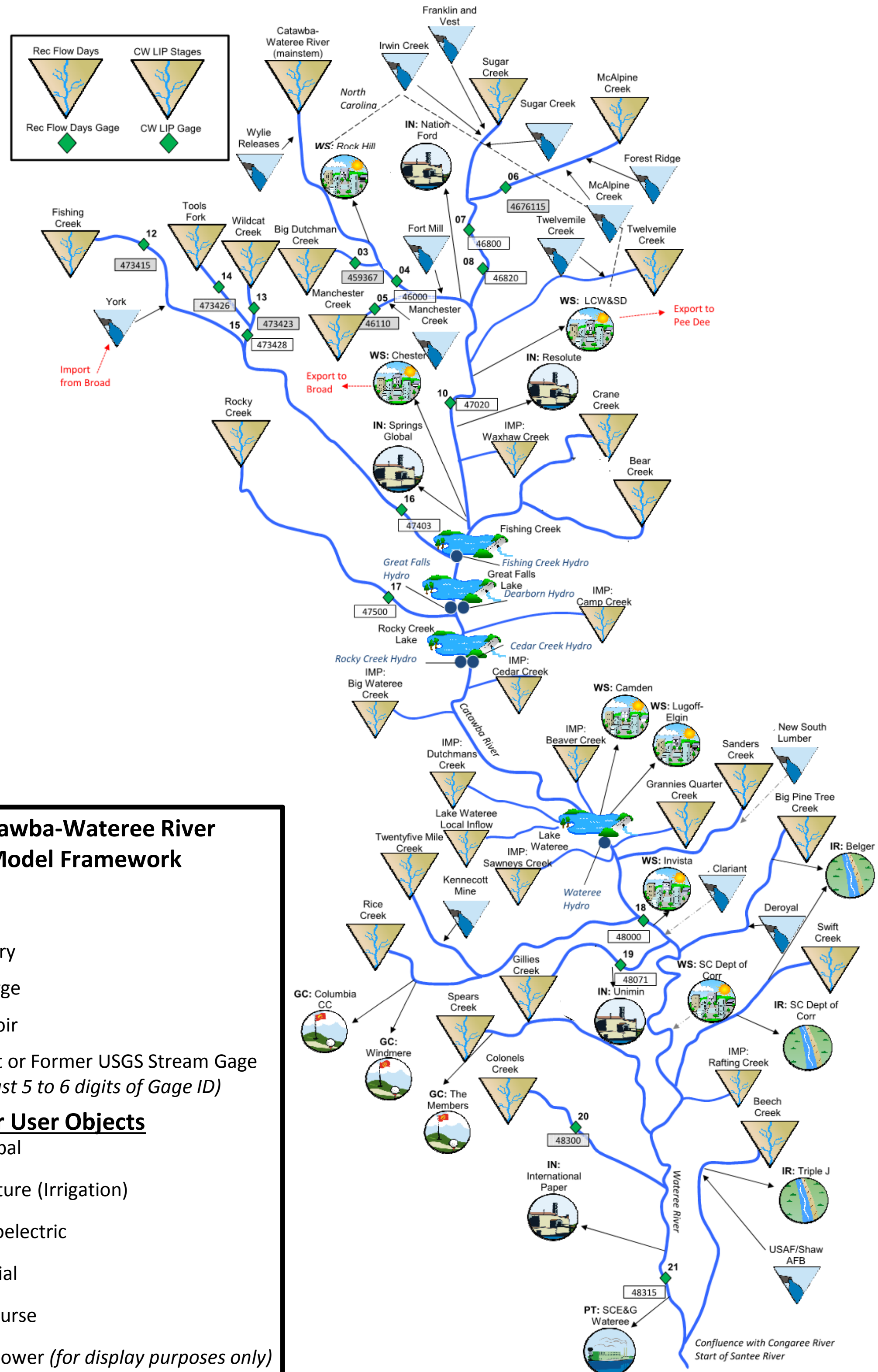


Figure 4-1. Catawba-Wateree River Basin SWAM Model Framework

Model Objects

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

Water User Objects

- Municipal
- Agriculture (Irrigation)
- Thermoelectric
- Industrial
- Golf Course
- Hydropower *(for display purposes only)*
- Import or Export (Interbasin Transfer)
- Discharge from a Groundwater User*

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

- Rocky Creek and Cedar Creek pair on Rocky Creek Lake (Catawba River)
- Fishing Creek (Catawba River)

The Lake Wateree hydropower facility is not considered run-of-river. This facility has minimum flow requirements and unique release/operating rules, which are discussed further in Section 6.

4.4 Groundwater Users and Associated Discharge

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

In the Catawba-Wateree River Basin, only one significant industrial groundwater withdrawal was identified – SC Dept Corr, which had a corresponding, significant discharge to surface water. It is represented by a Water User object. There were also two groundwater users, Clariant and New South Lumber, 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.

4.5 Implicit Tributaries

At certain locations along the main stem of the Catawba-Wateree 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 Catawba-Wateree Model is provided in Section 6. These are tributaries which do not have current and significant withdrawals or discharges; however, their contribution of flow to the main stem is important to include. Including them as implicit tributaries facilitates adding them later, as explicit tributaries, in the event a significant use or discharge is contemplated.

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 – 2010 for tributaries, and mid-2006-2010 for the mainstem) rather than the full record of estimated hydrology.

In contrast, the baseline model is intended to represent current demands and operations in the basin combined with an extended period of estimated hydrology. This model will serve as the starting point for any future predictive simulations with the model (e.g., planning or permitting support) and should be maintained as a useful “baseline” point of reference. For this model, the simulation period extends back to 1951, the start of the hydrologic record for the Catawba-Wateree River Basin. Each element in the baseline model is assigned water use rates that reflect current demands only and are not time variable (except seasonal). Current demands were estimated by averaging water use data over the past ten years (2004 – 2010) for most users, on a monthly basis. These monthly demands are repeated in the baseline model for each simulation year. Similarly, reservoir operations defined in the baseline model are based on current rules, guidelines, and minimum release requirements. In certain instances, future rules that are not yet in effect, can be included (and can be toggled on or off in the model). A final difference between the two models is that only active water users are included in the baseline model. Inactive user objects included in the calibration model have been removed from the baseline model.

Section 6
Model Inputs

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

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

6.1 Model Tributaries

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

6.1.1 Explicit Tributary Objects: Headwater Flows

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

Explicit tributary objects are parameterized in SWAM with headwater flows, representing unimpaired flows at the top of the given modeled reach. These flows may be raw gage flow, area-prorated from calculated UIFs elsewhere in the basin, or output flows from existing models. As the Catawba-Wateree River Basin has drainage from North Carolina, the first draft of the calibration model used model output from the North Carolina CHEOPS model (HDR, 2014), which represents the managed (impaired) flow coming from North Carolina. HDR Inc. also provided reservoir release data back-calculated from Duke Energy’s operation records, which when compared to gage flow downstream at CAT04 (02146000) demonstrated a more suitable representation of historic flows. For the second draft of the calibration model, the CHEOPS output was replaced by the calculated reservoir release data. However, it became apparent that future uses of the model should have a mainstem with general patterns of natural hydrology being independent of altered release patterns from Lake Wylie.

Therefore, for the final calibration model and baseline model, mainstem flows have been set based on an unimpaired inflow dataset developed by HDR for the CHEOPS model node (CH7) at Lake Wylie and releases from Lake Wylie are represented by a discharge object. The model also contains two “dummy” tributary objects, ***Rec Flow Days*** and ***CW LIP Stages***, which do not contribute flows to the system but only populate their respective gages with key values which trigger conditional rules in User and Reservoir objects. ***Rec Flow Days*** triggers higher minimum releases for recreational flows and consists of a binary timeseries, where a flag of “1” indicates a weekend with increased flows, and “0” otherwise (see **Section 6.4.2** for more detail). This series is not relevant to the monthly model and is set entirely to “0.” ***CW LIP Stages*** represents a Low Inflow Protocol Stage Timeseries for Stages 0 to 4: values of “-1” indicate no action, “0” is a warning stage only and has no actions, and “1” or above have corresponding actions triggered in reservoirs and certain users (see **Section 6.4.1**).

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

6.1.2 Implicit Tributary Objects: Confluence Flows

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

6.1.3 Reach Gains and Losses

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

There are subtle differences in the way in which these gains and losses are characterized in the model inputs for non-mainstem tributary objects versus the mainstem tributary object, although they effectively achieve the same thing in the model calculations. For the mainstem, gain/loss factors are specified on a per unit mile basis. For example, if the mainstem headwater flow is 10 cfs in a given timestep with a gain factor of 0.1 per mile specified for the entire mainstem reach, then the model applies a rate of gain of 1 cfs/mile throughout the length of the mainstem. At the end of a 5-mile reach with no other inflows or outflow, the flow would be 15 cfs. For all other tributary objects, subbasin flow factors are specified as a total subbasin flow gain factor, used to calculate total natural (unimpaired) flow at the end of the designated reach. For example, if a tributary flow is 10 cfs in a given timestep, with a subbasin flow factor of 5, then the end-of-reach flow (with no other inflows or outflows) is 50 cfs. The model linearly interpolates when calculating the unimpaired flow at intermediary points in the reach. The differences between mainstem vs. non-mainstem factors reflect physical differences between the two types of tributary objects as represented in SWAM. For non-

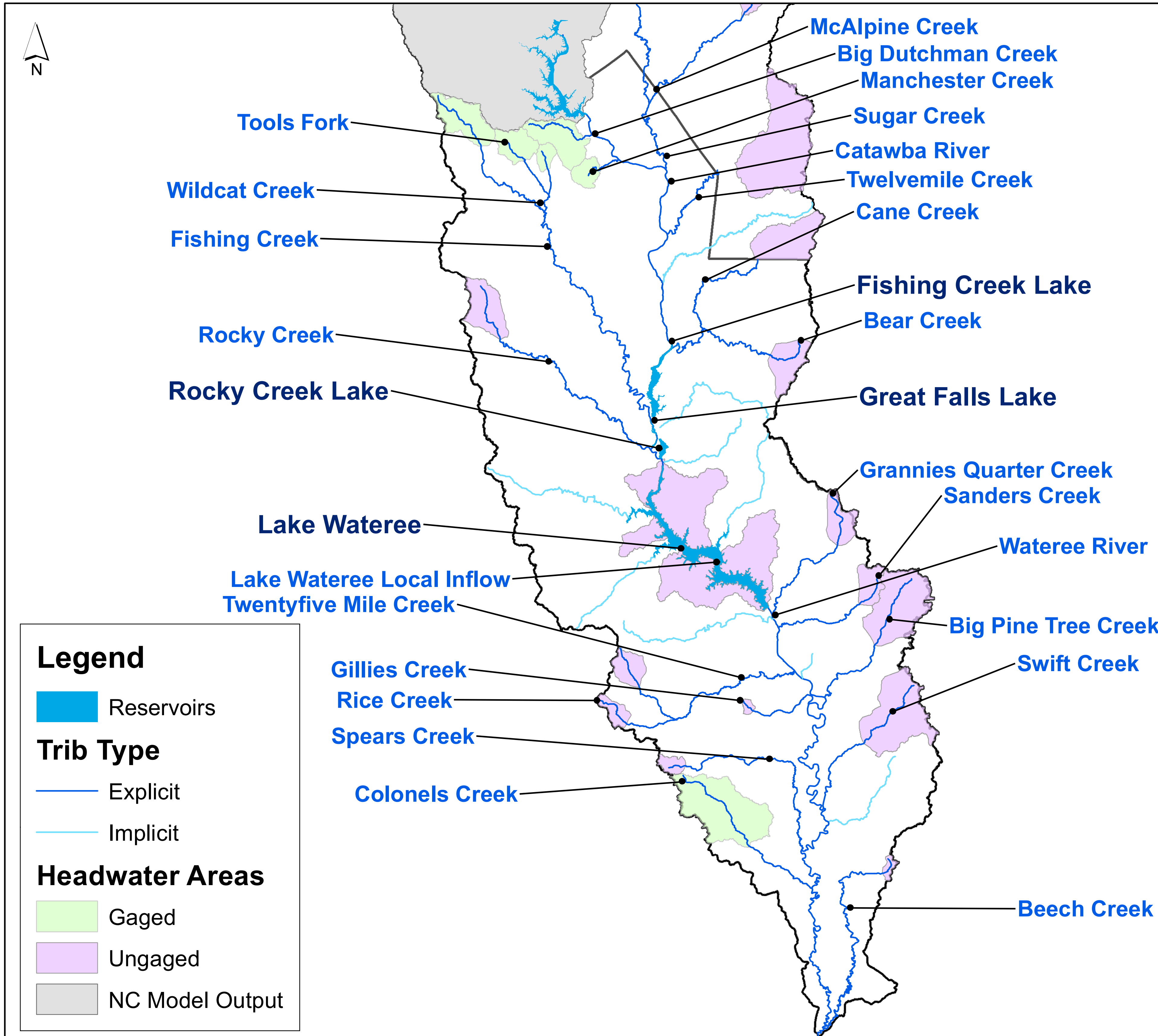
Table 6-1. Gages and Reference Gages Used for Headwater Flows on Explicit Tributaries

	Headwater Input			USGS Reference Gage (Unimpaired)		
Project ID	**Type**	**USGS Number**	**SWAM Tributary**	**Project Gage ID**	**USGS Number**	**Stream**
CH7	Existing UIFs	-	Mainstem[1]	-	-	-
None	Model Input	-	Rec Flow Days	-	-	-
None	Model Input	-	CW LIP Stages	-	-	-
CAT03	Gaged	021459367	Big Dutchman Creek	-	-	-
CAT05	Gaged	02146110	Manchester Creek	-	-	-
CAT12	Gaged	021473415	Fishing Creek	-	-	-
CAT13	Gaged	021473423	Wildcat Creek	-	-	-
CAT14	Gaged	021473426	Tools Fork	-	-	-
CAT20	Gaged	02148300	Colonels Creek	-	-	-
CAT206	Ungaged	-	McAlpine Creek	CAT06	0214676115	McAlpine Creek
CAT205	Ungaged	-	Sugar Creek	CAT07	02146800	Sugar Creek
CAT207	Ungaged	-	Twelvemile Creek			
CAT210	Ungaged	-	Cane Creek	CAT11	02147240	Bear Creek
CAT211	Ungaged	-	Bear Creek			
CAT212	Ungaged	-	Grannies Quarter Creek	CAT17	02147500	Rocky Creek
CAT217	Ungaged	-	Twentyfive Mile Creek			
CAT400	Ungaged	-	Wateree Local Inflow			
CAT219	Ungaged	-	Sanders Creek	CAT19	02148071	Gillies Creek
CAT213	Ungaged	-	Rice Creek	CAT20	2148300	Colonels Creek
CAT214	Ungaged	-	Big Pine Tree Creek			
CAT215	Ungaged	-	Rocky Creek			
CAT216	Ungaged	-	Gillies Creek			
CAT220	Ungaged	-	Swift Creek			
CAT221	Ungaged	-	Spears Creek			
CAT222	Ungaged	-	Beech Creek			

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

	Ungaged Basin	USGS Reference Gage (Unimpaired)		
Project ID	**SWAM Tributary**	**Project Gage ID**	**USGS Number**	**Stream**
CAT303	Cedar Creek	CAT17	02147500	Rocky Creek
CAT305	Big Wateree Creek	CAT17		
CAT307	Dutchmans Creek	CAT17		
CAT309	Beaver Creek	CAT17		
CAT311	Sawneys Creek	CAT17		
CAT315	Waxhaw Creek	CAT17		
CAT317	Camp Creek	CAT17		
CAT313	Rafting Creek	CAT20	02148300	Colonels Creek

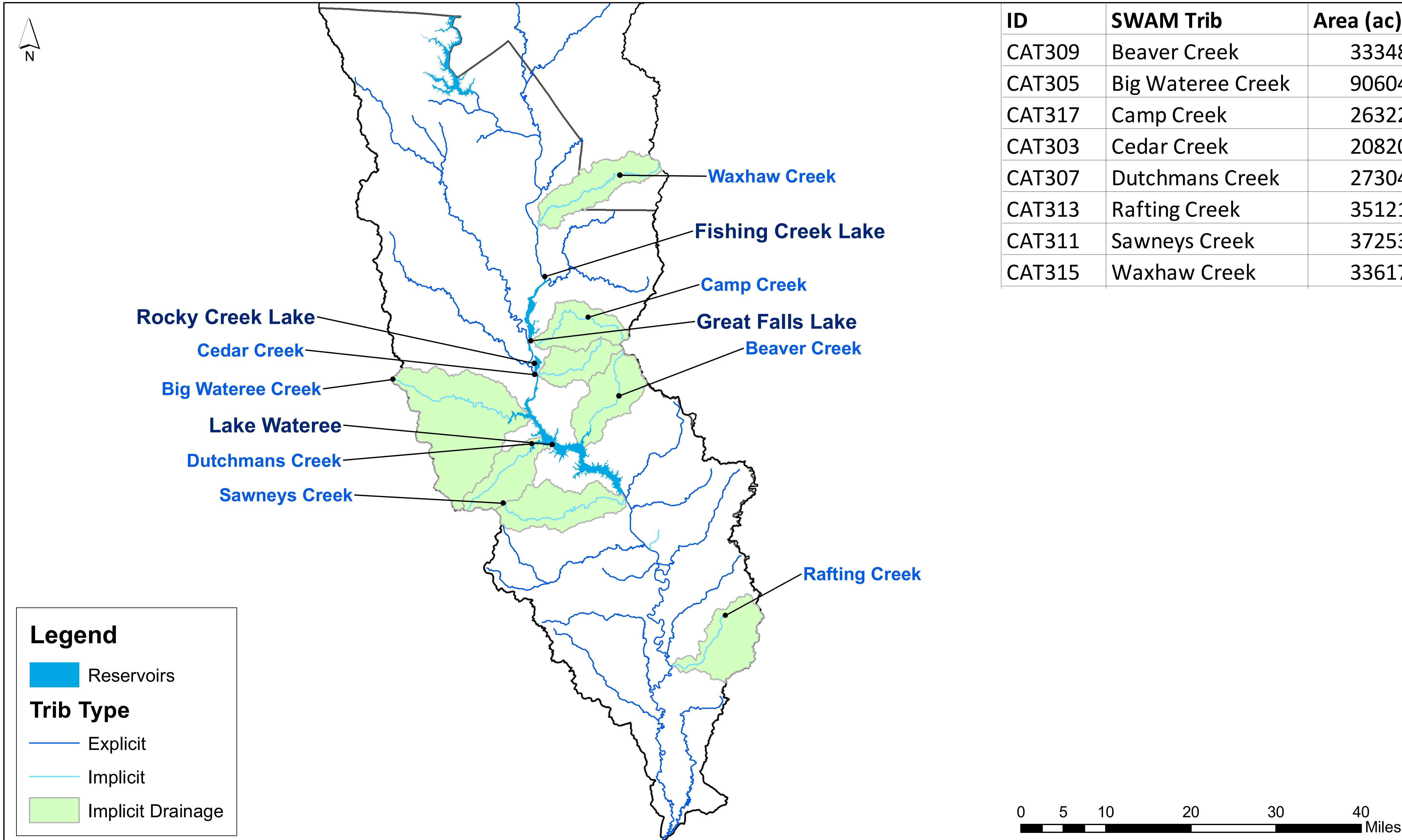
[1] HDR-developed inflow dataset



ID	SWAM Trib	Type	Area (ac)
CAT03	Big Dutchman Creek	USGS	10757
CAT05	Manchester Creek	USGS	3750
CAT12	Fishing Creek	USGS	10484
CAT13	Wildcat Creek	USGS	2300
CAT14	Tools Fork	USGS	6256
CAT20	Colonels Creek	USGS	25718
CAT205	Sugar Creek	Ungaged	8151
CAT206	McAlpine Creek	Ungaged	10443
CAT207	Twelvemile Creek	Ungaged	34355
CAT210	Cane Creek	Ungaged	13073
CAT211	Bear Creek	Ungaged	8340
CAT212	Grannies Quarter Creek	Ungaged	6597
CAT213	Twentyfive Mile Creek	Ungaged	5312
CAT214	Sanders Creek	Ungaged	5162
CAT215	Rice Creek	Ungaged	3304
CAT216	Big Pine Tree Creek	Ungaged	20105
CAT217	Rocky Creek	Ungaged	9894
CAT219	Gillies Creek	Ungaged	825
CAT220	Swift Creek	Ungaged	22222
CAT221	Spears Creek	Ungaged	2386
CAT222	Beech Creek	Ungaged	1254
CAT400	Lake Wateree Local Inflow	Ungaged	64164
CH7	Mainstem	NC Model Output	736261

0 5 10 20 30 40 Miles

Figure 6-1. Headwater Areas for Explicit Tributaries in the Catawba-Wateree Basin



ID	SWAM Trib	Area (ac)
CAT309	Beaver Creek	33348
CAT305	Big Wateree Creek	90604
CAT317	Camp Creek	26322
CAT303	Cedar Creek	20820
CAT307	Dutchmans Creek	27304
CAT313	Rafting Creek	35121
CAT311	Sawneys Creek	37253
CAT315	Waxhaw Creek	33617

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Figure 6-2. Implicit Tributaries in the Catawba-Wateree Basin mainstem tributaries, flow gains are usually dominated by easily-quantifiable increases in drainage area with distance downstream and therefore easily parameterized with drainage area-based subbasin flow factors. For the mainstem, however, the bulk of the drainage area changes are already captured by the tributary objects and any additional changes in flow are more likely to be attributable to subsurface hydrologic interactions or highly localized surface runoff. Such flow changes are more easily represented with per mile gain/loss factors. Both mainstem and tributary flow factors can be spatially variable in the model for up to five different sub-reaches. For further discussion on SWAM reach gain/loss factors, please refer to the SWAM User's Manual. Tributary object gain/loss and subbasin flow factors are the primary calibration parameters in the model, as discussed in Section 7. Recognizing the uncertainty in these parameters, factors are adjusted, as appropriate, to achieve a better match of modeled vs. measured downstream flows. As a starting point in the model, however, overall non-mainstem tributary subbasin flow factors were prescribed in the model based only on drainage area ratios (headwater vs. confluence). Drainage areas are shown in Figures 6-1 and 6-2 and corresponding tributary and mainstem flow factors are summarized in **Table 6-3**.

6.2 Reservoirs

Four reservoirs are represented in the Catawba-Wateree River Basin Model: Fishing Creek Reservoir, Great Falls Lake, Rocky Creek Lake, and Lake Wateree. **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 in **Tables 6-5** to **6-7**, which consist mostly of information adapted from the existing CHEOPS model (HDR, 2014). The exceptions are capacities and dead pools, which were estimated from historical reservoir elevations.

6.2.1 Evaporation

In SWAM, evaporative losses can be specified using monthly-varying seasonal rates (inches per day or percent volume) or with a user-specified timeseries of monthly or daily evaporative losses (inches per month or inches per day). In both the calibration and baseline models, evaporative losses are specified using a timeseries developed during the UIF process. Evaporation was computed using the Hargreaves method from daily temperature data and latitude, and further adjusted by pan evaporation data compiled by Purvis (undated). Temperature stations for were chosen based on proximity to pan evaporation sites. Temperature and evaporation stations used in developing evaporative loss estimated are listed in Table 6-4**.**

6.2.2 Direct Precipitation

Typically, large reservoirs in SWAM release to an explicit tributary object and have an additional tributary representing local inflow and direct precipitation. Since Lake Wateree is the largest reservoir in the Catawba-Wateree River Basin, direct precipitation to the surface of Lake Wateree was included as part of the local inflow tributary object. The local runoff aspect of this tributary object was estimated via area proration of an appropriate unimpaired flow.

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

Table 6-3. Model Tributary Inputs

SWAM Tributary Object	Tributary Type	Confluence Stream	Confluence Location (mile)	Area (ac)	Headwater ID	End Mile	Original Drainage Ratio	Subbasin Flow Factor (unitless)[2]
Catawba-Wateree River (Mainstem)	Explicit	None	None	3,595,000	None	3.7	-	1*
						19.9	-	1*
						44.9	-	0*
						73.8	-	0*
						125	-	1*
Bear Creek	Explicit	Cane Creek	14.4	42,874	CAT211	10.4	5.1	5.1
Beech Creek	Explicit	Mainstem	115.9	9,600	CAT222	31.3	7.7	7.7
Big Dutchman Creek	Explicit	Mainstem	2.4	11,358	CAT03	1.0	1.1	1.1
Big Pine Tree Creek	Explicit	Mainstem	78	41,781	CAT216	9.6	2.1	2.1
Cane Creek	Explicit	Mainstem	31.2	104,700	CAT210	13.5	3.8	3.8
						22.0	4.7	4.7
Colonels Creek	Explicit	Mainstem	117.3	44,659	CAT20	8.2	1.7	1.7
Fishing Creek	Explicit	Mainstem	39.4	185,009	CAT12	11.5	3.0	3.0
						31.2	11.5	10.0
						47.3	14.9	13.1
Gillies Creek	Explicit	Mainstem	80.9	7,718	CAT219	3.1	6.6	5.0
						7.9	9.4	9.4
Grannies Quarter Creek	Explicit	Mainstem	67.1	45,325	CAT212	4.6	5.5	5.5
						11.7	6.9	6.9
Manchester Creek	Explicit	Mainstem	6.6	7,742	CAT05	2.4	2.1	2.1
McAlpine Creek	Explicit	Sugar Creek	20.4	61,169	CAT206	15.9	5.9	3.4
Rice Creek	Explicit	Twentyfive Mile Creek	5.5	9,188	CAT215	5.2	2.8	2.8
Rocky Creek	Explicit	Mainstem	42.5	127,967	CAT217	8.3	3.9	3.9
						21.4	11.7	11.7
						25.5	12.9	13.2
Sanders Creek	Explicit	Mainstem	68.6	26,204	CAT214	10.1	5.1	5.1
Spears Creek	Explicit	Mainstem	110.4	45,262	CAT221	5.4	5.8	5.8
						24.0	19.0	19.0
Sugar Creek	Explicit	Mainstem	11.4	176,331	CAT205	20.3	9.8	12.5
						24.4	13.1	13.1
						30.8	14.1	14.1

[2] On the mainstem, these are referred to as "gain/loss factors", not "subbasin flow factors."

Table 6-3. Model Tributary Inputs (continued)

SWAM Tributary Object	Tributary Type	Confluence Stream	Confluence Location (mile)	Area (ac)	Headwater ID	End Mile	Original Drainage Ratio	Subbasin Flow Factor (unitless) [3]
Swift Creek	Explicit	Mainstem	102.3	39,957	CAT220	9.6	1.8	1.8
Tools Fork	Explicit	Wildcat Creek	2.6	9,721	CAT14	4.4	1.6	2.1
Twelvemile Creek	Explicit	Mainstem	18.4	94,876	CAT207	14.5	2.8	2.8
Twentyfive Mile Creek	Explicit	Mainstem	73.5	79,719	CAT213	5.4	3.0	3.0
						9.6	7.6	7.6
						23.0	13.3	13.3
Wildcat Creek	Explicit	Fishing Creek	11.6	19,023	CAT13	4.8	4.0	3.3
Beaver Creek	Implicit	Mainstem	58.3	33,348	CAT309	0.1	1.0	1.0
Big Wateree Creek	Implicit	Mainstem	50.2	90,604	CAT305	0.1	1.0	1.0
Camp Creek	Implicit	Mainstem	43.8	26,322	CAT317	0.1	1.0	1.0
Cedar Creek	Implicit	Mainstem	44.6	20,820	CAT303	0.1	1.0	1.0
Dutchmans Creek	Implicit	Mainstem	2.4	27,304	CAT307	0.1	1.0	1.0
Rafting Creek	Implicit	Mainstem	104.2	35,121	CAT313	0.1	1.0	1.0
Sawneys Creek	Implicit	Mainstem	67.5	37,253	CAT311	0.1	1.0	1.0
Waxhaw Creek	Implicit	Mainstem	24.5	33,616	CAT315	0.1	1.0	1.0

[3] On the mainstem, these are referred to as “gain/loss factors”, not “subbasin flow factors.”

Table 6-4. Reservoir Inputs

Reservoir	Fishing Creek Reservoir	Great Falls Lake	Rocky Creek Lake	Lake Wateree
Purpose	Power, recreation, industry, and water supply	Power	Power, recreation, and water supply	Power, recreation, and water supply
Receiving Stream	Mainstem (Catawba River)	Mainstem (Catawba River)	Mainstem (Catawba River)	Mainstem (Wateree River)
Temperature Station for Evaporation	Camden USC00381310	Camden USC00381311	Camden USC00381312	Camden USC00381313
Evaporation Station	Florence USC00383111	Florence USC00383112	Florence USC00383113	Florence USC00383114
Precipitation Station	Kershaw USC00384690/ Great Falls USC00383700	Kershaw USC00384690/ Great Falls USC00383700	Kershaw USC00384690/ Great Falls USC00383700	Wateree USC00388979
Release Location (mi)	38.8	42.2	44	66.4
Storage Capacity (MG)	12,607	1,909	6,957	83,144
Dead Pool (MG)	5,842	338	1,951	56,405
Operating Rules	Advanced	Advanced	Advanced	Advanced

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

6.2.3 Area-Capacity Relationships and Flood Control Outflow

Area-capacity relationships for the four reservoirs are summarized in **Table 6-5**. The area-capacity relationships are represented in SWAM with 12 points or less, which in some cases is a simplified representation of the full tabular relationship.

SWAM treats flood flows (when reservoirs are at capacity) simply as bypass flow. Generally, flood control outflow relationships are not needed, and not assigned. For Lake Wateree, no specific volume to flood control outflow relationships were assigned. The remaining three, Fishing Creek Reservoir, Rocky Creek Lake, and Great Falls Lake, do have releases when water elevation exceeds its normal pool, which are listed in **Table 6-7**.

Table 6-5. Reservoir Area-Capacity Relationship

Reservoir	Volume (MG)	Area (Acres)
Fishing Creek Reservoir	0	0
	870	423
	3,279	1,232
	5,842	1,964
	9,678	2,774
	15,058	4,085
Great Falls Lake	0	0
	91	42
	338	123
	594	197
	998	305
	1,909	474
Rocky Creek Lake	0	0
	103	53
	393	132
	999	247
	2,040	399
	3,638	590
	6,957	879
	8,839	1,049
Lake Wateree	0	0
	3,155	1,075
	8,724	2,697
	22,713	6,076
	42,395	8,929
	79,380	11,581
	127,386	19,915
	169,443	22,989

6.2.4 Releases and Operating Rules

Reservoir release locations are assigned in the model based on best available information for dam and outflow locations. Actual modeled releases are calculated in the model based on prescribed operating rules and release targets (see SWAM User's Manual). Enhancements to SWAM reservoir rules now include three types of advanced operations: minimum releases, storage curves, and instream flow targets. All four modeled Catawba-Wateree River Basin reservoirs have these advanced rules. **Table 6-6** summarizes which of these three types of rules apply to each reservoir, the rule set priority, and the corresponding dates and conditions. While SWAM performs reservoir calculations in terms of volume, elevations are also displayed for ease of comparison to existing rules. Unless otherwise noted, these elevations are in the NGVD29 datum.

Duke Energy owns and operates all four reservoirs in Catawba-Wateree River Basin Model. Two reservoirs also serve as municipal and industrial water supply. **WS: Camden** and **WS: Lugoff-Elgin** both have intakes on Lake Wateree and **WS: Chester** and **IN: Springs Global** have intakes on Fishing Creek Reservoir. All reservoirs have minimum releases, as well as modified minimum releases dependent on LIP Stage (see **Section 6.4.1**) or recreation in the case for Great Falls Lake or Lake Wateree (see **Section 6.4.2**). All reservoirs except Lake Wateree have a consistent, year-round storage target. For Lake Wateree, the listed seasonal targets have the ramping feature enabled. The ramping feature mimics the actual operation, whereby an operator will gradually release or retain water throughout a period, with the goal of meeting the target at the end of the period. Maximum release rates for each reservoir, as provided by Duke Energy, were also included to ensure that the model would not release more water through the hydropower facilities than is operationally possible. The maximum releases are: 11,918 cfs for Fishing Creek Reservoir; 10,332 cfs for Great Falls Lake (through the Dearborn and Great Falls developments); 10,962 cfs for Rocky Creek Lake; and 15,466 cfs for Lake Wateree.

6.3 Water Users

6.3.1 Sources of Supply

Table 6-8 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, a number of minor differences exist between the calibration and baseline model with respect to water users. **IN: Whibco Blaney** and **IN: Cinergy Solutions** exist only as objects in the calibration model as they ceased withdrawals in 1997 and 2005, respectively. Two objects contain different categories of permits within their calibration demand timeseries—**WS: Invista** includes values from a former industrial intake and **IN: Springs Global** includes values from a former water supply intake. Additionally, Lancaster County Water & Sewer District (**WS: LCW&SD**) has a former intake on Bear Creek which ceased in 1993 and thus **WS: LCW&SD-Bear Creek** only exists in the calibration model. **WS: Rock Hill** only represents a now infrequently-used intake downstream of Lake Wylie with the Lake Wylie intake now providing most of the supply. **IN: International Paper** and **WS: SC Dept Corr** both use groundwater, with the latter being sourced entirely from groundwater.

Several out-of-basin and out-of-state sources are represented as Discharge objects (discussed below) and therefore do not appear in **Table 6-8**.

Table 6-6. Advanced Reservoir Rules

Reservoir	Priority	Type	Target	Months	Conditioned On:
Fishing Creek Reservoir	1	Minimum Release (cfs)	440	Jan - Dec	CW LIP Gage less than 1 cfs
			236	Jan - Dec	CW LIP Gage equals 1 cfs
			117	Jan - Dec	CW LIP Gage equals 2 cfs
			100	Jan - Dec	CW LIP Gage greater than 2 cfs
	2	Storage Curve (MG)	9678 (415.2')	Jan - Dec	
Great Falls Lake	1	Minimum Release (cfs)	550	May 16 - Feb 14	CW LIP Gage less than 1 cfs
			950	Feb 15 - May 15	CW LIP Gage less than 1 cfs
			538	May 16 - Feb 14	CW LIP Gage equals 1 cfs AND Rec Flows Gage equals 0 cfs
			698	Feb 15 - May 15	CW LIP Gage equals 1 cfs AND Rec Flows Gage equals 0 cfs
			531	May 16 - Feb 14	CW LIP Gage equals 2 cfs
			551	Feb 15 - May 15	CW LIP Gage equals 2 cfs
			530	May 16 - Feb 14	CW LIP Gage greater than 2 cfs
			530	Feb 15 - May 15	CW LIP Gage greater than 2 cfs
	2	Storage Curve (MG)	1274 (353.3')	Jan - Dec	
Rocky Creek Lake	1	Minimum Release (cfs)	445	Jan - Dec	CW LIP Gage less than 1 cfs
			262	Jan - Dec	CW LIP Gage equals 1 cfs
			155	Jan - Dec	CW LIP Gage equals 2 cfs
			140	Jan - Dec	CW LIP Gage greater than 2 cfs
	2	Storage Curve (MG)	5017 (281.9')	Jan - Dec	
Lake Wateree	1	Minimum Release (cfs)	930	Jun 1 - Feb 14	CW LIP Gage less than 1 cfs AND Rec Flows Gage less than 1 cfs
			2400	Feb 15 - Feb 28	CW LIP Gage less than 1 cfs AND Rec Flows Gage less than 1 cfs
			2700	Mar - Apr	CW LIP Gage less than 1 cfs AND Rec Flows Gage less than 1 cfs
			2400	May 1 - May 15	CW LIP Gage less than 1 cfs AND Rec Flows Gage less than 1 cfs
			1250	May 16 - May 31	CW LIP Gage less than 1 cfs AND Rec Flows Gage less than 1 cfs
			1311	Jun 1 - Feb 14	CW LIP Gage less than 1 cfs AND Rec Flows Gage equals 1 cfs
			2475	Feb 15 - Feb 28	CW LIP Gage less than 1 cfs AND Rec Flows Gage equals 1 cfs
			2713	Mar - Apr	CW LIP Gage less than 1 cfs AND Rec Flows Gage equals 1 cfs
			2475	May 1 - May 15	CW LIP Gage less than 1 cfs AND Rec Flows Gage equals 1 cfs
			1565	May 16 - May 31	CW LIP Gage less than 1 cfs AND Rec Flows Gage equals 1 cfs

Table 6-6. Advanced Reservoir Rules (continued)

Reservoir	Priority	Type	Target	Months	Conditioned On:
Lake Wateree	2	Minimum Release (cfs)	852	Jun 1 - Feb 14	CW LIP Gage equals 1 cfs AND Rec Flows Gage less than 1 cfs
			1440	Feb 15 - Feb 28	CW LIP Gage equals 1 cfs AND Rec Flows Gage less than 1 cfs
			1560	Mar - Apr	CW LIP Gage equals 1 cfs AND Rec Flows Gage less than 1 cfs
			1440	May 1 - May 15	CW LIP Gage equals 1 cfs AND Rec Flows Gage less than 1 cfs
			980	May 16 - May 31	CW LIP Gage equals 1 cfs AND Rec Flows Gage less than 1 cfs
			1005	Jun 1 - Feb 14	CW LIP Gage equals 1 cfs AND Rec Flows Gage equals 1 cfs
			1470	Feb 15 - Feb 28	CW LIP Gage equals 1 cfs AND Rec Flows Gage equals 1 cfs
			1565	Mar - Apr	CW LIP Gage equals 1 cfs AND Rec Flows Gage equals 1 cfs
			1470	May 1 - May 15	CW LIP Gage equals 1 cfs AND Rec Flows Gage equals 1 cfs
			1106	May 16 - May 31	CW LIP Gage equals 1 cfs AND Rec Flows Gage equals 1 cfs
	3	Minimum Release (cfs)	807	Jun 1 - Feb 14	CW LIP Gage equals 2 cfs
			880	Feb 15 - Feb 28	CW LIP Gage equals 2 cfs
			895	Mar - Apr	CW LIP Gage equals 2 cfs
			880	May 1 - May 15	CW LIP Gage equals 2 cfs
			823	May 16 - May 31	CW LIP Gage equals 2 cfs
			800	Jan - Dec	CW LIP Gage greater than 2 cfs
	4	Storage Curve (MG)	64898 (220.5')	Jan	
			72017 (222.5')	Feb	
			72017 (222.5')	Mar - Oct	
			64898 (220.5')	Nov	
			63169 (220')	Dec	

Table 6-7. Flood Control Outflow

Reservoir	% Volume	Outflow (cfs)
Fishing Creek Reservoir	0	0
	91.8	0
	92.7	483,991
	100	511,184
Great Falls Lake	0	0
	84.2	0
	92	483,991
	100	511,184
Rocky Creek Lake	0	0
	80.9	0
	81.3	40,161
	84.5	45,960
	88.2	55,378
	92	67,116
	95.9	80,861
	100	96,429

Table 6-8. Water User Objects and Sources of Supply Included in the Catawba-Wateree River Basin Model

Model Object ID	Facility Name	Source of Supply	Intake ID	Diversion Location (mi)	Permit Limit (MGM)	Note
WS: Chester	R.W. Hemphill WTP	Fishing Creek Reservoir/Catawba River	12WS002S01	38.8	815.3	1
GC: The Members	The Members Club At Woodcreek And Wildewood	Spears Creek	28GC006S01	0.5	7.19	1
IR: Belger	Belger Farms	Swift Creek	28IR011S01	2.6	16.744	1,4
		Big Pine Tree Creek	28IR011S02	1.5	4.446	1,4
IN: Whibco Blaney	Whibco Blaney Plant	Gillies Creek	28IN003S01	0.4	-	2
MI: Unimin	Unimin Corp	Gillies Creek	28MI002S01	0.2	58	1
			28MI002S02		68	1
WS: Camden	City of Camden	Lake Wateree/Wateree River	28WS001S01	66.4	418.5	1
WS: Lugoff-Elgin	Lugoff-Elgin Water Authority	Lake Wateree/Wateree River	28WS004S01	66.4	390.6	1
WS: Invista	Invista Sarl*	Wateree River	28WS006S01	74	281	1
IN: Springs Global	Springs-Grace Bleachery	Fishing Creek Reservoir/Catawba River	29WS003S01	38.8	-	2
	Springs Global US Inc		29IN004S01		937.4	1
WS: LCW&SD-Bear Creek	Lancaster County Water & Sewer District	Bear Creek	29WS001S01	5	-	2

Table 6-8. Water User Objects and Sources of Supply Included in the Catawba-Wateree River Basin Model (continued)

<table>
<tr><th>Model Object ID</th><th>Facility Name</th><th>Source of Supply</th><th>Intake ID</th><th>Diversion Location (mi)</th><th>Permit Limit (MGM)</th><th>Note</th></tr>
<tr><td>WS: LCW&SD</td><td></td><td>Catawba River</td><td>29WS005S01</td><td>18.7</td><td>3100</td><td>1</td></tr>
<tr><td>GC: Columbia CC</td><td>Columbia Country Club</td><td>Rice Creek</td><td>40GC001S01</td><td>0.5</td><td>49.104</td><td>1</td></tr>
<tr><td>IN: International Paper</td><td>International Paper Company Eastover Mill</td><td>Wateree River</td><td>40IN002S01</td><td>125.2</td><td>1861</td><td>1</td></tr>
<tr><td>PT: SCE&G Wateree</td><td>SCE&G-Wateree Station</td><td>Wateree River</td><td>40PT001S01</td><td>131.5</td><td>1976</td><td>1</td></tr>
<tr><td>IR: Triple J</td><td>Triple J Farms</td><td>Beech Creek</td><td>43IR011S01</td><td>3.9</td><td>56.48</td><td>1,4</td></tr>
<tr><td rowspan="11">IR: SC Dept of Corr</td><td rowspan="11">SC Dept of Corr Wateree Riv Co</td><td rowspan="6">Swift Creek</td><td>43IR054S01</td><td rowspan="6">6</td><td>7</td><td>1,4</td></tr>
<tr><td>43IR054S02</td><td>35</td><td>1,4</td></tr>
<tr><td>43IR054S05</td><td>13.705</td><td>1,4</td></tr>
<tr><td>43IR054S06</td><td>30.1</td><td>1,4</td></tr>
<tr><td>43IR054S07</td><td>14.4</td><td>1,4</td></tr>
<tr><td>43IR054S10</td><td>6.21</td><td>1,4</td></tr>
<tr><td rowspan="5">Wateree River</td><td>43IR054S03</td><td rowspan="5">104</td><td>19.148</td><td>1,4</td></tr>
<tr><td>43IR054S04</td><td>7.585</td><td>1,4</td></tr>
<tr><td>43IR054S08</td><td>7.418</td><td>1,4</td></tr>
<tr><td>43IR054S09</td><td>7.418</td><td>1,4</td></tr>
<tr><td>43IR054S11</td><td>10</td><td>1,4</td></tr>
<tr><td>IN: Nation Ford</td><td>Nation Ford Chemical Co</td><td>Catawba River</td><td>46IN002S01</td><td>5.8</td><td>133.9</td><td>1</td></tr>
<tr><td>IN: Resolute</td><td>Resolute FP US Inc</td><td>Catawba River</td><td>46IN006S01</td><td>20</td><td>2009</td><td>1</td></tr>
<tr><td>IN: Cinergy Solutions</td><td>Cinergy Solutions of Rock Hill, LLC</td><td>Catawba River</td><td>46IN004S01</td><td>3.5</td><td>-</td><td>2</td></tr>
<tr><td>WS: Rock Hill</td><td>City of Rock Hill</td><td>Catawba River</td><td>46WS003S01</td><td>3.2</td><td>1860</td><td>1</td></tr>
<tr><td>GC: Windmere</td><td>Windmere Golf Club</td><td>Rice Creek</td><td>NA</td><td>1.1</td><td>-</td><td>3</td></tr>
</table>

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 is in the framework by request, but has no permit information

Note 4 indicates registered limit for irrigation.

6.3.2 Demands

Table 6-9 presents the monthly demand for Municipal (WS), Industrial (IN), Mining (MI), and Thermoelectric (PT) Water User objects in the baseline model. Monthly irrigation demands for Golf Course (GC) and Agricultural (IR) Water User objects are presented in **Table 6-10**. The baseline model monthly demand assigned to each Water User object was calculated by averaging monthly demands (as reported to DHEC) over the ten-year period from 2004 through 2013 for most users, with one exception. **IN: Unimin** only started withdrawing water in 2010, thus values from 2010 through 2013 form its baseline values. Only one user withdraws both surface water and a significant amount of groundwater, which is **IN: International Paper**. **GC: Windmere** and **IR: Belger** were included in the framework but have no reported values from which baseline demands could be estimated.

In the calibration model, demands for the calibration period (1983 through 2010, for tributaries) 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/Interstate 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 Catawba-Wateree River Basin Model, only one water user imports water from outside the basin and exists only as a Discharge object, **York Import**, as its water is sourced from the Broad River Basin. Six discharge objects represent return flows from North Carolina along tributaries that cross the state boundary: **Franklin and Vest WTP**, **Irwin Creek WWTP**, **Sugar Creek WWTP**, **Forest Ridge WWTP**, **McAlpine Creek WWTP**, and **Twelvemile Creek WWTP**.

6.3.4 Consumptive Use and Return Flows

As discussed in Section 4.2, return flows (discharges) can be simulated two ways in SWAM. They can be associated with a Water User object (calculated return flows) or specified within a Discharge object (prescribed discharges). **Table 6-11** summarizes the calibration and baseline model objects representing return flows, their location, and the percent of return flow assigned to each location. In this table, the "*% of Return Flow*" represents the allocation to one or more discharge locations, not the consumptive use percentage. In many instances, multiple NPDES discharge locations associated with a unique Water User object were lumped together, based on their close proximity to one another (e.g., all pipes for **IN: Resolute** returns were combined). The primary intake for **WS: Rock Hill** resides in Lake Wylie and outside of the model boundaries, thus its associated discharges, **Fort Mill** and **Manchester Creek**, have been split into separate discharge objects rather than be contained within the Rock Hill user object. **Town of Lancaster** is the only stand-alone inactive discharger included only for the calibration model. The only other inactive discharger is represented as a consumptive use within the calibration-only **IN: Cinergy Solutions** object. No returns are assumed for golf course and agricultural irrigation (i.e., 100% consumptive use).

Table 6-12 presents the monthly percent consumptive use for water users with known return flows. For all municipal and industrial water users, consumptive use was calculated from DHEC-reported withdrawals and discharges over the baseline period (2004 through 2013). The one mine, **MI: Unimin**, has a general use discharge permit, which have flows that do not require reporting to DHEC. Instead, returns for this water user is defined by the estimated percent of return flow indicated in its surface water withdrawal permit.

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

6.4 Low Inflow Protocol and Recreation Flows

6.4.1 Low Inflow Protocol

To conserve storage capacity in the system of reservoirs within the Catawba-Wateree River Basin, Duke Energy proposed a low inflow protocol (LIP). The LIP was incorporated as part of the Catawba-Wateree Project's Comprehensive Relicensing Agreement (CRA) and included in the FERC Permit issued on November 25, 2015. As described in the FERC Permit, the LIP "sets forth formal procedures for operating the reservoirs in drought conditions that are based on weather and watershed inflow triggers which would advance through four stages of conservation and management, as the duration of the drought conditions increase." The goal of the LIP is to take the actions needed in the river basin to delay the point at with the Project's usable water storage inventory is fully depleted.

Advancement from "normal" conditions to LIP stage 0, 1, 2, 3, and 4 is determined by three trigger points. The trigger points are (1) the Storage Index, (2) the Drought Monitor (3-month average), and (3) monitored USGS streamflow gages. The storage index is based on the Duke's entire system of reservoirs in the basin, including those in North Carolina which are not included in the SWAM model. Because of this, and given that the SWAM model mainstem headwater flows (releases from Lake Wylie) must come from the CHEOPS model, a predetermined LIP timeseries, consistent with the modeled hydrology, is used in the SWAM model. The predetermined LIP timeseries must correspond to the CHEOPS model run which provides inflows to the SWAM model mainstem. The LIP timeseries is input as a "dummy" tributary object ("***CW LIP Stages***") with a corresponding "dummy" flow gage ("***CW LIP Gage")***. A value of "-1" is used for normal conditions, "0 for Stage 0, "1" is used for Stage 1, "2" is used for Stage 2, and so forth. There are no model-associated actions for normal conditions or Stage 0.

The LIP-specified actions associated with Stages 1 through 4 are included in the Reservoir and Water User objects. The actions that pertain to reservoirs (hydropower operations) include reductions in minimum flows and reductions in minimum reservoir elevations. According to Duke (Ed Bruce, pers. comm.), the minimum flow reductions and reservoir elevation reductions work synergistically, in that a reduction of minimum flows at a particular reservoir should not result in the reservoir's elevation dropping below the corresponding minimum elevation for that stage, except perhaps under severe drought conditions. In that instance, the LIP-specified minimum releases would take priority over the reservoir's minimum elevation. With this in mind, the Reservoir object includes advanced operating rules conditioned upon the LIP timeseries with a focus on minimum flow reductions. When the LIP moves from stage 0 to 1, 2, 3 or 4, conditional rules in each reservoir object specify the appropriate reduction in minimum flow (release) from each reservoir. For Lake Wateree and Great Falls Reservoir, a second condition associated with recreation flow requirements is also included, and is further discussed in the next section.

The minimum flow from reservoirs associated with each LIP stage are shown in **Table 6-14**. These were calculated based on the descriptions provided in the LIP, and in consultation with Duke (Ed Bruce, pers. comm.). For example, under Stage 1, Duke must "reduce the Project Flow Requirements by 60% of the difference between the normal project Flow Requirements and the Critical Flows."

The LIP-specified actions that pertain to Water User objects include reductions in water usage. These apply to public water supply intakes (WS objects) and irrigation intakes (IR users with a capacity greater than 100,000 gpd). For example, under Stage 1, the goal is to "reduce water usage by 3-5% (or more) from the amount that otherwise would be expected". This reduction is incorporated in SWAM using the Conservation feature, and setting Advanced Conservation Rules. A percent reduction associated with the appropriate LIP stage is included, and is conditioned upon the ***CW LIP Gage***, which reads the LIP timeseries contained in the LIP tributary object.

6.4.2 Recreational Flows

Recreation flow requirements exist for Lake Wateree and Great Falls/Dearborn; however, Duke does not currently have the infrastructure in place to meet recreational flow requirements at Great Falls/Dearborn. They do expect to have it within 5 years. The recreational flow requirements for both lakes are included in Table 6-14, and minimum releases in SWAM are conditioned appropriately on both the required recreational flows and LIP stage. Recreational flows are only required for 5 hours on certain days. Since SWAM's minimum timestep is 1 day, the recreational flow requirements in Table 6-14 represent a weighted 24-hour average flow requirement. The weighted averages are calculated using a combination of the recreational flow requirements (5 out of 24 hours) and the non-rec minimum flow requirements corresponding to the given LIP stage (19 out of 24 hours).

Similar to the LIP timeseries, a recreational flow time series is input as a "dummy" tributary object ("***Rec Flow Days***") with corresponding "dummy" flow gage ("***Rec Flow Days Gage"***). A value of "0" is used for non-rec flow days and a value of "1" is used for recreational flow days. Since the schedule for recreational flow days is established by Duke on an annual basis, a generic schedule must be used for most years of the simulation. This baseline timeseries can be adjusted by the user, as needed in the future, to match appropriate weekdays and holidays when recreational flows are typically required.

6.5 Summary

This section has presented the form and numerical values of data that are input into the Catawba-Wateree 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 Catawba-Wateree River Basin model, these calibration inputs only included reach hydrologic gain/loss factors and, to a very limited extent, reservoir operating rule targets.

Table 6-9. Baseline Model Average Monthly Demand for IN, MI, PT, and WS Water Users

Baseline Model Average Monthly Demand (MGD)							
Month	**WS: Rock Hill**	**MI: Unimin**	**IN: International Paper**	**PT: SCE&G Wateree**	**IN: Nation Ford**	**IN: Resolute**	**WS: Camden**
Permit Limit (MGD)	**61.2**	**4.1**	**61.2**	**65.0**	**4.4**	**66.1**	**13.8**
Jan	0.0	0.5	29.9	23.8	2.0	29.5	2.1
Feb	0.0	0.8	30.2	23.6	2.0	29.7	2.1
Mar	0.0	1.1	28.8	22.4	2.0	28.9	2.2
Apr	0.0	0.9	29.7	23.3	2.0	29.8	2.3
May	0.0	1.1	29.2	23.3	2.0	29.5	2.5
Jun	0.0	1.3	31.9	25.6	2.0	30.2	2.6
Jul	0.0	0.7	32.2	25.8	2.0	30.2	2.7
Aug	0.0	0.8	32.3	25.7	1.9	29.8	2.6
Sep	0.0	1.1	30.9	25.0	1.8	29.6	2.6
Oct	0.0	0.7	29.0	23.0	2.0	29.0	2.3
Nov	0.0	0.7	30.3	23.9	2.1	28.3	2.2
Dec	0.0	0.7	30.2	24.0	2.2	28.4	2.1
Month	**IN: Springs Global**	**WS: Lugoff-Elgin**	**WS: LCW&SD**	**WS: Chester**	**WS: Invista**	**WS: SC Dept Corr**	
Permit Limit (MGD)	**30.8**	**12.8**	**102.0**	**26.8**	**9.2**	**-**	
Jan	4.1	1.9	13.8	2.7	2.1	0.3	
Feb	3.7	1.9	13.6	2.9	2.2	0.3	
Mar	3.7	1.9	13.8	2.8	2.1	0.2	
Apr	3.4	2.2	15.9	2.9	2.2	0.3	
May	3.7	2.5	18.5	3.0	2.3	0.3	
Jun	4.1	2.7	19.4	3.1	2.4	0.3	
Jul	4.1	2.5	19.5	3.2	2.4	0.3	
Aug	4.2	2.5	18.5	3.2	2.5	0.3	
Sep	3.5	2.5	18.4	3.2	2.3	0.3	
Oct	3.2	2.1	17.5	2.9	2.0	0.3	
Nov	3.3	1.9	15.4	2.8	2.0	0.3	
Dec	3.2	1.9	14.0	2.7	1.9	0.3	

Permit limits shown in MGD rather than MGM for comparative purposes. Actual permit limits are in MGM.
WS: SC Dept Corr is sourced entirely from groundwater.

Table 6-10. Baseline Model Average Monthly Demand for GC and IR Water Users

Baseline Model Average Monthly Demand (MGD)									
Month	GC: The Members	GC: Columbia CC	GC: Tega Cay	GC: River Hills CC	GC: Windmere	IR: Belger	IR: Triple J	IR: SC Dept of Corr	IR: Peach Tree
Jan	0.01	0.02	0.02	0.00	-	-	0.00	0.01	0.00
Feb	0.01	0.02	0.03	0.01	-	-	0.00	0.01	0.00
Mar	0.02	0.07	0.08	0.02	-	-	0.00	0.37	0.00
Apr	0.13	0.15	0.10	0.07	-	-	0.00	1.05	0.00
May	0.18	0.24	0.16	0.17	-	-	0.06	1.06	0.01
Jun	0.23	0.21	0.18	0.17	-	-	0.16	1.18	0.02
Jul	0.24	0.25	0.19	0.23	-	-	0.16	1.12	0.02
Aug	0.20	0.21	0.14	0.19	-	-	0.18	0.88	0.02
Sep	0.16	0.24	0.14	0.15	-	-	0.04	0.19	0.01
Oct	0.09	0.10	0.09	0.06	-	-	0.00	0.06	0.01
Nov	0.05	0.05	0.06	0.03	-	-	0.00	0.01	0.00
Dec	0.03	0.02	0.03	0.01	-	-	0.00	0.01	0.00

Table 6-11. Returns and Associated Model Objects

Model Object ID	Facility Name	NPDES Pipe ID	Associated Water Permit	Discharge Tributary	Model River Mile	% of Return Flow
Returns Represented Within Water User Objects						
IN: International Paper	International Paper/Eastover	SC0038121-001	40IN002	Wateree River	128.2	100
IN: Nation Ford	Nation Ford Chemical Company	SC0035360-01A	46IN002	Catawba River	5.9	100
IN: Resolute	Bowater Inc/Coated Paper Div	SC0001015	46IN006	Catawba River	20.2	100
IN: Springs Global	Springs Global/Grace Complex	SC0003255	29IN004	Catawba River	30.6	100
WS: Invista	Invista S.A.R.L./Camden	SC0002585-001	28WS006	Wateree River	74.2	100
MI: Unimin	Unimin Corporation-Lugoff Facility	SCG730382	28MI002	Gillies Creek	0.3	100
PT: SCE&G Wateree	SCE&G/Wateree Station	SC0002038-03A	40PT001	Wateree River	132.4	100
WS: Camden	Camden WWTF	SC0021032-001	28WS001	Wateree River	75.2	81
	Camden Water Treatment Plant	SCG646025		Grannies Quarter Creek	9.6	19
WS: Chester	Chester/Lando-Manetta Plant	SC0001741-001	12WS002	Fishing Creek	24.7	7.3
	Great Falls WWTF	SC0021211-001		Rocky Creek	25.1	13.5
	Chester/Rocky Creek Plant	SC0036056-001		Rocky Creek	0.2	27.3
	Robert W. Hemphill Filtration Plant	SCG646007		Catawba River	30.3	2.1
	Chester/Sandy River WWTF	SC0036081-001		**Out of basin (Broad)**	**999**	49.8
WS: LCW&SD	CWS/Lamplighter Village SD	SC0030112-001	29WS005	McAlpine Creek	14.2	1.9
	Lancaster/Catawba River	SC0046892-001		Cane Creek	22.0	20.9
	Catawba River WTP	SCG646000		Catawba River	19.0	6.9
	Lancaster Co/Indianland WWTP	SC0047864-001		Catawba River	11.6	2.7
	Kershaw/Hanging Rock Creek	SC0025798-001		**Out of basin (Pee Dee)**	**1000**	67.6
WS: Lugoff-Elgin	Lugoff-Elgin Water Authority Water Plant	SCG646020	28WS004	Wateree River	66.7	25.6
	Kershaw Co/Lugoff WWTF	SC0039870-001		Wateree River	73.3	74.4
IN: Cinergy Solutions*	Greens of Rock Hill	SC0001783	46IN004S01	Catawba River	4.3	100
WS: SC Dept Corr	SC Dept Corr/Wateree River	SC0045349-001	43WS011G	Wateree River	99.1	100
Transbasin/Interstate Imports Represented by Discharge Objects						
York Import	York/Fishing Creek WWTF	SC0038156-001	46WS002	Fishing Creek	2.4	-
Franklin and Vest WTP	Franklin and Vest WTP	NC0084549	*none*	Sugar Creek	0.4	-
Irwin Creek WWTP	Irwin Creek WWTP	NC0024945	*none*	Sugar Creek	3.7	-
Sugar Creek WWTP	Sugar Creek WWTP	NC0024937	*none*	Sugar Creek	17.6	-
Forest Ridge WWTP	Forest Ridge WWTP	NC0029181	*none*	McAlpine Creek	0.3	-
McAlpine Creek	McAlpine Creek	NC0024970	*none*	McAlpine Creek	11.9	-
Twelvemile Creek WWTP	Twelvemile Creek WWTP	NC0085359	*none*	Twelvemile Creek	0.5	-
In-basin Returns Represented by Individual or Aggregated Discharge Objects						
Fort Mill WWTF	Fort Mill WWTF	SC0020371-001	46WS003	Catawba River	4.1	-
Manchester Creek WWTP	Rock Hill/Manchester Creek	SC0020443-001	46WS003	Manchester Creek	4.2	-
IN: Clariant	Clariant LSM (America) Inc	SC0002682-001	28IN008G	Spears Creek	75.4	-
IN: New South Lumber	New South Lumber Co/Camden Plant	SC0047384-001	28IN010G	Sanders Creek	25.4	-
Deroyal	Deroyal Textiles	SC0002518-001	*none*	Big Pine Tree Creek	5.9	-
USAF/Shaw AFB	USAF/Shaw Air Force Base	SC0024970-002	*none*	Beech Creek	4.2	-
Kennecott Mine	Kennecott/Ridgeway Gold Mine	SC0041378-003	*none*	Twentyfive Mile Creek	9.1	-
Town of Lancaster	Lancaster, Town of*	SC0022080-001	*none*	Bear Creek	9.9	-

Note: Returns outside of the Catawba-Wateree River Basin are indicated in ***bold****.*

** Only represented in the calibration model*

Table 6-12. Baseline Model Monthly Consumptive Use Percentage

Baseline Model Average Monthly Consumptive Use (%)							
Month	**WS: Rock Hill**	**MI: Unimin**	**IN: International Paper**	**PT: SCE&G Wateree**	**IN: Nation Ford**	**IN: Resolute**	**WS: Camden**
Jan	-	20.0	5.0	73.6	10.0	7.7	18.2
Feb	-	20.0	3.1	75.2	10.9	8.1	10.9
Mar	-	20.0	5.2	76.1	12.5	8.9	12.3
Apr	-	20.0	8.8	77.4	10.7	12.4	21.5
May	-	20.0	6.2	75.7	10.9	24.9	33.9
Jun	-	20.0	7.2	73.8	10.4	29.1	38.9
Jul	-	20.0	6.5	73.0	11.1	28.2	39.9
Aug	-	20.0	3.8	73.6	10.8	23.5	34.7
Sep	-	20.0	3.2	75.3	11.1	28.1	40.0
Oct	-	20.0	8.1	77.8	10.4	30.1	38.1
Nov	-	20.0	5.3	81.9	11.7	27.2	30.9
Dec	-	20.0	4.7	74.8	7.3	16.8	21.7
Month	**IN: Springs Global**	**WS: Lugoff-Elgin**	**WS: LCW&SD**	**WS: Chester**	**WS: Invista**	**WS: SC Dept Corr**	
Jan	1.0	74.2	67.3	40.4	85.5	30.5	
Feb	1.0	68.5	64.9	31.3	79.3	34.3	
Mar	1.0	69.3	66.3	29.3	89.8	29.5	
Apr	1.0	75.0	71.8	39.1	83.2	32.1	
May	1.0	76.5	77.0	46.4	84.1	34.1	
Jun	1.0	79.4	76.9	46.4	80.4	33.2	
Jul	1.0	74.6	77.7	52.1	77.9	35.4	
Aug	1.0	75.0	74.9	46.9	79.7	35.9	
Sep	1.0	77.1	75.8	50.9	76.4	33.1	
Oct	1.0	75.7	76.7	50.4	73.5	33.5	
Nov	1.0	73.7	73.0	46.6	70.8	36.6	
Dec	1.0	70.7	68.4	31.1	75.2	35.4	

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

Monthly Return Flow (MGD)							
Month	Franklin and Vest WTP	Irwin Creek WWTP	Sugar Creek WWTP	Forest Ridge WWTP	McAlpine Creek WWTP	Twelvemile Creek WWTP	Manchester Creek WWTP
Jan	2.1	9.3	13.0	0.1	48.7	3.0	9.8
Feb	2.2	9.6	12.1	0.1	51.1	3.1	10.1
Mar	1.8	9.6	12.6	0.1	51.9	3.1	10.5
Apr	1.9	9.3	12.8	0.1	47.5	2.8	9.4
May	2.1	8.7	12.4	0.1	45.7	2.6	8.7
Jun	2.3	9.1	12.8	0.1	47.0	2.7	8.9
Jul	2.4	8.7	12.8	0.1	44.6	2.5	8.6
Aug	2.5	9.1	13.1	0.1	45.2	2.6	8.8
Sep	2.5	9.0	12.6	0.1	45.3	2.6	8.6
Oct	2.4	8.4	12.3	0.1	44.4	2.6	8.5
Nov	2.3	8.7	13.0	0.1	46.0	2.8	9.1
Dec	2.3	8.9	12.9	0.1	48.0	3.1	9.7
Month	Fort Mill WWTF	Clariant	New South Lumber	Deroyal	USAF/ Shaw AFB	Kennecott Mine	York Import
Jan	0.9	0.3	1.2	0.1	0.8	1.2	1.2
Feb	1.0	0.3	1.1	0.1	0.9	0.4	1.2
Mar	1.0	0.2	1.2	0.1	0.7	0.7	1.3
Apr	0.9	0.2	0.9	0.1	0.7	1.1	1.2
May	0.9	0.2	0.9	0.1	0.6	1.7	1.0
Jun	0.9	0.2	1.0	0.1	0.6	0.7	1.1
Jul	0.8	0.2	1.0	0.1	0.6	0.5	1.0
Aug	0.9	0.2	1.0	0.1	0.7	0.9	1.0
Sep	0.9	0.2	1.1	0.1	0.8	1.3	1.2
Oct	0.9	0.3	1.3	0.1	0.8	0.9	1.0
Nov	0.9	0.2	1.3	0.1	0.7	0.5	1.1
Dec	0.9	0.3	1.2	0.1	0.8	0.8	1.2

Table 6-14. Minimum Flows Under LIP Stages 1 through 4

Fishing Creek & Rocky Creek/Cedar Creek

Development	Normal Minimum Flow (cfs)	Critical Flows (cfs)	Minimum Flow for each LIP Stage (cfs): Stage 1 (60%)	Stage 2 (95%)	Stage 3 (100%)	Stage 4 (100%)
Fishing Creek	440	100	236	117	100	100
Rocky Creek - Cedar Creek	445	140	262	155	140	140

Great Falls/Dearborn

Date	Recreational Flow (cfs)	Weighted Required flow on Rec Flow Day (cfs)	Bypass Flow (cfs)	Critical Flows (cfs)	Minimum Flow for each LIP Stage (cfs): Stage 1 (60%)	Stage 2 (95%)	Stage 3 (100%)	Stage 4 (100%)
May 16 to Feb 14 and on Non-Rec Flow Days	*NA*	*NA*	550	530	**538**	**531**	**530**	**530**
Feb 15 to May 15 and on Non-Rec Flow Days	*NA*	*NA*	950	530	**698**	**551**	**530**	**530**
May 16 to Feb 14 and on Rec Flow Days	5,800	1,644	550	530	**976**	**531**	**530**	**530**
Feb 15 to May 15 and on Rec Flow Days	5,800	1,960	950	530	**1,102**	**551**	**530**	**530**

No Rec Flows required for Stages 2, 3 or 4

Wateree

Rec vs. Non-Rec Flow Day	Date	Recreational Flow (cfs)	Weighted Required flow on Rec Flow Day (cfs)	Min. Instaneous Flow*	Critical Flows (cfs)	Minimum Flow for each LIP Stage (cfs): Stage 1 (60%)	Stage 2 (95%)	Stage 3 (100%)	Stage 4 (100%)
Non-Rec Flow Days	1-Jan	*NA*	*NA*	930	800	**852**	**807**	**800**	**800**
	1-Feb	*NA*	*NA*	930	800	**852**	**807**	**800**	**800**
	15-Feb	*NA*	*NA*	2400	800	**1,440**	**880**	**800**	**800**
	1-Mar	*NA*	*NA*	2700	800	**1,560**	**895**	**800**	**800**
	1-Apr	*NA*	*NA*	2700	800	**1,560**	**895**	**800**	**800**
	1-May	*NA*	*NA*	2400	800	**1,440**	**880**	**800**	**800**
	16-May	*NA*	*NA*	1250	800	**980**	**823**	**800**	**800**
	1-Jun	*NA*	*NA*	930	800	**852**	**807**	**800**	**800**
	1-Jul	*NA*	*NA*	930	800	**852**	**807**	**800**	**800**
	1-Aug	*NA*	*NA*	930	800	**852**	**807**	**800**	**800**
	1-Sep	*NA*	*NA*	930	800	**852**	**807**	**800**	**800**
	1-Oct	*NA*	*NA*	930	800	**852**	**807**	**800**	**800**
	1-Nov	*NA*	*NA*	930	800	**852**	**807**	**800**	**800**
	1-Dec	*NA*	*NA*	930	800	**852**	**807**	**800**	**800**
Rec Flow Days	1-Jan	2,760	1,311	930	800	**1,005**	**807**	**800**	**800**
	1-Feb	2,760	1,311	930	800	**1,005**	**807**	**800**	**800**
	15-Feb	2,760	2,475	2400	800	**1,470**	**880**	**800**	**800**
	1-Mar	2,760	2,713	2700	800	**1,565**	**895**	**800**	**800**
	1-Apr	2,760	2,713	2700	800	**1,565**	**895**	**800**	**800**
	1-May	2,760	2,475	2400	800	**1,470**	**880**	**800**	**800**
	16-May	2,760	1,565	1250	800	**1,106**	**823**	**800**	**800**
	1-Jun	2,760	1,311	930	800	**1,005**	**807**	**800**	**800**
	1-Jul	2,760	1,311	930	800	**1,005**	**807**	**800**	**800**
	1-Aug	2,760	1,311	930	800	**1,005**	**807**	**800**	**800**
	1-Sep	2,760	1,311	930	800	**1,005**	**807**	**800**	**800**
	1-Oct	2,760	1,311	930	800	**1,005**	**807**	**800**	**800**
	1-Nov	2,760	1,311	930	800	**1,005**	**807**	**800**	**800**
	1-Dec	2,760	1,311	930	800	**1,005**	**807**	**800**	**800**

* Minimum insantaneuous flow treated as a daily minimum flow in SWAM

No Rec Flows required for Stages 2, 3 or 4

Section 7

Model Calibration/Verification

7.1 Philosophy and Objectives

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

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

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

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

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

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

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

7.2 Methods

Model calibration in the Catawba-Wateree River Basin was performed using two different periods of historical hydrology. For the tributaries to the Catawba and Wateree rivers, the modeled flows were compared against measured flows over the period 1983 through 2010. This 27-year record provides a good range of hydrologic and climate variability in the basin to adequately test the modeled tributaries, including extended high and low flow periods. For the Catawba and Wateree rivers (the mainstem), modeled flows and reservoir storage/elevations were compared to measured flows and reservoir storage/elevations over the period from June 2006 through December 2010, which reflects the initial period of hydroelectric operations after the implementation of the Comprehensive Relicensing Agreement (CRA). The operating rules included in SWAM for the calibration period reflect the CRA operations, with a few exceptions. For example, bypass flows and some recreational flows were not implemented by Duke, or were only implemented during portions of the period of analysis. Recreational flows are only required for 5 hours on certain days; since SWAM's minimum timestep is 1 day, the increased minimum release is instead represented by a weighted 24-hour average flow. The triggers for recreational releases were set to every occurrence of the last full weekend of April, every weekend in May through October, and every Memorial Day, 4th of July and Labor Day. This is simply a generic schedule as Duke establishes their own schedule on an annual basis.

Minimum flow releases and consumptive withdrawal reductions that are triggered actions of the LIP were also included in the calibration model. In the first draft of the calibration with LIP, it was noted that the LIP-specified minimum reservoir elevations and minimum flows were already being met for Fishing Creek, Great Falls, and Rocky Creek, when the LIP was in effect. For Lake Wateree, the modeled minimum release marginally dropped below the LIP-specified minimum flow for only a few days during the simulation. With the inclusion of the LIP, calibration results have improved (further discussion in **Section 7.3**), but it is evident from both modeling results and correspondence with Duke that these rules were not always strictly followed.

7.2.1 Calibration Steps

Guided by the principles described in Section 7.1, the following specific steps were followed (in order) as part of the calibration/verification process:

1. Tributary headwater flows were extended to the tributary confluence points using drainage area ratios to calculate tributary object subbasin flow factors (see Section 6).

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

3. Intermediary subbasin flow factors were adjusted for tributary objects to achieve adequate modeled vs. measured comparisons at selected tributary gage targets, based on monthly timestep modeling.

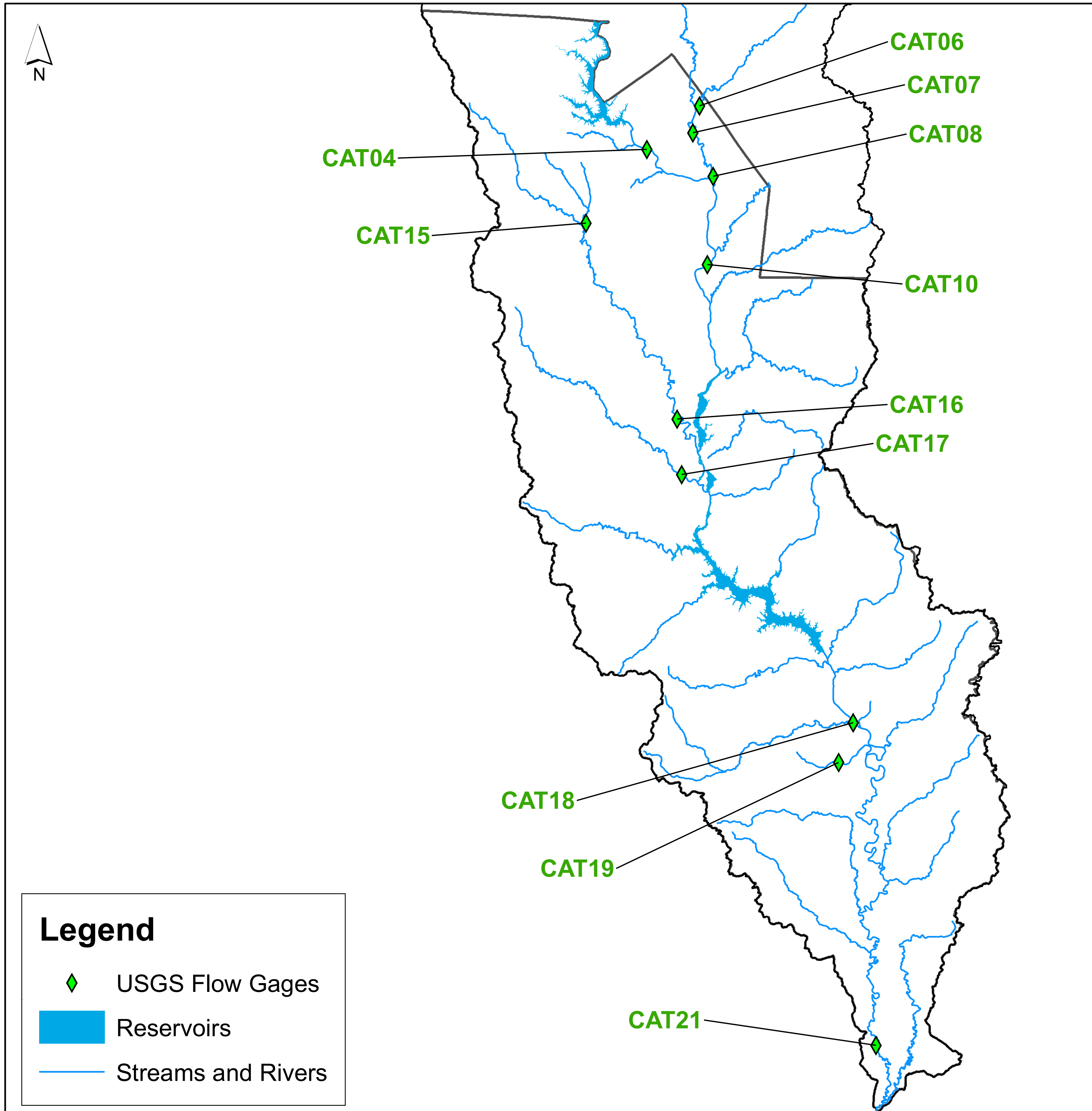
4. Mainstem reach gain/loss factors (per unit length) were adjusted to better achieve calibration at mainstem gage locations, based on monthly timestep modeling. This factor can be varied in multiple locations along the main stem.

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

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

7. Lastly, all water users in the model were checked to ensure that historical demands were being fully met in the model or, alternatively, if demands were not being met during certain periods, that there was a sensible explanation for the modeled shortfalls.

All USGS flow gages at downstream locations in the basin with reasonable records within the targeted calibration period were used to assess model performance and guide the model calibration steps described above. The gages used for calibration are shown in **Figure 7-1**. Note that in order to minimize the uncertainty in the calibration targets, only gaged (i.e. measured) flow records were used to assess model performance as part of this exercise. No ungaged flow estimates or record filling techniques were used to supplement this data set (although many of the input flows were developed through various record extensions techniques). Note also that all upstream basin water use and



Project Gage ID	USGS Number	Tributary Object	Periods of Record	Basin Area (sq. mi.)	River Mile
CAT04	02146000	Mainstem	4/1942 - 8/1995 10/1995 - 12/2010	3048	4
CAT06	0214676115	McAlpine Creek	10/2005 - 12/2010	95	15
CAT07	02146800	Sugar Creek	4/2006 - 12/2010	263	24
CAT08	02146820	Sugar Creek	5/2001 - 9/2002	275	30
CAT10	02147020	Mainstem	1/1992 - 9/1994 10/1995 - 12/2010	3538	20
CAT15	021473428	Wildcat Creek	8/1998 - 6/2001 1/2006 - 12/2010	30	4
CAT16	02147403	Fishing Creek	2/2001 - 10/2003	280	40
CAT17	02147500	Rocky Creek	3/1951 - 9/1981 8/1986 - 12/2010	196	24
CAT18	02148000	Mainstem	10/1929 - 9/1983 5/1984 - 12/2010	5057	738
CAT19	02148071	Gillies Creek	4/1994 - 9/1997	8	3
CAT21	02148315	Mainstem	7/1968 - 2/1983 5/1983 - 12/2010	5554	131

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Figure 7-1. USGS Streamflow Gages Used in Calibration operations are implicitly represented in these gaged data, thereby providing an ideal target to which the combination of estimated UIFs and historic water uses could be compared.

7.2.2 Reservoir Levels and Storage

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

- The model uses a static set of reservoir operating rules throughout the calibration period. In reality, reservoir level and storage fluctuations outside of predefined ranges often occur due to operator decisions that are not consistent with normal operating rules.

- The model also uses a static set of (current) reservoir characteristics throughout the calibration period (e.g., dam height). Modifications to dams, hydropower plants, bypass reaches, and spillways during the calibration period are not accounted for.

7.2.3 Calibration Parameters and Performance Metrics

As indicated above, options for model calibration parameters (i.e. those that are adjusted to achieve better modeled vs. measured matches) are limited to a small group of inputs with relatively high associated uncertainty. In general, these might include any of the following: mainstem hydrologic gain/loss factors, tributary subbasin flow factors, reservoir operational rules, assumed consumptive use percentages, and return flow locations and/or lag times associated with outdoor use. However, the primary calibration parameters in SWAM are the reach gain/loss factors. Adjustments to other parameters are secondary and often not required. For the Catawba-Wateree Basin model calibration, only reach gain/loss and subbasin flow factors, and to a limited extent advanced rules for some reservoirs, were adjusted as part of the calibration process. The final model reach gains/losses are presented in **Section 6**, **Table 6-3**.

A number of performance metrics were used to assess the model's ability to reproduce past basin hydrology and operations. These include: monthly and daily water user supply delivery and/or shortfalls, monthly and daily timeseries plots of both river flow and reservoir levels, annual and monthly mean flow values, monthly and daily percentile plots of river flow values, annual 7-day low flows with a 10-year recurrence interval (7Q10), and mean flow values averaged over the entire period of record.

The reliability of past water supply to meet specific water user demands is an important consideration in the calibration process to ensure that water user demands and supply portfolios are properly represented in the model, as well as providing checks on supply availability at specific points of withdrawal. Timeseries plots, both monthly and daily, are used to assess the model's ability to simulate observed temporal variation and patterns in flow and storage data and to capture an appropriate range of high and low flow values. Percentile plots are useful for assessing the model's ability to reproduce the range of flows, including extreme events, observed in the past (and are particularly important when considering that the value of a long-term planning model like this is its ability to predict the frequency at which future flow thresholds might be exceeded, or the frequency that various amounts of water will be available). Monthly statistics provide valuable information on the model's ability to generally reproduce seasonal patterns, while annual totals and period of record mean flows help confirm the overall water balance represented in the model. Lastly, regulatory low flows (7Q10) are of specific interest as the model could be used to predict such low flows as a function of future impairment. However, the limitations of the daily model and supporting data should be properly considered in assessing model performance on this particular metric. Note that for the purposes of this exercise a simplified 7Q10 calculation was employed. Our approach used the Excel percentile function to estimate the 10-year recurrence interval (10^{th} 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). Record quality of specific streamflow gages are discussed below.[1] Seasonal and annual patterns in both flow and reservoir storage data are reproduced well by the model. Monthly fluctuations (timeseries) and extreme conditions (percentiles) are also well reproduced by the model for most sites. Modeled vs. measured cumulative flow over the entire calibration period was compared at select sites to confirm that there was not an overall bias toward too high or too low of flows. Using the monthly timestep, the comparisons indicate that, where there is at least ten 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 spatial and temporal availability of gage records is more limited compared to other basins (such as the Broad River Basin) however. Of the eleven gages used in calibration, only the four mainstem gages and one gage on Rocky Creek had more than 10 years of data.

Three areas of special consideration are described below.

- Sugar Creek and McAlpine Creek along the state border with North Carolina hold multiple sources of uncertainty. The North Carolina sections of these rivers contain five discharge

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

facilities, with McAlpine Creek WWTP (treated water from the Charlotte-Mecklenburg area) by itself supplying significantly high flows (~47 MGD on average). The flows and locations for these plants were extracted from the existing CHEOPS model (HDR, 2014), but were only available in monthly timesteps. This added uncertainty as these streams can exhibit considerably low flows. Additionally, the three South Carolina gages on these streams (CAT06, CAT07, CAT08) all only have a few years of record and gage quality reports range from poor to fair at best for daily discharges. CAT06 could only be calibrated to a partial record as it is affected by variable backwater conditions at high flows.

- As discussed in Section 6, the original calibration model used CHEOPs managed flows out of Lake Wylie for mainstem flows. Subsequently, HDR Inc. provided Lake Wylie releases back-calculated from operations records, which when used, improved the calibration with respect to the nearby downstream gage CAT04. The CHEOPS model may have been enforcing required releases that did not historically occur, thus providing more water on the mainstem than observed. The final version of the calibration model now uses area-prorated unimpaired flows originally developed for the CHEOPS model at Lake Wylie. This removes the potential of altered release patterns from Lake Wylie impacting mainstem gains and losses.

- The second gage downstream of Lake Wateree, CAT21, was calibrated to only parts of its record. This site has an intervening channel reach and when bankfull capacity is exceeded during high flows daily mean discharges are not recorded. The reports state a threshold of 10,000 cfs, but when comparing flows to those upstream at CAT18, it appears this threshold is more approximate than precise.

Table 7-1 contains modeled and measured averages over the full period of record, along with the available number of years for comparison. For seven of the eleven gages, modeled mean flow values were within 2% of measured mean flows, and the remaining three were within 6.5% of measured mean flows. This indicates that the overall water balance is well represented and there are no obvious missing or excess sources of flow in the model. Monthly flow percentiles are also well captured by the model across nearly all sites. Monthly flow percentile deviations are all generally within 5 - 15% with no clear bias one way or the other.

Table 7-1. Annual Flow Statistics

Project ID	Station	Modeled Average	Measured Average	% Diff Average	Years of Record
CAT04*	CATAWBA RIVER NEAR ROCK HILL, SC	2,726.0	2,749.4	-0.9%	28
CAT10*	CATAWBA RIVER BELOW CATAWBA, SC	3,258.8	3,352.8	-2.8%	19
CAT18*	WATEREE RIVER NR. CAMDEN, SC	4,010.4	3,955.7	1.4%	28
CAT21*	WATEREE R. BL EASTOVER, SC	2,819.0	2,829.1	-0.4%	28
CAT06	MCALPINE CREEK AT SR2964 NR CAMP COX, SC	111.1	111.5	-0.4%	6
CAT07	SUGAR CREEK NEAR FORT MILL, SC	359.0	384.2	-6.5%	5
CAT08	SUGAR CR. NR FT. MILL, S.C.	241.1	229.9	4.9%	2
CAT15	WILDCAT CREEK BELOW ROCK HILL, SC	18.9	19.1	-1.1%	9
CAT16	FISHING CREEK BELOW FORT LAWN, SC	240.2	248.0	-3.1%	3
CAT17	ROCKY CREEK AT GREAT FALLS, SC	146.7	149.0	-1.5%	25
CAT19	GILLIES CREEK NEAR LUGOFF, SC	12.7	12.5	1.3%	4

* Mainstem Gage

Monthly reservoir storage and level comparisons, while clearly simplified due to the static assumptions (rules) incorporated into the model, were aimed at achieving the specified targets, and not necessarily reproducing exact dynamic responses to historic withdrawal rates. Given these static rules, the three reservoirs with year-round storage targets (Fishing Creek, Rocky Creek, and Great Falls) simply stayed at the same volume for the entire calibration, with some small variations in the daily simulation. These reservoirs had minimum releases and user withdrawals, but were not severe enough to impact the lesser-priority storage/elevation targets.

Some of the differences in observed and simulated reservoir levels are attributed to anomalies in reservoir operations associated with reservoir maintenance, or other non-routine activities. Other differences are attributed to the fact that the simulated reservoirs were governed by rules and targets that, while often achievable in the model, may have been subject to other operational decisions or constraints that are not represented.

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

In terms of daily timestep simulations, daily flow fluctuations are generally well captured by the model. Modeled daily percentile plots exhibit excellent agreement with measured data for most mainstem and tributary locations. CAT21 shows some deviations in the high flows, but this is the gage where flows above 10,000 cfs are not recorded. The few discrepancies are likely primarily attributable to the lack of reach routing and overall simplified representation of hydrologic processes in the model, common to all water allocation models. However, these discrepancies are generally within 20% of gaged flows and deemed acceptable for the daily model.

Modeled regulatory low flow values (7Q10) are within 1.5% to 11.1% of measured values at the four mainstem (Catawba-Wateree River) gages. There is no pattern to over- or under-predicting for each gage. For the tributaries, only CAT17 on Rocky Creek has more than 10 years of data to support comparison of the measured vs. modeled 7Q10 flows. The measured (and calculated) 7Q10 flow of 0.03 cfs compares favorably to the modeled 7Q10 flow of 1.1 cfs, given the extremely low flows at this location.

A table comparing model and measured 7Q10 flows is provided at the end of Appendix B. It is important to realize that low flows in the model are highly sensitive to modeled basin water use and operations. Small errors in estimated (or reported) withdrawals or modeled reservoir releases can have a significant impact on modeled annual low flows. Consequently, model uncertainty associated with this metric is relatively high and additional model adjustments to improve this calibration fit are generally not justified.

Additionally, the model adequately hindcasts delivered water supply for each of the water users in the model. Simulated supply roughly equals simulated demand for all users, with no significant shortfalls. One exception is a simulated shortage in April 1986, February 2001, and May 2002 for both **WS: Camden** and **WS: Lugoff-Elgin**, when Lake Wateree elevations were simulated to drop below the critical intake elevation. None of these instances occur during the focused calibration period of 2006-2010 for the mainstem and likely can be attributed to current operations and LIP rules being applied well-before they were in effect.

Though the mainstem calibration is only based on 2006-2010, the drought years of 2007 and 2008 merit further review to assess model behavior during low inflow periods. Of the four reservoirs, Lake Wateree has the most complex operations, sensitivity to inflows, and user dependence. **Figure 7.2** demonstrates how the model follows the seasonal rule curve set by the CRA in 2006 and how the daily storage historically has varied. Before the drought, Lake Wateree was operated generally near the rule curve, but with a fair amount of variability. Starting in the summer of 2007, operators deviated from the rules and lowered the lake about two months ahead of schedule. Then, in late 2007, they raised it to its spring target about two months early.

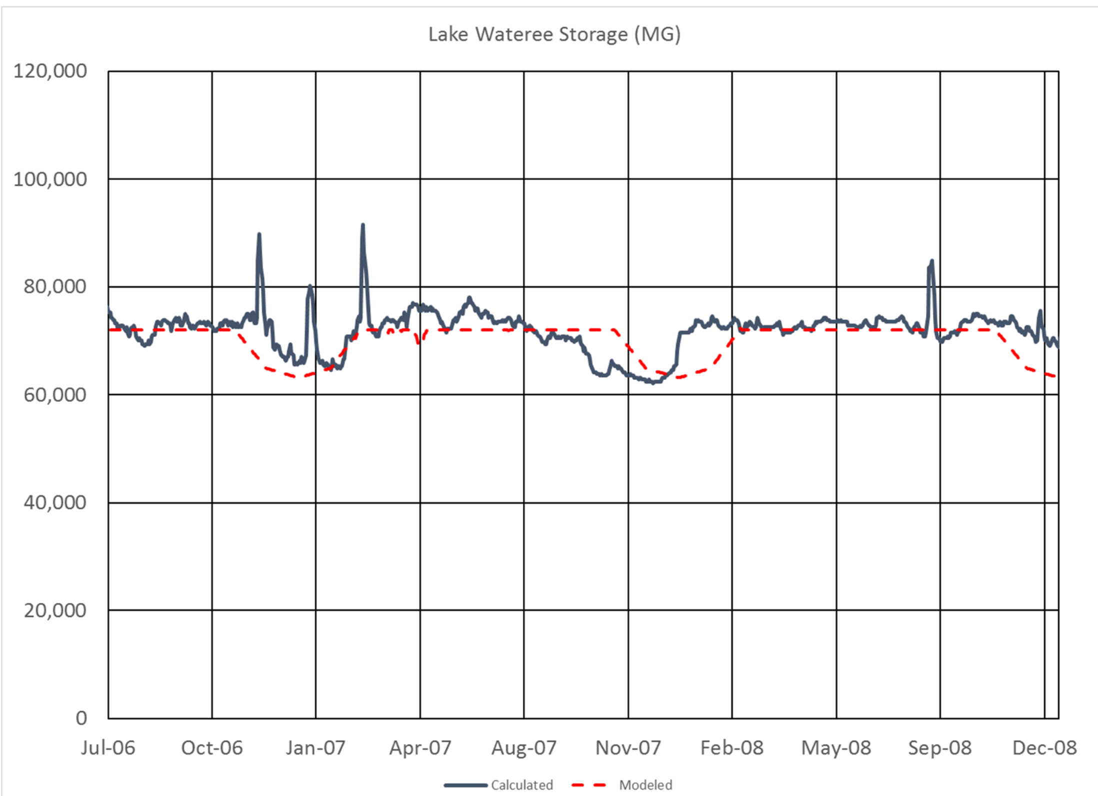

Figure 7.2: Lake Wateree During Drought Years

Unlike in other basins with large reservoirs that have complex operating rules (e.g., the Broad and Saluda river basins), the availability of gages upstream and downstream of Lake Wateree is limited. The nearest upstream mainstem gage to Lake Wateree is CAT10, upstream of Fishing Creek Reservoir. Though calibration results are excellent for CAT10, mainstem flows pass through all of the remaining reservoirs and therefore assessing the inflows comes with a great deal of uncertainty. CAT18 is downstream of Lake Wateree and is a key calibration point, but is not immediately downstream of the lake. It also contains contributing flow from several ungaged model tributaries. **Figure 7.3** (with comparisons at both log and normal scales) highlights the model's performance at this gage during the drought years of 2007-2008. Although the model misses some of the small, daily peaks, overall the characteristics of this low flow period are well-simulated.

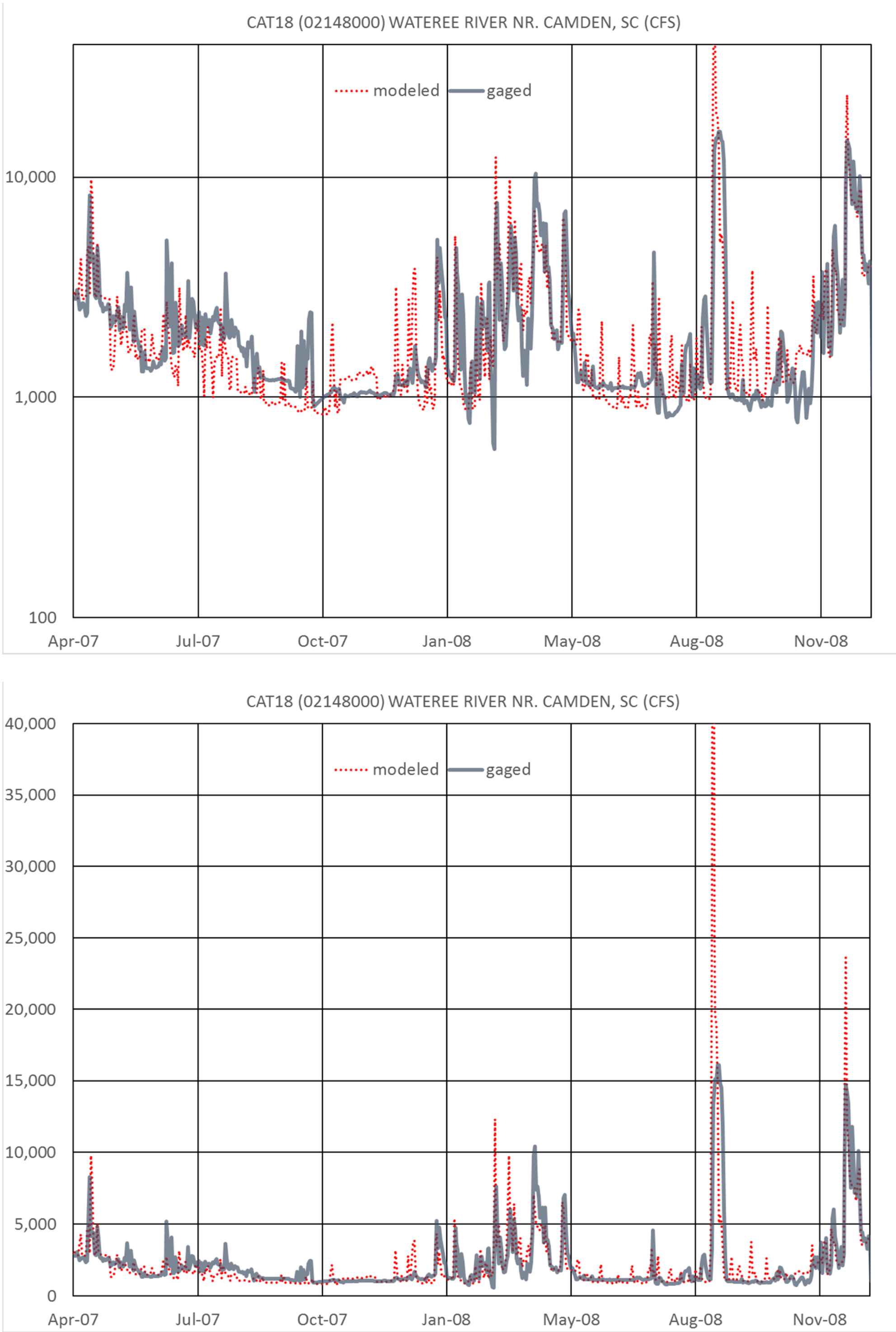

Figure 7.3: CAT18 During Drought Years

Section 8

User Guidelines for the Baseline Model

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

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

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

Users will also be able to change the duration of a model run in order to focus on specific years or hydrologic conditions. For example, the default model will run on a daily or monthly time step from 1929 through 2010 in order to test scenarios over the full historic period of recorded hydrologic conditions. In some cases, though, it may be useful to compile output over just the period corresponding to the drought of record, or an unusually wet period.

Since the model begins below Lake Wylie, having output from the Catawba-Wateree CHEOPS model is a requirement. To output time series that will be needed are (1) daily and monthly flows from Lake Wylie and (2) the pre-determined daily and monthly LIP stages (as discussed in Section 6). It is envisioned that several different output Lake Wylie flow and LIP time series will be made available to the SWAM user, based on CHEOPS model scenarios that have already been performed as part of the Catawba-Wateree master planning process. If scenarios are contemplated that have not already been run in the CHEOPS model, it will be necessary to run the CHEOPS model first, to generate the output needed for the SWAM model.

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

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

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

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

Section 9

References

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Appendix A

Catawba-Wateree River Basin Model Monthly Calibration Results

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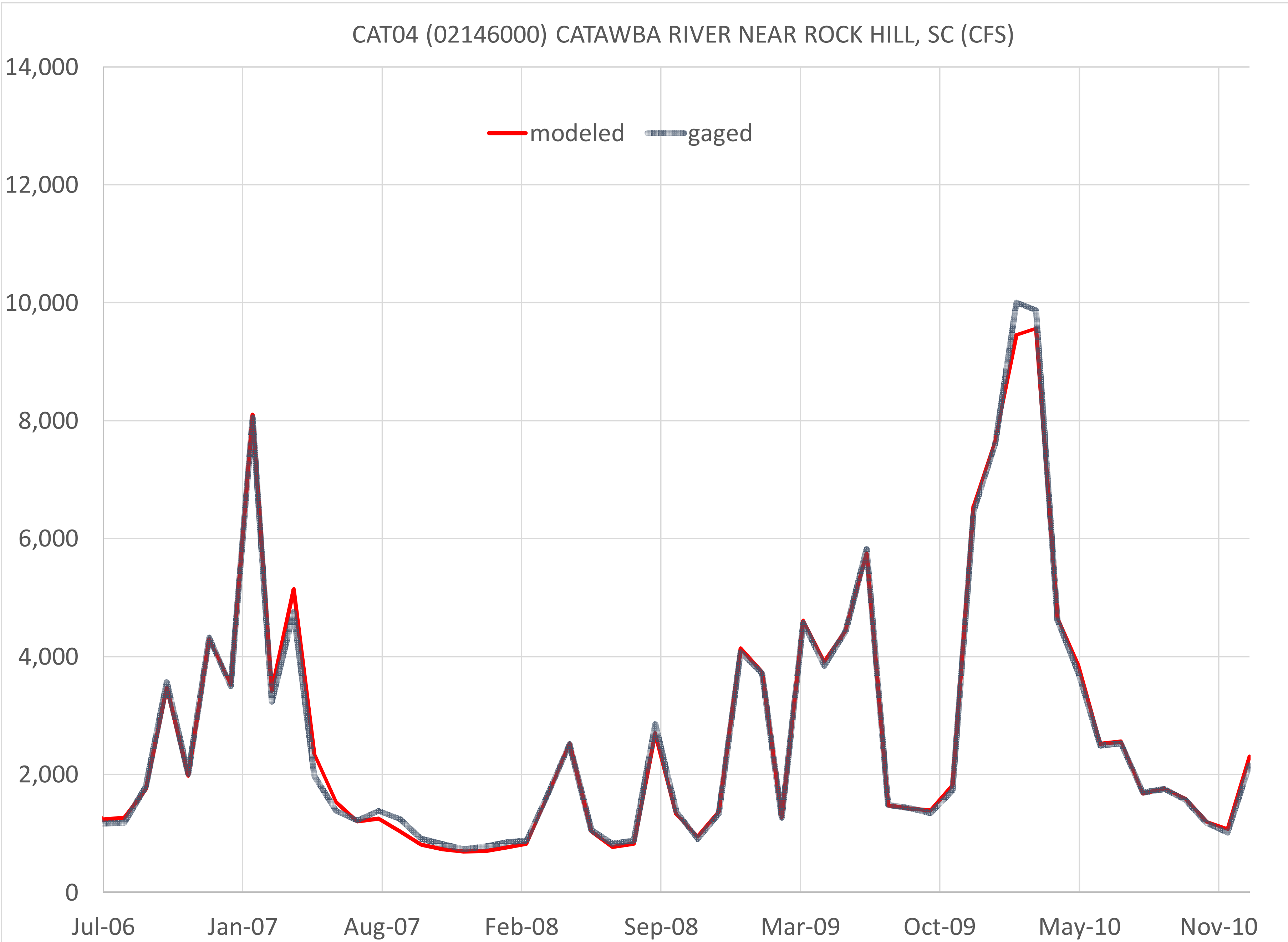
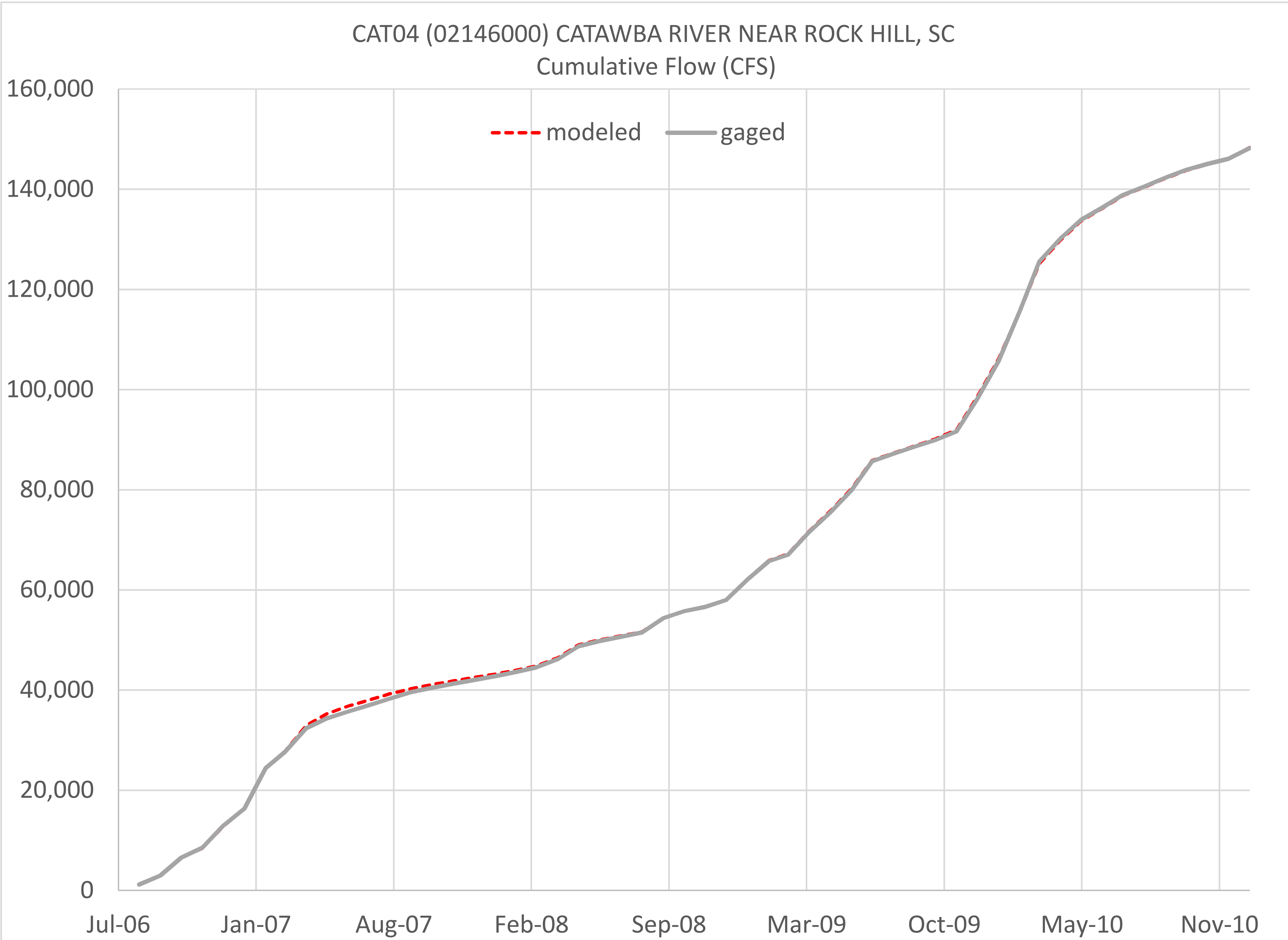
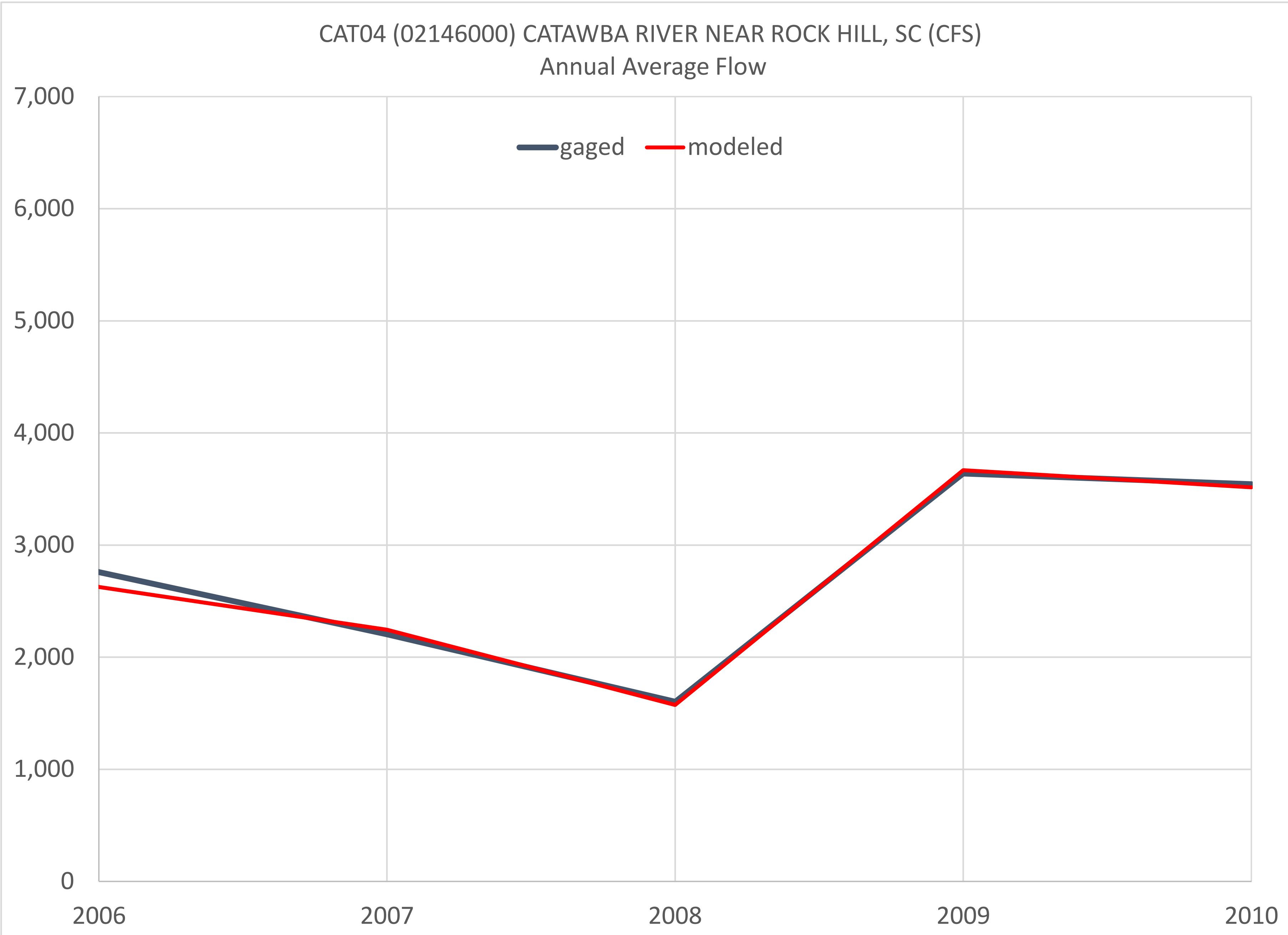
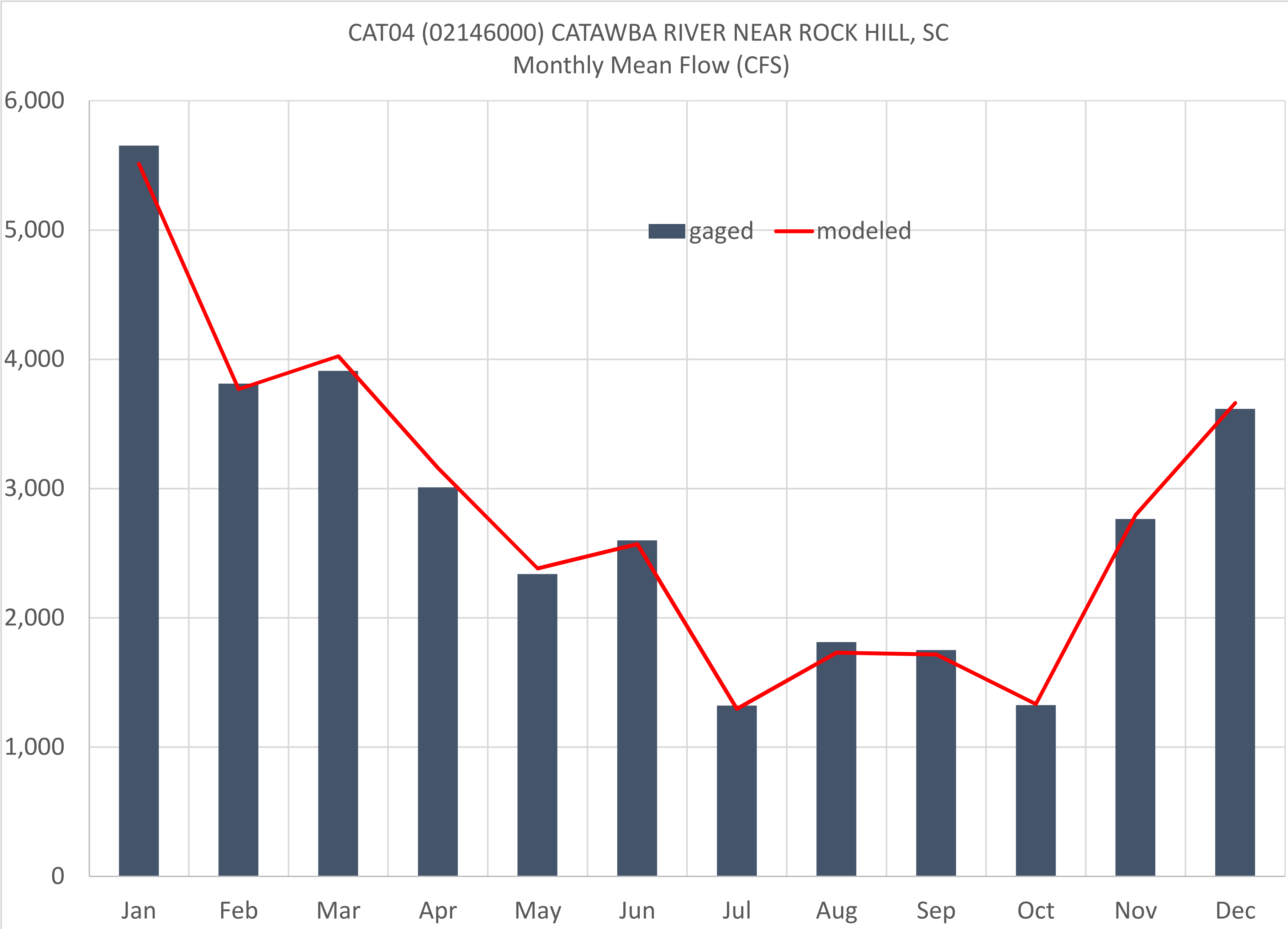

CAT04 (02146000) CATAWBA RIVER NEAR ROCK HILL, SC (CFS)
modeled
gaged
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Jul-06
Jan-07
Aug-07
Feb-08
Sep-08
Mar-09
Oct-09
May-10
Nov-10



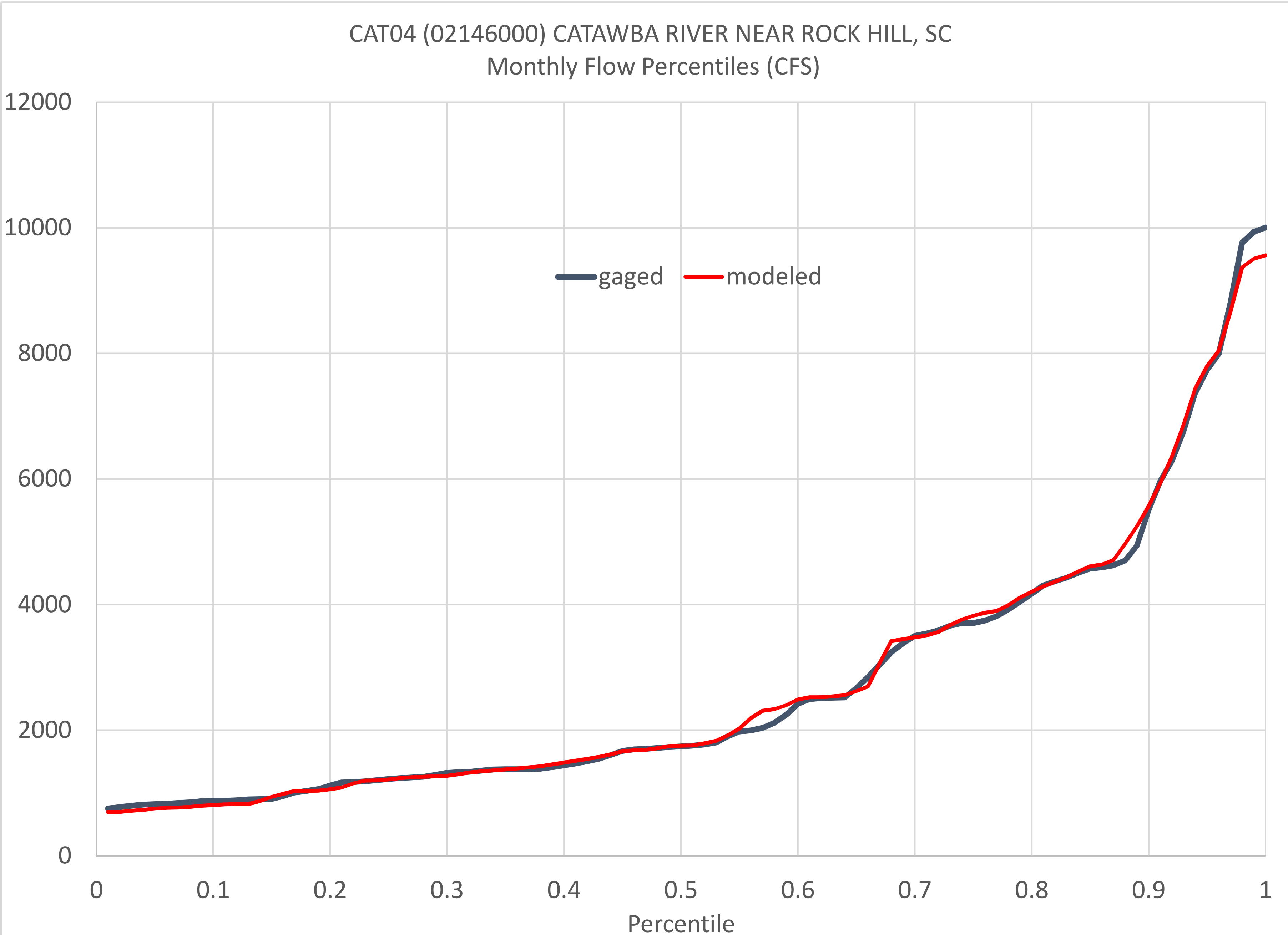
CAT04 (02146000) CATAWBA RIVER NEAR ROCK HILL, SC
Cumulative Flow (CFS)
modeled
gaged
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
Jul-06
Jan-07
Aug-07
Feb-08
Sep-08
Mar-09
Oct-09
May-10
Nov-10



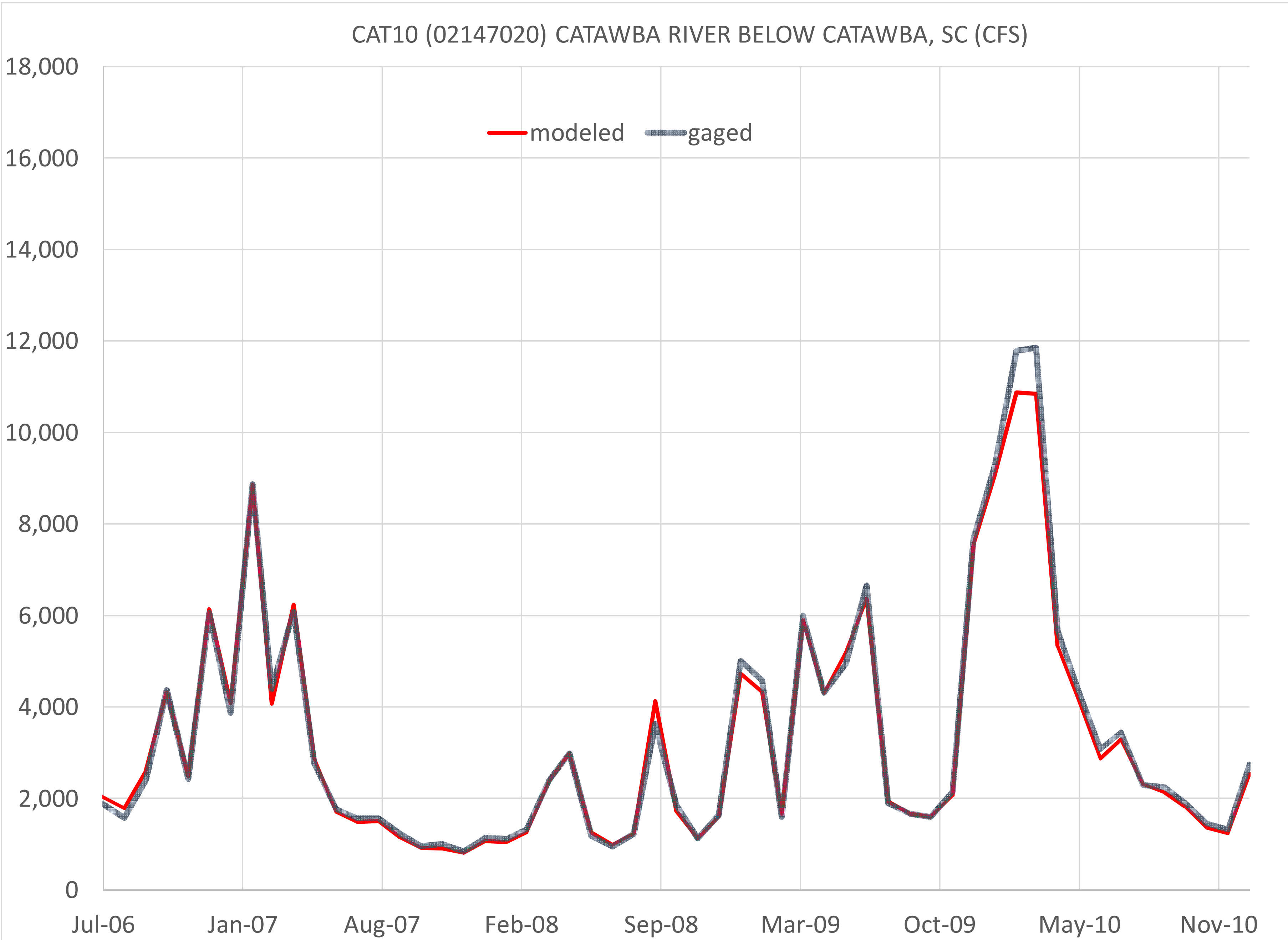
CAT04 (02146000) CATAWBA RIVER NEAR ROCK HILL, SC (CFS)
Annual Average Flow
gaged
modeled
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
2006
2007
2008
2009
2010

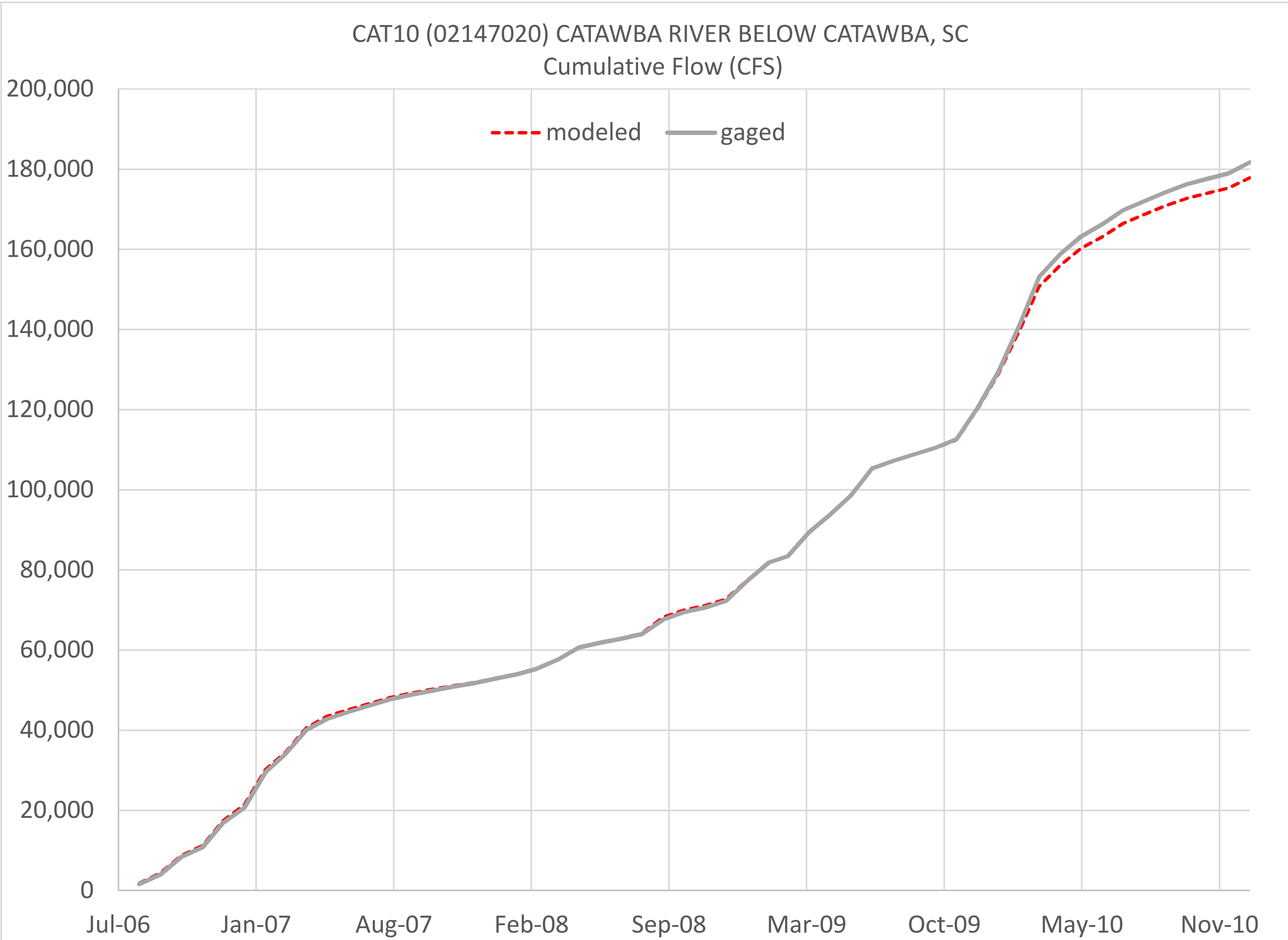


CAT04 (02146000) CATAWBA RIVER NEAR ROCK HILL, SC
Monthly Mean Flow (CFS)
gaged
modeled
6,000
5,000
4,000
3,000
2,000
1,000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

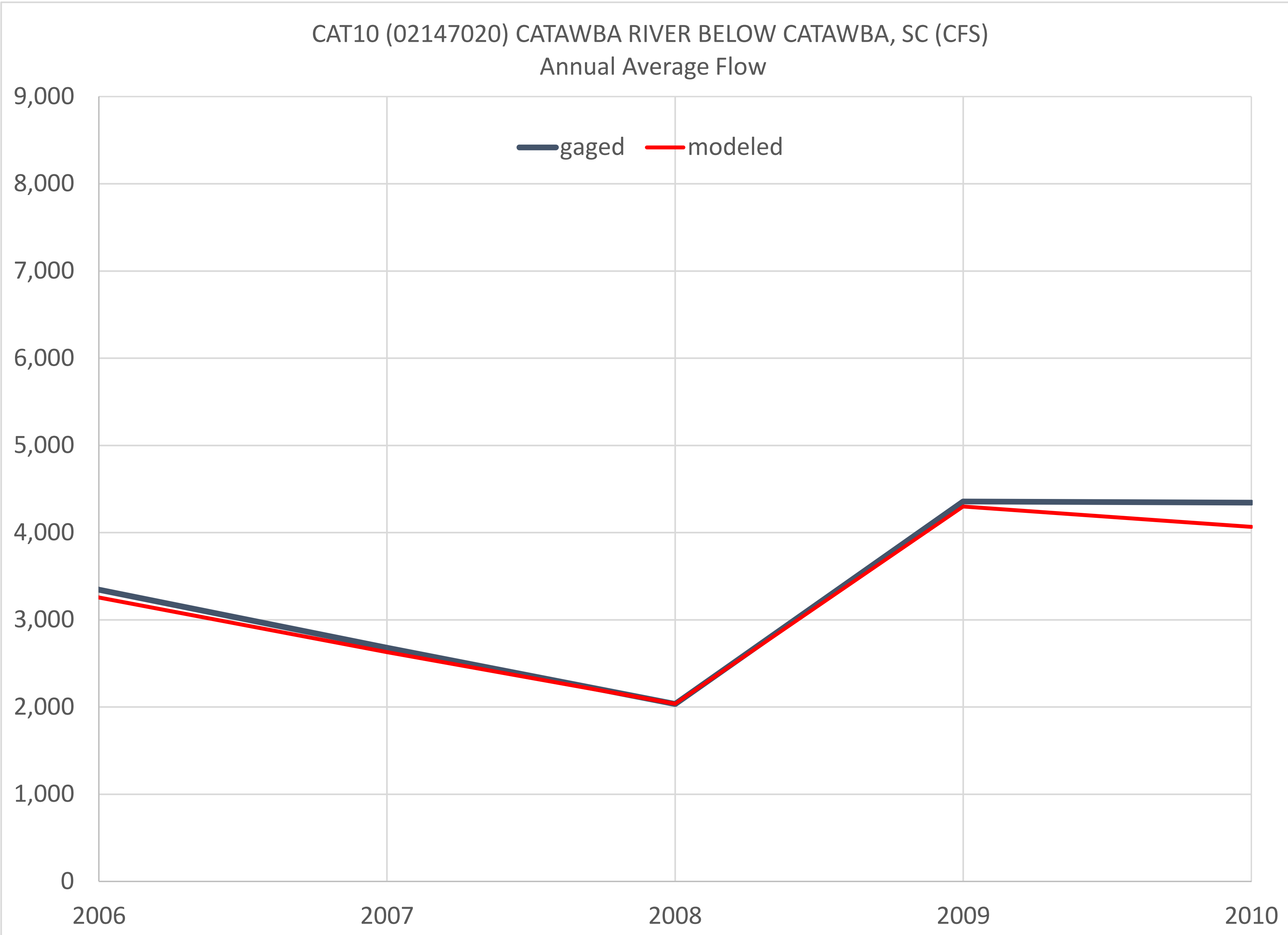


CAT04 (02146000) CATAWBA RIVER NEAR ROCK HILL, SC
Monthly Flow Percentiles (CFS)
12000
10000
8000
6000
4000
2000
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile
gaged
modeled

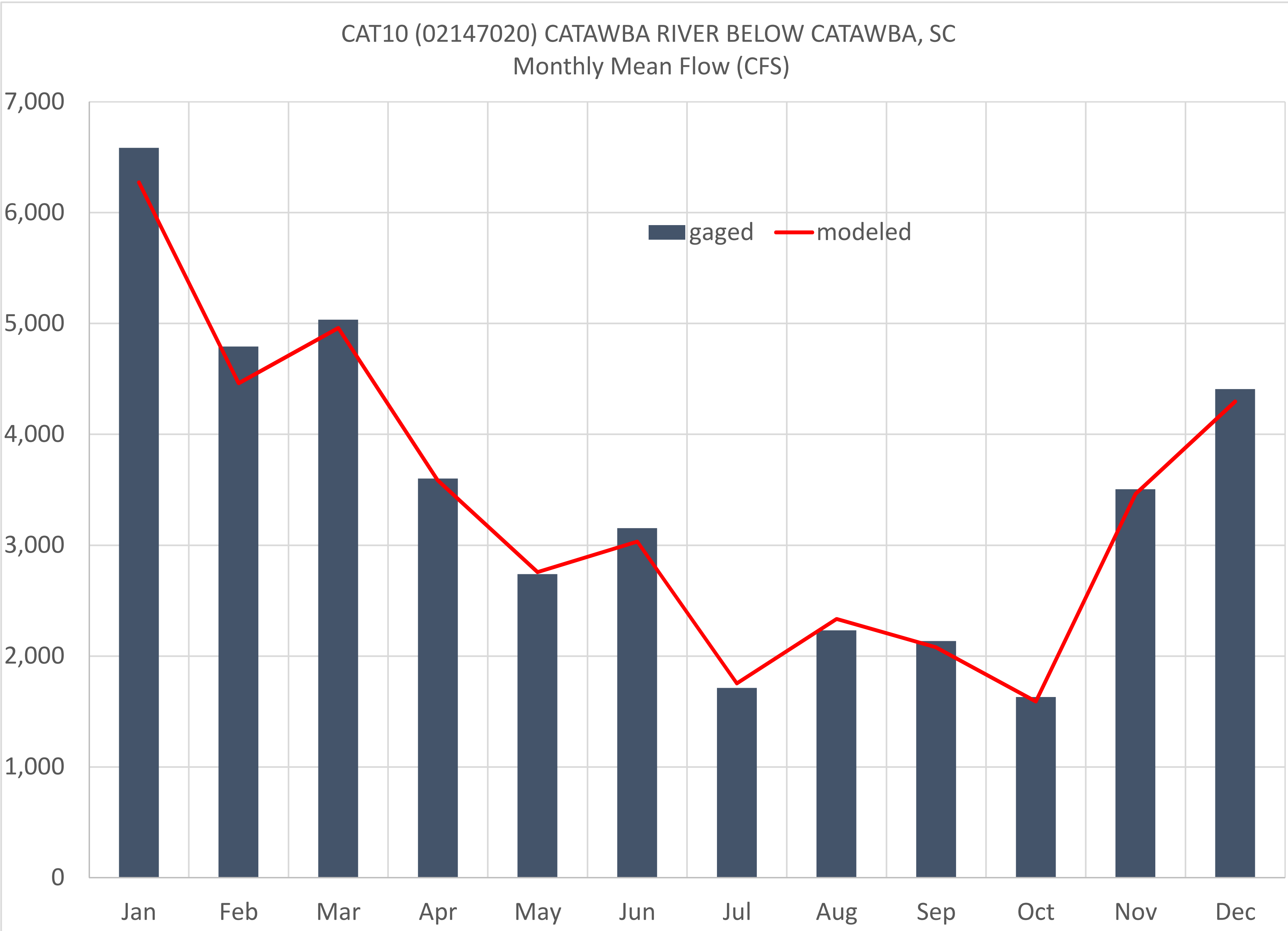

CAT10 (02147020) CATAWBA RIVER BELOW CATAWBA, SC (CFS)
modeled
gaged
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Jul-06
Jan-07
Aug-07
Feb-08
Sep-08
Mar-09
Oct-09
May-10
Nov-10



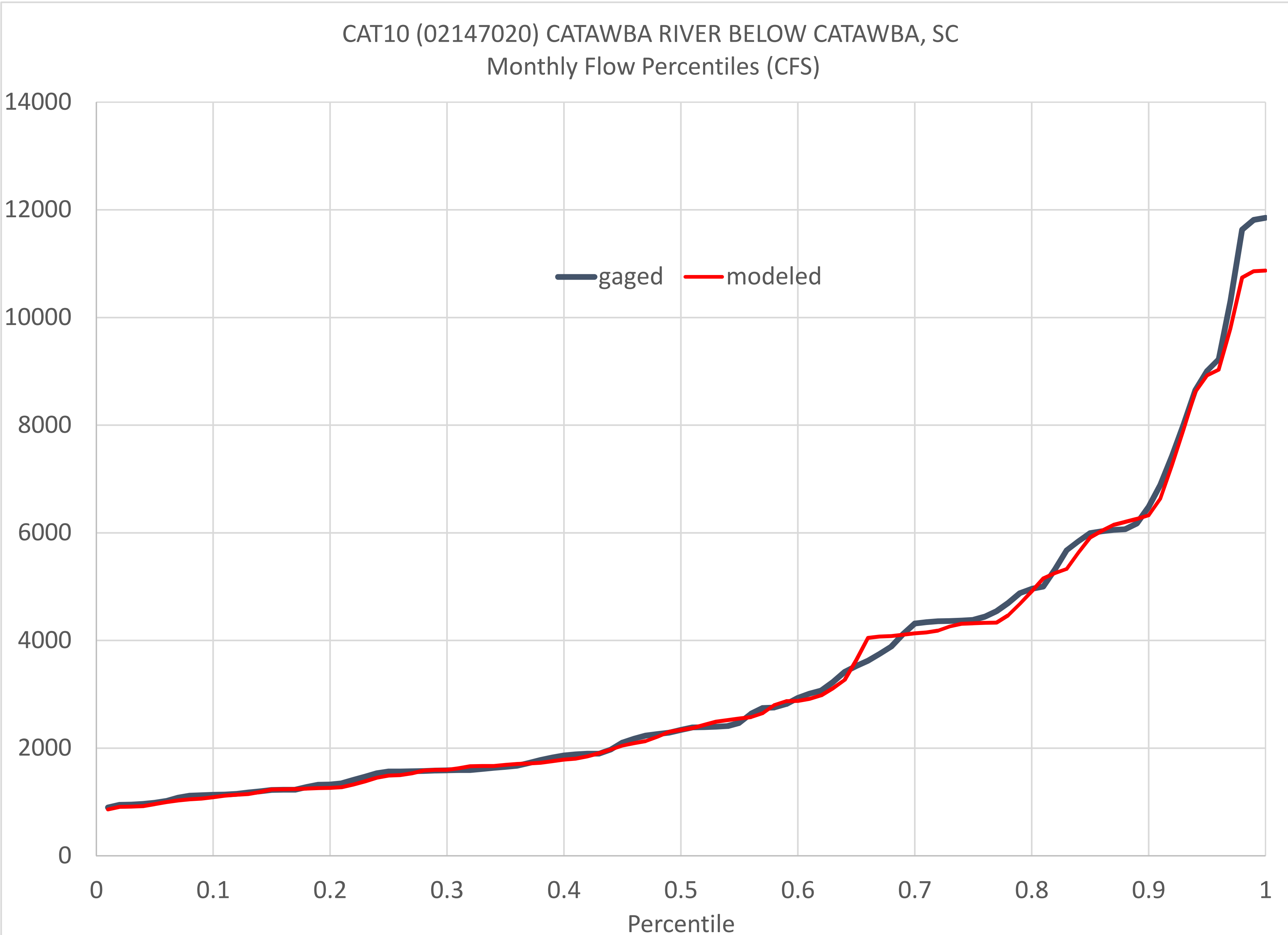
CAT10 (02147020) CATAWBA RIVER BELOW CATAWBA, SC
Cumulative Flow (CFS)
modeled
gaged
200,000
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
Jul-06
Jan-07
Aug-07
Feb-08
Sep-08
Mar-09
Oct-09
May-10
Nov-10

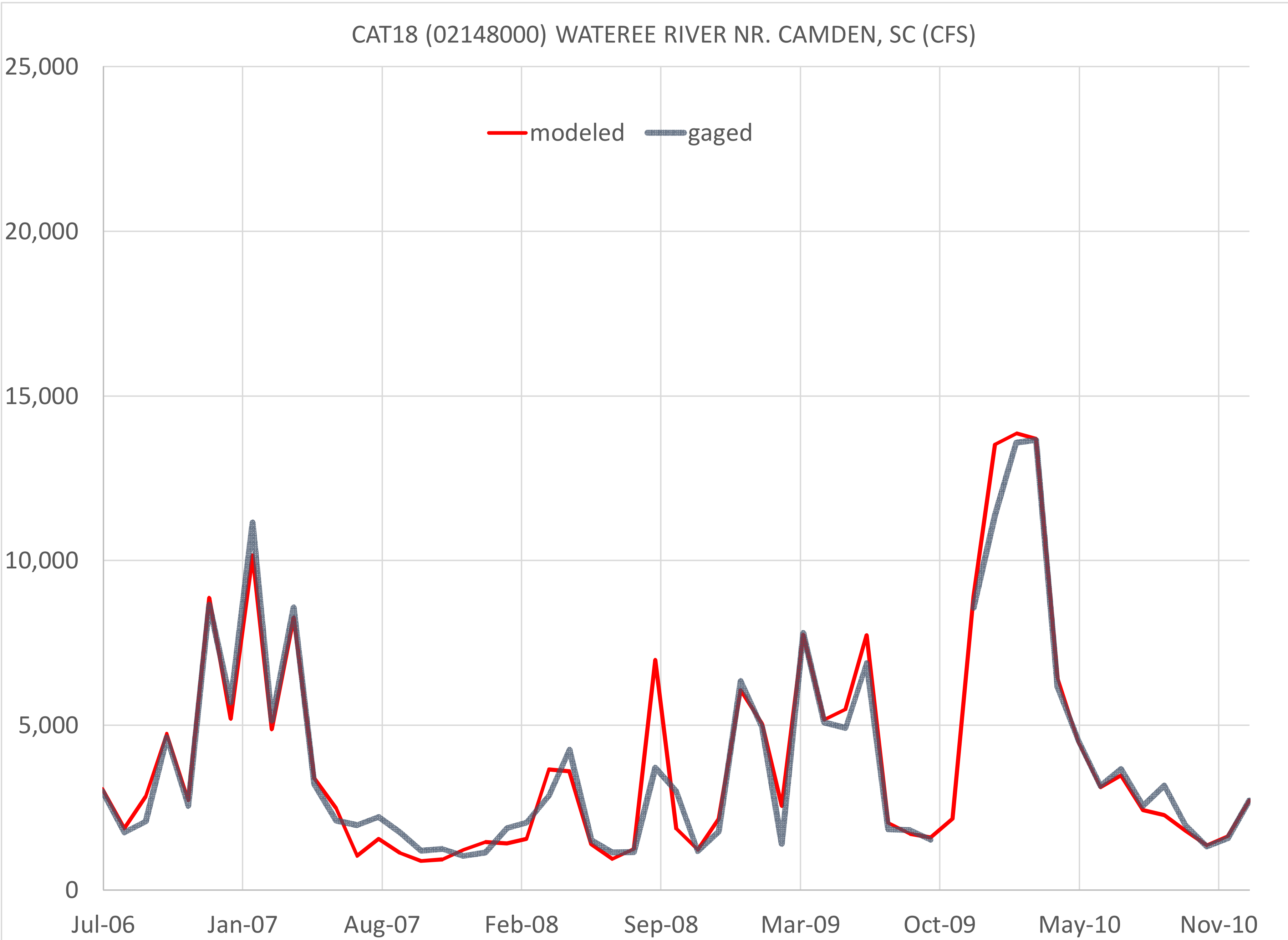


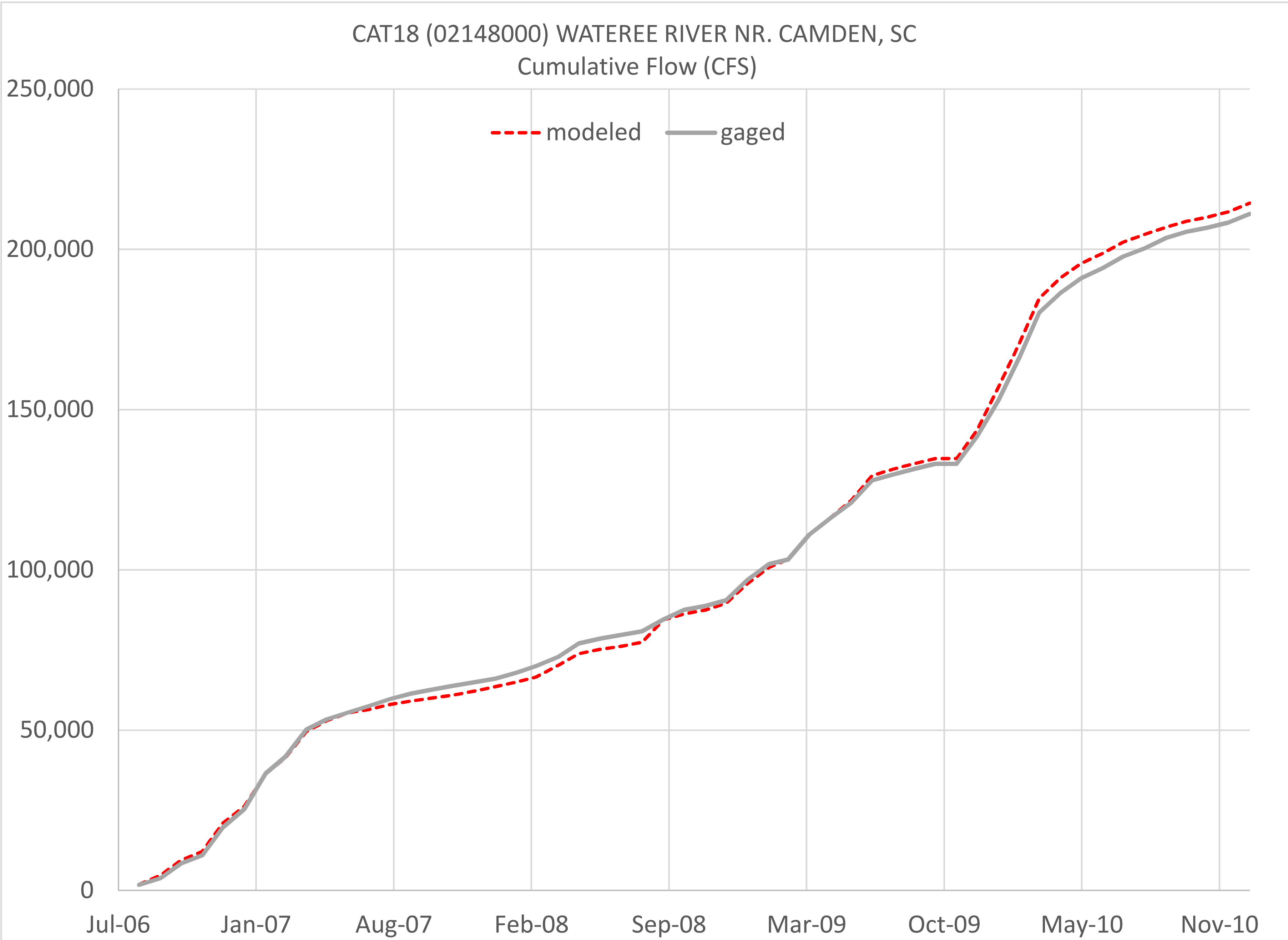
CAT10 (02147020) CATAWBA RIVER BELOW CATAWBA, SC (CFS)
Annual Average Flow
gaged
modeled
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
2006
2007
2008
2009
2010



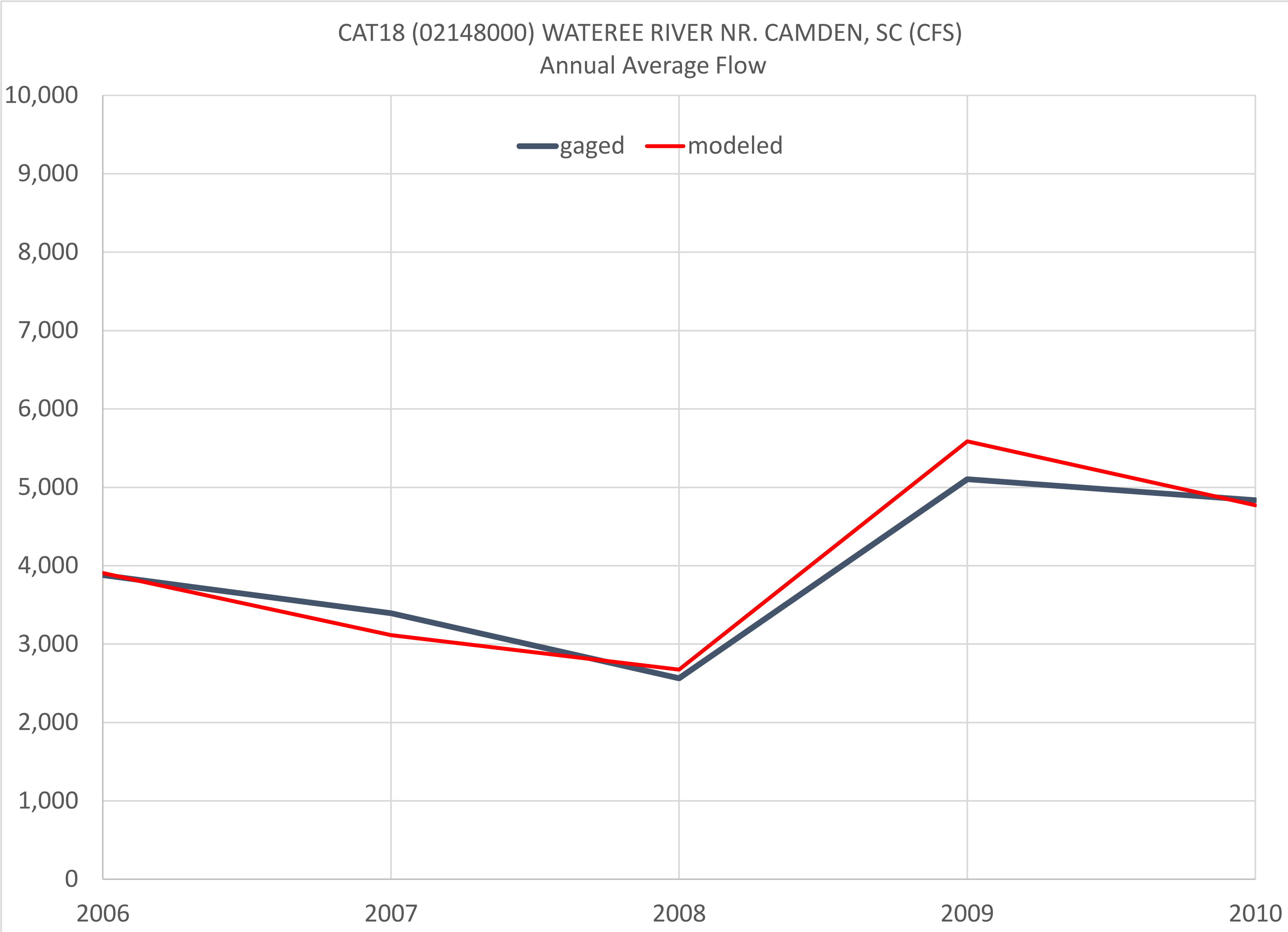
CAT10 (02147020) CATAWBA RIVER BELOW CATAWBA, SC
Monthly Mean Flow (CFS)
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
gaged
modeled
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

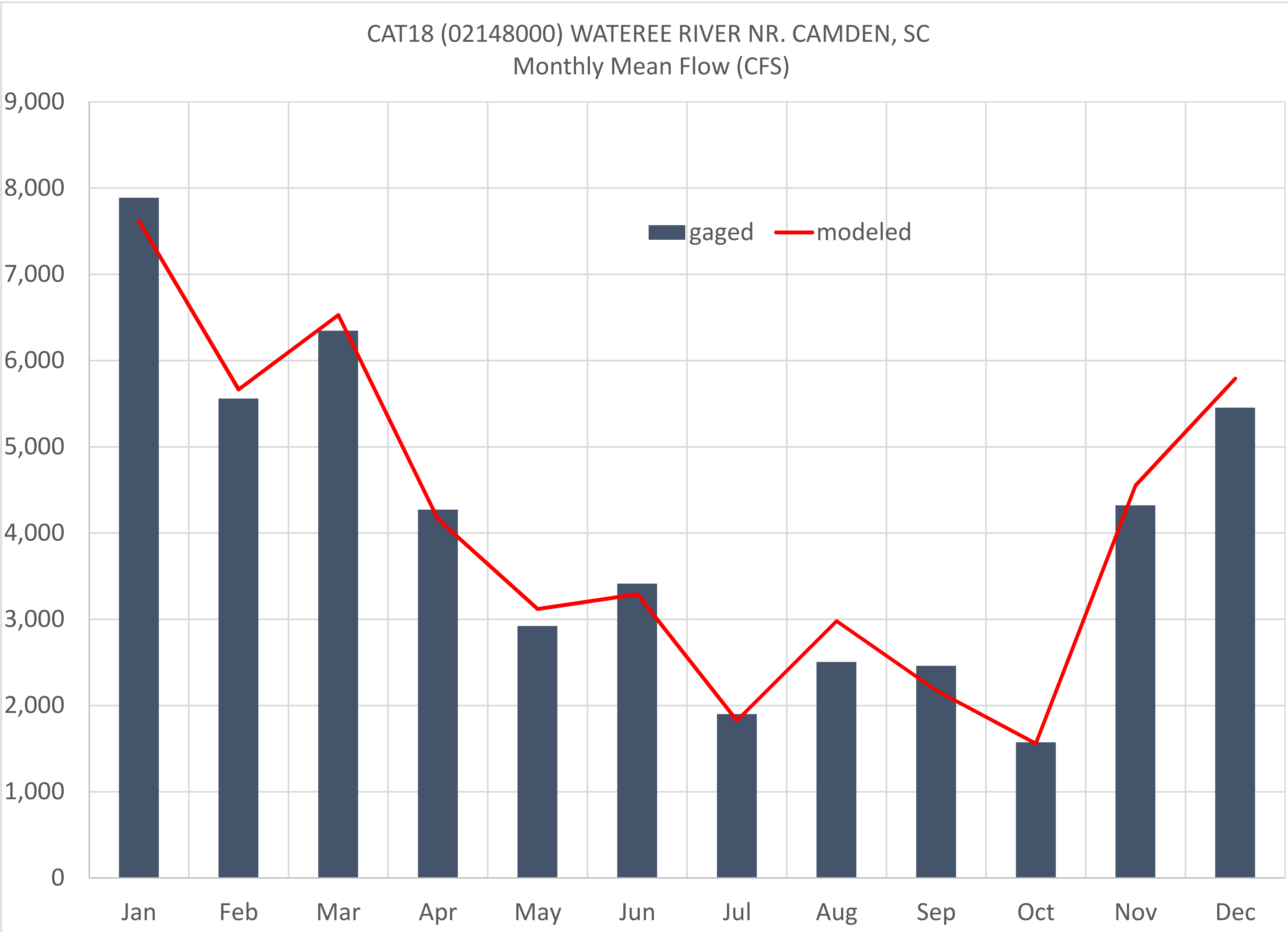

CAT10 (02147020) CATAWBA RIVER BELOW CATAWBA, SC
Monthly Flow Percentiles (CFS)
gaged
modeled
14000
12000
10000
8000
6000
4000
2000
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

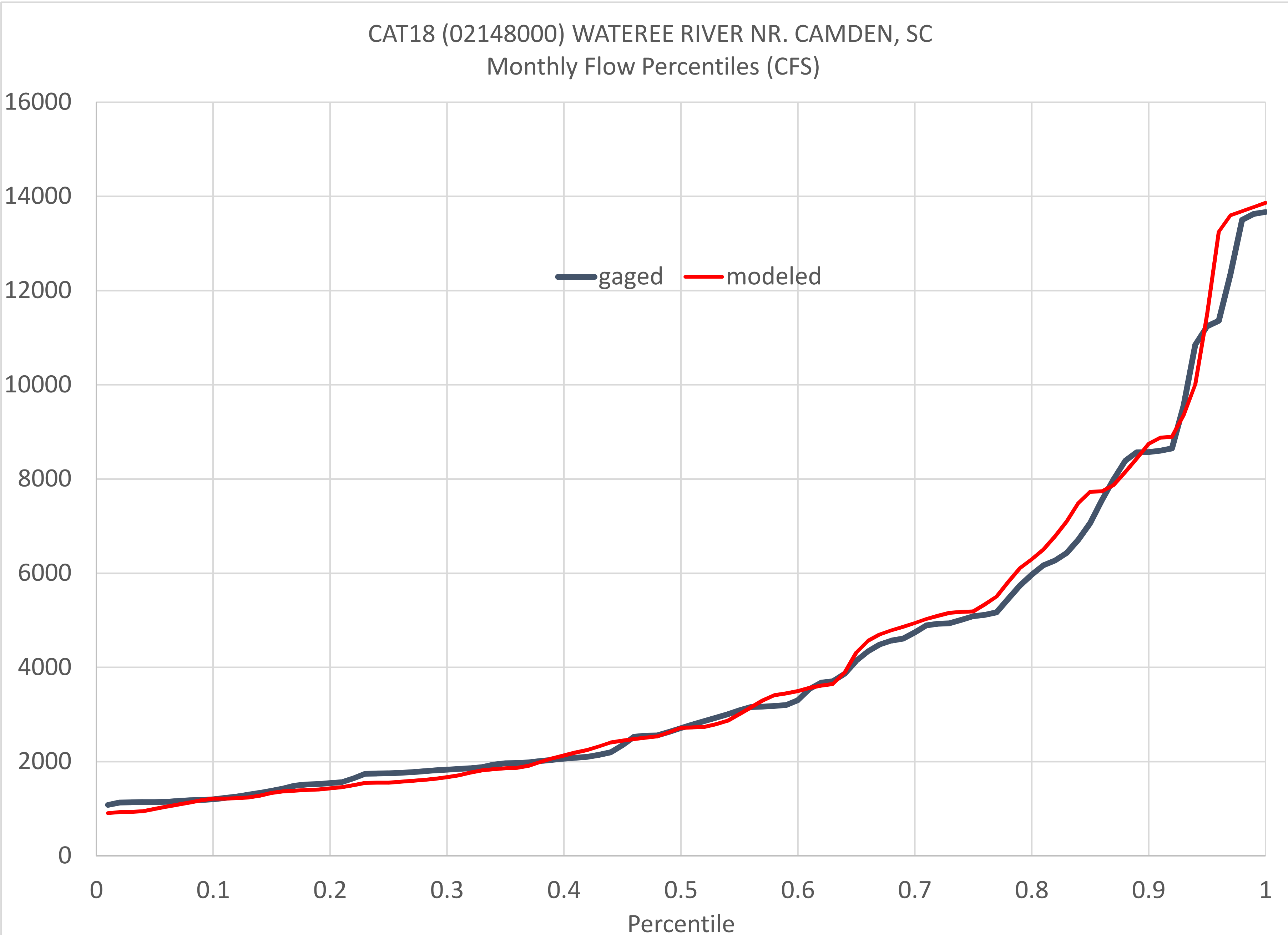

CAT18 (02148000) WATEREE RIVER NR. CAMDEN, SC (CFS)
modeled
gaged
25,000
20,000
15,000
10,000
5,000
0
Jul-06
Jan-07
Aug-07
Feb-08
Sep-08
Mar-09
Oct-09
May-10
Nov-10



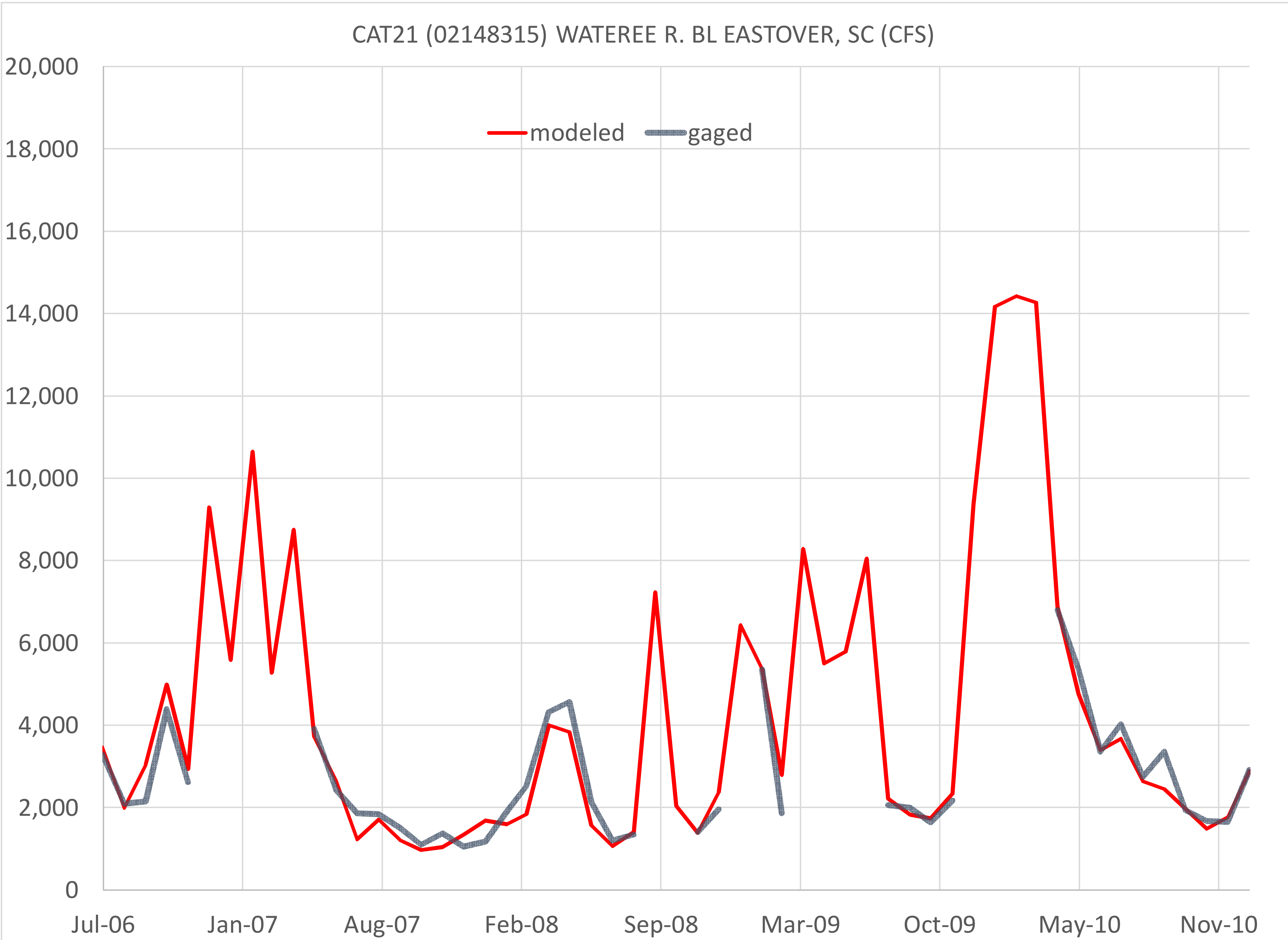
CAT18 (02148000) WATEREE RIVER NR. CAMDEN, SC
Cumulative Flow (CFS)
modeled
gaged
250,000
200,000
150,000
100,000
50,000
0
Jul-06
Jan-07
Aug-07
Feb-08
Sep-08
Mar-09
Oct-09
May-10
Nov-10

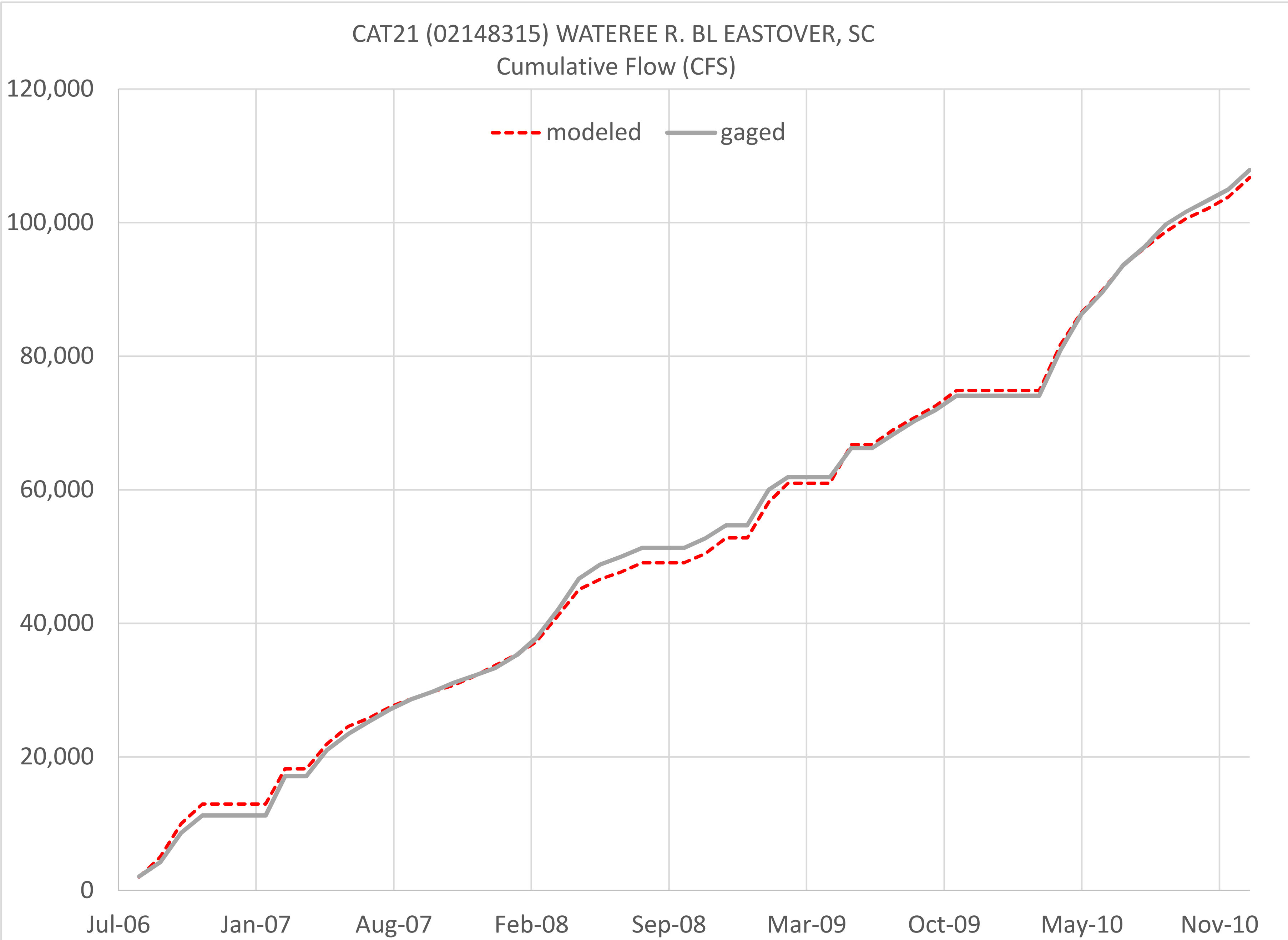

CAT18 (02148000) WATEREE RIVER NR. CAMDEN, SC (CFS)
Annual Average Flow
gaged
modeled
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
2006
2007
2008
2009
2010


CAT18 (02148000) WATEREE RIVER NR. CAMDEN, SC
Monthly Mean Flow (CFS)
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
gaged
modeled
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

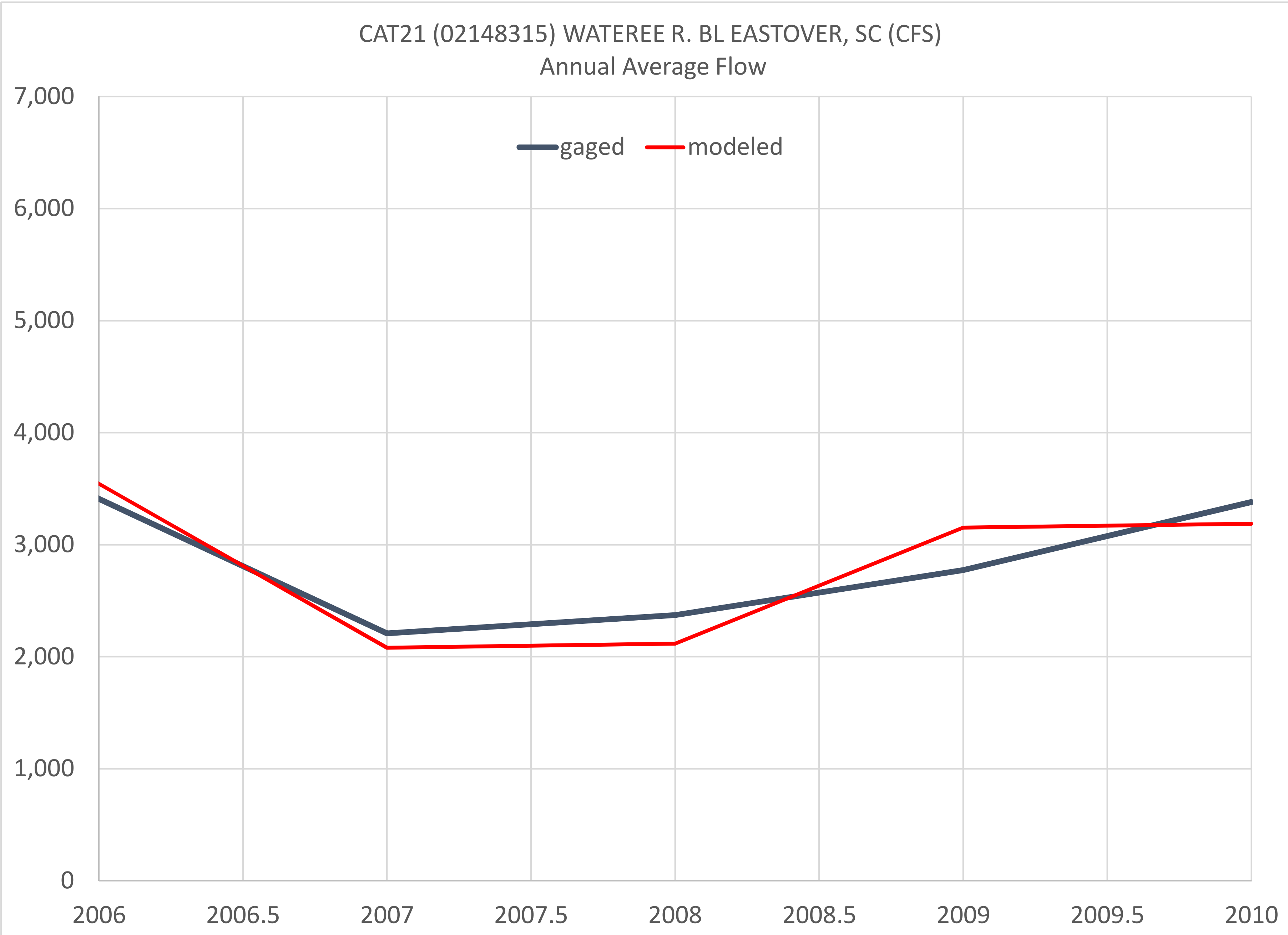


CAT18 (02148000) WATEREE RIVER NR. CAMDEN, SC
Monthly Flow Percentiles (CFS)
gaged
modeled
16000
14000
12000
10000
8000
6000
4000
2000
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

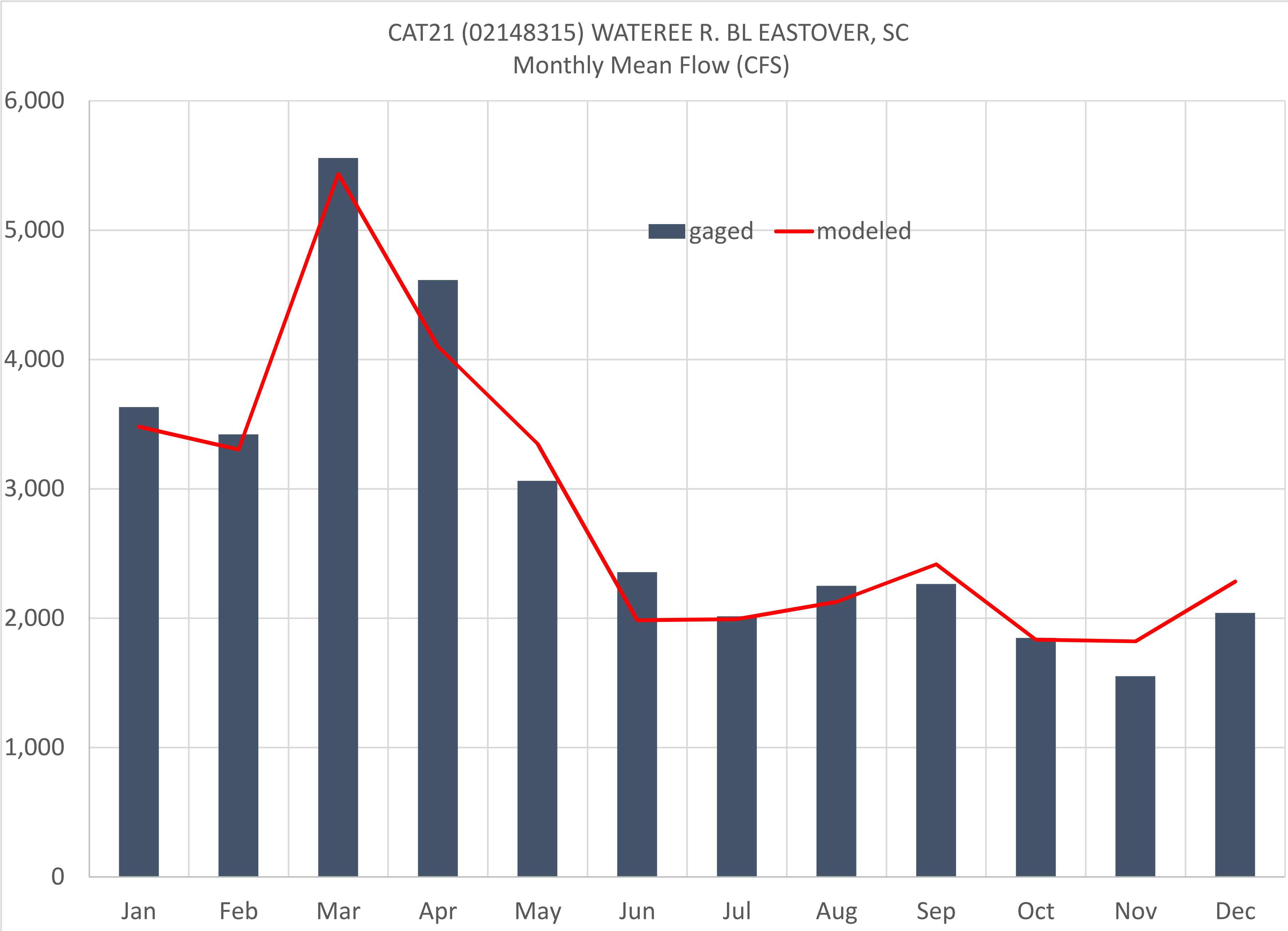

CAT21 (02148315) WATEREE R. BL EASTOVER, SC (CFS)
modeled
gaged
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Jul-06
Jan-07
Aug-07
Feb-08
Sep-08
Mar-09
Oct-09
May-10
Nov-10



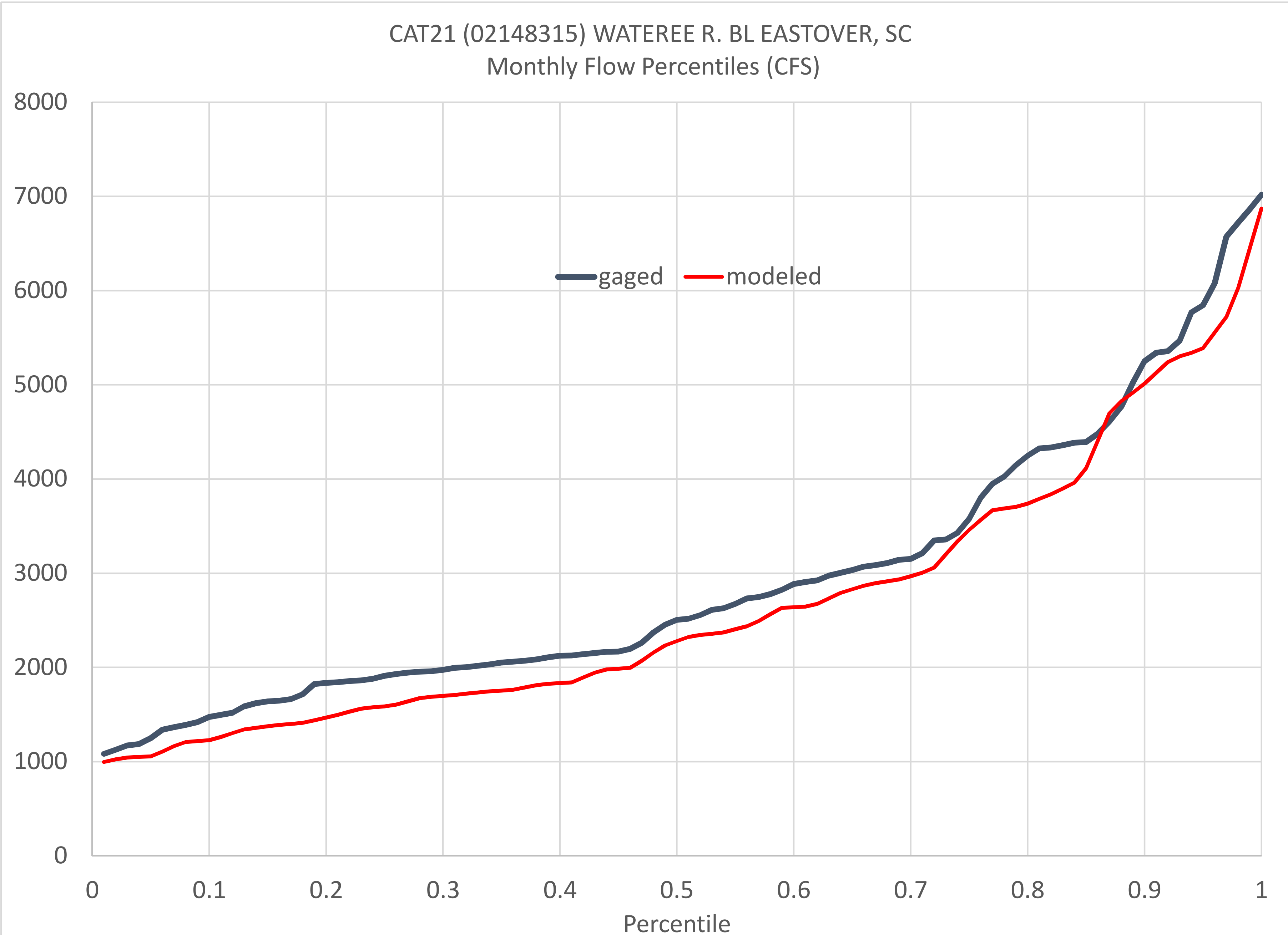
CAT21 (02148315) WATEREE R. BL EASTOVER, SC
Cumulative Flow (CFS)
modeled
gaged
120,000
100,000
80,000
60,000
40,000
20,000
0
Jul-06
Jan-07
Aug-07
Feb-08
Sep-08
Mar-09
Oct-09
May-10
Nov-10



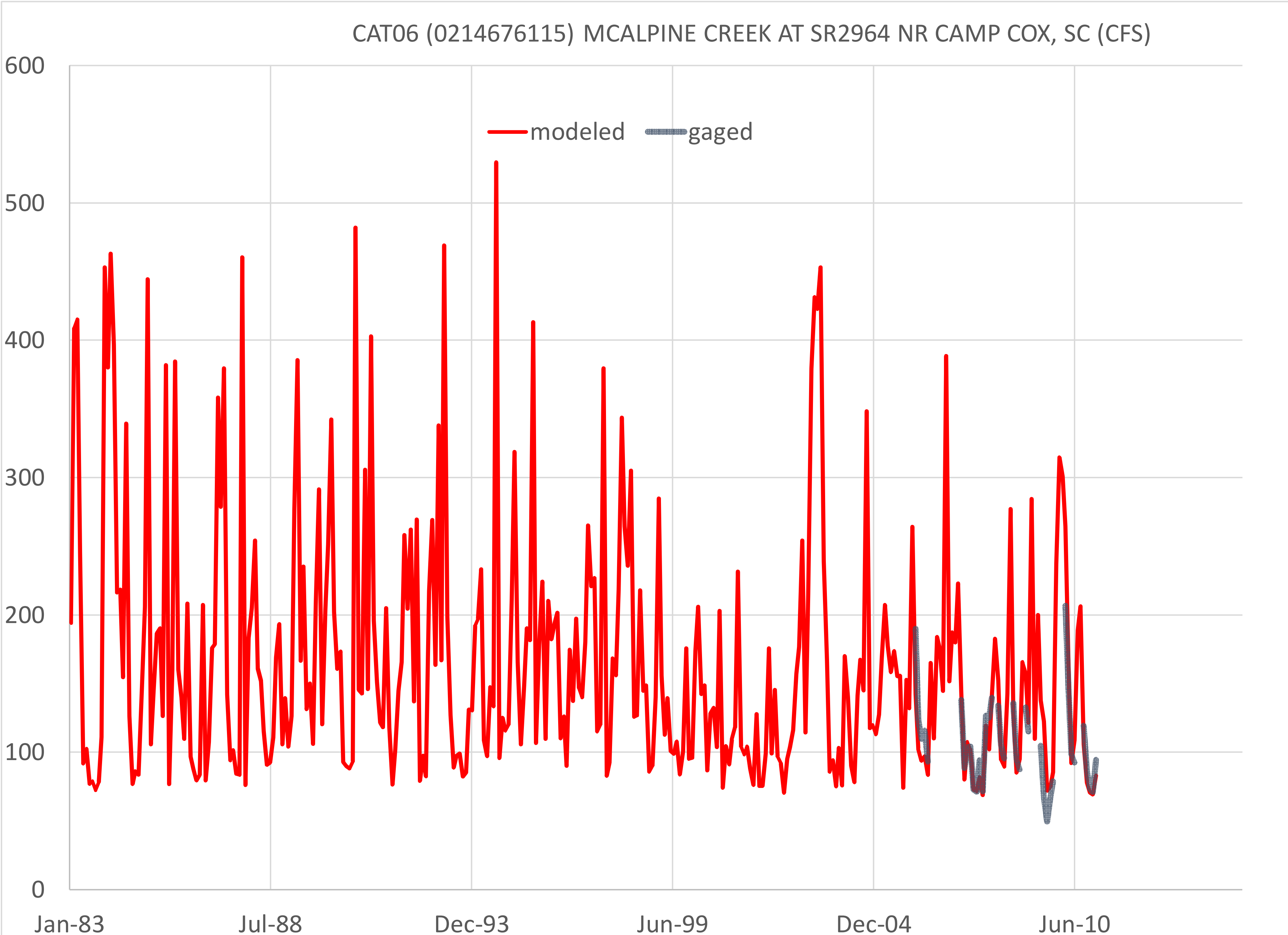
CAT21 (02148315) WATEREE R. BL EASTOVER, SC (CFS)
Annual Average Flow
gaged
modeled
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
2006
2006.5
2007
2007.5
2008
2008.5
2009
2009.5
2010

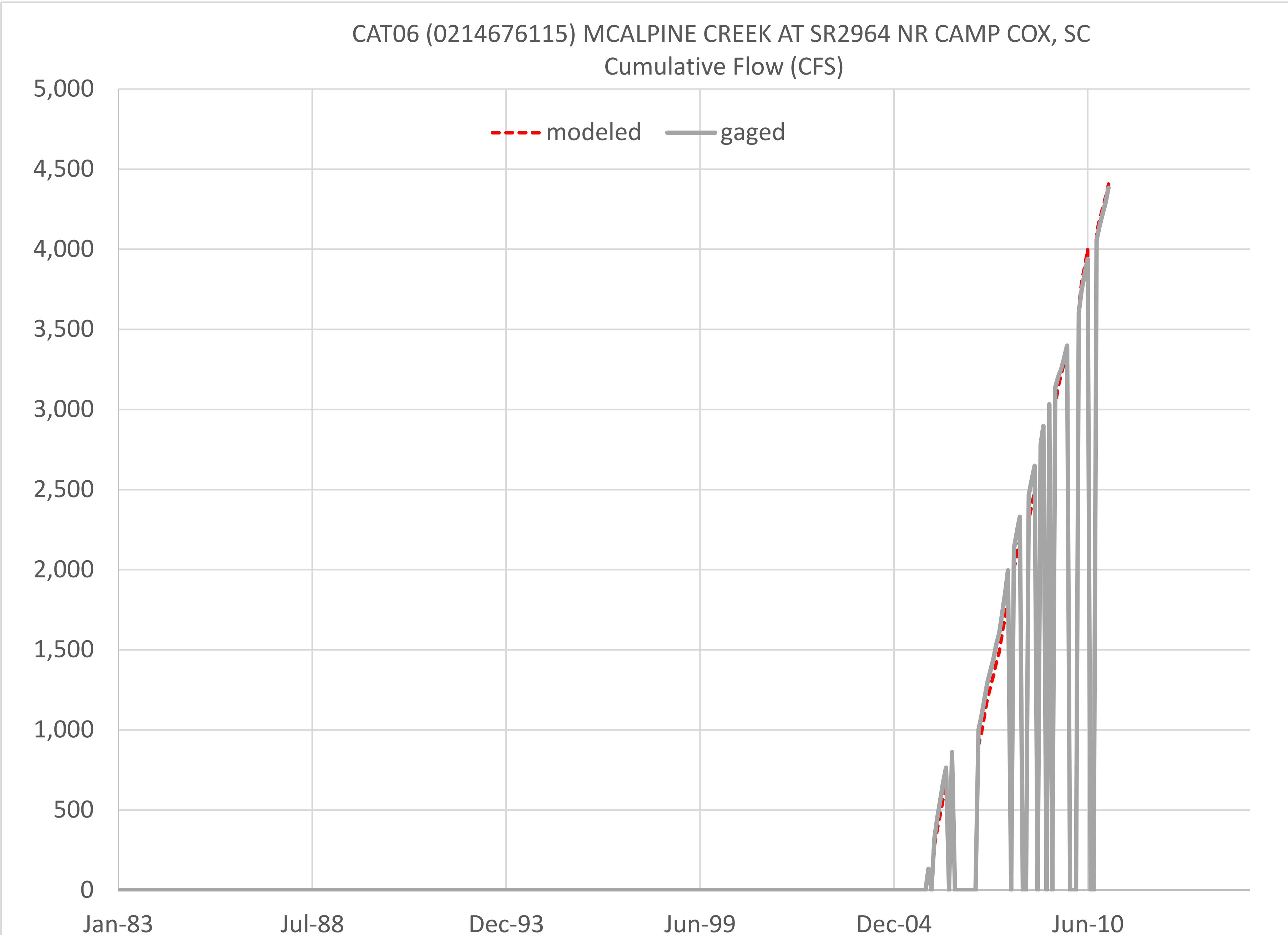


CAT21 (02148315) WATEREE R. BL EASTOVER, SC
Monthly Mean Flow (CFS)
6,000
5,000
4,000
3,000
2,000
1,000
0
gaged
modeled
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

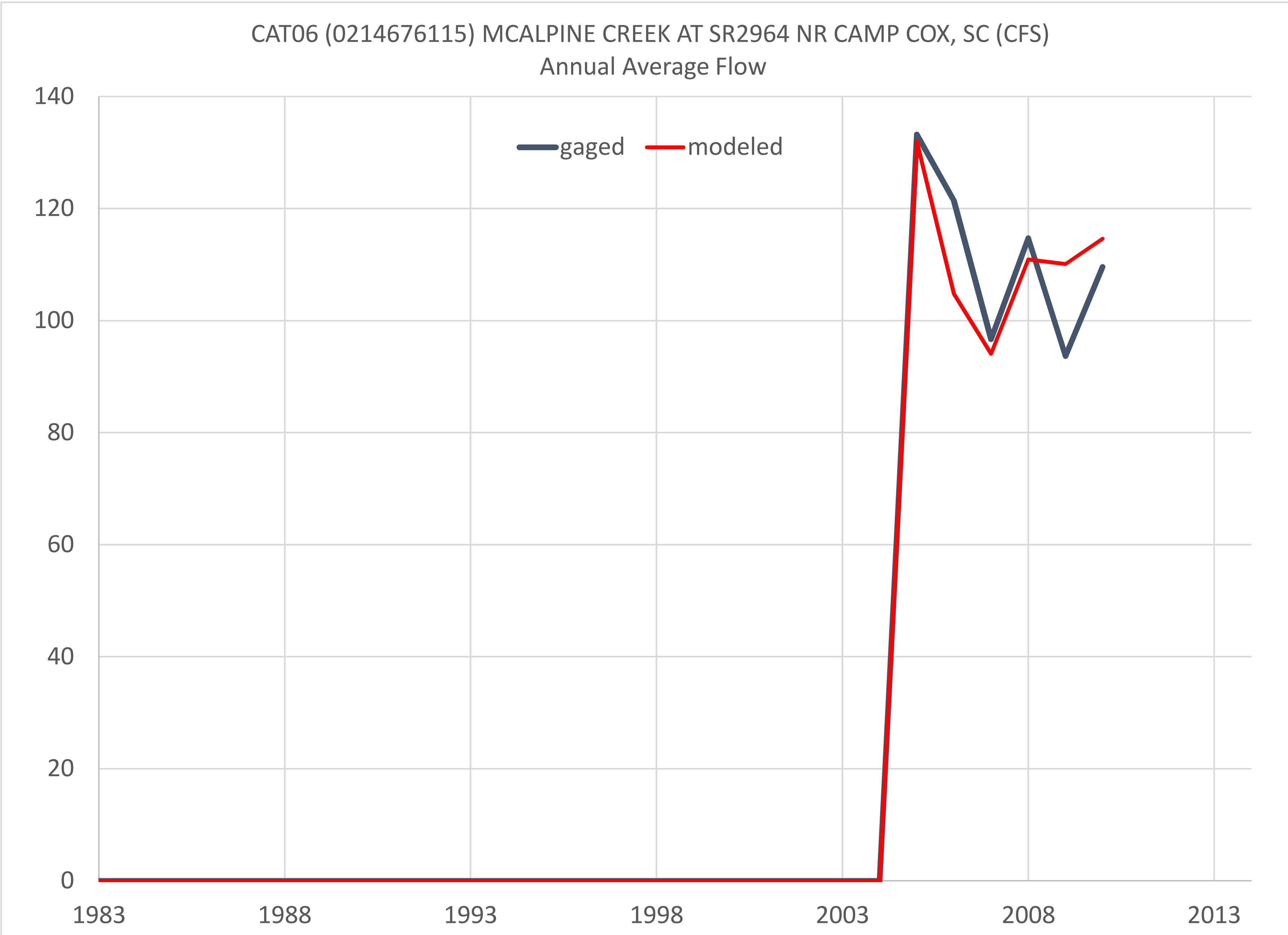


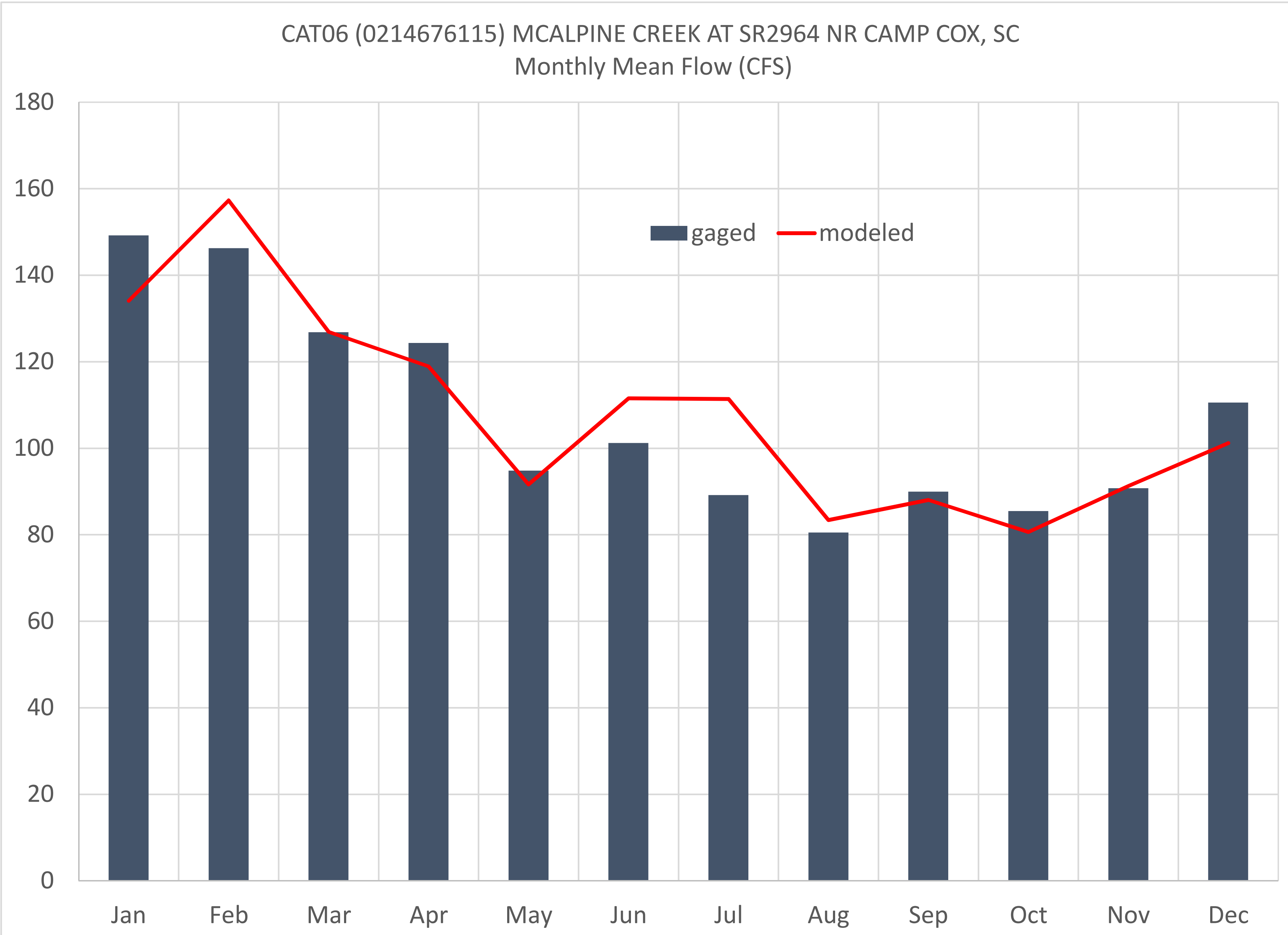
CAT21 (02148315) WATEREE R. BL EASTOVER, SC
Monthly Flow Percentiles (CFS)
8000
7000
6000
5000
4000
3000
2000
1000
0
gaged
modeled
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

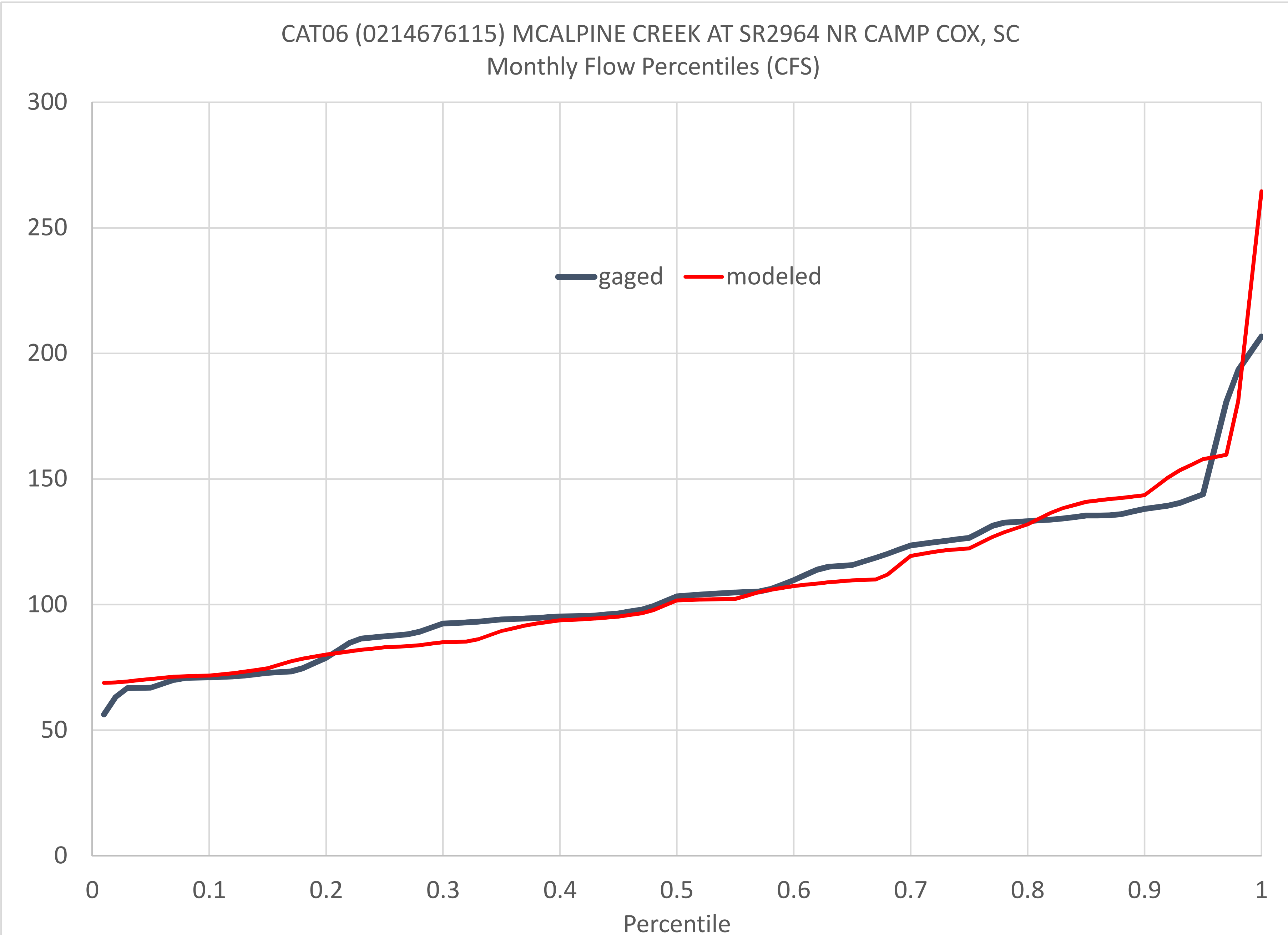

CAT06 (0214676115) MCALPINE CREEK AT SR2964 NR CAMP COX, SC (CFS)
modeled
gaged
600
500
400
300
200
100
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10



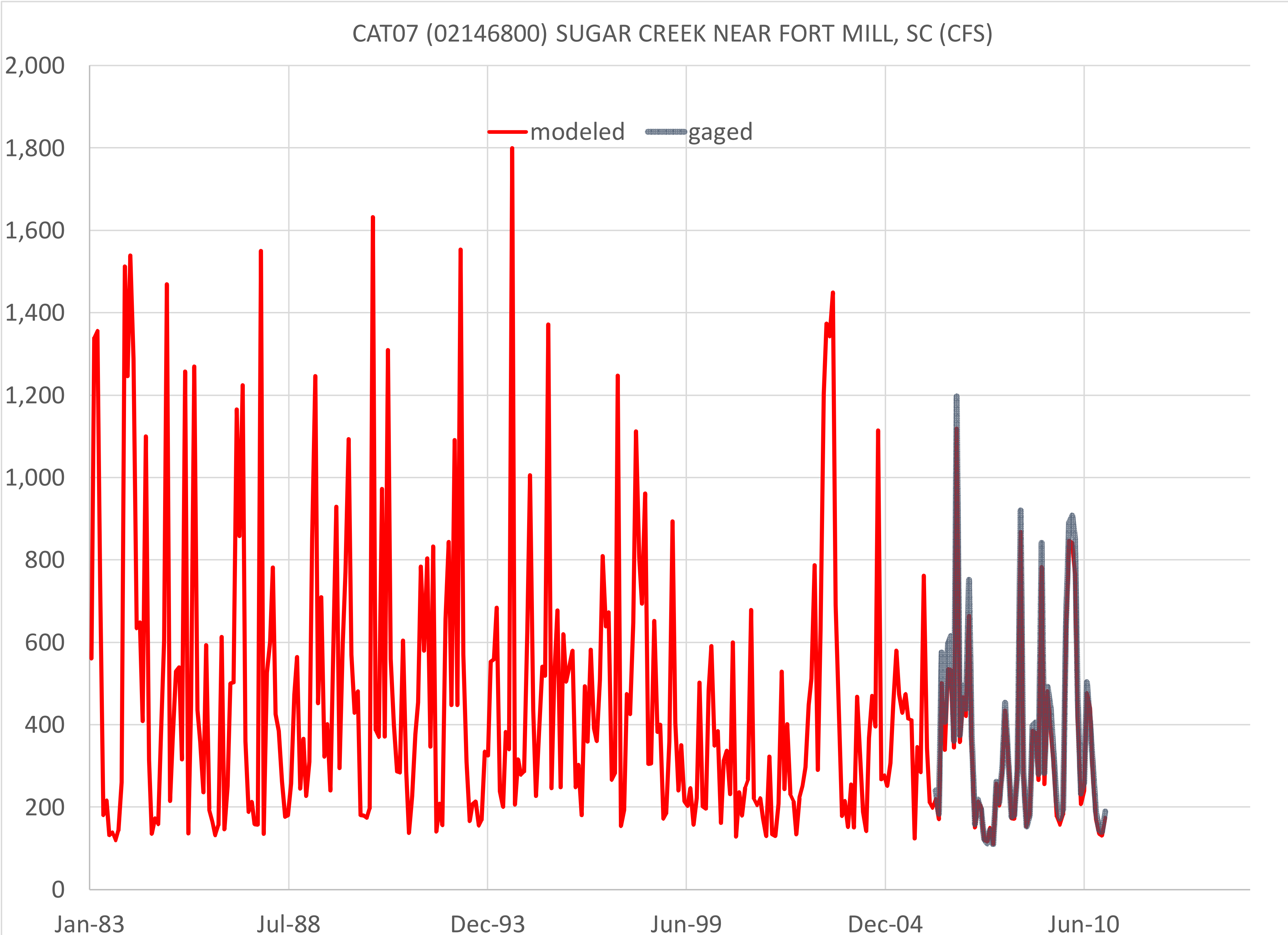
CAT06 (0214676115) MCALPINE CREEK AT SR2964 NR CAMP COX, SC
Cumulative Flow (CFS)
modeled
gaged
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

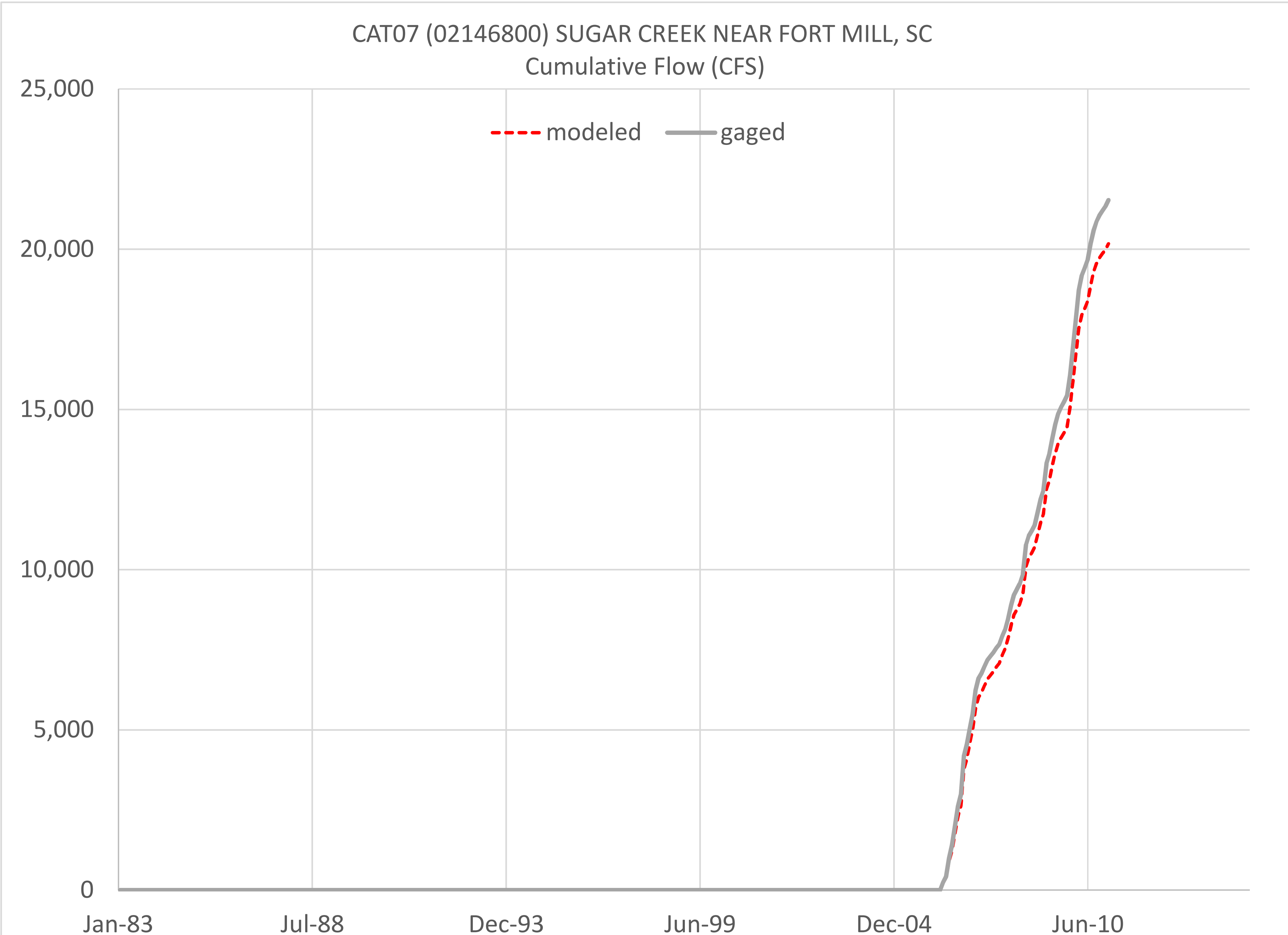

CAT06 (0214676115) MCALPINE CREEK AT SR2964 NR CAMP COX, SC (CFS)
Annual Average Flow
gaged
modeled
140
120
100
80
60
40
20
0
1983
1988
1993
1998
2003
2008
2013


CAT06 (0214676115) MCALPINE CREEK AT SR2964 NR CAMP COX, SC
Monthly Mean Flow (CFS)
gaged
modeled
180
160
140
120
100
80
60
40
20
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

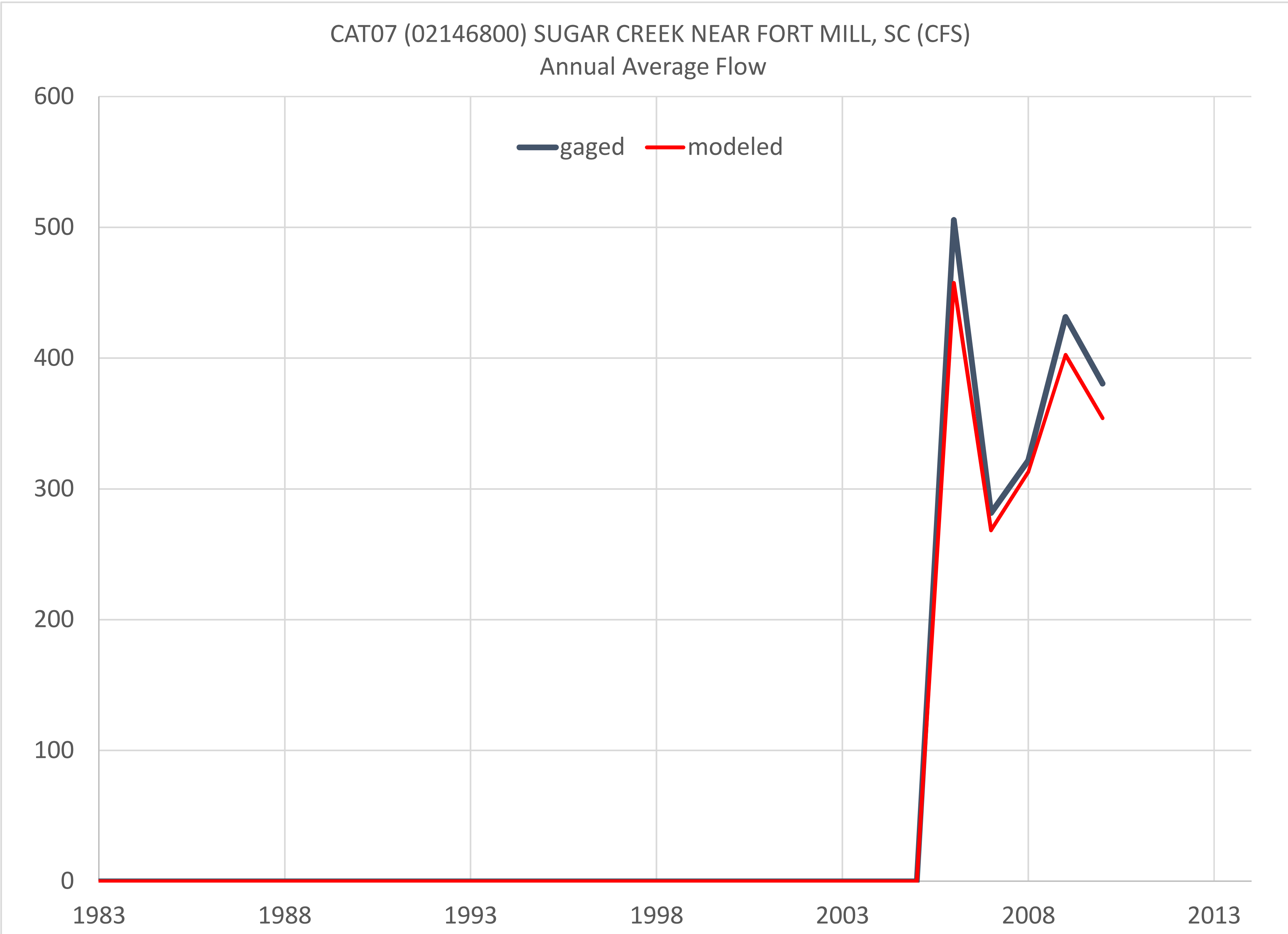


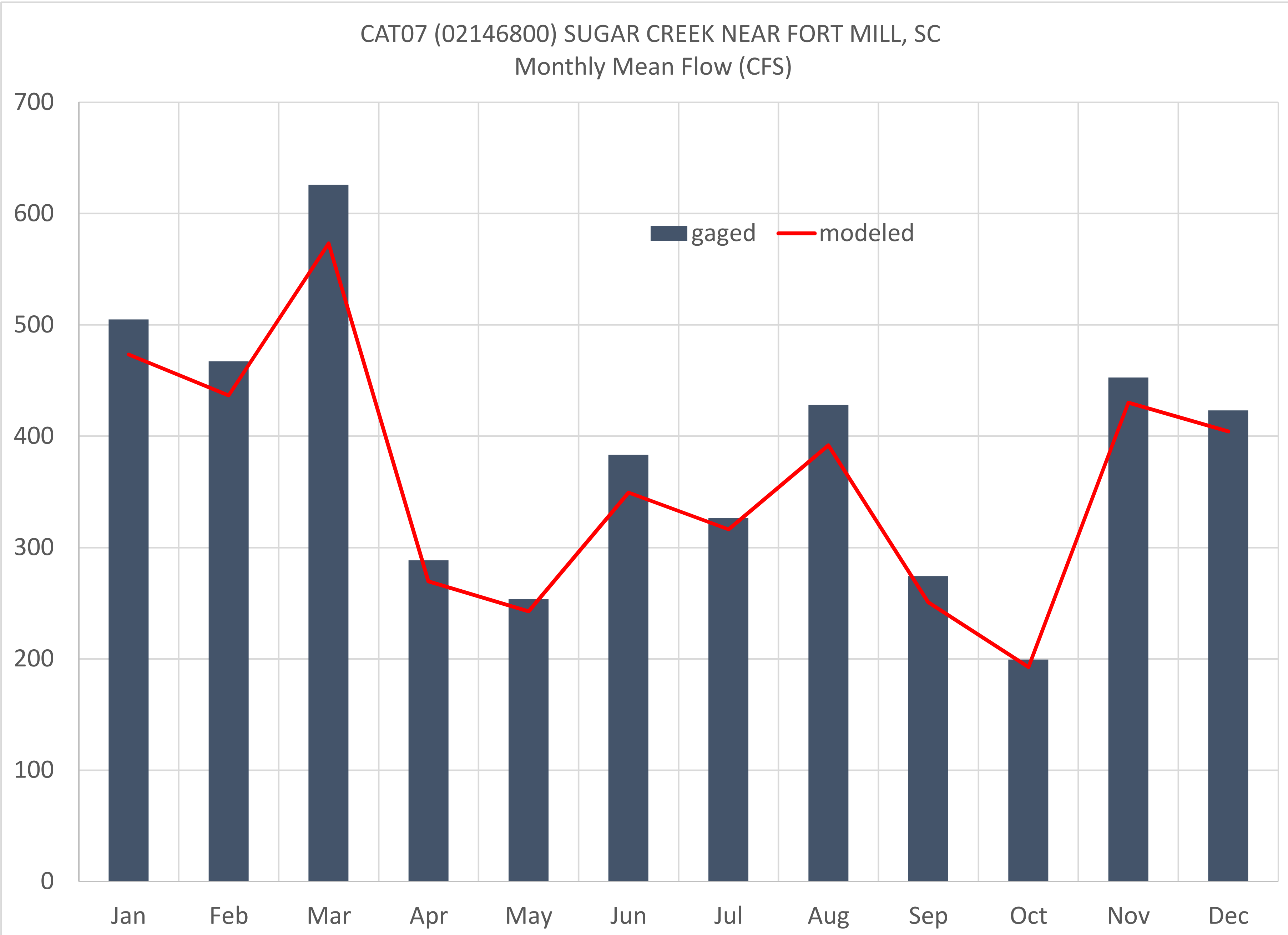
CAT06 (0214676115) MCALPINE CREEK AT SR2964 NR CAMP COX, SC
Monthly Flow Percentiles (CFS)
300
250
200
150
100
50
0
gaged
modeled
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

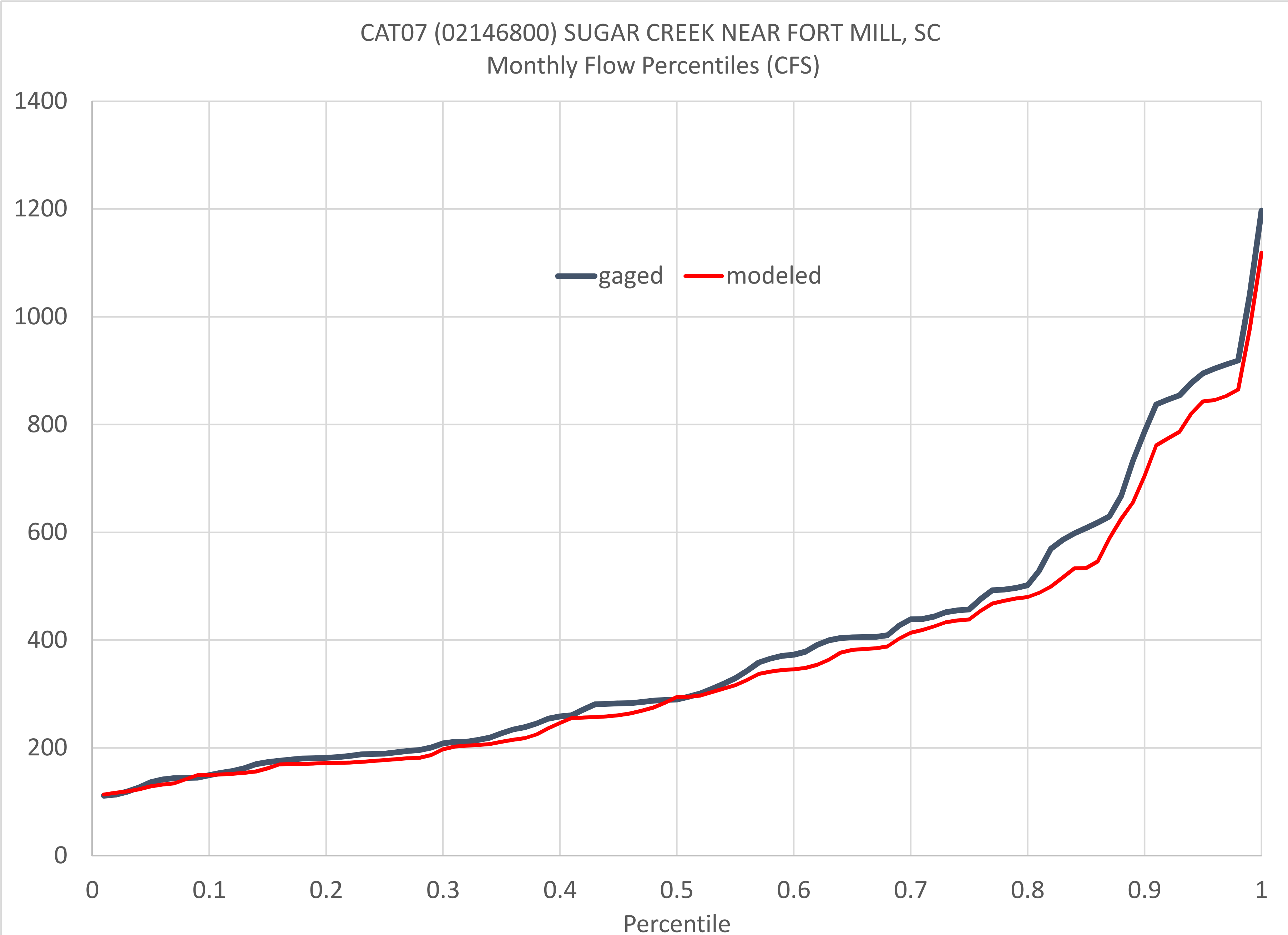

CAT07 (02146800) SUGAR CREEK NEAR FORT MILL, SC (CFS)
modeled
gaged
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

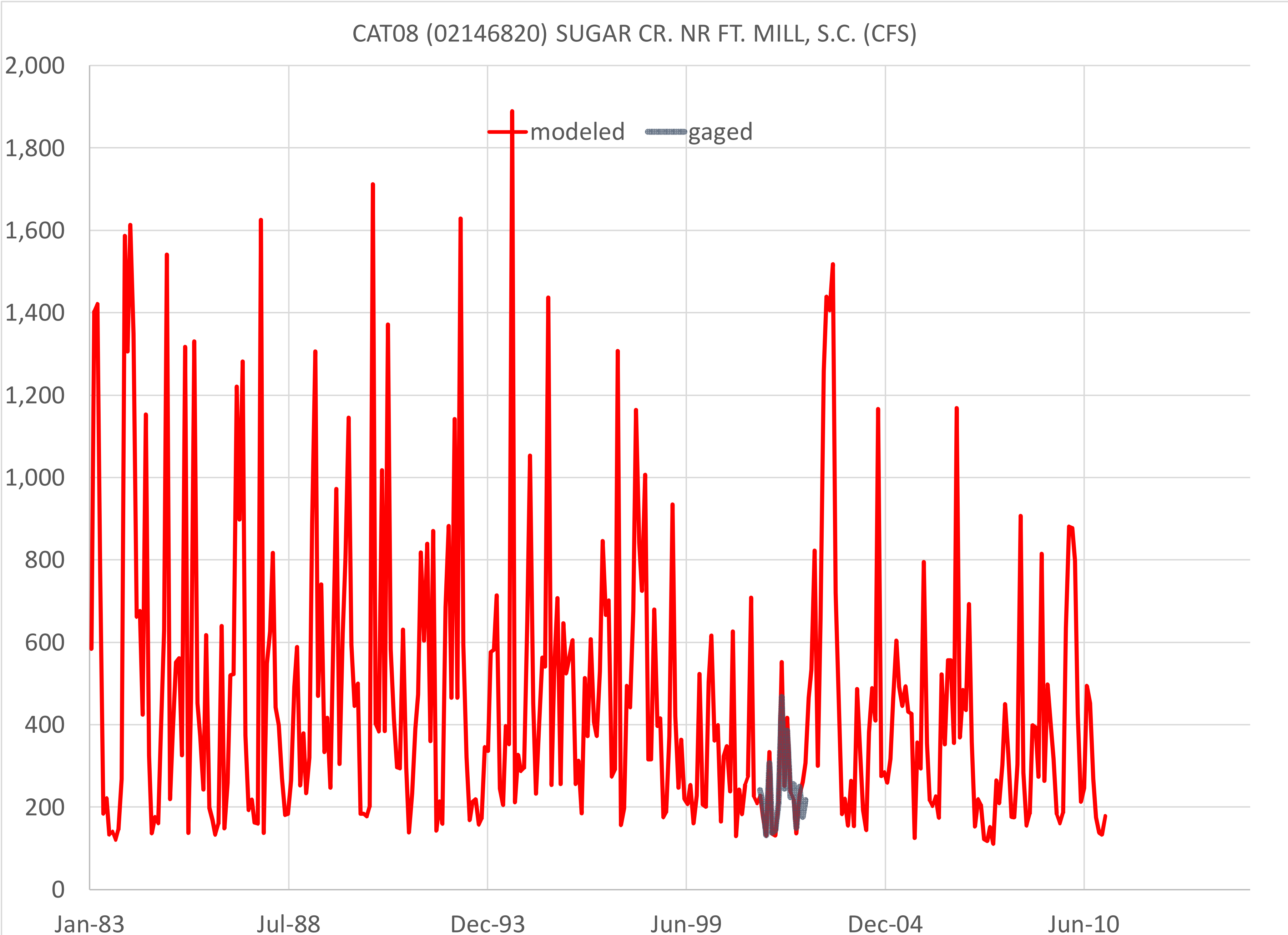


CAT07 (02146800) SUGAR CREEK NEAR FORT MILL, SC
Cumulative Flow (CFS)
modeled
gaged
25,000
20,000
15,000
10,000
5,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

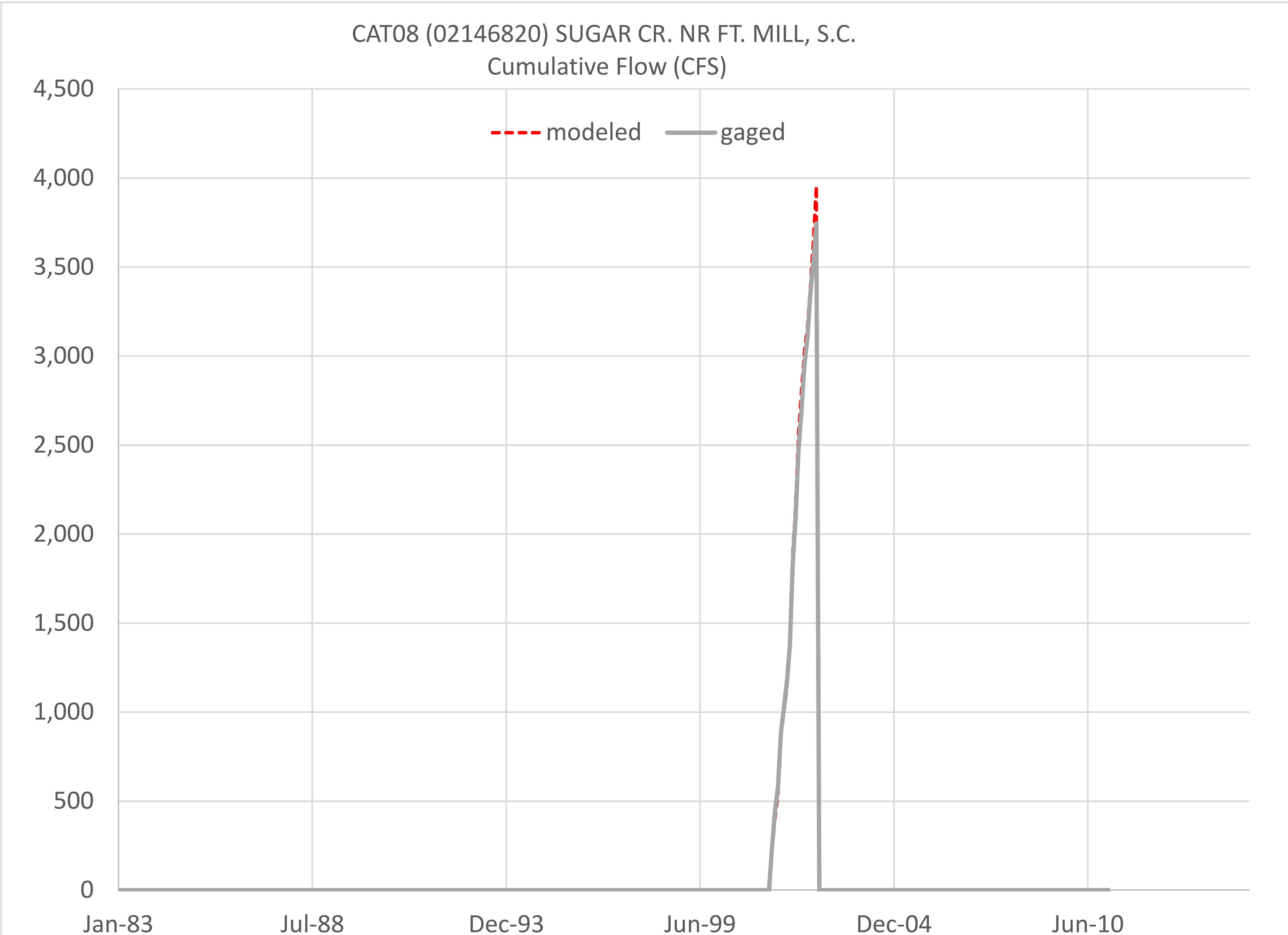

CAT07 (02146800) SUGAR CREEK NEAR FORT MILL, SC (CFS)
Annual Average Flow
gaged
modeled
600
500
400
300
200
100
0
1983
1988
1993
1998
2003
2008
2013

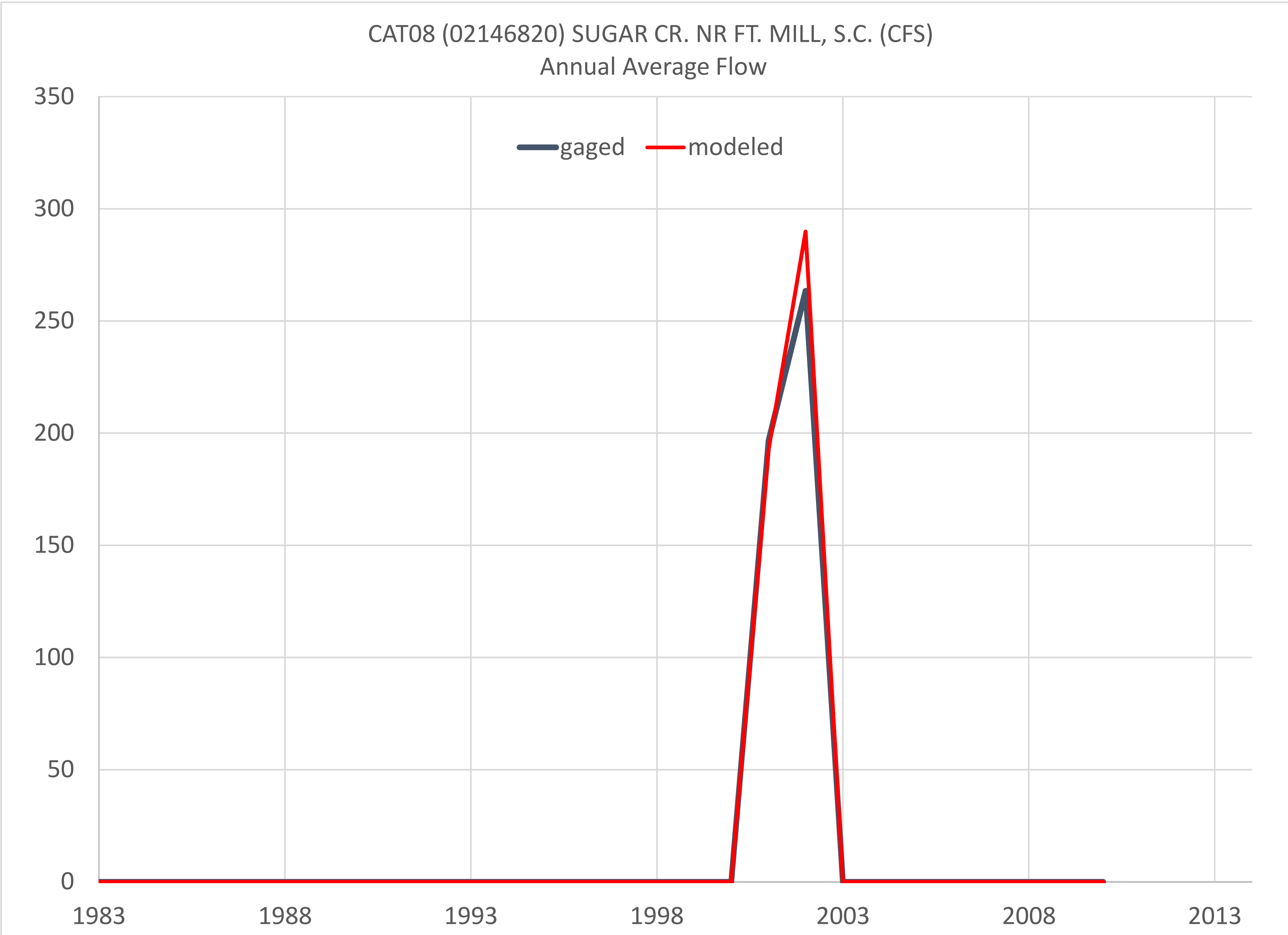

CAT07 (02146800) SUGAR CREEK NEAR FORT MILL, SC
Monthly Mean Flow (CFS)
gaged
modeled
700
600
500
400
300
200
100
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

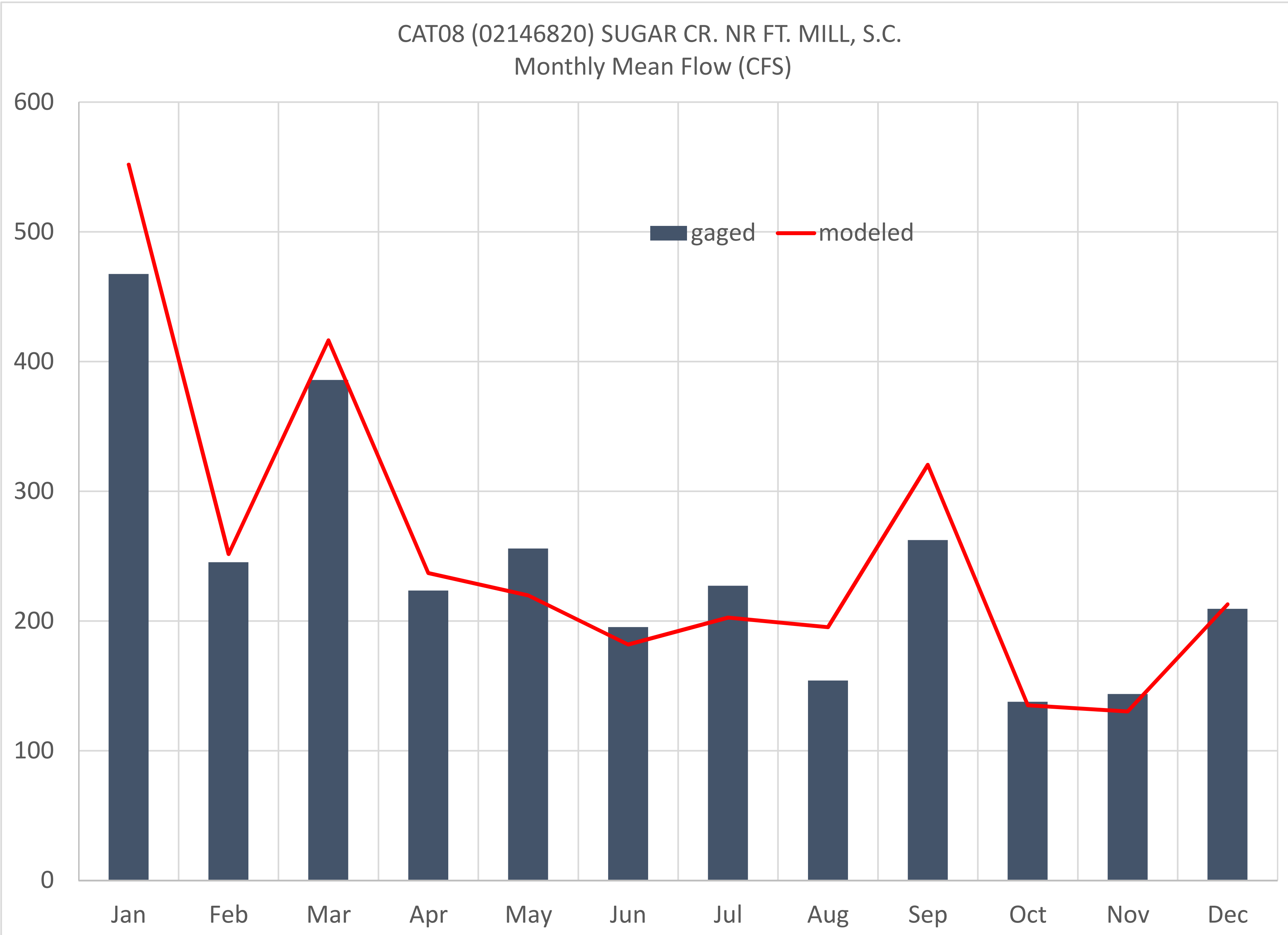

CAT07 (02146800) SUGAR CREEK NEAR FORT MILL, SC
Monthly Flow Percentiles (CFS)
gaged
modeled
1400
1200
1000
800
600
400
200
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile



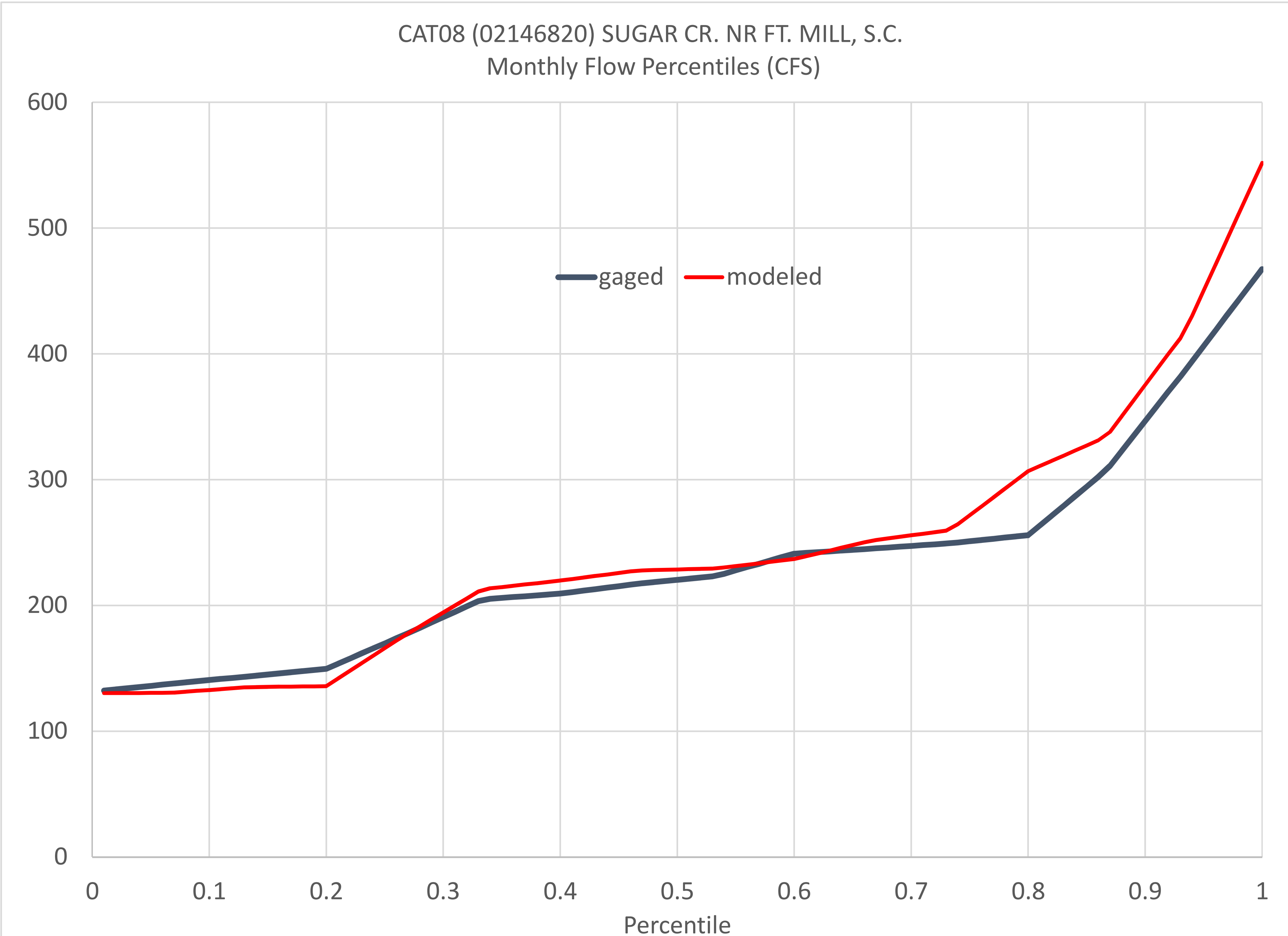
CAT08 (02146820) SUGAR CR. NR FT. MILL, S.C. (CFS)
modeled
gaged
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

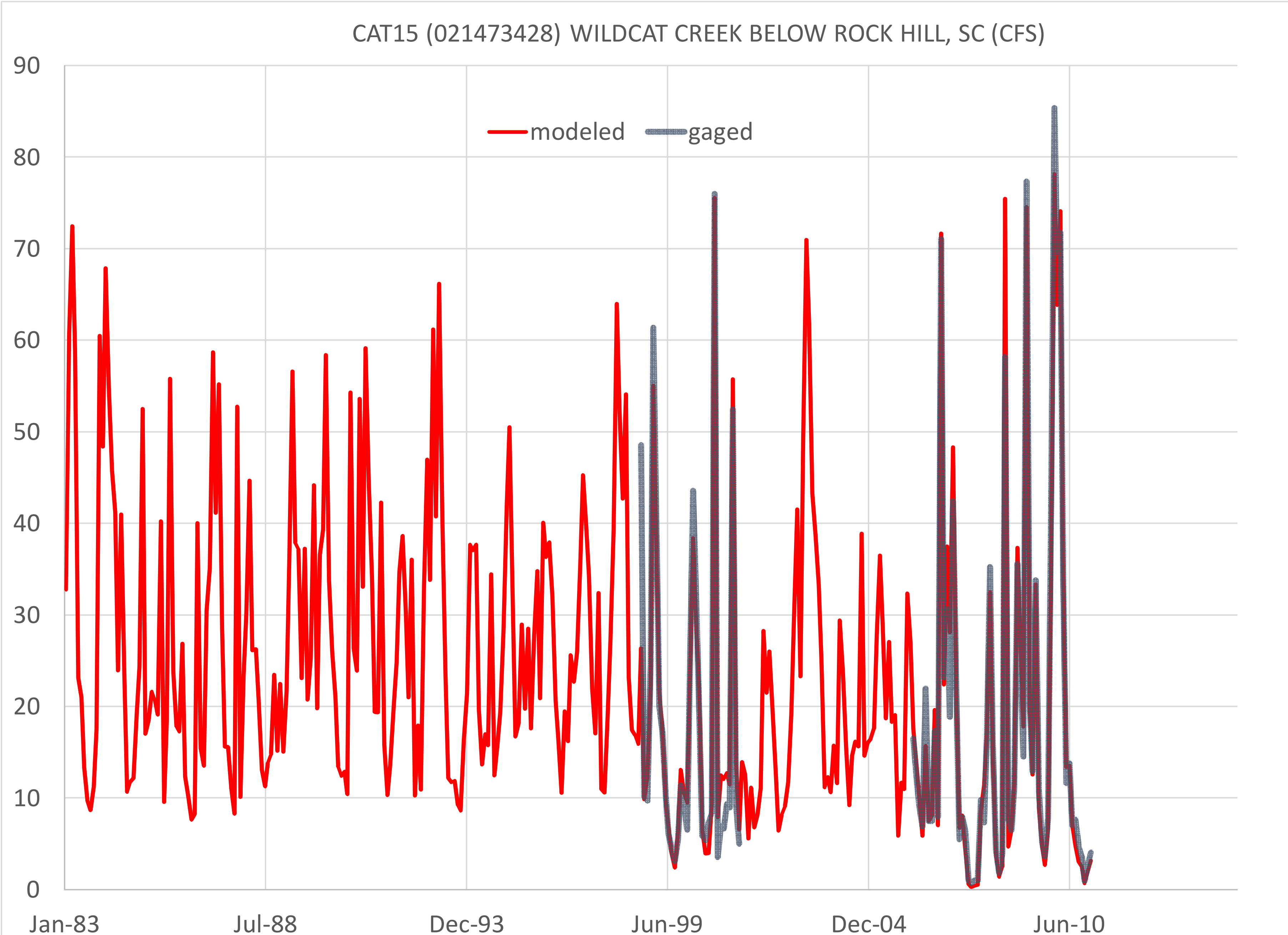

CAT08 (02146820) SUGAR CR. NR FT. MILL, S.C.
Cumulative Flow (CFS)
modeled
gaged
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

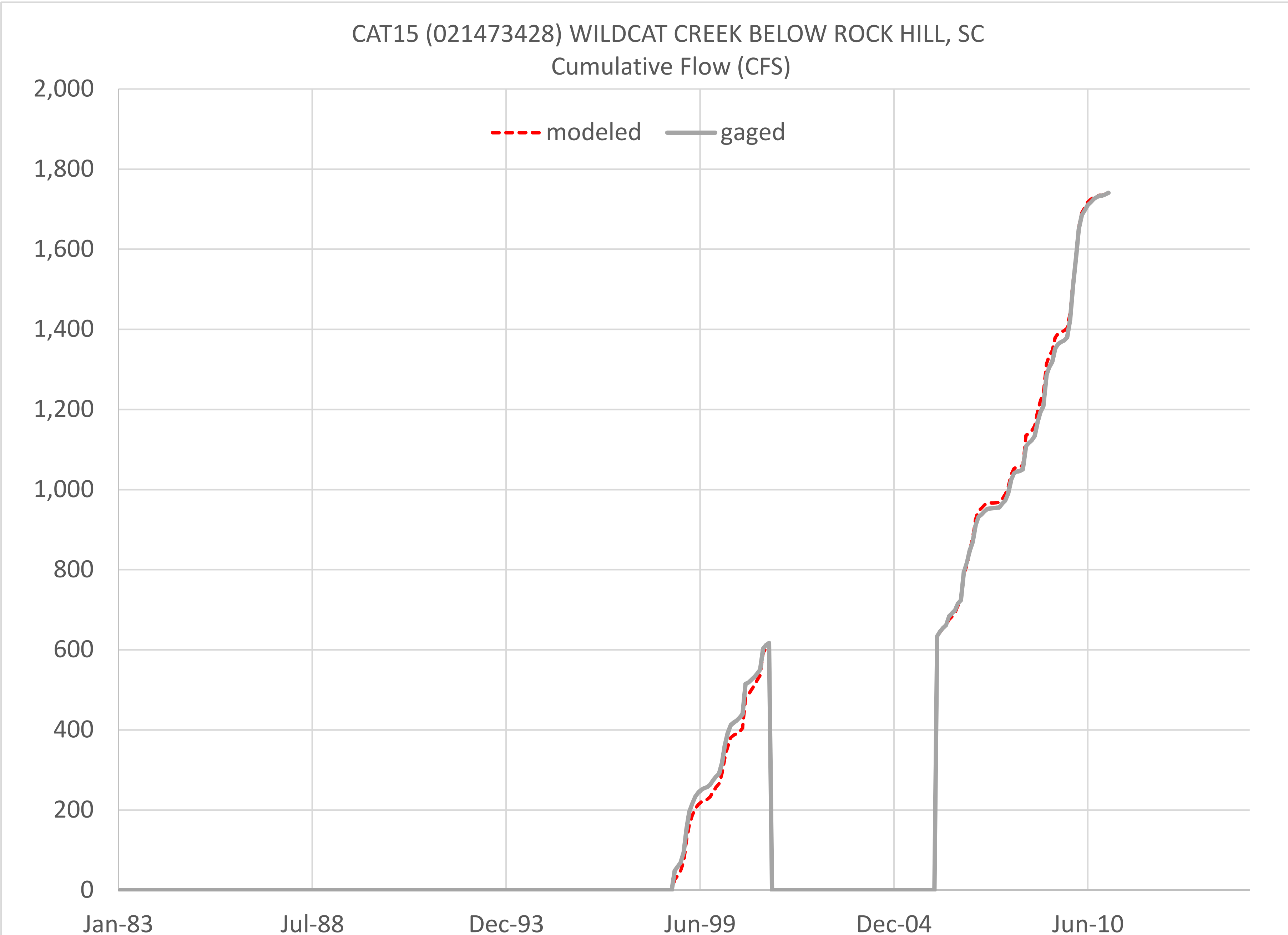

CAT08 (02146820) SUGAR CR. NR FT. MILL, S.C. (CFS)
Annual Average Flow
gaged
modeled
350
300
250
200
150
100
50
0
1983
1988
1993
1998
2003
2008
2013



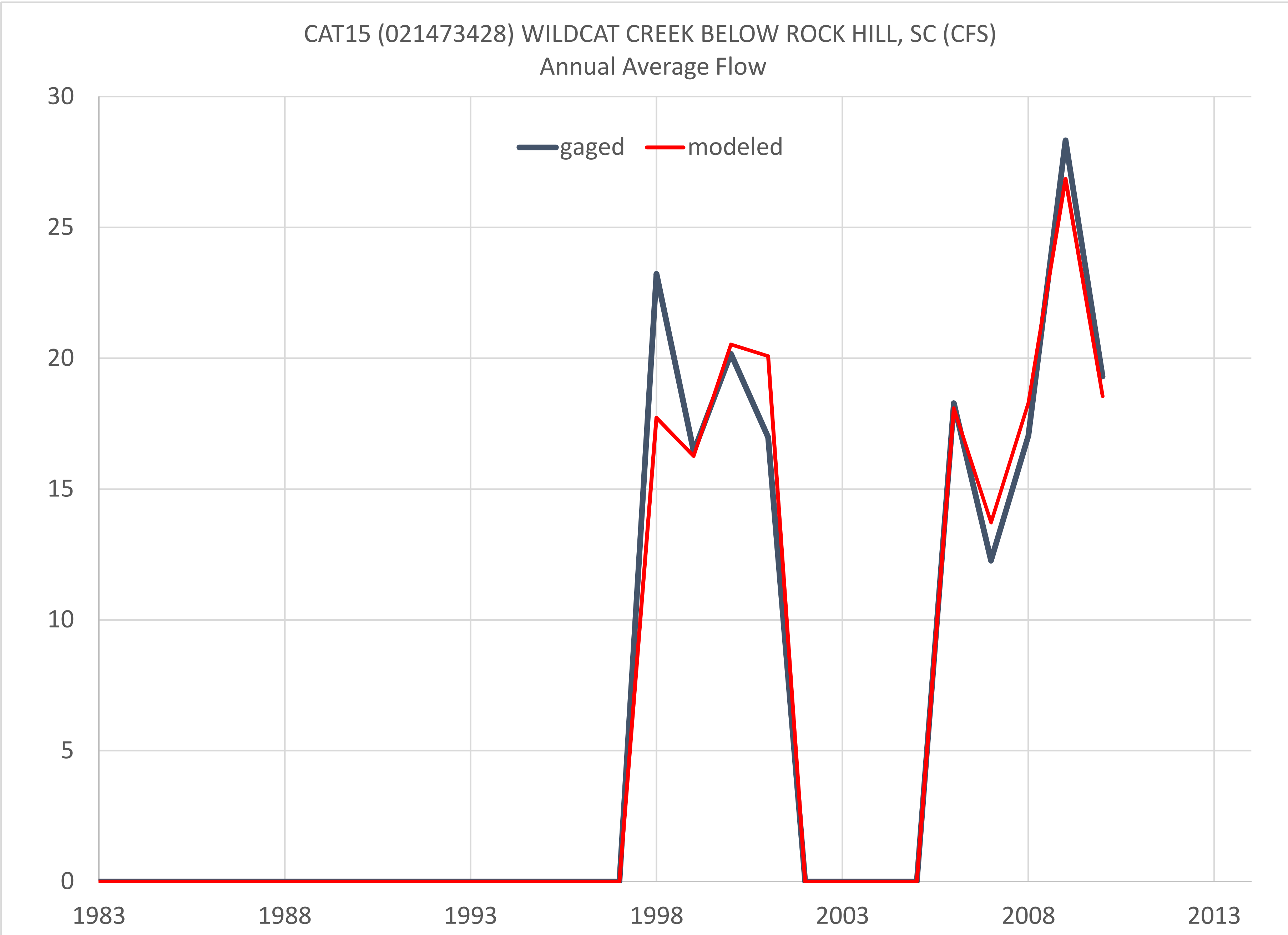
CAT08 (02146820) SUGAR CR. NR FT. MILL, S.C.
Monthly Mean Flow (CFS)
600
500
400
300
200
100
0
gaged
modeled
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


CAT08 (02146820) SUGAR CR. NR FT. MILL, S.C.
Monthly Flow Percentiles (CFS)
600
500
400
300
200
100
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile
gaged
modeled

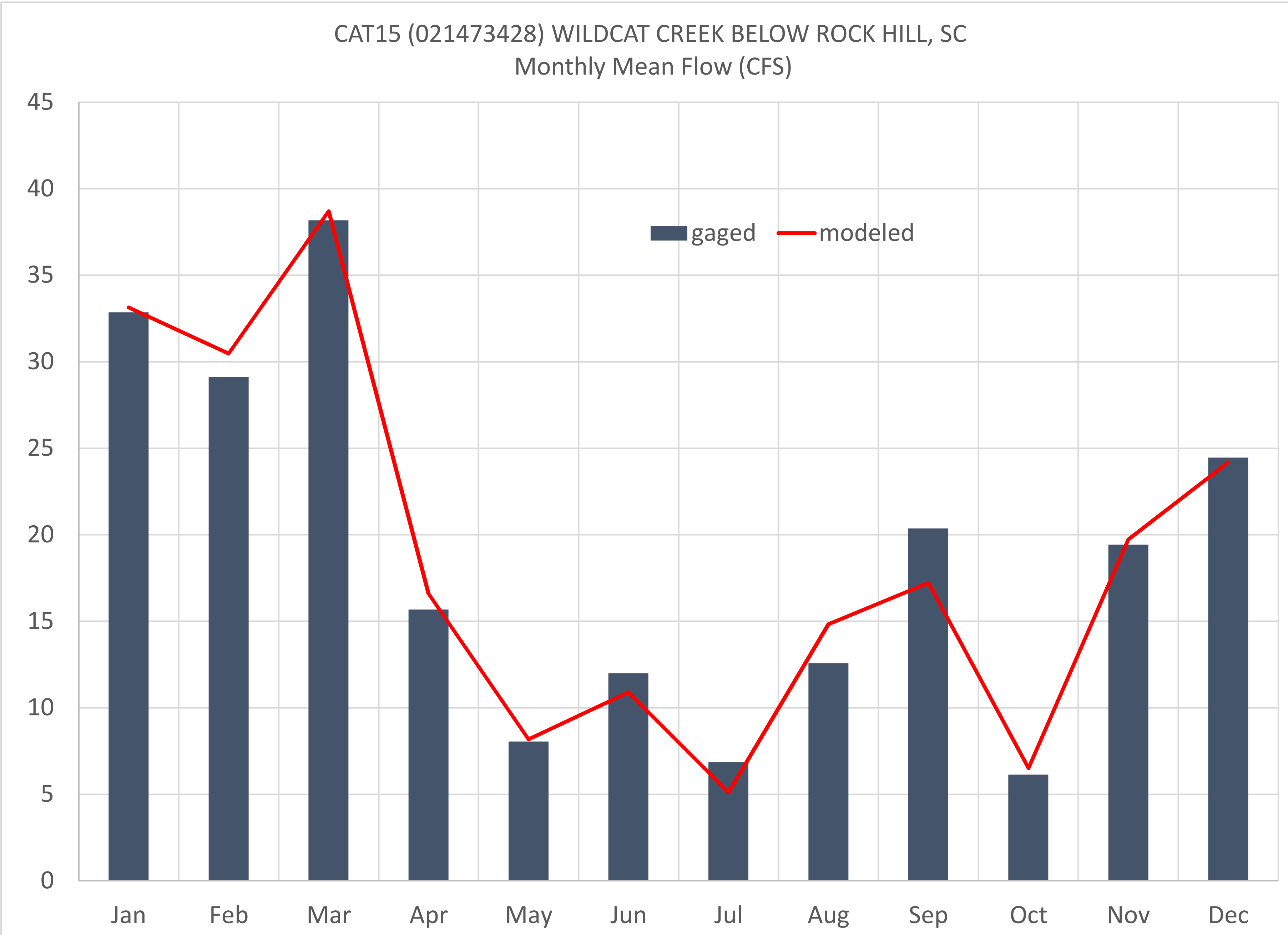

CAT15 (021473428) WILDCAT CREEK BELOW ROCK HILL, SC (CFS)
modeled
gaged
90
80
70
60
50
40
30
20
10
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10



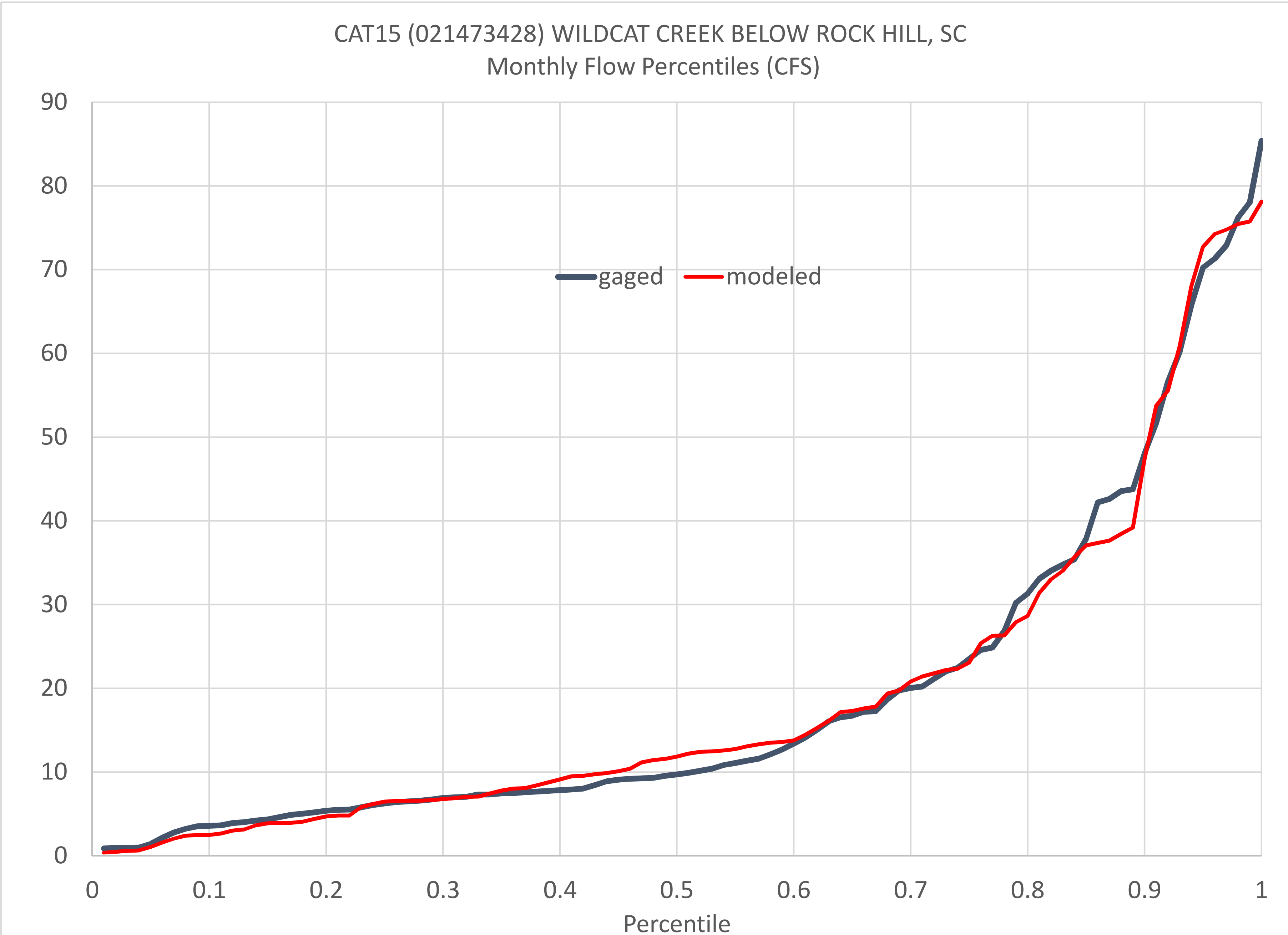
CAT15 (021473428) WILDCAT CREEK BELOW ROCK HILL, SC
Cumulative Flow (CFS)
modeled
gaged
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

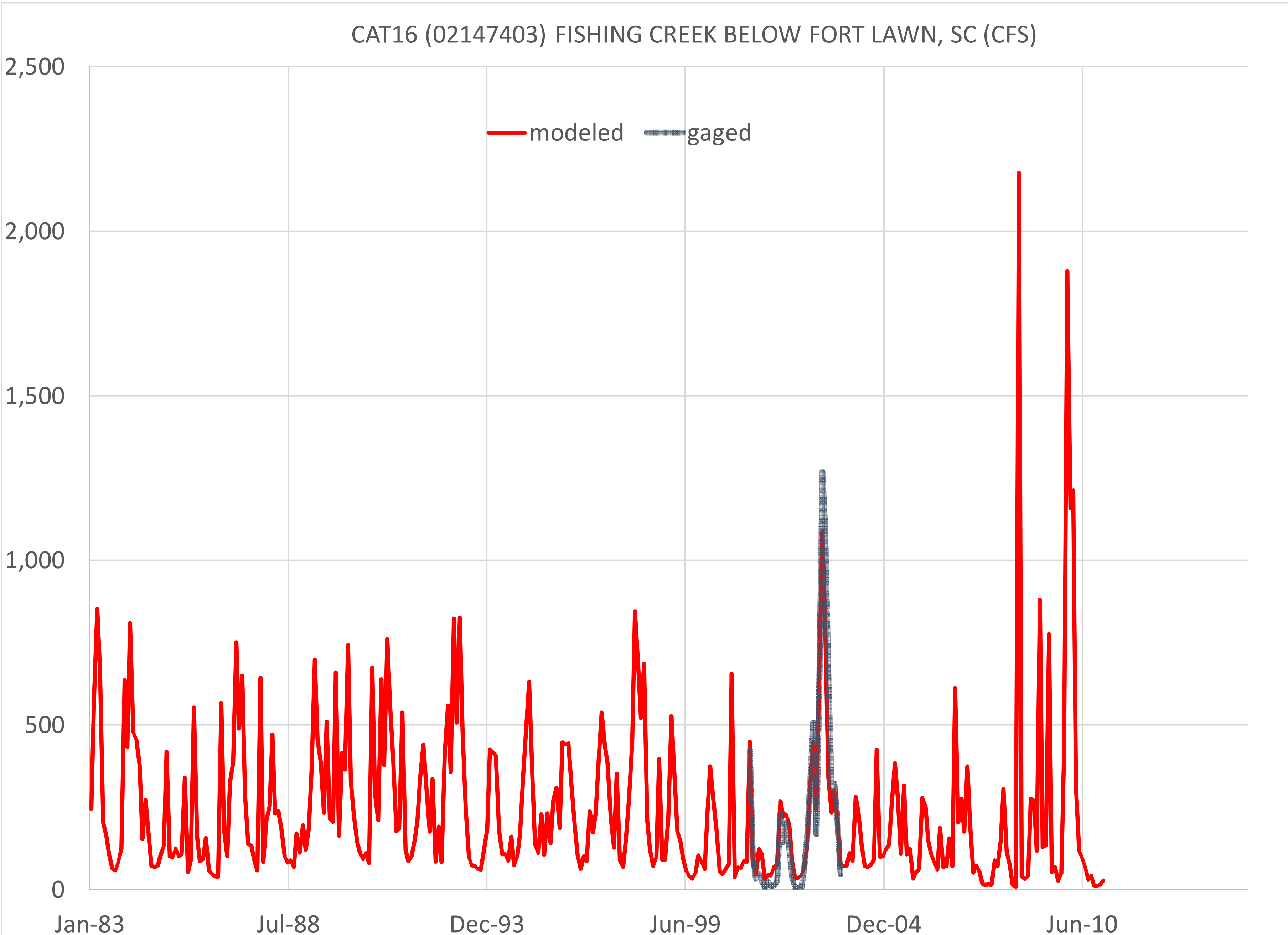


CAT15 (021473428) WILDCAT CREEK BELOW ROCK HILL, SC (CFS)
Annual Average Flow
gaged
modeled
30
25
20
15
10
5
0
1983
1988
1993
1998
2003
2008
2013

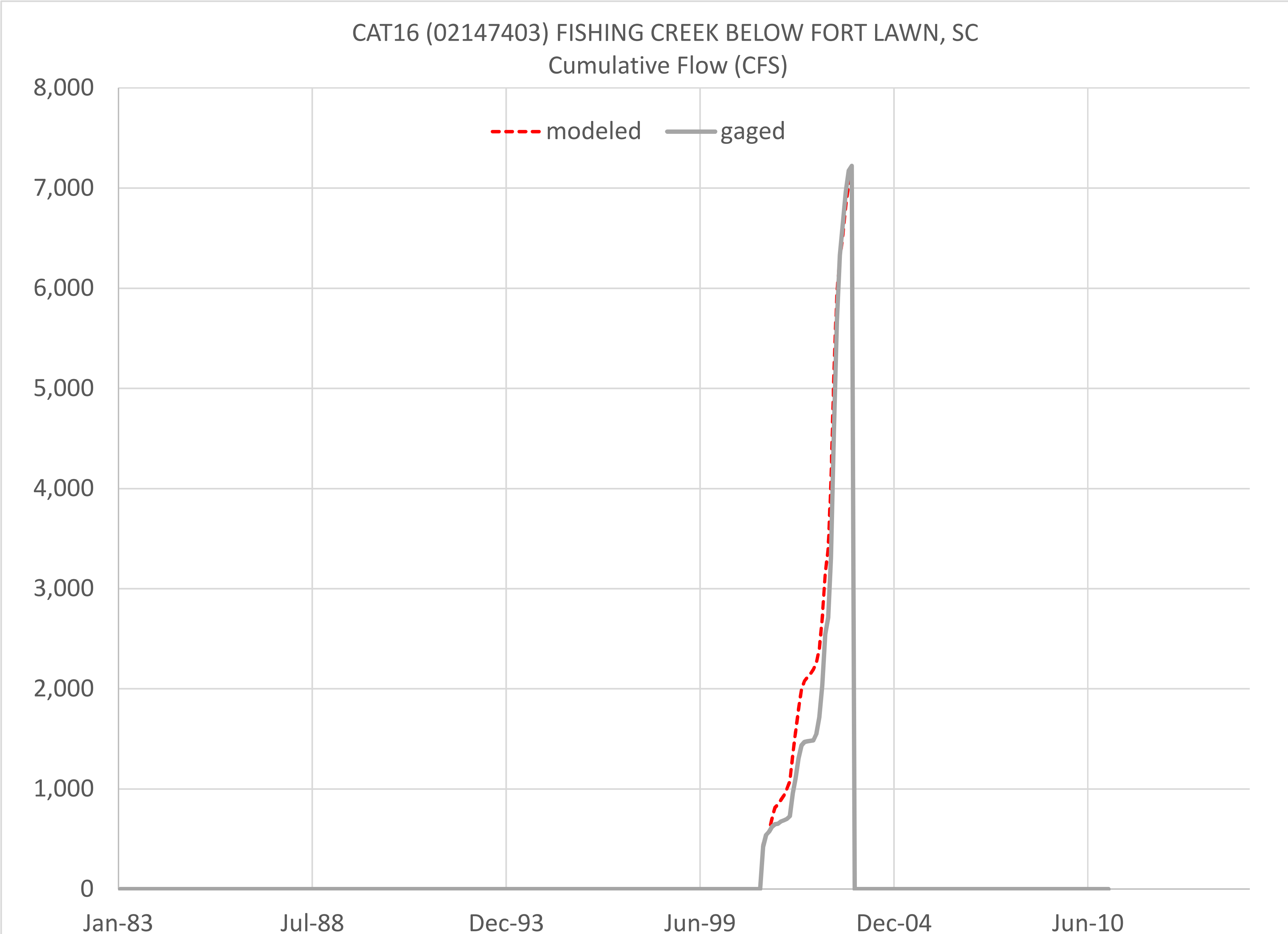


CAT15 (021473428) WILDCAT CREEK BELOW ROCK HILL, SC
Monthly Mean Flow (CFS)
gaged
modeled
0
5
10
15
20
25
30
35
40
45
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

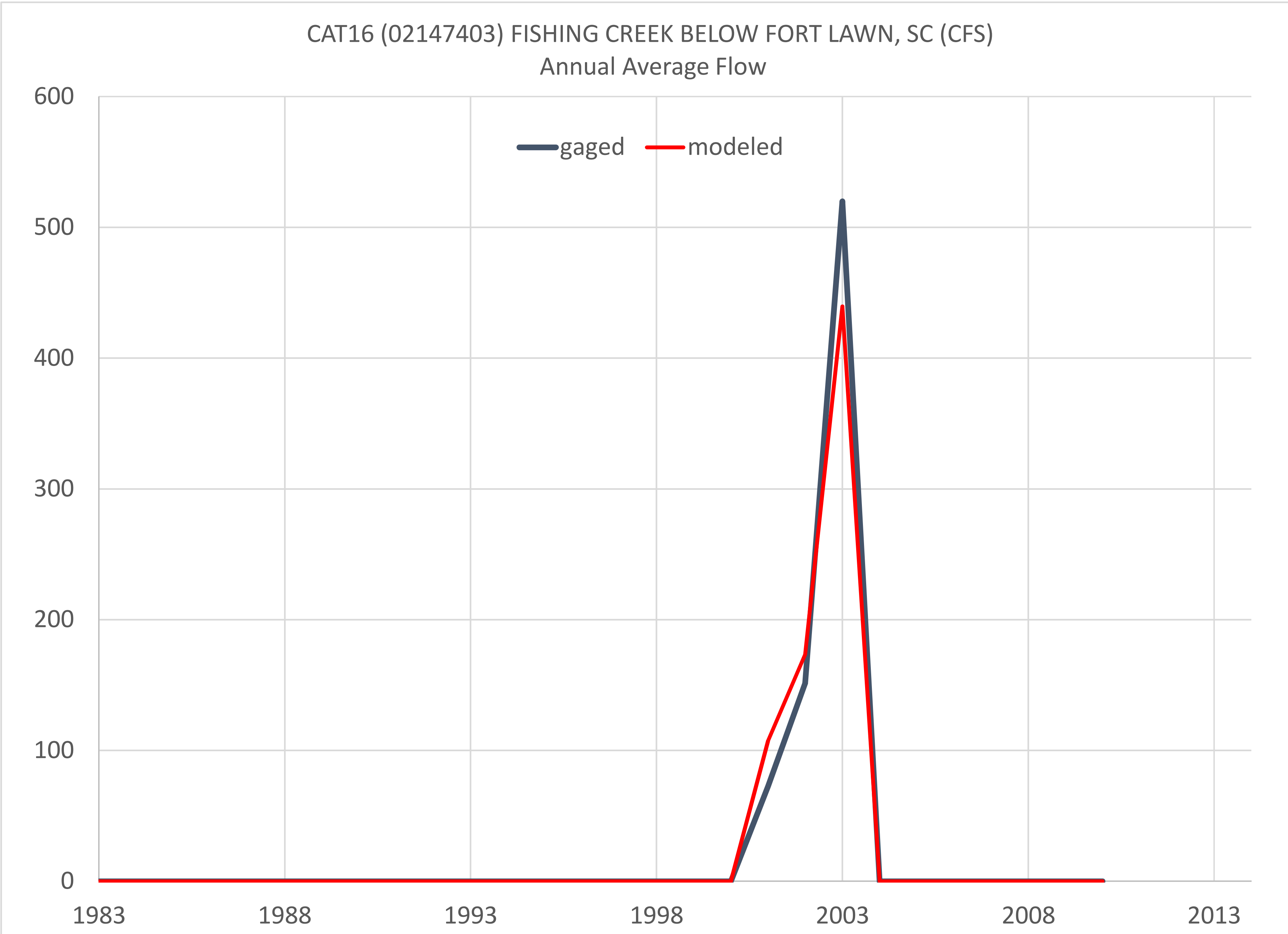

CAT15 (021473428) WILDCAT CREEK BELOW ROCK HILL, SC
Monthly Flow Percentiles (CFS)
gaged
modeled
0
10
20
30
40
50
60
70
80
90
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile



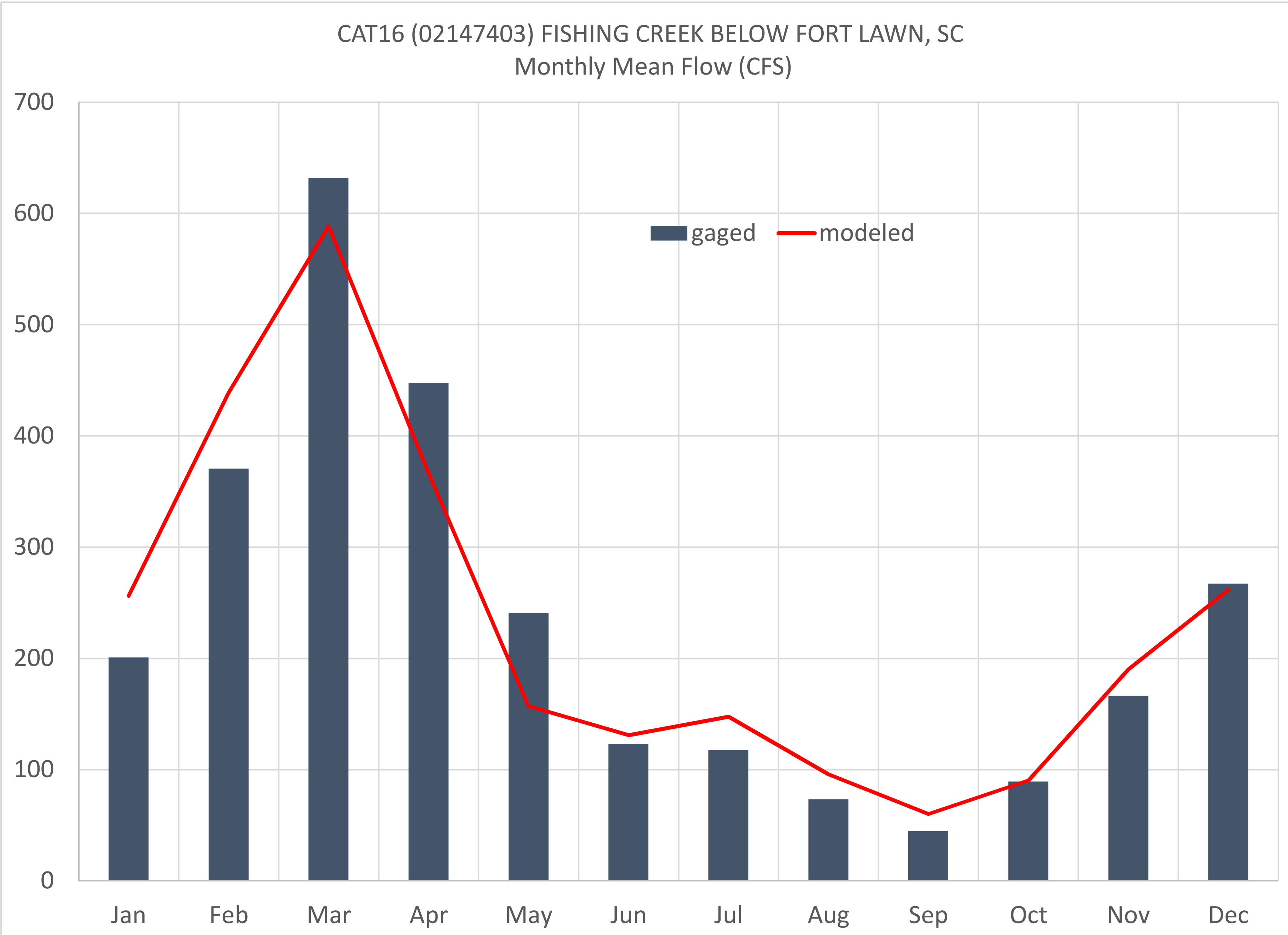
CAT16 (02147403) FISHING CREEK BELOW FORT LAWN, SC (CFS)
modeled
gaged
2,500
2,000
1,500
1,000
500
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

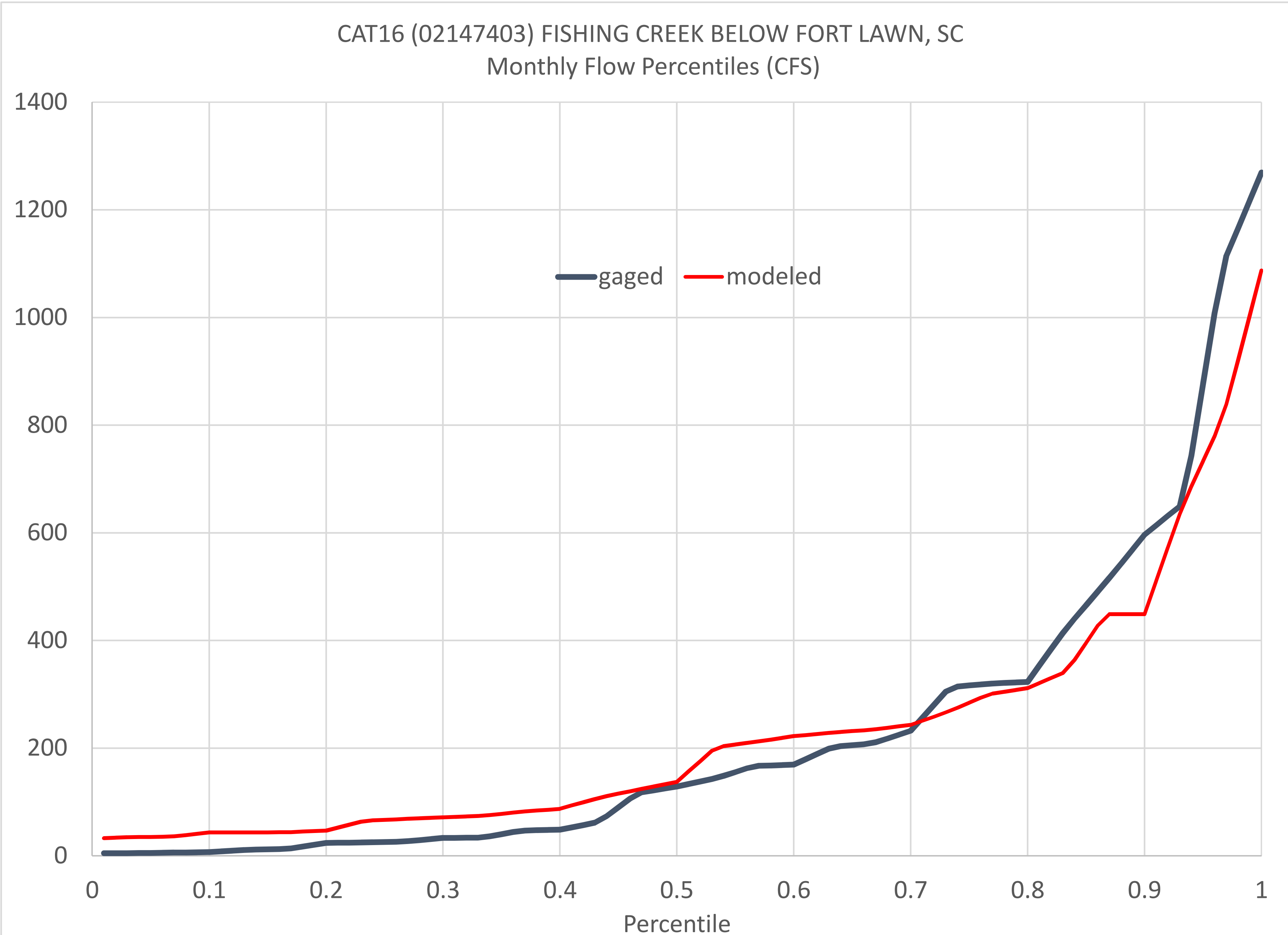


CAT16 (02147403) FISHING CREEK BELOW FORT LAWN, SC
Cumulative Flow (CFS)
modeled
gaged
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

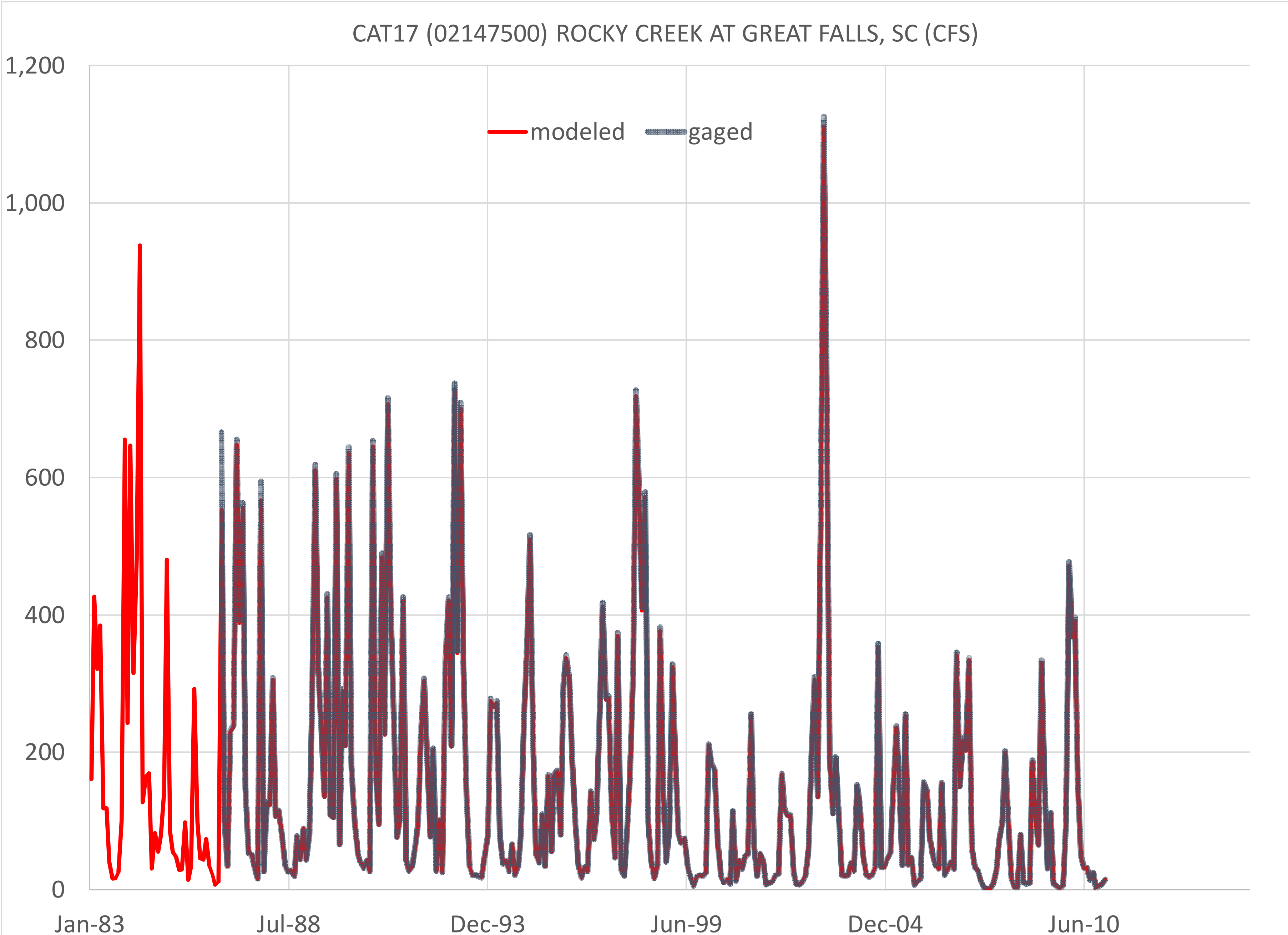


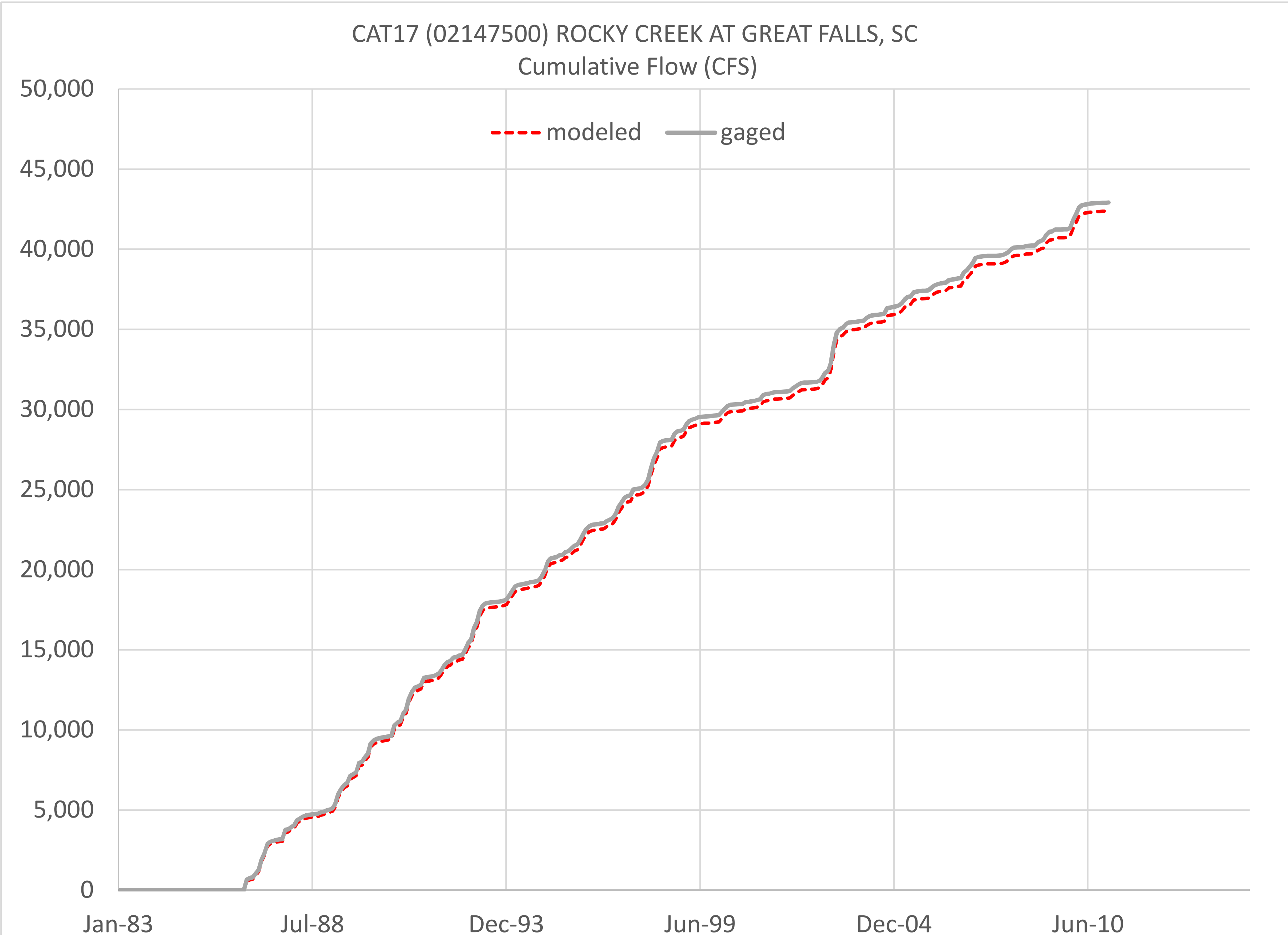
CAT16 (02147403) FISHING CREEK BELOW FORT LAWN, SC (CFS)
Annual Average Flow
gaged
modeled
600
500
400
300
200
100
0
1983
1988
1993
1998
2003
2008
2013

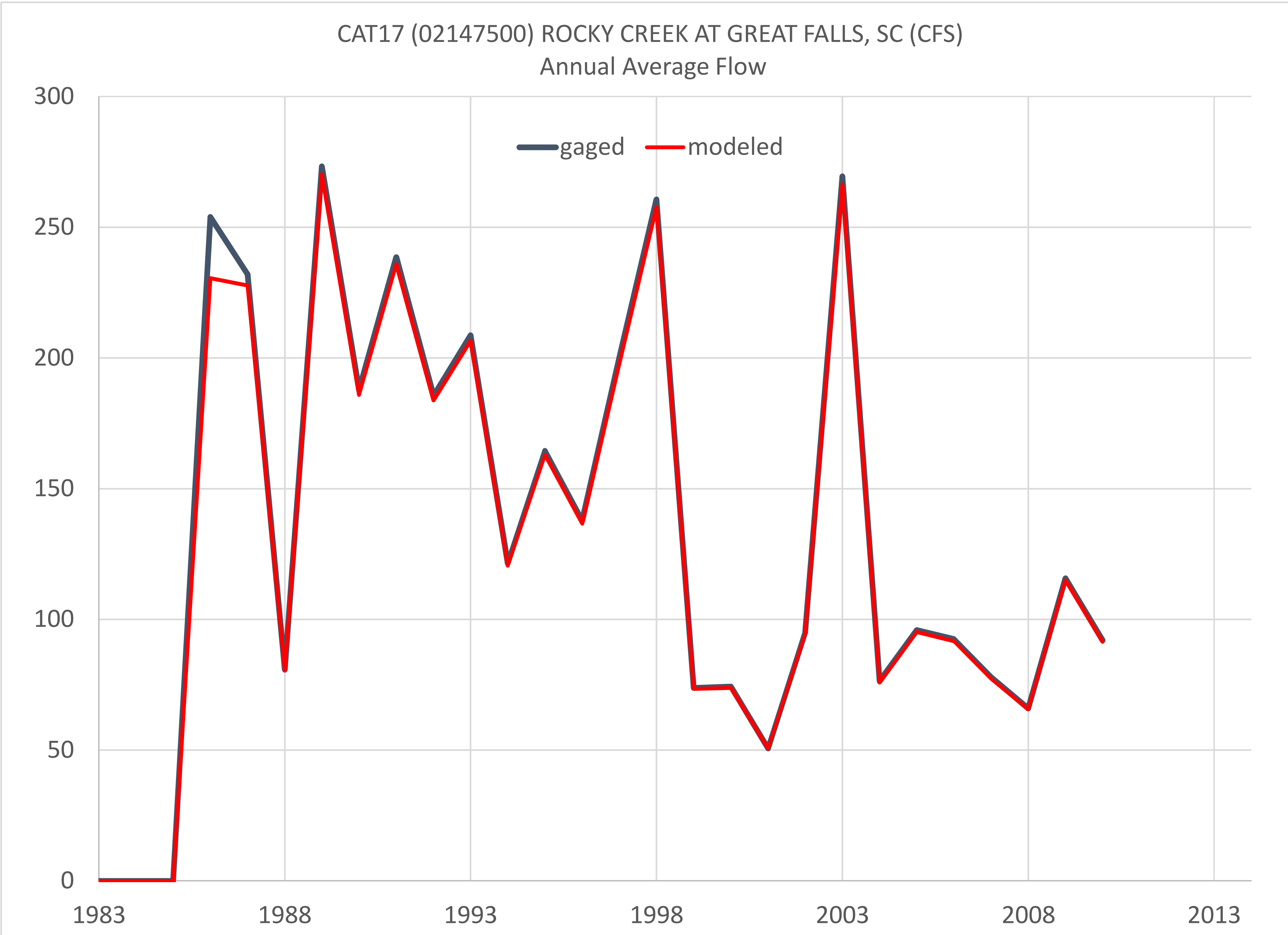

CAT16 (02147403) FISHING CREEK BELOW FORT LAWN, SC
Monthly Mean Flow (CFS)
gaged
modeled
0
100
200
300
400
500
600
700
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

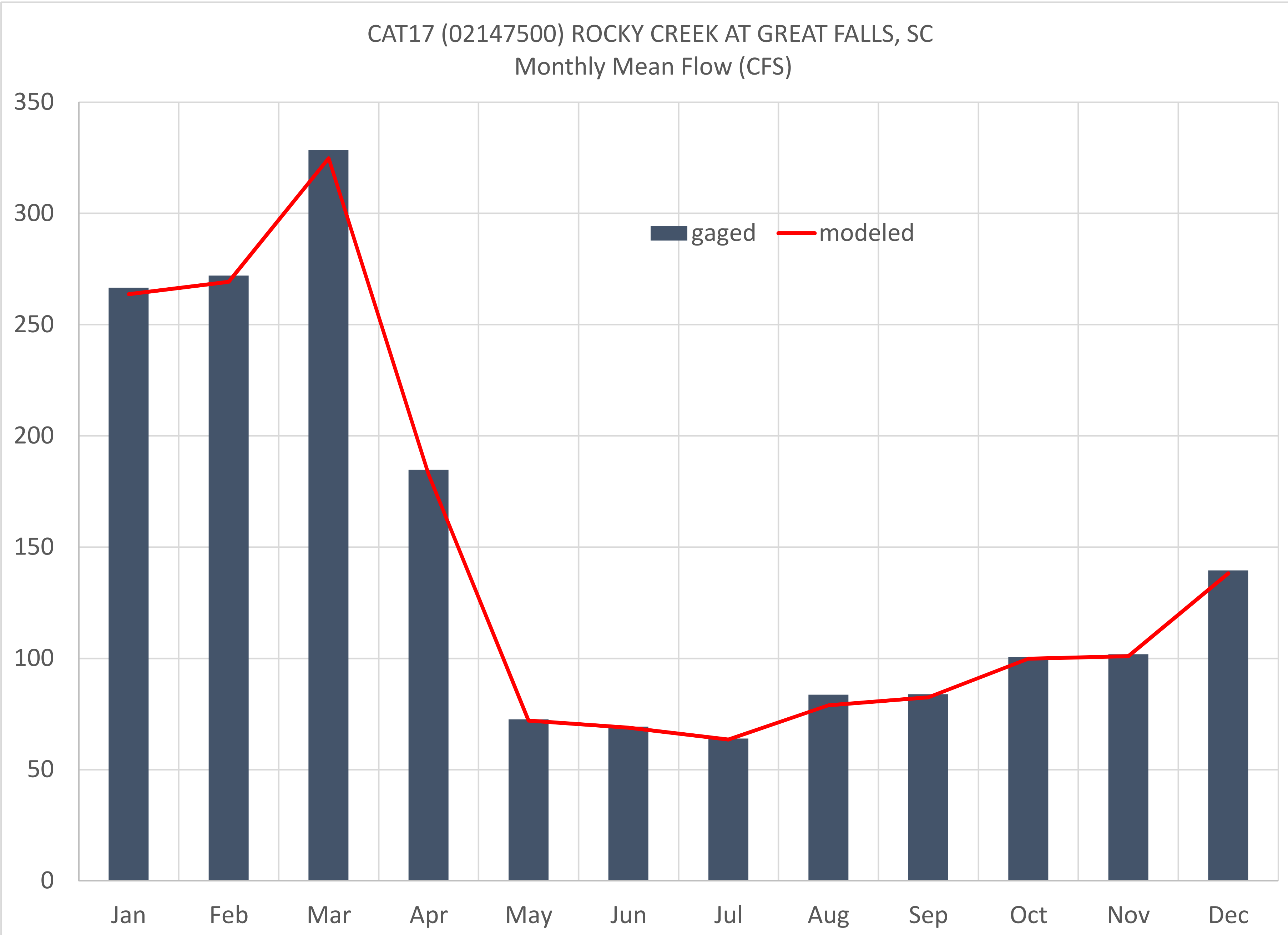


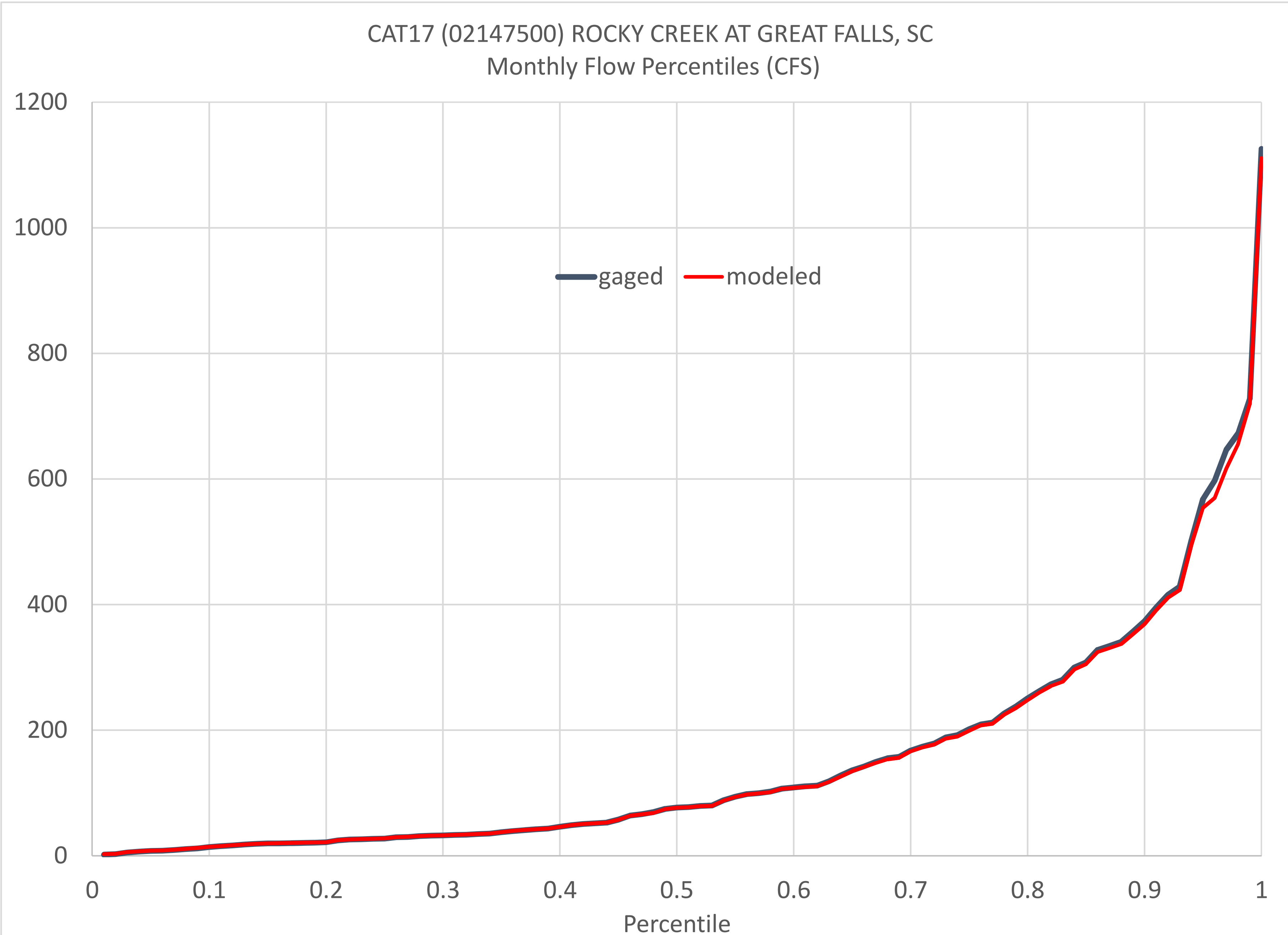
CAT16 (02147403) FISHING CREEK BELOW FORT LAWN, SC
Monthly Flow Percentiles (CFS)
1400
1200
1000
800
600
400
200
0
gaged
modeled
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

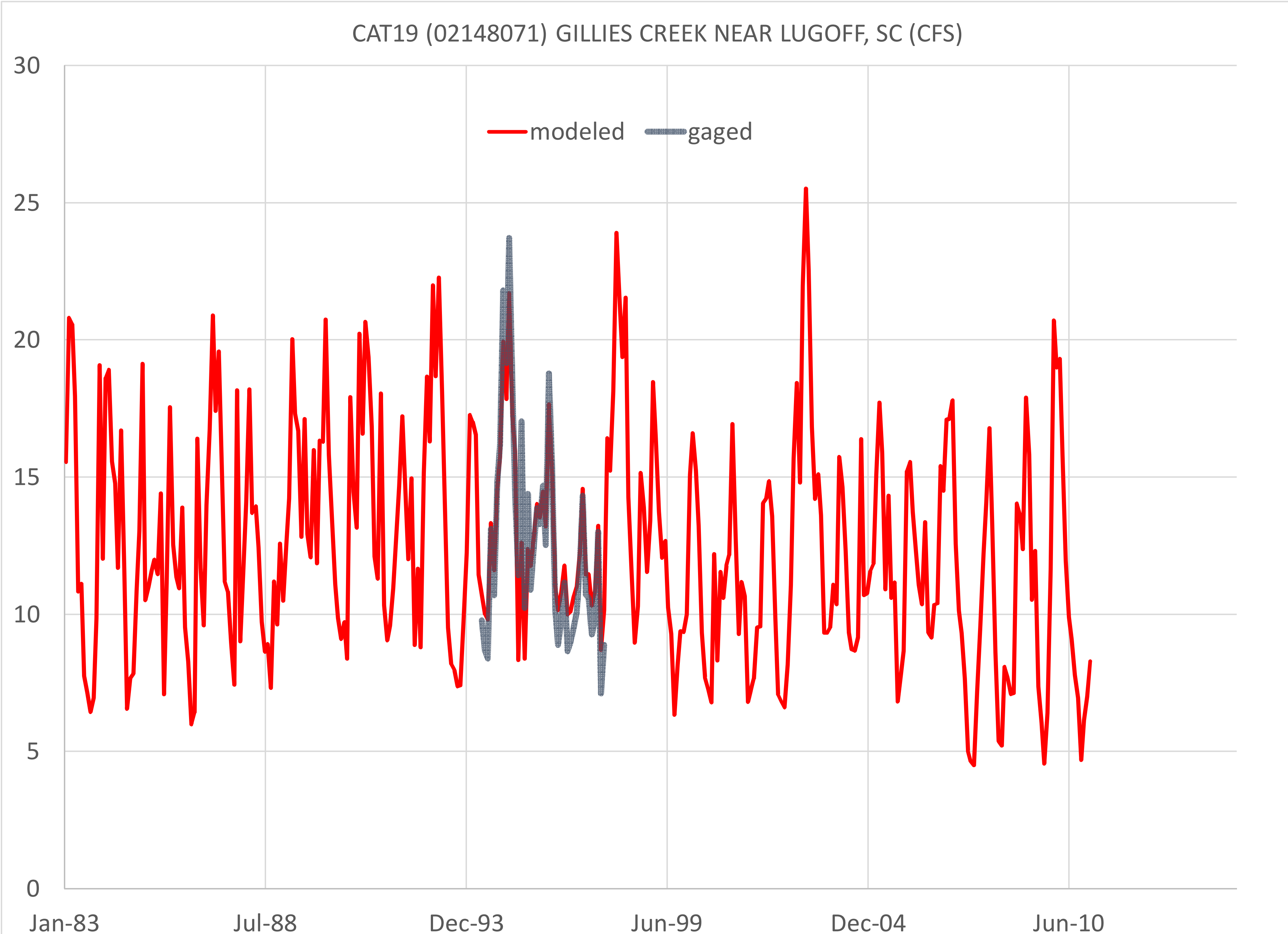

CAT17 (02147500) ROCKY CREEK AT GREAT FALLS, SC (CFS)
modeled
gaged
1,200
1,000
800
600
400
200
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10


CAT17 (02147500) ROCKY CREEK AT GREAT FALLS, SC
Cumulative Flow (CFS)
modeled
gaged
50,000
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

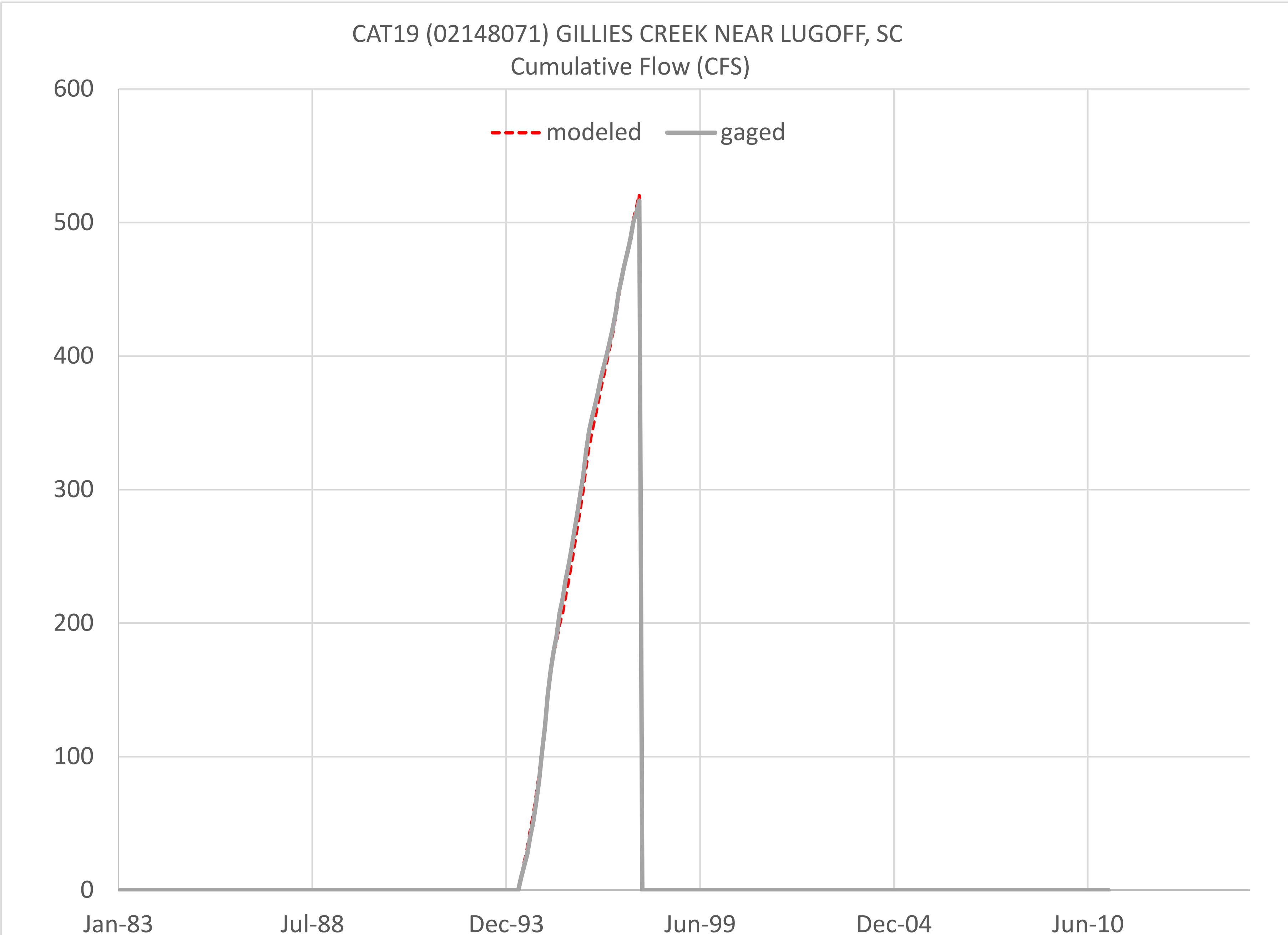

CAT17 (02147500) ROCKY CREEK AT GREAT FALLS, SC (CFS)
Annual Average Flow
gaged
modeled
300
250
200
150
100
50
0
1983
1988
1993
1998
2003
2008
2013

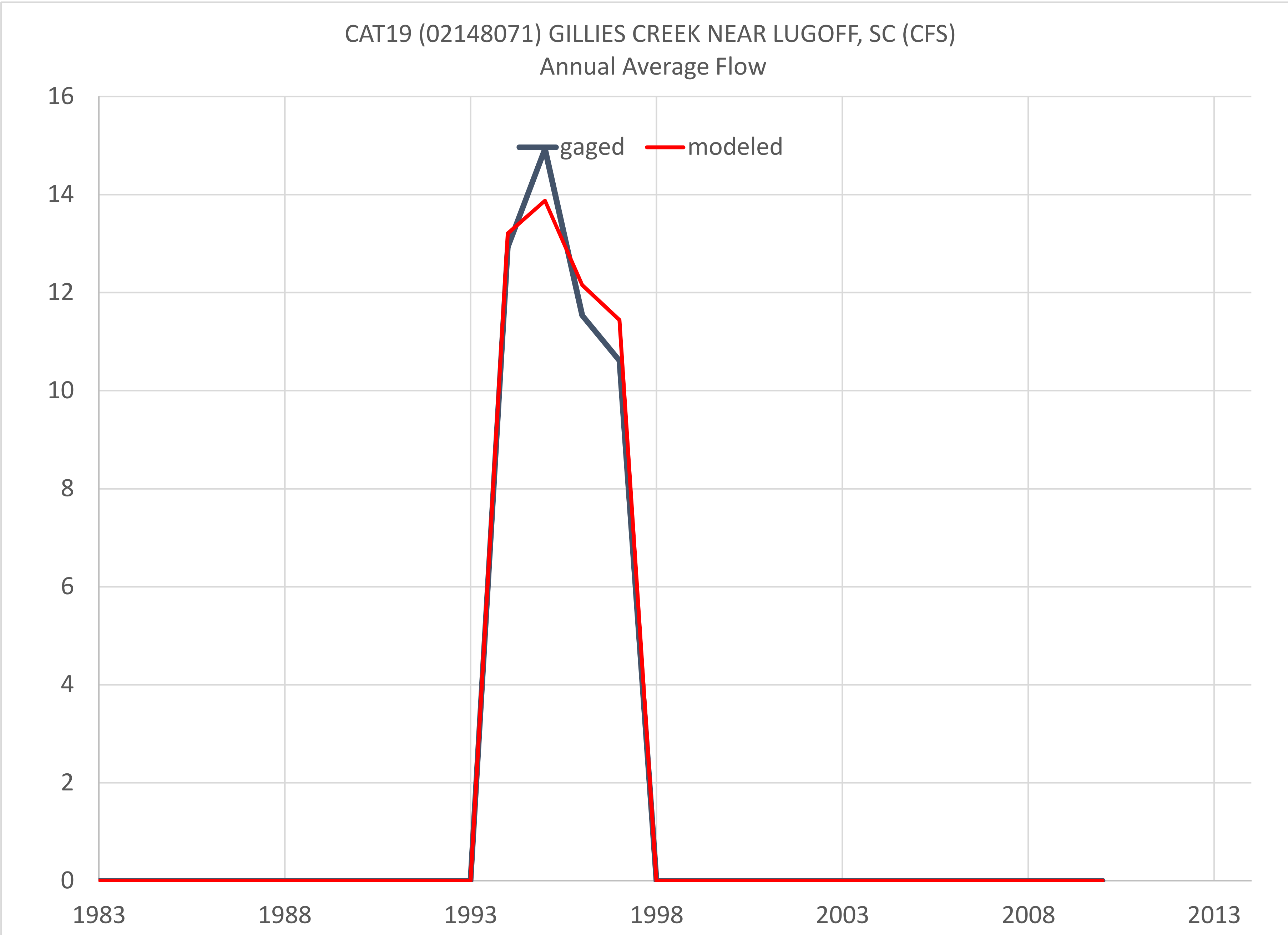

CAT17 (02147500) ROCKY CREEK AT GREAT FALLS, SC
Monthly Mean Flow (CFS)
gaged
modeled
350
300
250
200
150
100
50
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

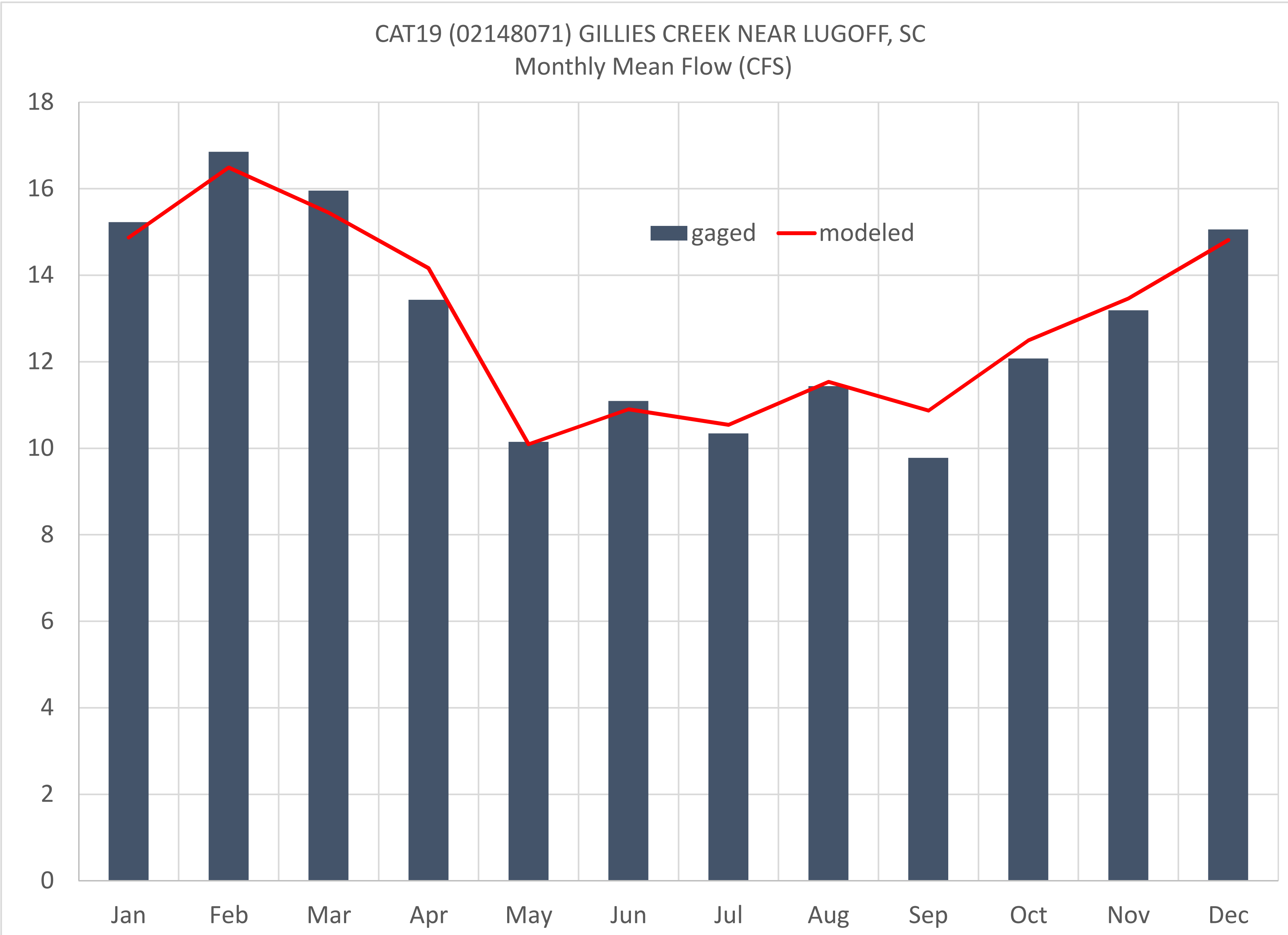

CAT17 (02147500) ROCKY CREEK AT GREAT FALLS, SC
Monthly Flow Percentiles (CFS)
gaged
modeled
1200
1000
800
600
400
200
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

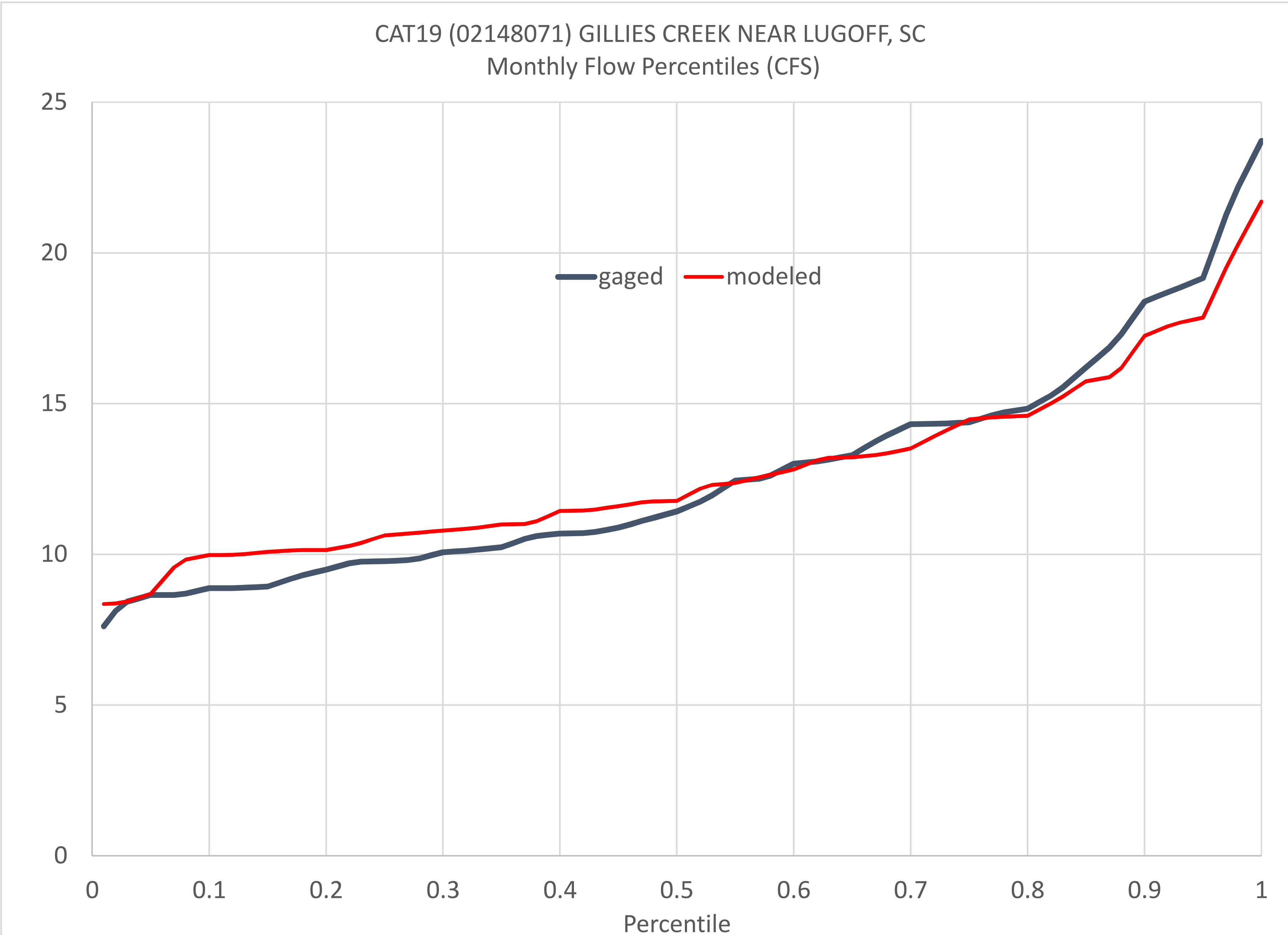


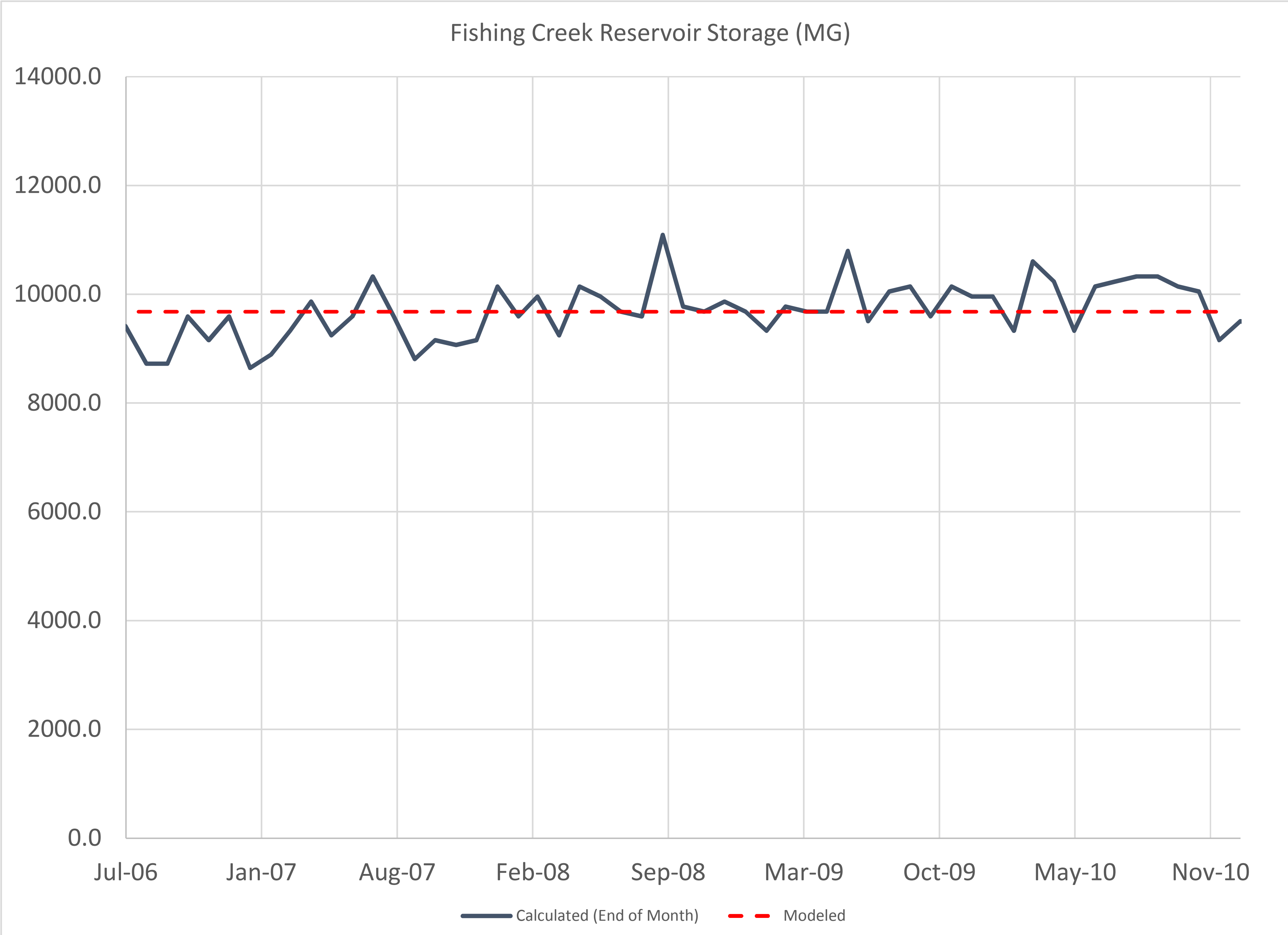
CAT19 (02148071) GILLIES CREEK NEAR LUGOFF, SC (CFS)
modeled
gaged
30
25
20
15
10
5
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

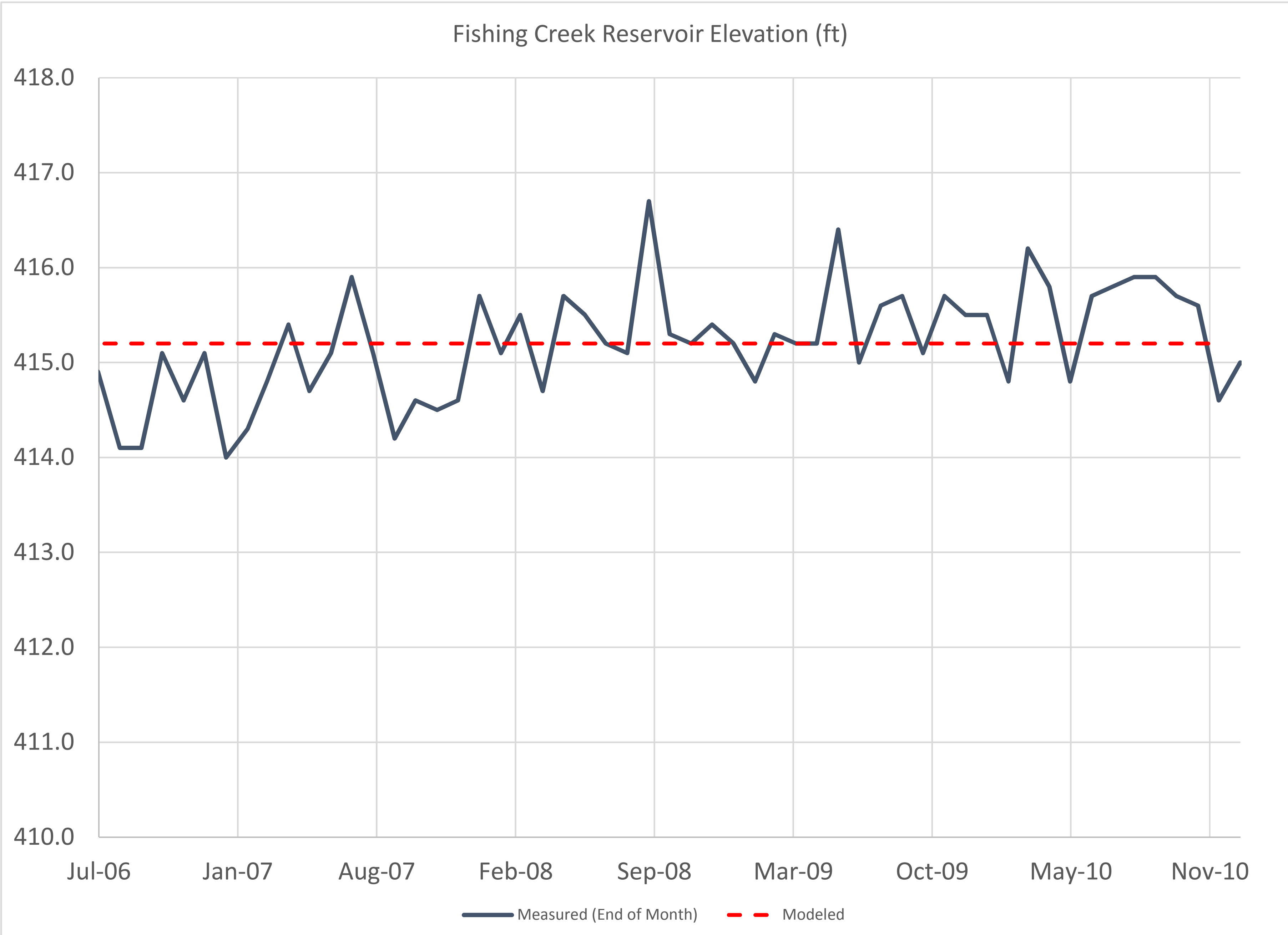

CAT19 (02148071) GILLIES CREEK NEAR LUGOFF, SC
Cumulative Flow (CFS)
modeled
gaged
600
500
400
300
200
100
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

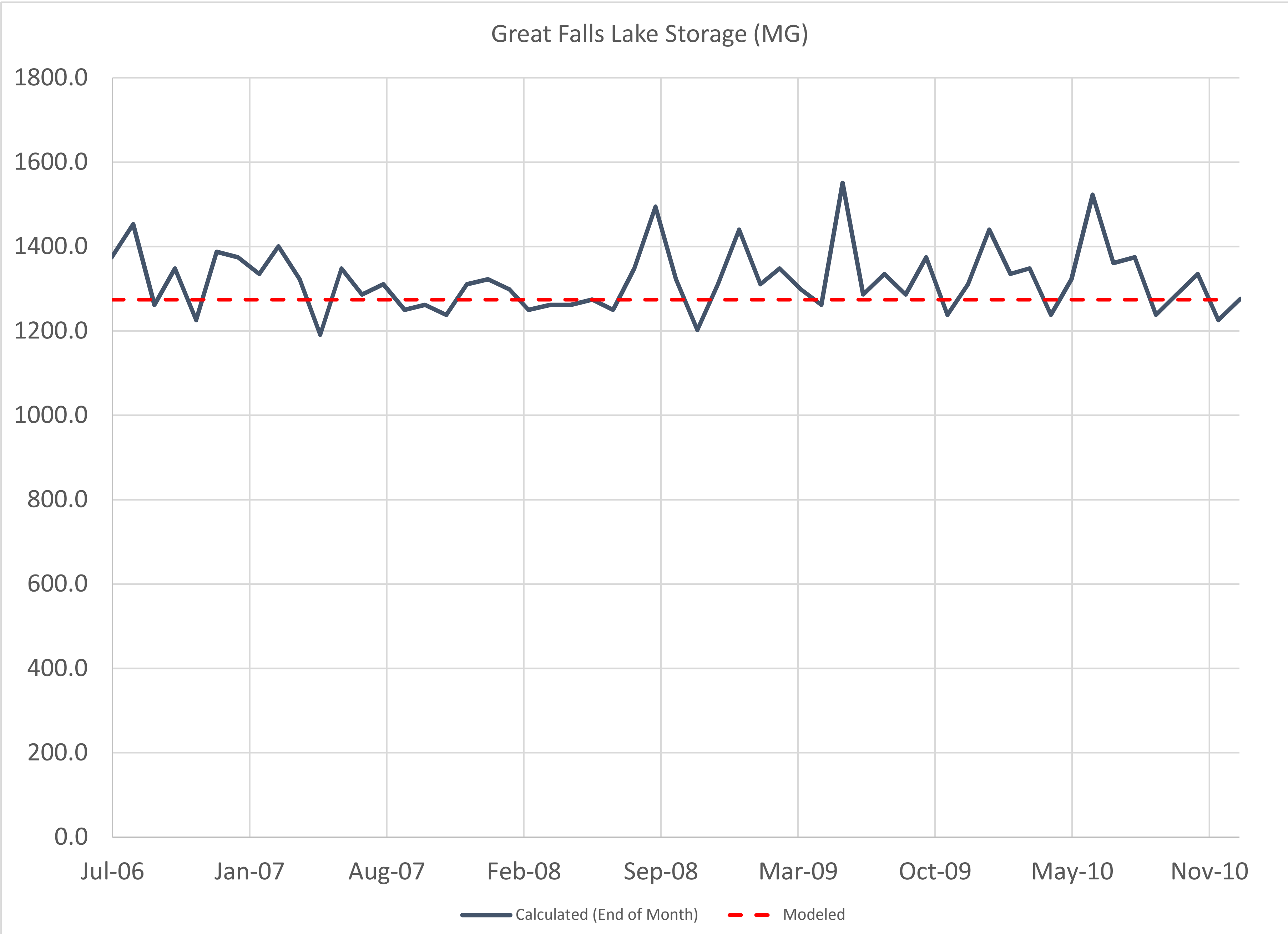

CAT19 (02148071) GILLIES CREEK NEAR LUGOFF, SC (CFS)
Annual Average Flow
gaged
modeled
16
14
12
10
8
6
4
2
0
1983
1988
1993
1998
2003
2008
2013


CAT19 (02148071) GILLIES CREEK NEAR LUGOFF, SC
Monthly Mean Flow (CFS)
gaged
modeled
0
2
4
6
8
10
12
14
16
18
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

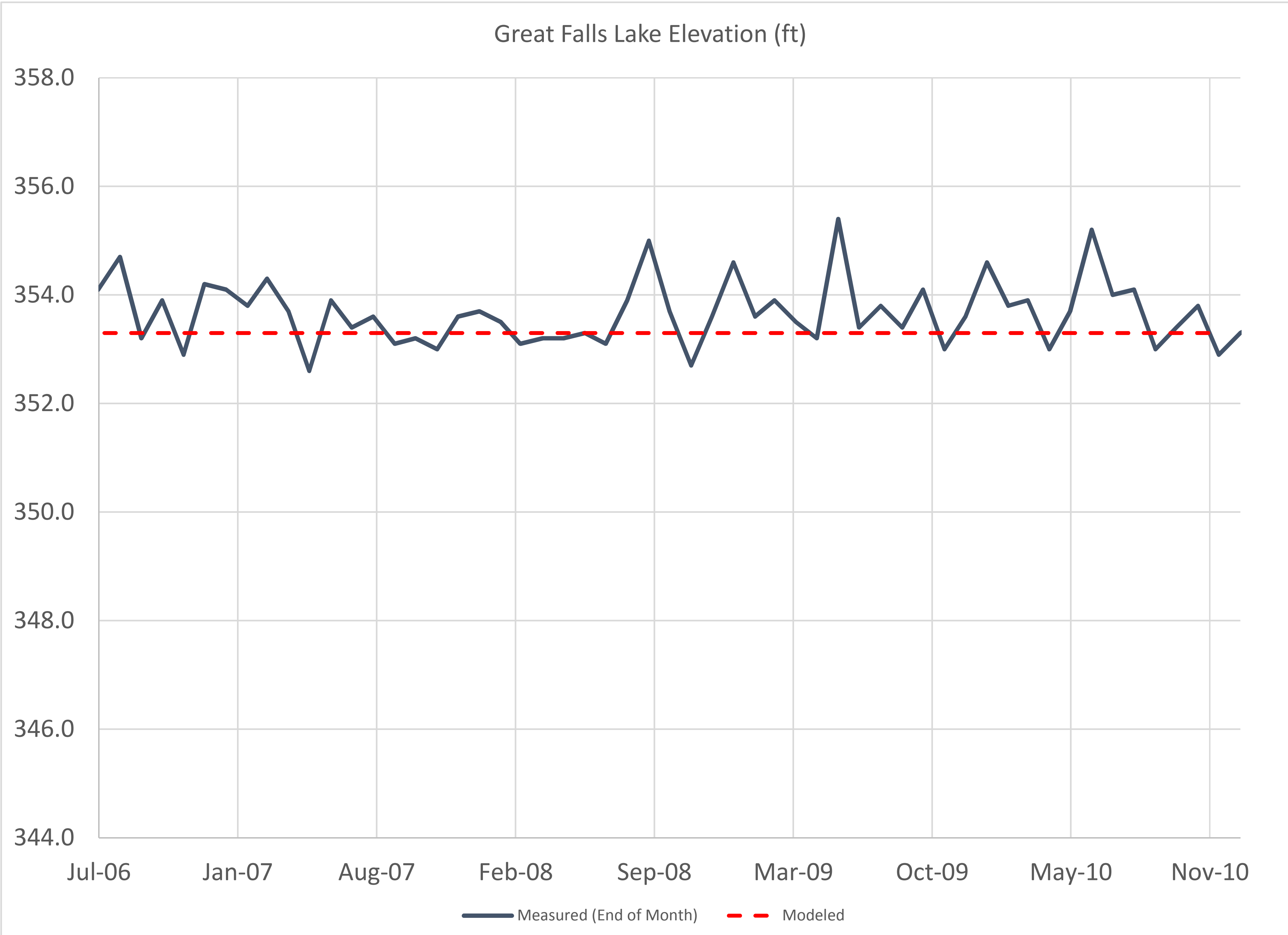

CAT19 (02148071) GILLIES CREEK NEAR LUGOFF, SC
Monthly Flow Percentiles (CFS)
gaged
modeled
25
20
15
10
5
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile


Fishing Creek Reservoir Storage (MG)
14000.0
12000.0
10000.0
8000.0
6000.0
4000.0
2000.0
0.0
Jul-06
Jan-07
Aug-07
Feb-08
Sep-08
Mar-09
Oct-09
May-10
Nov-10
Calculated (End of Month)
Modeled

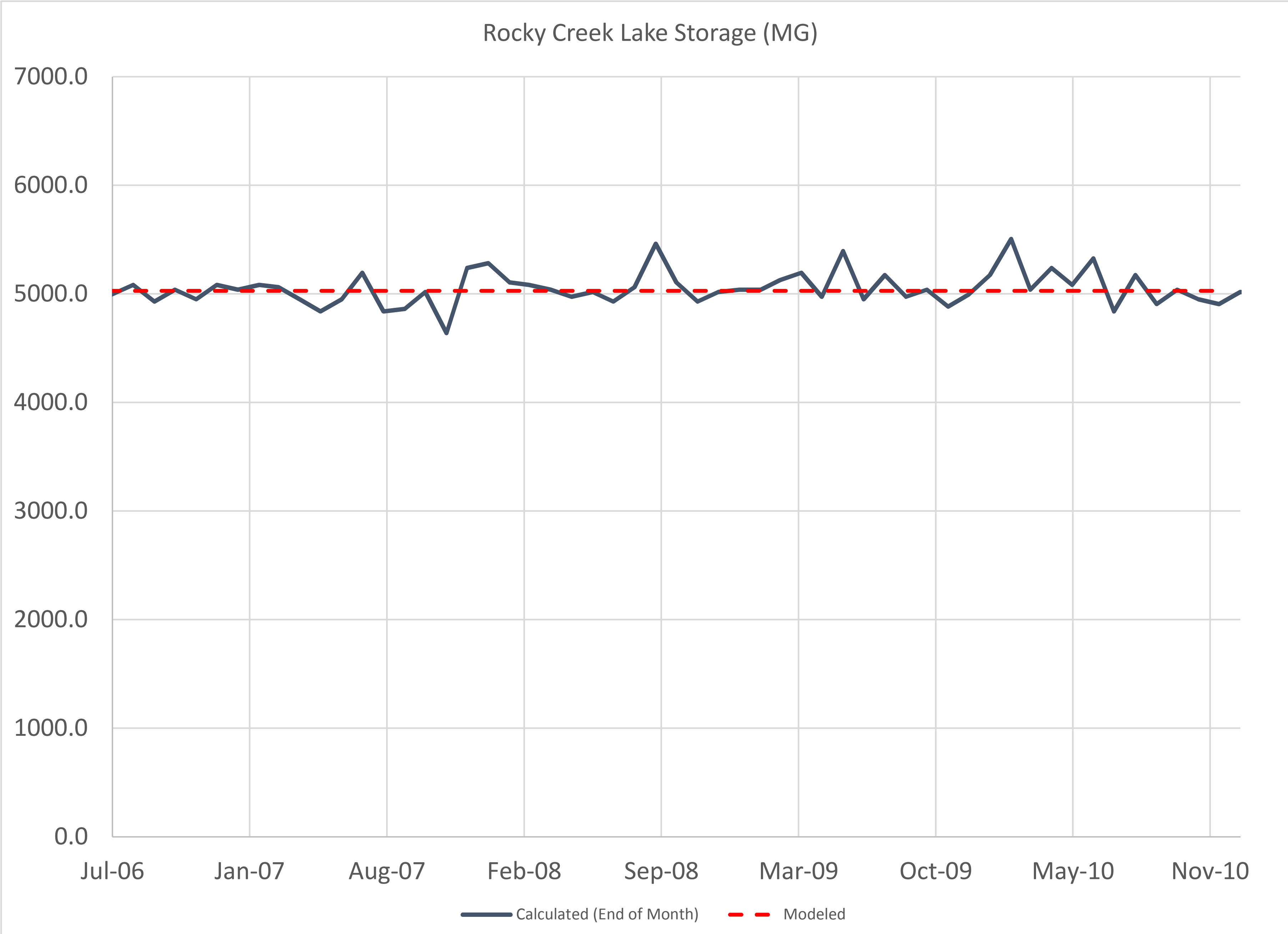

Fishing Creek Reservoir Elevation (ft)
418.0
417.0
416.0
415.0
414.0
413.0
412.0
411.0
410.0
Jul-06
Jan-07
Aug-07
Feb-08
Sep-08
Mar-09
Oct-09
May-10
Nov-10
Measured (End of Month)
Modeled



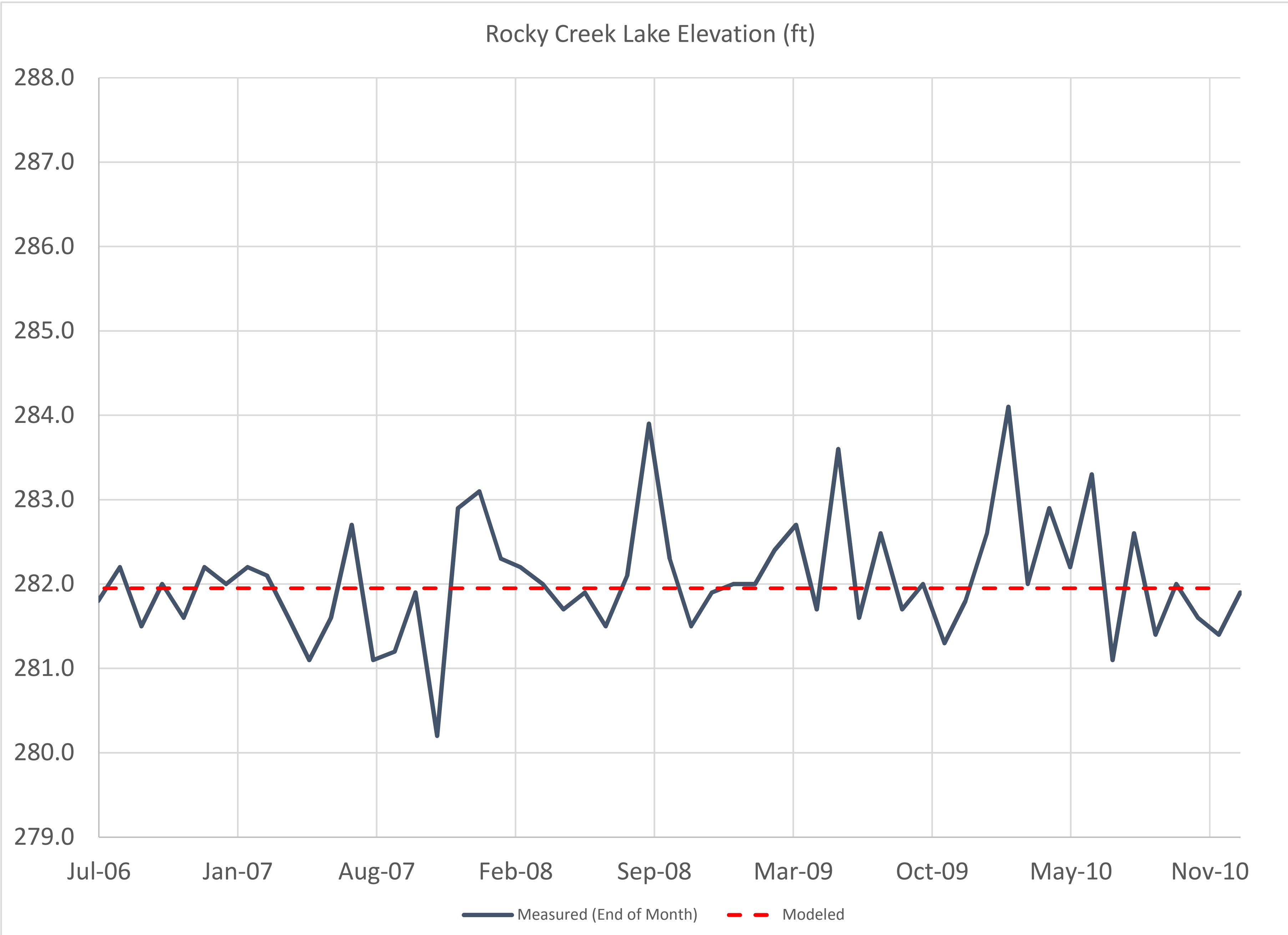
Great Falls Lake Storage (MG)
1800.0
1600.0
1400.0
1200.0
1000.0
800.0
600.0
400.0
200.0
0.0
Jul-06
Jan-07
Aug-07
Feb-08
Sep-08
Mar-09
Oct-09
May-10
Nov-10
Calculated (End of Month)
Modeled

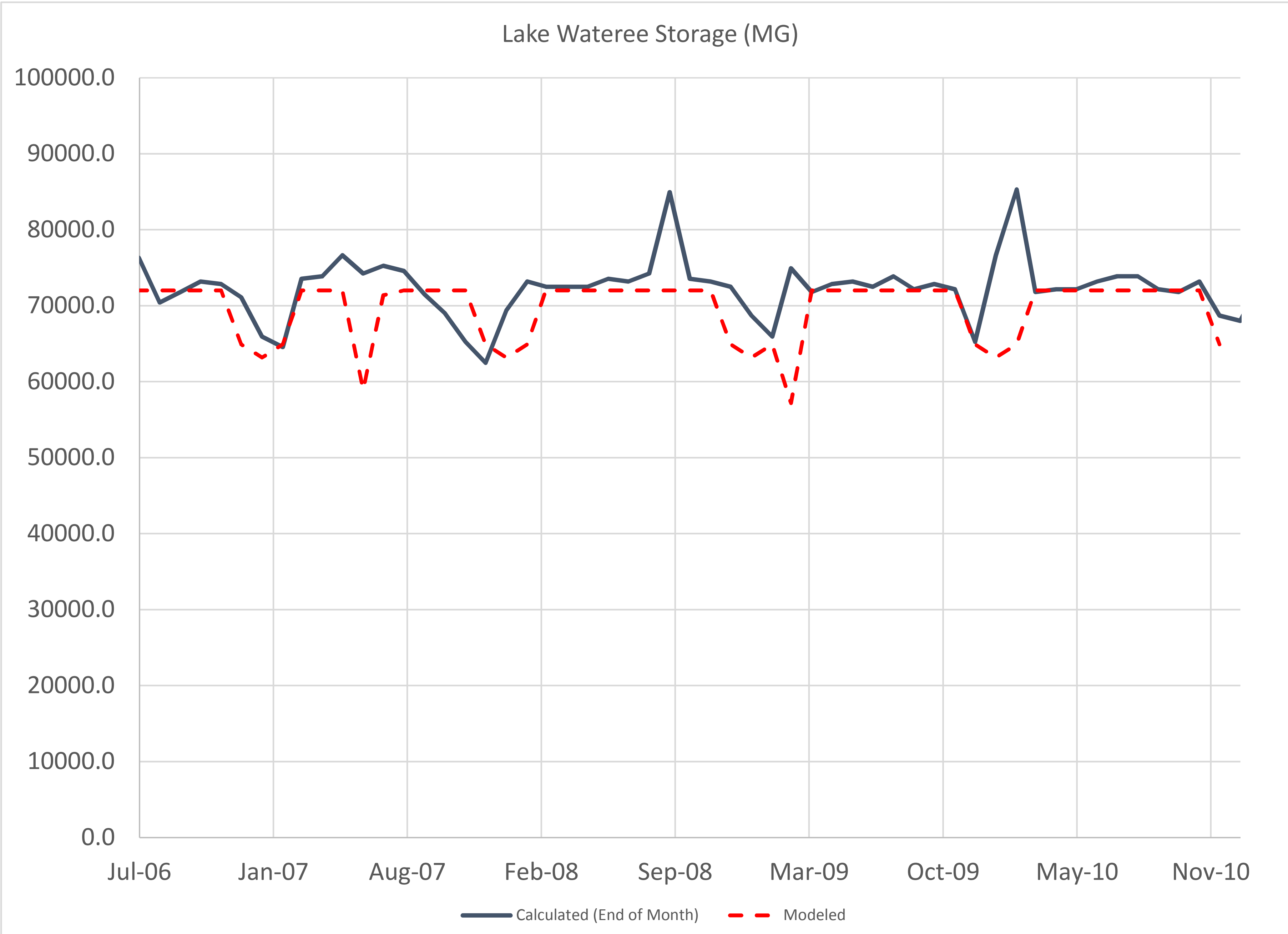


Great Falls Lake Elevation (ft)
358.0
356.0
354.0
352.0
350.0
348.0
346.0
344.0
Jul-06
Jan-07
Aug-07
Feb-08
Sep-08
Mar-09
Oct-09
May-10
Nov-10
Measured (End of Month)
Modeled

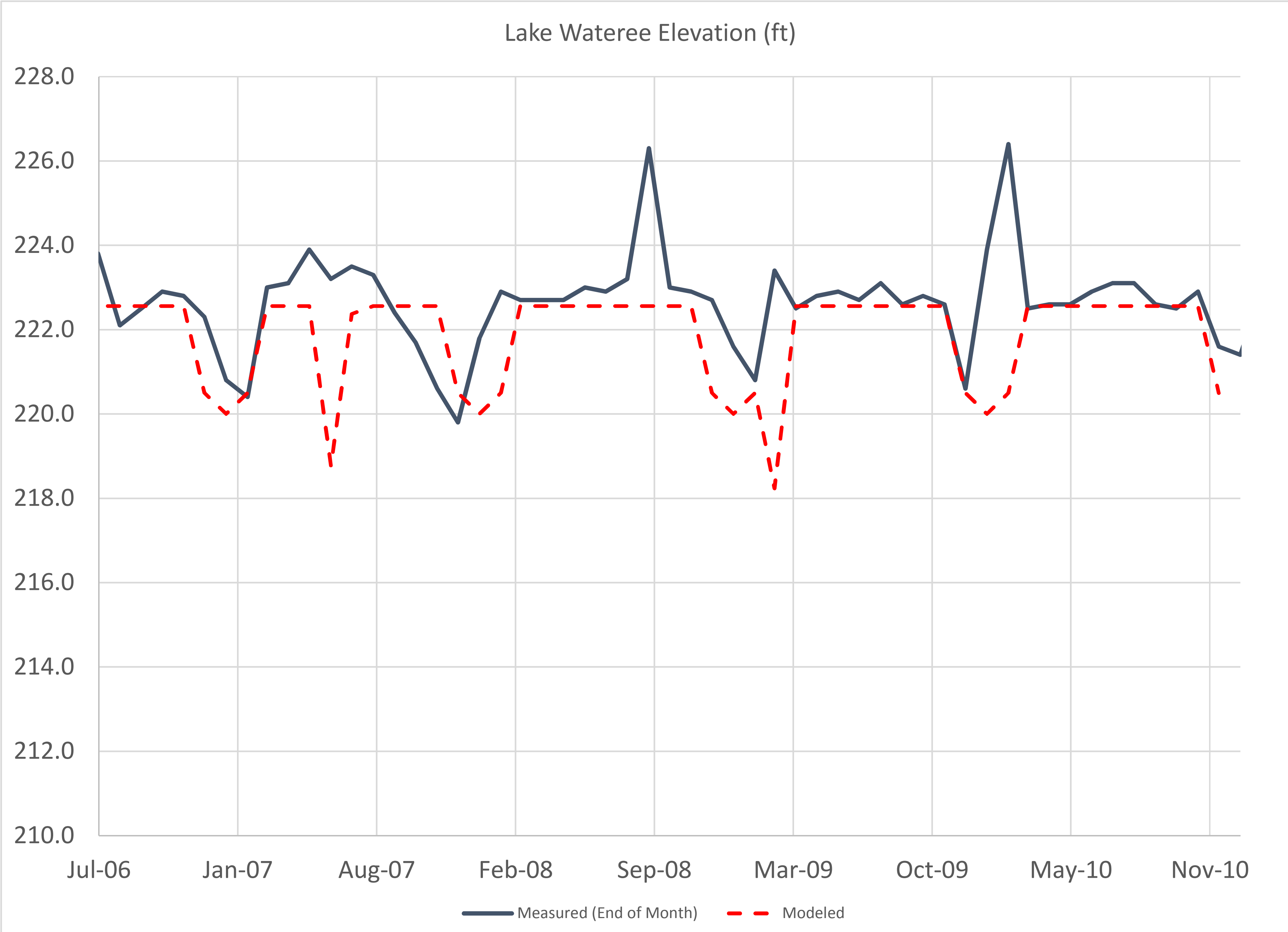


Rocky Creek Lake Storage (MG)
7000.0
6000.0
5000.0
4000.0
3000.0
2000.0
1000.0
0.0
Jul-06
Jan-07
Aug-07
Feb-08
Sep-08
Mar-09
Oct-09
May-10
Nov-10
Calculated (End of Month)
Modeled


Rocky Creek Lake Elevation (ft)
288.0
287.0
286.0
285.0
284.0
283.0
282.0
281.0
280.0
279.0
Jul-06
Jan-07
Aug-07
Feb-08
Sep-08
Mar-09
Oct-09
May-10
Nov-10
Measured (End of Month)
Modeled



Lake Wateree Storage (MG)
100000.0
90000.0
80000.0
70000.0
60000.0
50000.0
40000.0
30000.0
20000.0
10000.0
0.0
Jul-06
Jan-07
Aug-07
Feb-08
Sep-08
Mar-09
Oct-09
May-10
Nov-10
Calculated (End of Month)
Modeled

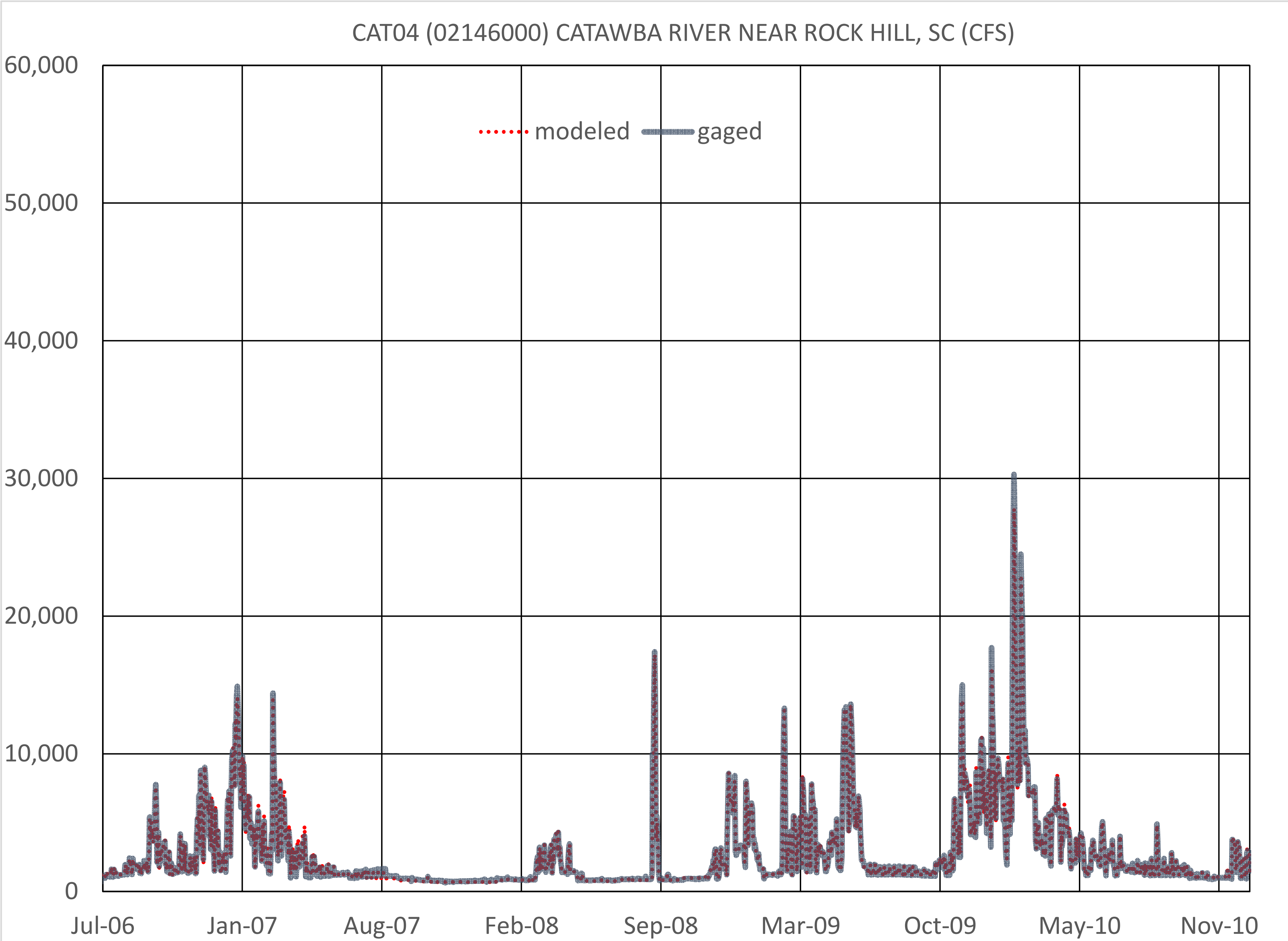


Lake Wateree Elevation (ft)
228.0
226.0
224.0
222.0
220.0
218.0
216.0
214.0
212.0
210.0
Jul-06
Jan-07
Aug-07
Feb-08
Sep-08
Mar-09
Oct-09
May-10
Nov-10
Measured (End of Month)
Modeled

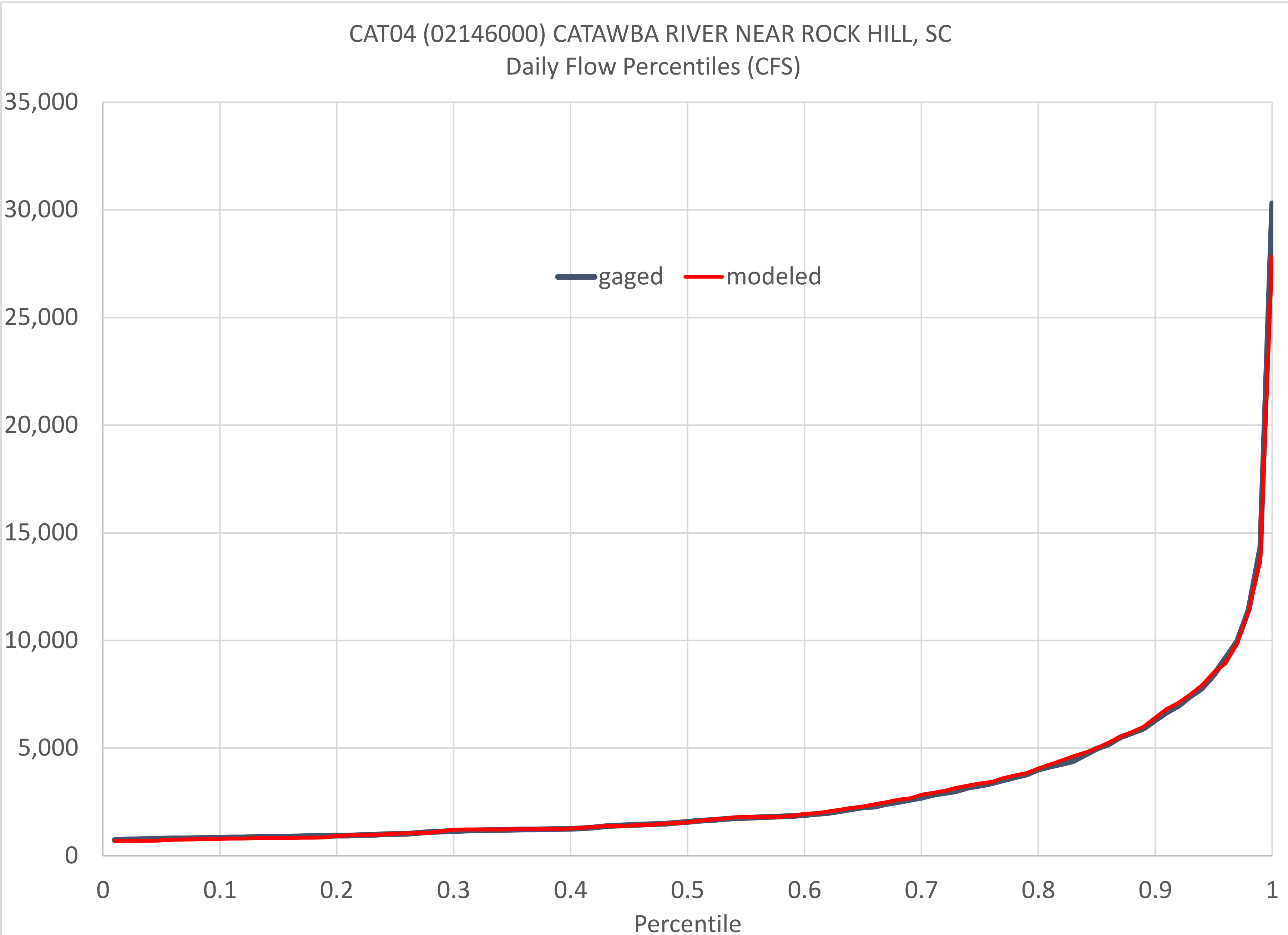
Appendix B

Catawba-Wateree River Basin Model Daily Calibration Results

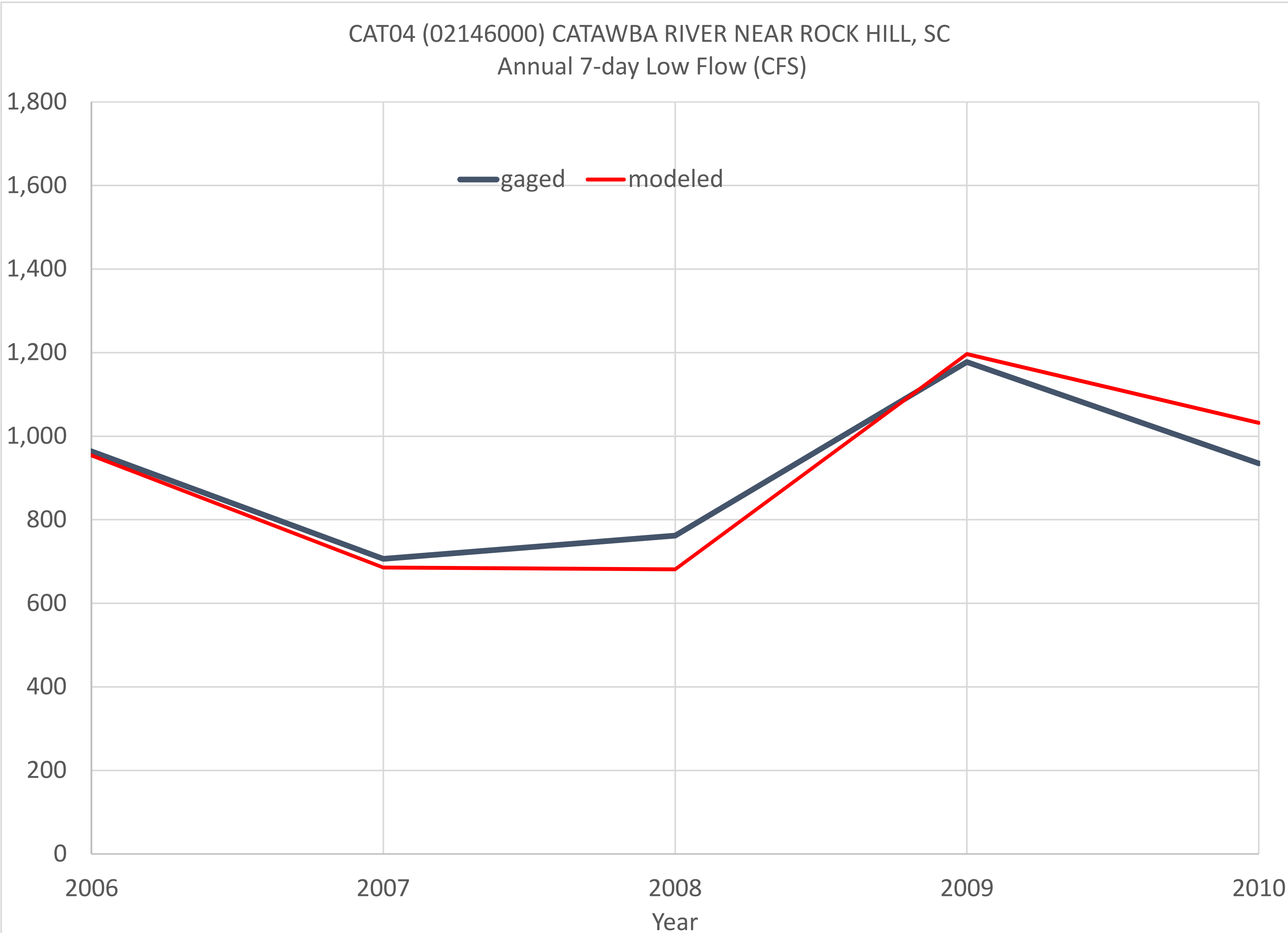
CDM Smith

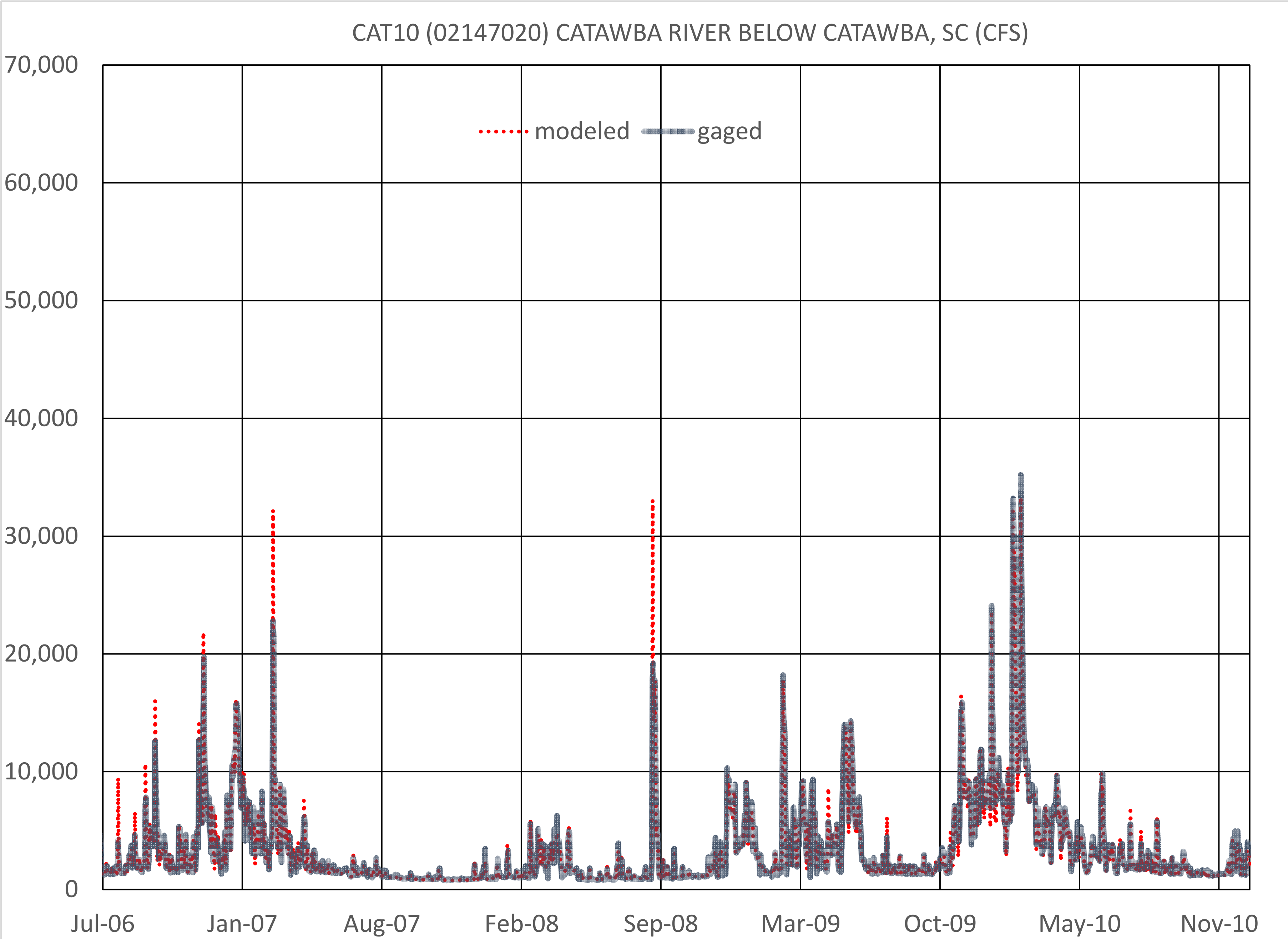


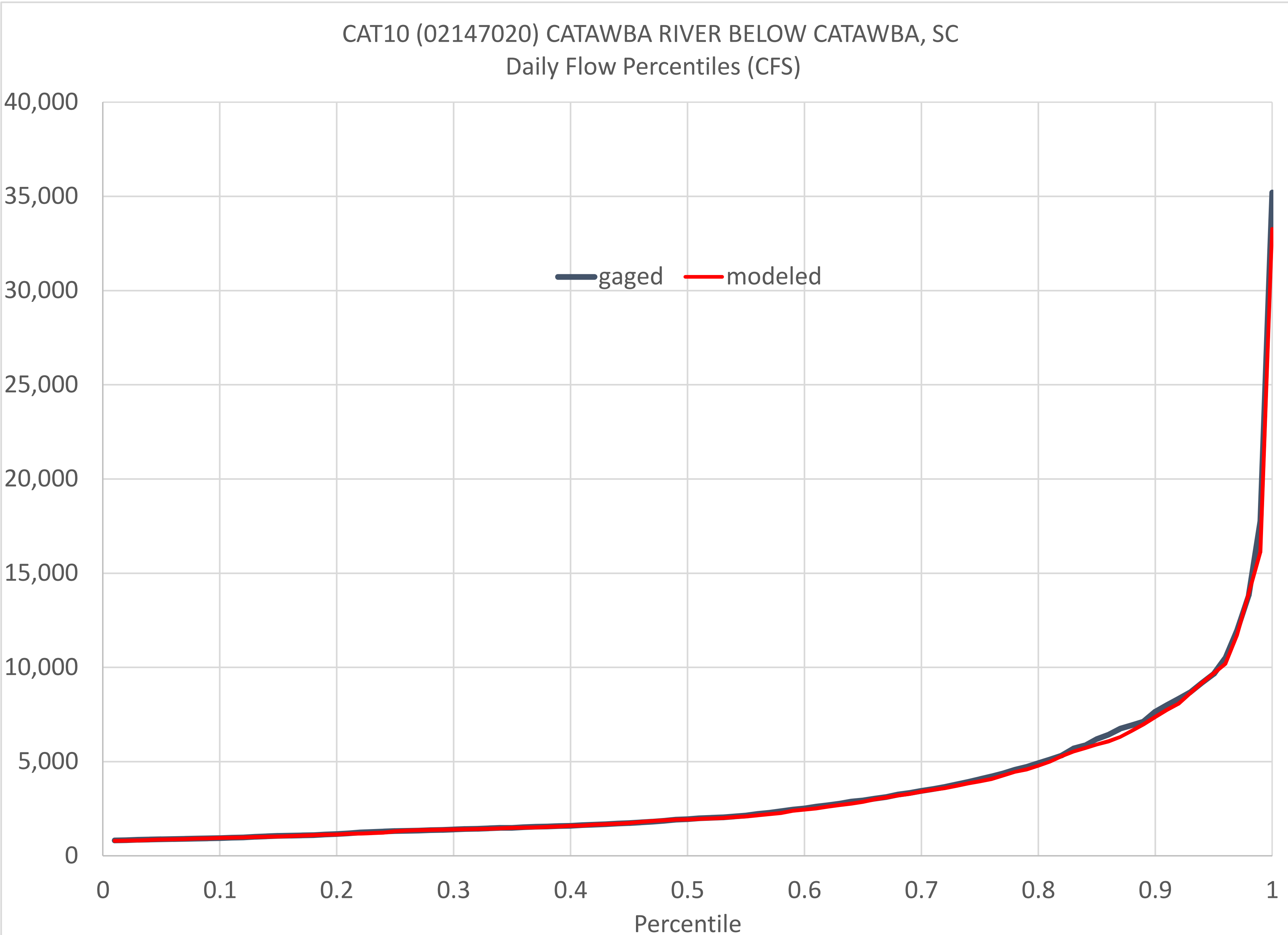
CAT04 (02146000) CATAWBA RIVER NEAR ROCK HILL, SC (CFS)
modeled
gaged
60,000
50,000
40,000
30,000
20,000
10,000
0
Jul-06
Jan-07
Aug-07
Feb-08
Sep-08
Mar-09
Oct-09
May-10
Nov-10

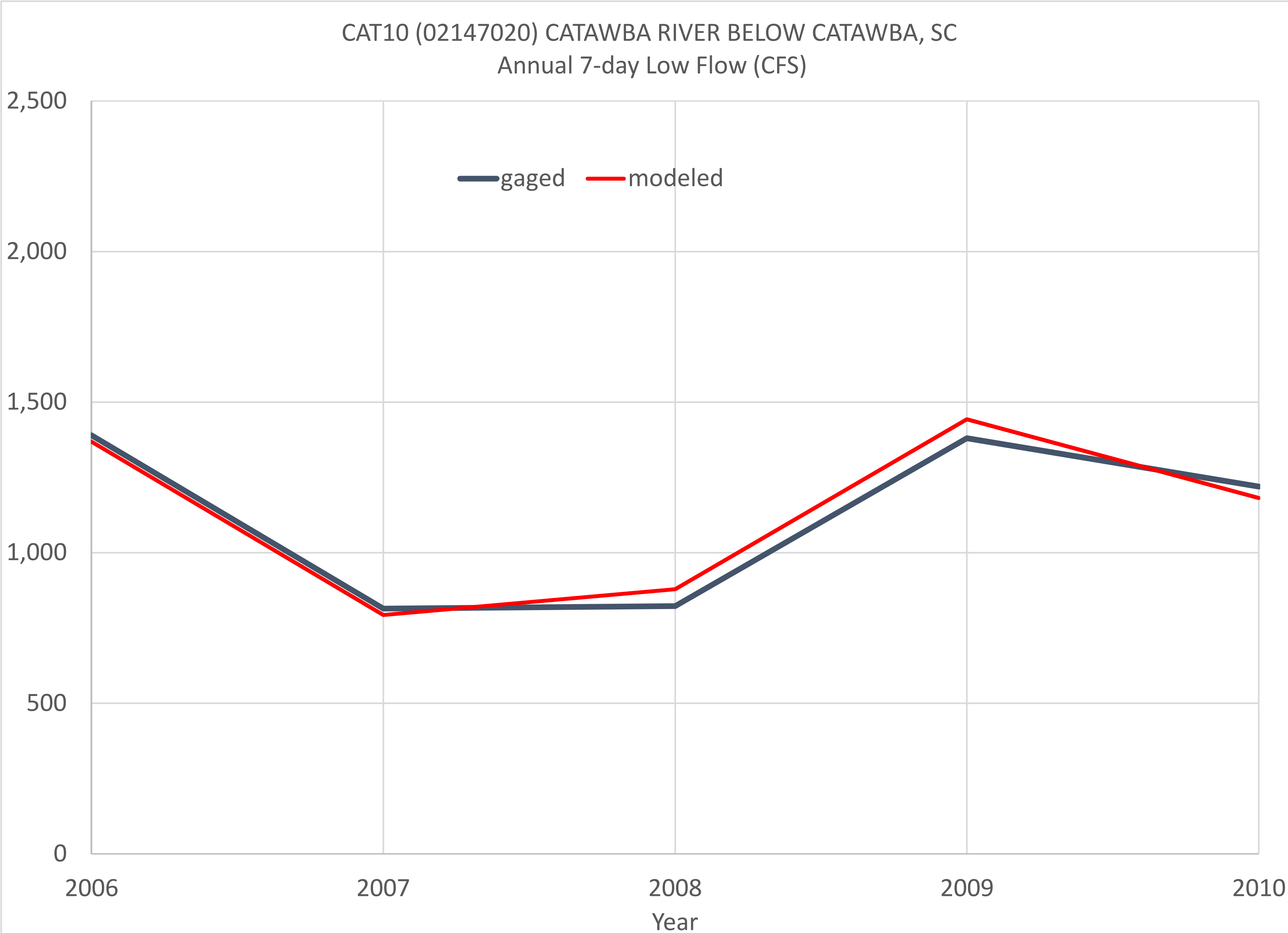


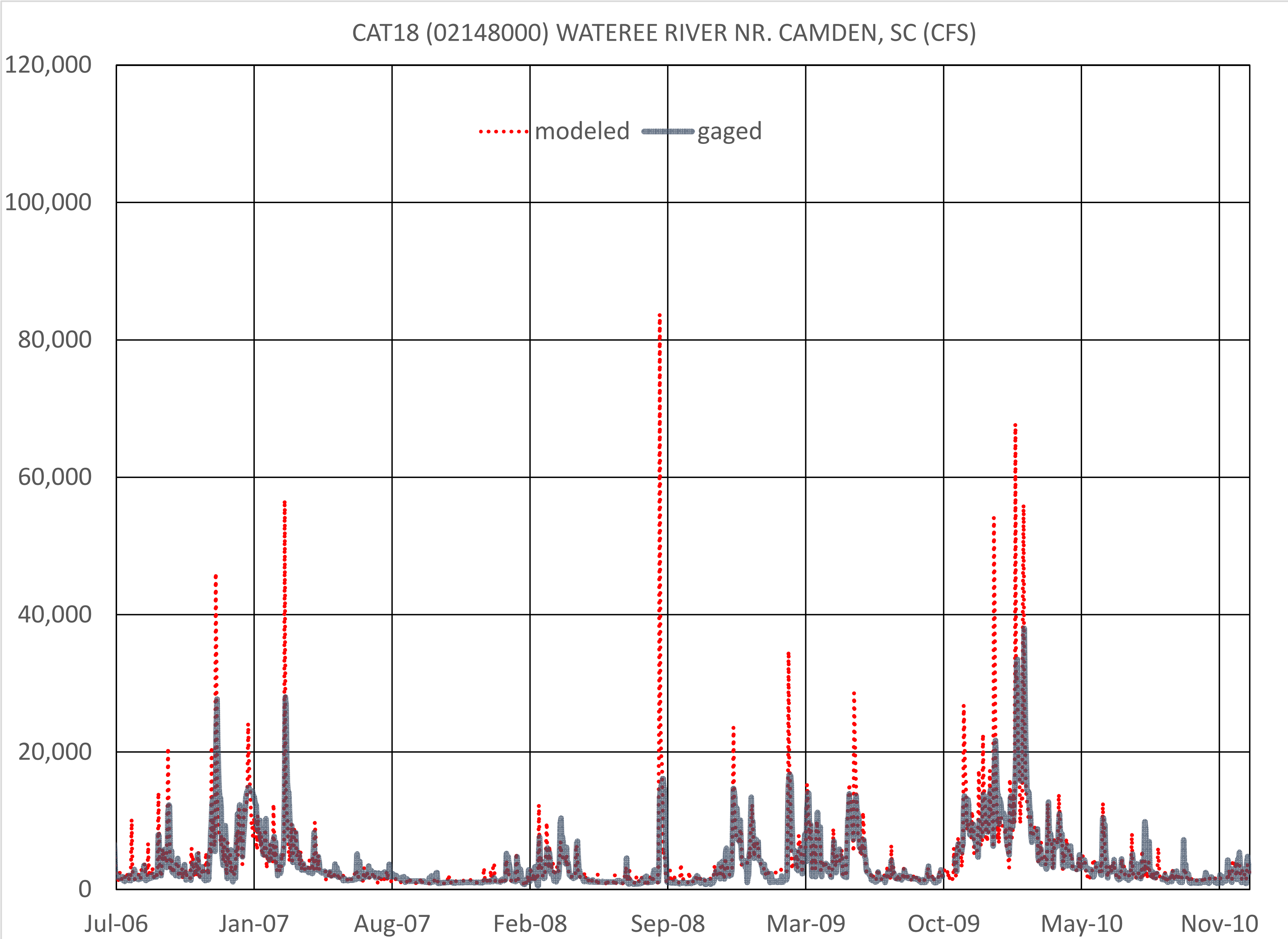
CAT04 (02146000) CATAWBA RIVER NEAR ROCK HILL, SC
Daily Flow Percentiles (CFS)
gaged
modeled
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile


CAT04 (02146000) CATAWBA RIVER NEAR ROCK HILL, SC
Annual 7-day Low Flow (CFS)
gaged
modeled
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
2006
2007
2008
2009
2010
Year

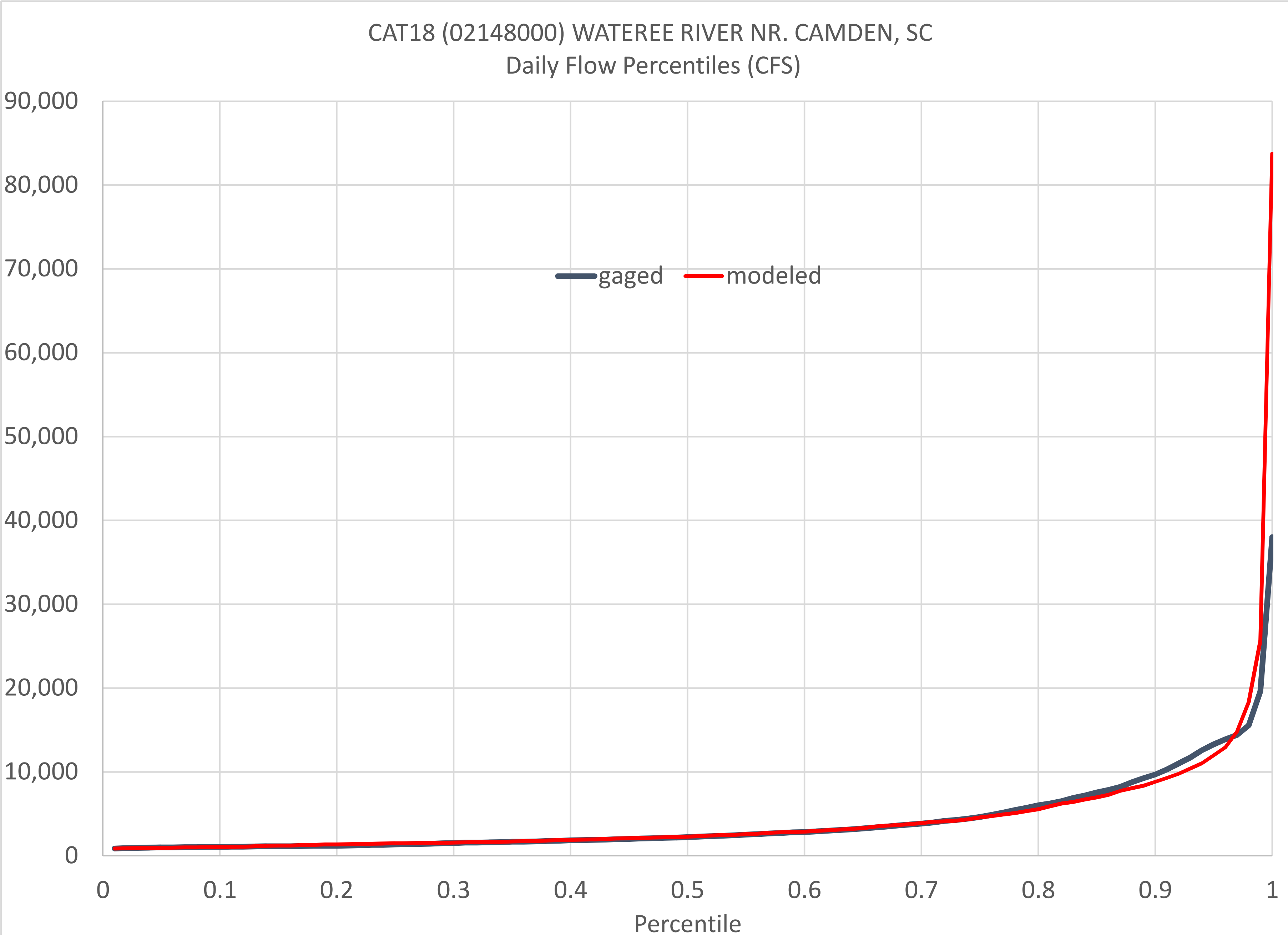

CAT10 (02147020) CATAWBA RIVER BELOW CATAWBA, SC (CFS)
modeled
gaged
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Jul-06
Jan-07
Aug-07
Feb-08
Sep-08
Mar-09
Oct-09
May-10
Nov-10


CAT10 (02147020) CATAWBA RIVER BELOW CATAWBA, SC
Daily Flow Percentiles (CFS)
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
gaged
modeled
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

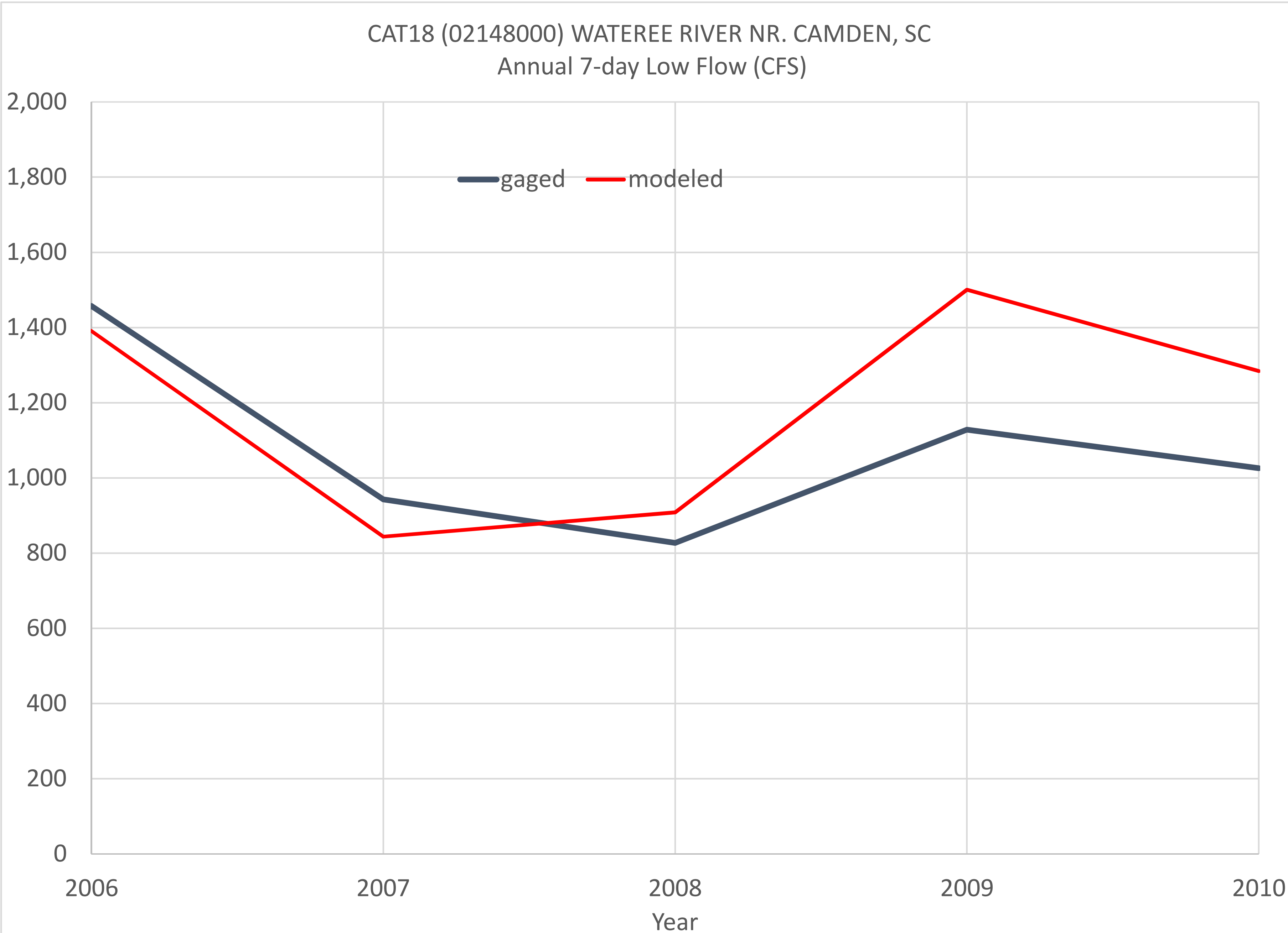

CAT10 (02147020) CATAWBA RIVER BELOW CATAWBA, SC
Annual 7-day Low Flow (CFS)
gaged
modeled
2,500
2,000
1,500
1,000
500
0
2006
2007
2008
2009
2010
Year



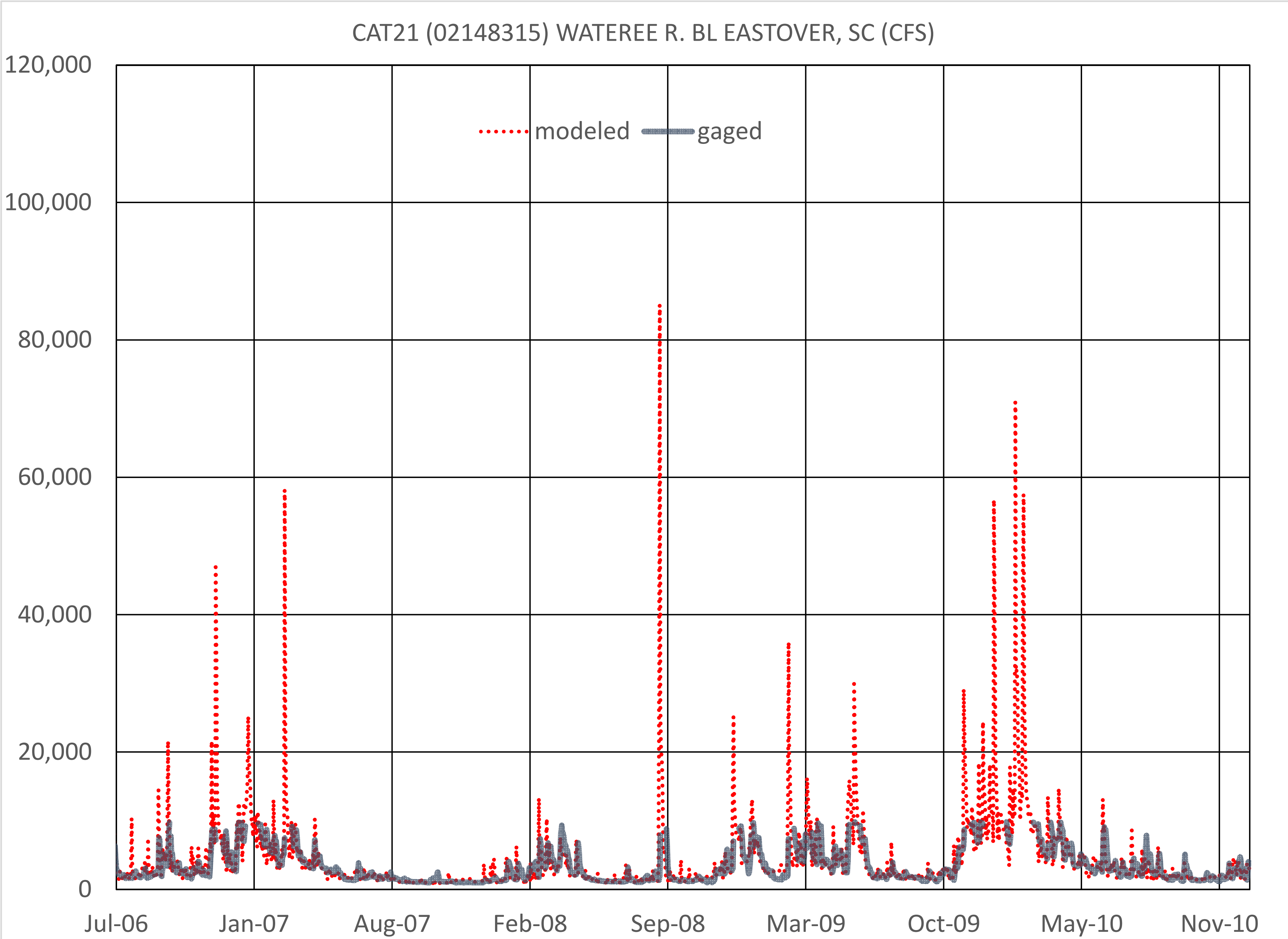
CAT18 (02148000) WATEREE RIVER NR. CAMDEN, SC (CFS)
modeled
gaged
120,000
100,000
80,000
60,000
40,000
20,000
0
Jul-06
Jan-07
Aug-07
Feb-08
Sep-08
Mar-09
Oct-09
May-10
Nov-10



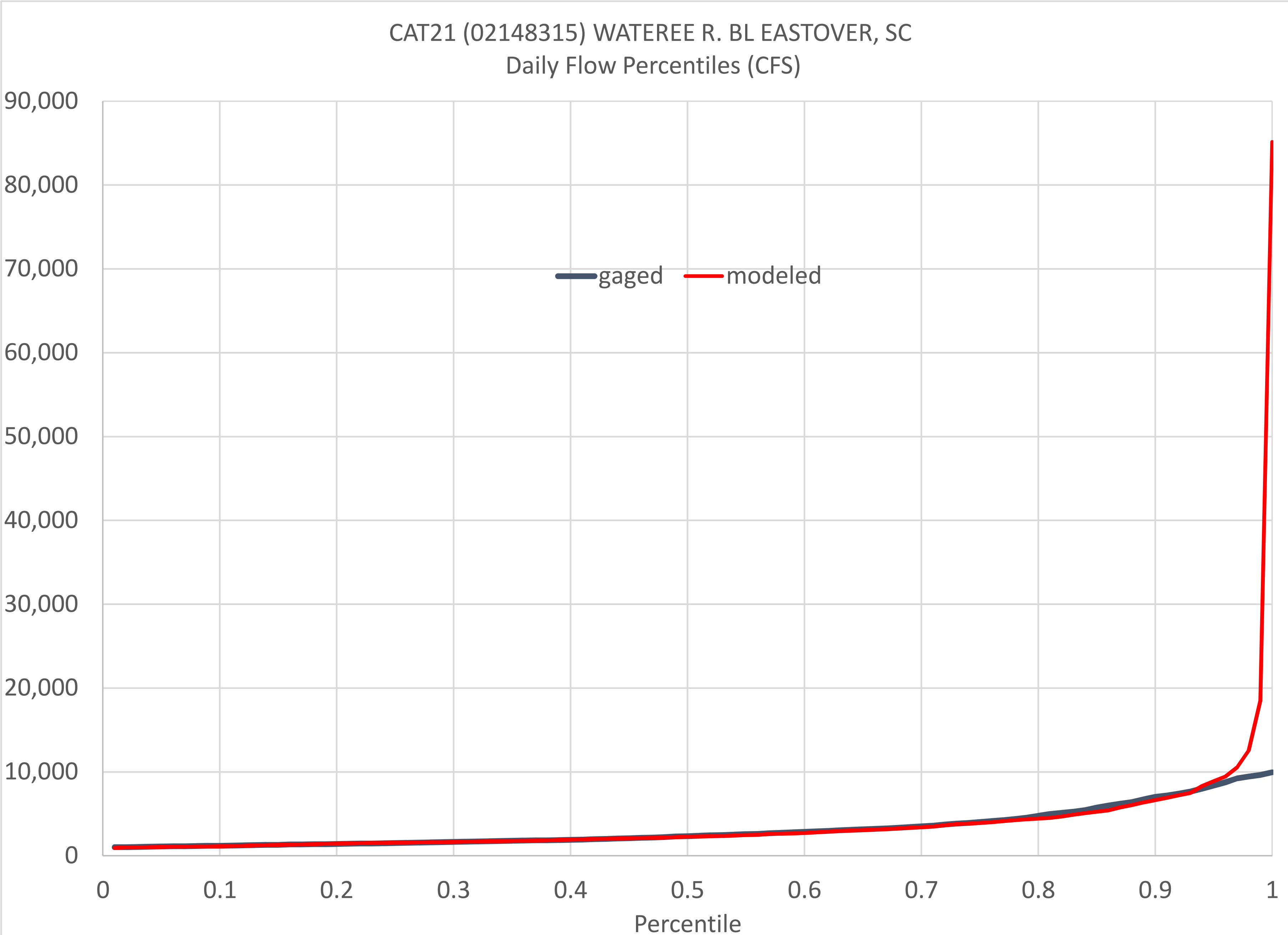
CAT18 (02148000) WATEREE RIVER NR. CAMDEN, SC
Daily Flow Percentiles (CFS)
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
gaged
modeled
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile



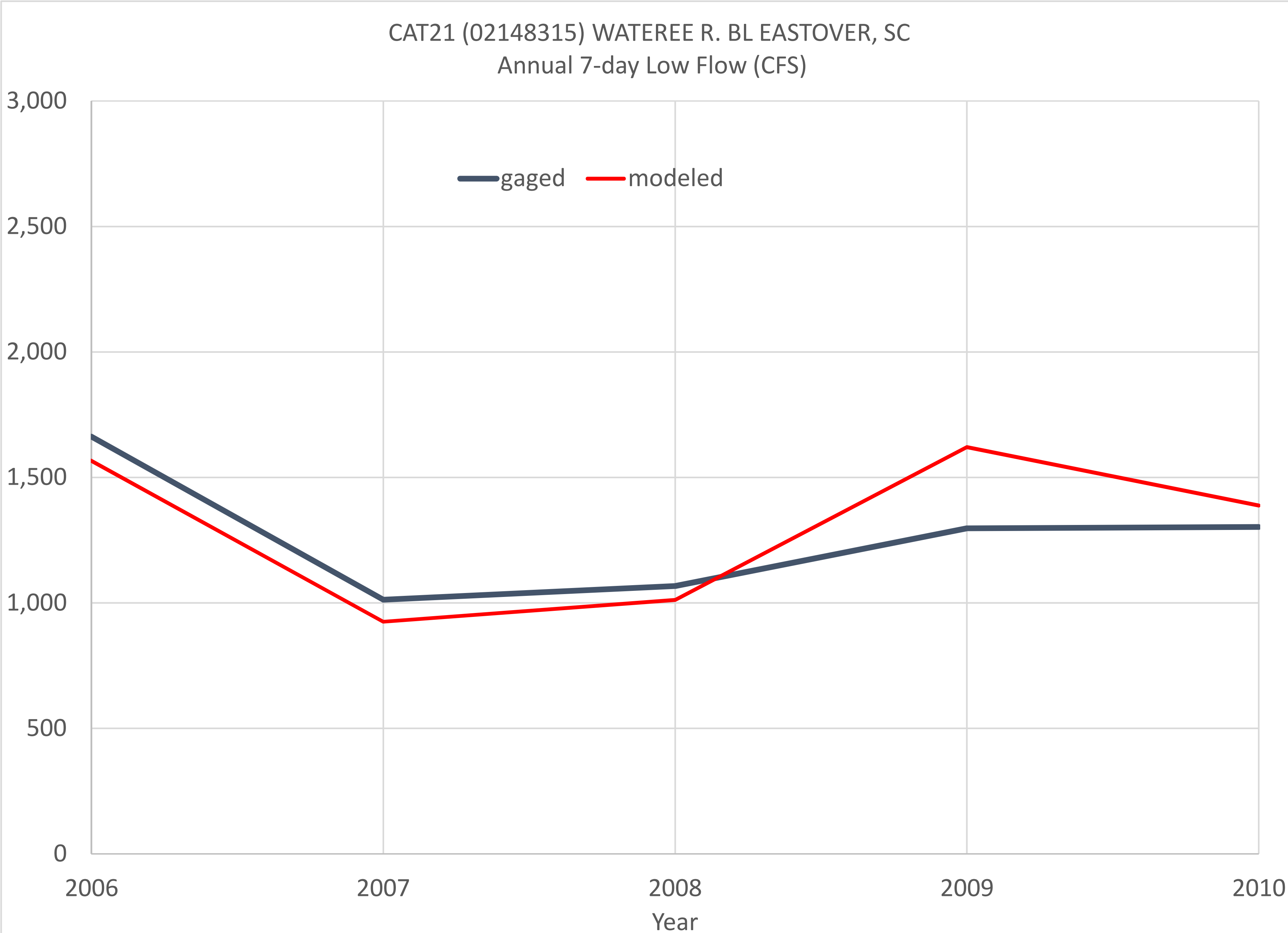
CAT18 (02148000) WATEREE RIVER NR. CAMDEN, SC
Annual 7-day Low Flow (CFS)
gaged
modeled
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
2006
2007
2008
2009
2010
Year



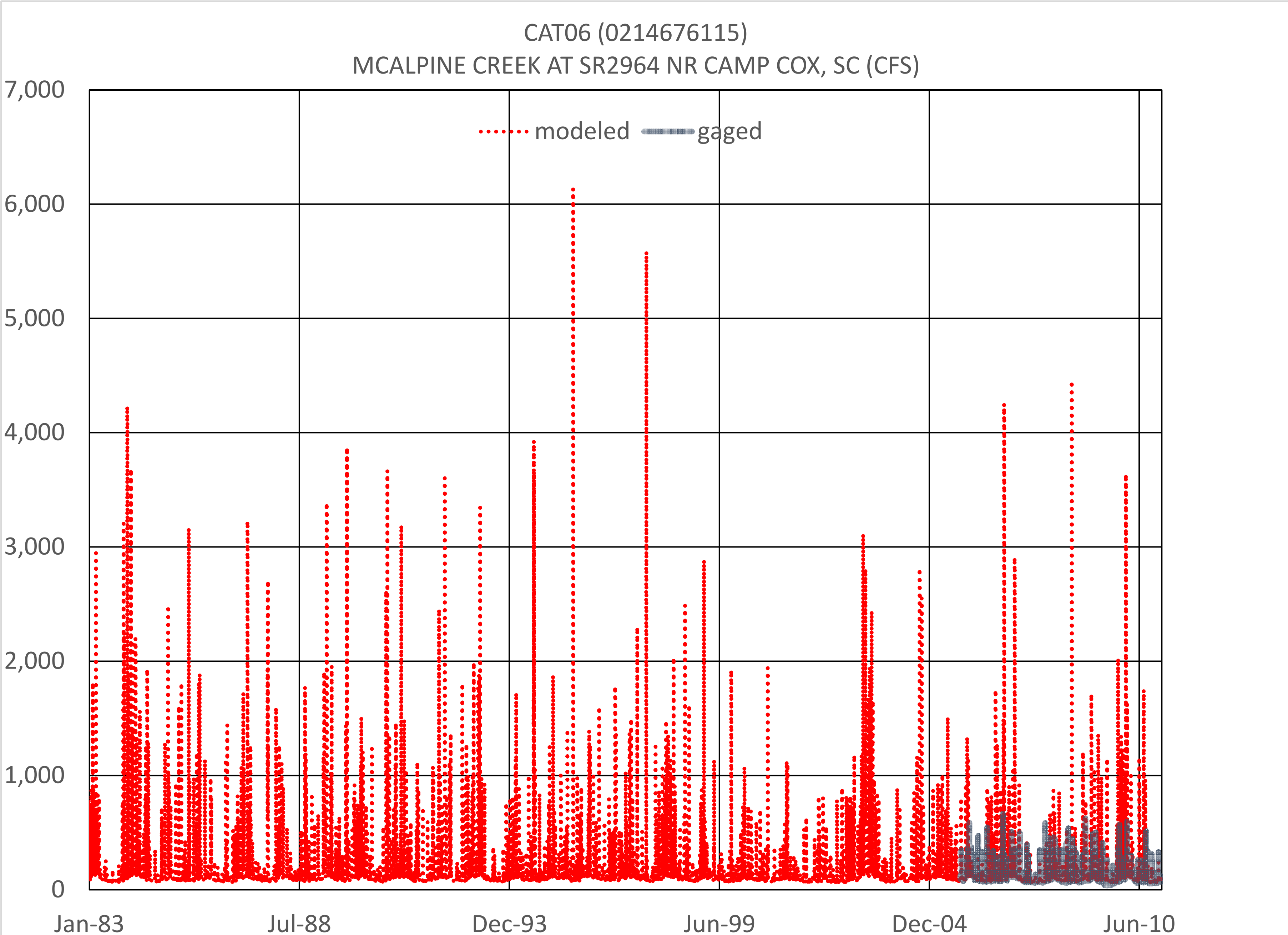
CAT21 (02148315) WATEREE R. BL EASTOVER, SC (CFS)
modeled
gaged
120,000
100,000
80,000
60,000
40,000
20,000
0
Jul-06
Jan-07
Aug-07
Feb-08
Sep-08
Mar-09
Oct-09
May-10
Nov-10



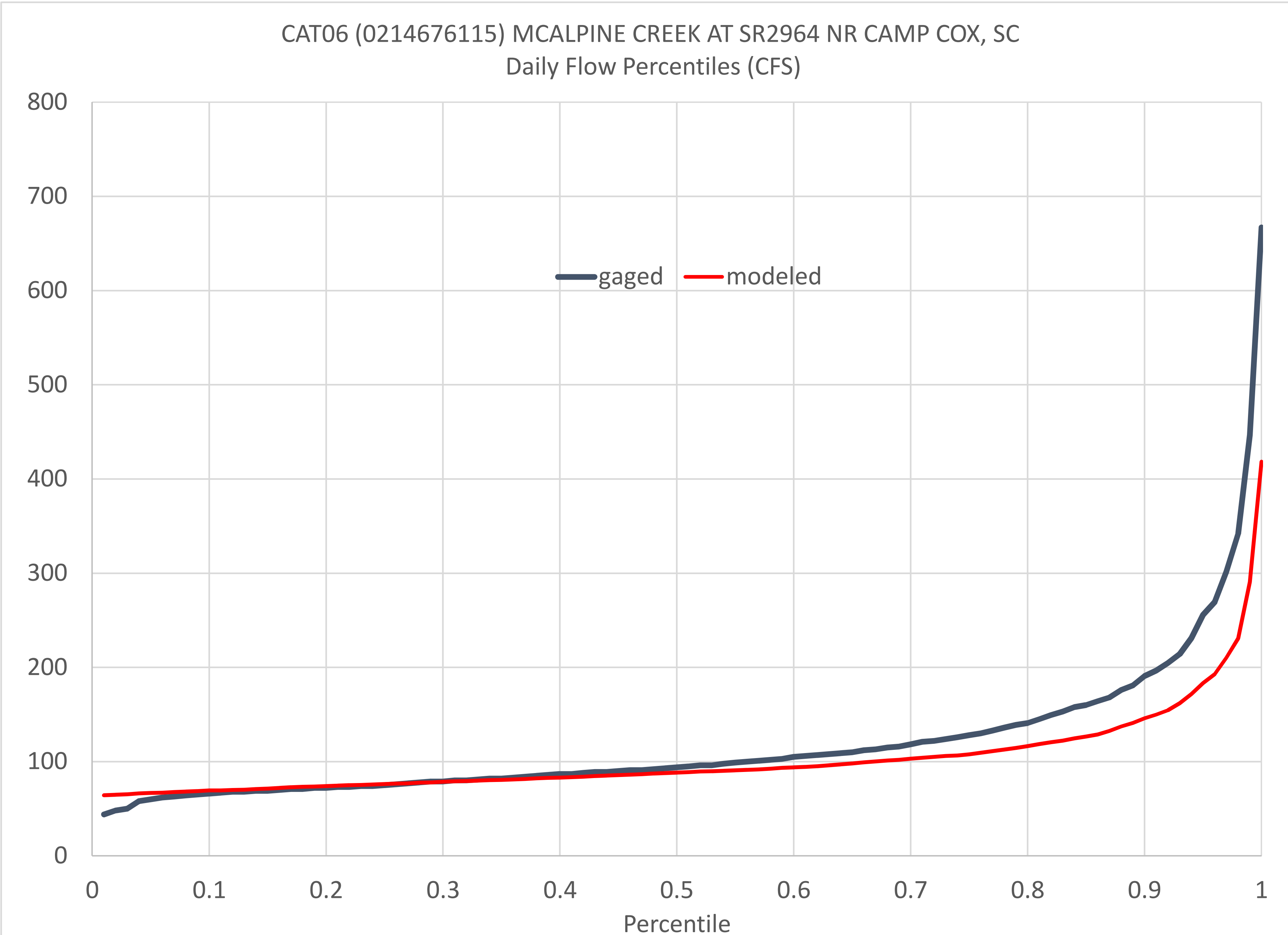
CAT21 (02148315) WATEREE R. BL EASTOVER, SC
Daily Flow Percentiles (CFS)
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
gaged
modeled
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

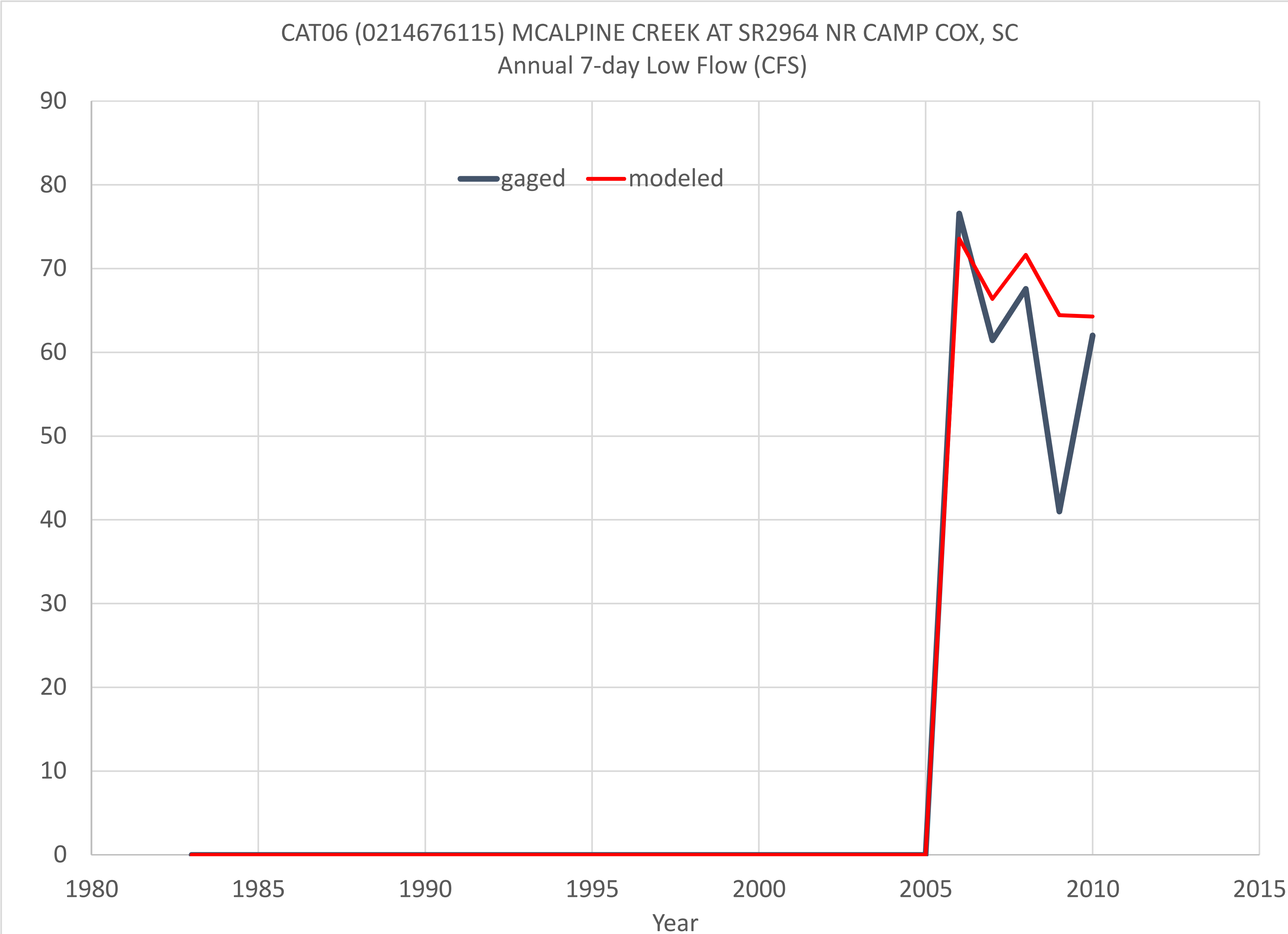


CAT21 (02148315) WATEREE R. BL EASTOVER, SC
Annual 7-day Low Flow (CFS)
gaged
modeled
3,000
2,500
2,000
1,500
1,000
500
0
2006
2007
2008
2009
2010
Year

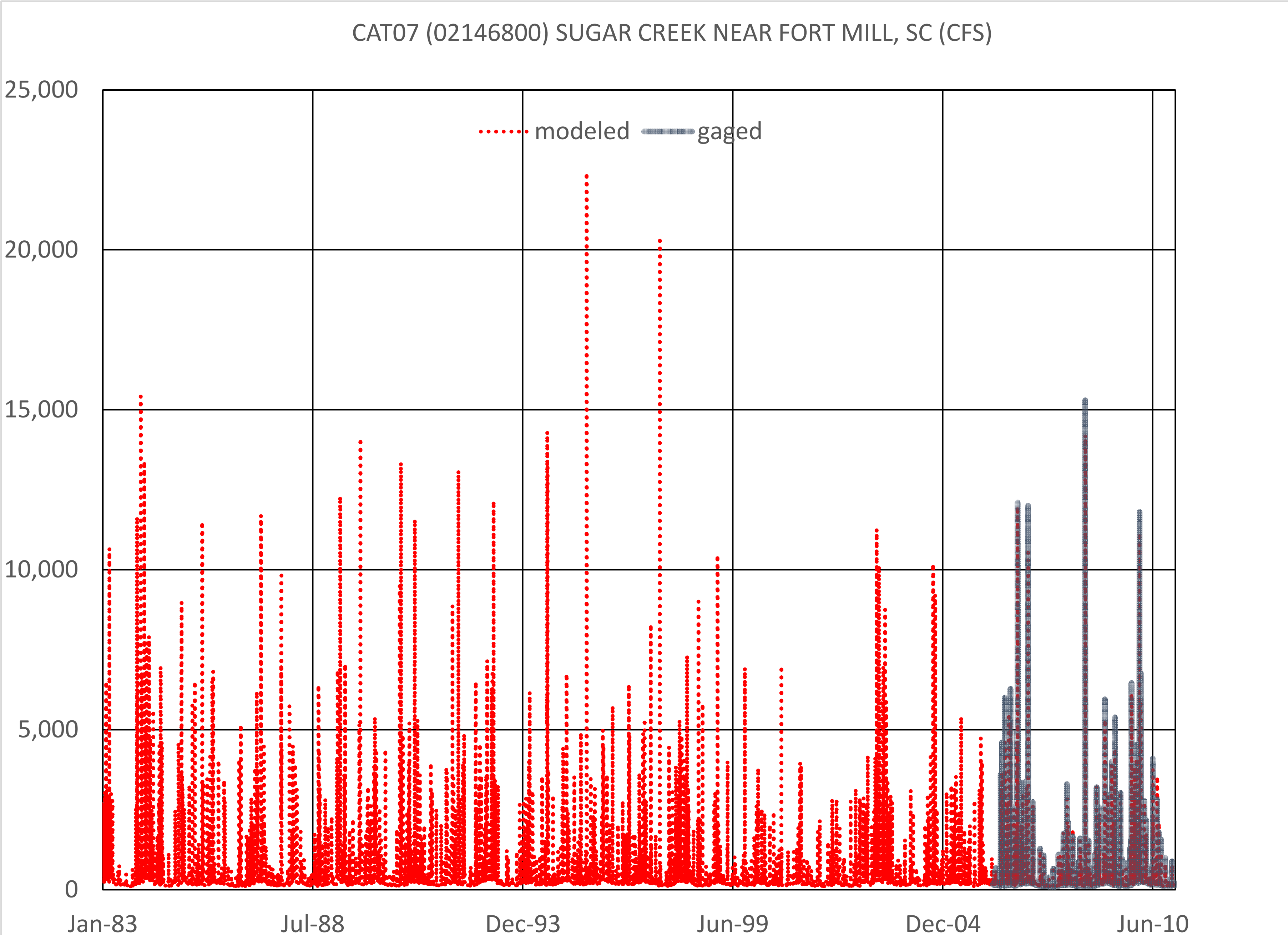


CAT06 (0214676115)
MCALPINE CREEK AT SR2964 NR CAMP COX, SC (CFS)
modeled
gaged
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

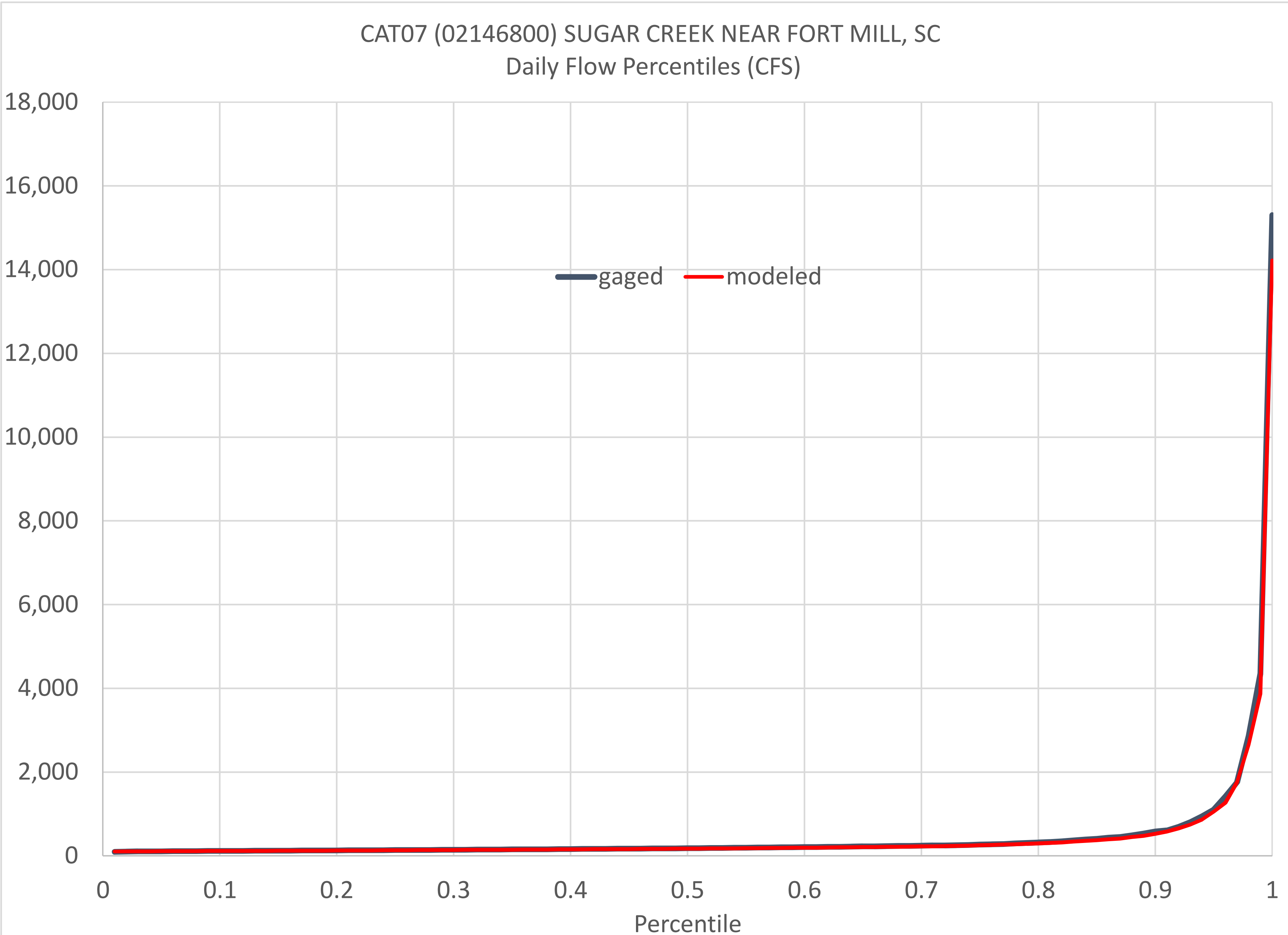

CAT06 (0214676115) MCALPINE CREEK AT SR2964 NR CAMP COX, SC
Daily Flow Percentiles (CFS)
gaged
modeled
800
700
600
500
400
300
200
100
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

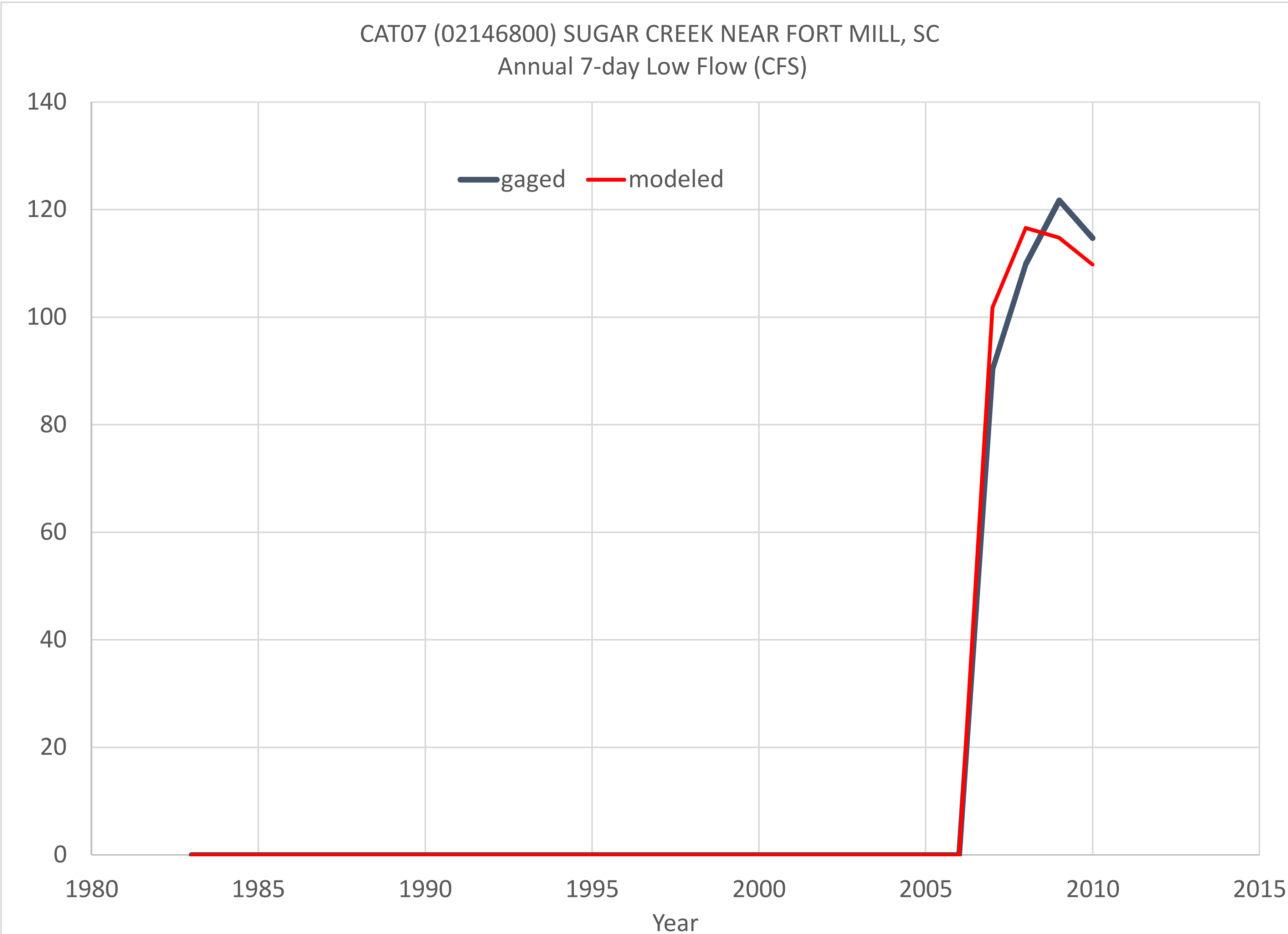


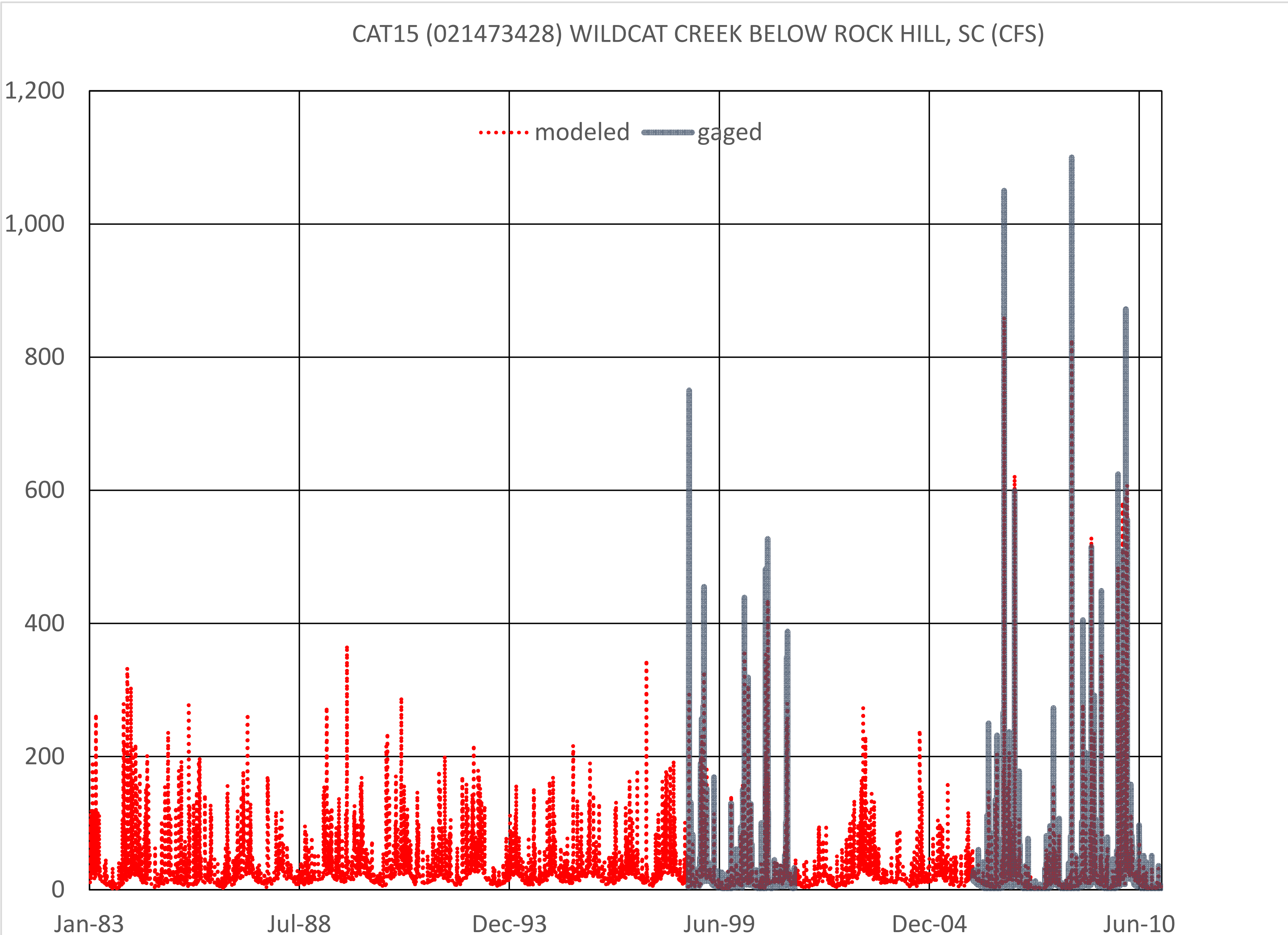
CAT06 (0214676115) MCALPINE CREEK AT SR2964 NR CAMP COX, SC
Annual 7-day Low Flow (CFS)
gaged
modeled
0
10
20
30
40
50
60
70
80
90
1980
1985
1990
1995
2000
2005
2010
2015
Year

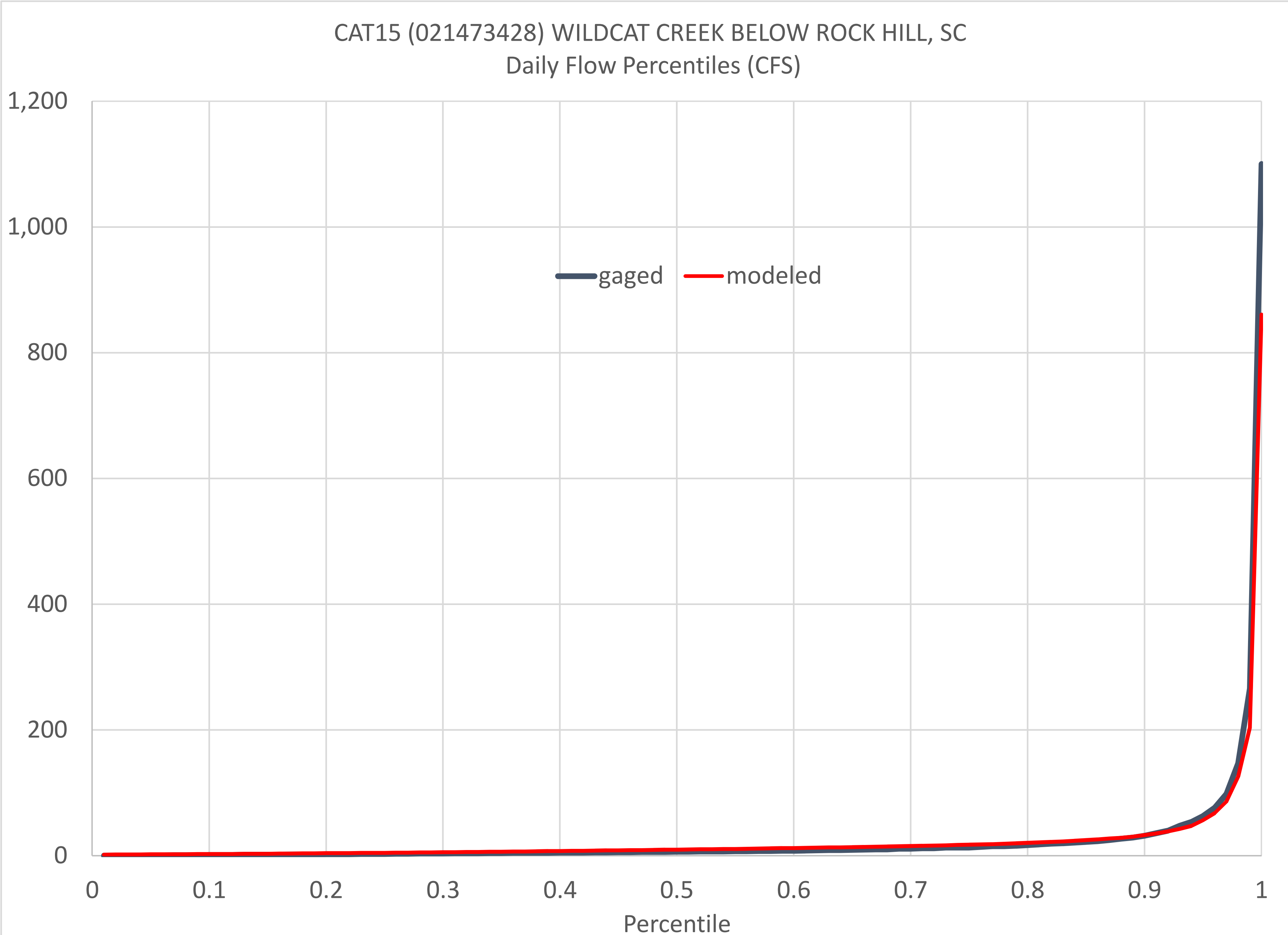


CAT07 (02146800) SUGAR CREEK NEAR FORT MILL, SC (CFS)
modeled
gaged
25,000
20,000
15,000
10,000
5,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

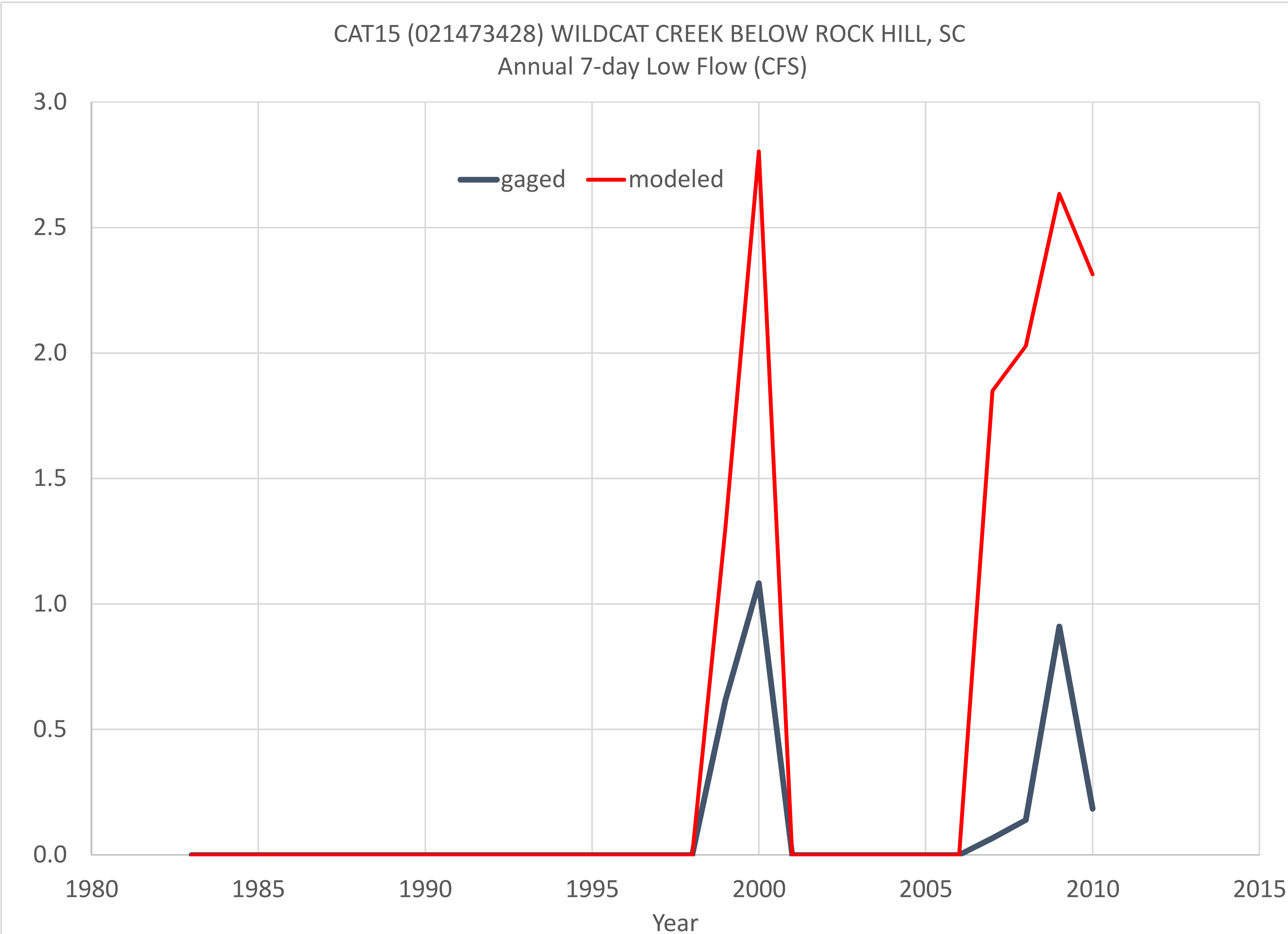

CAT07 (02146800) SUGAR CREEK NEAR FORT MILL, SC
Daily Flow Percentiles (CFS)
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
gaged
modeled
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

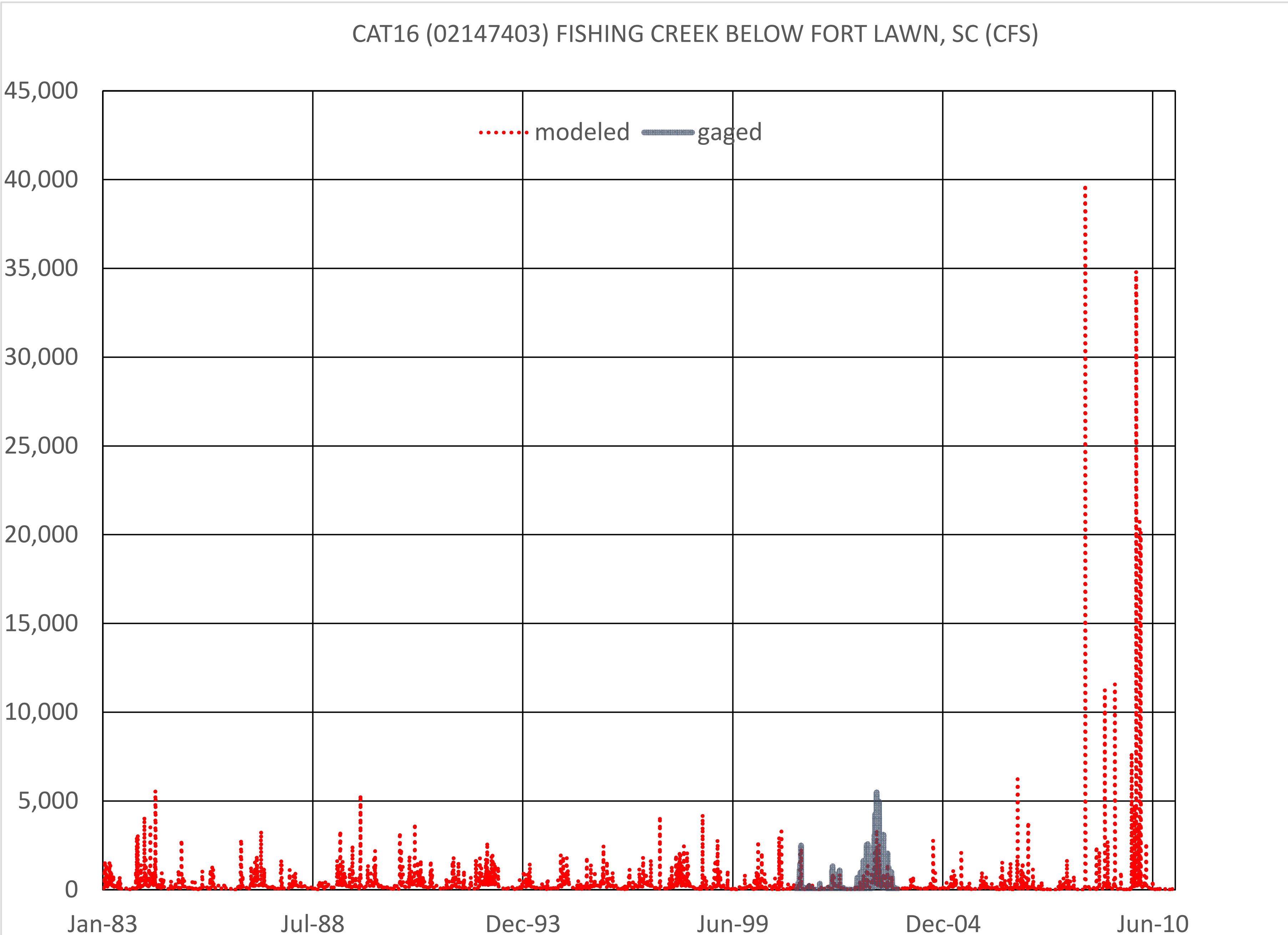

CAT07 (02146800) SUGAR CREEK NEAR FORT MILL, SC
Annual 7-day Low Flow (CFS)
gaged
modeled
0
20
40
60
80
100
120
140
1980
1985
1990
1995
2000
2005
2010
2015
Year


CAT15 (021473428) WILDCAT CREEK BELOW ROCK HILL, 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

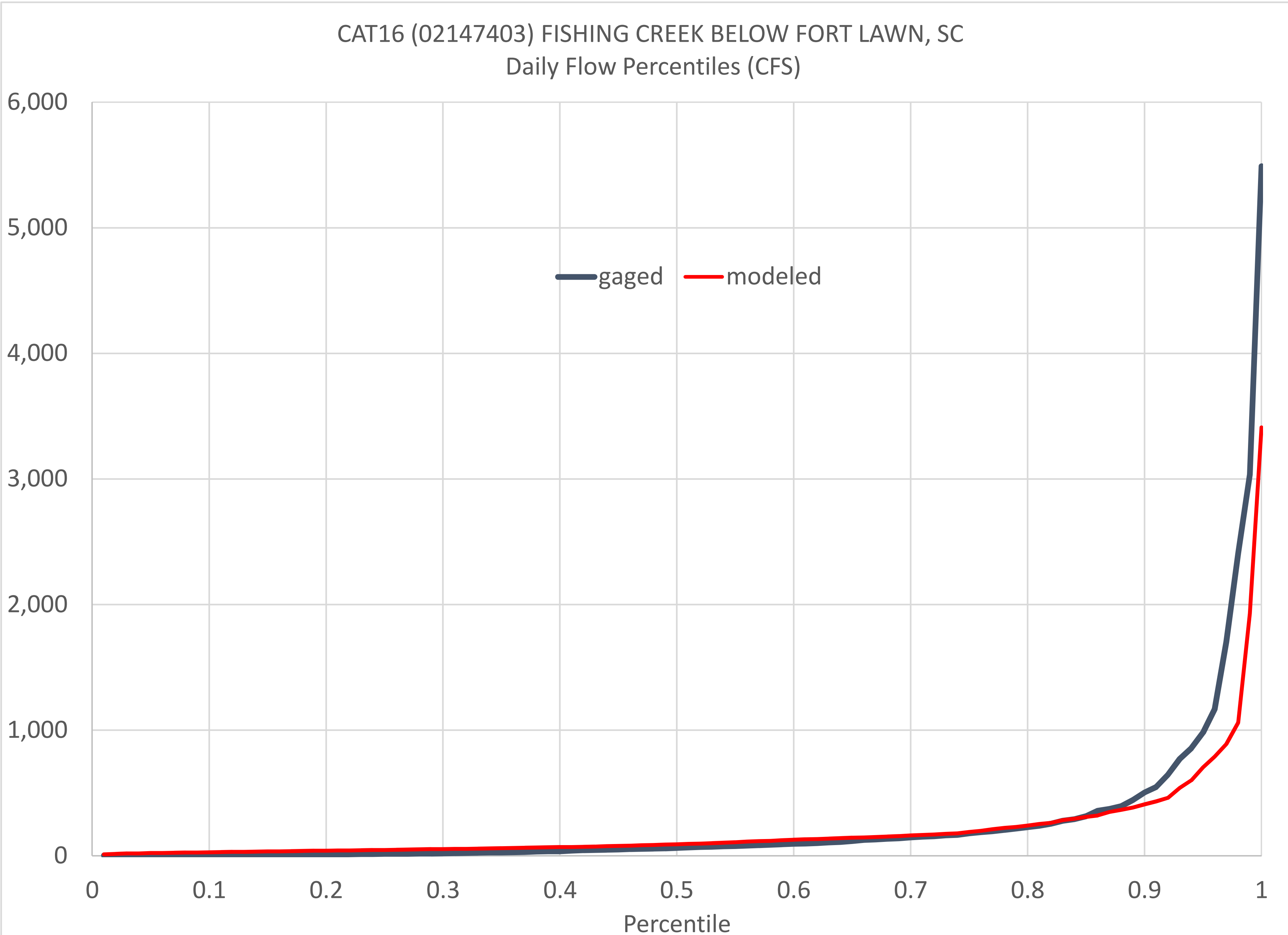


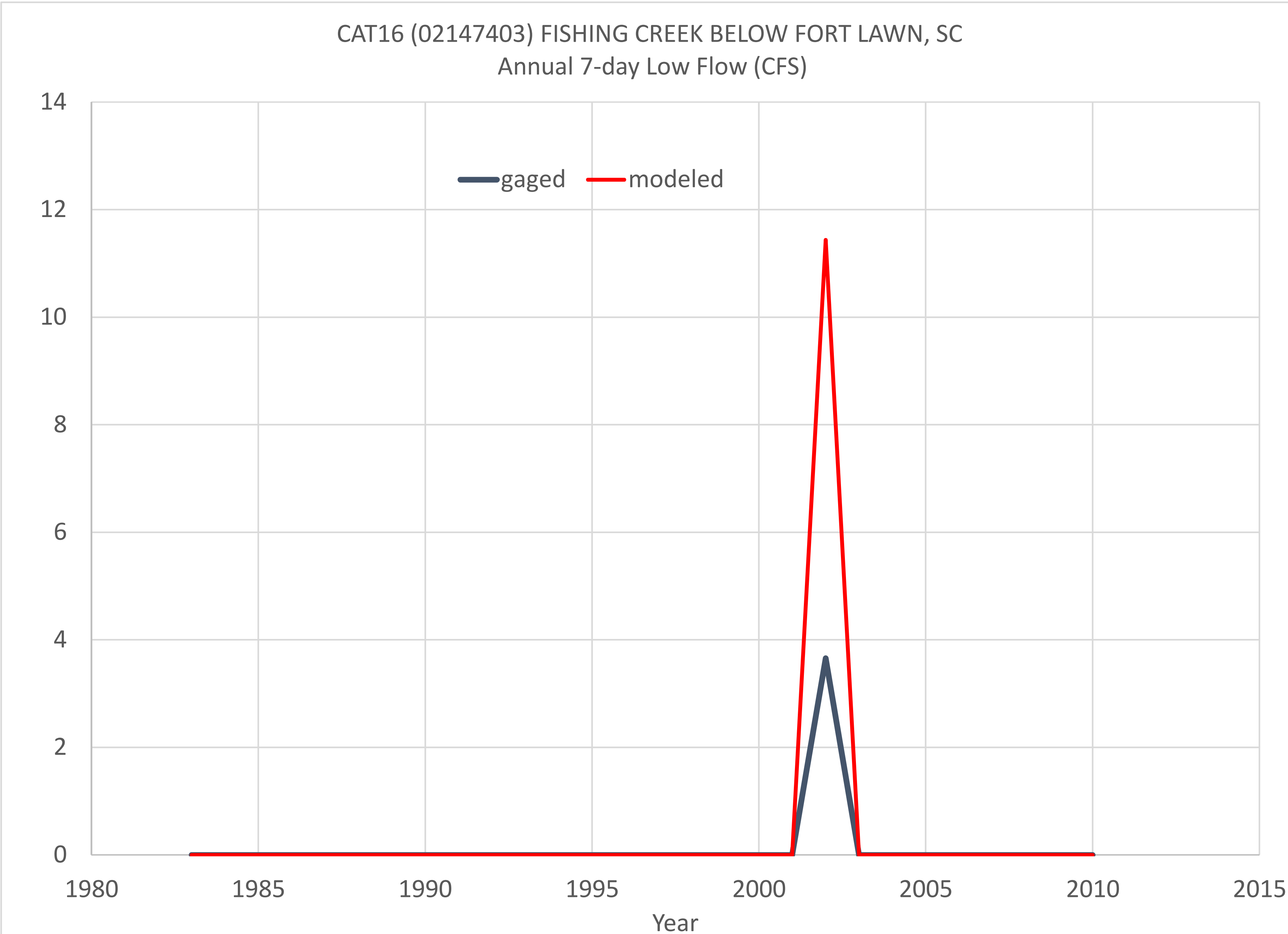
CAT15 (021473428) WILDCAT CREEK BELOW ROCK HILL, SC
Daily Flow Percentiles (CFS)
1,200
1,000
800
600
400
200
0
gaged
modeled
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile


CAT15 (021473428) WILDCAT CREEK BELOW ROCK HILL, SC
Annual 7-day Low Flow (CFS)
gaged
modeled
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1980
1985
1990
1995
2000
2005
2010
2015
Year

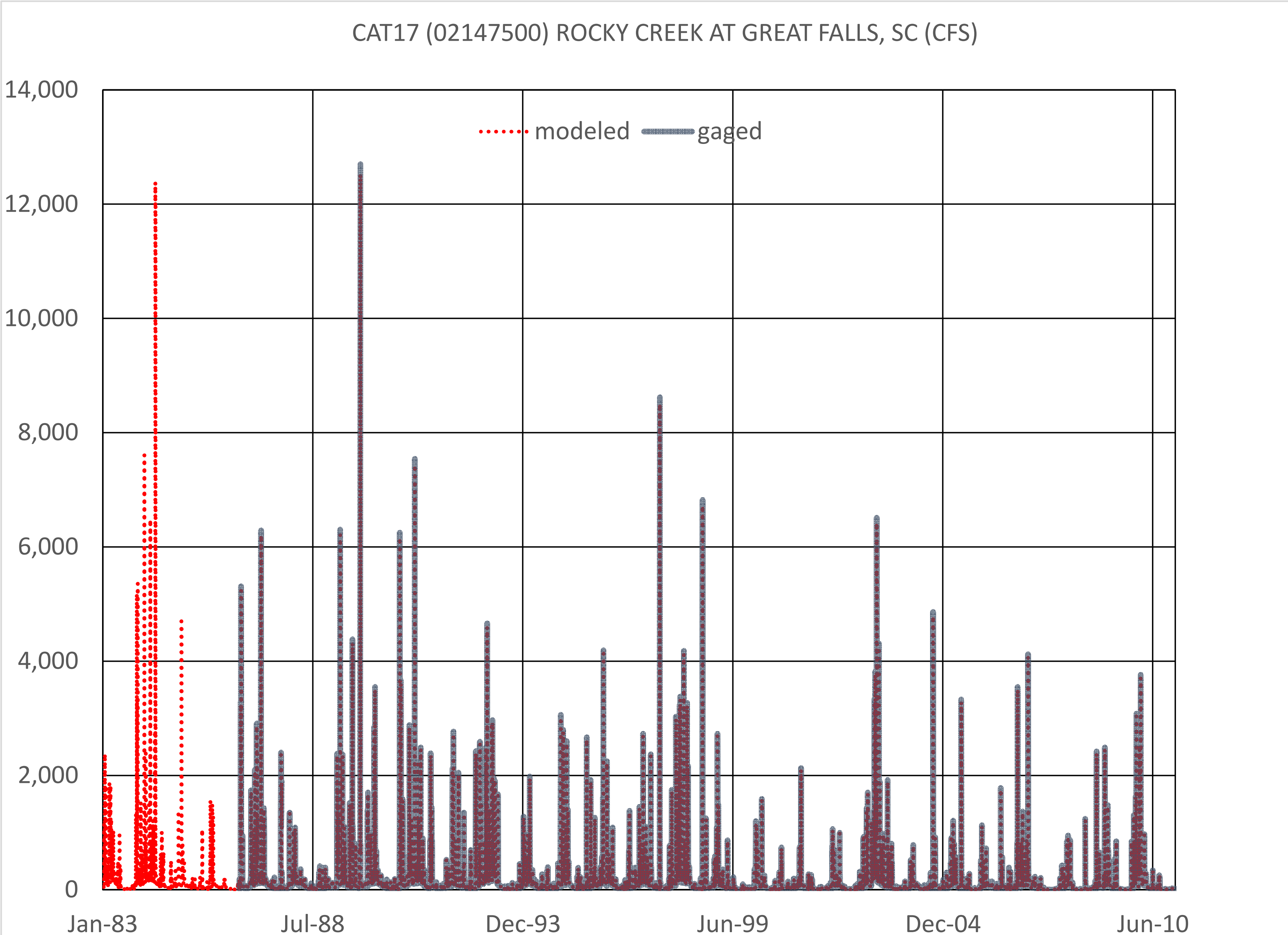


CAT16 (02147403) FISHING CREEK BELOW FORT LAWN, SC (CFS)
modeled
gaged
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

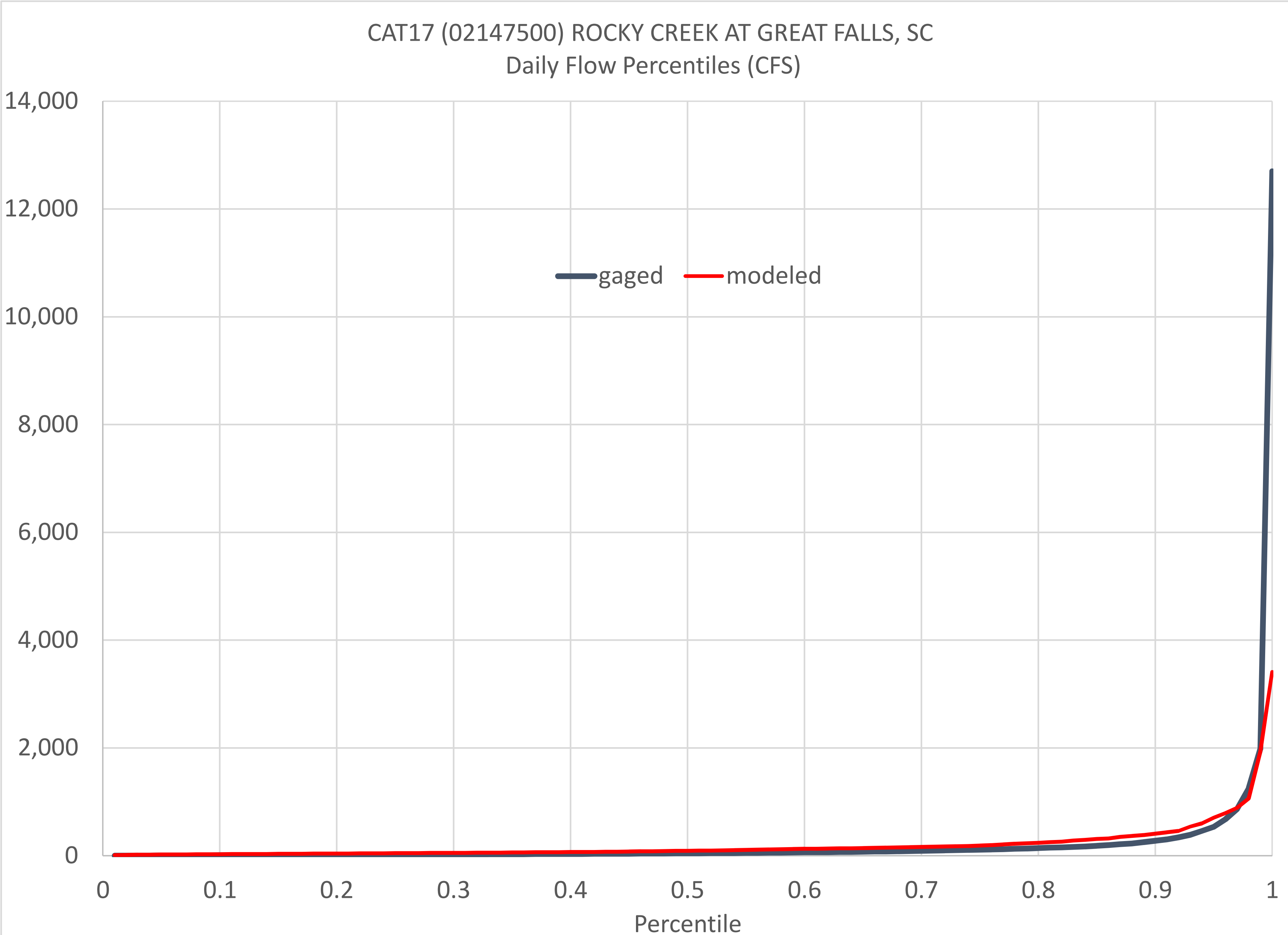

CAT16 (02147403) FISHING CREEK BELOW FORT LAWN, SC
Daily Flow Percentiles (CFS)
gaged
modeled
6,000
5,000
4,000
3,000
2,000
1,000
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

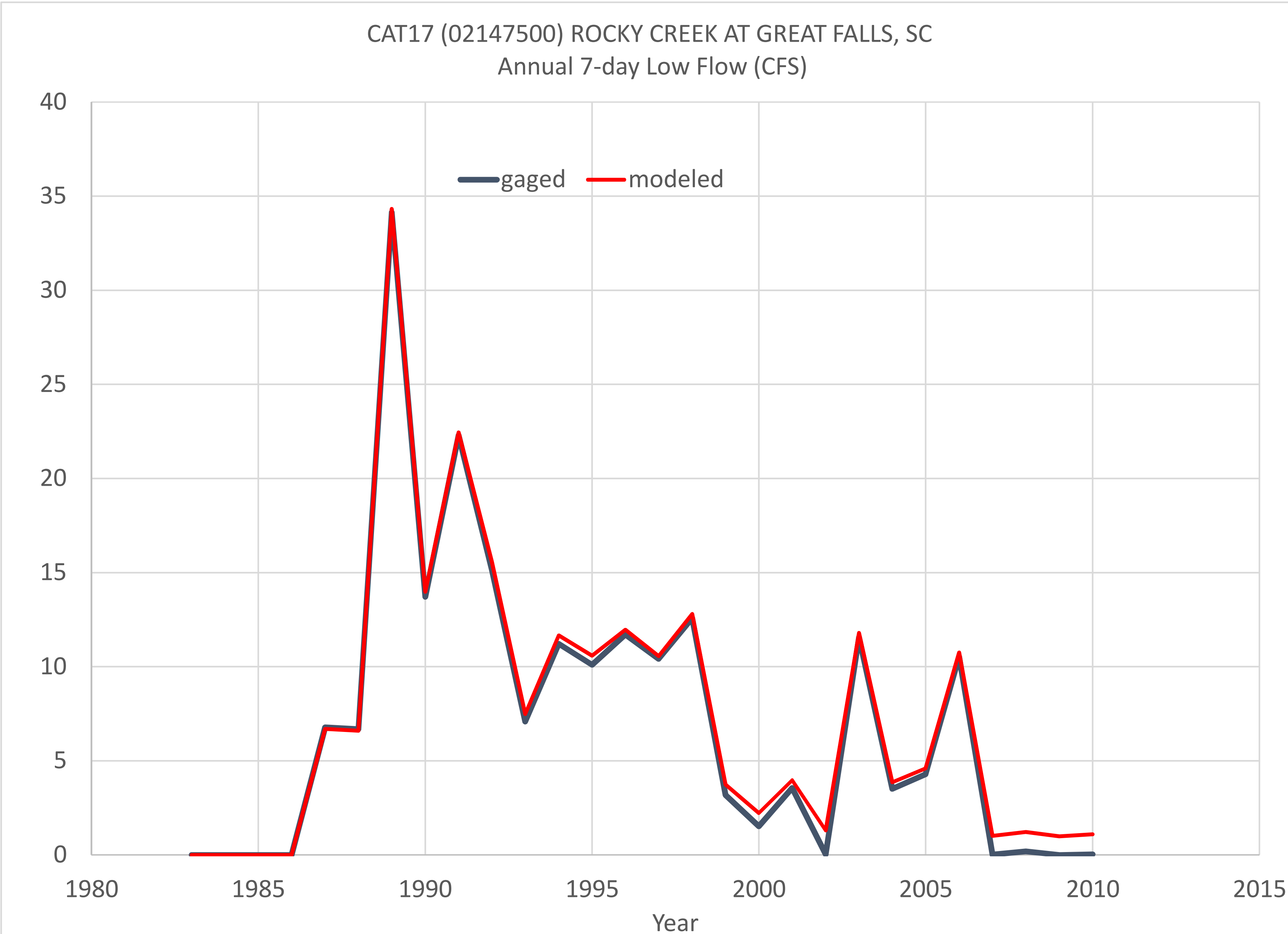


CAT16 (02147403) FISHING CREEK BELOW FORT LAWN, SC
Annual 7-day Low Flow (CFS)
gaged
modeled
14
12
10
8
6
4
2
0
1980
1985
1990
1995
2000
2005
2010
2015
Year

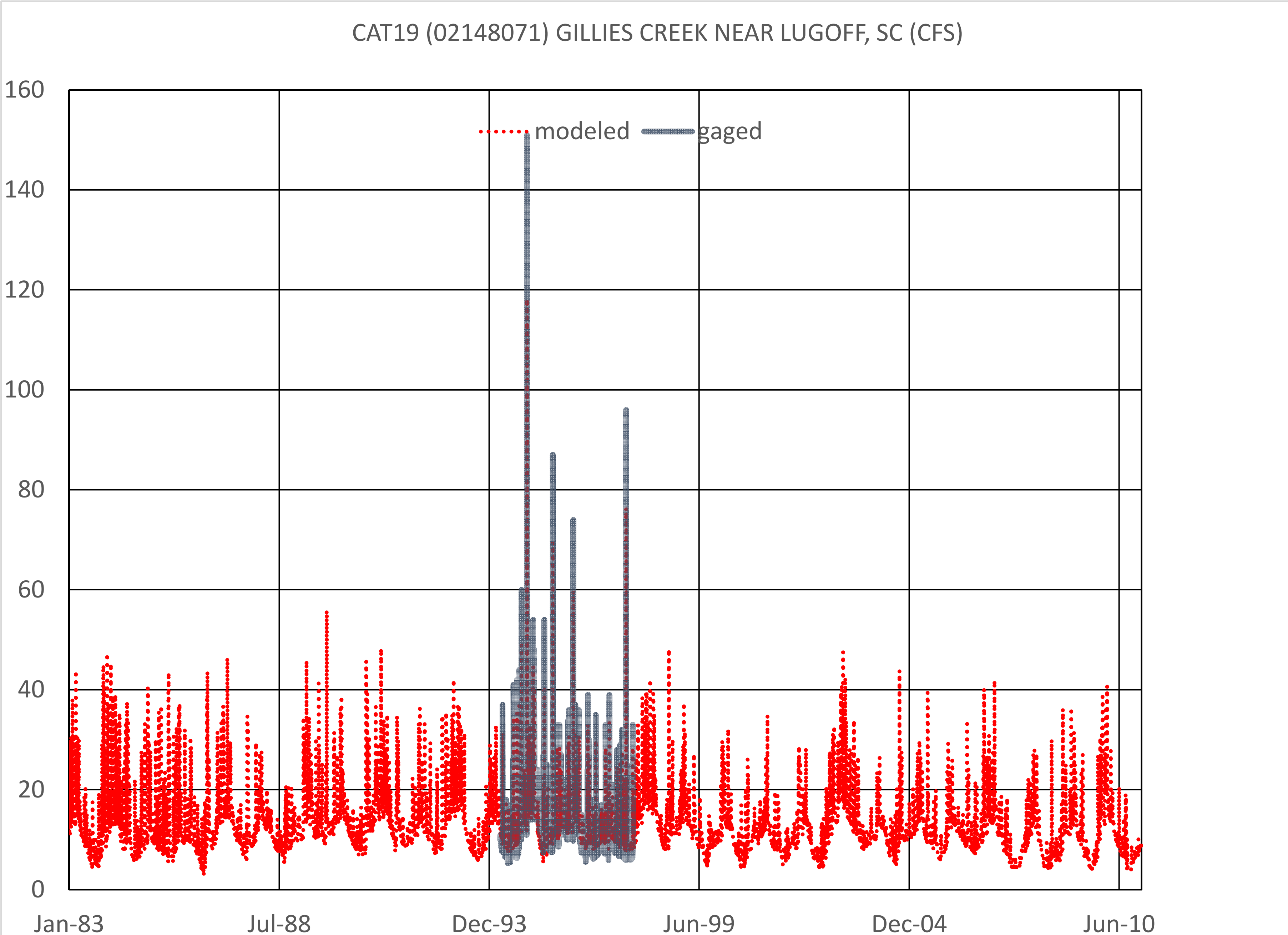


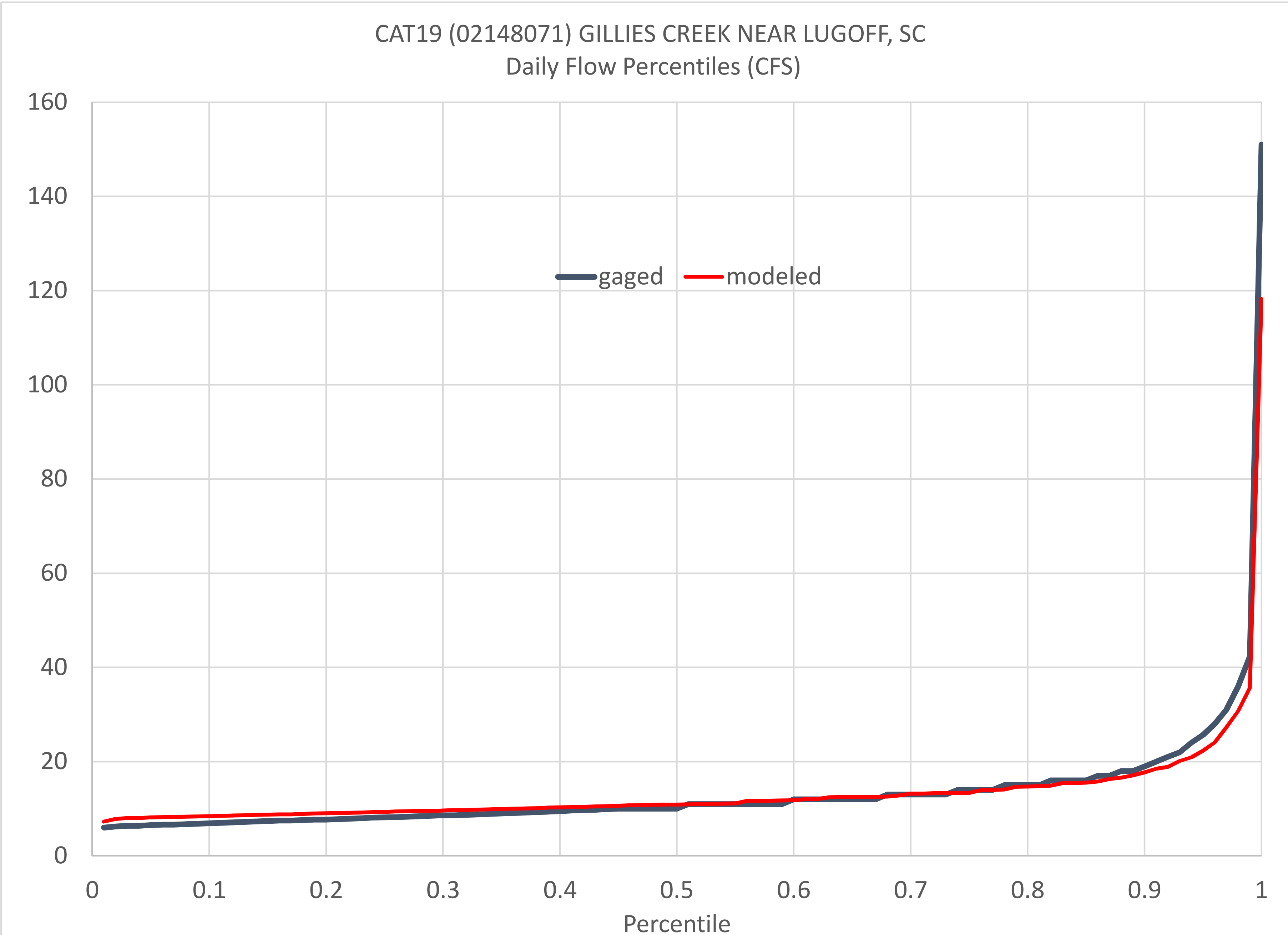
CAT17 (02147500) ROCKY CREEK AT GREAT FALLS, SC (CFS)
modeled
gaged
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10

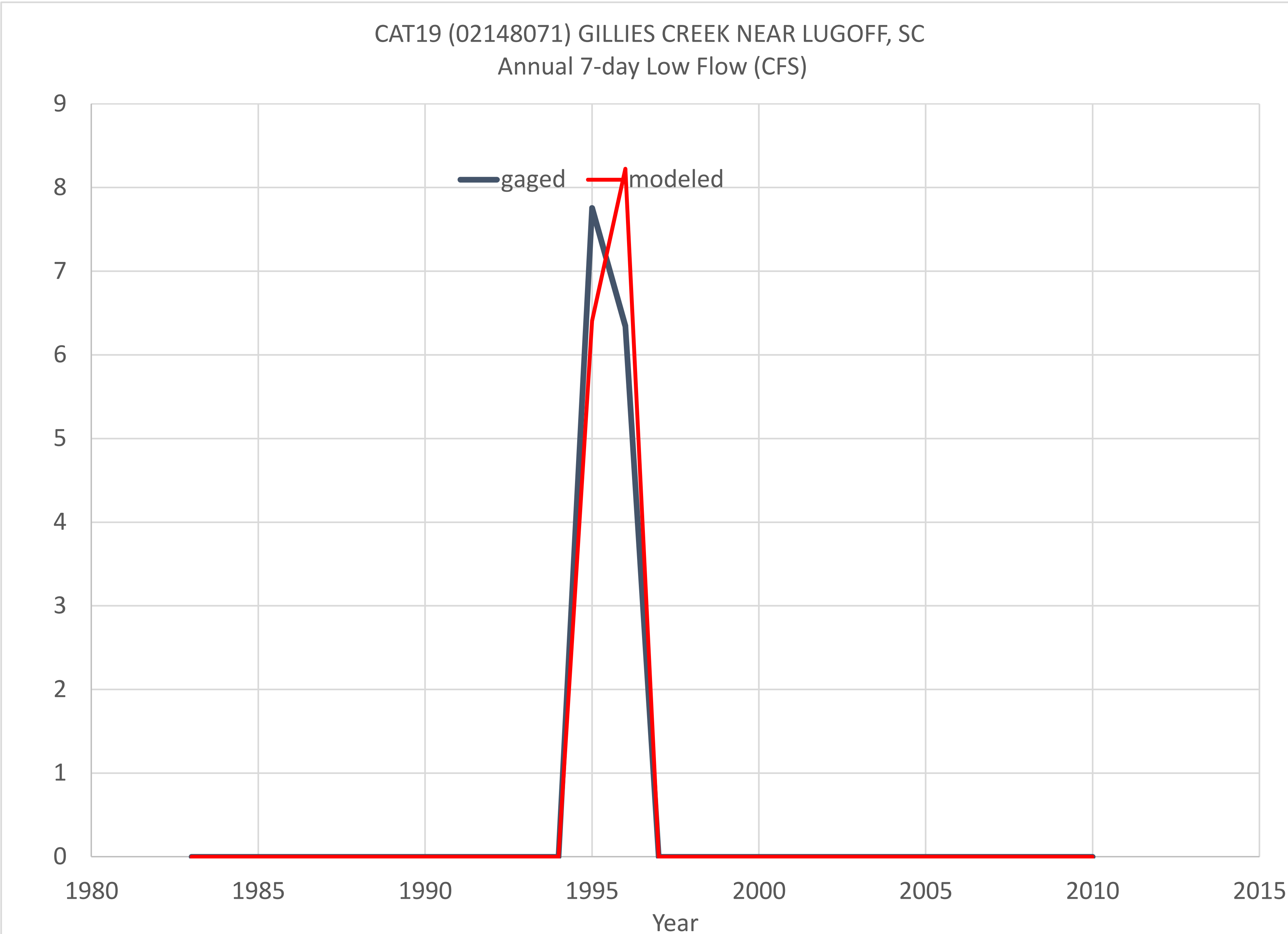

CAT17 (02147500) ROCKY CREEK AT GREAT FALLS, SC
Daily Flow Percentiles (CFS)
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
gaged
modeled
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

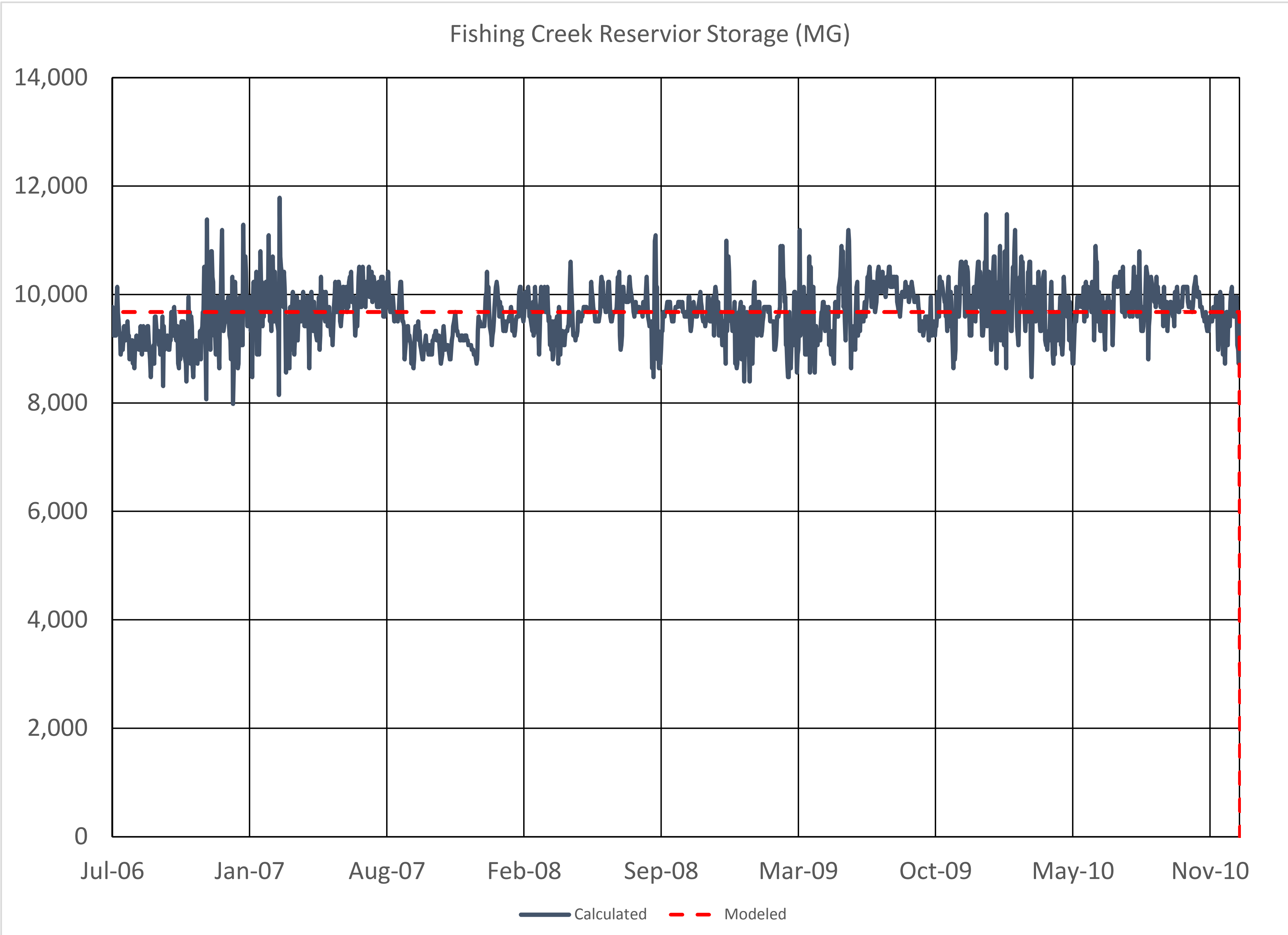


CAT17 (02147500) ROCKY CREEK AT GREAT FALLS, SC
Annual 7-day Low Flow (CFS)
gaged
modeled
0
5
10
15
20
25
30
35
40
1980
1985
1990
1995
2000
2005
2010
2015
Year

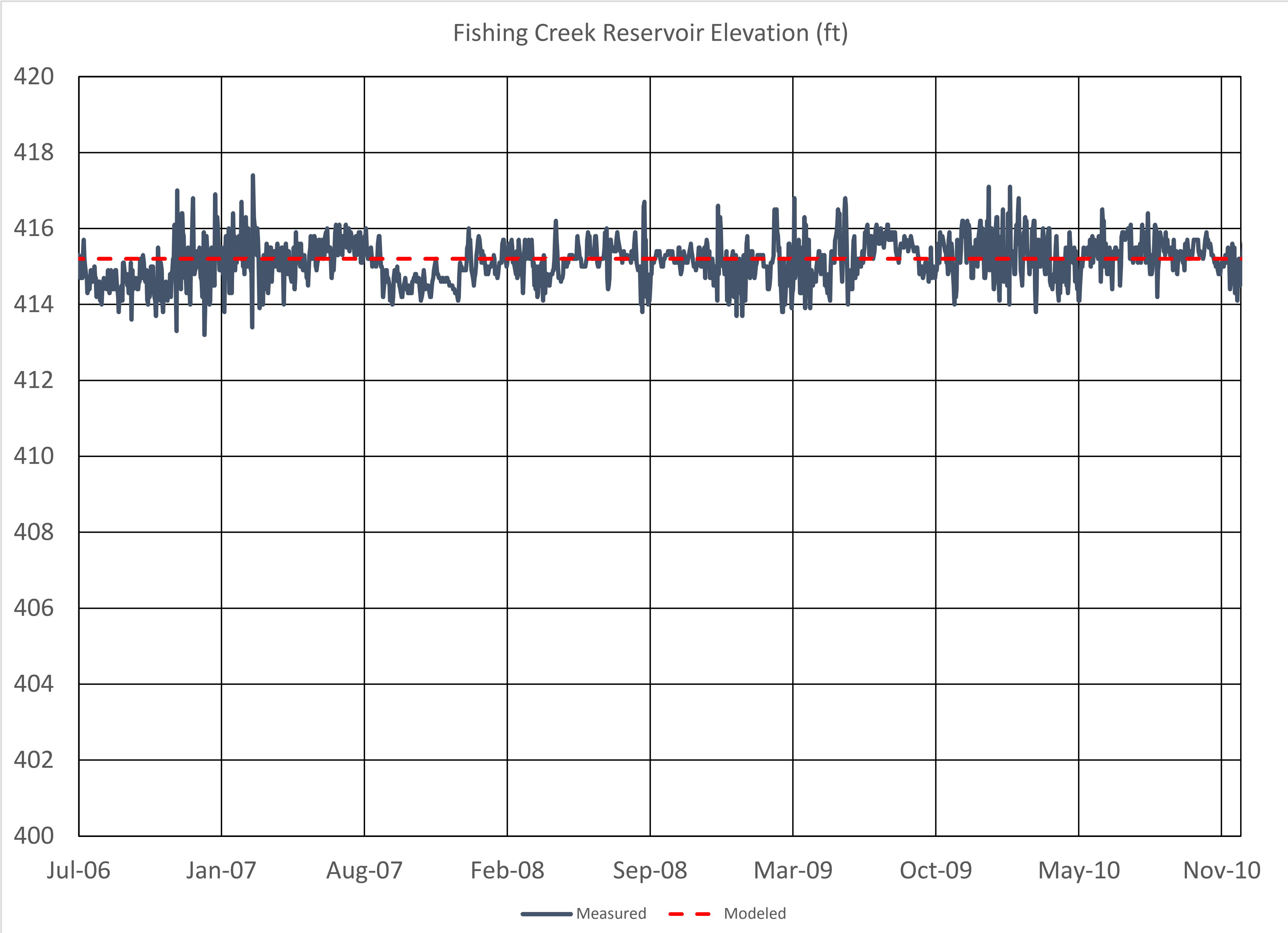

CAT19 (02148071) GILLIES CREEK NEAR LUGOFF, SC (CFS)
modeled
gaged
160
140
120
100
80
60
40
20
0
Jan-83
Jul-88
Dec-93
Jun-99
Dec-04
Jun-10


CAT19 (02148071) GILLIES CREEK NEAR LUGOFF, SC
Daily Flow Percentiles (CFS)
gaged
modeled
160
140
120
100
80
60
40
20
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

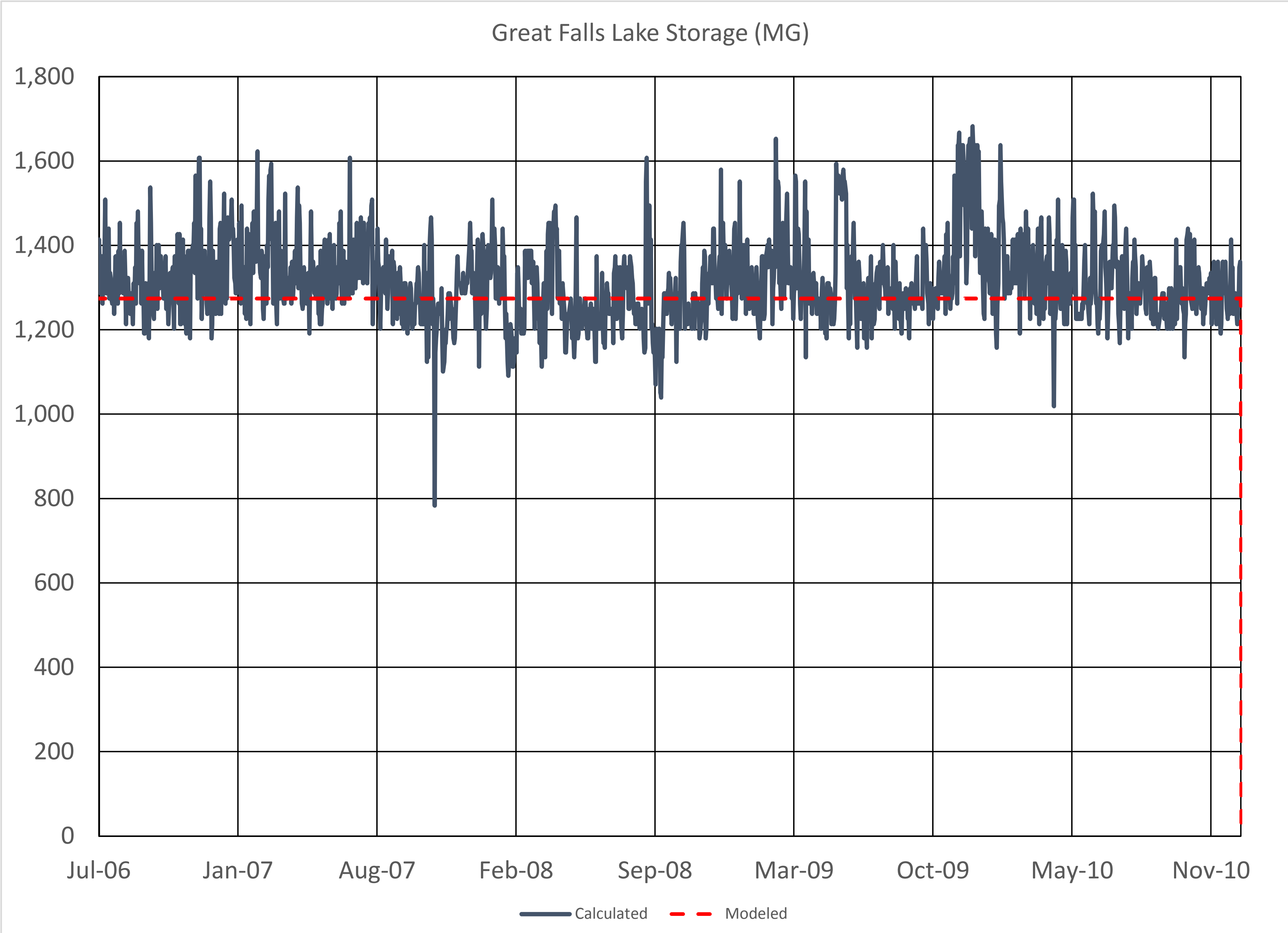

CAT19 (02148071) GILLIES CREEK NEAR LUGOFF, SC
Annual 7-day Low Flow (CFS)
gaged
modeled
0
1
2
3
4
5
6
7
8
9
1980
1985
1990
1995
2000
2005
2010
2015
Year

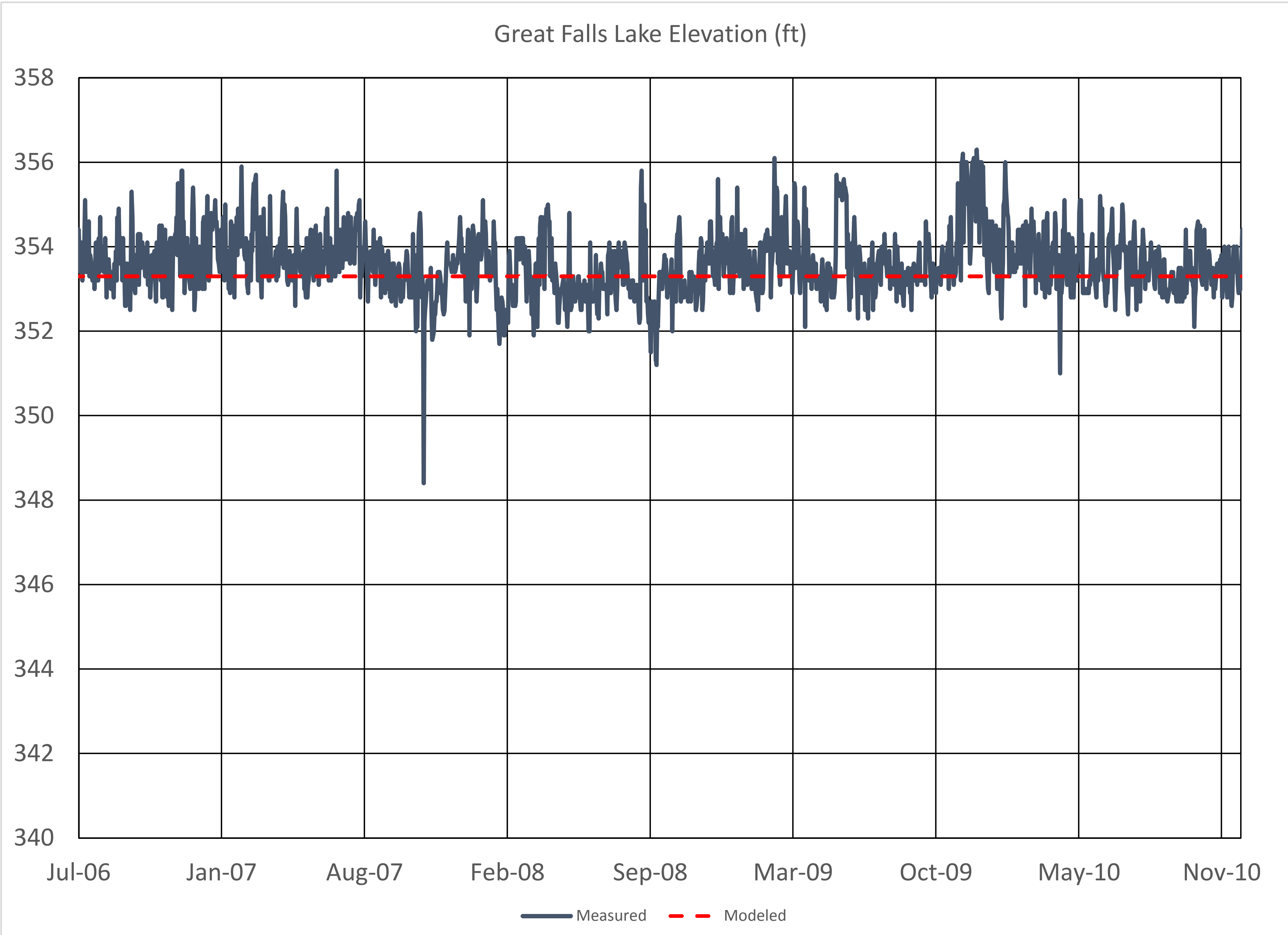


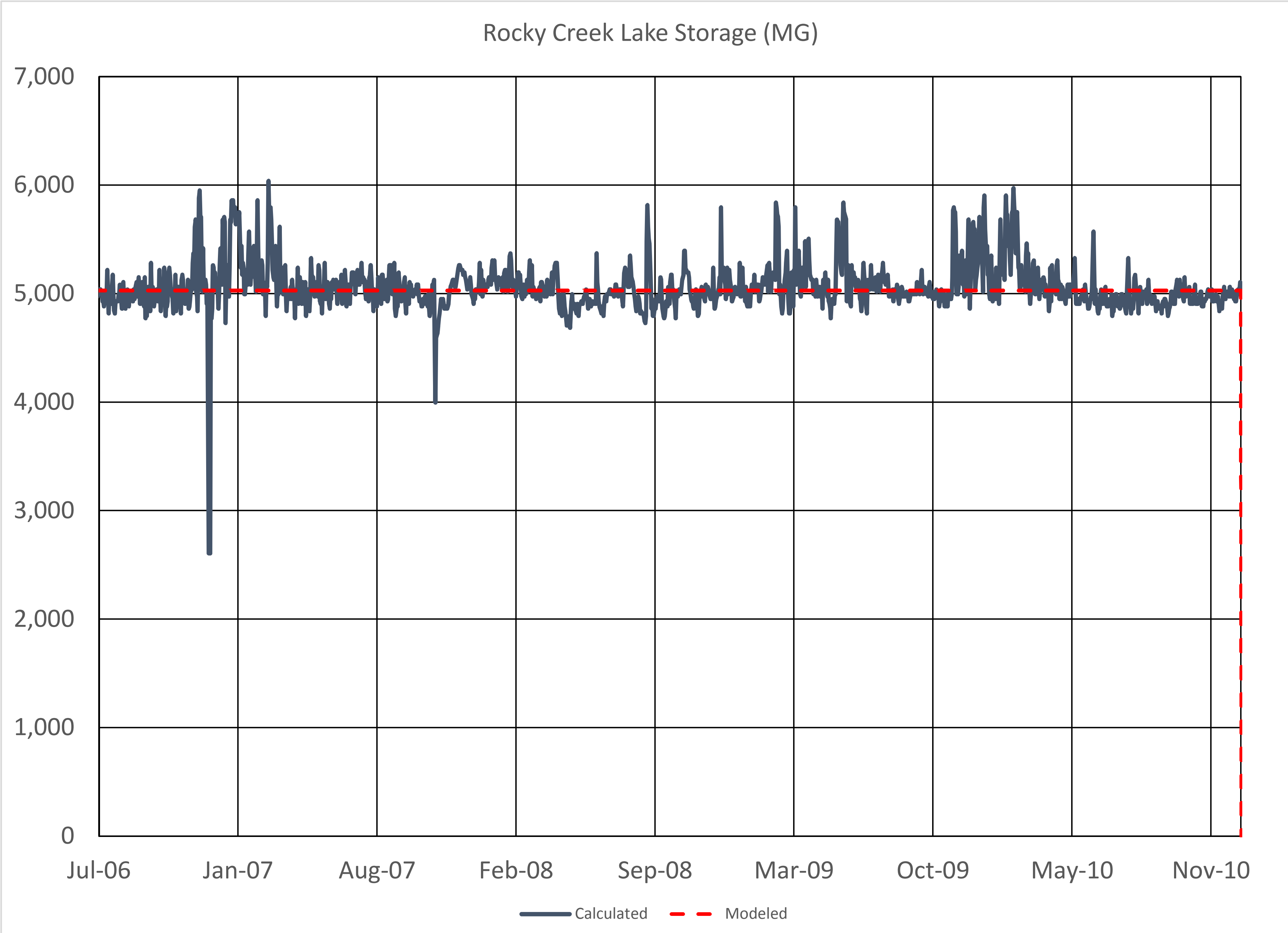
Fishing Creek Reservior Storage (MG)
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Jul-06
Jan-07
Aug-07
Feb-08
Sep-08
Mar-09
Oct-09
May-10
Nov-10
Calculated
Modeled



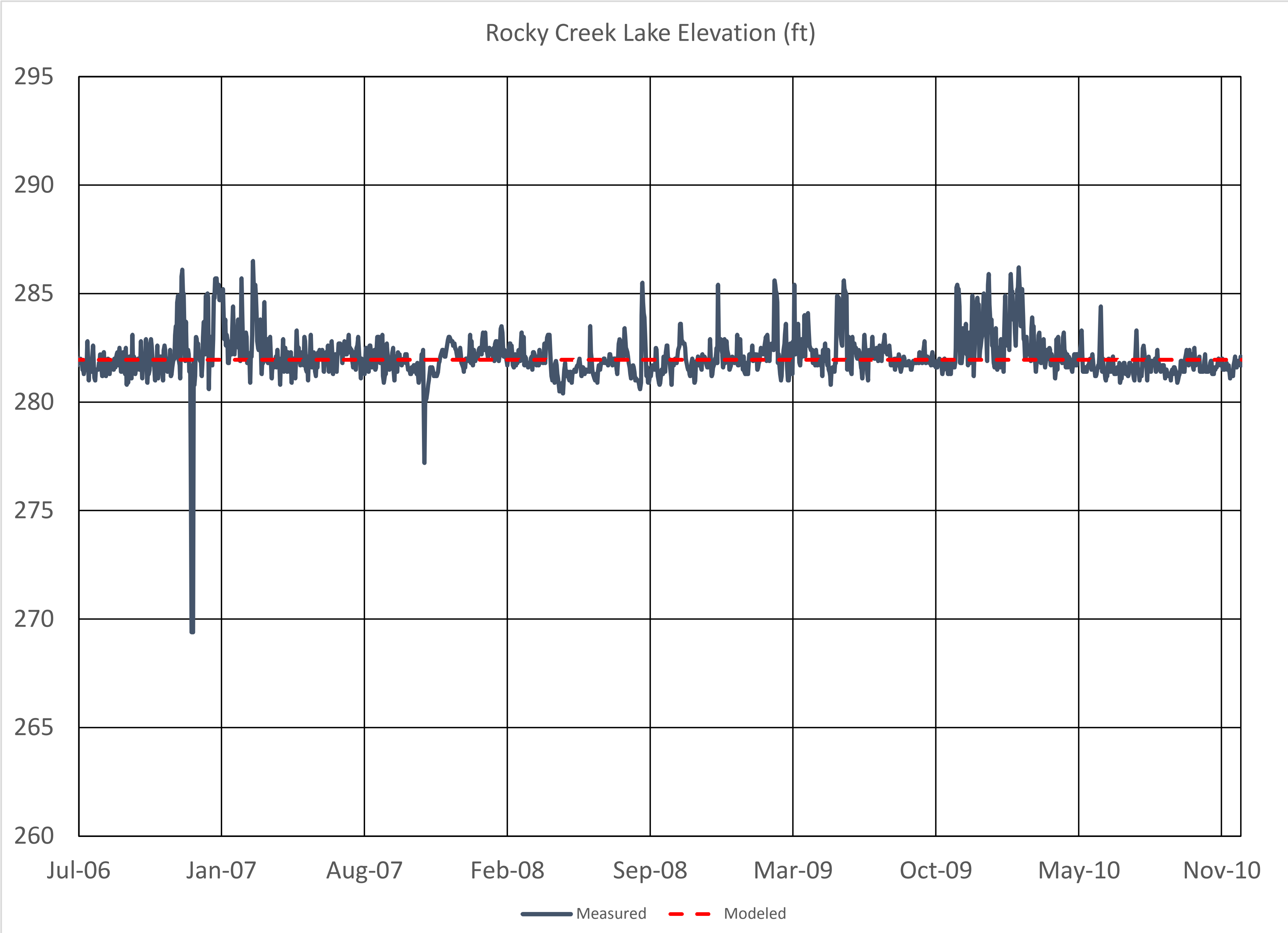
Fishing Creek Reservoir Elevation (ft)
420
418
416
414
412
410
408
406
404
402
400
Jul-06
Jan-07
Aug-07
Feb-08
Sep-08
Mar-09
Oct-09
May-10
Nov-10
Measured
Modeled

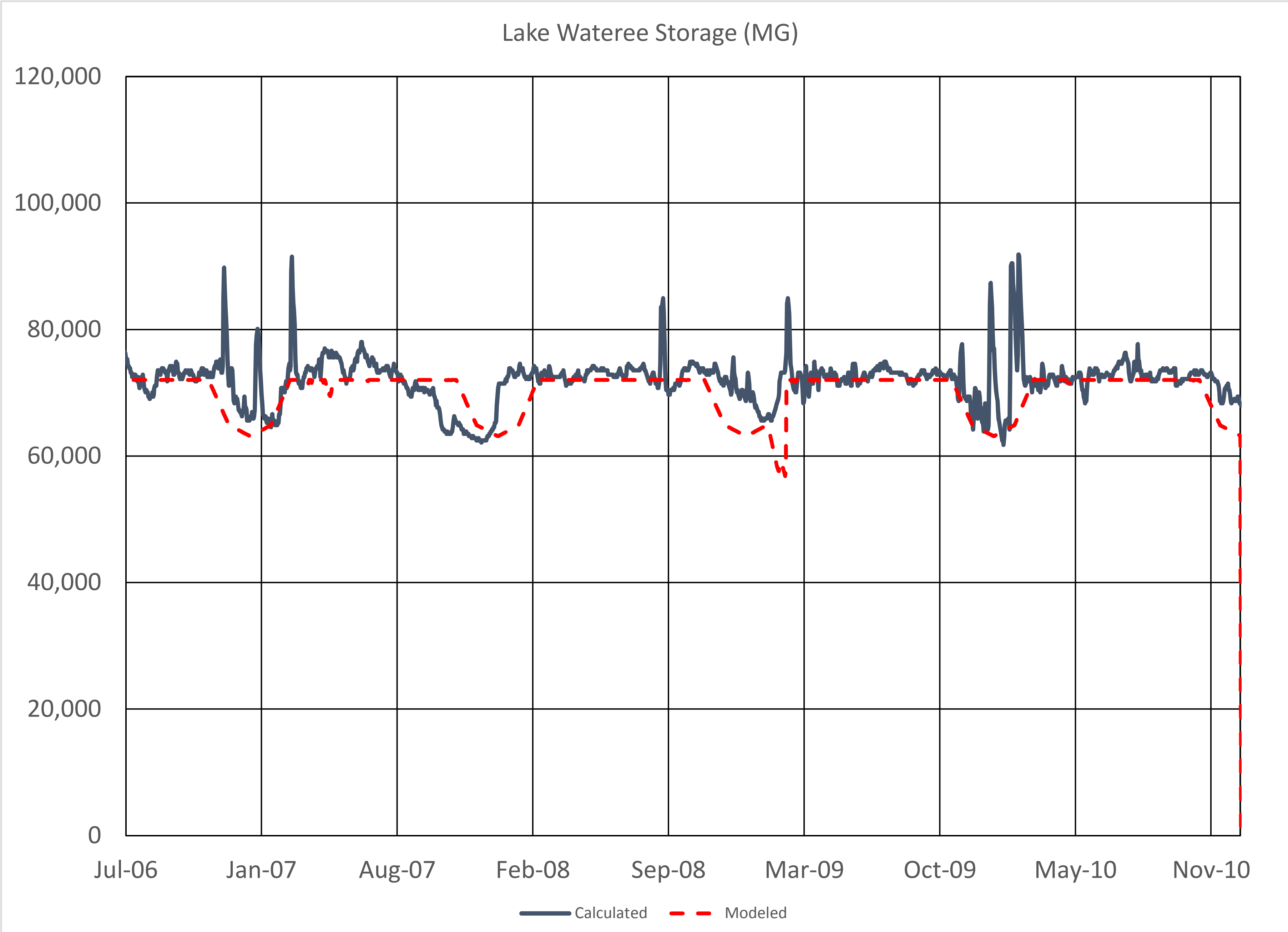

Great Falls Lake Storage (MG)
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
Jul-06
Jan-07
Aug-07
Feb-08
Sep-08
Mar-09
Oct-09
May-10
Nov-10
Calculated
Modeled


Great Falls Lake Elevation (ft)
358
356
354
352
350
348
346
344
342
340
Jul-06
Jan-07
Aug-07
Feb-08
Sep-08
Mar-09
Oct-09
May-10
Nov-10
Measured
Modeled

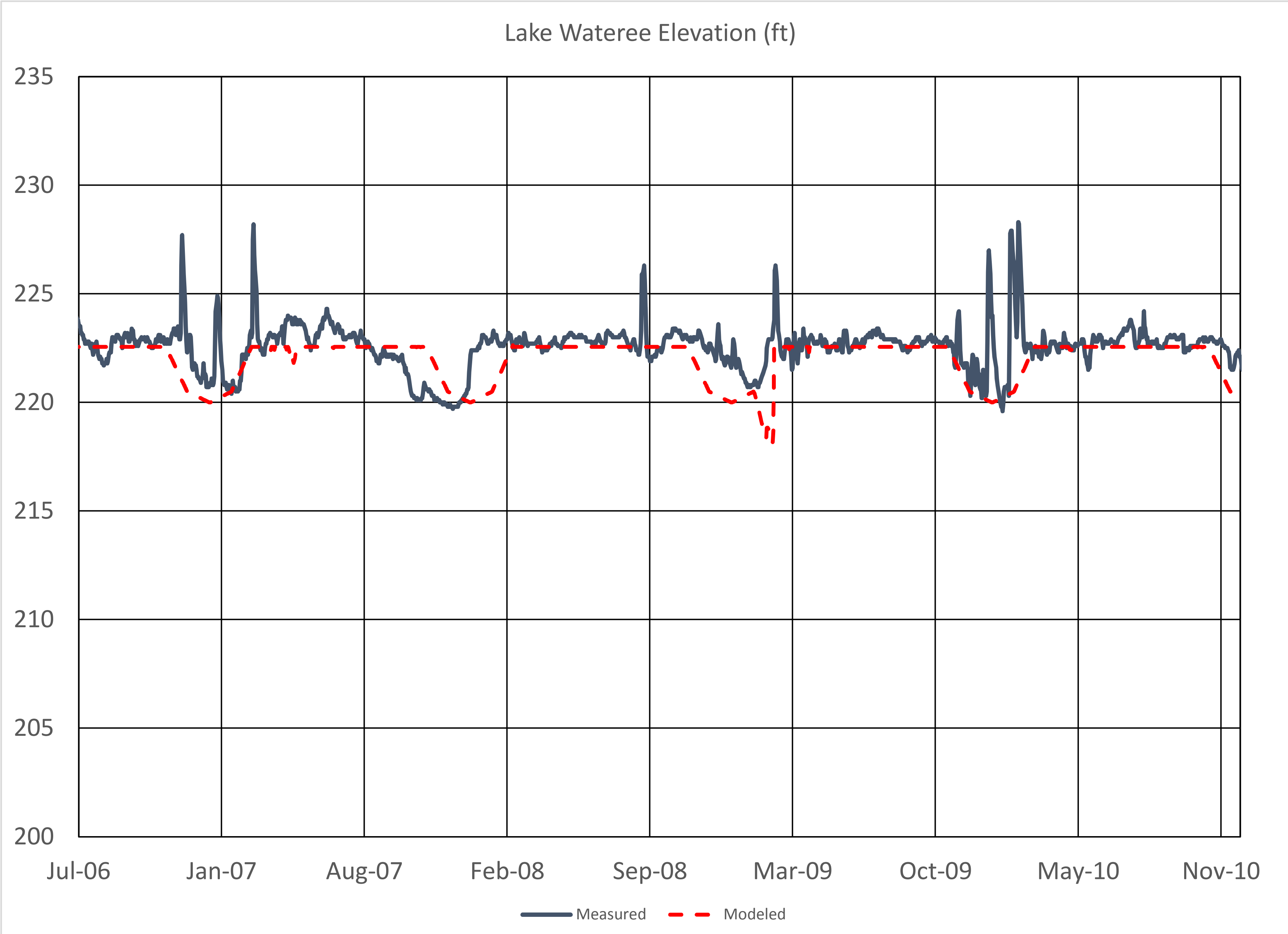


Rocky Creek Lake Storage (MG)
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Jul-06
Jan-07
Aug-07
Feb-08
Sep-08
Mar-09
Oct-09
May-10
Nov-10
Calculated
Modeled


Rocky Creek Lake Elevation (ft)
295
290
285
280
275
270
265
260
Jul-06
Jan-07
Aug-07
Feb-08
Sep-08
Mar-09
Oct-09
May-10
Nov-10
Measured
Modeled



Lake Wateree Storage (MG)
120,000
100,000
80,000
60,000
40,000
20,000
0
Jul-06
Jan-07
Aug-07
Feb-08
Sep-08
Mar-09
Oct-09
May-10
Nov-10
Calculated
Modeled



Lake Wateree Elevation (ft)
235
230
225
220
215
210
205
200
Jul-06
Jan-07
Aug-07
Feb-08
Sep-08
Mar-09
Oct-09
May-10
Nov-10
Measured
Modeled

Annual 7 day Low Flows: Modeled (Page 1)

Year	CATAWBA RIVER NEAR ROCK HILL, SC	CATAWBA RIVER BELOW CATAWBA, SC	WATEREE RIVER NR. CAMDEN, SC	WATEREE R. BL EASTOVER, SC	BIG DUTCHMAN CREEK AT ROCK HILL, SC	MANCHESTER CREEK AT ROCK HILL, SC	MCALPINE CREEK AT SR2964 NR CAMP COX, SC	SUGAR CREEK NEAR FORT MILL, SC
ID->	CAT04	CAT10	CAT18	CAT21	CAT03	CAT05	CAT06	CAT07
1983	1193.8		1350.9	1445.9				
1984	1293.8		1637.1	1958.7				
1985	1042.3		1479.9	1680.5				
1986	901.7		1122.0	1318.9				
1987	1193.0		1615.5	1735.9				
1988	782.2		1098.6	1363.7				
1989	813.8		1572.4	1841.4				
1990	1201.3		1610.0	1807.3				
1991	1189.3		1614.1	1835.9				
1992	1022.8		1695.0	1880.5				
1993	1032.3	1282.3	1474.6	1631.2				
1994	1039.8		1707.6	1903.3				
1995			1639.0	1913.5				
1996	1389.7	1660.4	1800.2	1984.7				
1997	1147.5	1418.1	1506.5	1661.2				
1998	1194.5	1461.4	1699.3	1875.0				
1999	804.4	1049.0	1215.3	1344.5				
2000	812.5	1057.0	1198.8	1412.6				
2001	1031.0	1228.6	1144.5	1365.0				
2002	666.9	853.2	878.7	999.2				
2003	1597.6	2116.6	2226.8	1853.7				
2004	1384.8	1639.0	1641.2	1784.8				
2005	1310.0	1625.8	1631.1	1751.2				
2006	954.1	1369.2	1390.5	1545.7			73.6	
2007	685.9	795.7	834.2	906.6	0.1	0.0	66.4	101.8
2008	681.4	882.0	839.1	938.3	0.1	0.2	71.6	116.6
2009	1196.7	1443.0	1436.1	1549.3	0.3	0.1	64.4	114.7
2010	1032.0	1181.7	1224.7	1328.8	0.3	0.1	64.3	109.8

Annual 7 day Low Flows: Measured

Year	CATAWBA RIVER NEAR ROCK HILL, SC	CATAWBA RIVER BELOW CATAWBA, SC	WATEREE RIVER NR. CAMDEN, SC	WATEREE R. BL EASTOVER, SC	BIG DUTCHMAN CREEK AT ROCK HILL, SC	MANCHESTER CREEK AT ROCK HILL, SC	MCALPINE CREEK AT SR2964 NR CAMP COX, SC	SUGAR CREEK NEAR FORT MILL, SC
ID->	CAT04	CAT10	CAT18	CAT21	CAT03	CAT05	CAT06	CAT07
1983	905.4		836.0	1369.9				
1984	922.7		471.0	1017.7				
1985	570.6		497.1	1171.6				
1986	626.4		368.7	698.3				
1987	618.6		723.0	1451.4				
1988	639.9		808.4	1106.0				
1989	959.3		1036.4	1614.3				
1990	1006.4		1293.1	1581.4				
1991	674.9		1053.9	1448.6				
1992	823.9		1394.3	1982.9				
1993	727.4	807.0	895.1	1275.7				
1994	1027.9		1368.6	1682.9				
1995			1621.4	2188.6				
1996	1213.3	1164.7	1225.4	1624.3				
1997	834.7	1179.1	1011.9	1295.7				
1998	760.1	881.6	1100.7	1657.1				
1999	853.0	959.3	1238.3	1392.9				
2000	725.4	922.7	1354.3	1438.6				
2001	550.6	965.7	977.1	766.6				
2002	473.7	907.1	828.9	801.4				
2003	1338.0	1664.4	2055.7	2407.1				
2004	1294.3	1707.1	1627.1	1607.1				
2005	1016.0	1055.7	957.7	1257.1				
2006	963.9	1390.0	1457.1	1662.9			76.6	
2007	706.1	814.3	942.9	1012.9	0.1	0.0	61.4	90.3
2008	762.3	823.0	827.1	1067.1	0.1	0.2	67.6	109.9
2009	1177.3	1380.0	1128.6	1297.1	0.2	0.1	41.0	121.7
2010	934.7	1220.0	1026.3	1302.9	0.3	0.1	62.0	114.7

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

Approximate 7Q10 Comparison - Modeled vs. Measured

Year	CATAWBA RIVER NEAR ROCK HILL, SC	CATAWBA RIVER BELOW CATAWBA, SC	WATEREE RIVER NR. CAMDEN, SC	WATEREE R. BL EASTOVER, SC	ROCKY CREEK AT GREAT FALLS, SC
ID->	CAT04	CAT10	CAT18	CAT21	CAT17
Modeled	683	830	836	919	1.11
Measured	729	818	873	1035	0.03
% Diff.	-6.2%	1.5%	-4.3%	-11.1%	3604%

Annual 7 day Low Flows: Modeled (Page 2)

Year	TOOLS FORK CREEK NEAR ROCK HILL, SC	WILDCAT CREEK NEAR ROCK HILL, SC	WILDCAT CREEK BELOW ROCK HILL, SC	FISHING CREEK @ HWY 5 BELOW YORK, SC	FISHING CREEK BELOW FORT LAWN, SC	ROCKY CREEK AT GREAT FALLS, SC	GILLIES CREEK NEAR LUGOFF, SC	COLONELS CREEK NEAR LEESBURG,S.C.
ID->	**CAT14**	**CAT13**	**CAT15**	**CAT12**	**CAT16**	**CAT17**	**CAT19**	**CAT20**
1983								
1984								
1985								
1986								
1987						6.7		
1988						6.6		
1989						34.3		
1990						14.0		
1991						22.4		
1992						15.6		
1993						7.5		
1994						11.7		
1995						10.6	6.4	
1996						12.0	8.2	
1997						10.6		
1998						12.8		
1999	0.1	0.3	1.3			3.7		
2000	0.1		2.8			2.2		
2001						4.0		
2002					11.4	1.3		
2003						11.8		
2004						3.9		
2005						4.6		10.1
2006						10.8		6.2
2007	0.0		1.8			0.9		
2008	0.0		2.0			1.1		
2009	0.1		2.6	0.9		1.0		
2010	0.0		2.3	0.1		1.1		

Annual 7 day Low Flows: Measured

Year	TOOLS FORK CREEK NEAR ROCK HILL, SC	WILDCAT CREEK NEAR ROCK HILL, SC	WILDCAT CREEK BELOW ROCK HILL, SC	FISHING CREEK @ HWY 5 BELOW YORK, SC	FISHING CREEK BELOW FORT LAWN, SC	ROCKY CREEK AT GREAT FALLS, SC	GILLIES CREEK NEAR LUGOFF, SC	COLONELS CREEK NEAR LEESBURG,S.C.
ID->	**CAT14**	**CAT13**	**CAT15**	**CAT12**	**CAT16**	**CAT17**	**CAT19**	**CAT20**
1983								
1984								
1985								
1986								
1987						6.8		
1988						6.7		
1989						34.1		
1990						13.7		
1991						22.3		
1992						15.1		
1993						7.1		
1994						11.2		
1995						10.1	7.8	
1996						11.7	6.3	
1997						10.4		
1998						12.6		
1999	0.1	0.3	0.6			3.2		
2000	0.1		1.1			1.5		
2001						3.6		
2002					3.7	0.0		
2003						11.6		
2004						3.5		
2005						4.3		10.0
2006						10.5		6.1
2007	0.0		0.1			0.0		
2008	0.0		0.1			0.2		
2009	0.1		0.9	0.9		0.0		
2010	0.0		0.2	0.1		0.0		

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

Appendix C

Guidelines for Representing Multi-Basin Water Users in SWAM

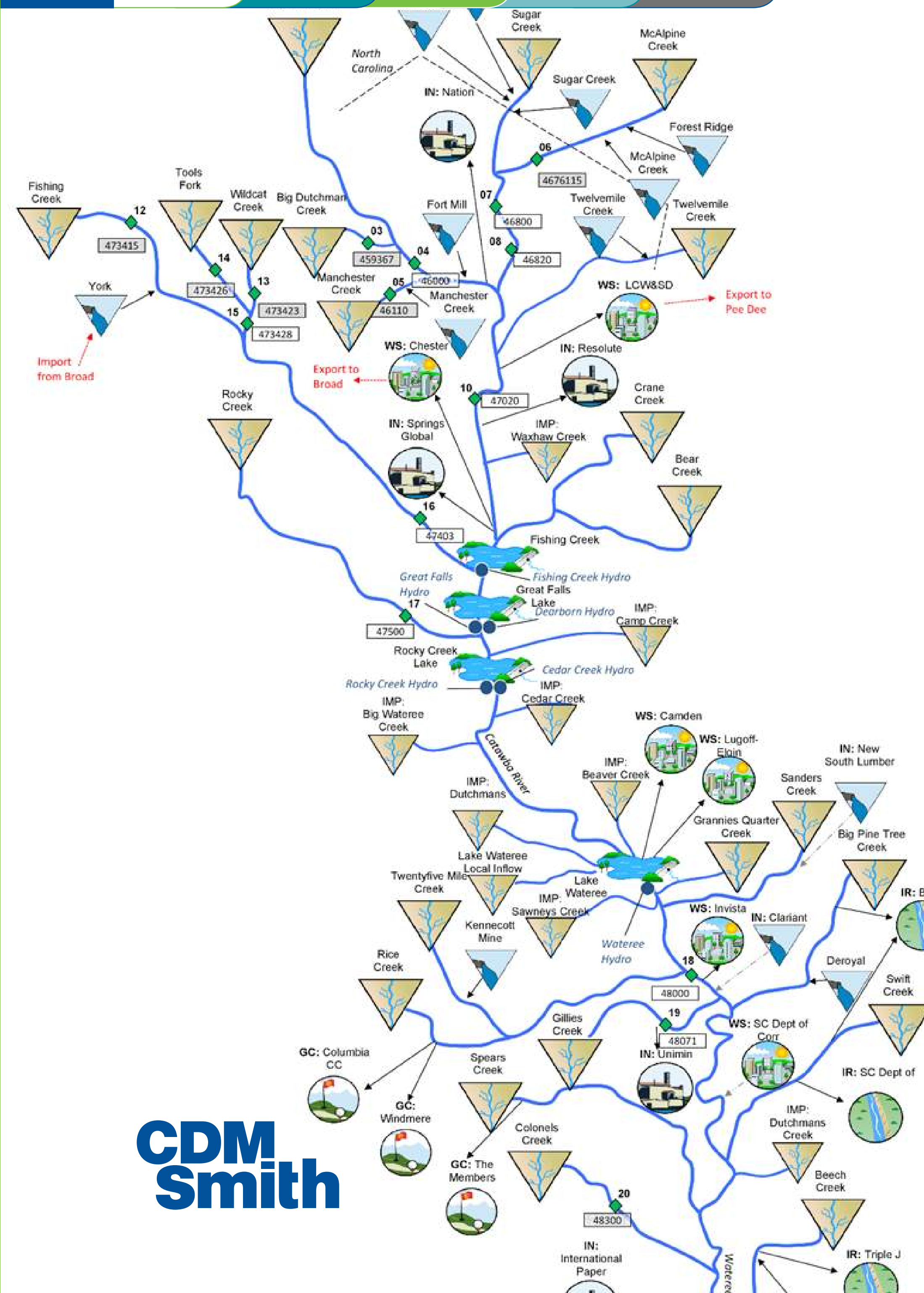
CDM Smith

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.


Sugar Creek
McAlpine Creek
North Carolina
IN: Nation
Sugar Creek
Forest Ridge
06
4676115
McAlpine Creek
Fishing Creek
Tools Fork
Wildcat Creek
Big Dutchman Creek
Fort Mill
07
46800
Twelvemile Creek
Twelvemile Creek
12
473415
03
459367
04
08
46820
14
473426
13
473423
Manchester Creek
05
46000
46110
Manchester Creek
WS: LCW&SD
Export to Pee Dee
York
15
473428
Import from Broad
WS: Chester
Export to Broad
IN: Resolute
10
47020
Crane Creek
Rocky Creek
IN: Springs Global
IMP: Waxhaw Creek
Bear Creek
16
47403
Fishing Creek
Fishing Creek Hydro
Great Falls Hydro
Great Falls Lake
17
Dearborn Hydro
47500
IMP: Camp Creek
Rocky Creek Lake
Cedar Creek Hydro
Rocky Creek Hydro
IMP: Cedar Creek
IMP: Big Wateree Creek
Catawba River
WS: Camden
WS: Lugoff-Elgin
IN: New South Lumber
IMP: Beaver Creek
IMP: Dutchmans
Sanders Creek
Grannies Quarter Creek
Big Pine Tree Creek
Lake Wateree Local Inflow
Twentyfive Mile Creek
Lake Wateree
IMP: Sawneys Creek
WS: Invista
IN: Clariant
Kennecott Mine
Wateree Hydro
18
48000
Deroyal
Swift Creek
Rice Creek
Gillies Creek
19
48071
IN: Unimin
WS: SC Dept of Corr
GC: Columbia CC
GC: Windmere
Spears Creek
IR: SC Dept of
IMP: Dutchmans Creek
GC: The Members
Colonels Creek
Beech Creek
20
48300
IN: International Paper
IR: Triple J
Wateree R

CDM Smith