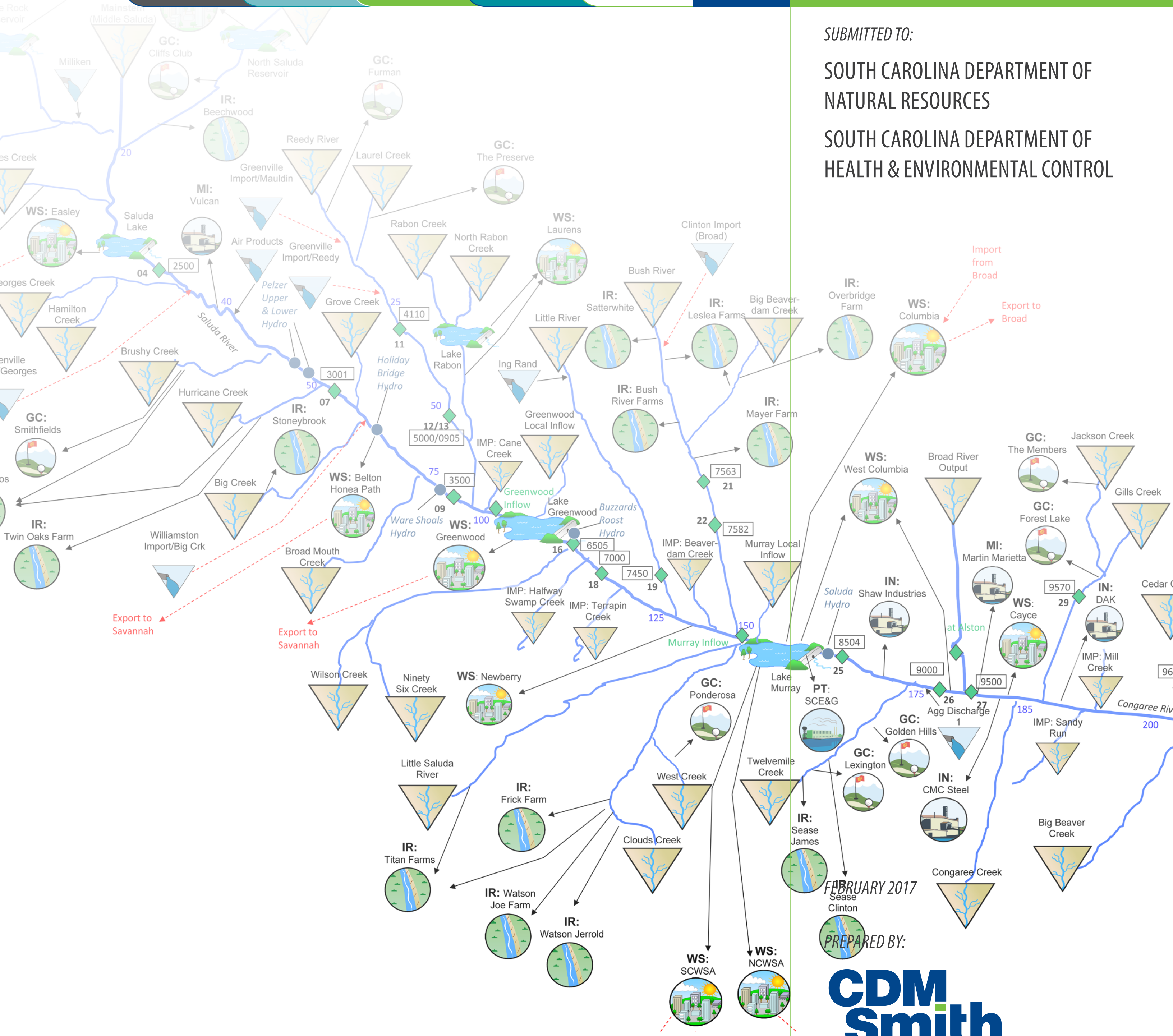
SOUTH CAROLINA
SURFACE WATER QUANTITY MODELS
SALUDA RIVER BASIN MODEL

SUBMITTED TO:

SOUTH CAROLINA DEPARTMENT OF NATURAL RESOURCES

SOUTH CAROLINA DEPARTMENT OF HEALTH & ENVIRONMENTAL CONTROL



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Section 1

Purpose

This document, the Saluda 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 Saluda 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 Saluda River Basin Model is provided in the *Simplified Water Allocation Model (SWAM) User's Manual* (CDM Smith, 2015).

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

The model will simulate historic hydrologic conditions from 1925 through 2013. Defining and developing this hydrologic period of record required numerous assumptions and estimations of past flow and water use patterns, which were vetted during the calibration process. The purpose of the models is not to reproduce with high accuracy the flow on any given day in history. Rather, the purpose is to reproduce with confidence the frequency at which natural and managed flows have reached any given threshold, and by extension, how they might reach these thresholds under future use conditions. To this end, one important objective of model formulation was to reproduce hydrologic peaks and low flows on a monthly and daily basis, recession patterns on a monthly and daily basis, and average flows over months and years.

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

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

Lastly, the model is intended to support a large user base, including staff at DNR and DHEC along with stakeholders throughout the Saluda 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 Saluda River Basin Model. Where appropriate, additional discussion has been included in this report, to elaborate on specific aspects covered in the Modeling Plan.

Section 4

Saluda Model Framework

The initial Saluda River Basin SWAM Model Framework was developed in collaboration with South Carolina DNR and DHEC, and was presented in the memorandum *Saluda Basin SWAM Model Framework* (CDM Smith, March 2015). The proposed framework was developed as a starting point for representing the Saluda Basin river network and its significant water withdrawals and discharges. The guiding principles in determining what elements of the Saluda 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 Saluda 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 Saluda, some additional tributaries may be added explicitly if warranted as candidates to support future use (or these can be easily added at any time in the future as permit applications are received).

During model development, simplifications were made in some areas, while more detail was added in others. **Figure 4-1** visually depicts the SWAM model framework, including tributaries, water users, and dischargers. As the framework is presented in the following paragraphs, changes made to the original model framework are noted.

4.1 Representation of Water Withdrawals

As noted above, significant withdrawals include those that have a permit or registration – which indicated that they may withdraw over 3 million gallons in any month. For several of the municipal water users represented in Saluda Model, withdrawal data includes both water used directly by that water user and water sold to other major municipal water users who are included as separate objects in the model. For example, permit #23WS002 associated with the Greenville Water User object, includes water used directly by Greenville as well as water sold to Easley Combined Utilities, who has their own withdrawal permit. Greenville water also sells water to other smaller systems.

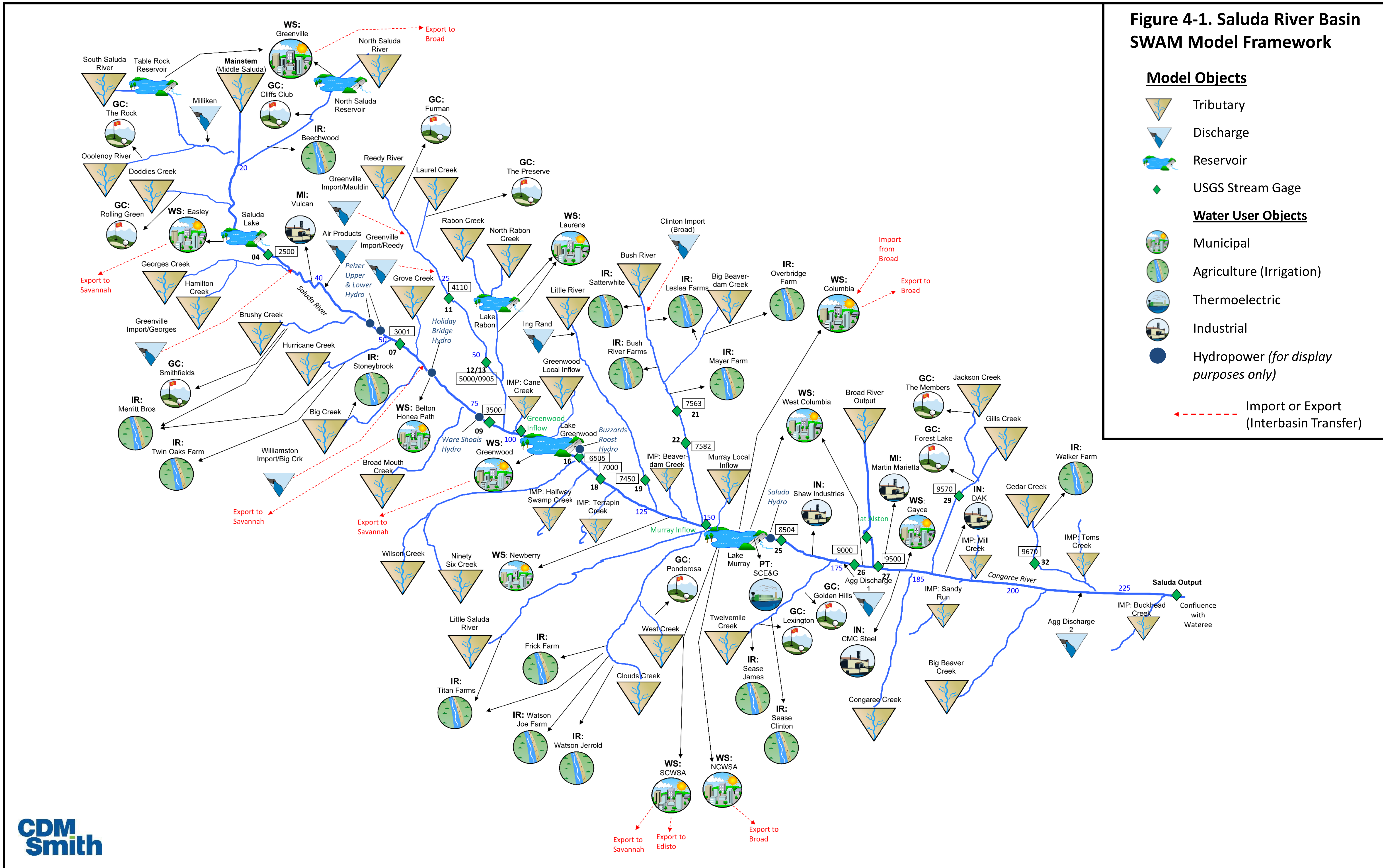

Figure 4-1. Saluda River Basin SWAM Model Framework

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

4.2 Representation of Discharges

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

In the Saluda 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 were deemed significant enough to include in the model; however, these industries either purchase water from another permit holder or withdraw (or supplement) using groundwater. They did not have their own surface water withdrawal permit. These include: Milliken, Air Products and Ingersoll Rand.

- Below Lake Murray, several small municipal and industrial discharges were aggregated together based on their close proximity, and are represented by two Discharge objects. These include Bush River, CWS/Watergate, Woodland Hills, CWS/I-20, and CWS/Friarsgate, which are represented by the Agg Discharge 1 object; and Devro and Westinghouse which are represented by the Agg Discharge 2 object. None of these dischargers have their own surface water withdrawal permit.

- Water withdrawn by Greenville Water from Lake Keowee in the Savannah Basin, and then discharged in the Saluda Basin is represented by three separate Discharge objects. These discharge objects represent wastewater discharges by Renewable Water Resources (ReWa) at their Mauldin Road, Georges Creek, and Lower Reedy River wastewater treatment facilities.

- Water withdrawn by the City of Clinton in the Broad River Basin, and then discharged in the Saluda Basin is represented by a Discharge object.

4.3 Representation of Hydropower Facilities

In the original model framework, the hydropower facilities in the Saluda Basin were represented with Instream Flow objects. The use of an Instream Flow object allows for the inclusion of a minimum release which can be prioritized or at least closely tracked in the model. As operational information was collected for each hydropower facility, it became clear that most of the facilities in the Saluda operate essentially as run-of-river facilities where inflow equals outflow on an instantaneous basis. Since these run-of-river hydropower facilities neither impact the water balance (no storage) nor have associated flow requirements or consumption, they can be generally ignored in the model framework. Therefore, the following hydropower facilities are no longer represented as Instream Flow objects; however, there locations are still noted in the model's visual framework:

- Upper and Lower Pelzer Hydros
- Holiday Bridge Hydro
- Ware Shoals Hydro

The Saluda Dam and Hydro on Lake Murray and Buzzard's Roost Hydro on Lake Greenwood are the two facilities that are not run-of-river. Each facility has minimum flow requirements and unique release/operating rules, which are discussed further in Section 6. The rules for these two facilities are specified within the Lake Murray and Lake Greenwood reservoir objects.

4.4 Groundwater Users and Associated Discharge

Although the Saluda 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 Saluda Basin, no significant, municipal groundwater withdrawals were identified which had a corresponding, significant discharge to surface water; therefore, there are no groundwater users that are represented by a Water User object.

4.5 Implicit Tributaries

At certain locations along the main stem of the Saluda 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 Saluda Model is provided in Section 6. These are tributaries which are not as likely to support future use as the explicitly represented tributaries; however, their contribution of flow to the main stem is important to include.

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Section 5

Model Versions

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

The calibration model was developed to determine the "best fit" value of key model hydrologic parameters, as described in Section 7. Its utility beyond the calibration exercise is limited as the calibration model has been developed to recreate historical conditions which are not necessarily representative of current or planned future conditions. This model was parameterized using historical water use and reservoir operations data to best reflect past conditions in the basin. These data include time-varying river and reservoir withdrawals and consumptive use estimates and historical reservoir release and operational rules. Also included in the calibration version of the model are water users that may be no longer active but were active during the selected calibration period. As discussed in Section 7, the simulation period for this version of the model focuses on the recent past (1983 – 2013) rather than the full record of estimated hydrology.

In contrast, the baseline model is intended to represent current demands and operations in the basin combined with an extended period of estimated hydrology. This model will serve as the starting point for any future predictive simulations with the model (e.g., planning or permitting support) and should be maintained as a useful "baseline" point of reference. For this model, the simulation period extends back to 1925, the start of the hydrologic record for the Saluda River Basin. Each element in the baseline model is assigned water use rates that reflect current demands only and are not time variable (except seasonal). Current demands were estimated by averaging water use data over the past ten years (2004 – 2013), on a monthly basis. These monthly demands are repeated in the baseline model for each simulation year. Similarly, reservoir operations defined in the baseline model are based on current rules, guidelines, and minimum release requirements. In certain instances, future rules that are not yet in effect, were included (and can be toggled on or off in the model). An example of a future rule is the required minimum release associated with the Lake Murray Striped Bass Flow Enhancement Flow Regime. This requirement is part of the Saluda Hydro Federal Energy Relicense (FERC), which is still pending. A final difference between the two models is that only active water users are included in the baseline model. Inactive user objects included in the calibration model have been removed from the baseline model.

Section 6

Model Inputs

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

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

6.1 Model Tributaries

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

6.1.1 Explicit Tributary Objects: Headwater Flows

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

Explicit tributary objects are parameterized in SWAM with headwater flows, representing unimpaired flows at the top of the given modeled reach. These flows may be raw gage flow, or area-prorated from calculated UIFs elsewhere in the basin. **Table 6-1** summarizes the gages, or in many instances, the reference gages used to develop headwater flows. **Figure 6-1** highlights the upstream drainage areas associated with the explicit tributary headwater flows. Green polygons correspond to unimpaired USGS gaged flow and purple polygons correspond to estimated ungaged flows. The inset table designates the project ID for each flow point, whether it was gaged or ungaged, the name of the tributary, and the corresponding drainage area in acres.

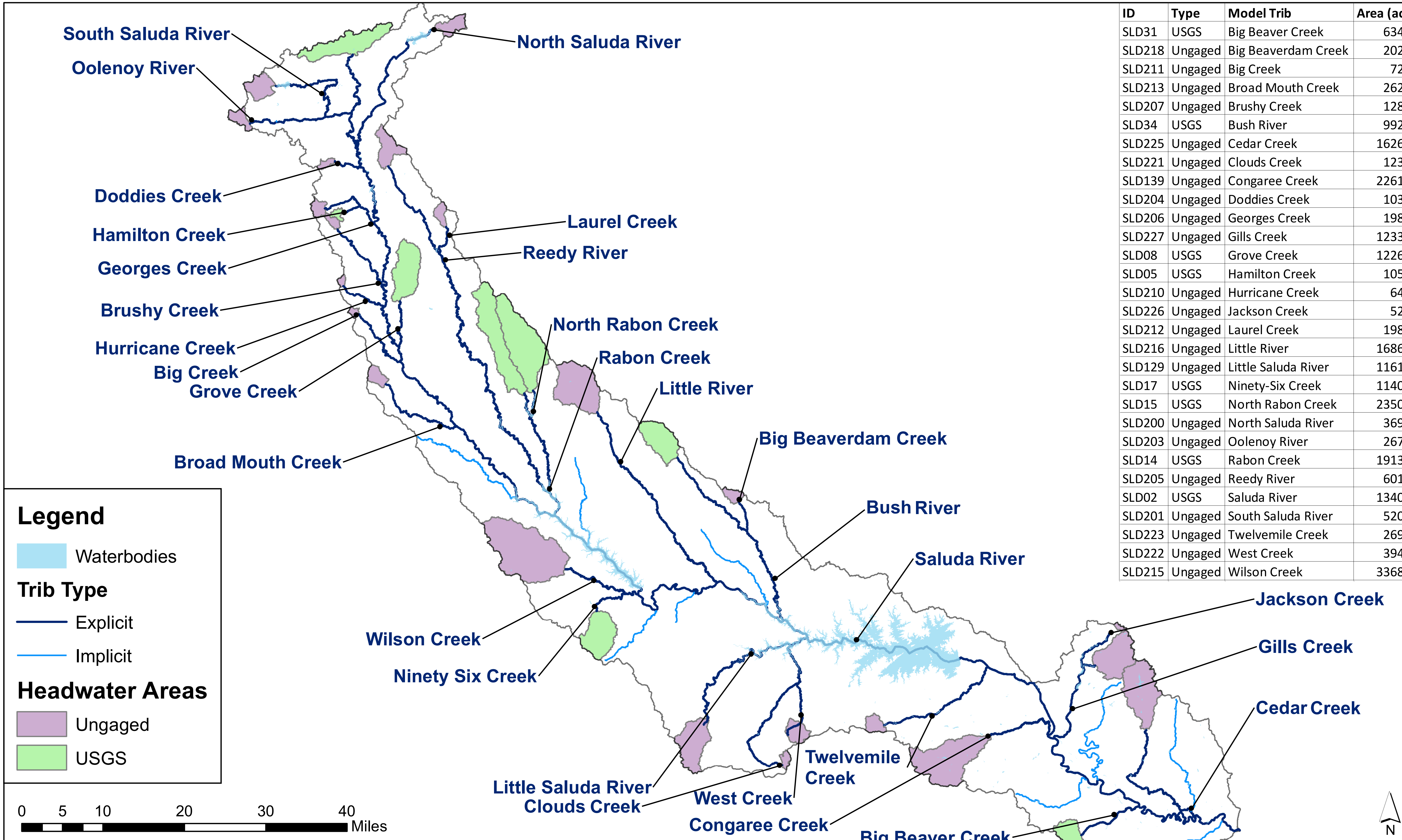
6.1.2 Implicit Tributary Objects: Confluence Flows

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 nine implicit tributaries and two local inflows (represented with implicit tributary objects) for Lake Murray and Lake Greenwood. The inset table provides the corresponding drainage area in acres.

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
SLD201	Ungaged	-	South Saluda River	SLD01	02162290	South Saluda River
SLD200	Ungaged	-	North Saluda River	SLD03	021623975	North Saluda River
SLD203	Ungaged	-	Oolenoy River	SLD04	02162500	Mainstem (Saluda River)*
SLD204	Ungaged	-	Doddies Creek			
SLD206	Ungaged	-	Georges Creek	SLD06	02163000	Mainstem (Saluda River)*
SLD210	Ungaged	-	Hurricane Creek			
SLD211	Ungaged	-	Big Creek	SLD09	02163500	Mainstem (Saluda River)*
SLD213	Ungaged	-	Broad Mouth Creek			
SLD212	Ungaged	-	Laurel Creek	SLD11	02164110	Reedy River
SLD205	Ungaged	-	Reedy River	SLD13	021650905	Reedy River
SLD215	Ungaged	-	Wilson Creek	SLD18	02167000	Mainstem (Saluda River)*
SLD129	Ungaged	-	Little Saluda River	SLD19	02167450	Mainstem (Saluda River)*
SLD216	Ungaged	-	Little River			
SLD221	Ungaged	-	Clouds Creek			
SLD218	Ungaged	-	Big Beaverdam Creek	SLD21	02167563	Bush River
SLD222	Ungaged	-	West Creek	SLD25	02168504	Mainstem (Saluda River)*
SLD223	Ungaged	-	Twelvemile Creek	SLD26	02169000	Mainstem (Saluda River)*
SLD139	Ungaged	-	Congaree Creek	SLD28	02169550	Congaree Creek
SLD226	Ungaged	-	Jackson Creek	SLD29	02169570	Gills Creek
SLD227	Ungaged	-	Gills Creek			
SLD225	Ungaged	-	Cedar Creek	SLD32	02169670	Cedar Creek
SLD207	Ungaged	-	Brushy Creek	SLD33	02162700	Middle Branch
SLD02	Gaged	02162350	Mainstem (Middle Saluda River)*	-	-	-
SLD05	Gaged	02162525	Hamilton Creek	-	-	-
SLD08	Gaged	021630967	Grove Creek	-	-	-
SLD14	Gaged	02165200	Rabon Creek (South Rabon Creek)*	-	-	-
SLD15	Gaged	021652801	North Rabon Creek	-	-	-
SLD17	Gaged	02166970	Ninety-Six Creek	-	-	-
SLD31	Gaged	02169630	Big Beaver Creek	-	-	-
SLD34	Gaged	02167557	Bush River	-	-	-

*Actual river name in parenthesis



ID	Type	Model Trib	Area (ac)
SLD31	USGS	Big Beaver Creek	6342
SLD218	Ungaged	Big Beaverdam Creek	2020
SLD211	Ungaged	Big Creek	728
SLD213	Ungaged	Broad Mouth Creek	2622
SLD207	Ungaged	Brushy Creek	1280
SLD34	USGS	Bush River	9921
SLD225	Ungaged	Cedar Creek	16269
SLD221	Ungaged	Clouds Creek	1234
SLD139	Ungaged	Congaree Creek	22615
SLD204	Ungaged	Doddies Creek	1031
SLD206	Ungaged	Georges Creek	1987
SLD227	Ungaged	Gills Creek	12330
SLD08	USGS	Grove Creek	12267
SLD05	USGS	Hamilton Creek	1050
SLD210	Ungaged	Hurricane Creek	640
SLD226	Ungaged	Jackson Creek	525
SLD212	Ungaged	Laurel Creek	1986
SLD216	Ungaged	Little River	16861
SLD129	Ungaged	Little Saluda River	11617
SLD17	USGS	Ninety-Six Creek	11408
SLD15	USGS	North Rabon Creek	23509
SLD200	Ungaged	North Saluda River	3697
SLD203	Ungaged	Oolenoy River	2671
SLD14	USGS	Rabon Creek	19135
SLD205	Ungaged	Reedy River	6010
SLD02	USGS	Saluda River	13402
SLD201	Ungaged	South Saluda River	5203
SLD223	Ungaged	Twelvemile Creek	2698
SLD222	Ungaged	West Creek	3948
SLD215	Ungaged	Wilson Creek	33685

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

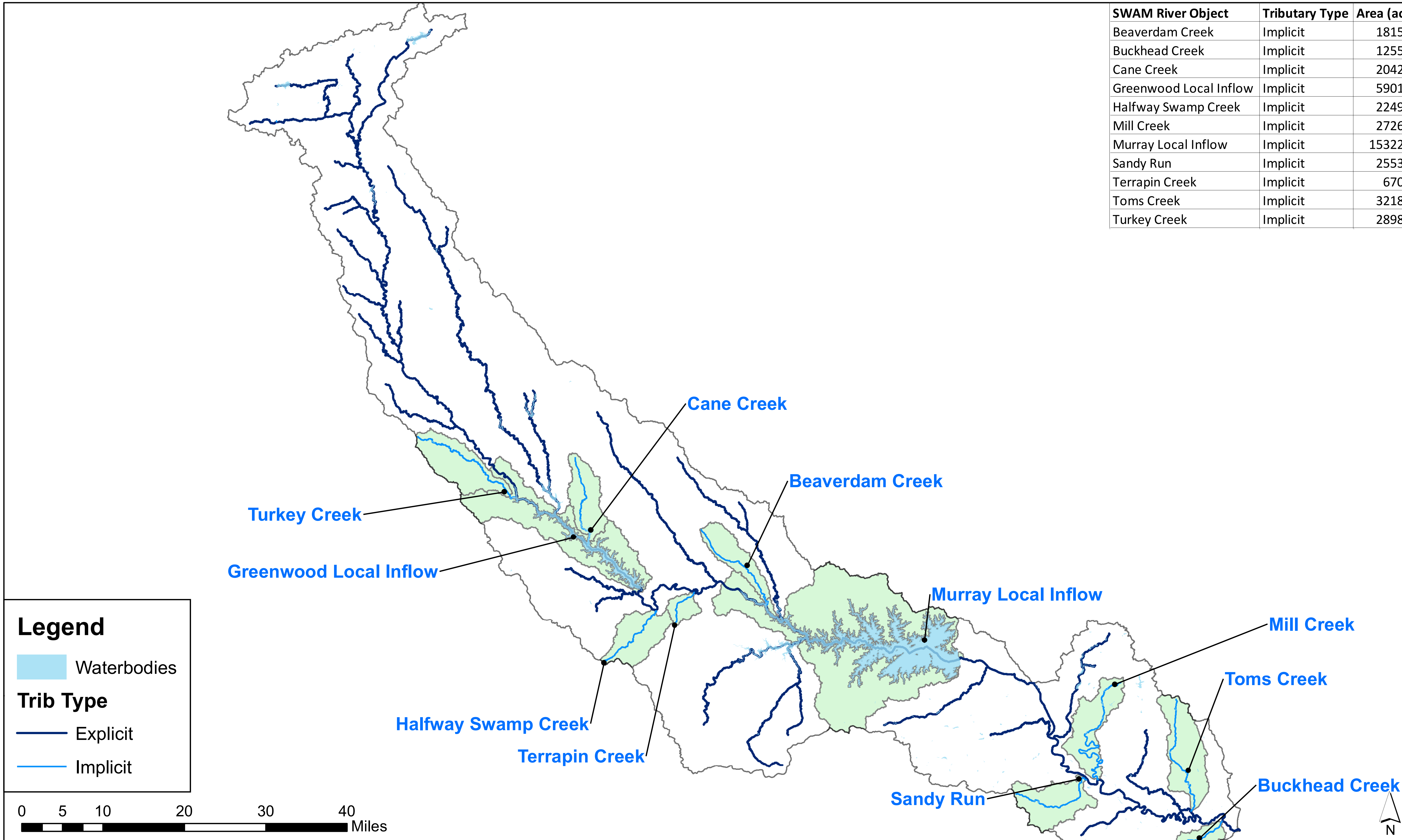

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Figure 6-2. Implicit Tributaries in the Saluda River Basin

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

	Ungaged Basin	USGS Reference Gage (Unimpaired)		
Project ID	SWAM Tributary	Project Gage ID	USGS Number	Stream
SLD115	Turkey Creek	SLD16	02166501	Saluda River
SLD161	Halfway Swamp Creek	SLD17	02166970	Ninety-Six Creek
SLD163	Terrapin Creek			
SLD301	Lake Greenwood Inflow	SLD19	02167450	Little River
SLD160	Cane Creek			
SLD302	Lake Murray Inflow			
SLD162	Beaverdam Creek	SLD21	02167563	Bush River
SLD167	Buckhead Creek	SLD31	02169630	Big Beaver Creek
SLD164	Sandy Run	SLD32	02169670	Cedar Creek
SLD165	Mill Creek			
SLD166	Toms Creek			

6.1.3 Reach Gains and Losses

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

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

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

6.2 Reservoirs

Six reservoirs are represented in the Saluda River Basin Model: Table Rock Reservoir, North Saluda Reservoir, Saluda Lake, Lake Rabon, Lake Greenwood, and Lake Murray. **Table 6-4** provides a summary of model inputs and other information used to characterize each reservoir. Additional details and explanation for certain reservoir inputs are summarized below.

6.2.1 Evaporation

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

6.2.2 Direct Precipitation

Direct precipitation to the surface of Lake Greenwood and Lake Murray was included as part of the local inflow tributary object. Direct precipitation to the other four, much smaller reservoirs was considered insignificant, and not explicitly included in the model. However, precipitation rates were factored into the calculation of non-negative net evaporation rates for these smaller reservoirs. In other words, when evaporation was equal to or exceeded precipitation, precipitation was subtracted from the gross evaporation rate to calculate net rates. For timesteps where precipitation exceeded evaporation, net evaporation rates were set to zero.

6.2.3 Area-Capacity Relationships and Flood Control Outflow

Area-capacity relationships for the six 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. No bathymetric or area-capacity information was found for Saluda Lake; therefore, this reservoir has area-capacity defined by known empty and full surface areas, and a very simplified linear relationship is assumed.

Table 6-3. Model Tributary Inputs

SWAM Tributary Object	Tributary Type	Confluence Stream	Confluence Location (mile)	Confluence Drainage Area (ac)	Headwater ID	End Mile	Drainage Area Ratio	Subbasin Flow Factor (unitless)
Mainstem	Explicit	none	none	2,055,737	SLD02	32	*NA*	0.07*
						56		0.01*
						82		0.02*
						117		0*
						500		0.05*
Big Beaver Creek	Explicit	Mainstem	204	29,047	SLD31	9	4.6	4.6
Big Beaverdam Creek	Explicit	Bush River	16	7,766	SLD218	4	3.8	3.8
Big Creek	Explicit	Mainstem	60	12,452	SLD211	11	17.1	17.1
Broad Mouth Creek	Explicit	Mainstem	74	21,733	SLD213	14	8.3	8.3
Brushy Creek	Explicit	Mainstem	46	23,341	SLD207	11	18.2	18.2
Bush River	Explicit	Mainstem	139	77,215	SLD34	19	7.0	1.25
						26		2.53
						32		5
Cedar Creek	Explicit	Mainstem	221	103,061	SLD225	9	4.4	2.4
						24		4.4
Clouds Creek	Explicit	Mainstem	143	71,743	SLD221	1	46.0	4
						28		50
Congaree Creek	Explicit	Mainstem	185	99,229	SLD139	17	4.4	4.4
Doddies Creek	Explicit	Mainstem	23	7,207	SLD204	4	7.0	7
Georges Creek	Explicit	Mainstem	35	21,123	SLD206	9	9.3	9.3
Gills Creek	Explicit	Mainstem	186	47,111	SLD227	7	2.8	1.2
						15		2.8
Grove Creek	Explicit	Mainstem	57	22,217	SLD08	8	1.8	1.8
Hamilton Creek	Explicit	Georges Creek	6	2,581	SLD05	2	2.5	2.5
Hurricane Creek	Explicit	Mainstem	50	9,585	SLD210	6	15.0	15
Jackson Creek	Explicit	Gills Creek	3	12,291	SLD226	8	23.4	23.4
Laurel Creek	Explicit	Reedy River	15	7,449	SLD212	4	3.8	3.8
Little River	Explicit	Mainstem	128	147,256	SLD216	30	8.7	8.5
						41		8.7
Little Saluda River	Explicit	Mainstem	142	141,298	SLD129	27	12.2	12.2
Ninety-Six Creek	Explicit	Mainstem	110	91,523	SLD17	9	6.7	3.7
North Rabon Creek	Explicit	Rabon Creek	3	32,931	SLD15	4	1.4	1.4
North Saluda River	Explicit	Mainstem	19	48,294	SLD200	3	13.1	3
						23		13.1
Oolenoy River	Explicit	South Saluda River	18	31,454	SLD203	12	11.8	11.8
Rabon Creek	Explicit	Reedy River	65	81,324	SLD14	4	2.5	1
						18		2.5
Reedy River	Explicit	Mainstem	95	257,031	SLD205	27.5	28.0	13
						59		24
						69		26
South Saluda	Explicit	Mainstem	12	66,442	SLD201	2	6.7	2
						21		6.7
Twelvemile Creek	Explicit	Mainstem	174	30,029	SLD223	18	11.1	11.1
West Creek	Explicit	Clouds Creek	19	15,019	SLD222	8	3.8	3.8
Wilson Creek	Explicit	Ninety-Six Creek	7	49,512	SLD215	11	1.5	1.5
Beaverdam Creek	Implicit	Mainstem	135	18,157	SLD162	0	1	1
Broad River	Implicit	Mainstem	176	3,412,232	NA	10	1	0.75
Buckhead Creek	Implicit	Mainstem	227	12,559	SLD167	0	1	1
Cane Creek	Implicit	Mainstem	99	20,426	SLD160	0	1	1
Greenwood Local Inflow	Implicit	Mainstem	100	59,014	SLD301	1	1	0.1
Halfway Swamp Creek	Implicit	Mainstem	113	22,496	SLD161	0	1	1
Mill Creek	Implicit	Mainstem	197	27,263	SLD165	0	1	1
Murray Local Inflow	Implicit	Mainstem	149	153,221	SLD302	1	1	0.75
Sandy Run	Implicit	Mainstem	195	25,537	SLD164	0	1	1
Terrapin Creek	Implicit	Mainstem	124	6,700	SLD163	0	1	1
Toms Creek	Implicit	Cedar Creek	22	32,183	SLD166	0	1	1
Turkey Creek	Implicit	Mainstem	88	28,989	SLD115	0	1	1

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

Table 6-4. Reservoir Inputs

Reservoir	Purpose	Receiving Stream	Temperature Station for Evaporation	Precipitation Station	Release Location (mi)	Storage Capacity (MG)	Initial Storage (MG)	Dead Pool (MG)	Area-Capacity Table	Operating Rules
Table Rock	Water supply	South Saluda River	Clemson W381111	NA	2	8,856	5,000	3,577	Simple	No minimum releases or storage targets
North Saluda	Water supply	North Saluda River	Greer W03870	NA	3	23,899	20,000	10,836	Simple	No minimum releases or storage targets
Saluda Lake	Power, water supply, and industry	Mainstem (Saluda)	Clemson 381770	NA	30	2,450	2,000	0	Simple	No minimum releases or storage targets
Lake Rabon	Water supply, flood control & recreation	Rabon Creek	Union 388786	NA	4	2,946	2,500	0	Simple	No minimum releases or storage targets
Lake Greenwood	Power, recreation, and water supply	Mainstem (Saluda)	Union 388786	USHCN Gage 385017	101	82,760	50,000	10,000	Simple	Minimum release at Buzzards Roost Hydro dependent on season and reservoir inflow[1]; Monthly storage targets
Lake Murray	Power, recreation, and water supply	Mainstem (Saluda)	Columbia W13883	USHCN Gage 385200	169	654,238	500,000	447,354	Simple	Minimum release requirement to maintain 285 cfs at USGS gage 02169000[2]; Monthly storage targets; The Low Inflow Protocol and the Striped Bass Enhancement Flow Regime of the pending FERC license are optional rules that can be selected[3]

Note 1 *- For Buzzard's Roost Hydro, during November through June (non-peaking months), the minimum flow release is 400 cfs or the inflow, whichever is smaller. During July through October minimum flow release is 400 cfs when inflow is above 566 cfs; (b) 300 cfs when inflow is between 566 and 466 cfs; (c) 205 cfs when inflow is between 466 and 366 cfs; and (d) 225 cfs or inflow, whichever is less when inflow is below 366 cfs. During calibration, storage targets were set based on the guide curve in effect between 1993 and 2009.*

Note 2 *- For historical Lake Murray operations (calibration model only), the rules are based on maintaining at least 285 cfs at USGS gage 02169000 (just downstream of Twelvemile Creek), year round. If Twelvemile Creek confluence flow is >= 285 cfs in a given timestep, then there is no Lake Murray release requirement. If Twelvemile Creek flow is < 285 cfs, then the lake minimum release = 285 – Twelvemile Creek flow. During calibration, the "Previous Existing Rule Curve" was used to set target reservoir elevations. The baseline model target elevations have been set per the new "Target Reservoir Elevation" curve, as contained in the pending FERC license. Lake levels suggest that this curve has been followed since 2009.*

Note 3 *- For Lake Murray, the pending FERC license includes a Maintenance, Emergency and Low Inflow Protocol (MELIP) and a Striped Bass Enhancement Flow Regime. The rules associated with these, which will be incorporated in the baseline model, are summarized in Appendix D.*

Table 6-5. Reservoir Area-Capacity Relationship

Reservoir	Volume (MG)	Area (Acres)
Table Rock Reservoir	0	0
	5,619	380
	6,198	398
	6,522	407
	7,061	423
	7,622	443
	8,213	460
	8,826	476
	8,856	478
North Saluda Reservoir	0	0
	16,022	848
	16,667	865
	17,312	882
	17,957	899
	18,663	913
	19,261	931
	20,503	970
	21,789	1,003
	22,447	1,018
	23,121	1,033
	23,899	1,052
Saluda Lake	0	0
	3,000	330
Lake Rabon	0	0
	1,303	400
	3,258	600
	5,213	800
	7,168	1,000
	9,123	1,200
	11,078	1,400
Lake Greenwood	0	0
	2,781	2,459
	5,561	3,576
	11,122	4,694
	19,464	5,812
	29,869	6,929
	42,627	8,047
	56,749	9,165
	72,090	10,282
	78,443	10,729
	87,974	11,400
	108,745	12,518
Lake Murray	0	0
	447,354	35,600
	470,766	37,300
	495,375	39,100
	521,189	41,000
	548,296	43,000
	576,713	45,000
	606,558	47,000
	622,064	48,000
	637,967	49,000
	654,258	50,900

For Lake Rabon, the area-capacity relationship is derived from the curve provided in as-built drawings. The storage capacity (top of the dam) is much higher than normal pool capacity specified in the model. The dams' spillways pass flood waters, keeping reservoir levels well below the top of the dam. The model includes a normal pool capacity of 2,946 million gallons (MG), but includes a flood control outflow beginning at 90% full, as shown in **Table 6-6**. During calibration, a very small flood control outflow was assigned to Saluda Lake to better reflect observed historical operations. All other reservoirs are not assigned a specific flood control outflow.

For Lake Murray, the area-capacity relationship is based on data provided by SCE&G as included in their pending FERC license application. The volume for Lake Murray reflects gross storage. Until the most recent FERC application, only usable storage had been estimated.

Table 6-6. Flood Control Outflow

Reservoir	% Volume	Outflow (cfs)
Table Rock	0	0
	100	0
North Saluda	0	0
	45	0
	100	0
Saluda Lake	0	0
	100	0
Lake Rabon	0	0
	89	0
	90	12
	100	12
Lake Greenwood	0	0
	100	0
Lake Murray	0	0
	100	0

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). Of the six Saluda River Basin reservoirs, only Lake Greenwood and Lake Murray have pre-defined operating rules that merit inclusion in the model. These are summarized in Table 6-4. Both reservoirs are operated following a rule curve. The monthly storage targets defined by the rule curves which were input into the baseline model and calibration model are provided in **Table 6-7**. For each reservoir, different rules curves were in effect during the calibration period, compared to the rule curves followed today and incorporated into the baseline model.

Table 6-7. Reservoir Monthly Storage Targets (in Million Gallons)

Reservoir	Model	Jan	Feb	Mar	Apr	May	Jun
Lake Greenwood	Calibration	68,080	84,568	84,568	84,568	84,568	84,568
	Baseline	70,556	84,797	84,797	84,797	84,797	84,797
Lake Murray	Calibration	520,649	621,634	621,634	621,634	621,634	507,559
	Baseline	621,630	621,630	621,630	621,630	621,630	621,630

Reservoir	Model	Jul	Aug	Sep	Oct	Nov	Dec
Lake Greenwood	Calibration	84,568	84,568	76,978	76,978	76,978	76,978
	Baseline	84,797	84,797	84,797	84,797	70,556	70,556
Lake Murray	Calibration	507,559	507,559	507,559	507,559	507,559	507,559
	Baseline	621,630	621,630	591,107	591,107	591,107	561,920

6.2.4.1 Lake Greenwood

Lake Greenwood's release rule specifies minimum releases through the dam dependent on season (peak vs. non-peaking months) and reservoir inflow, representing operations of the Buzzards Roost Hydro. In addition to these prescribed release targets, monthly storage targets are prescribed and serve as a second set of considerations for calculating reservoir releases and operations.

6.2.4.2 Lake Murray

For the calibration model, Lake Murray's releases are calculated in the model based on flows at USGS gage 02169000 (SLD26), where a mean daily flow of at least 285 cfs must be maintained. As with Lake Greenwood, monthly storage targets are also included in the model, as secondary considerations in simulated operations. In simulations of future conditions, per the pending FERC license, Lake Murray's releases may include striped bass environmental flow requirements as defined by Instream Flow Incremental Flow Methodology Study. Additionally, the pending FERC license includes a Maintenance, Emergency, and Low Inflow Protocol (MELIP) which includes a complex set of rules that apply when 14-day net inflow to the lake falls below seasonal minimum flow releases. These rules, which are summarized in **Appendix D** will be prescribed in the baseline model as optional release rules that can be turned on/off by the user.

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, only several minor differences exist between the calibration and baseline model with respect to water users. Most notably, Duke Power's Lee Steam Station came off-line in late 2014, and therefore it is not included in the baseline model. Several out-of-basin sources are represented as Discharge objects (discussed below) and therefore don't appear in Table 6-8.

6.3.2 Demands

Table 6-9 presents the monthly demand for Municipal (WS), Industrial (IN), Mining (MI), and Thermopower (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. Demands for the calibration period (1983 through 2013) were input as a timeseries of monthly values based on monthly withdrawals reported to DHEC and supplemented by data collected from each water user by CDM Smith.

6.3.3 Transbasin Imports

In South Carolina, there are many examples of water users who access source waters in multiple river basins and/or discharge return flows to multiple basins. In order to consistently represent transbasin imports and exports in the SWAM models, a set of guidelines were developed, which are summarized in **Appendix C – Guidelines for Representing Multi-Basin Water Users in SWAM**. In the Saluda River Basin Model, several water users import water from outside the basin. These include:

- The City of Columbia (**WS: Columbia**) imports water from the Broad River Canal Plant located in the Broad River Basin, in addition to its withdrawal in the Saluda Basin on Lake Murray. In both the calibration and baseline models, the import of water from the Broad is treated as a transbasin import in SWAM, and is recognized as Source Water Account #2.

- The Town of Williamston, until 1997, had an intake on Big Creek, a tributary to the Saluda River. In 1997, Williamston stopped withdrawing from Big Creek and began importing water from the Savannah River Basin. In the calibration model, Williamston is represented as a Water User object (**WS: Williamston**) and the Big Creek withdrawal is included as the source over the entire calibration period, but the demand is dropped to zero after 1997. In the baseline model, Williamston is represented as a Discharge object (**Williamston Import**), reflecting the fact that its only source comes from outside the Saluda River Basin, but return flows discharge inside the basin.
- The City of Clinton is represented as a Discharge object (**Clinton Import**), as its water is sourced exclusively from the Broad River Basin, with return flow discharges to the Saluda River Basin.
- Greenville Water System, which serves the City of Greenville and provides water to other, nearby systems, has three sources of surface water. Two sources, Table Rock Reservoir and North Saluda Reservoir, are located in the Saluda River Basin. The third source is Lake Keowee located in the Savannah River Basin. Consistent with the guidelines, the **WS: Greenville** Water User object accounts for water sourced only in the Saluda. Water sourced from the Savannah is considered a secondary supply and is represented by three Discharge objects, **Greenville Import/Georges**, **Greenville Import/Mauldin**, and **Greenville Import/Reedy**. In the Savannah River Basin Model, a **WS: Greenville Export** Water User object will represent the Lake Keowee withdrawal.
- The monthly demand associated with the City of Columbia's Broad River Canal withdrawal is presented in **Table 6-11**. As noted above, all other transbasin imports are treated as discharges, and are represented by Discharge objects.

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

Model Object ID	Facility Name	Source of Supply	Intake ID	Diversion Location (mi)	Permit Limit (MGM)	Note
GC: Cliffs Club	Cliffs Club At Valley	North Saluda River	23GC013S01	7	13.4	1
GC: Forest Lake	Forest Lake Club	Gills Creek	40GC002S01	4	11.3	1
GC: Furman	Furman University Golf Club	Reedy River	23GC004S01	1	41	1
			23GC004S02		26.8	
GC: Golden Hills	Golden Hills Golf & Country Club	Twelvemile Creek	32GC007S01	12	32.6	1
GC: Lexington	Country Club of Lexington	Twelvemile Creek	32GC004S01	6	22.3	1
GC: Ponderosa	Ponderosa Country Club	West Creek	32GC010S01	3	44.6	1
GC: Rolling Green	Rolling Green Golf Club	Doddies Creek	39GC002S01	1	15.8	1
GC: Smithfields	Smithfields Country Club	Brushy Creek	39GC003S01	1	44.6	1
GC: The Members	The Members Club At Wildewood	Jackson Creek	40GC005S03	1	9.8	1
			40GC005S05		6.7	
			40GC005S06		3.4	

Model Object ID	Facility Name	Source of Supply	Intake ID	Diversion Location (mi)	Permit Limit (MGM)	Note
GC: The Preserve	The Preserve At Verdae	Laurel Creek	23GC014S01	1	58	1
GC: The Rock	The Rock At Jocassee Gc	Oolenoy River	39GC006S01	1	7.1	1
IN: CMC Steel	CMC Steel South Carolina	Congaree River	32IN051S01	181	48.3	1
IN: DAK	DAK (Eastman Chemical /SC Operations)	Congaree River	09IN001S01	189	5491	1
IN: Shaw Industries	Shaw Industries Group Plant 8S	Saluda River	32IN006S01	171	1365	1
IR: Beechwood	Beechwood Farm	North Saluda River	23IR026S01	15	12	1,4
IR: Bush River Farms	Bush River Farms	Bush River	36IR035S01	14	17	1,4
IR: Frick Farm	Frick Farm	Clouds Creek	41IR010S03	5	80	1,4
IR: Leslea Farms	Leslea Farms	Bush River	36IR037S01	10	3.8	1,4
		Big Beaverdam Creek	36IR037S02			
		Bush River	36IR037S03	2	12.1	1,4
IR: Mayer Farm	Mayer Farm	Bush River	36IR009S01	16	6.5	1,4
			36IR009S02			
IR: Merritt Bros	Merritt Bros Inc	Brushy Creek	37IR017S01	6	3	1,4
			37IR017S02		7	
		Hurricane Creek	37IR017S03	1	7	
			37IR017S04		0.6	
IR: Overbridge Farm	Overbridge Farm LLC	Big Beaverdam Creek	36IR002S01	1	10.6	1,4
IR: Satterwhite Farm	Satterwhite Farms	Bush River	36IR004S01	8	4	1,4
			36IR004S02	8	NA	1,4
IR: Sease Clinton	Sease Clinton Farms	Twelvemile Creek	32IR005S01	7	9.5	1,4
			32IR005S02		10.2	
			32IR005S03		10	
IR: Sease James	Sease James R Farms Inc	Twelvemile Creek	32IR021S01	3	5.6	1,4
			32IR021S02		20.4	
			32IR021S03		7.1	
			32IR021S04		6.7	
			32IR021S06	1	21.8	
IR: Stoneybrook	Stoneybrook	Big Creek	04IR002S01	1	3	1,4
IR: Titan Farms	Titan Farms	Clouds Creek	41IR014S01	4	20	1,4
			41IR014S03		40	
			41IR014S04		15	
		Little Saluda River	41IR014S08	2	25	
IR: Twin Oaks Farm	Twin Oaks Farm	Hurricane Creek	04IR001S01	3	3	1,4
IR: Walker Farm	Walker Farm	Cedar Creek	40IR001S01	1	3	1,4
IR: Watson Jerrold Farm	Watson Jerrold & Sons	Clouds Creek	02IR011S09	1	180	1,4
IR: Watson Joe Farm	Watson Joe Farm	Clouds Creek	41IR004S01	3	7	1,4
			41IR004S02	3	47	1,4
MI: Martin Marietta	Martin Marietta Materials - Cayce Quarry	Congaree River	32MI001S01	180	66.96	1

Model Object ID	Facility Name	Source of Supply	Intake ID	Diversion Location (mi)	Permit Limit (MGM)	Note
MI: Vulcan Mining	Vulcan Materials	Saluda River	04MI001S01	40	16	1
PT: Duke Lee Station	Duke Energy Carolinas LLC	Saluda River	04PT001S01	58	NA	2
PT: SCE&G	SCE&G - McMeekin Station	Saluda River/Lake Murray	32PT001S01	169	5175	1
WS: Belton Honea Path	Belton-Honea Path WTP	Saluda River	04WS005S01	65	124	1
WS: Cayce	City of Cayce WTP	Congaree River	32WS004S02	182	722.3	1
WS: Columbia	City of Columbia - Lake Murray Water Plant	Saluda River/Lake Murray	40WS002S02	169	3875	1
	City of Columbia - Canal Water Plant	Out of basin (Broad)	40WS054S01	999	3875	1,3
WS: Easley	Easley Combined Utilities - D.L. Moore WTP	Saluda River	39WS001S01	30	1116	1
WS: Greenville	Greenville Water L.B. Stovall Plant	North Saluda River/North Saluda Res	23WS002S01	3	1860	1
		South Saluda River/Table Rock Res	23WS002S02	2	1085	1
		South Saluda River/Table Rock Res	23WS002S03	2	992	2
WS: Greenwood	City of Greenwood (Wise Plant)	Saluda River/Lake Greenwood	24WS001S01 24WS001S02	101	852.5	1
WS: Laurens	Laurens WTP	Little River	30WS002S01	1	NA	2
		Rabon Creek	30WS002S02	6	1106	1
		Rabon Creek/Lake Rabon	30WS002S03	4	911	1
WS: NCWSA	NCWSA - Lake Murray WTP	Saluda River/Lake Murray	36WS002S01	169	186	1
WS: Newberry	City Of Newberry WTP	Saluda River	36WS001S01	129	682	1
WS: SCWSA	SCWSA - Raw Water Intake	Saluda River/Lake Murray	41WS003S01	169	465	1
WS: West Columbia	West Columbia WTP	Saluda River	32WS008S01	177	260.4	1
		Saluda River/Lake Murray	32WS052S01	169	1054	1
WS: Williamston	Town of Williamston	Big Creek	04WS011S01	5	NA	2

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 only in the calibration model.

Note 3 indicates the withdrawal occurs outside the Saluda Basin.

Note 4 indicates registered limit for irrigation

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

Baseline Model Average Monthly Demand (MGD)								
Month	IN: CMC Steel	IN: DAK	IN: Shaw Industries	MI: Martin Marietta	MI: Vulcan Mining	PT: SCE&G	WS: Belton Honea	WS: Cayce
Permit Limit (MGD)-->	1.6	180.6	44.9	2.2	0.5	170.2	4.1	23.8
Jan	0.2	55.2	21.5	0.9	0.0	140.1	1.9	2.7
Feb	0.2	56.7	20.9	0.8	0.0	122.6	1.9	2.8
Mar	0.1	57.7	20.8	0.8	0.0	114.3	1.8	2.9
Apr	0.1	60.2	22.0	1.0	0.0	88.9	1.9	3.1
May	0.2	66.3	23.5	0.7	0.0	125.8	2.2	3.4
Jun	0.2	74.0	25.0	0.8	0.0	150.7	2.4	3.5
Jul	0.2	78.1	26.8	0.8	0.5	155.5	2.2	3.5
Aug	0.1	76.1	27.8	0.9	0.4	149.0	2.3	3.6
Sep	0.2	70.1	26.8	0.9	0.0	109.2	2.2	3.4
Oct	0.2	61.7	25.0	0.9	0.0	99.4	2.0	3.2
Nov	0.2	55.1	23.0	0.7	0.0	117.1	2.0	3.0
Dec	0.2	52.3	22.0	0.6	0.0	128.9	1.9	2.8

Baseline Model Average Monthly Demand (MGD)								
Month	WS: Columbia	WS: Easley	WS: Greenville	WS: Greenwood	WS: Laurens	WS: NCWSA	WS: Newberry	WS: W. Columbia
Permit Limit (MGD)-->	127.5	36.7	129.5	28.0	66.3	6.1	22.4	43.2
Jan	51.8	7.1	25.6	9.6	2.1	0.7	1.1	9.4
Feb	51.4	6.8	25.9	9.7	2.1	0.7	0.9	9.5
Mar	53.7	6.9	27.4	9.6	2.1	0.7	0.8	9.9
Apr	61.1	7.7	32.0	10.3	2.3	0.8	1.3	12.0
May	68.1	8.8	37.8	11.1	2.2	0.8	1.8	13.9
Jun	72.1	9.3	41.9	11.7	2.3	0.9	1.9	14.7
Jul	75.1	9.5	43.5	12.0	2.4	0.9	2.0	14.6
Aug	73.0	9.4	42.8	11.9	2.5	0.8	2.0	14.0
Sep	69.3	8.7	40.0	11.1	2.5	0.8	1.8	13.5
Oct	63.4	8.2	35.0	10.6	2.3	0.8	1.6	11.6
Nov	57.5	7.4	29.9	10.0	2.2	0.7	1.4	10.3
Dec	51.9	7.1	24.9	9.4	2.2	0.7	1.0	9.7

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

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

Baseline Model Average Monthly Demand (MGD)											
Month	GC: Cliffs Club	GC: Forest Lake	GC: Furman	GC: Golden Hills	GC: Lexington	GC: Ponderosa	GC: Rolling Green	GC: Smithfield CC	GC: The Members	GC: The Preserve	GC: The Rock
Limit (MGD)-->	0.44	0.37	2.23*	1.07	0.73	1.47	0.52	1.47	0.65*	1.91	0.23
Jan	0.01	0.03	0.00	0.00	0.01	0.03	0.00	0.01	0.01	0.01	0.01
Feb	0.01	0.01	0.00	0.01	0.00	0.04	0.01	0.04	0.01	0.01	0.01
Mar	0.05	0.05	0.01	0.01	0.02	0.06	0.11	0.13	0.02	0.02	0.02
Apr	0.10	0.14	0.02	0.03	0.10	0.07	0.10	0.17	0.06	0.06	0.04
May	0.10	0.14	0.03	0.03	0.13	0.10	0.16	0.21	0.16	0.16	0.07
Jun	0.15	0.15	0.05	0.04	0.11	0.10	0.20	0.25	0.19	0.19	0.06
Jul	0.14	0.20	0.06	0.05	0.12	0.11	0.12	0.28	0.21	0.21	0.07
Aug	0.10	0.14	0.07	0.05	0.11	0.10	0.13	0.25	0.24	0.24	0.07
Sep	0.14	0.18	0.07	0.05	0.12	0.09	0.14	0.17	0.17	0.16	0.06
Oct	0.09	0.10	0.04	0.04	0.08	0.06	0.08	0.17	0.09	0.08	0.04
Nov	0.05	0.07	0.01	0.03	0.03	0.05	0.02	0.02	0.04	0.03	0.02
Dec	0.01	0.03	0.00	0.01	0.00	0.02	0.00	0.02	0.01	0.01	0.01

Baseline Model Average Monthly Demand (MGD)											
Month	IR: Beechwood	IR: Bush River Farms	IR: Frick Farm	IR: LesLea Farms	IR: Mayer Farm	IR: Merrit Bros	IR: Overbridge Farm	IR: Satterwhite Farm	IR: Sease Clinton	IR: Sease James	IR: Stonybrook
Limit (MGD)-->	0.39	0.56	2.63	0.52*	0.21*	0.58*	0.35	0.13*	0.33*	0.72*	0.10
Jan	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.08	0.00
Feb	0.00	0.13	0.00	0.00	0.00	0.00	0.00	0.02	0.04	0.15	0.01
Mar	0.03	0.41	0.00	0.00	0.05	0.00	0.00	0.02	0.06	0.27	0.01
Apr	0.13	0.51	0.00	0.01	0.05	0.00	0.02	0.02	0.08	0.54	0.01
May	0.13	0.52	0.37	0.04	0.05	0.02	0.02	0.03	0.12	0.66	0.01
Jun	0.17	0.54	0.90	0.12	0.05	0.04	0.02	0.05	0.18	0.69	0.02
Jul	0.29	0.53	0.73	0.15	0.04	0.07	0.01	0.04	0.25	0.69	0.02
Aug	0.29	0.53	0.48	0.07	0.02	0.07	0.05	0.04	0.23	0.79	0.03
Sep	0.31	0.55	0.16	0.07	0.02	0.04	0.02	0.03	0.21	0.82	0.02
Oct	0.13	0.52	0.07	0.00	0.03	0.01	0.00	0.02	0.13	0.78	0.00
Nov	0.03	0.08	0.00	0.00	0.03	0.00	0.00	0.02	0.09	0.50	0.00
Dec	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.02	0.04	0.22	0.00

	Baseline Model Average Monthly Demand (MGD)				
Month	IR: Titan Farms	IR: Twin Oaks Farm	IR: Walker Farm	IR: Watson Jerrold	IR: Watson Joe Farm
Limit (MGD)-->	0.82	0.11	0.10	5.92	1.75*
Jan	0.04	0.00	0.00	0.29	0.00
Feb	0.04	0.00	0.00	0.34	0.00
Mar	0.50	0.00	0.00	0.47	0.00
Apr	0.98	0.01	0.00	0.64	0.10
May	1.38	0.01	0.00	1.19	0.16
Jun	1.71	0.02	0.01	1.51	0.19
Jul	1.60	0.03	0.00	1.82	0.19
Aug	1.08	0.02	0.00	1.78	0.20
Sep	0.95	0.02	0.00	1.72	0.20
Oct	0.33	0.00	0.00	1.27	0.14
Nov	0.01	0.00	0.00	0.81	0.03
Dec	0.01	0.00	0.00	0.43	0.00

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

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

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

Table 6-11. Baseline Model Monthly Transbasin Imports

	Baseline Model Avg Monthly Transbasin Import (MGD)
Month	**WS: Columbia**
Jan	25.7
Feb	25.4
Mar	27.2
Apr	31.6
May	34.7
Jun	36.7
Jul	38.6
Aug	38.3
Sep	35.6
Oct	32.9
Nov	29.2
Dec	25.2

6.3.4 Consumptive Use and Return Flows

As discussed in Section 4.2, return flows (discharges) can be simulated two ways in SWAM. They can be associated with a Water User object or specified within a Discharge object. **Table 6-12** 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., Duke's four Lee Steam Station Discharges were lumped together in the calibration model). No returns are assumed for golf course and agricultural irrigation (i.e., 100% consumptive use).

Table 6-13 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 two mines, Vulcan and Martin Marietta, have general use discharge permits, which have flows that do not require reporting to DHEC. Instead, returns for these two water users is defined by the estimated percent of return flow indicated in their surface water withdrawal permits. For SCE&G McMeekin Station, NPDES records of discharges were inconsistent and incomplete, therefore a consumptive use estimate of 26% was assumed based on previous (withdrawal permit) estimates developed by the facility. For the Duke power station (calibration model only), an assumed consumptive use value of 2.5% is used based on literature (Torcellini, 2003).

Table 6-14 presents the baseline model monthly average returns represented by a Discharge object. The returns were calculated by averaging the DHEC-reported discharges for the baseline period (2004 through 2013).

6.4 Summary

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

Table 6-12. 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: DAK	Eastman Chemical/SC Operations	SC0001333-001 SC0001333-01A SC0001333-01D SC0001333-01E SC0001333-01F SC0001333-01G	09IN001	Congaree River	191	100
IN: Shaw Industries	Shaw Industries Group/Columbia	SC0003557-001 SC0003557-002 SC0003557-003	32IN006	Congaree River	172	100
MI: Martin Marietta	Martin Marietta/Cayce Quarry	SCG730263-000	32MI001	Congaree River	181	100
MI: Vulcan Mining	Vulcan Const Mat/Lakeside	SCG730245-000	04MI001	Saluda River	41	100
PT: Lee Steam Station	Duke Energy/Lee Steam Station	SC0002291-001 SC0002291-002 SC0002291-003 SC0002291-004	04PT001	Saluda River	59	100
PT: SCE&G	SCE&G/McMeekin Steam Station	SC0002046-001 SC0002046-002 SC0002046-003 SC0002046-004 SC0002046-005	32PT001	Saluda River	170	100
WS: Belton Honea Path	**Due West WWTF**	**SC0022403-001**	04WS005	**Out of basin (Savannah)**	**1002**	**6**
WS: Belton Honea Path	Belton/Ducworth (Saluda)	SC0045896-001	04WS005	Saluda River	62	21
WS: Belton Honea Path	Belton/Ducworth (Saluda)	SC0045896-002 SC0045896-003	04WS005	Broad Mouth Creek	1	52
WS: Belton Honea Path/ WS: Greenwood	Ware Shoals/Dairy Street	SC0020214-001	04WS005/24WS001	Saluda River	81/81.5	21/11
WS: Cayce/WS: W. Columbia	Cayce WWTF	SC0024147-001	32WS004/32WS008/ 32WS052	Congaree River	183/184	100/86
WS: Columbia	Alpine Utilities/Stoop Creek	SC0029483-001	40WS002	Saluda River	173	6
WS: Columbia	East Rich CO PSD/Gills Creek	SC0038865-001	40WS002	Congaree River	183	85
WS: Columbia	**Chapin, Town of**	**SC0040631-001**	40WS002	**Out of basin (Broad)**	**1005**	**9**
WS: Columbia	**Richland Co/Broad River WWTF**	**SC0046621-001**	40WS002	**Out of basin (Broad)**	**1005**	**9**
WS: Columbia/WS: W. Columbia	Columbia/Metro Plant	SC0020940-001	40WS002/32WS008/ 32WS052	Congaree River	182.5/184	85/86
WS: Easley	**Easley/Golden Creek Lagoon**	**SC0023035-001**	39WS001	**Out of basin (Savannah)**	**1003**	**5**
WS: Easley	Easley/Georges Creek Lagoon	SC0023043-001	39WS001	Georges Creek	1	15
WS: Easley	Easley/Middle Branch WWTP	SC0039853-001	39WS001	Brushy Creek	3	80
WS: Greenville	ReWa/Marietta WWTP	SC0026883-001	23WS002	North Saluda River	15	6
WS: Greenville	Greenville/N Saluda & Table Rock WTP	SCG646033	23WS002	North Saluda River	15	6
WS: Greenville	**ReWa/Pelham WWTF**	**SC0033804-001**	23WS002	**Out of basin (Broad)**	**1001**	**48**
WS: Greenville	**ReWa/Durbin Creek**	**SC0040002-001**	23WS002	**Out of basin (Broad)**	**1001**	**48**
WS: Greenville	**ReWa/Gilder Creek**	**SC0040525-001**	23WS002	**Out of basin (Broad)**	**1001**	**48**
WS: Greenville	ReWa/Mauldin Road	SC0041211-001	23WS002	Reedy River	12	39
WS: Greenville	ReWa/Piedmont Regional WWTP	SC0048470-001	23WS002	Saluda River	49	7
WS: Greenwood	Greenwood/Wilson Creek WWTF	SC0021709-001	24WS001	Wilson Creek	1	76
WS: Greenwood	**Greenwood/West Alexander WWTF**	**SC0022870-001**	24WS001	**Out of basin (Savannah)**	**1009**	**6**
WS: Greenwood	Ninety Six WWTF	SC0036048-001	24WS001	Ninety Six Creek	81.5	11
WS: Laurens	Laurens Comm of PW/Laurens	SC0020702-001	30WS002	Little River	2	100
WS: Laurens	Laurens WTP	SCG646028	30WS002	Little River	2	100
WS: NCWSA	NCW&SA/Cannons Creek WWTP	SC0048313	36WS002	**Out of basin (Broad)**	**999**	100
WS: Newberry	Aiken PSA/Horse Creek WWTF	SC0024457	36WS001	**Out of basin (Savannah)**	**1011**	14
WS: Newberry	Newberry/Bush River WWTF	SC0024490-001	36WS001	Bush River	20	71
WS: Newberry	Saluda, Town of	SC0022381-001	36WS001	Little Saluda River	8	15
WS: Newberry	Newberry WTP	SCG646047	36WS001		8	15
WS: W. Columbia	Lexington/Coventry Woods SD	SC0026735-001	32WS008 /32WS052	Twelvemile Creek	12	14
WS: W. Columbia	Lexington Co/Edmund Landfill	SC0045110-001	32WS008 /32WS052	Congaree Creek	12	14

Table 6-12. Returns and Associated Model Objects (continued)

Model Object ID	Facility Name	NPDES Pipe ID	Associated Water Permit	Discharge Tributary	Model River Mile	% of Return Flow
Transbasin Imports Represented by Discharge Objects						
Clinton Import (Broad)	Laurens CO W&S/Clinton-Joanna	SC0037974-001	30WS001	Bush River	10	-
Greenville Import/Reedy (Savannah)	ReWa/Lower Reedy River Plant	SC0024261-001	23WS007	Reedy River	24	-
Greenville Import/Georges (Savannah)	ReWa/Georges Creek	SC0047309-001	23WS007	Saluda River	36	-
Greenville Import/Mauldin (Savannah)	ReWa/Mauldin Road	SC0041211-001	23WS007	Reedy River	12	-
Williamston Import/Big Crk (Savannah)**	Williamston/Big Creek East WWTP	SC0046841-001	04WS006	Big Creek	11	-
In-basin Returns Represented by Individual or Aggregated Discharge Objects						
Milliken	Milliken/Gayley Plant	SC0003191-001 SC0003191-T11	*none*	South Saluda River	19	-
Agg Discharge 1	CWS/Watergate Development	SC0027162-001	*none*	Saluda River	175	-
	Woodland Hills West SD	SC0029475-001				
	Bush River Utilities	SC0032743-001				
	CWS/I-20 Regional	SC0035564-001				
	CWS/Friarsgate SD	SC0036137-001				
Agg Discharge 2	Westinghouse Elec LLC/Columbia	SC0001848-001	*none*	Congaree River	195	-
	Devro Inc/Coria Division	SC0033367-001				
Air Products	Air Products & Chemicals, Inc	SC0048429-001	*none*	Saluda River	43	-
Ing Rand	Ingersoll Rand/G.W. Recovery Sys	SC0048534-001	*none*	Little River	10	-

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

** Only represented in the calibration model (came off-line in 2014).*

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

Table 6-13. Baseline Model Monthly Consumptive Use Percentage

	Monthly Consumptive Use (%)							
Month	**IN: CMC Steel**	**IN: DAK**	**IN: Shaw**	**MI: Martin Marietta**	**MI: Vulcan**	**PT: SCE&G**	**WS: Belton Honea**	**WS: Cayce**
Jan	5.0	1.0	3.0	50.0	90.0	26.0	18.0	16.2
Feb	5.0	1.0	3.0	50.0	90.0	26.0	20.8	13.0
Mar	5.0	1.0	3.0	50.0	90.0	26.0	16.2	15.6
Apr	5.0	1.0	3.0	50.0	90.0	26.0	25.2	26.5
May	5.0	1.0	3.0	50.0	90.0	26.0	37.4	35.3
Jun	5.0	1.0	3.0	50.0	90.0	26.0	39.6	36.5
Jul	5.0	1.0	3.0	50.0	90.0	26.0	44.0	36.0
Aug	5.0	1.0	3.0	50.0	90.0	26.0	46.2	32.3
Sep	5.0	1.0	3.0	50.0	90.0	26.0	49.1	32.9
Oct	5.0	1.0	3.0	50.0	90.0	26.0	43.4	28.9
Nov	5.0	1.0	3.0	50.0	90.0	26.0	38.4	24.7
Dec	5.0	1.0	3.0	50.0	90.0	26.0	23.8	17.5

Table 6-13. Baseline Model Monthly Consumptive Use Percentage (continued)

	Monthly Consumptive Use (%)							
Month	WS: Columbia	WS: Easley	WS: Greenville	WS: Greenwood	WS: Laurens	WS: NCWSA	WS: Newberry	WS: W. Columbia
Jan	8.9	61.3	23.5	5.2	20.5	54.5	23.7	30.0
Feb	6.7	61.8	24.6	5.5	23.9	51.3	18.1	30.0
Mar	6.1	61.5	28.3	6.6	25.0	54.0	20.7	30.0
Apr	19.2	68.4	40.4	14.2	29.4	58.7	25.6	30.0
May	31.1	72.7	48.4	23.0	33.0	63.1	33.4	30.0
Jun	34.0	71.9	52.8	29.4	32.6	63.2	34.5	30.0
Jul	36.8	72.7	57.4	29.7	28.4	64.9	36.4	30.0
Aug	29.5	73.9	54.3	28.2	22.7	68.9	36.0	30.0
Sep	28.6	71.9	54.4	26.5	16.3	70.2	34.1	30.0
Oct	26.7	72.2	48.7	22.2	18.4	66.8	32.3	30.0
Nov	19.3	67.6	37.9	16.7	11.4	63.7	28.7	30.0
Dec	10.8	61.1	23.1	10.8	13.8	57.7	21.6	30.0

Table 6-14. Baseline Model Monthly Return Flows for Discharge Objects

Monthly Return Flow (MGD)										
Month	Agg Disch 1	Agg Disch 2	Air Products	Clinton Import (Broad)	Williamston Import (Savannah)	Greenville Import/ Georges (Savannah)	Greenville Import/ Mauldin (Savannah)	Greenville Import/ Reedy (Savannah)	Ing Rand	Milliken
Jan	1.82	0.35	0.19	1.53	0.34	1.26	6.61	5.40	3.16	0.00
Feb	1.97	0.36	0.09	1.53	0.36	1.18	7.18	5.41	3.84	0.00
Mar	1.96	0.35	0.13	1.63	0.35	1.24	6.11	5.49	4.11	0.00
Apr	1.82	0.36	0.10	1.43	0.33	1.12	4.14	5.16	3.97	0.00
May	1.66	0.34	0.09	1.27	0.34	1.09	5.20	5.12	3.98	0.00
Jun	1.68	0.35	0.15	1.26	0.38	1.11	6.75	4.74	3.97	0.00
Jul	1.75	0.35	0.10	1.24	0.37	1.07	5.80	4.75	3.83	0.00
Aug	1.86	0.36	0.12	1.32	0.34	1.05	6.50	5.24	3.72	0.00
Sep	1.70	0.35	0.16	1.23	0.31	1.04	3.55	5.26	3.33	0.00
Oct	1.60	0.33	0.09	1.21	0.29	0.98	5.69	5.14	3.61	0.00
Nov	1.63	0.36	0.09	1.22	0.26	1.06	5.69	5.18	3.17	0.00
Dec	1.89	0.36	0.19	1.45	0.34	1.26	5.45	4.94	3.21	0.00

Mauldin Road discharge object excludes flows originating from Saluda sources. Milliken has not reported values since 2010.

Section 7

Model Calibration/Verification

7.1 Philosophy and Objectives

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

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

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

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

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

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

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

7.2 Methods

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

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 Saluda 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. Note that as a result of this review, specific monthly storage targets for Lake Murray were modified slightly from original estimates.

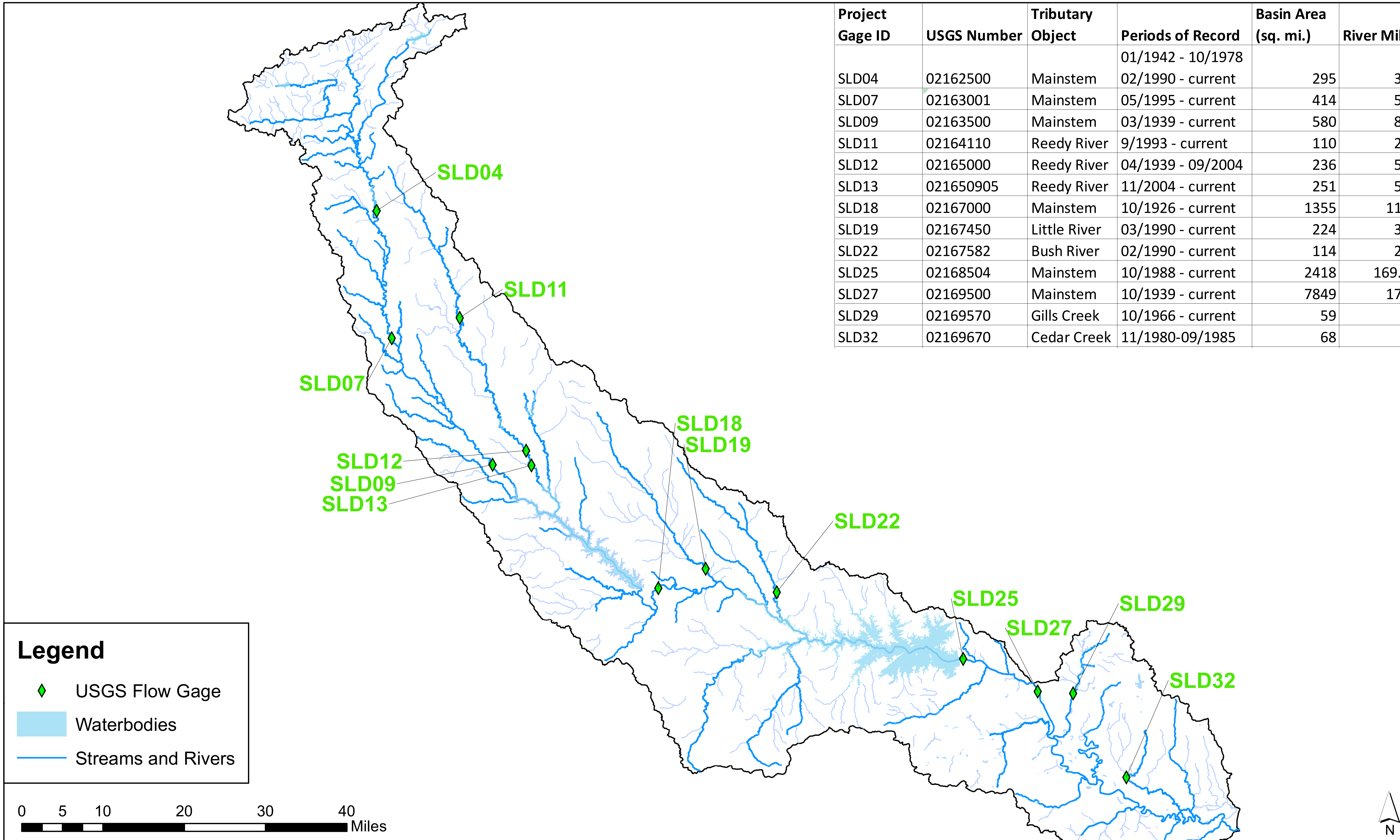
6. The adequacy of the daily timestep model was verified by reviewing daily output once the monthly model was calibrated.

All USGS flow gages at 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. Although it had a complete period of record, the Saluda River near Columbia gage was not used in calibration since the gages in close proximity upstream (Saluda River below Lake Murray) and downstream (Congaree River at Columbia) were available. The gages used for calibration are shown in **Figure 7-1**. Note that in order to minimize the uncertainty in our calibration targets, only gaged (i.e. measured) flow records were used to assess model performance as part of this exercise. No ungaged flow estimates or record filling techniques were used to supplement this data set (although many of the input flows were developed through various record extensions techniques). Note also that all upstream basin water use and operations are implicitly represented in these gaged data, thereby providing an ideal target to which the combination of estimated UIFs and historic water uses could be compared. In addition to the flow gages, reported historical reservoir levels (where available) were also used as calibration/verification targets.

Additionally, as described in Section 6, operational storage targets at Lake Murray are known to have changed in late 2002. This change is not represented in the calibration model, which assumes consistent operational rules throughout the simulation. Therefore, to avoid calibration bias at the two flow gages downstream of the lake (SLD25 and SLD27), the period November 2002 through December 2013 was excluded from the calibration analysis for Lake Murray and these two flow gage sites. Two short periods of known reservoir construction and dewatering, in 1990 and 1996, respectively, were also excluded from the analysis for these sites.

It should also be noted that there are confounding issues with the use of SLD27 (Congaree River at Columbia) as a calibration point. Since a large portion of the drainage area for this gage is located outside of the Saluda Basin (in the Broad River basin), this portion of the flow is not explicitly included in the model. Rather, gage data (Broad River near Alston) are used, with all upstream Broad River historical operations implicitly included in this data set. Area-weighting is used to extend these flows down to the confluence with the Saluda and then subbasin flow factor adjustments are included in the calibration process, as described above. However, Broad River operations below the Alston gage (e.g. City of Columbia Canal Plant) are not well captured, either implicitly or explicitly in this approach. Therefore, the assessment of calibration results at this location should consider this area of

Project Gage ID	USGS Number	Tributary Object	Periods of Record	Basin Area (sq. mi.)	River Mile
SLD04	02162500	Mainstem	01/1942 - 10/1978 02/1990 - current	295	32
SLD07	02163001	Mainstem	05/1995 - current	414	56
SLD09	02163500	Mainstem	03/1939 - current	580	82
SLD11	02164110	Reedy River	9/1993 - current	110	28
SLD12	02165000	Reedy River	04/1939 - 09/2004	236	59
SLD13	021650905	Reedy River	11/2004 - current	251	59
SLD18	02167000	Mainstem	10/1926 - current	1355	117
SLD19	02167450	Little River	03/1990 - current	224	30
SLD22	02167582	Bush River	02/1990 - current	114	26
SLD25	02168504	Mainstem	10/1988 - current	2418	169.5
SLD27	02169500	Mainstem	10/1939 - current	7849	178
SLD29	02169570	Gills Creek	10/1966 - current	59	7
SLD32	02169670	Cedar Creek	11/1980-09/1985	68	9



CDM Smith

Figure 7-1. USGS Streamflow Gages Used in Calibration

uncertainty. Once they are available, The Broad Basin baseline model output will be used in the Saluda baseline model to more accurately quantify Broad River inflows to the Saluda.

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

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

Note that Lake Murray storage targets in the model were increased by 1%, uniformly for all months, over actual operator targets as part of the model calibration process. The model was better able to achieve intended end-of-month storage targets, and actual historical end-of-month storage values, by aiming slightly higher at the beginning of each timestep. This inexact calculation in the model is a function of the model numerical scheme but is also likely comparable to actual operator error with respect to hitting storage targets. The tendency for the model to undershoot storage targets should be considered for future applications of the model, including the Saluda Basin baseline model. Baseline model storage targets, as noted previously, have been similarly increased by 1% over actual targets.

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

The reliability of past water supply to meet specific water user demands is an important consideration in the calibration process to ensure that water user demands and supply portfolios are properly represented in the model, as well as providing checks on supply availability at specific points of withdrawal. Timeseries plots, both monthly and daily, are used to assess the model's ability to simulate observed temporal variation and patterns in flow and storage data and to capture an appropriate range of high and low flow values. Percentile plots are useful for assessing the model's ability to reproduce the range of flows, including extreme events, observed in the past (and are particularly important when considering that the value of a long-term planning model like this is its ability to predict the frequency at which future flow thresholds might be exceeded, or the frequency that various amounts of water will be available). Monthly statistics provide valuable information on the model's ability to generally reproduce seasonal patterns, while annual totals and period of record mean flows help confirm the overall water balance represented in the model. Lastly, regulatory low flows (7Q10) are of specific interest as the model could be used to predict such low flows as a function of future impairment. However, the limitations of the daily model and supporting data should be properly considered in assessing model performance on this particular metric. Note that for the purposes of this exercise a simplified 7Q10 calculation was employed. Our approach used the Excel percentile function to estimate the 10 year recurrence interval (10th percentile) of modeled and measured 7 day low flows. This differs from the more standard methods often using specific fitted probability distributions (e.g. log-Pearson).

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

7.3 Results

Detailed monthly and daily model calibration results are provided in **Appendix A** and **B**, respectively. In general, a strong agreement between modeled and measured data is observed for all targeted sites. Discrepancies between modeled and measured flow data are generally within the reported range of uncertainty associated with the USGS flow data used to drive the models (5 – 20%) (USGS http://wdr.water.usgs.gov/current/documentation.html). Seasonal and annual patterns in both flow and reservoir storage data are reproduced well by the model. Monthly fluctuations (timeseries) and extreme conditions (percentiles) are also very well reproduced by the model for most sites.

Not surprisingly, the poorest fit occurs at the flow gage directly below Lake Murray (SLD25). This was expected as the flow at this site is governed almost entirely by lake operations and management decisions, rather than natural hydrology. Lake operations are represented in the model by a simplified set of operating rules that are assumed to be consistently followed and do not factor in human decision-making. Consequently, reproducing monthly or daily flows at this location was expected to be more challenging than at other sites. That being said, an excellent agreement in average flow (+2%) and monthly percentiles (within ± ~25%) is achieved by the model, confirming that long-term statistics are well captured. Additionally, the general pattern of high and low flow periods is very well represented by the model.

For all sites, modeled mean flow values, averaged over the full period of record, were all within 2% of measured mean flows. This indicates that the overall water balance is very well simulated in the model and there are no obvious missing or excess sources of flow in the model. Reservoir storage simulations, while clearly simplified, appear to be accurately replicating historical ranges and patterns of reported storage, particularly for the two largest reservoirs in the basin (Lake Greenwood and Lake Murray). Exceptions to this, as noted above, appear to be largely attributable to anomalies in reservoir operations likely associated with reservoir construction or maintenance activities.

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

In terms of daily timestep simulations, daily flow fluctuations are generally well captured by the model – in some cases surprisingly well (see SLD09 and SLD 27), given the lack of reach routing. The exception, again, is SLD25 (below Lake Murray), for reasons described above. These challenges are undoubtedly amplified for the daily timestep model. Modeled daily percentile plots exhibit excellent agreement with measured data for upstream mainstem locations (SLD04, SLD07, and SLD09), the furthest downstream location (SLD27), and all tributary locations. For SLD18 (Chappells), the model generally slightly under predicts daily flows for the 80th through the 95th percentile and then over predicts daily flows for the highest percentiles (> 95th). These discrepancies are likely primarily attributable to the lack of reach routing and overall simplified representation of hydrologic processes in the model, common to all water allocation models. However, these discrepancies are within 20% of gaged flows and deemed acceptable for the daily model.

Modeled regulatory low flow values (7Q10) are within 10% of measured values at mainstem gages SLD04, SLD18 and SLD27. For SLD07, SLD09, and SLD25, the model over predicts the 7Q10 by approximately 35%, which is deemed acceptable for this challenging metric, especially because the volume of water associated with the SLD09 deviation is very small and the available record of annual low flows is limited at SLD07 and SLD25 (for reasons described above). Further, 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 not justified.

Lastly, the model adequately hindcasts delivered water supply for each of the water users in the model. Simulated supply roughly equals simulated demand for all users, with no significant shortfalls. An exception to this is Duke Power's Lee Steam Station (which was retired in 2014) where there was significant uncertainty in reported and hindcasted withdrawal data due to the complex nature of their water use and lack of high-quality records (Ed Bruce, Duke Power, pers. comm., Aug 2015). Therefore, this historical shortfall was not rectified in the model. Additionally, some of the minor water users in the basins, primarily agricultural and golf course irrigators, show periodic shortfalls in the model during particularly low flow periods. For these instances, it is likely that reported or assumed surface water usage is inaccurate and irrigation was temporarily reduced due to supply limitations.

7.4 Focused Period Validation Exercises

7.4.1 Lake Greenwood

To support the validation of model calibration parameters, model performance was further analyzed for isolated shorter time periods of note. Firstly, Lake Greenwood monthly storage levels were examined during two known recent drought periods: 2001-2002 and 2007-2008. The objective of this exercise was to assess the model's sensitivity to short term drought conditions with respect to large reservoir storage fluctuations. Model storage level fluctuations were compared to prescribed monthly storage targets and actual reported fluctuations. As shown in **Figures 7-2** and **7-3**, during both drought periods, the model clearly exhibits a water-limited signal in the calculated Lake Greenwood storage levels, with significant deviations from the normal operating targets. Further, the deviations

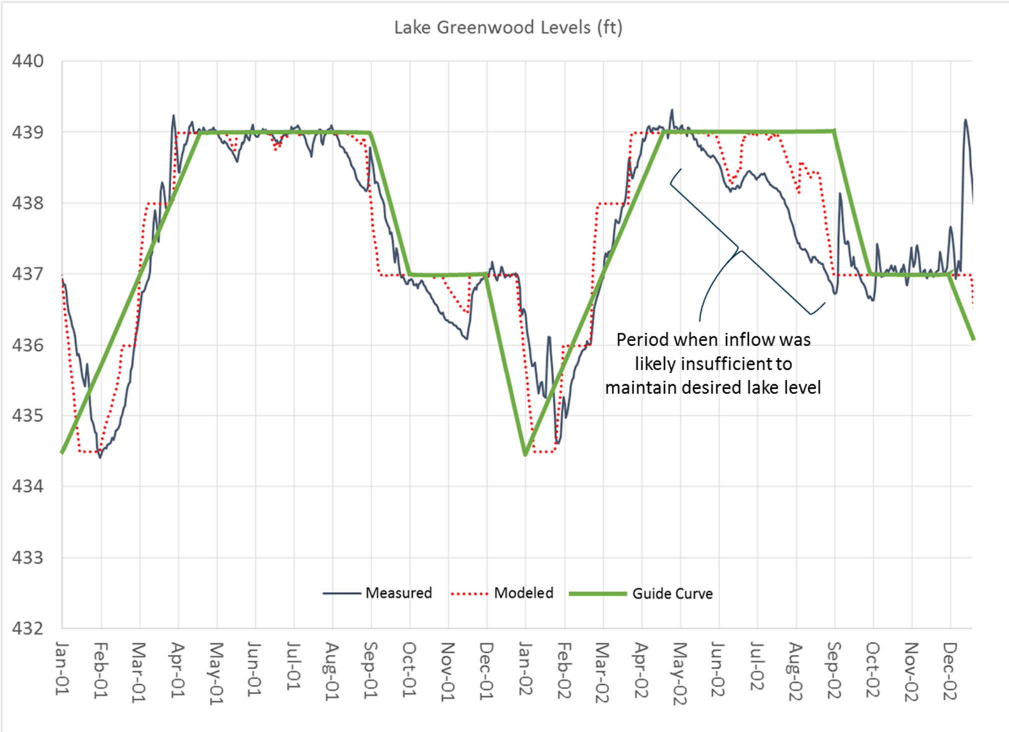


Figure 7-2. Comparison of Modeled and Measured Lake Greenwood Levels, 2001-2002 Drought Period

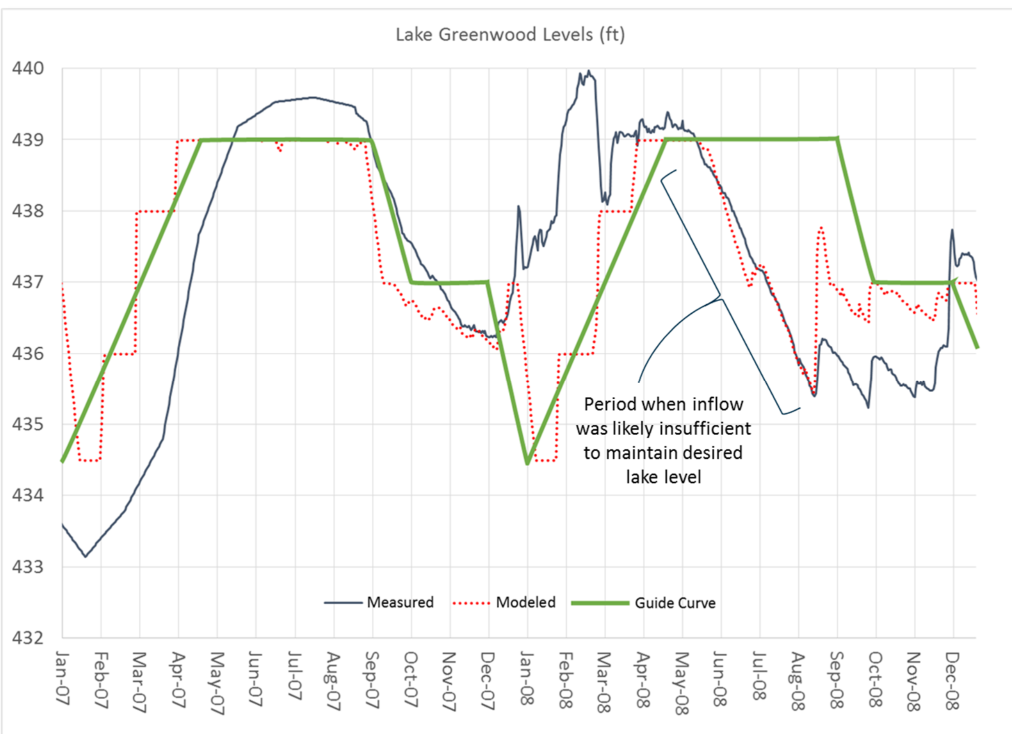


Figure 7-3. Comparison of Modeled and Measured Lake Greenwood Levels, 2007-2008 Drought Period

track reasonably well with actual reported levels during these periods. Differences (modeled vs. measured) are likely attributable to the unpredictability of operator response during the droughts and, possibly, to uncertainties in model evaporation rates during these high temperature months.

Secondly, the prescribed Lake Greenwood monthly storage targets in the model are only strictly accurate for the period 1993 to 2009. Outside of those years, operating rules deviated slightly from these targets. These deviations could, in theory, affect the hydrologic parameter calibration at downstream locations, with the most sensitive location being SLD18 (Saluda River at Chappells), directly downstream of the lake. To investigate, model parameters set using the wider calibration period were validated by applying the calibrated model to the more focused 1993 to 2009 period, when lake storage targets were more certain. In other words, our objective was to confirm that the model performs just as well within this higher certainty period compared to the overall calibration period. Model results were assessed at SLD18, as well as an additional site (SLD16, Lake Greenwood Tailrace) that was added only for this verification exercise. Note that SLD16 was not included in the original calibration data set because it has a limited period of record and is only 7 miles upstream of SLD18. Results (**Figure 7-4** and **7-5**) show that the model does a very good job of reproducing monthly river flows downstream of Lake Greenwood, comparable to the results associated with the wider period of calibration (see Appendix A). In addition to the monthly variability, simulation period modeled mean annual flow values closely match measured values for this isolated period (**Table 7-1**). Put another way, even if the calibration only focused on this shorter time period, with higher associated confidence in reservoir operations, the final calibration parameters (reach gain/loss factors) in the reach immediately downstream of the reservoir would be unchanged from the parameters developed from the wider data set, thus validating those parameters. There is limited evidence in the results of a small flow gain between the two locations that is missing from the model. However, flow differences are two small, relative to other uncertainties, to justify a change in calibration for this very short reach. Overall, these results lend additional confidence to the final set of model calibration parameters, described above.

Table 7-1. Model Validation Results, 1993-2009

Project Gage ID	Measured Flow (CFS)	Modeled Flow (CFS)	Percent Difference
SLD16, Lake Greenwood Tailrace	1,304	1,235	-5%
SLD18, Saluda River at Chappells	1,539	1,534	0.3%

7.4.2 Lake Murray

Lake Murray monthly storage levels were examined during the 2001-2002 drought period. The 2007-2008 was not examined since lake levels appeared to be maintained following the new guide curve, which was different than the guide curve used during the calibration. Model storage level fluctuations were compared to prescribed monthly storage targets and actual reported fluctuations. As shown in **Figure 7-6**, there is no clear response to drought conditions, primarily due to the fact that in late 2002, the lake levels were lowered to 345' (NAVD88) as a safety measure during construction of the backup dam. Prior to that, both actual and modeled Lake Murray elevations closely follow the guide curve, with only minor variations.

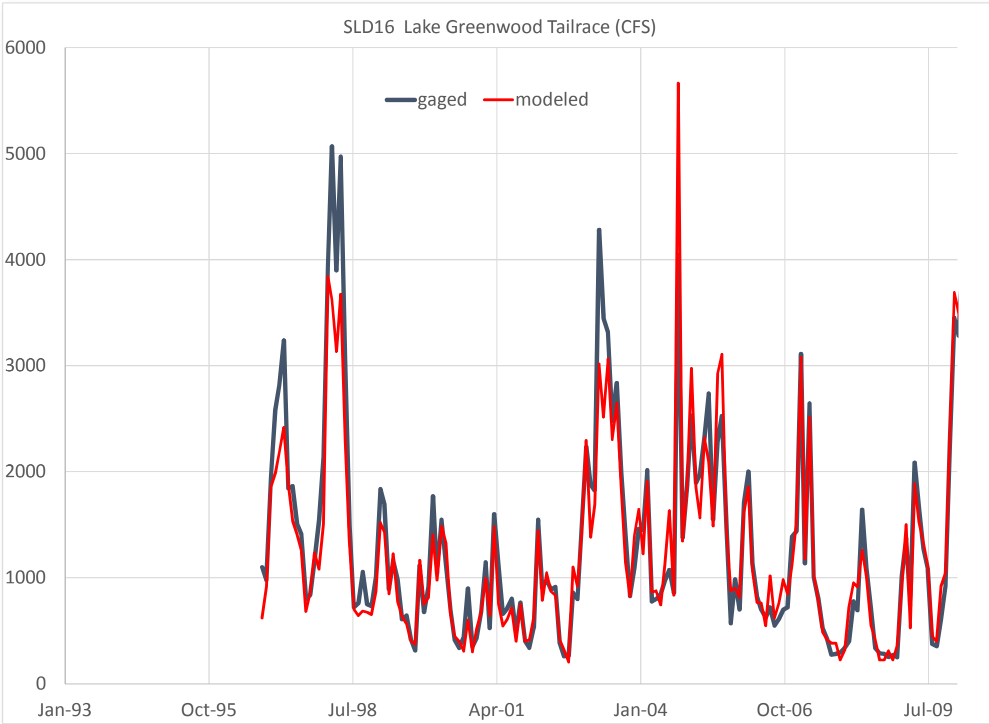


Figure 7-4. Model Validation Results: 1993 – 2009, Lake Greenwood Tailrace

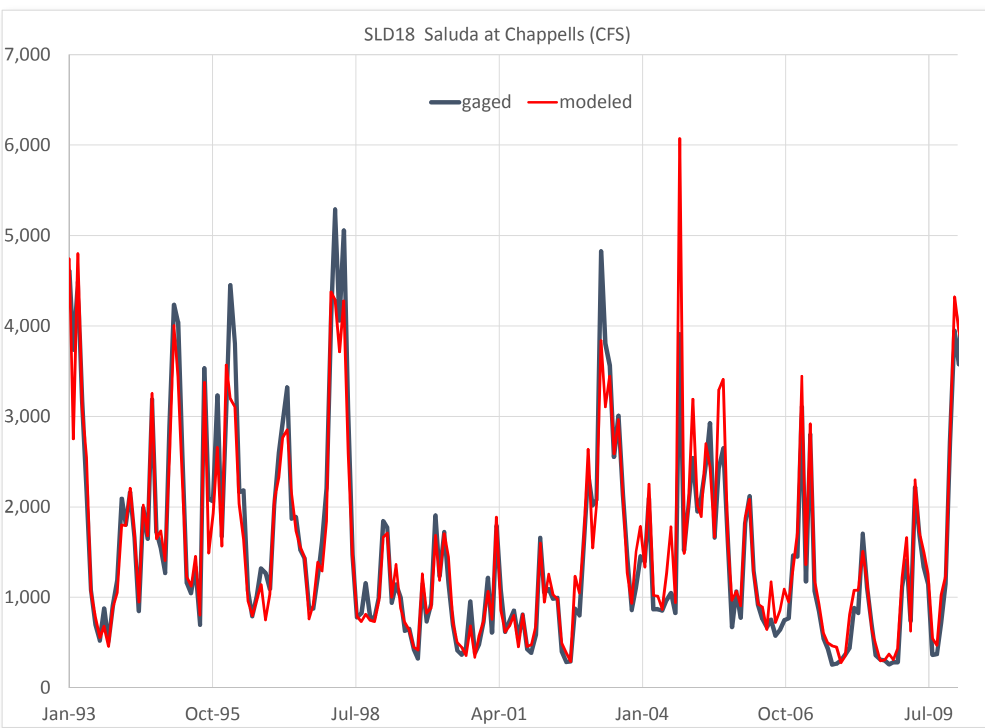


Figure 7-5. Model Validation Results: 1993 – 2009, Saluda River at Chappells

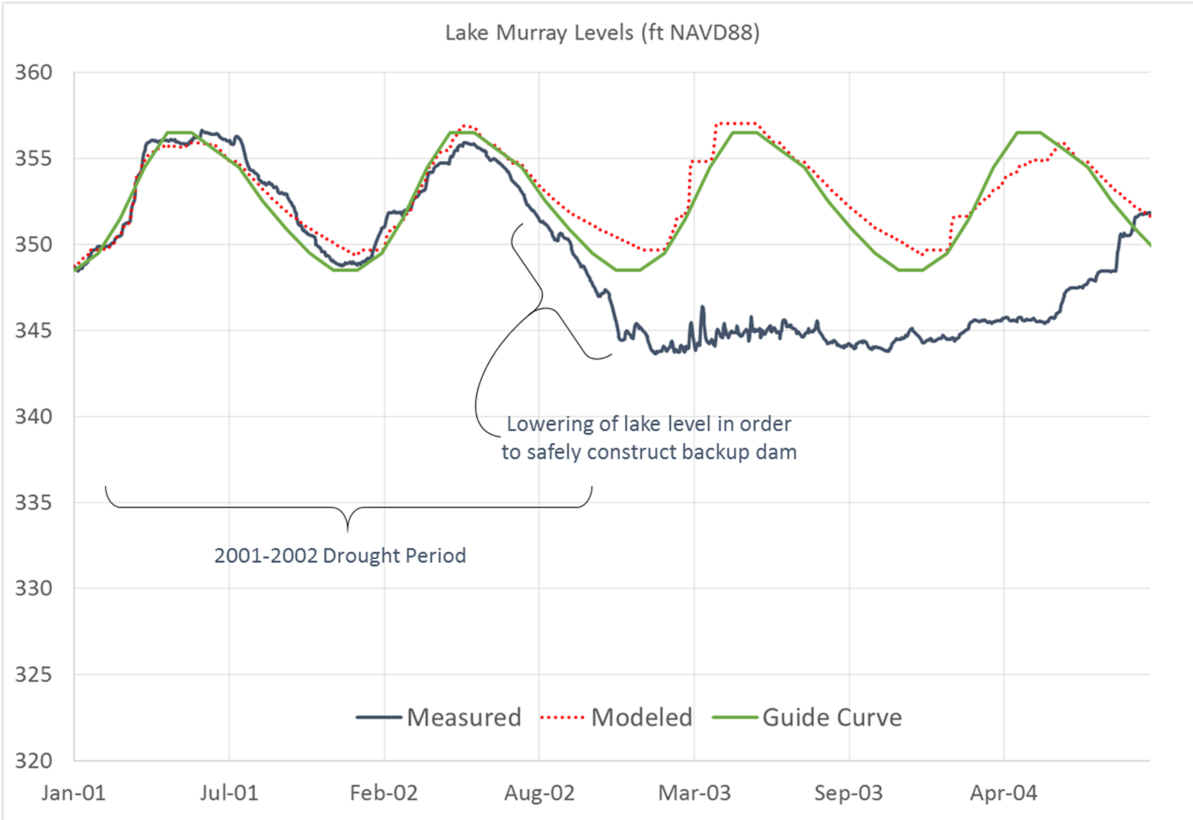


Figure 7-6. Comparison of Modeled and Measured Lake Murray Levels, 2001-2002 Drought Period

Section 8

User Guidelines for the Baseline Model

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

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

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

Users will also be able to change the duration of a model run in order to focus on specific years or hydrologic conditions. For example, the default model will run on a daily or monthly time step from 1925 through 2013 in order to test scenarios over the full historic period of recorded hydrologic conditions. In some cases, though, it may be useful to compile output over just the period corresponding to the drought of record, or an unusually wet period.

Flow conditions can also be changed by the user, though it will be important for the user to understand implications when unimpaired flows (naturalized flows) are replaced with other time series. In certain basins outside the Saluda, it will be useful to examine flows with either managed or unimpaired flows coming across state lines into South Carolina. In the Saluda Basin, it may 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* (CDM Smith, 2015). The User's Guide provides a description of the model objects, inputs, and outputs and provides guidelines for their use. A technical documentation section is included which provides detailed descriptions of the fundamental equations and algorithms used in SWAM.

Section 9

References

CDM Smith, 2015. *Simplified Water Allocation Model (SWAM) User's Manual, Version 2.0.*

Bruce, Ed (Duke Energy), August 2015. Personal Communication.

Torcellini, P., N. Long and R. Judkoff, 2003. *Consumptive Water Use for U.S. Power Production – Technical Report*. National Renewable Energy Laboratory (NREL/TP-550-33905).

Appendix A

Saluda River Basin Model

Monthly Calibration Results

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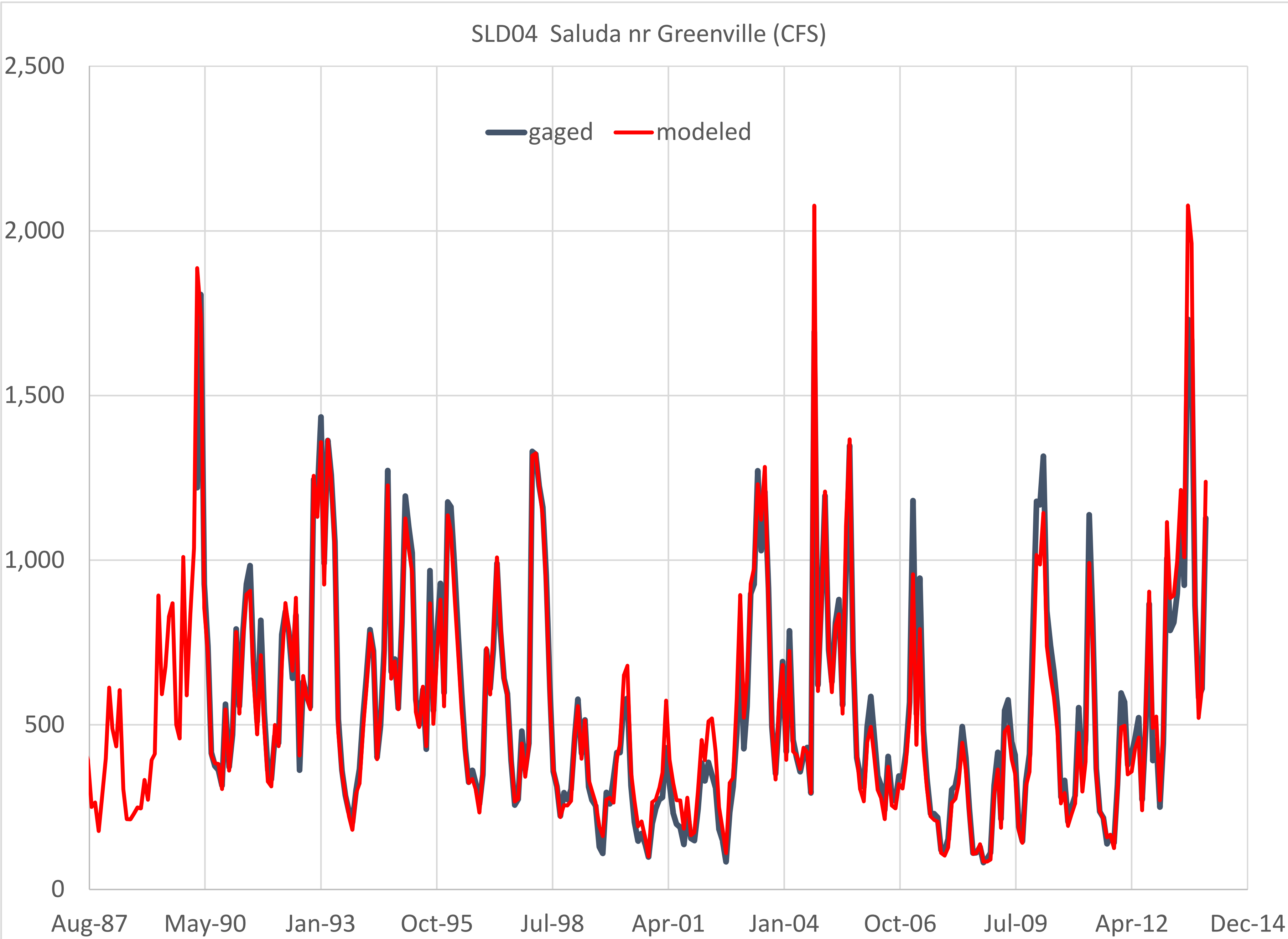
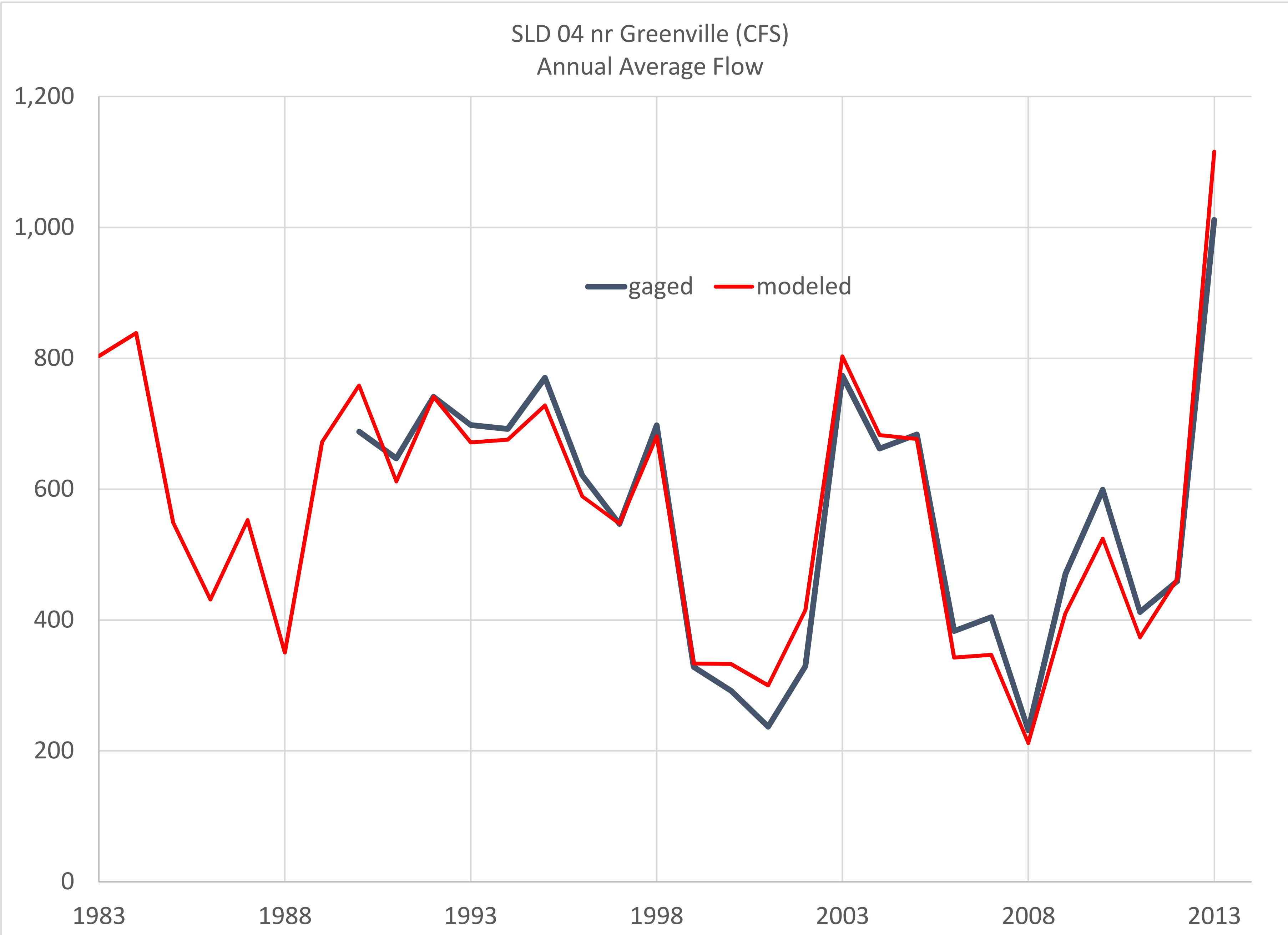
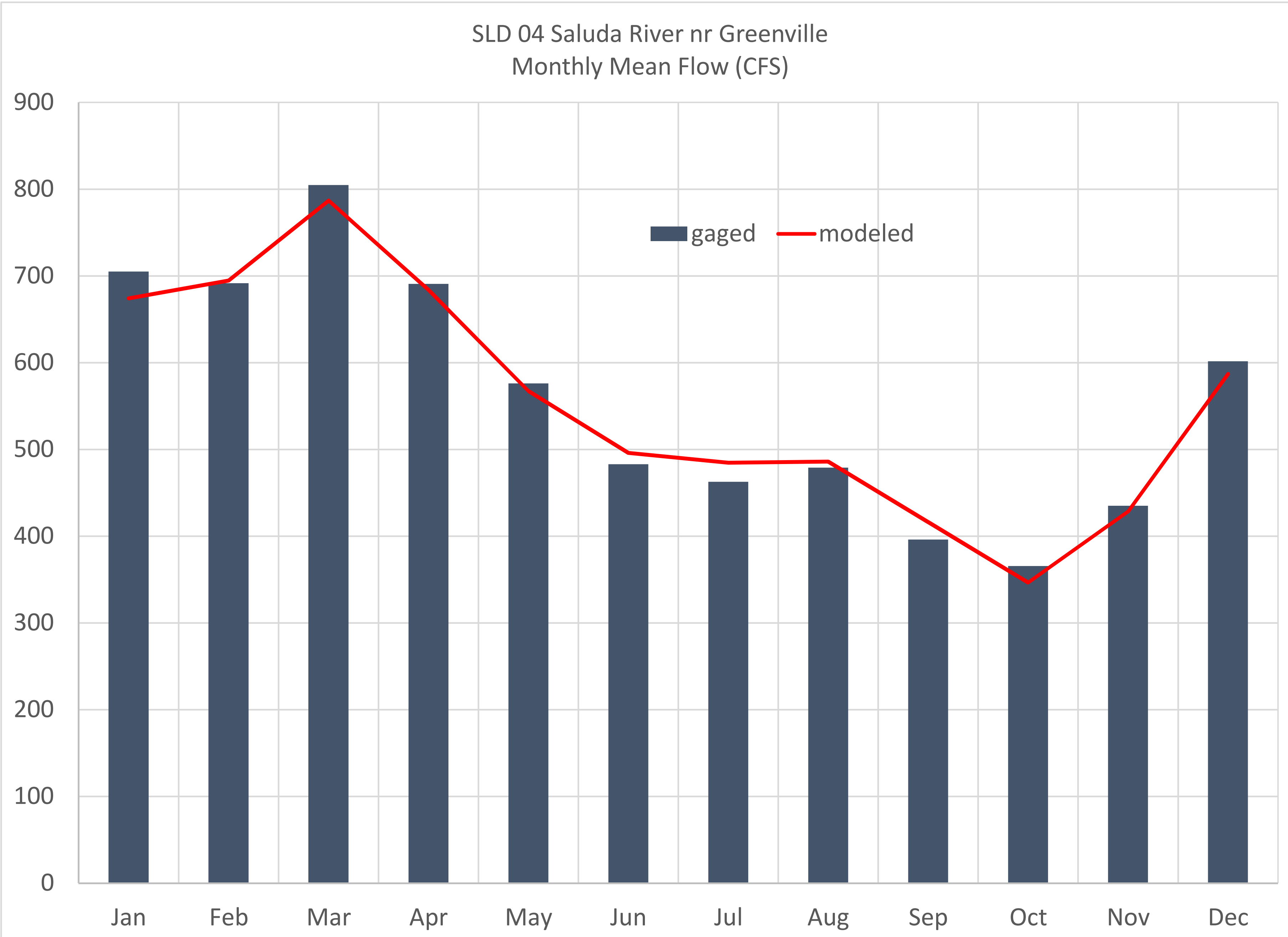
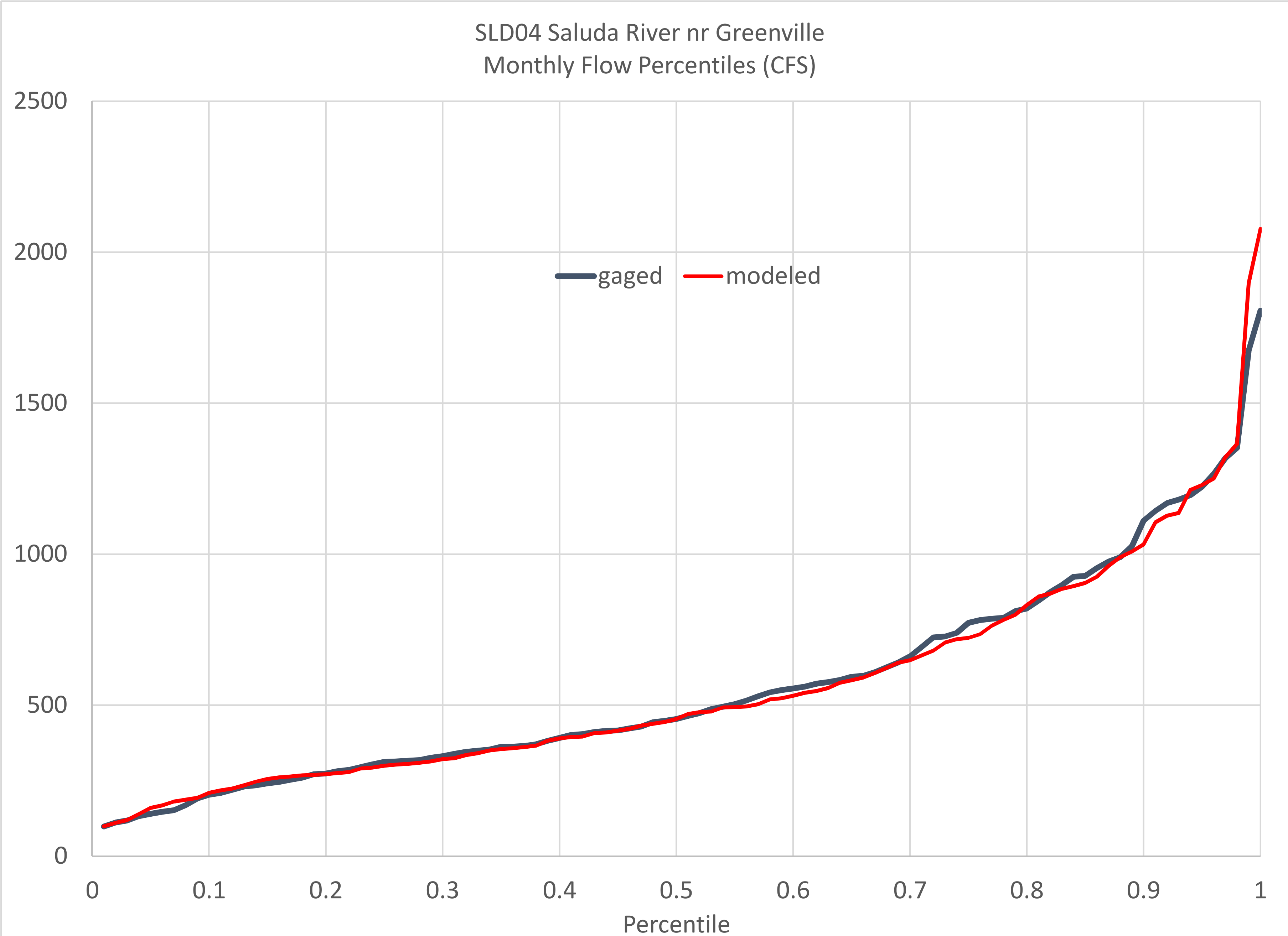
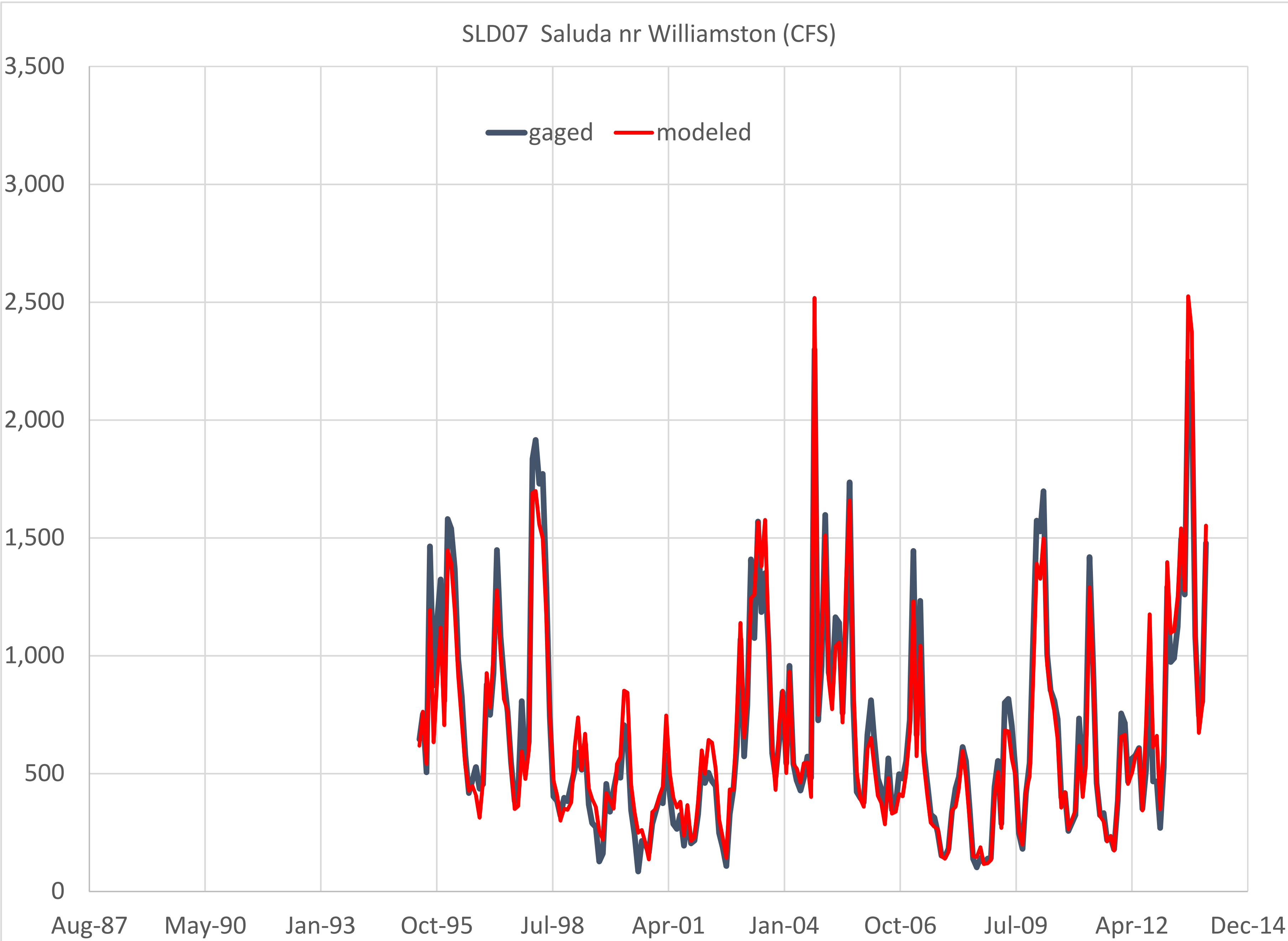

SLD04 Saluda nr Greenville (CFS)
2,500
2,000
1,500
1,000
500
0
gaged
modeled
Aug-87
May-90
Jan-93
Oct-95
Jul-98
Apr-01
Jan-04
Oct-06
Jul-09
Apr-12
Dec-14

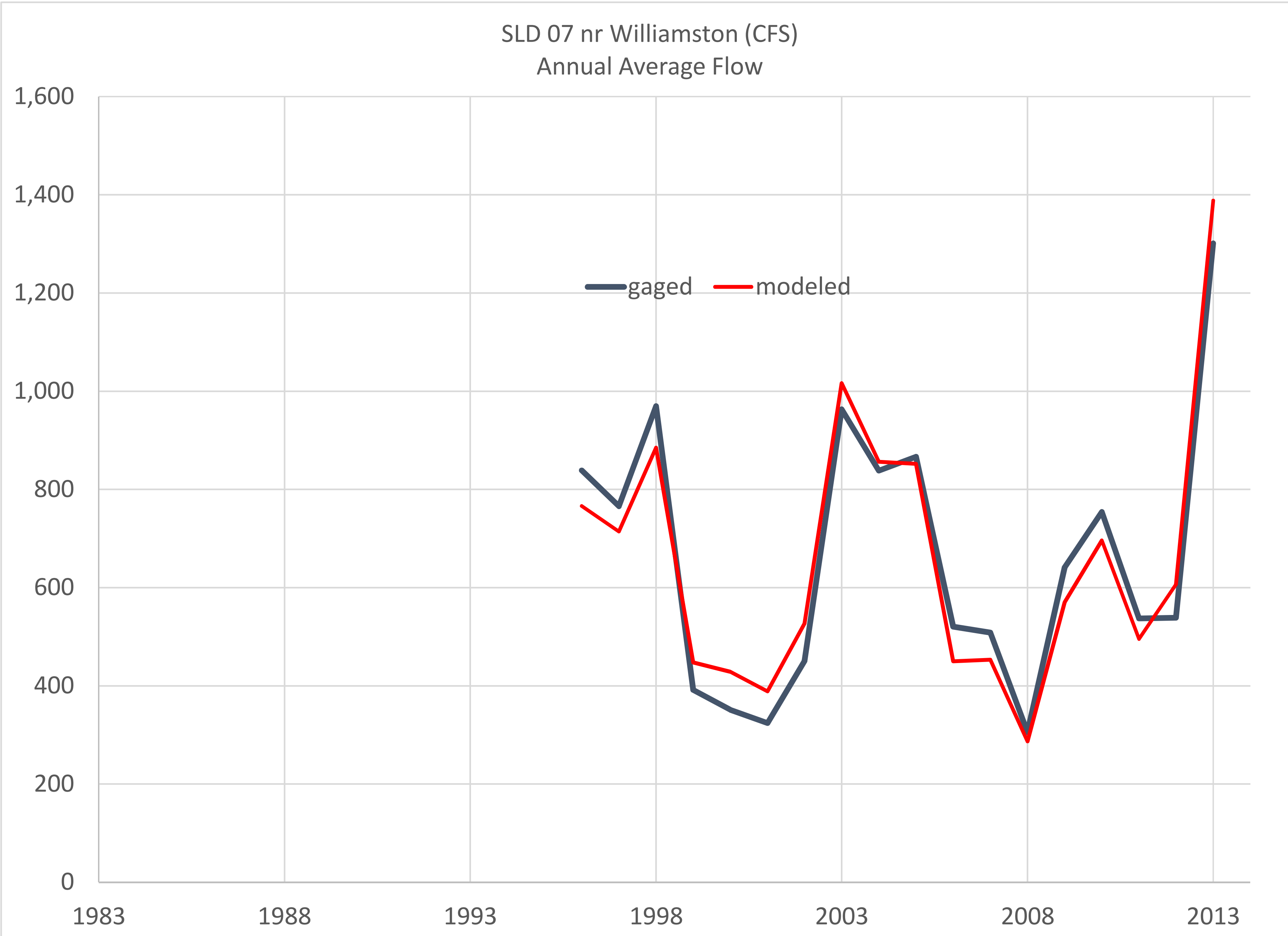

SLD 04 nr Greenville (CFS)
Annual Average Flow
1,200
1,000
800
600
400
200
0
1983
1988
1993
1998
2003
2008
2013
gaged
modeled



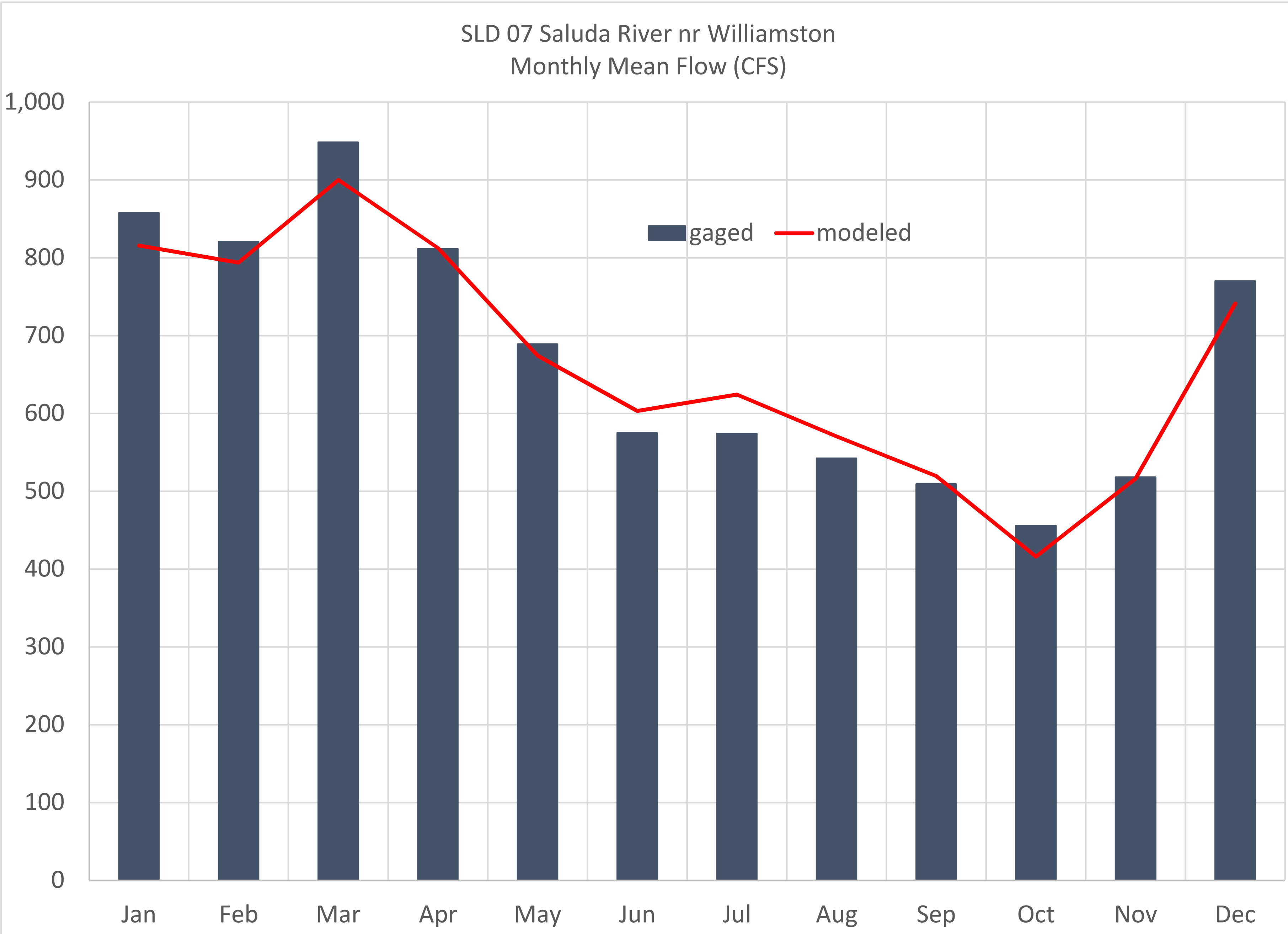
SLD 04 Saluda River nr Greenville
Monthly Mean Flow (CFS)
gaged
modeled
900
800
700
600
500
400
300
200
100
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

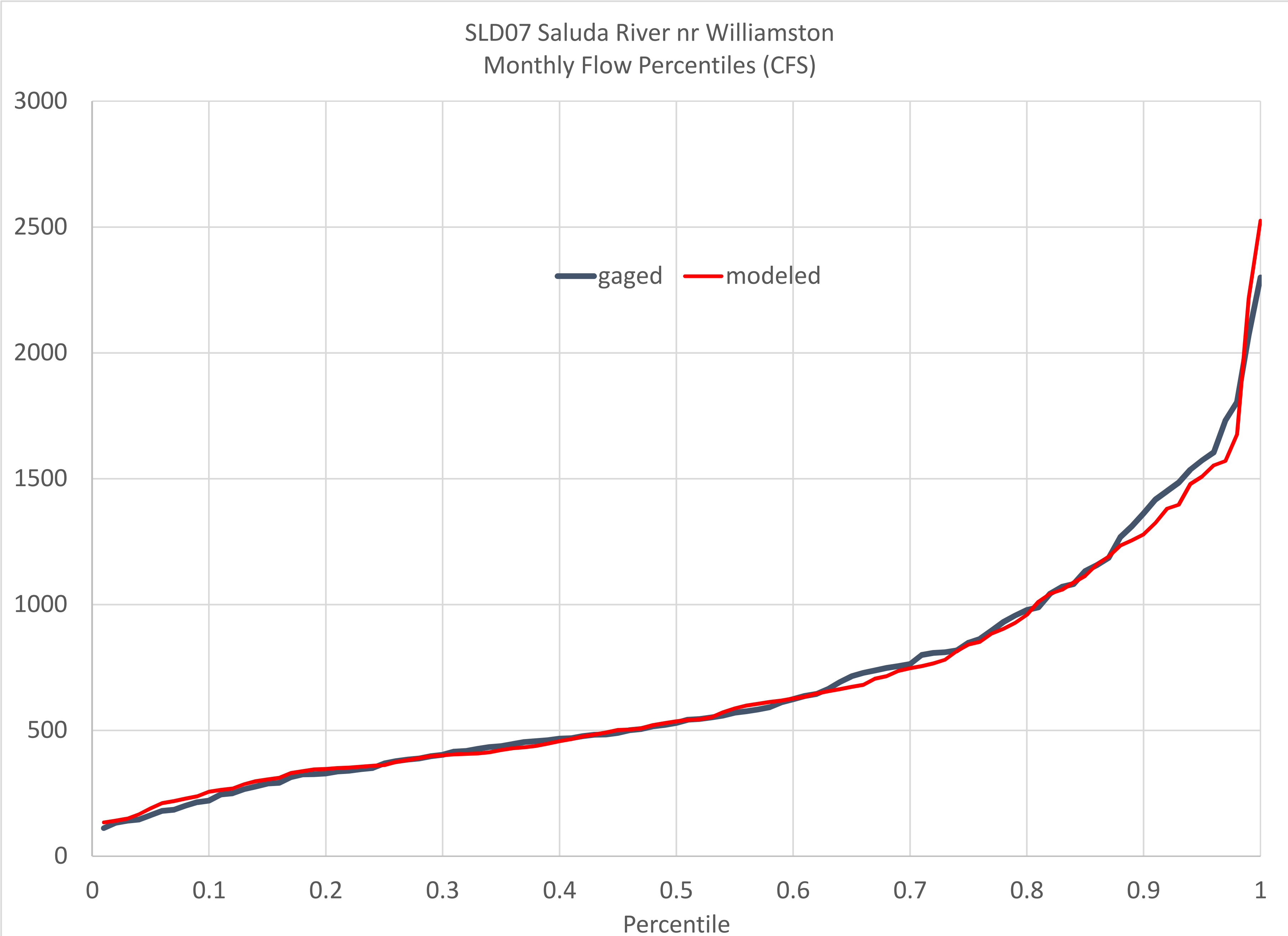

SLD04 Saluda River nr Greenville
Monthly Flow Percentiles (CFS)
2500
2000
1500
1000
500
0
gaged
modeled
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile


SLD07 Saluda nr Williamston (CFS)
gaged
modeled
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Aug-87
May-90
Jan-93
Oct-95
Jul-98
Apr-01
Jan-04
Oct-06
Jul-09
Apr-12
Dec-14



SLD 07 nr Williamston (CFS)
Annual Average Flow
gaged
modeled
1,600
1,400
1,200
1,000
800
600
400
200
0
1983
1988
1993
1998
2003
2008
2013


SLD 07 Saluda River nr Williamston
Monthly Mean Flow (CFS)
1,000
900
800
700
600
500
400
300
200
100
0
gaged
modeled
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec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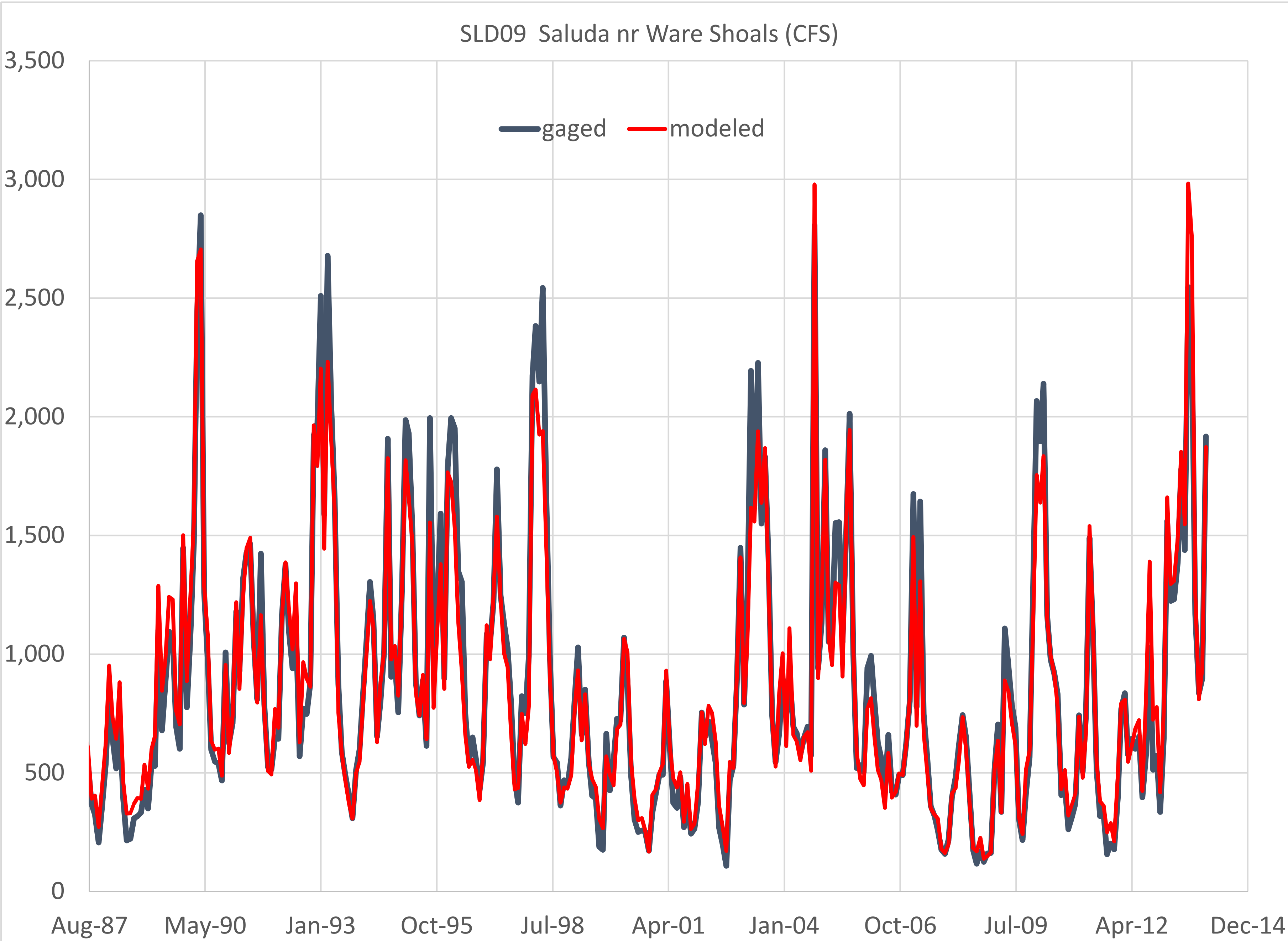
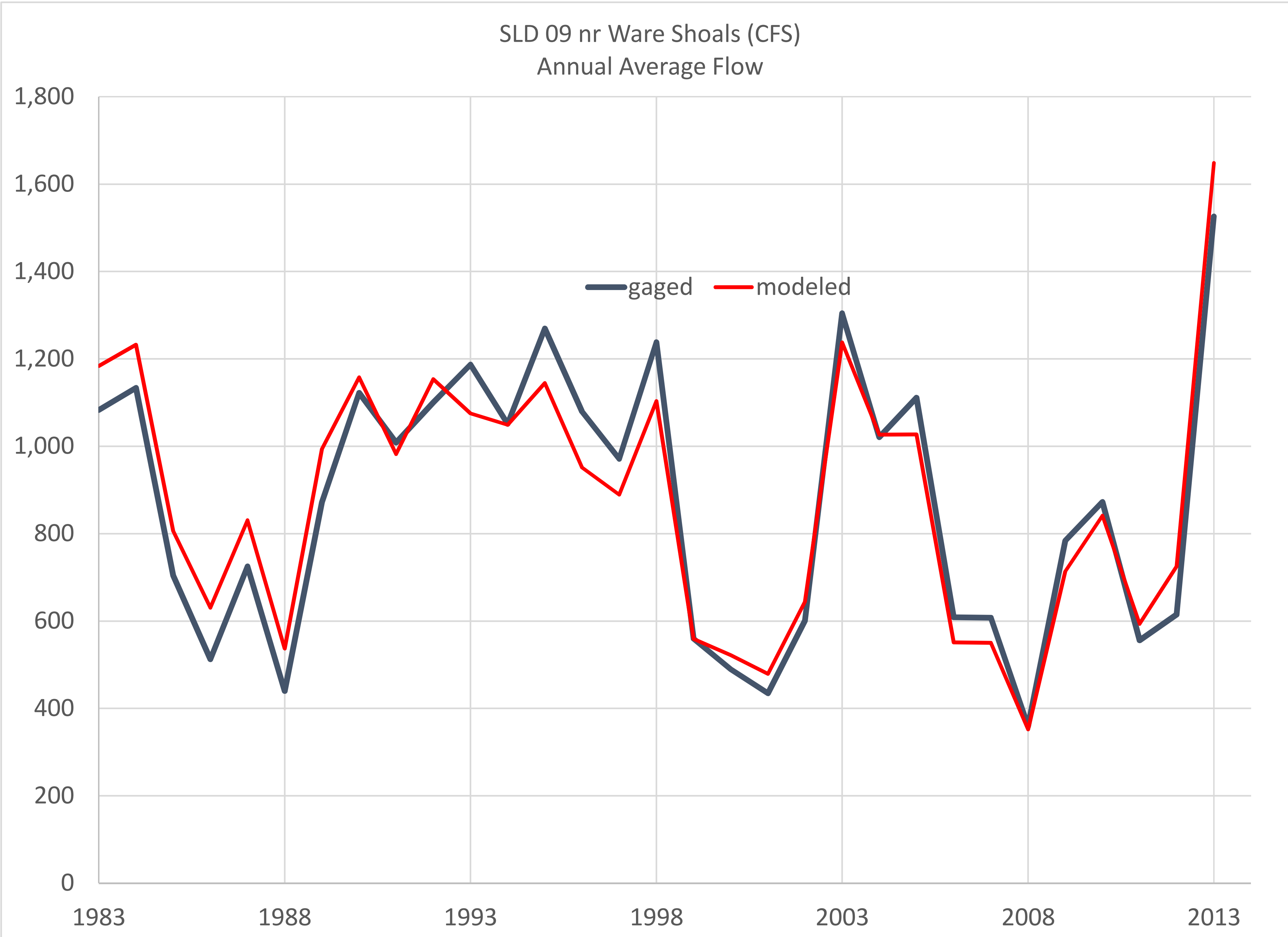
Monthly Flow Percentiles (CFS)
gaged
modeled
3000
2500
2000
1500
1000
500
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile


SLD09 Saluda nr Ware Shoals (CFS)
gaged
modeled
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Aug-87
May-90
Jan-93
Oct-95
Jul-98
Apr-01
Jan-04
Oct-06
Jul-09
Apr-12
Dec-14


SLD 09 nr Ware Shoals (CFS)
Annual Average Flow
gaged
modeled
1,800
1,600
1,400
1,200
1,000
800
600
400
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0
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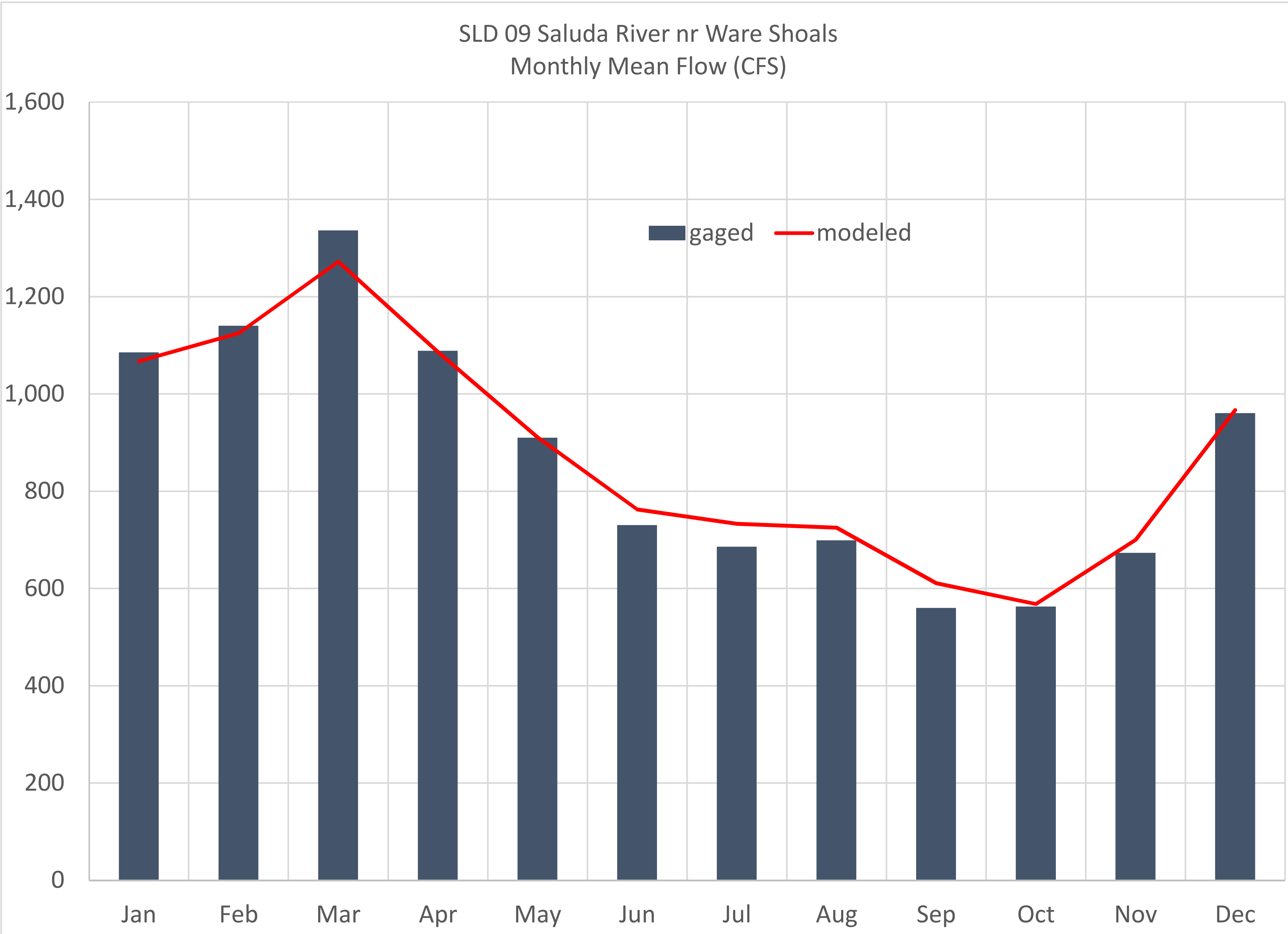
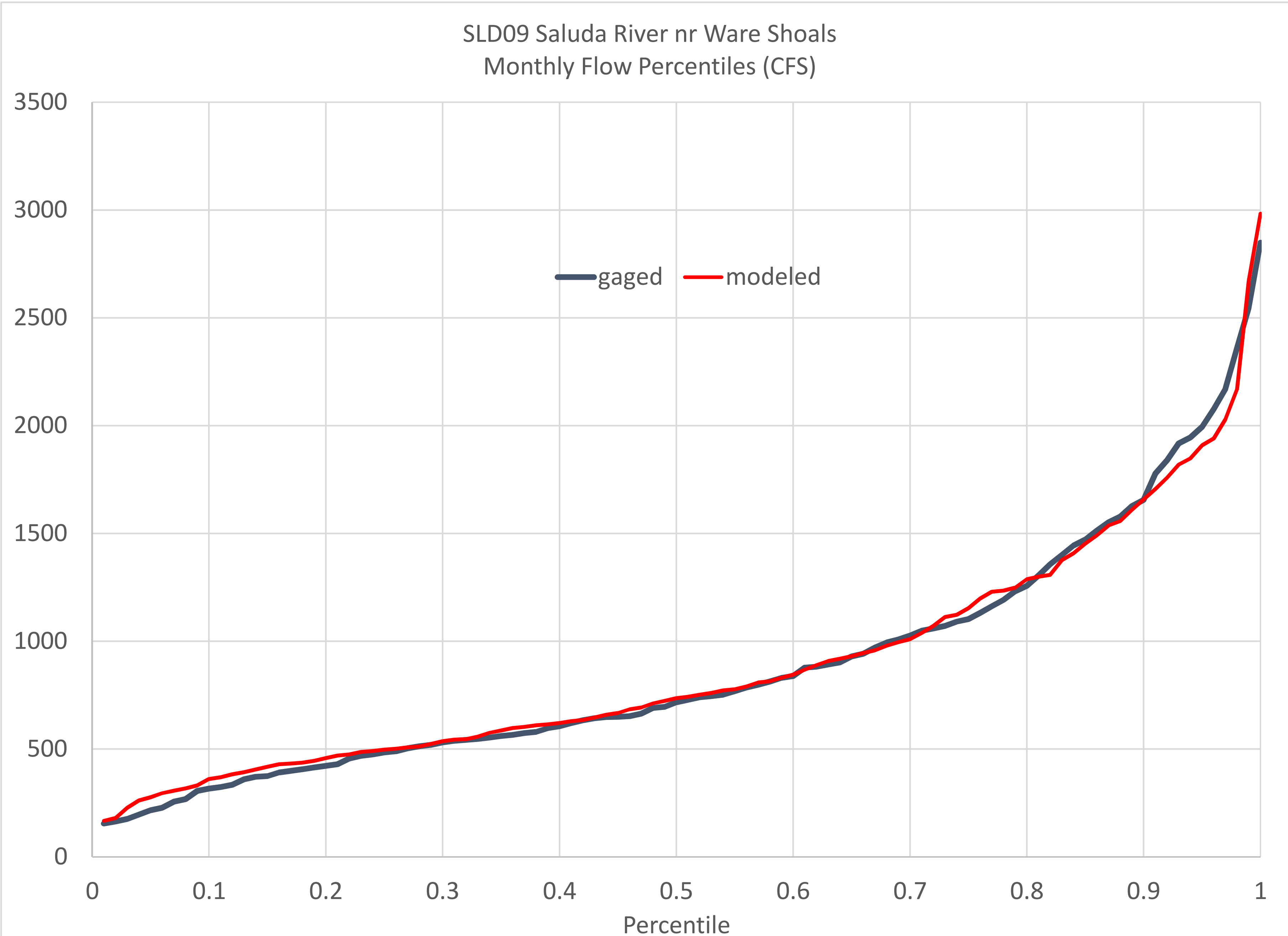
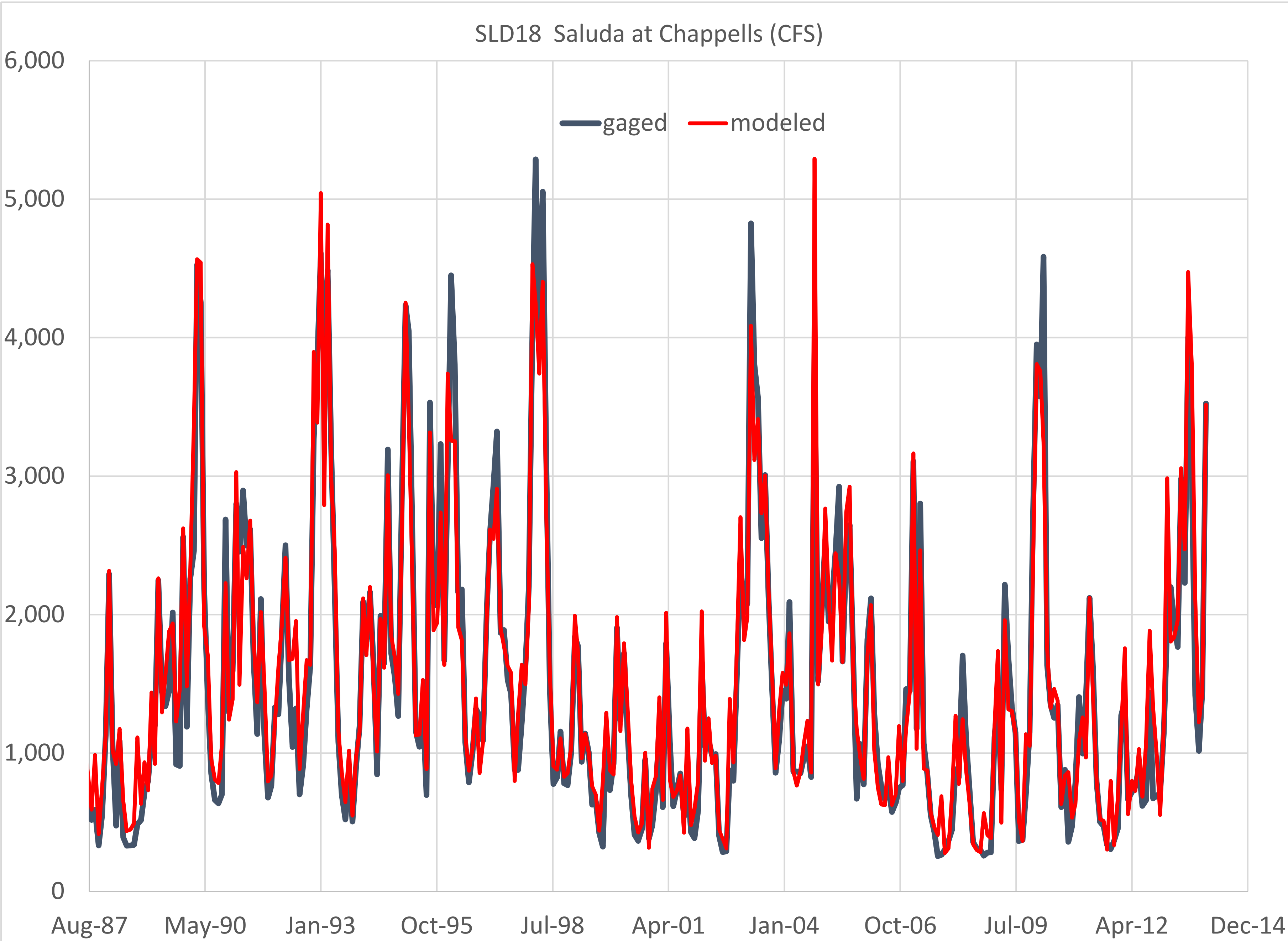
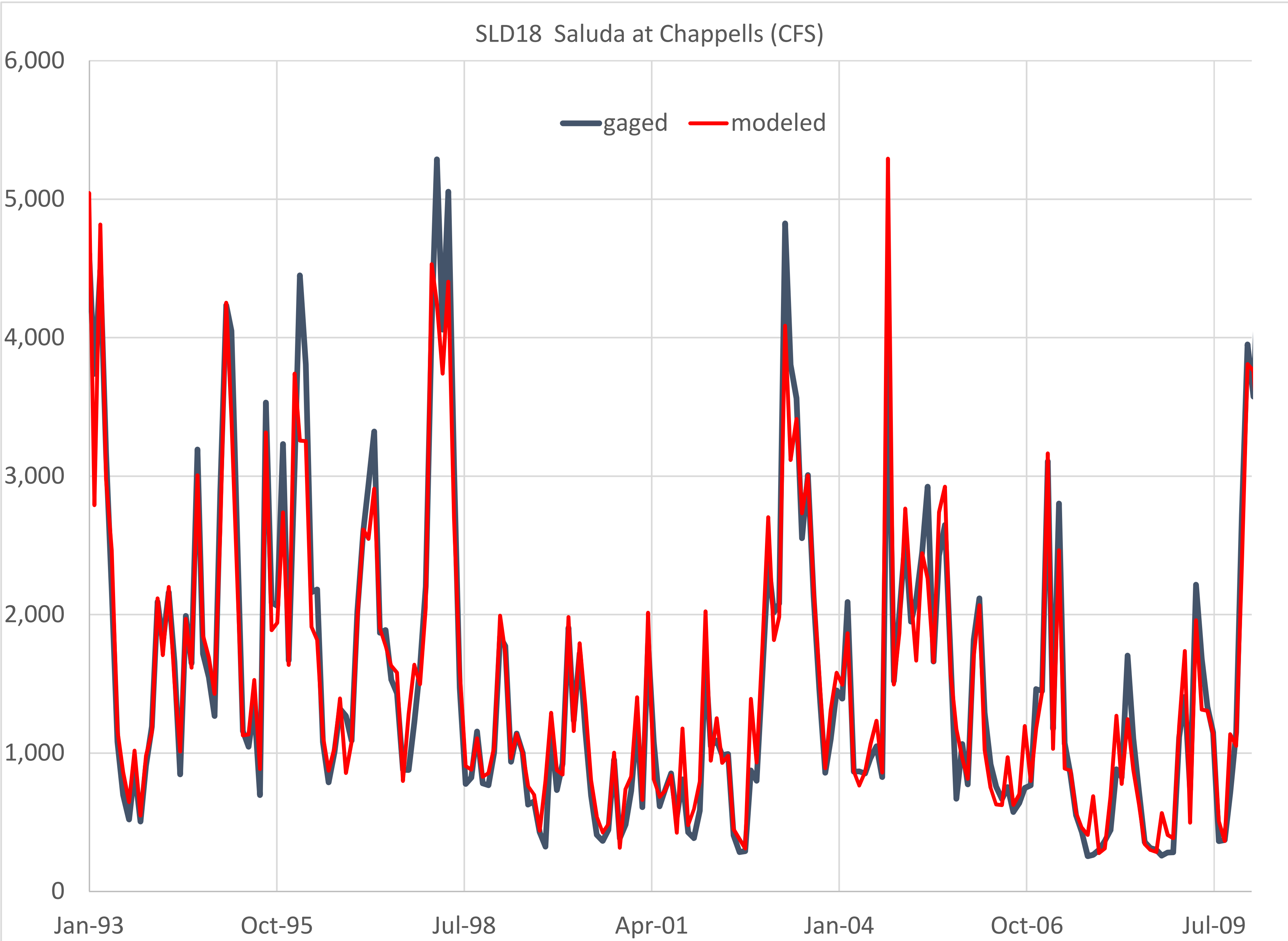
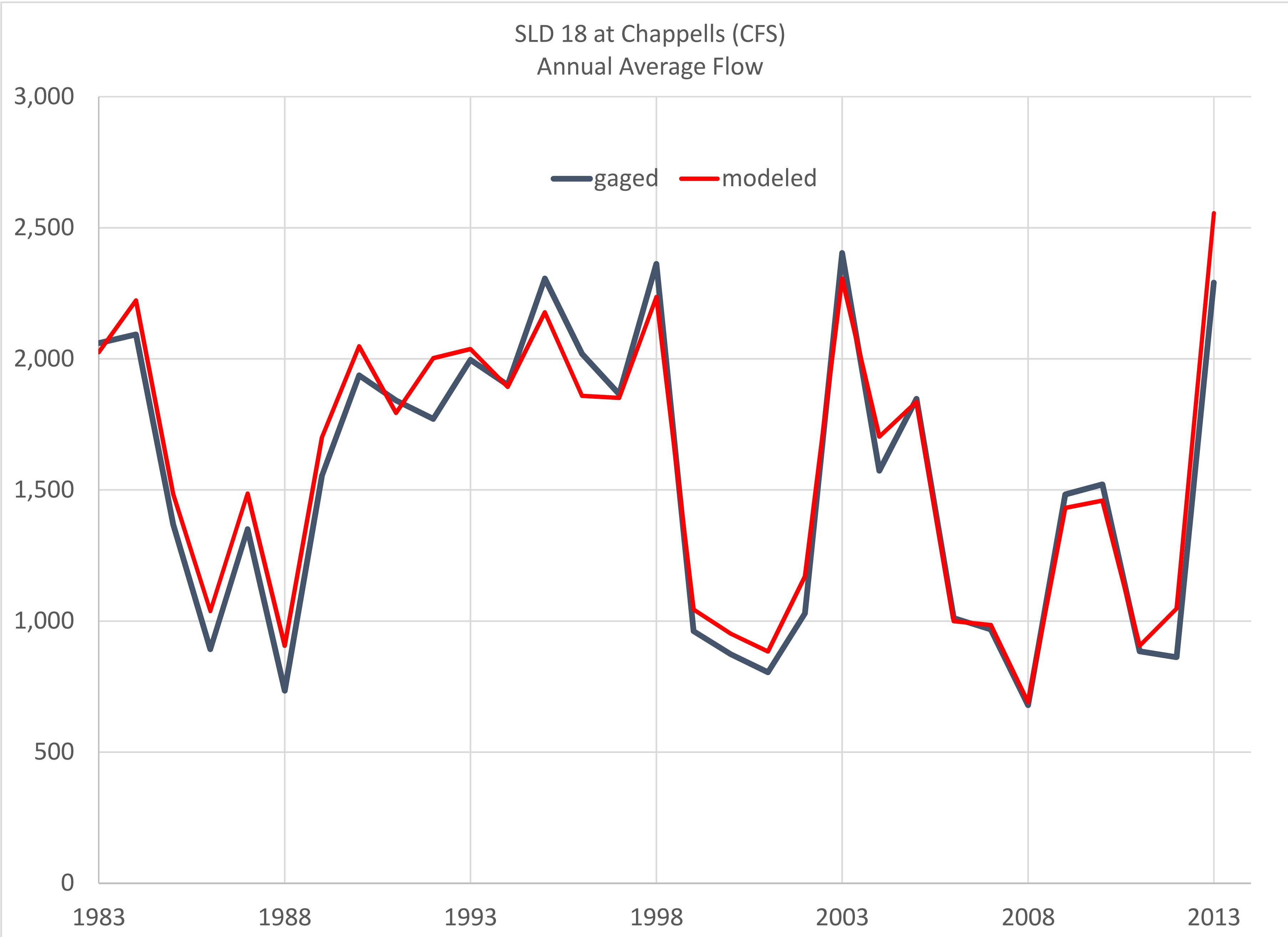
1988
1993
1998
2003
2008
2013


SLD 09 Saluda River nr Ware Shoals
Monthly Mean Flow (CFS)
gaged
modeled
1,600
1,400
1,200
1,000
800
600
400
200
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


SLD09 Saluda River nr Ware Shoals
Monthly Flow Percentiles (CFS)
gaged
modeled
3500
3000
2500
2000
1500
1000
500
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile


SLD18 Saluda at Chappells (CFS)
gaged
modeled
6,000
5,000
4,000
3,000
2,000
1,000
0
Aug-87
May-90
Jan-93
Oct-95
Jul-98
Apr-01
Jan-04
Oct-06
Jul-09
Apr-12
Dec-14


SLD18 Saluda at Chappells (CFS)
gaged
modeled
6,000
5,000
4,000
3,000
2,000
1,000
0
Jan-93
Oct-95
Jul-98
Apr-01
Jan-04
Oct-06
Jul-09



SLD 18 at Chappells (CFS)
Annual Average Flow
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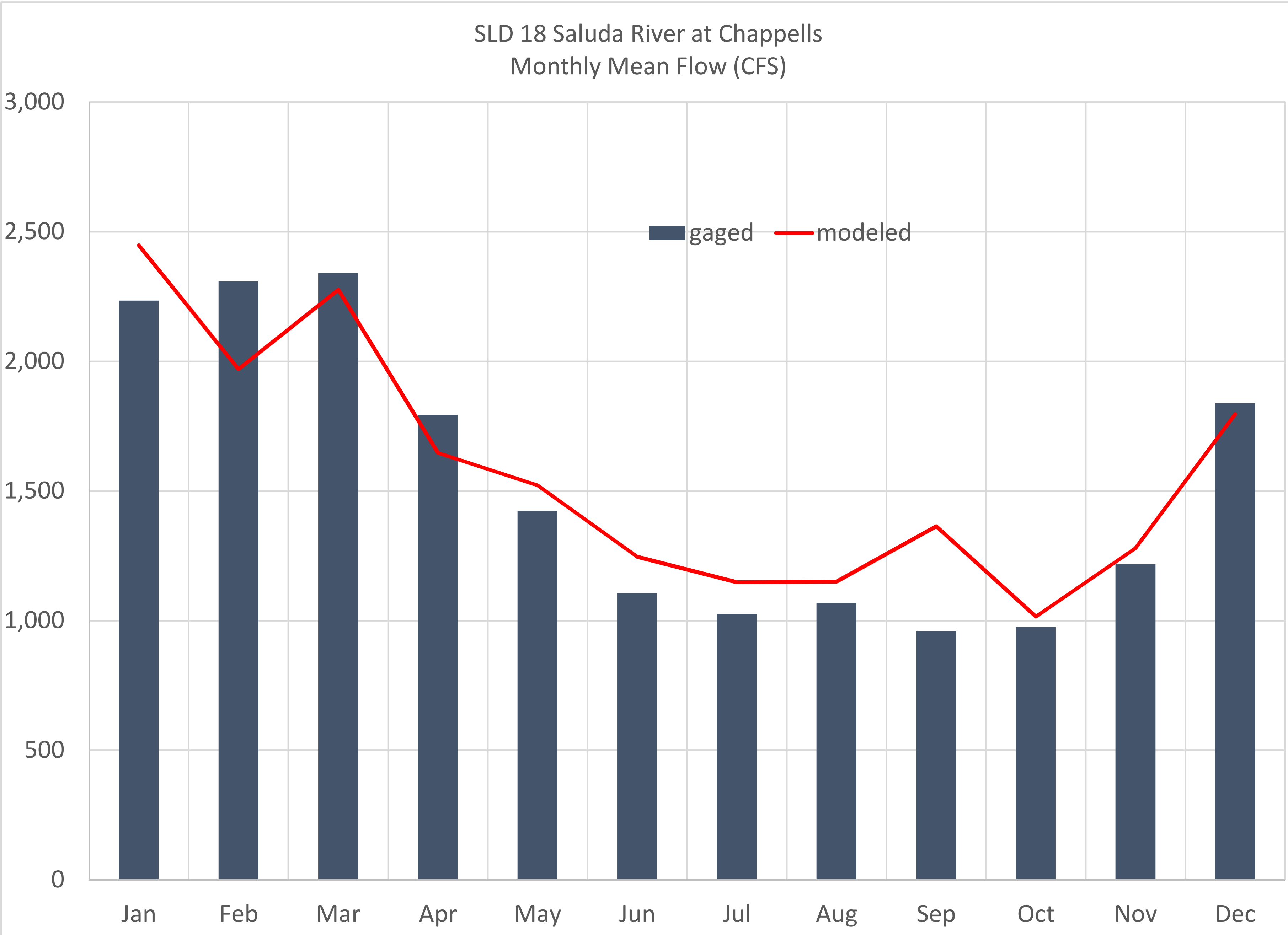
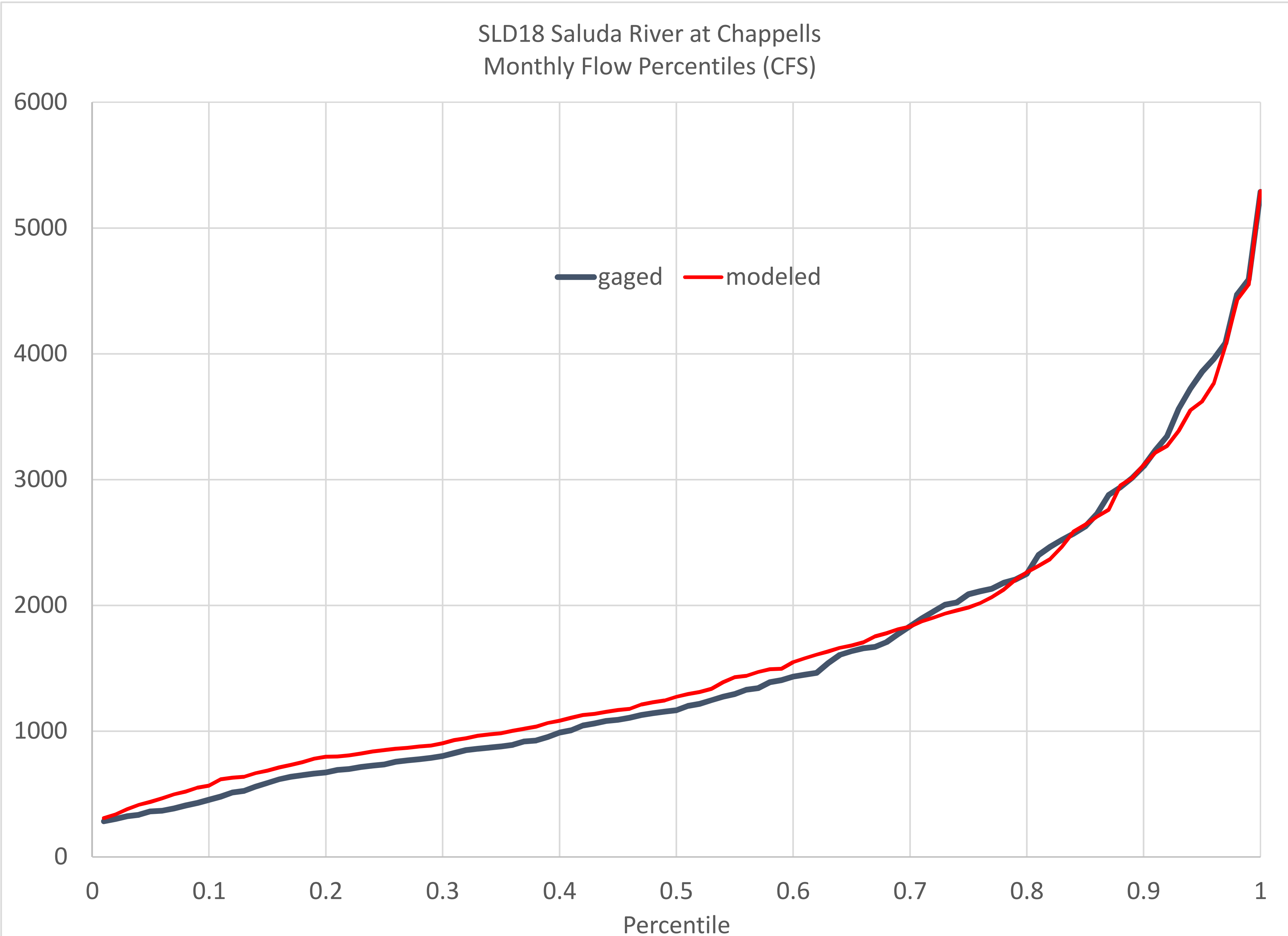
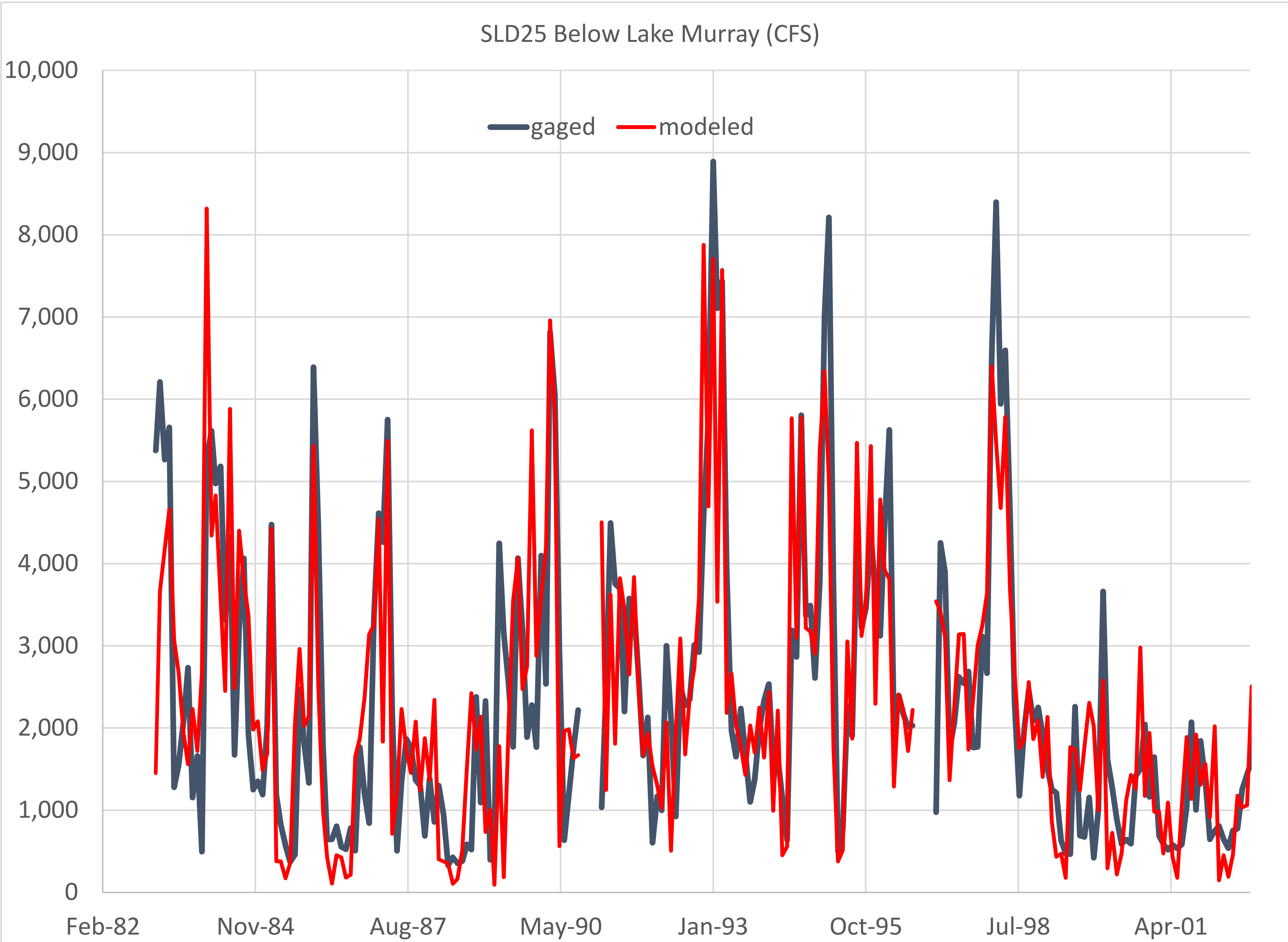
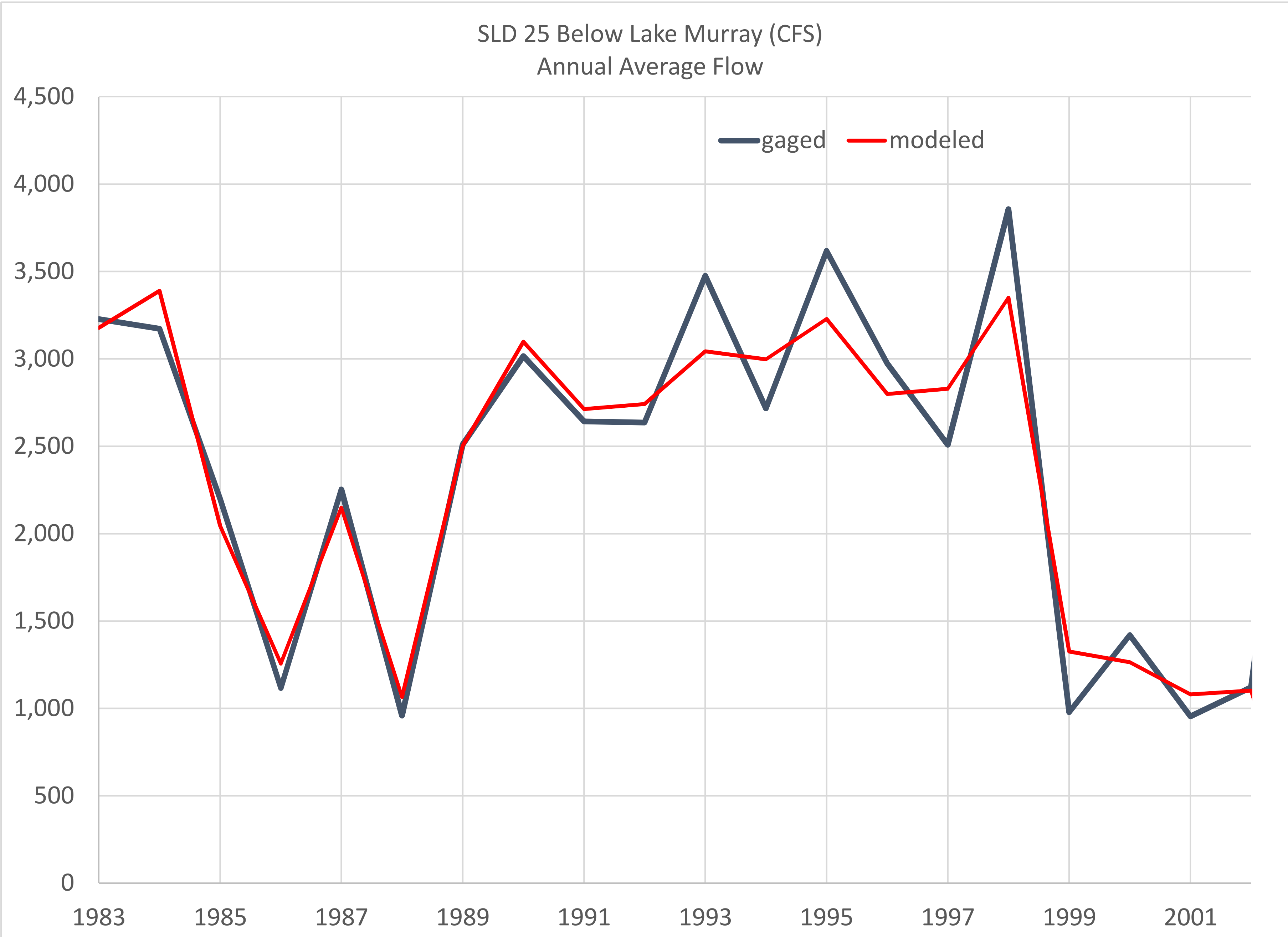
1,000
500
0
gaged
modeled
1983
1988
1993
1998
2003
2008
2013

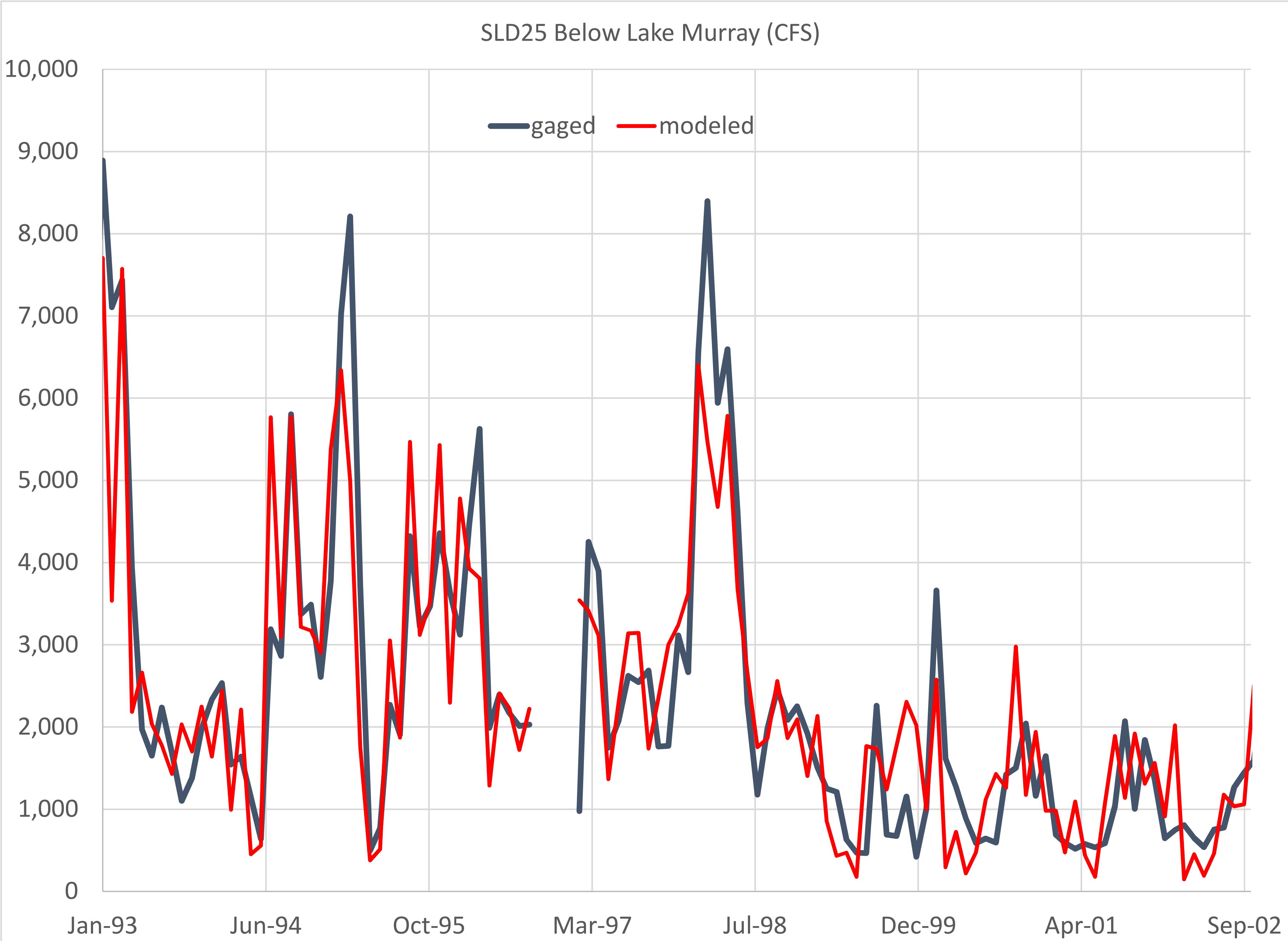

SLD 18 Saluda River at Chappells
Monthly Mean Flow (CFS)
gaged
modeled
3,000
2,500
2,000
1,500
1,000
500
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

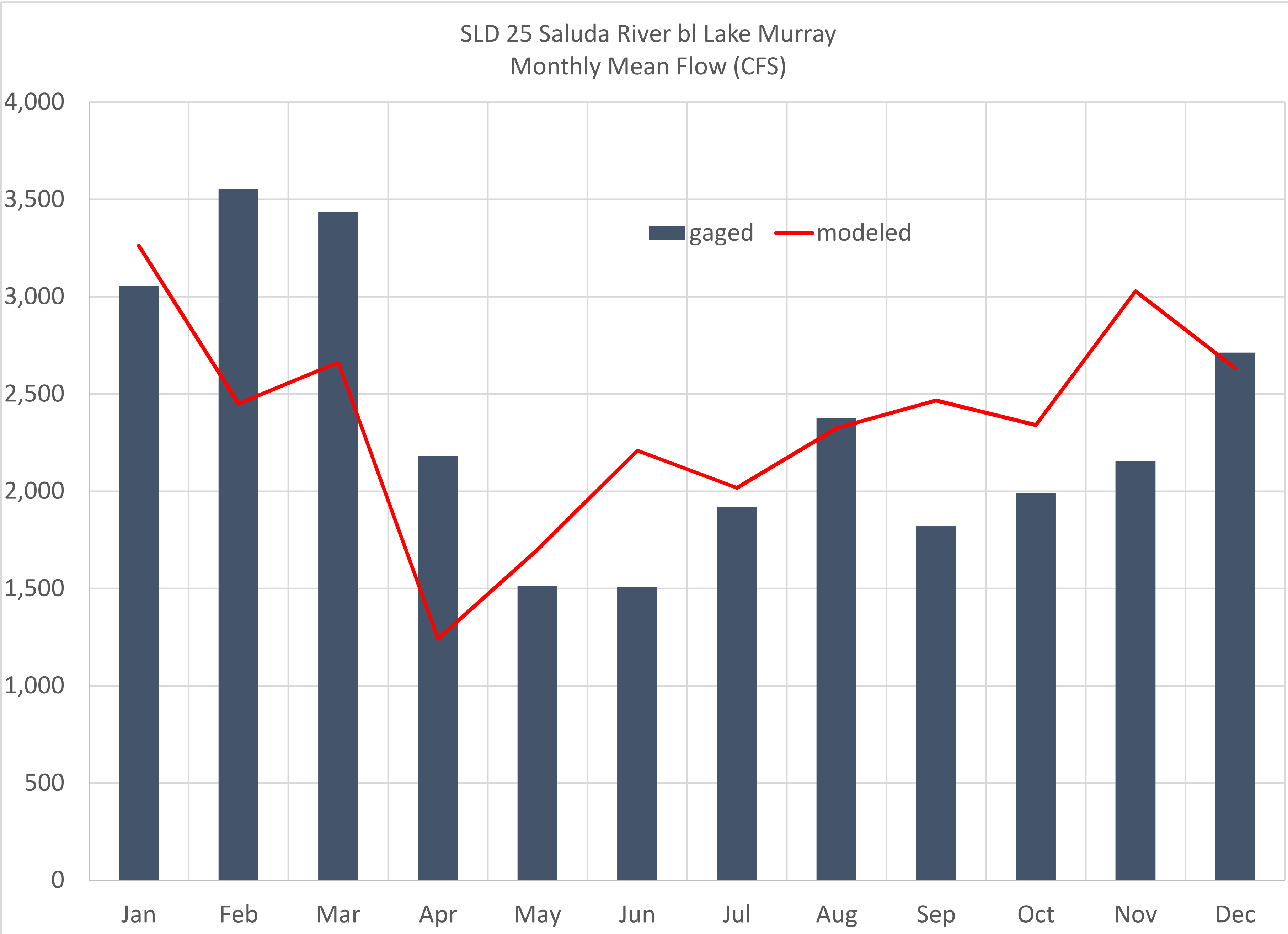

SLD18 Saluda River at Chappells
Monthly Flow Percentiles (CFS)
6000
5000
4000
3000
2000
1000
0
gaged
modeled
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile



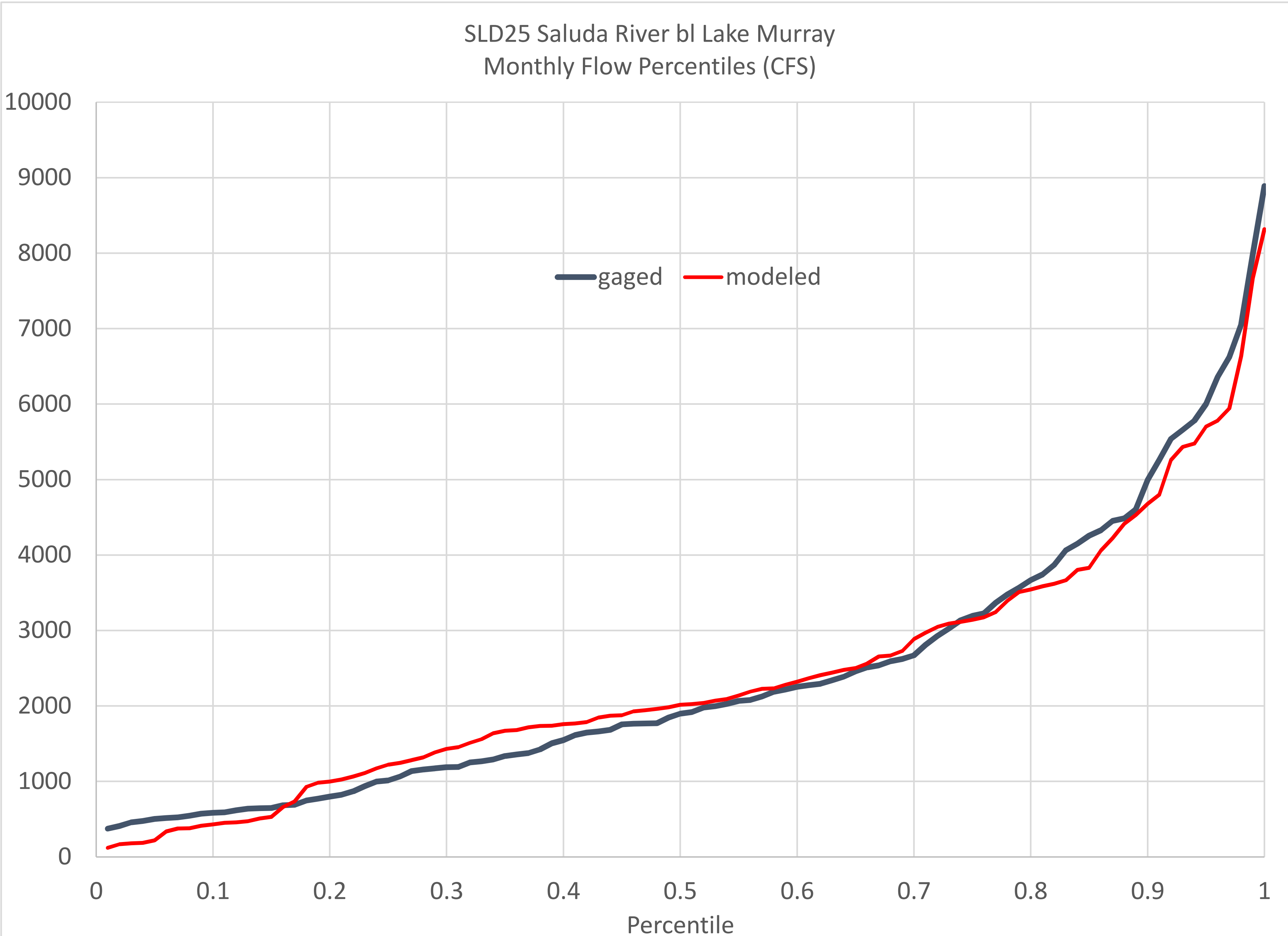
SLD25 Below Lake Murray (CFS)
gaged
modeled
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Feb-82
Nov-84
Aug-87
May-90
Jan-93
Oct-95
Jul-98
Apr-01


SLD 25 Below Lake Murray (CFS)
Annual Average Flow
gaged
modeled
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001

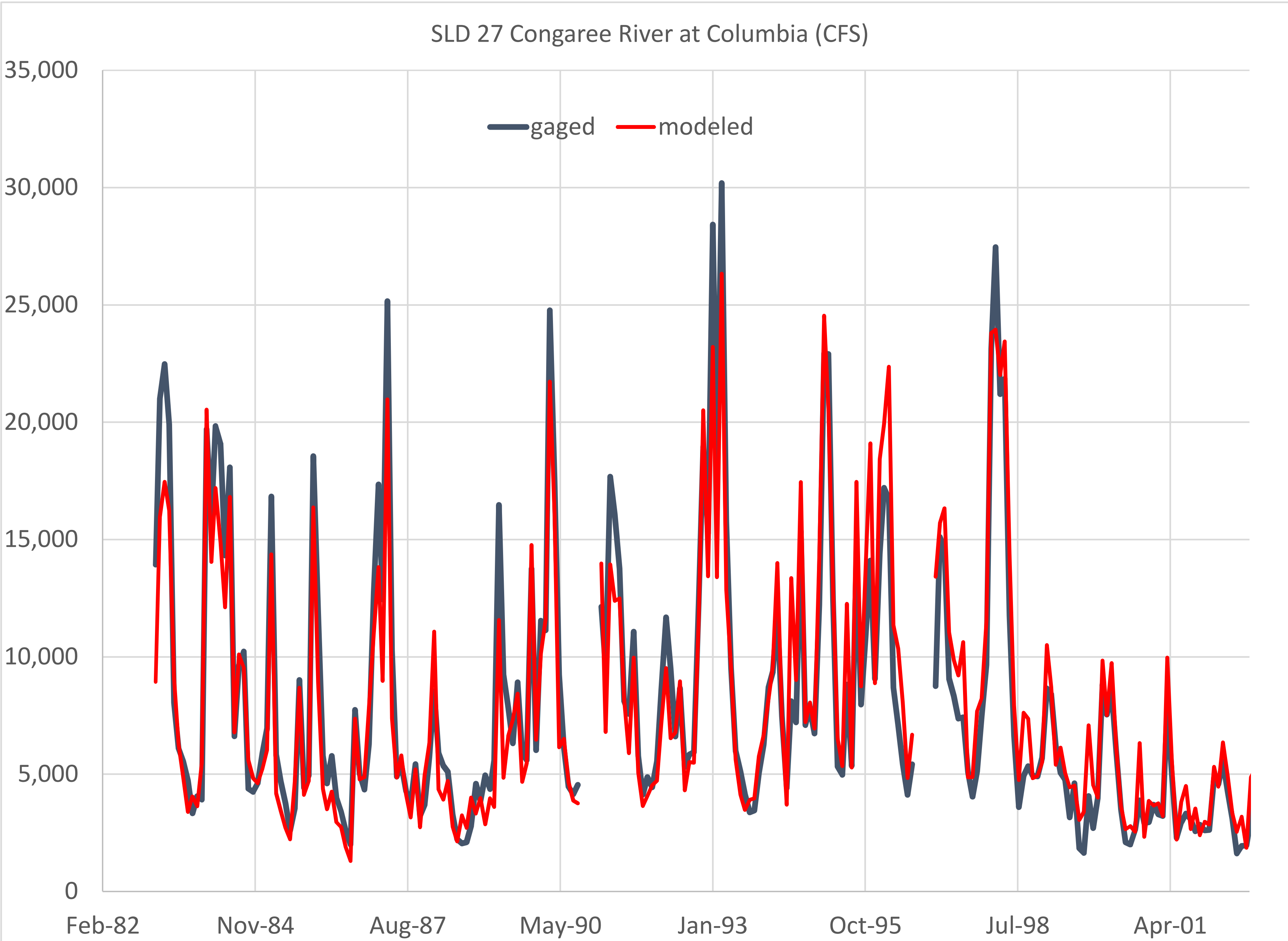

SLD25 Below Lake Murray (CFS)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
gaged
modeled
Jan-93
Jun-94
Oct-95
Mar-97
Jul-98
Dec-99
Apr-01
Sep-02

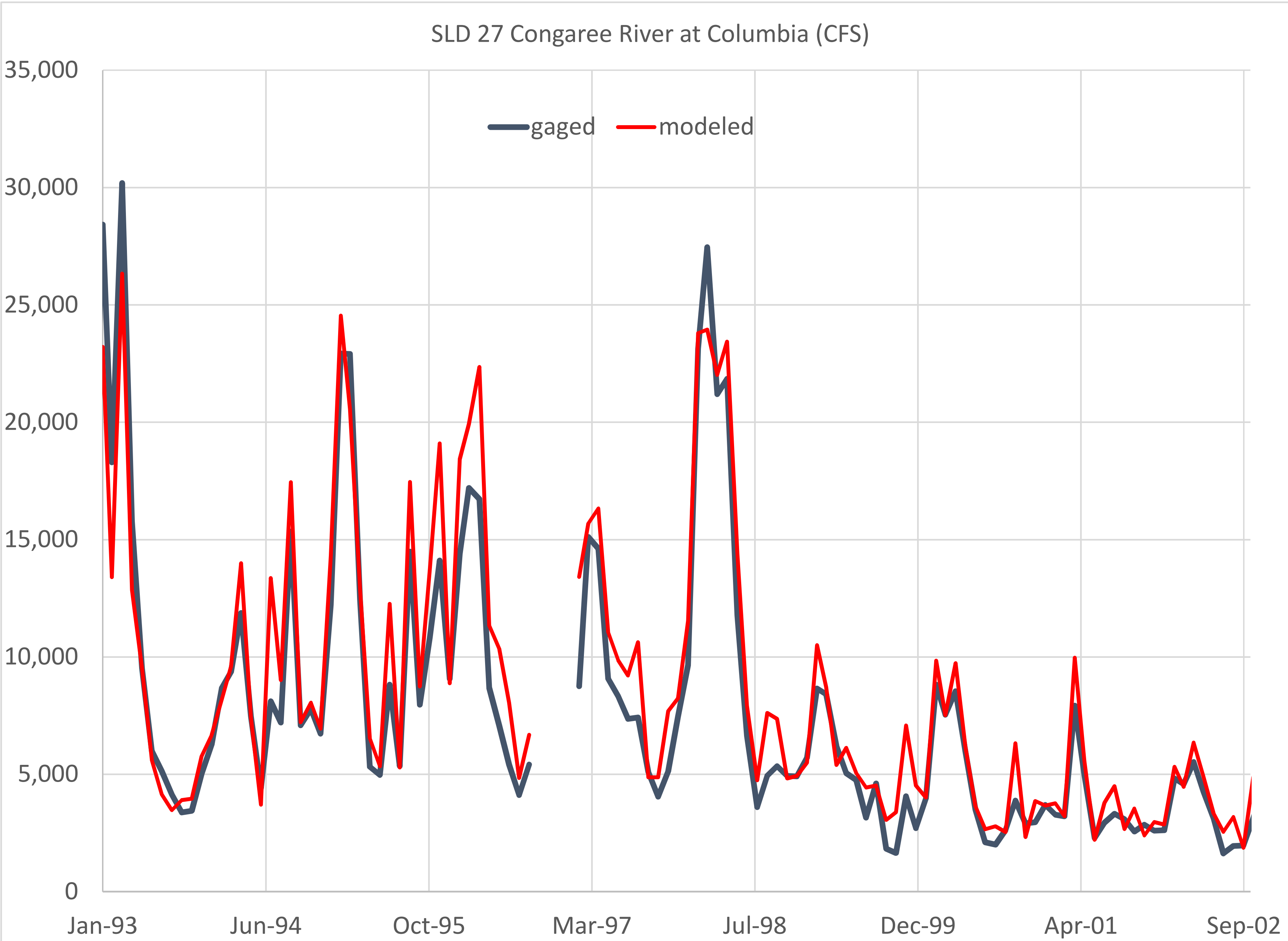


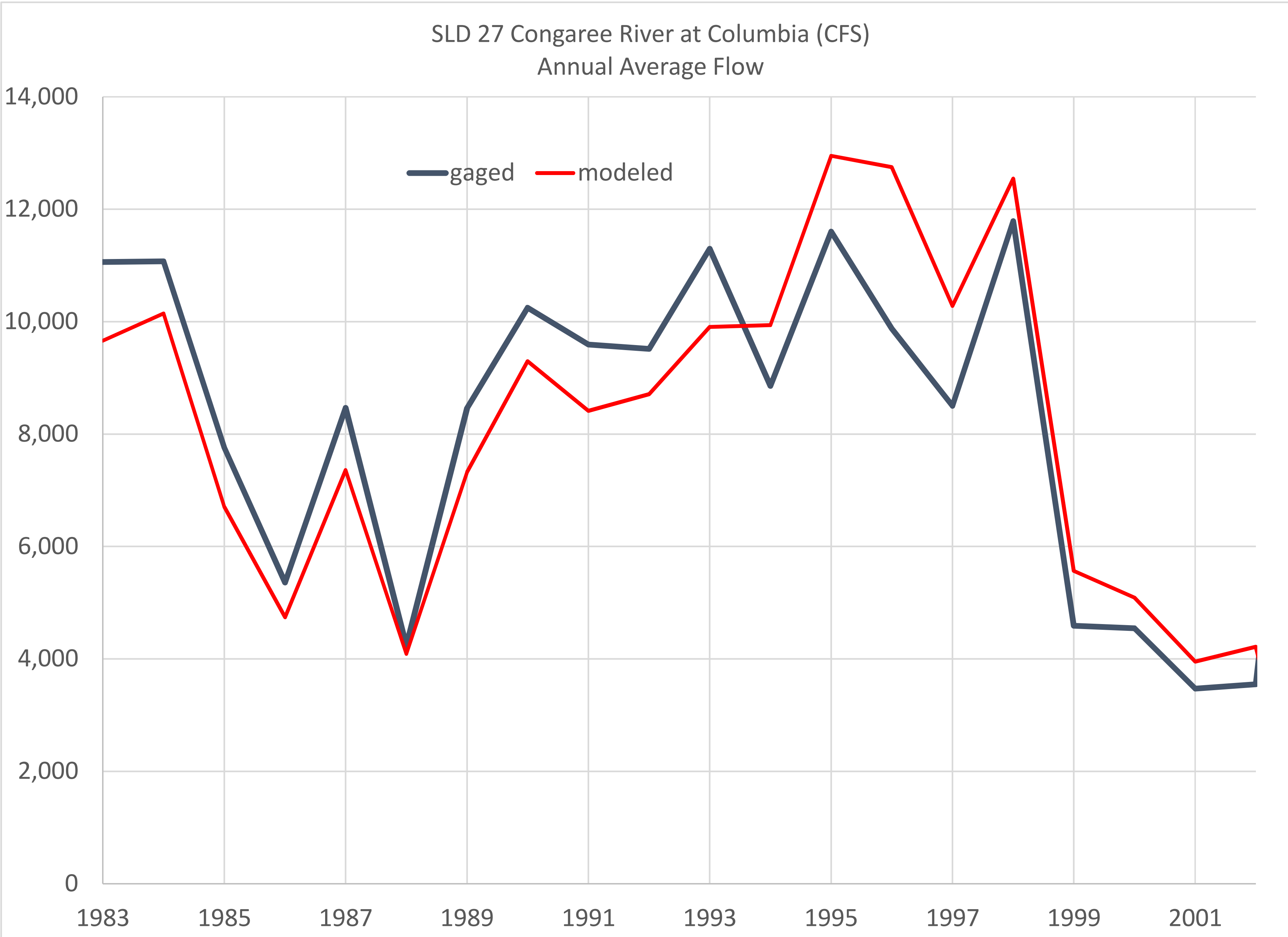
SLD 25 Saluda River bl Lake Murray
Monthly Mean Flow (CFS)
gaged
modeled
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

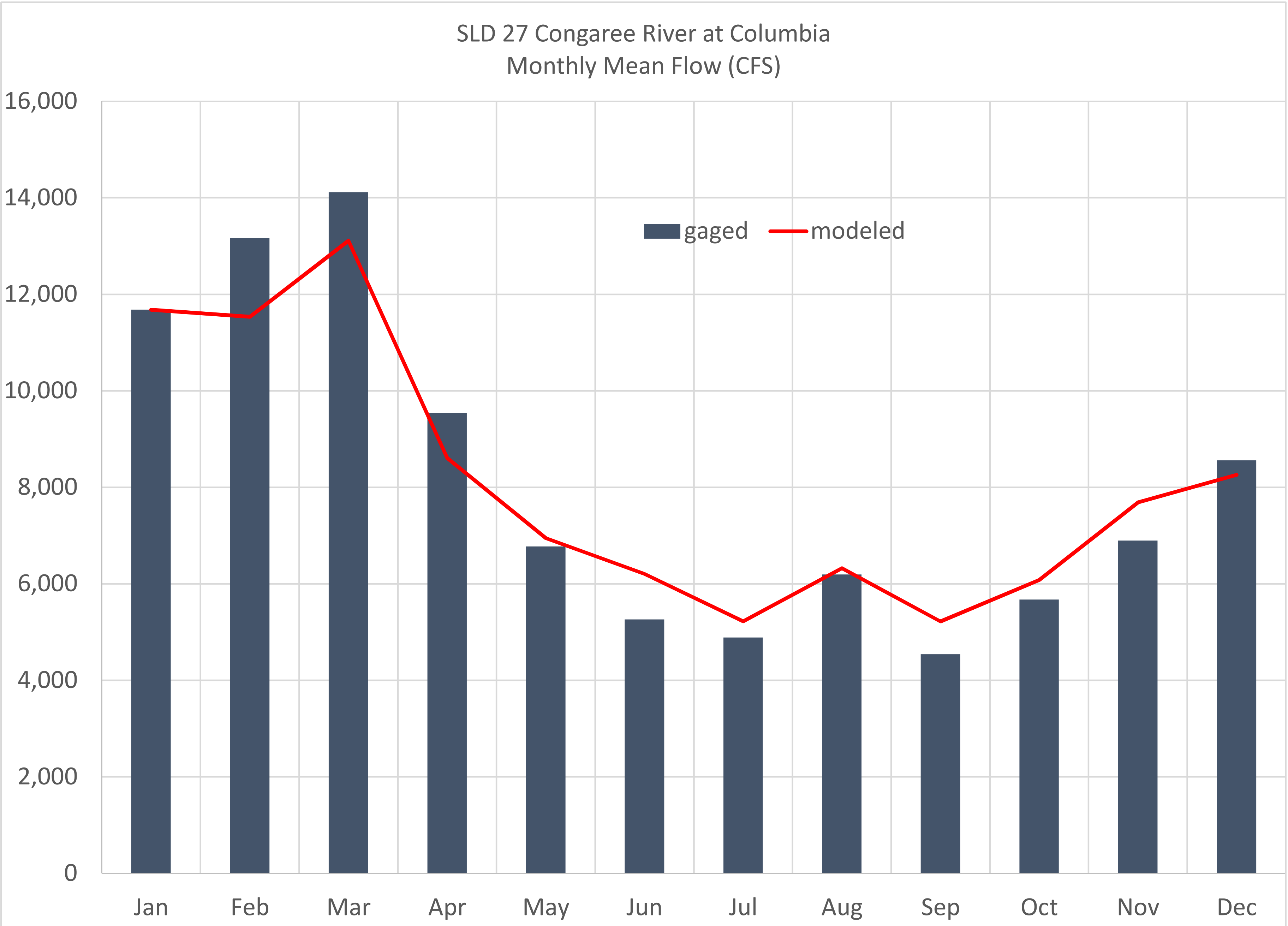


SLD25 Saluda River bl Lake Murray
Monthly Flow Percentiles (CFS)
gaged
modeled
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

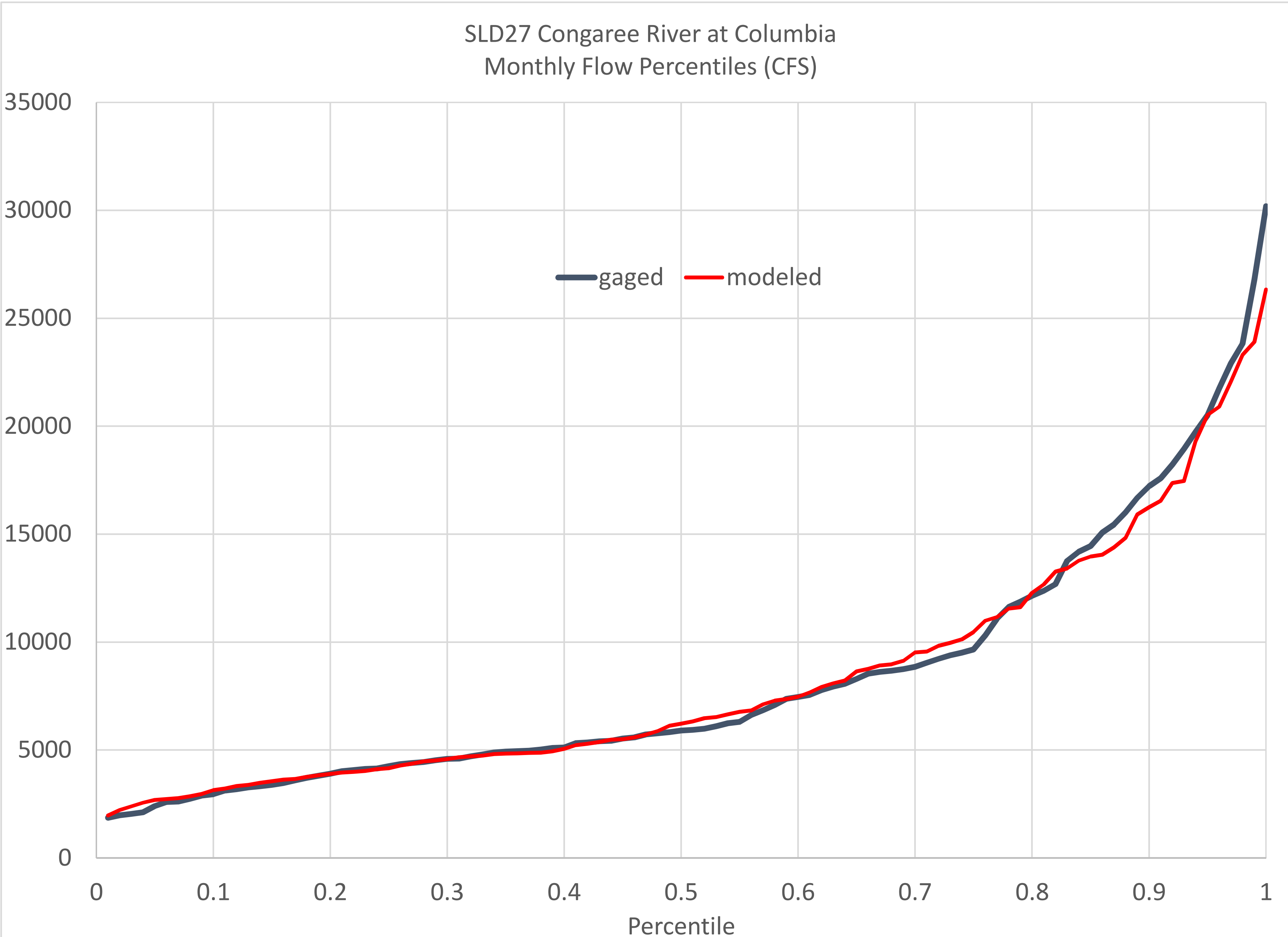

SLD 27 Congaree River at Columbia (CFS)
gaged
modeled
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
Feb-82
Nov-84
Aug-87
May-90
Jan-93
Oct-95
Jul-98
Apr-01

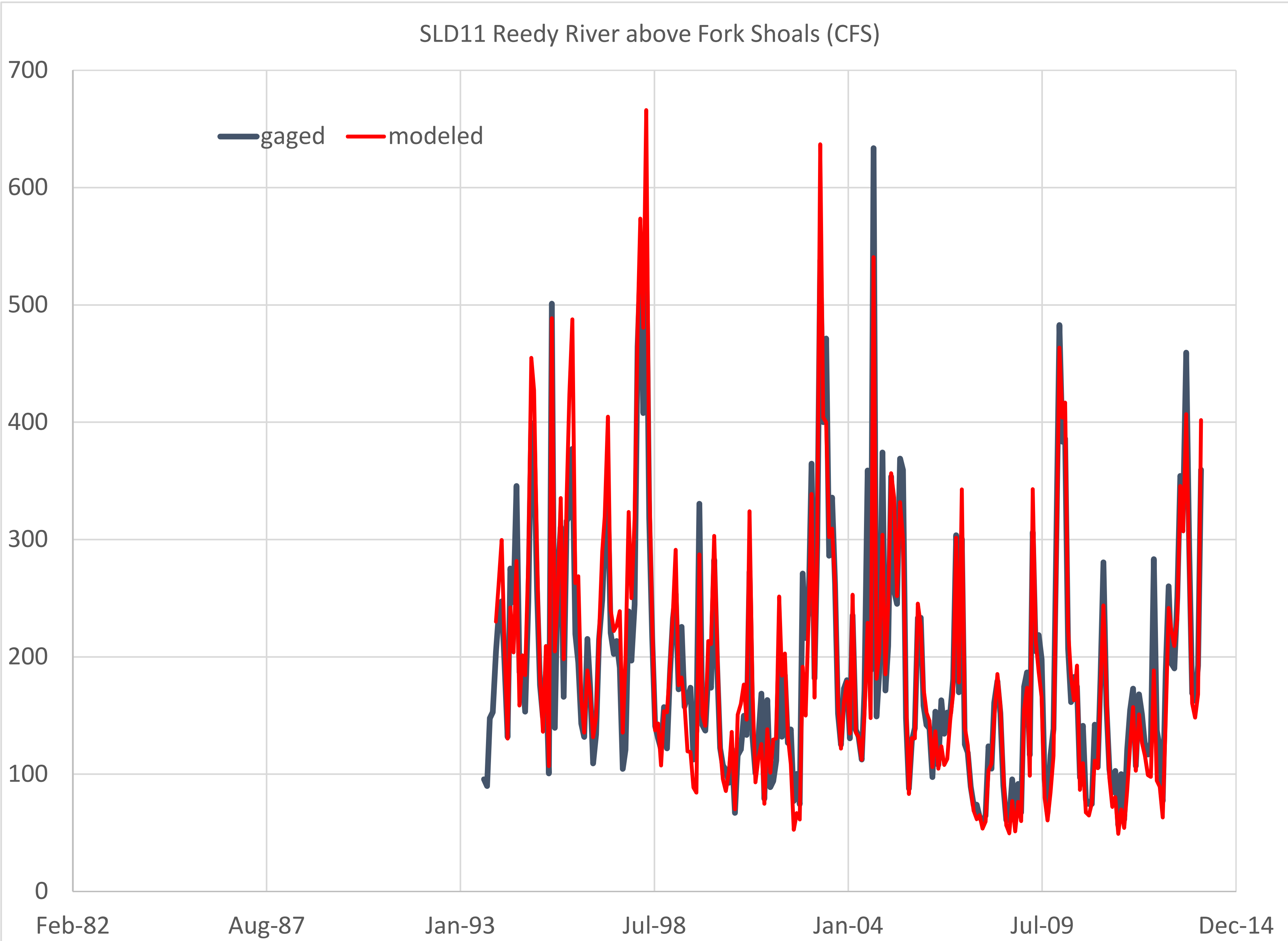

SLD 27 Congaree River at Columbia (CFS)
gaged
modeled
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
Jan-93
Jun-94
Oct-95
Mar-97
Jul-98
Dec-99
Apr-01
Sep-02


SLD 27 Congaree River at Columbia (CFS)
Annual Average Flow
gaged
modeled
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001

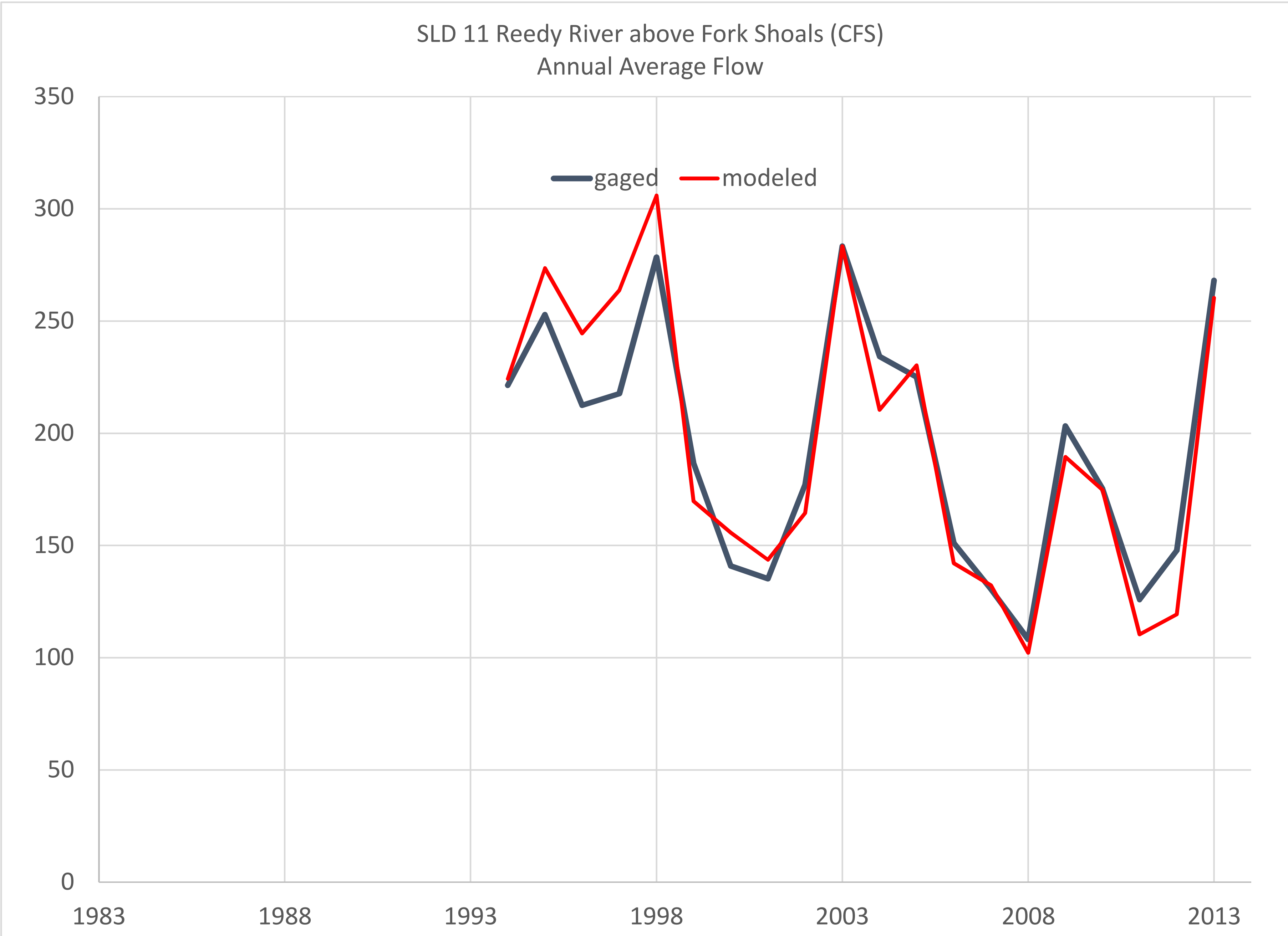


SLD 27 Congaree River at Columbia
Monthly Mean Flow (CFS)
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
gaged
modeled
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

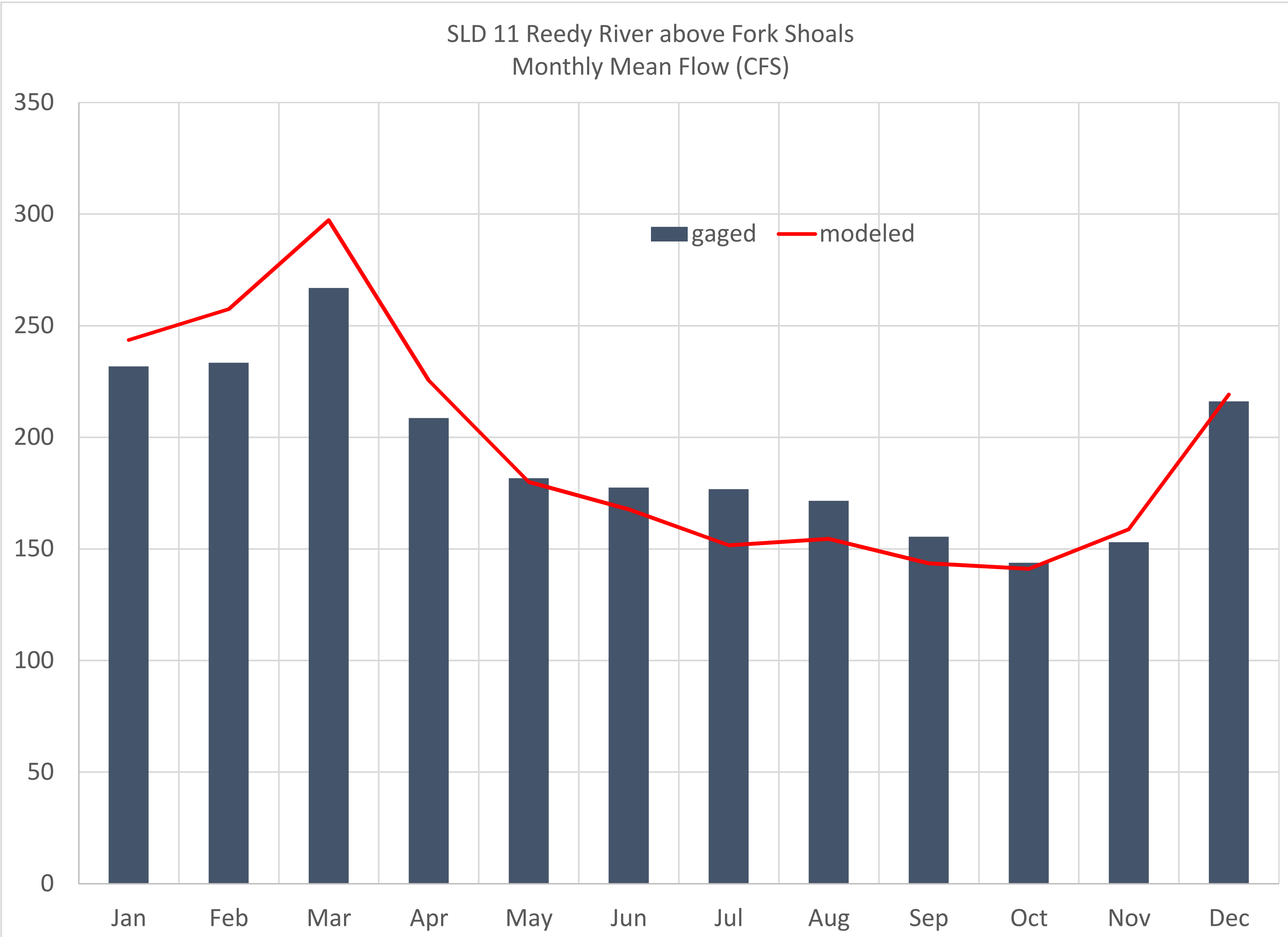

SLD27 Congaree River at Columbia
Monthly Flow Percentiles (CFS)
35000
30000
25000
20000
15000
10000
5000
0
gaged
modeled
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile



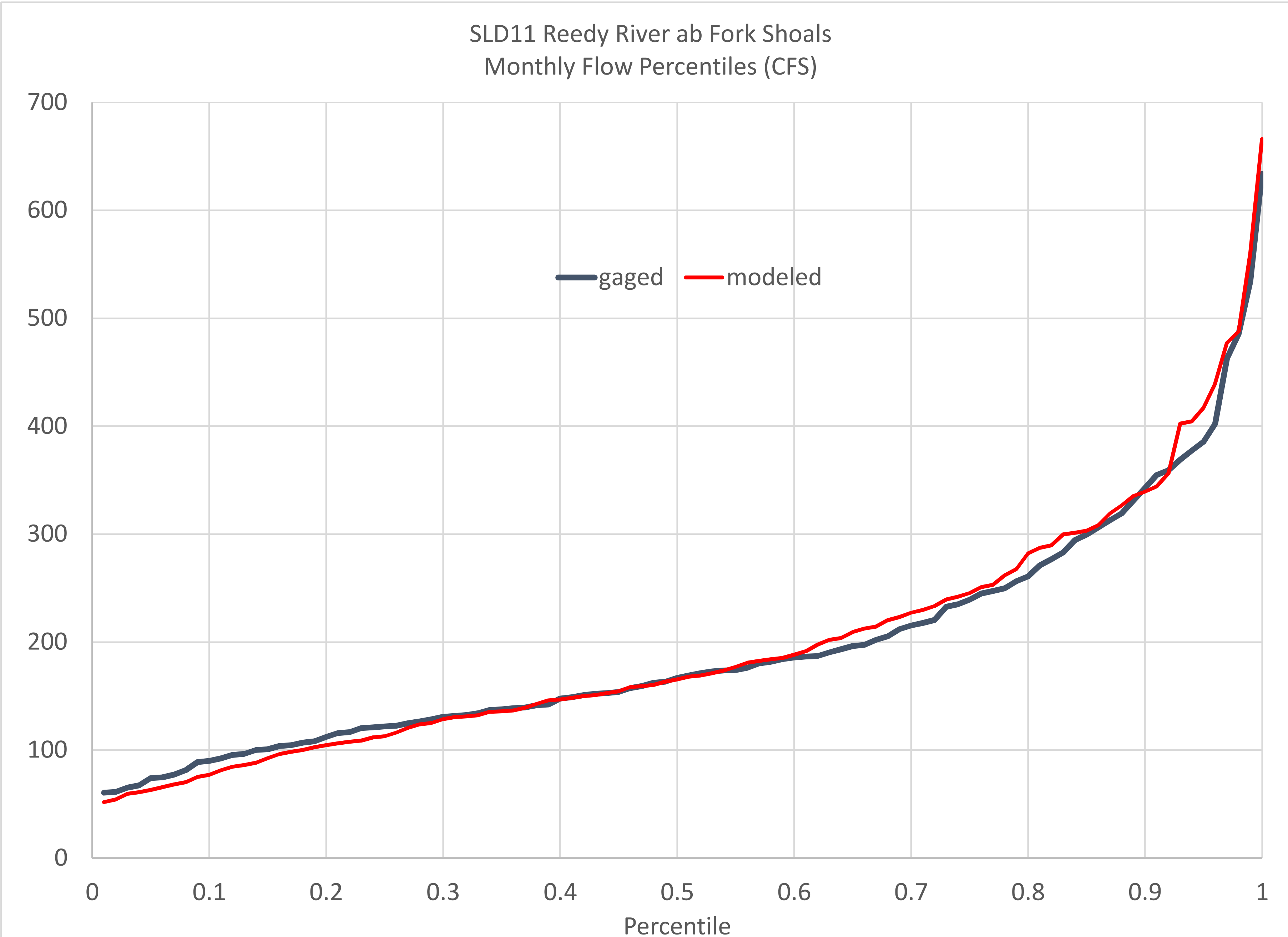
SLD11 Reedy River above Fork Shoals (CFS)
gaged
modeled
700
600
500
400
300
200
100
0
Feb-82
Aug-87
Jan-93
Jul-98
Jan-04
Jul-09
Dec-14

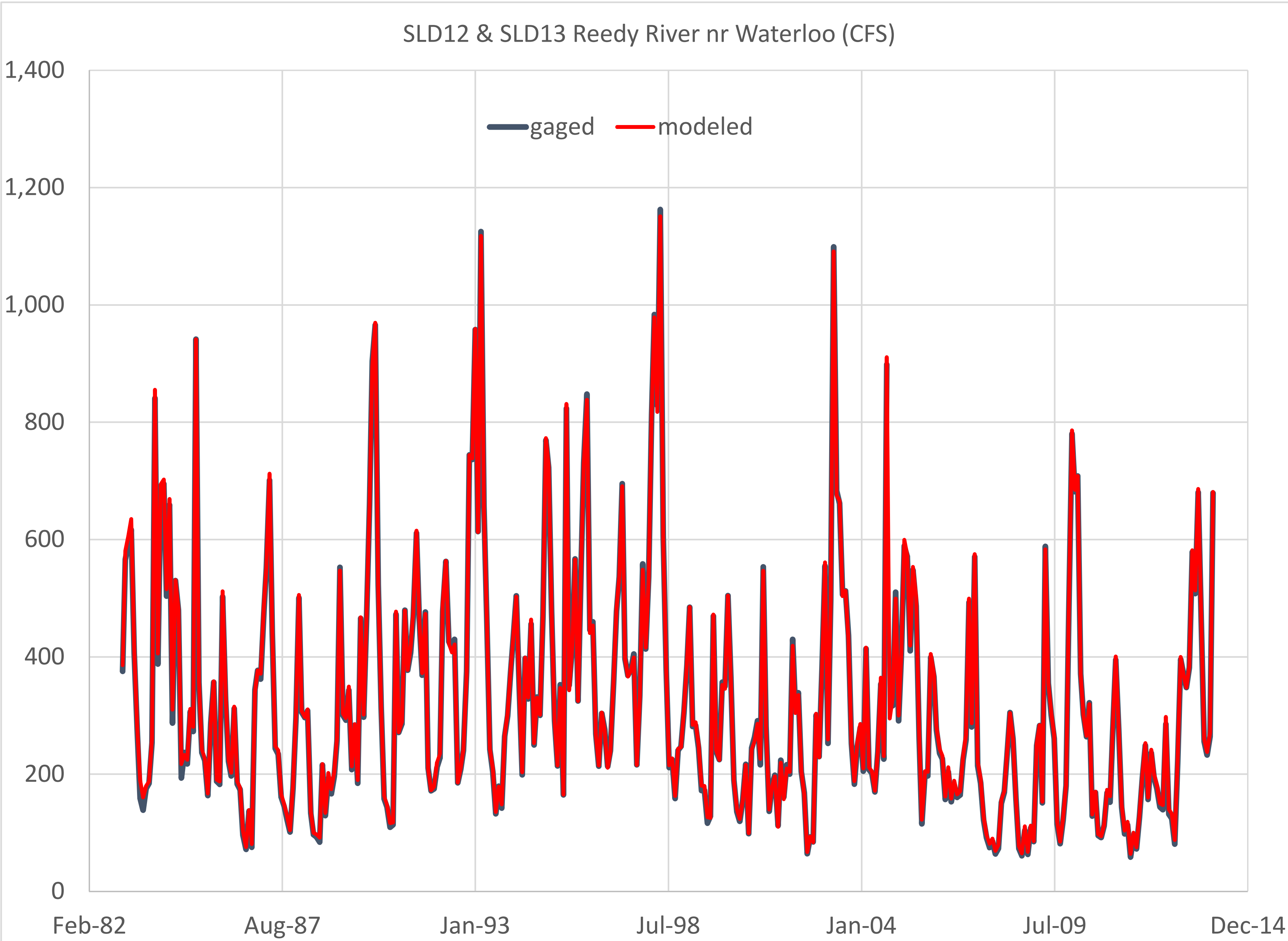


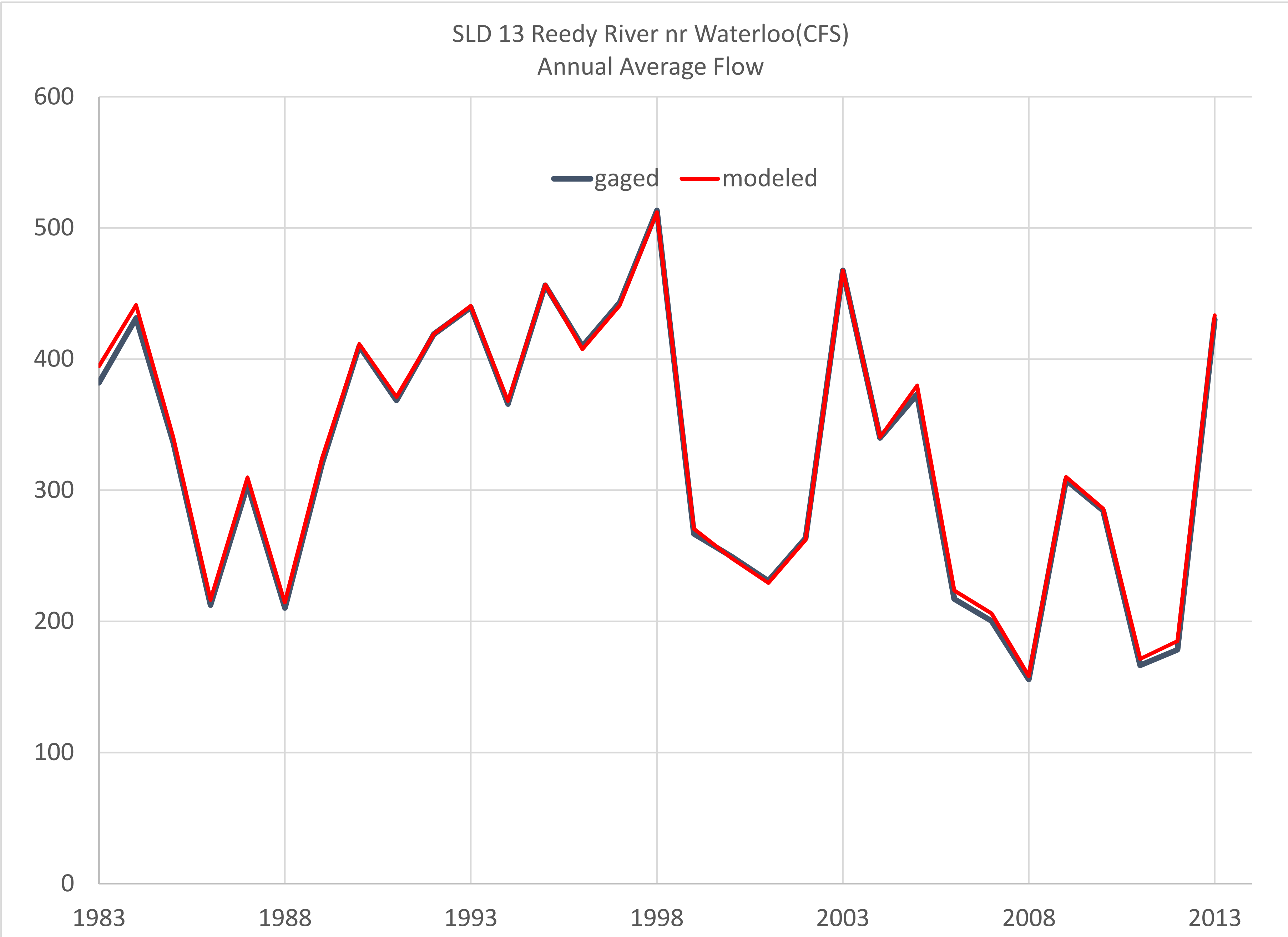
SLD 11 Reedy River above Fork Shoals (CFS)
Annual Average Flow
gaged
modeled
350
300
250
200
150
100
50
0
1983
1988
1993
1998
2003
2008
2013



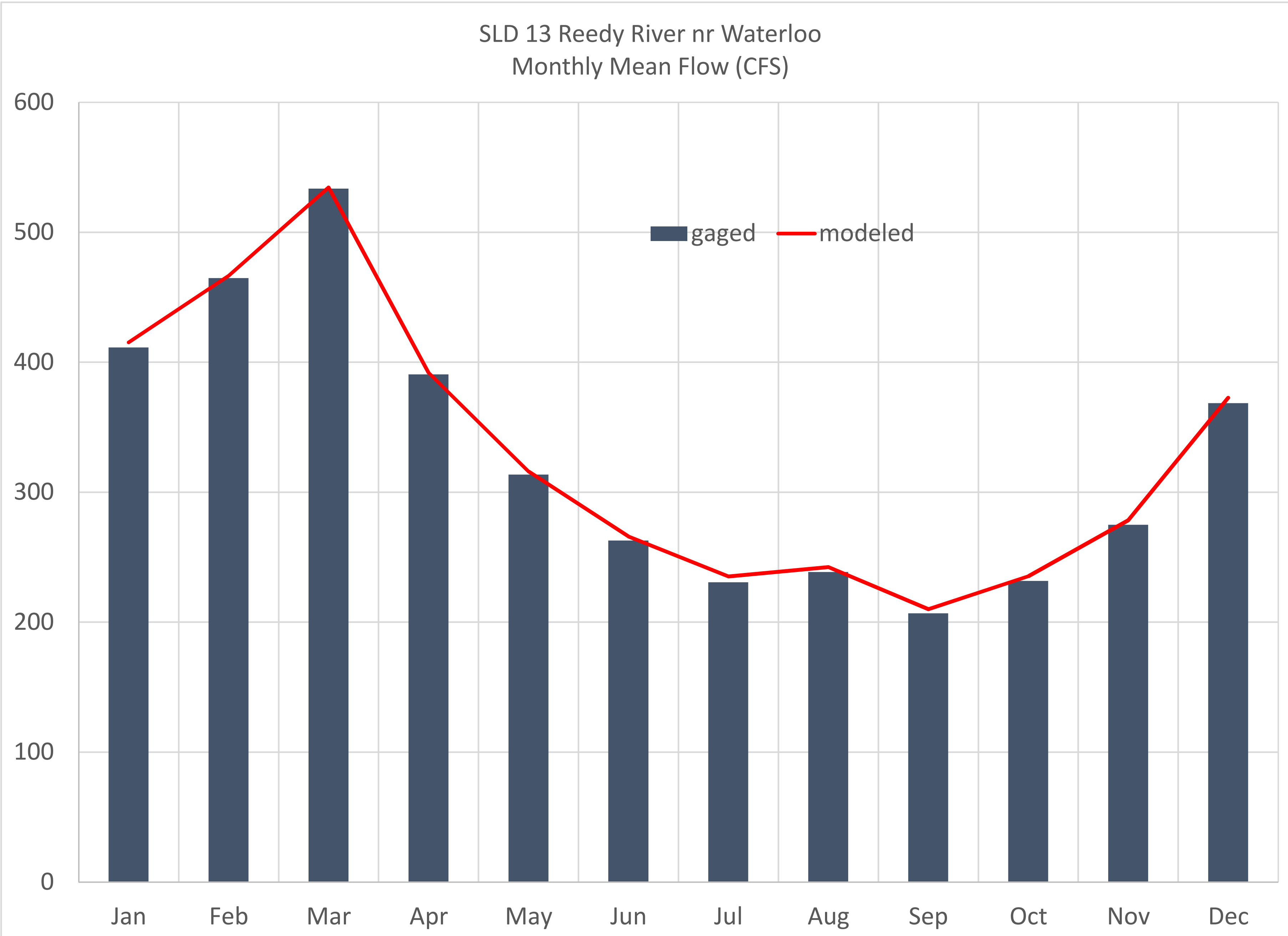
SLD 11 Reedy River above Fork Shoals
Monthly Mean Flow (CFS)
gaged
modeled
350
300
250
200
150
100
50
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


SLD11 Reedy River ab Fork Shoals
Monthly Flow Percentiles (CFS)
gaged
modeled
700
600
500
400
300
200
100
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

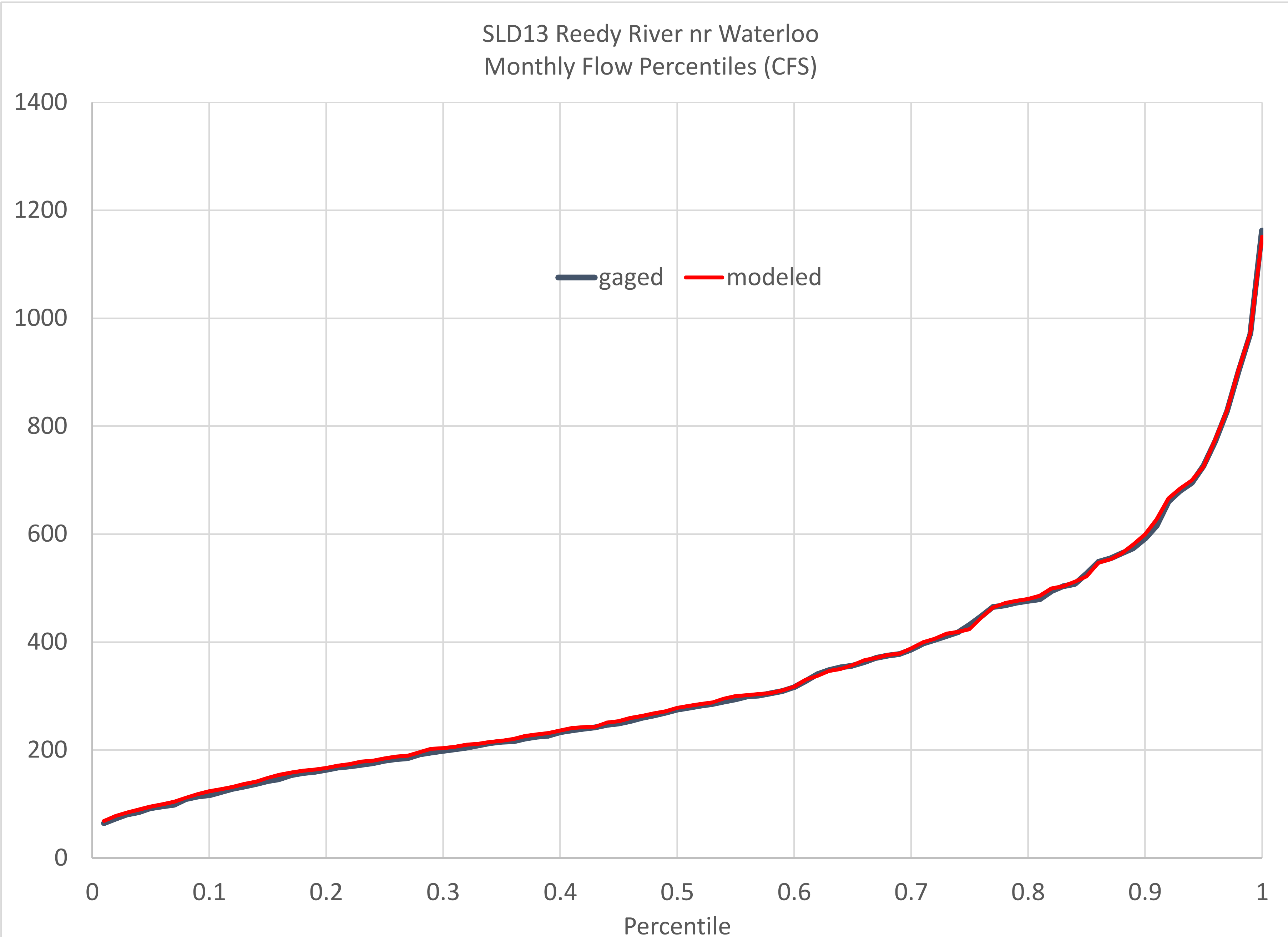

SLD12 & SLD13 Reedy River nr Waterloo (CFS)
gaged
modeled
1,400
1,200
1,000
800
600
400
200
0
Feb-82
Aug-87
Jan-93
Jul-98
Jan-04
Jul-09
Dec-14

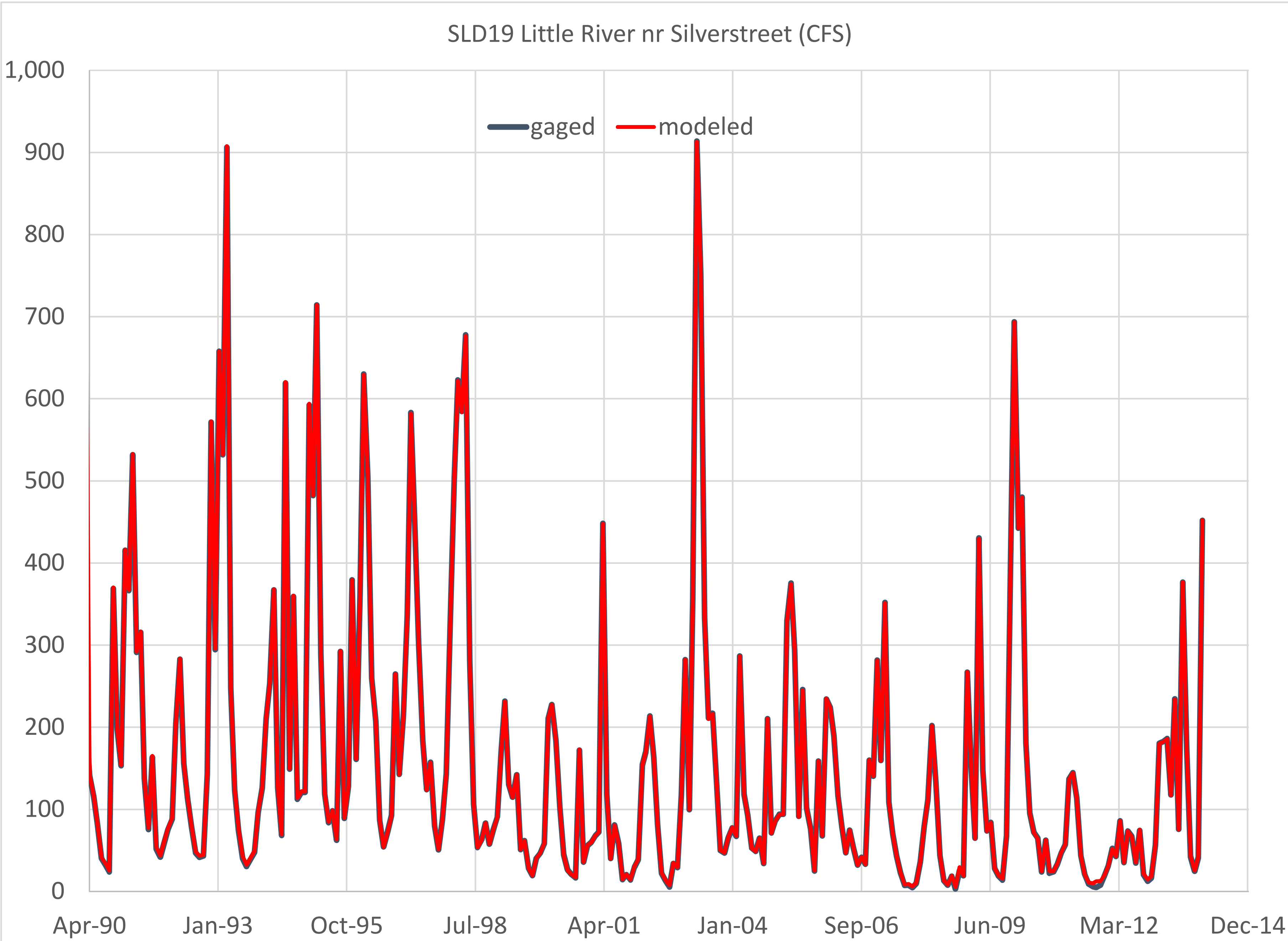


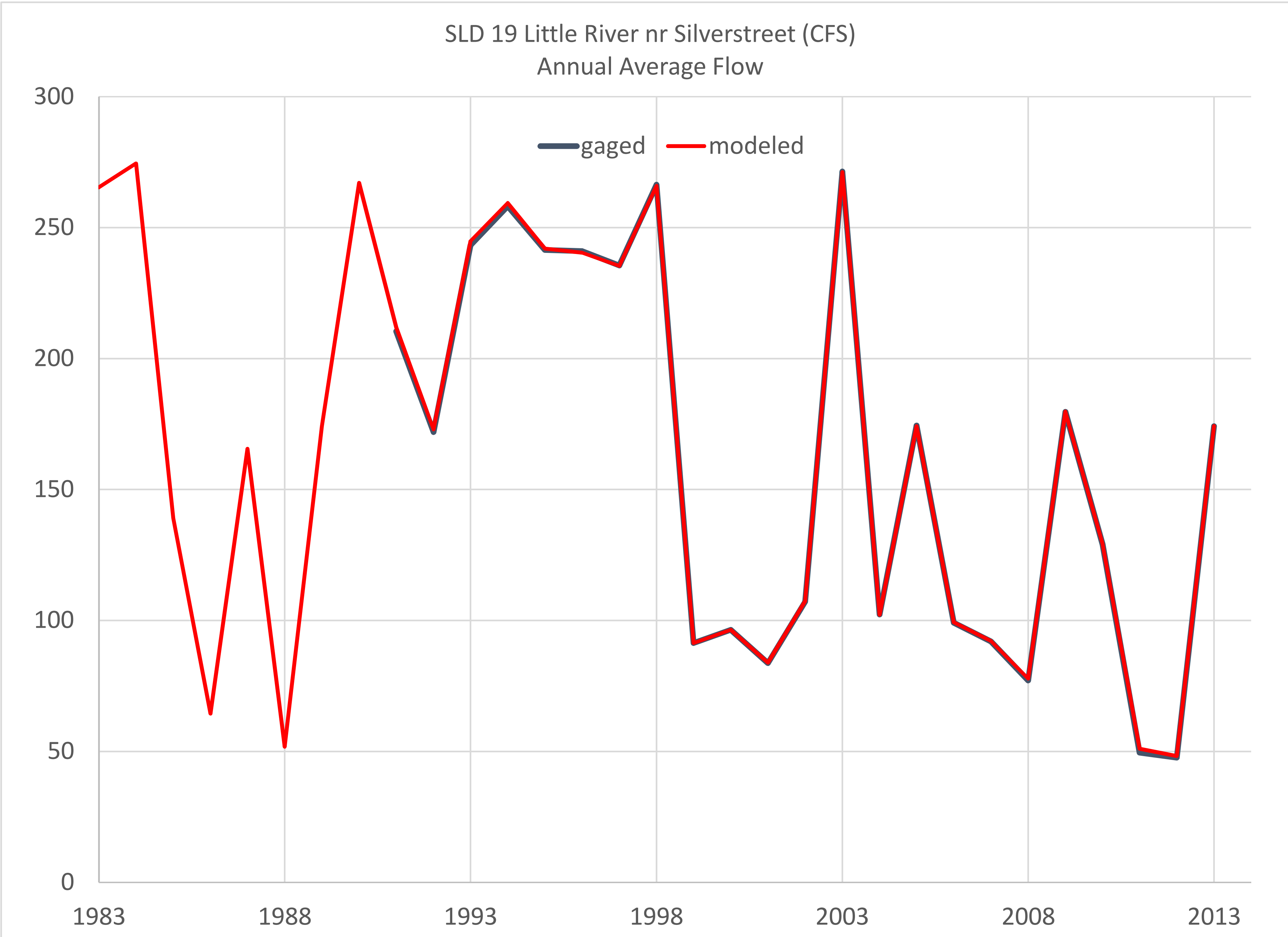
SLD 13 Reedy River nr Waterloo(CFS)
Annual Average Flow
gaged
modeled
600
500
400
300
200
100
0
1983
1988
1993
1998
2003
2008
2013



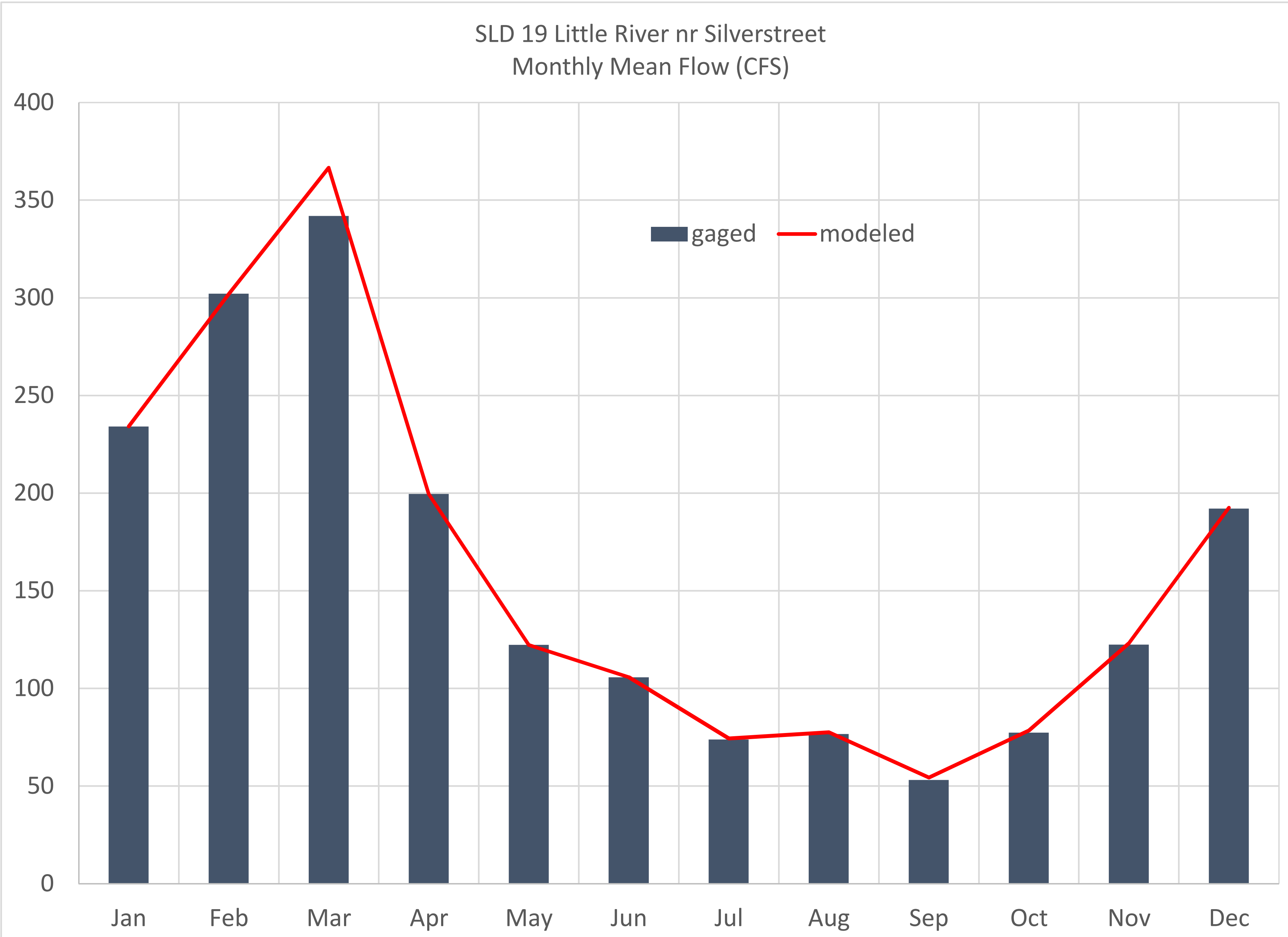
SLD 13 Reedy River nr Waterloo
Monthly Mean Flow (CFS)
gaged
modeled
600
500
400
300
200
100
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


SLD13 Reedy River nr Waterloo
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

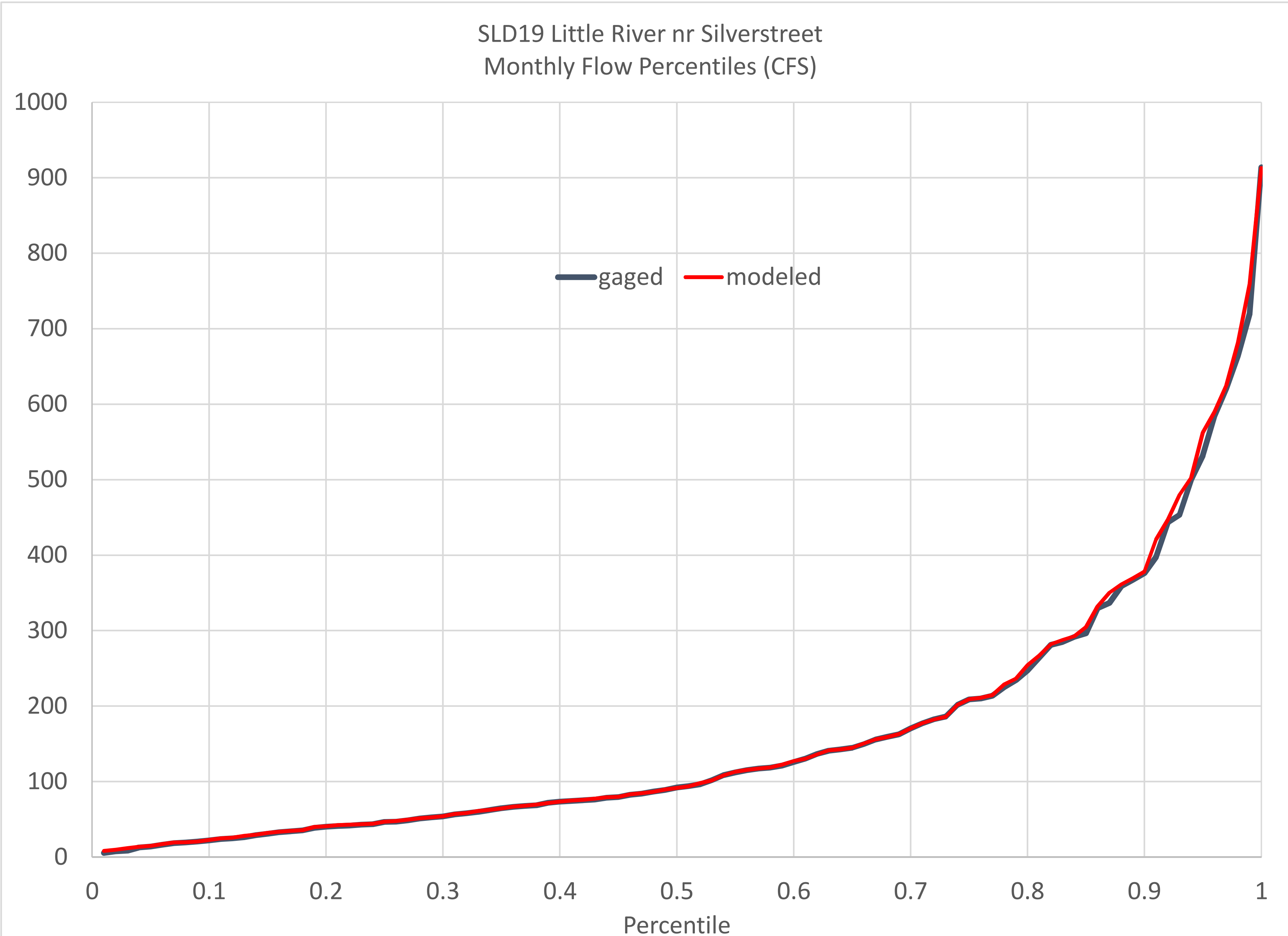

SLD19 Little River nr Silverstreet (CFS)
gaged
modeled
1,000
900
800
700
600
500
400
300
200
100
0
Apr-90
Jan-93
Oct-95
Jul-98
Apr-01
Jan-04
Sep-06
Jun-09
Mar-12
Dec-14

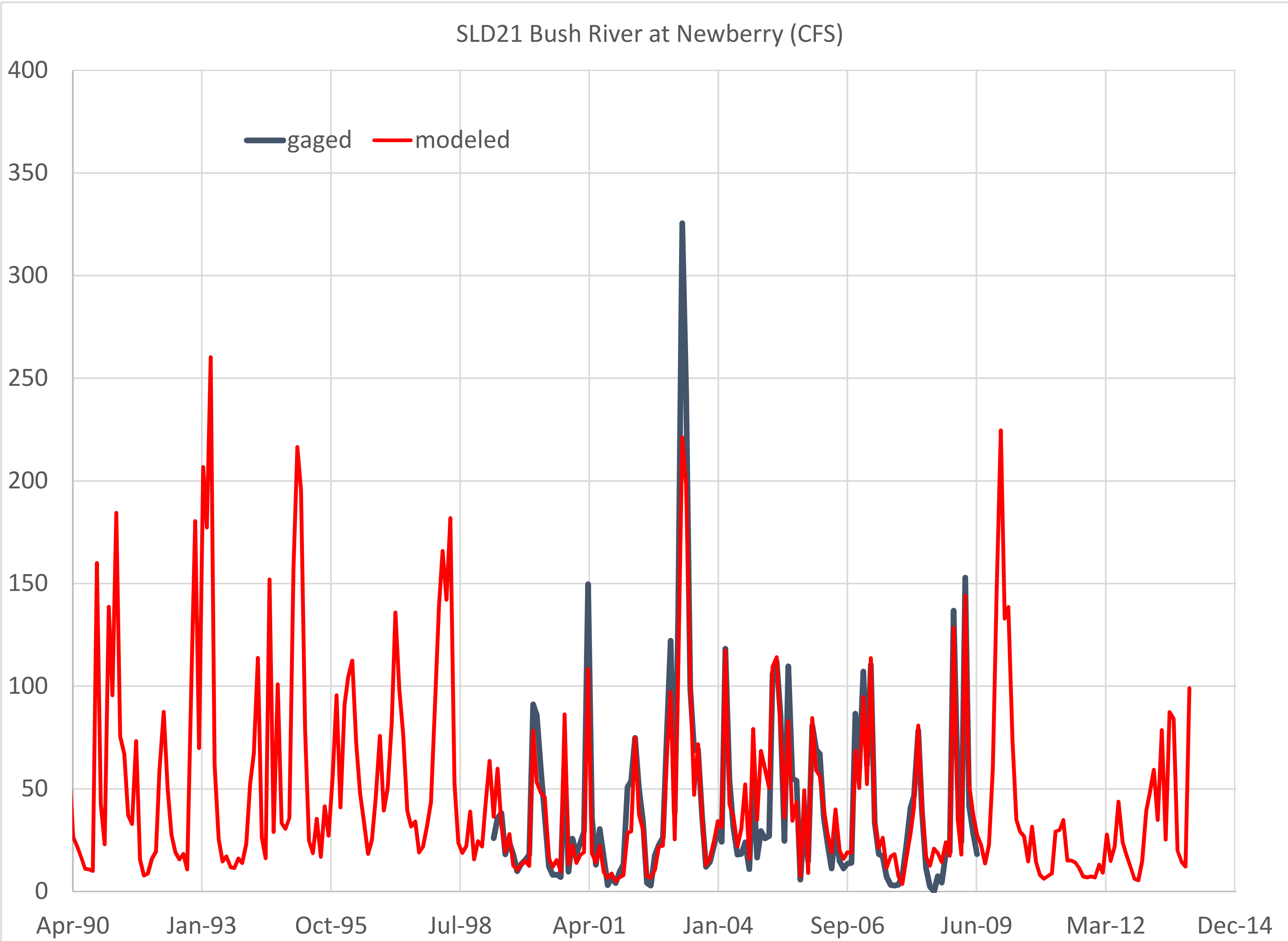


SLD 19 Little River nr Silverstreet (CFS)
Annual Average Flow
gaged
modeled
300
250
200
150
100
50
0
1983
1988
1993
1998
2003
2008
2013

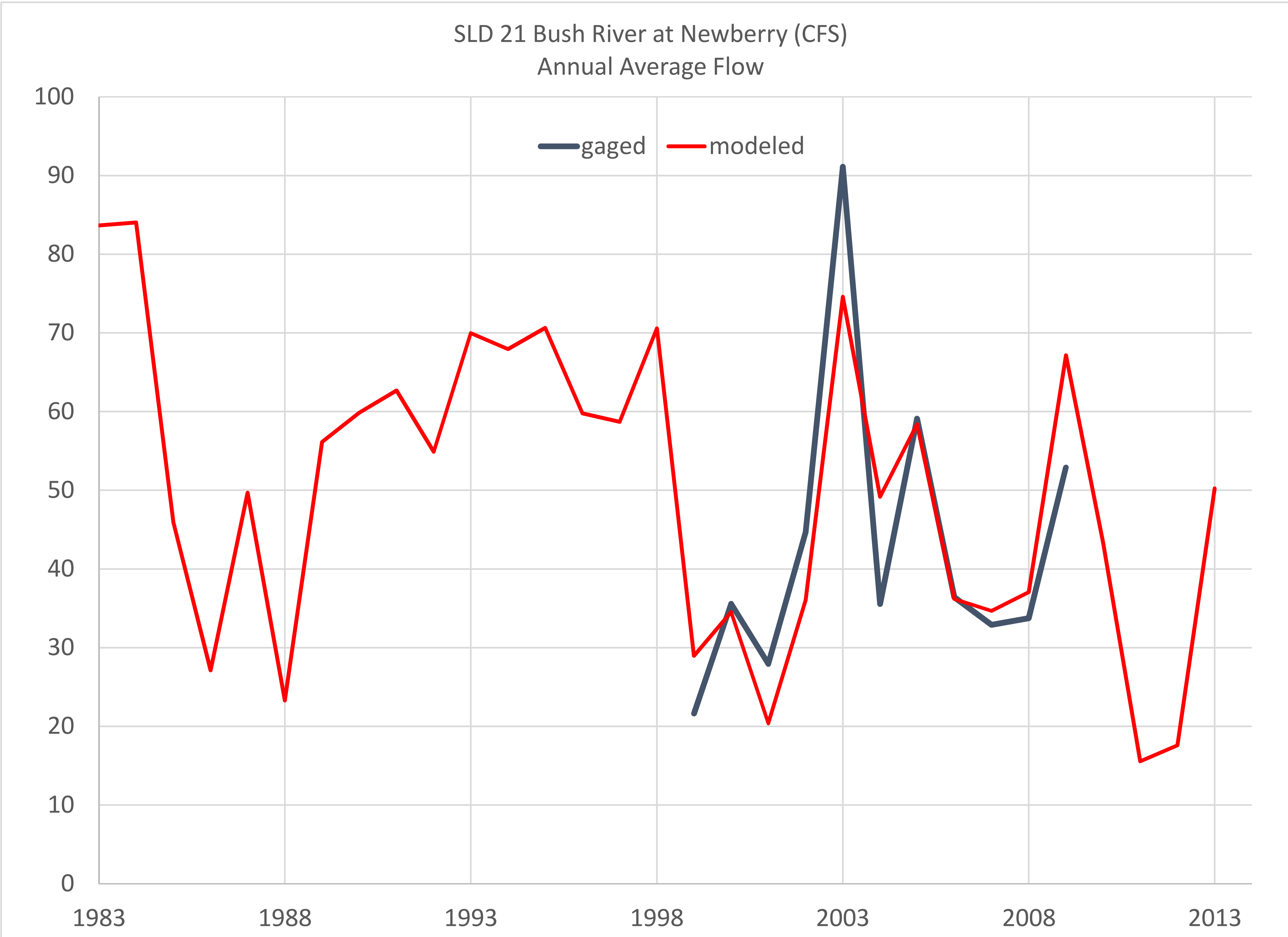


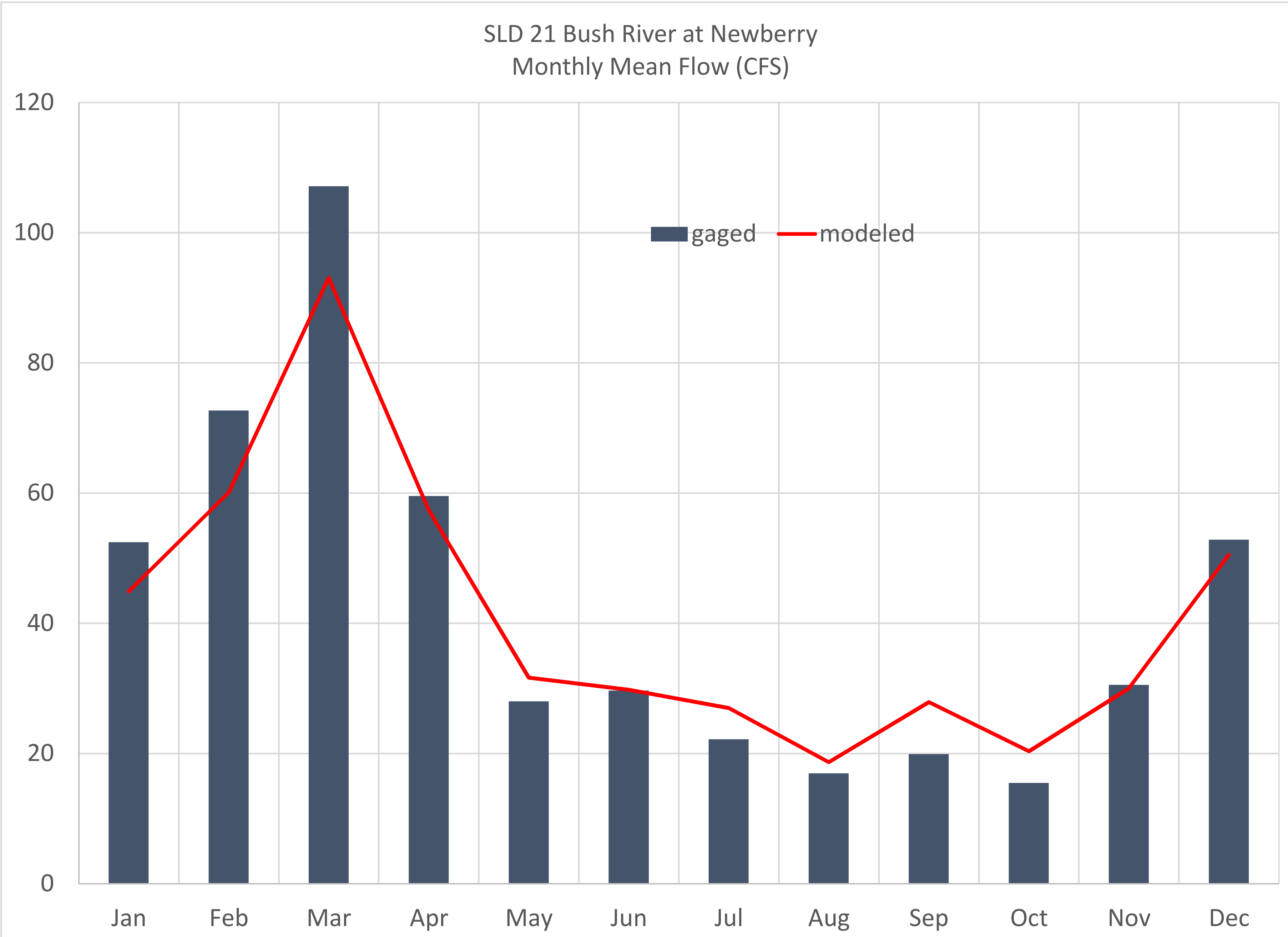
SLD 19 Little River nr Silverstreet
Monthly Mean Flow (CFS)
400
350
300
250
200
150
100
50
0
gaged
modeled
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

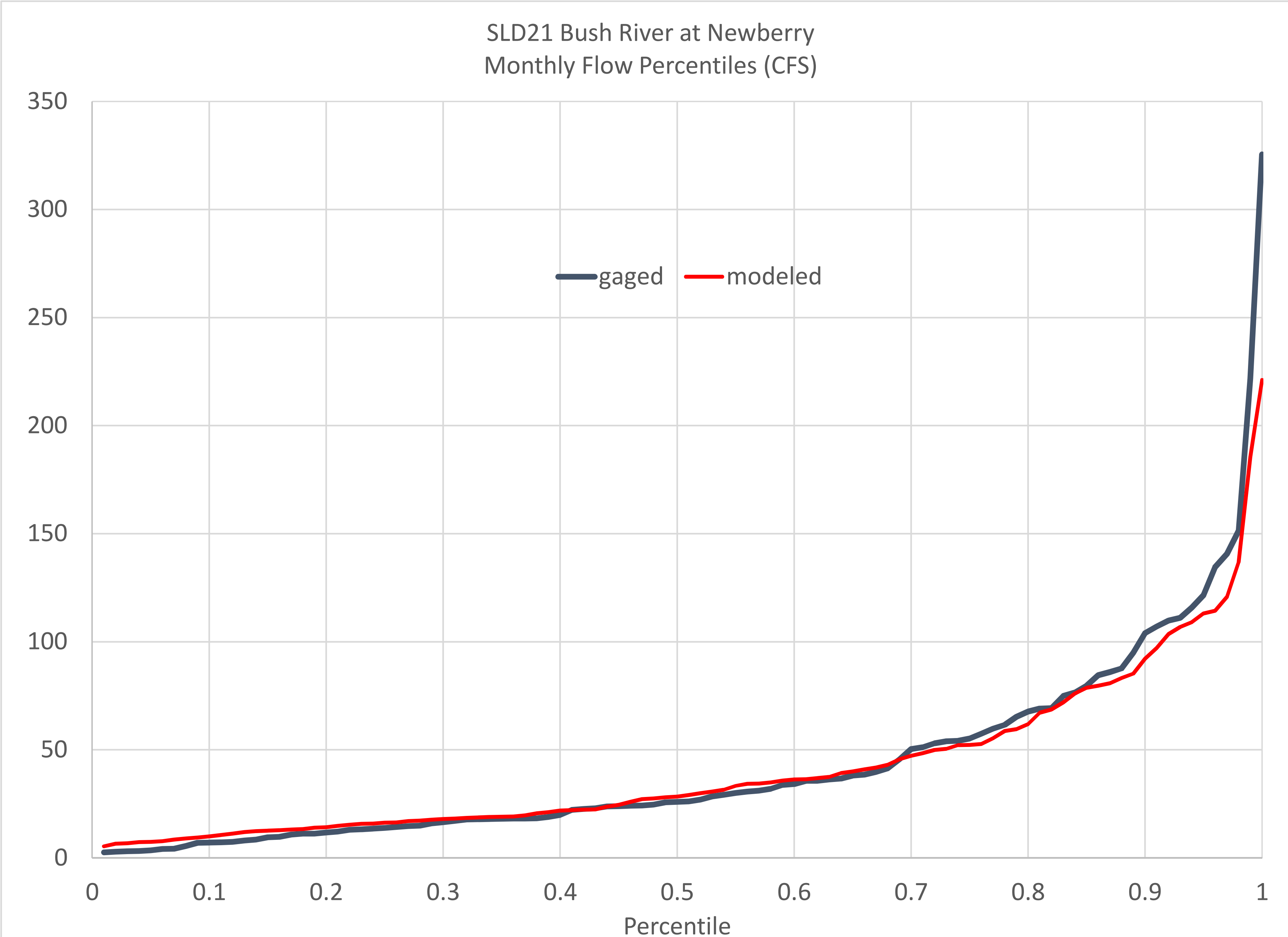

SLD19 Little River nr Silverstreet
Monthly Flow Percentiles (CFS)
1000
900
800
700
600
500
400
300
200
100
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile
gaged
modeled

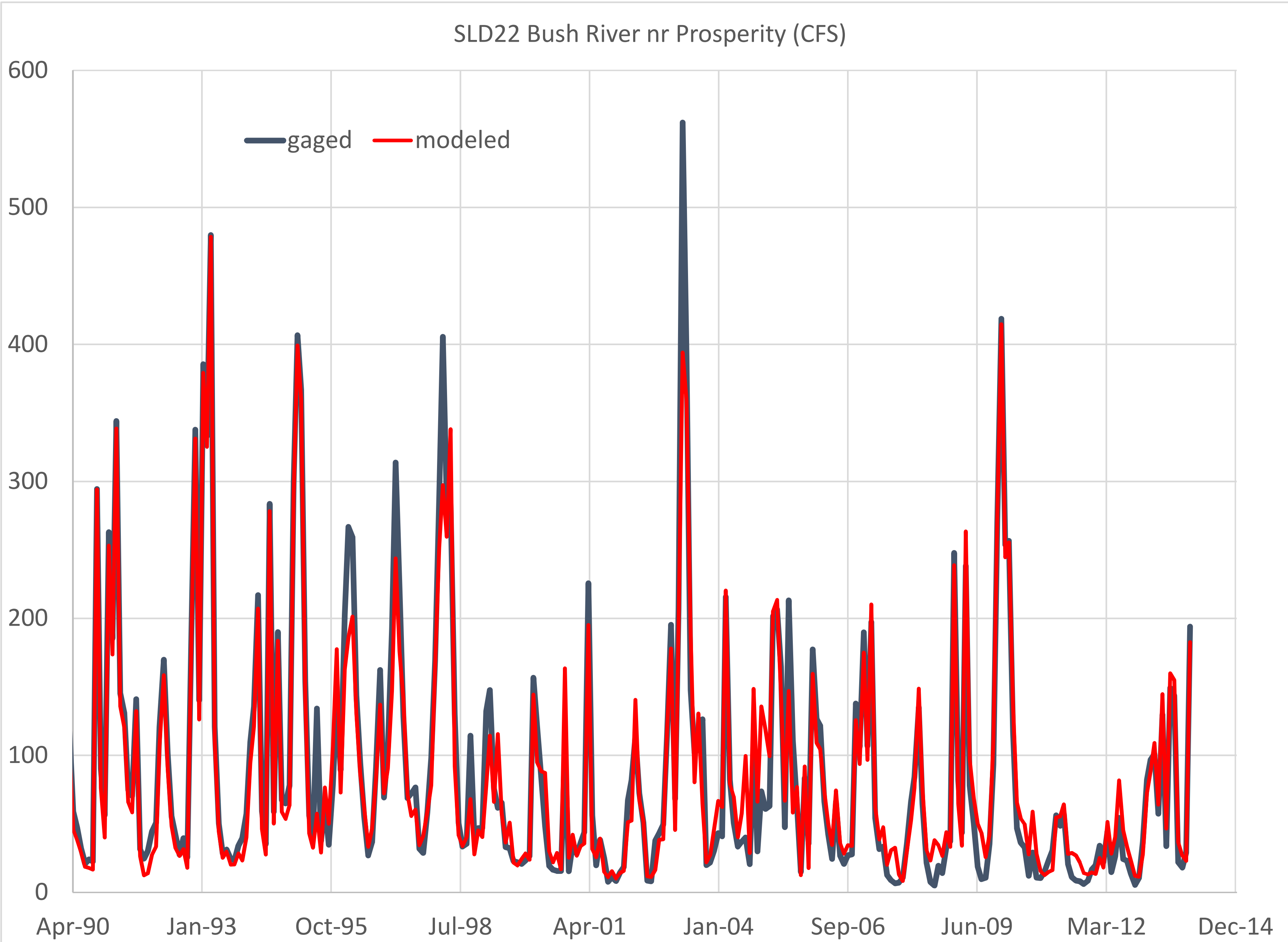


SLD21 Bush River at Newberry (CFS)
gaged
modeled
400
350
300
250
200
150
100
50
0
Apr-90
Jan-93
Oct-95
Jul-98
Apr-01
Jan-04
Sep-06
Jun-09
Mar-12
Dec-14

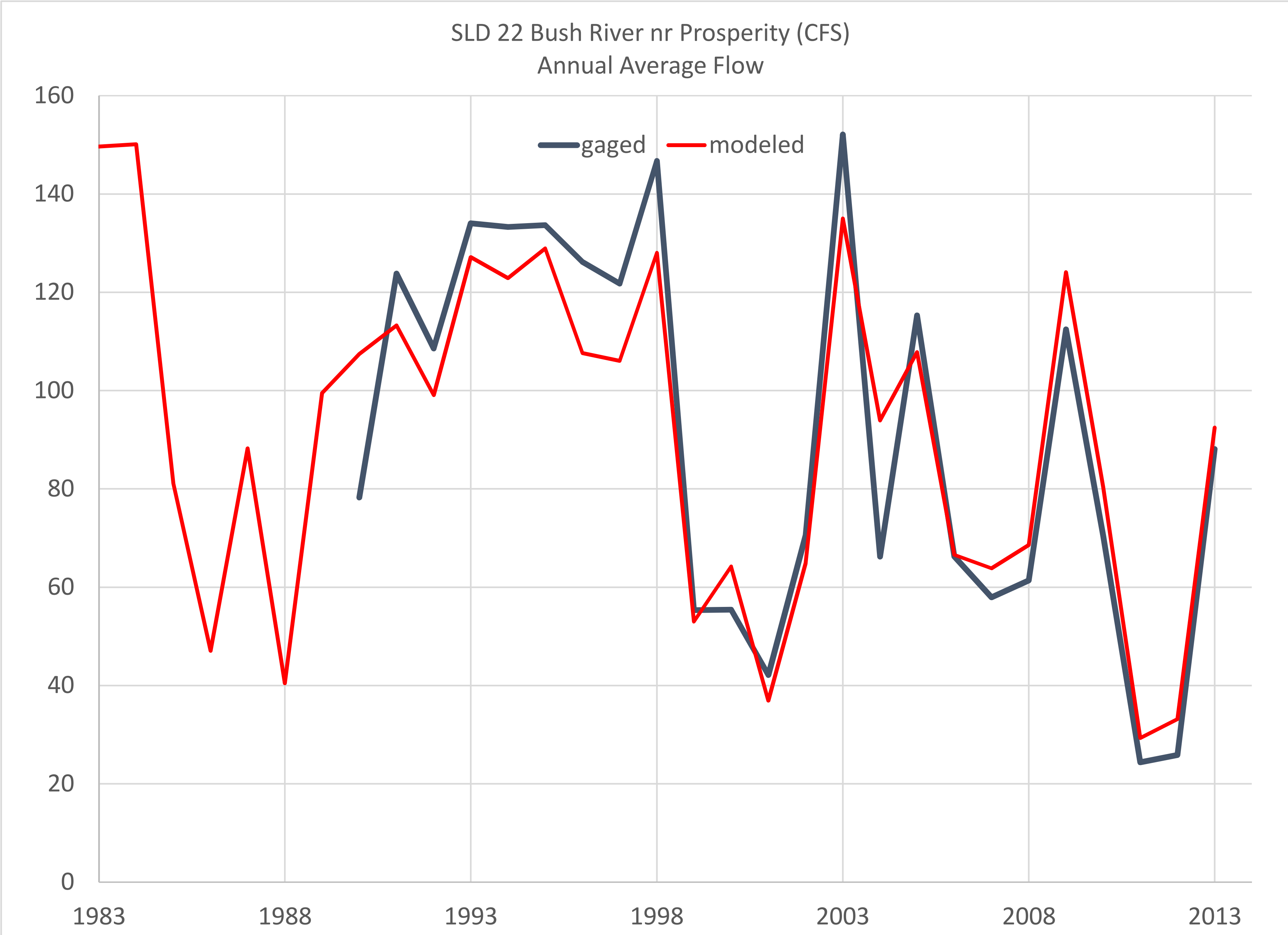

SLD 21 Bush River at Newberry (CFS)
Annual Average Flow
gaged
modeled
100
90
80
70
60
50
40
30
20
10
0
1983
1988
1993
1998
2003
2008
2013


SLD 21 Bush River at Newberry
Monthly Mean Flow (CFS)
gaged
modeled
120
100
80
60
40
20
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

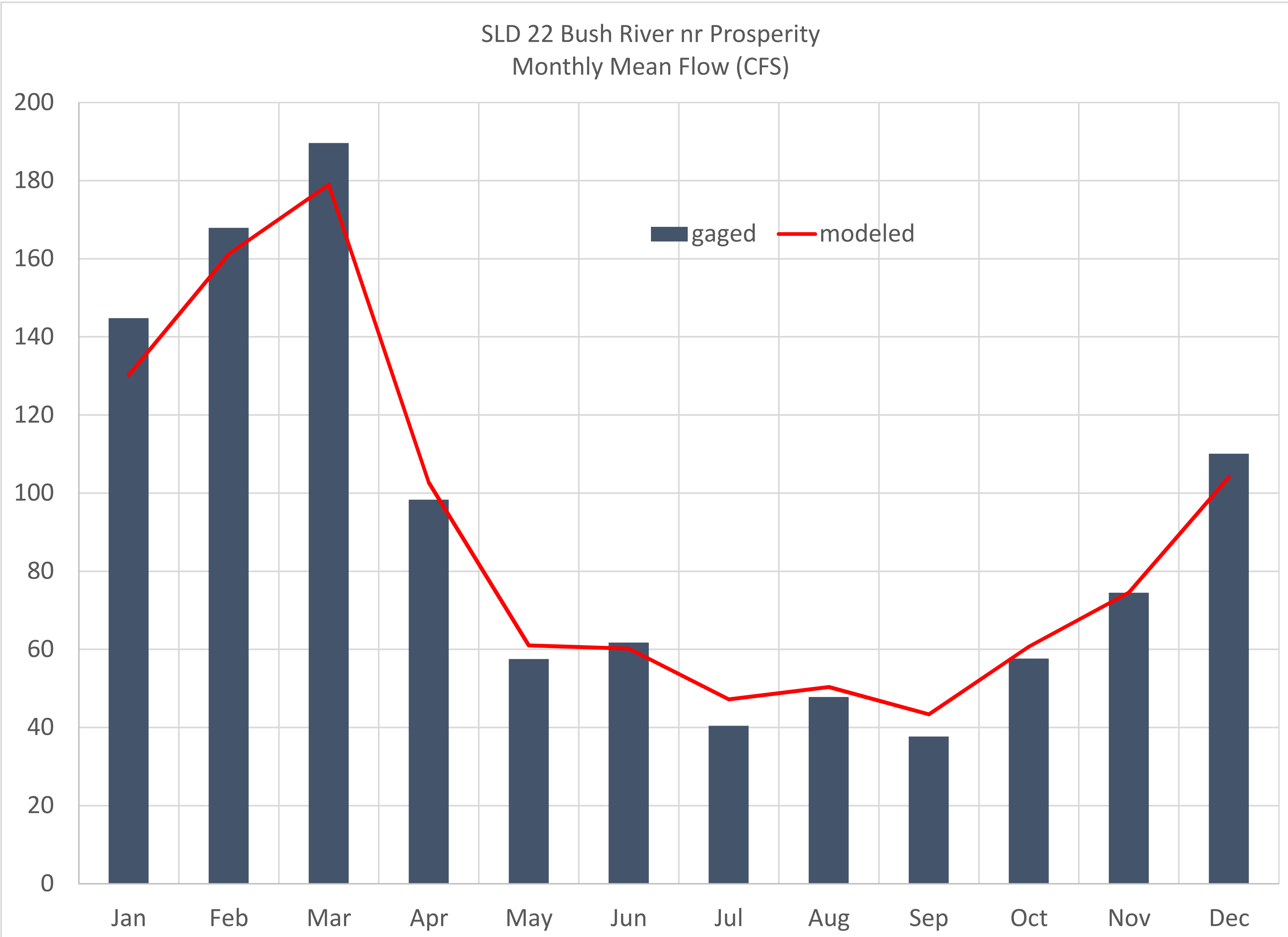

SLD21 Bush River at Newberry
Monthly Flow Percentiles (CFS)
350
300
250
200
150
100
50
0
gaged
modeled
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile



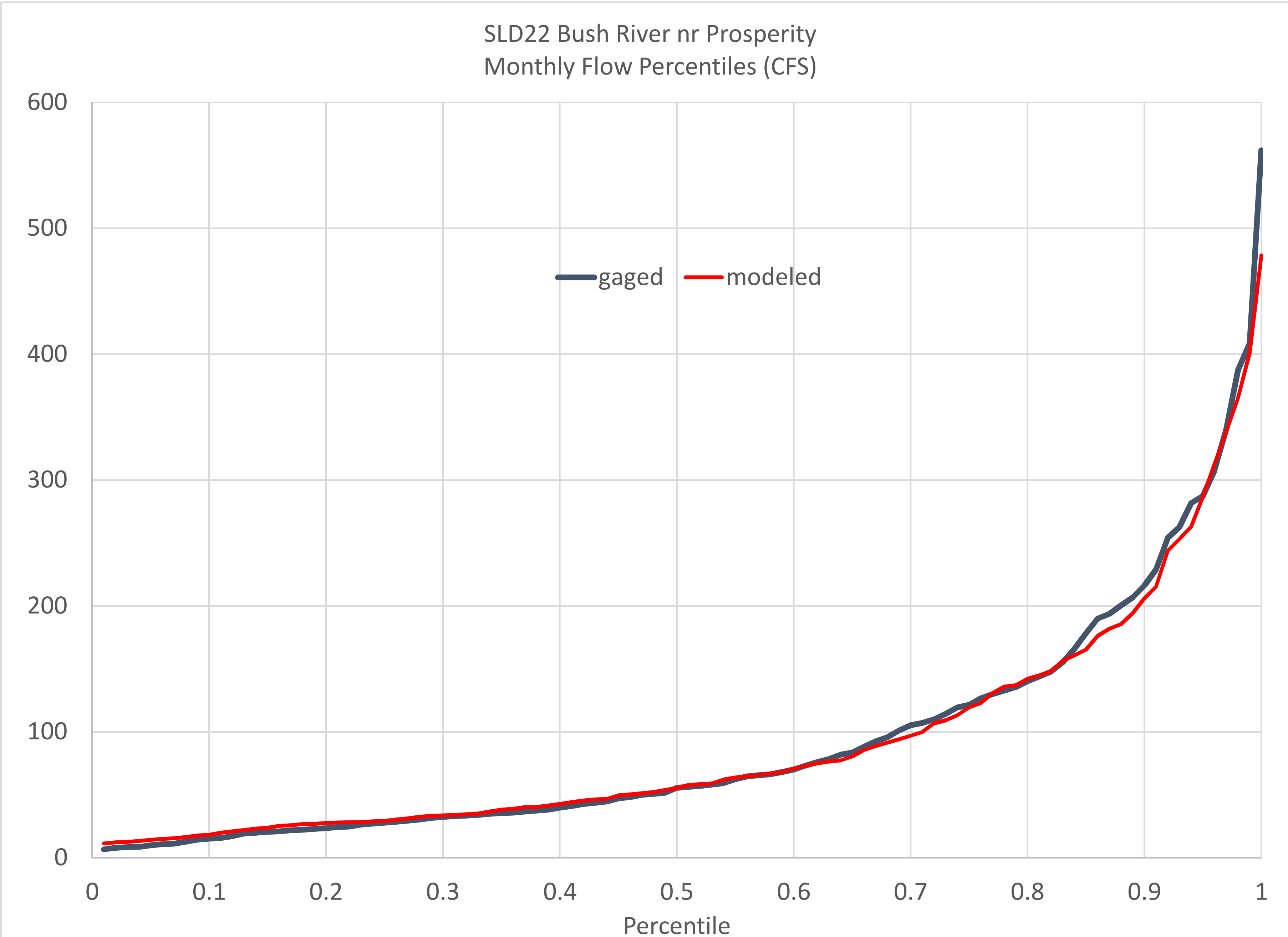
SLD22 Bush River nr Prosperity (CFS)
600
500
400
300
200
100
0
gaged
modeled
Apr-90
Jan-93
Oct-95
Jul-98
Apr-01
Jan-04
Sep-06
Jun-09
Mar-12
Dec-14

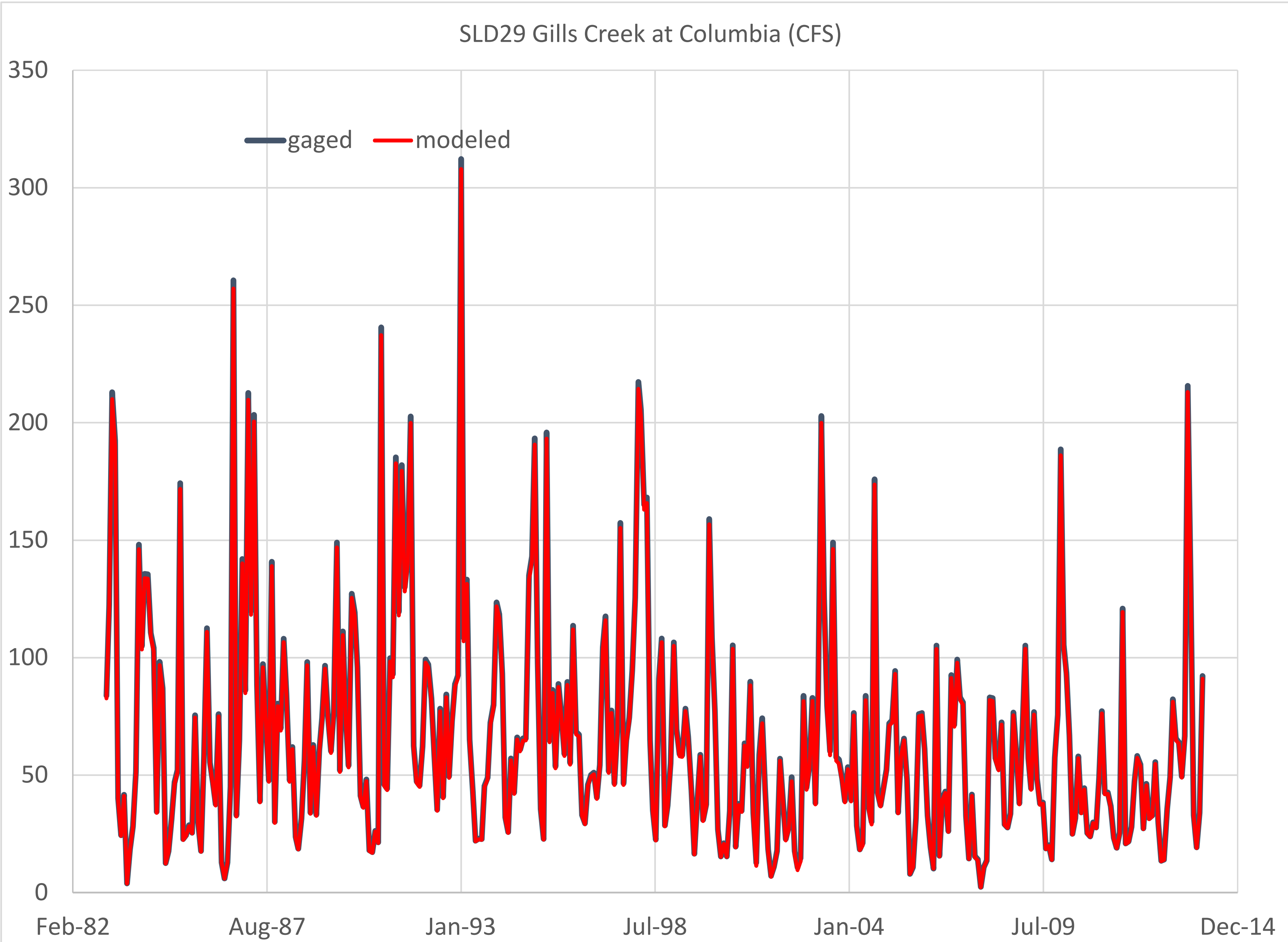


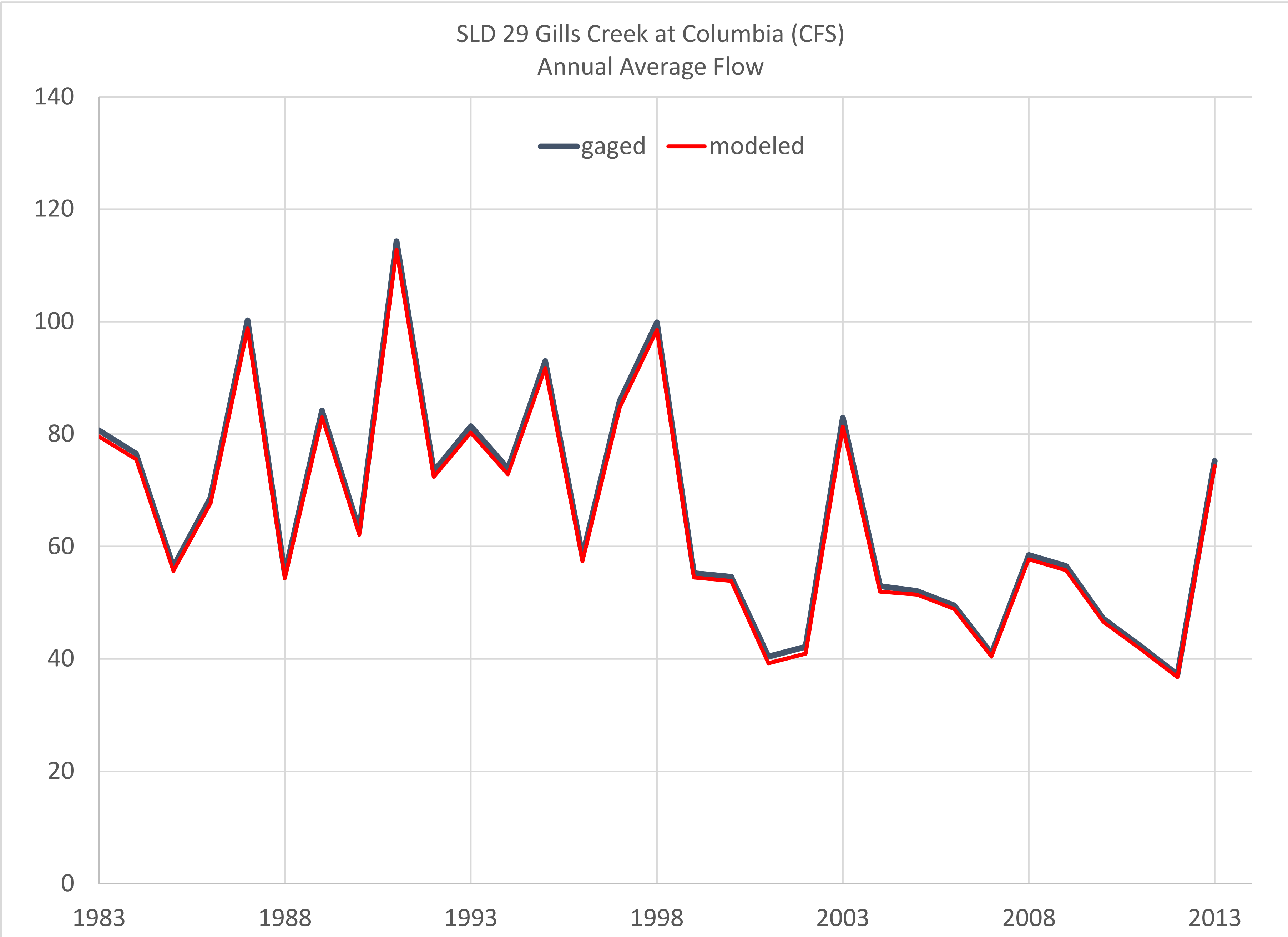
SLD 22 Bush River nr Prosperity (CFS)
Annual Average Flow
gaged
modeled
160
140
120
100
80
60
40
20
0
1983
1988
1993
1998
2003
2008
2013



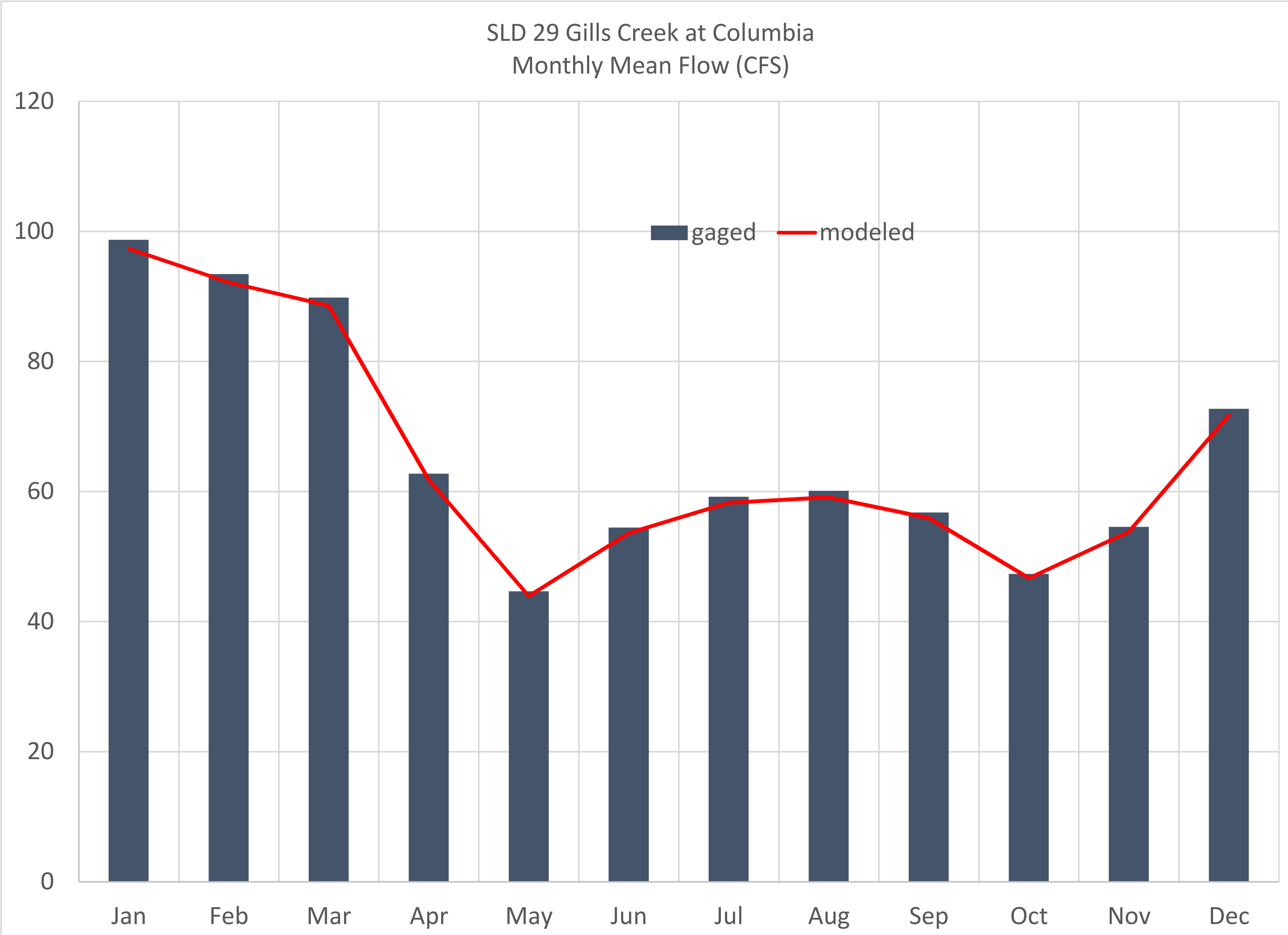
SLD 22 Bush River nr Prosperity
Monthly Mean Flow (CFS)
gaged
modeled
200
180
160
140
120
100
80
60
40
20
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

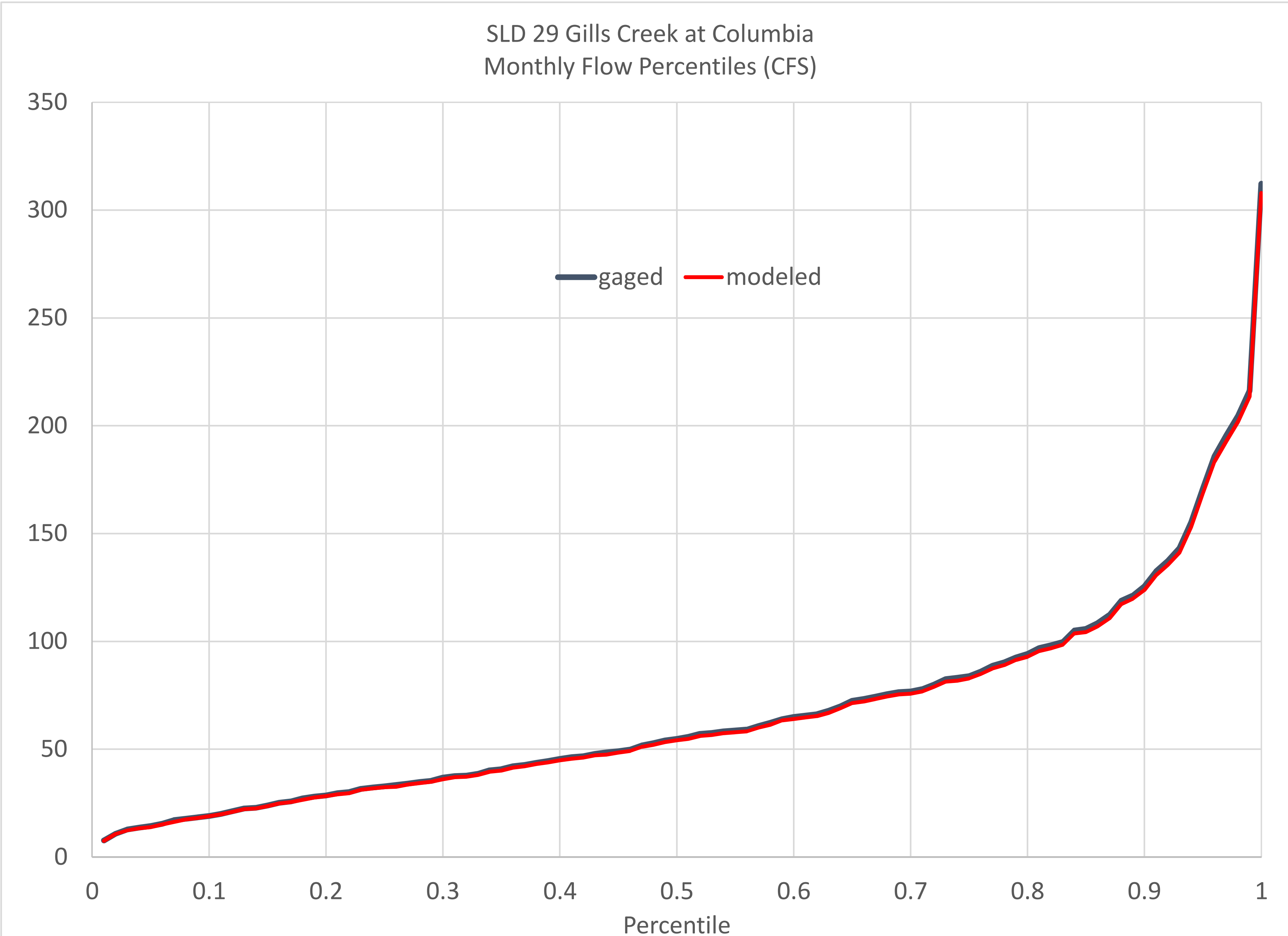

SLD22 Bush River nr Prosperity
Monthly Flow Percentiles (CFS)
gaged
modeled
0
100
200
300
400
500
600
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

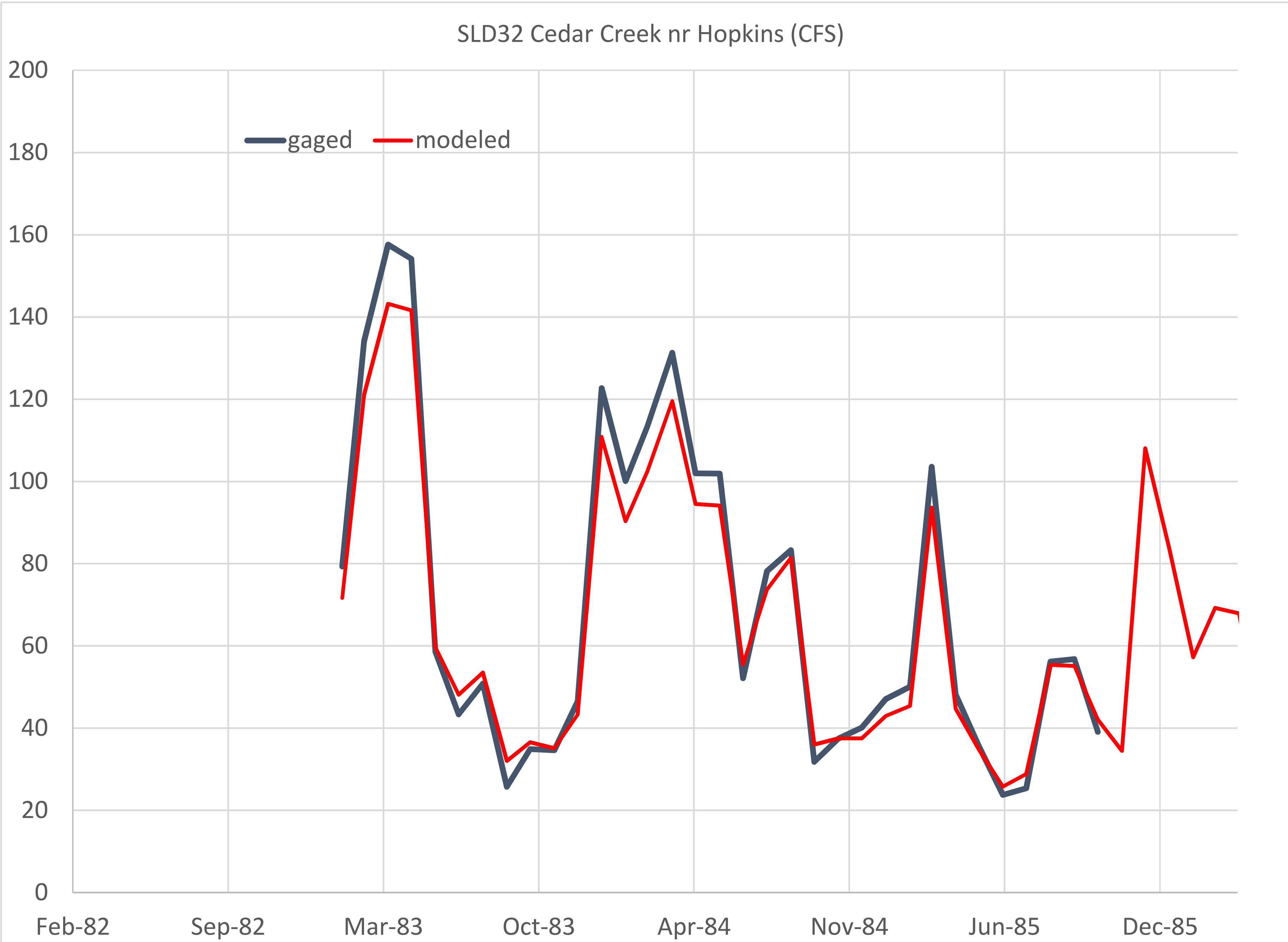

SLD29 Gills Creek at Columbia (CFS)
gaged
modeled
350
300
250
200
150
100
50
0
Feb-82
Aug-87
Jan-93
Jul-98
Jan-04
Jul-09
Dec-14

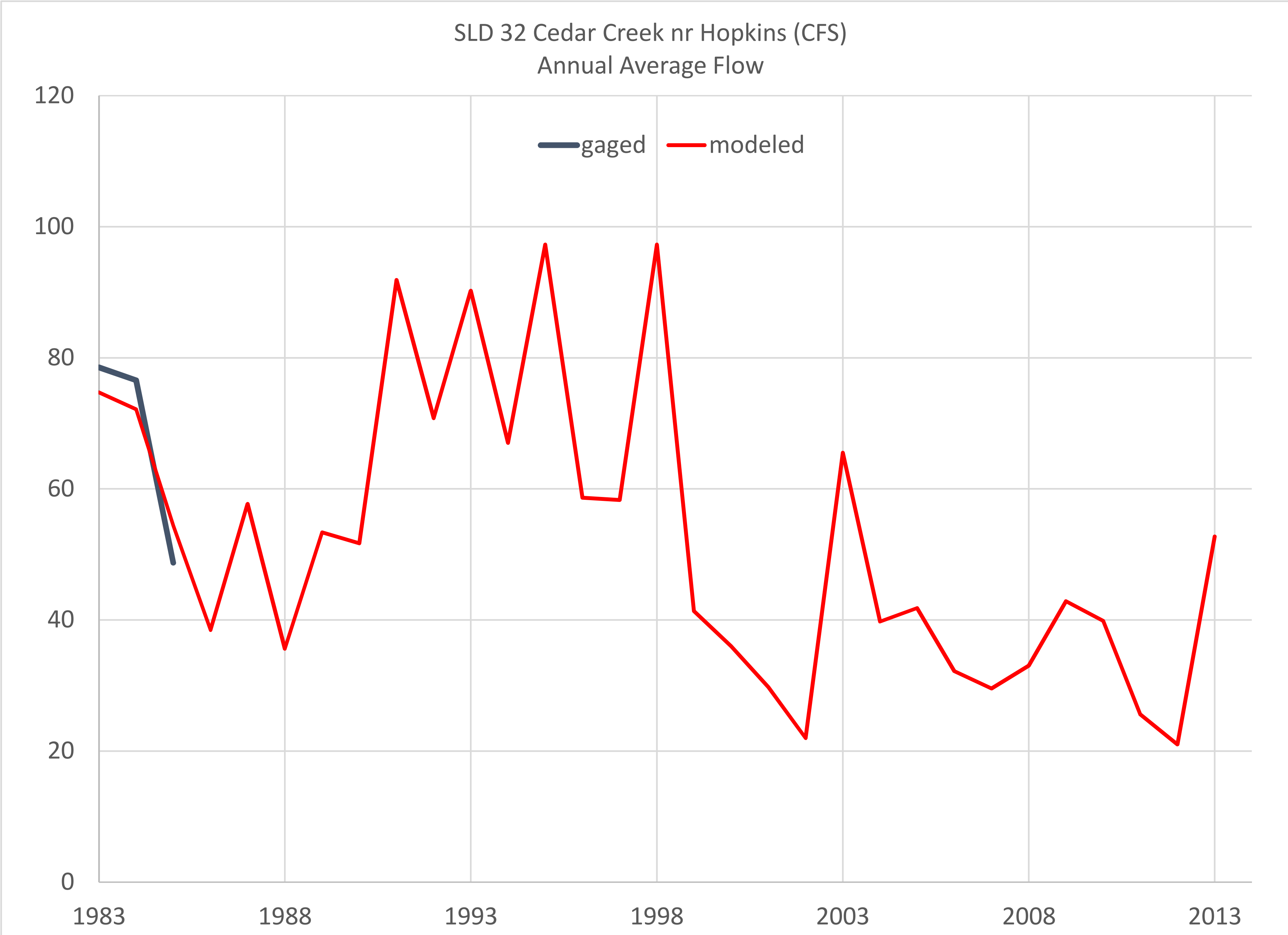


SLD 29 Gills Creek at Columbia (CFS)
Annual Average Flow
gaged
modeled
140
120
100
80
60
40
20
0
1983
1988
1993
1998
2003
2008
2013

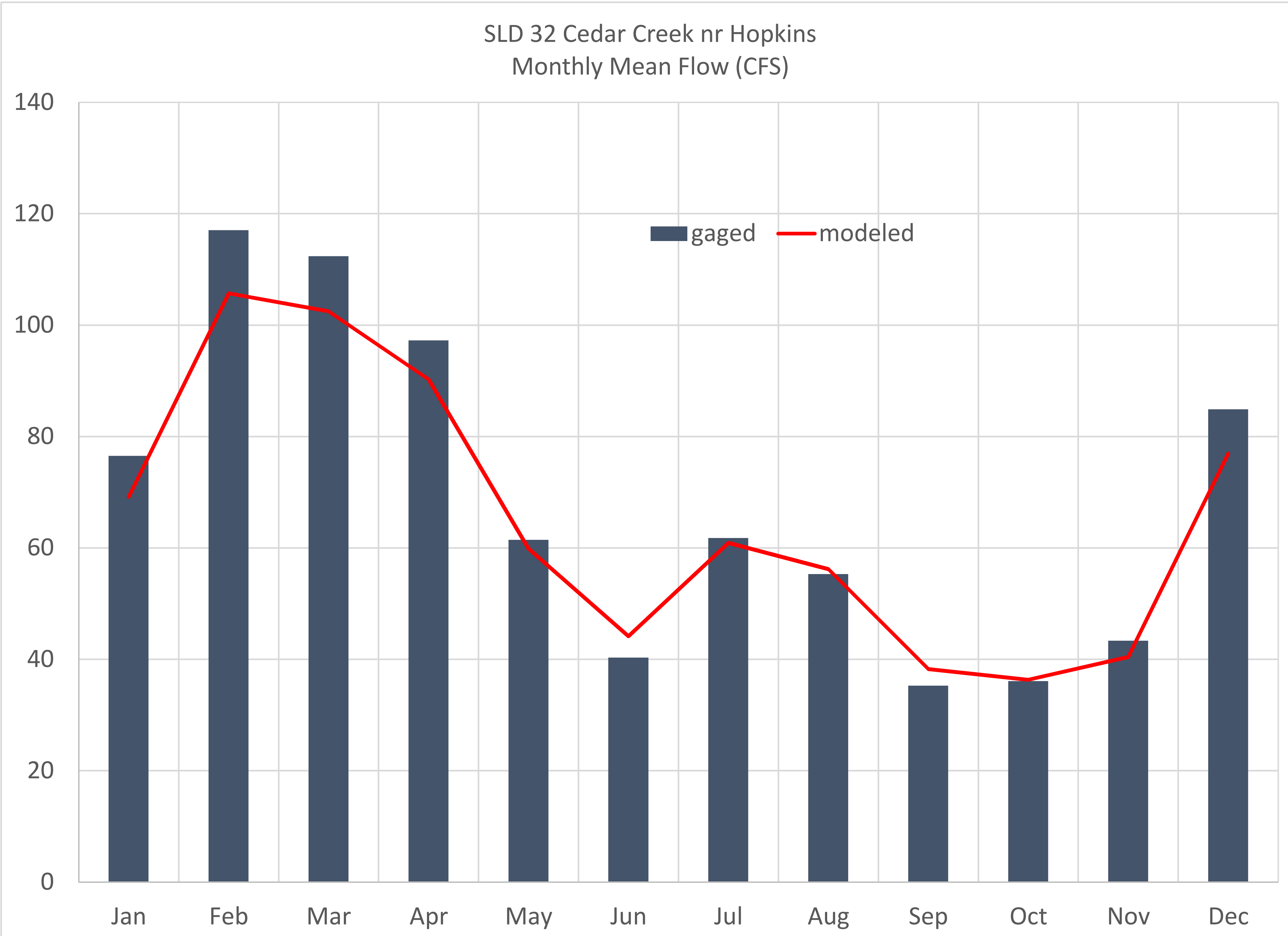

SLD 29 Gills Creek at Columbia
Monthly Mean Flow (CFS)
gaged
modeled
0
20
40
60
80
100
120
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

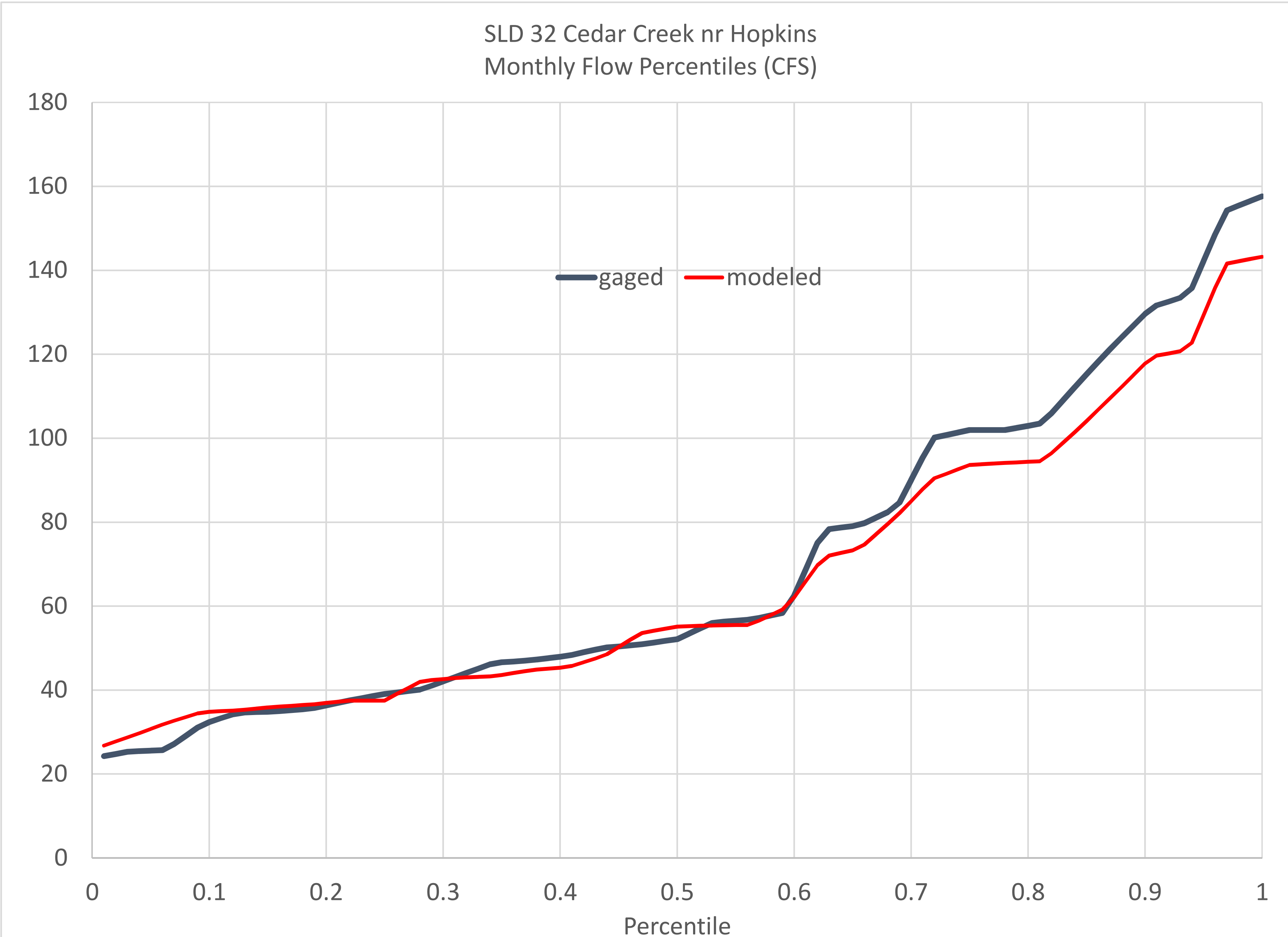

SLD 29 Gills Creek at Columbia
Monthly Flow Percentiles (CFS)
gaged
modeled
350
300
250
200
150
100
50
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

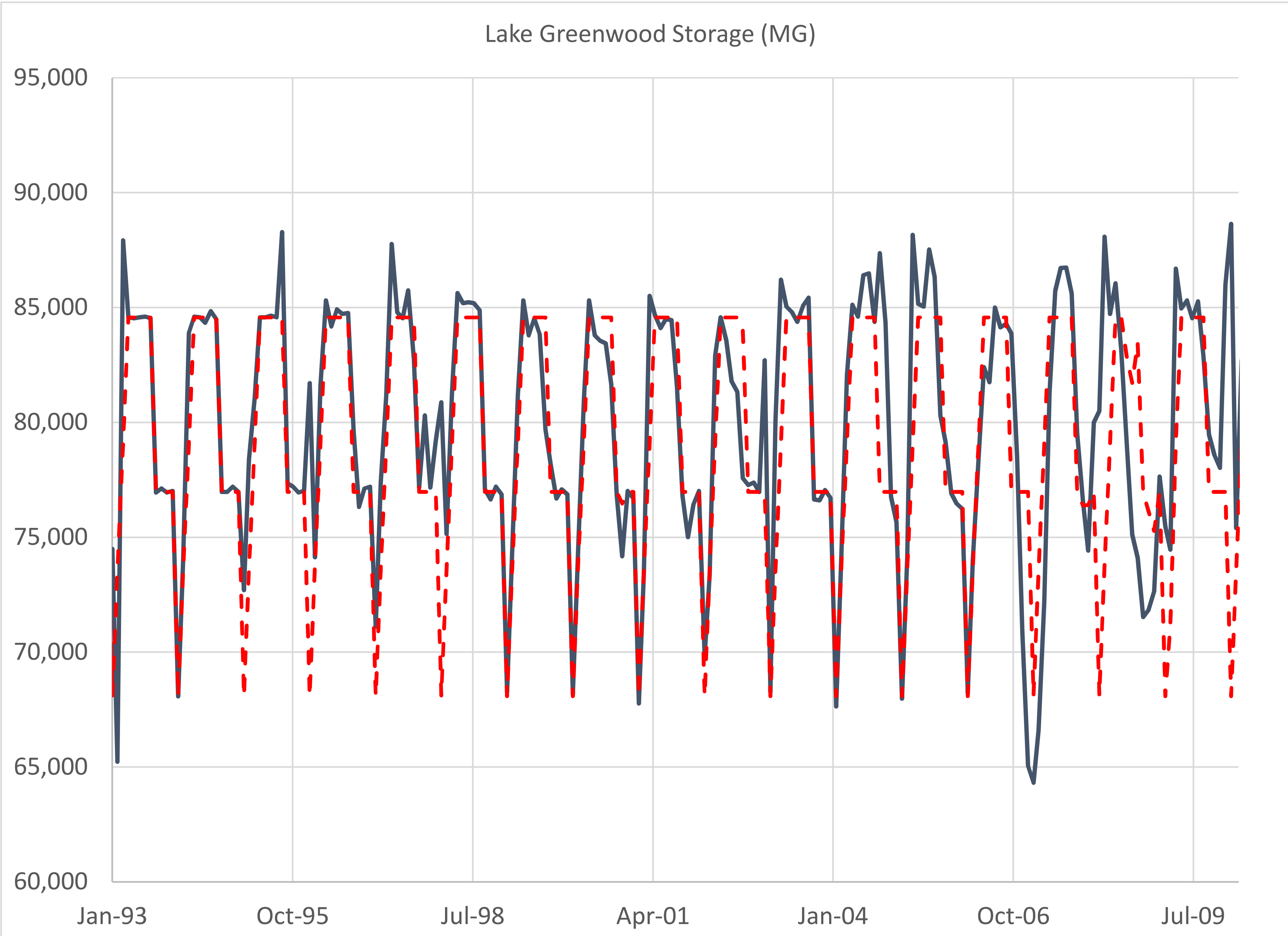

SLD32 Cedar Creek nr Hopkins (CFS)
200
180
160
140
120
100
80
60
40
20
0
gaged
modeled
Feb-82
Sep-82
Mar-83
Oct-83
Apr-84
Nov-84
Jun-85
Dec-85



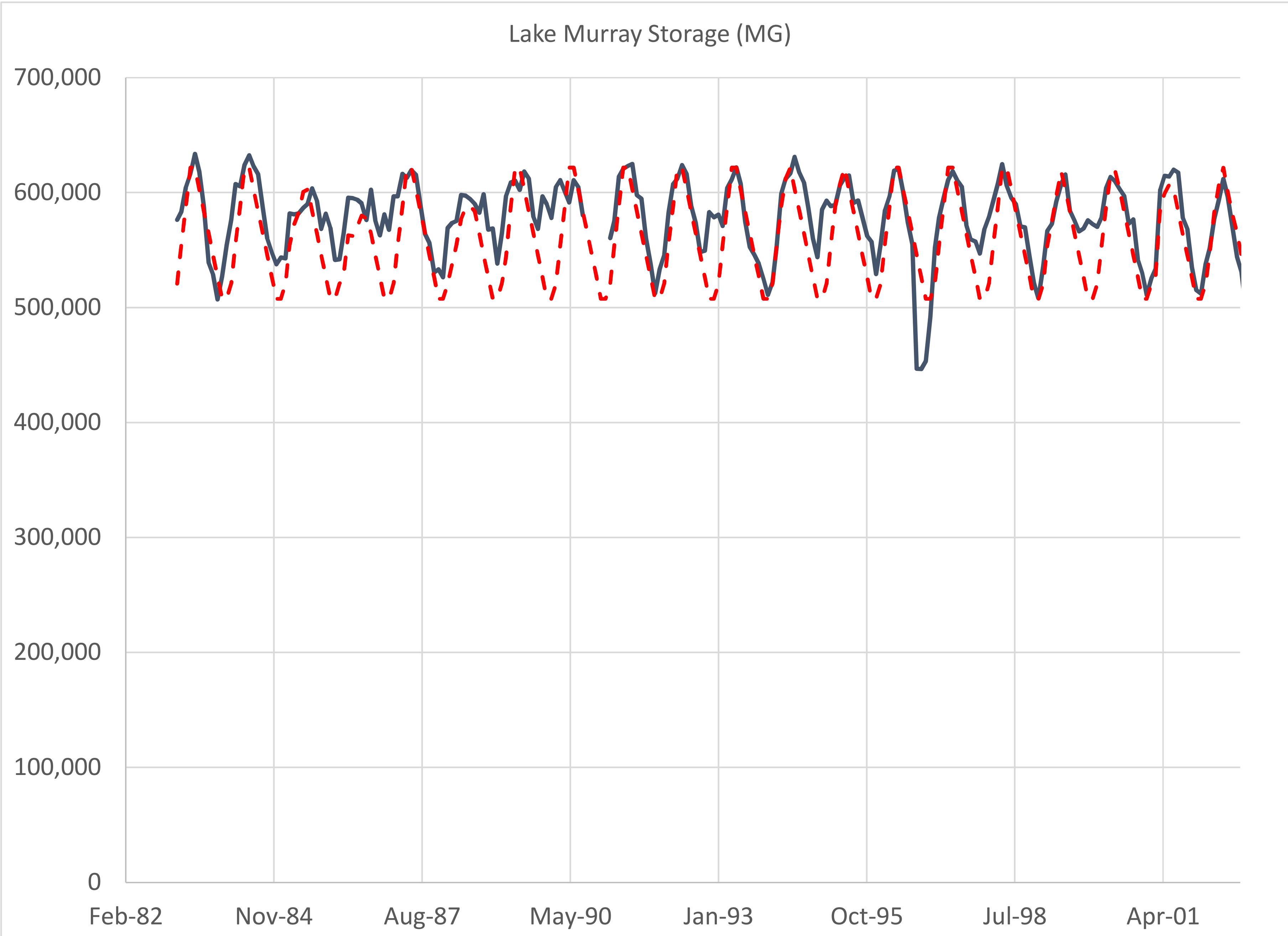
SLD 32 Cedar Creek nr Hopkins (CFS)
Annual Average Flow
gaged
modeled
120
100
80
60
40
20
0
1983
1988
1993
1998
2003
2008
2013


SLD 32 Cedar Creek nr Hopkins
Monthly Mean Flow (CFS)
gaged
modeled
0
20
40
60
80
100
120
140
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

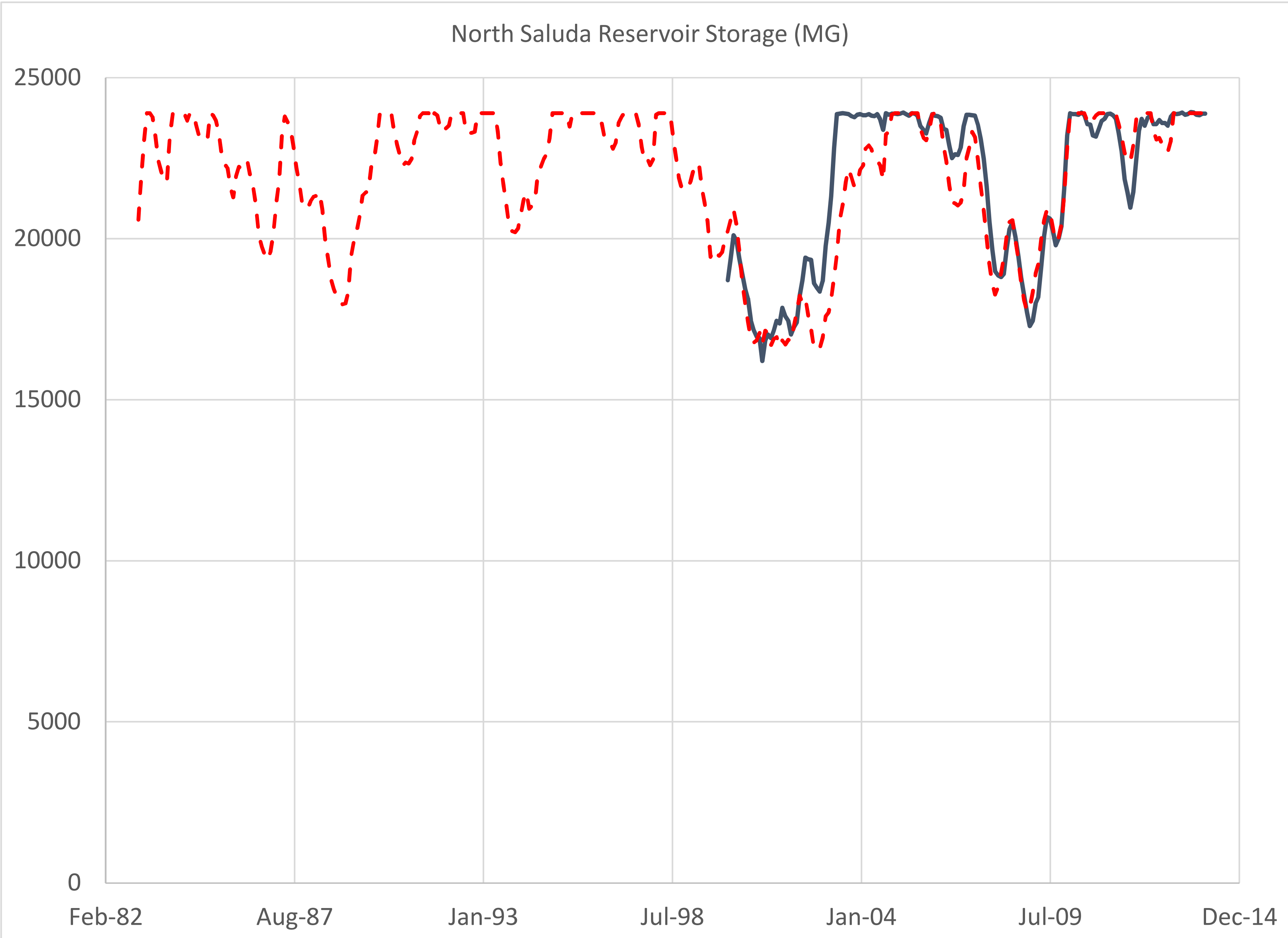

SLD 32 Cedar Creek nr Hopkins
Monthly Flow Percentiles (CFS)
gaged
modeled
180
160
140
120
100
80
60
40
20
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile



Lake Greenwood Storage (MG)
95,000
90,000
85,000
80,000
75,000
70,000
65,000
60,000
Jan-93
Oct-95
Jul-98
Apr-01
Jan-04
Oct-06
Jul-09



Lake Murray Storage (MG)
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
Feb-82
Nov-84
Aug-87
May-90
Jan-93
Oct-95
Jul-98
Apr-01


North Saluda Reservoir Storage (MG)
25000
20000
15000
10000
5000
0
Feb-82
Aug-87
Jan-93
Jul-98
Jan-04
Jul-09
Dec-14

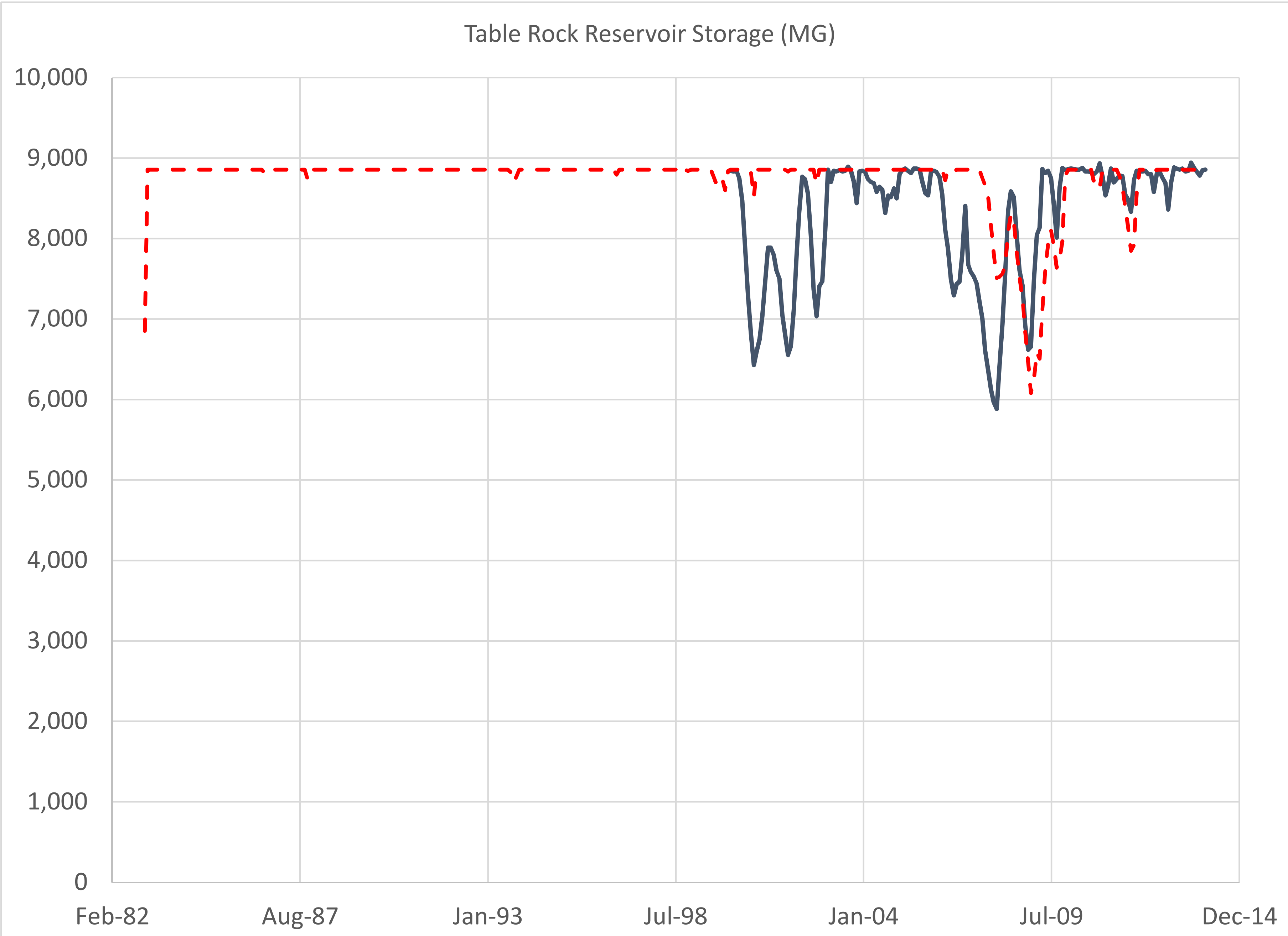
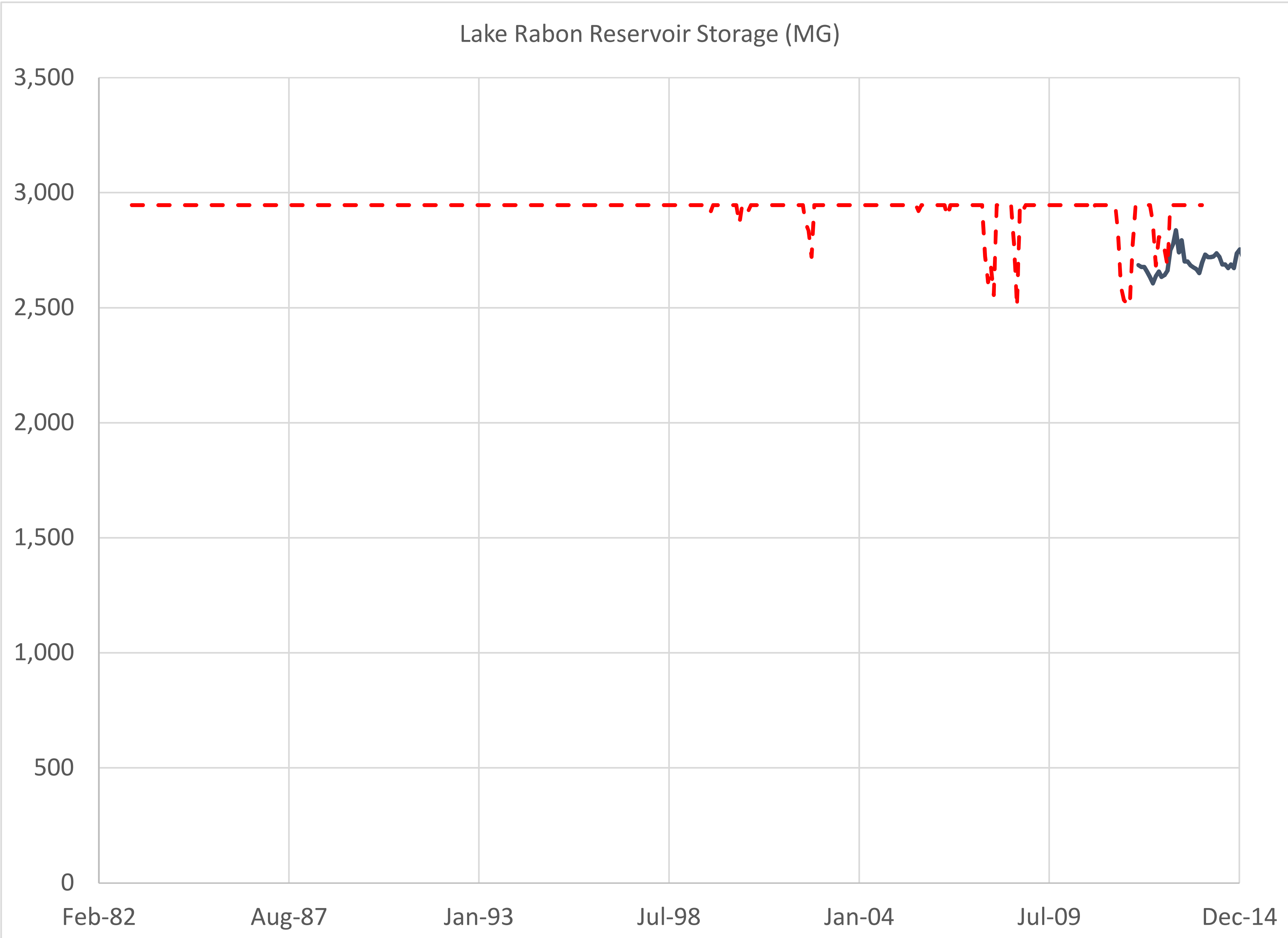


Table Rock Reservoir Storage (MG)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Feb-82
Aug-87
Jan-93
Jul-98
Jan-04
Jul-09
Dec-14

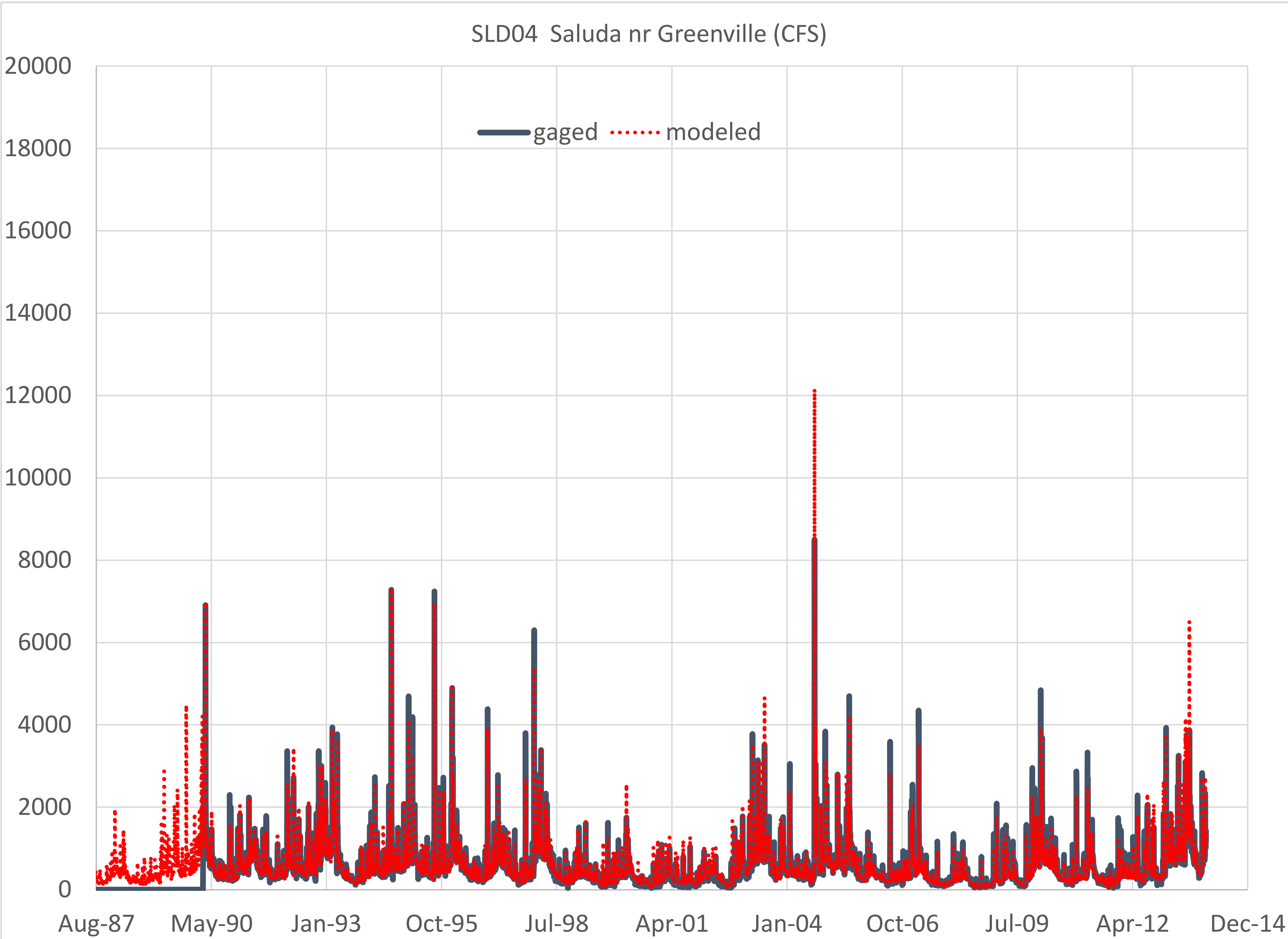


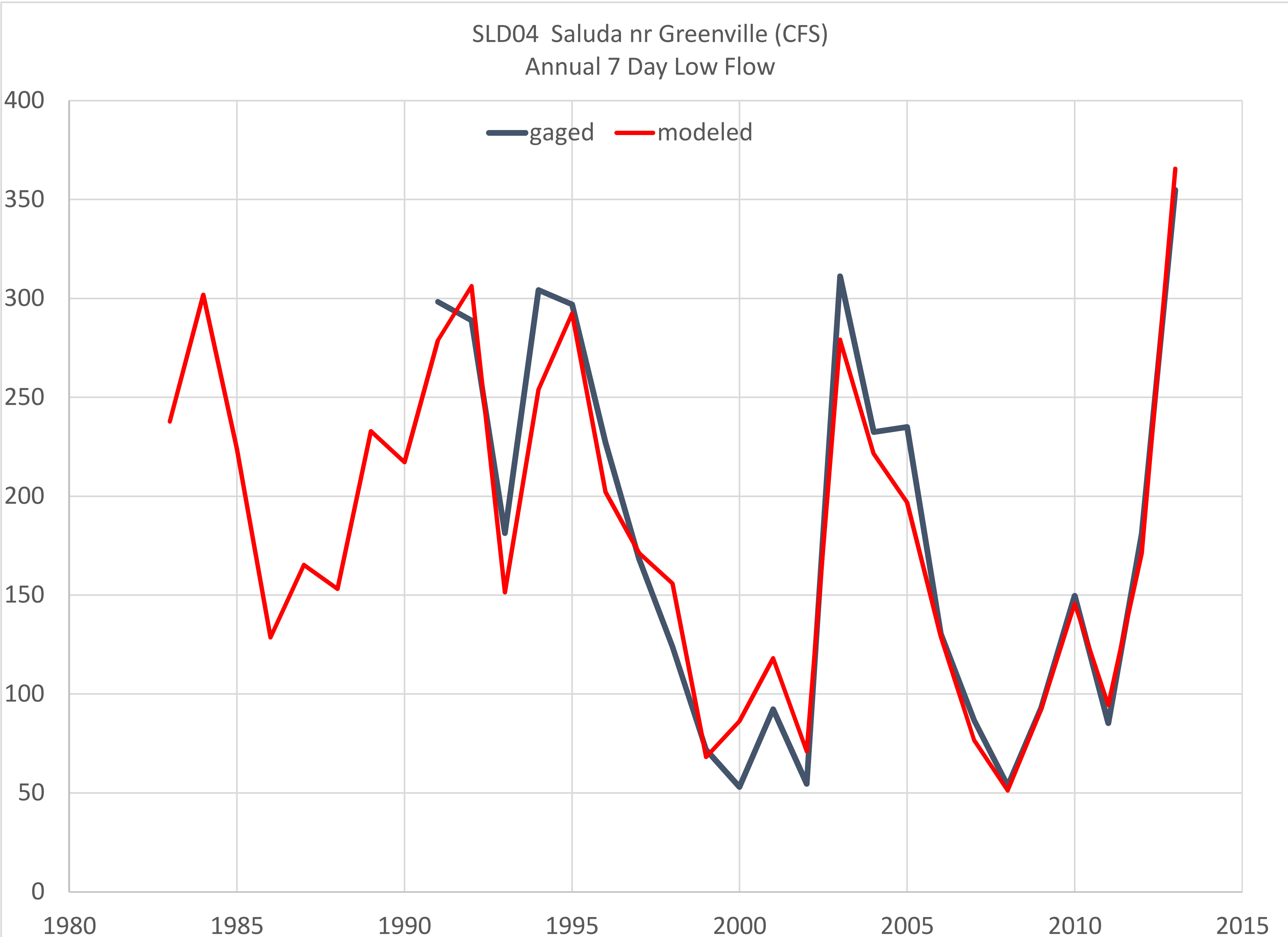
Lake Rabon Reservoir Storage (MG)
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Feb-82
Aug-87
Jan-93
Jul-98
Jan-04
Jul-09
Dec-14

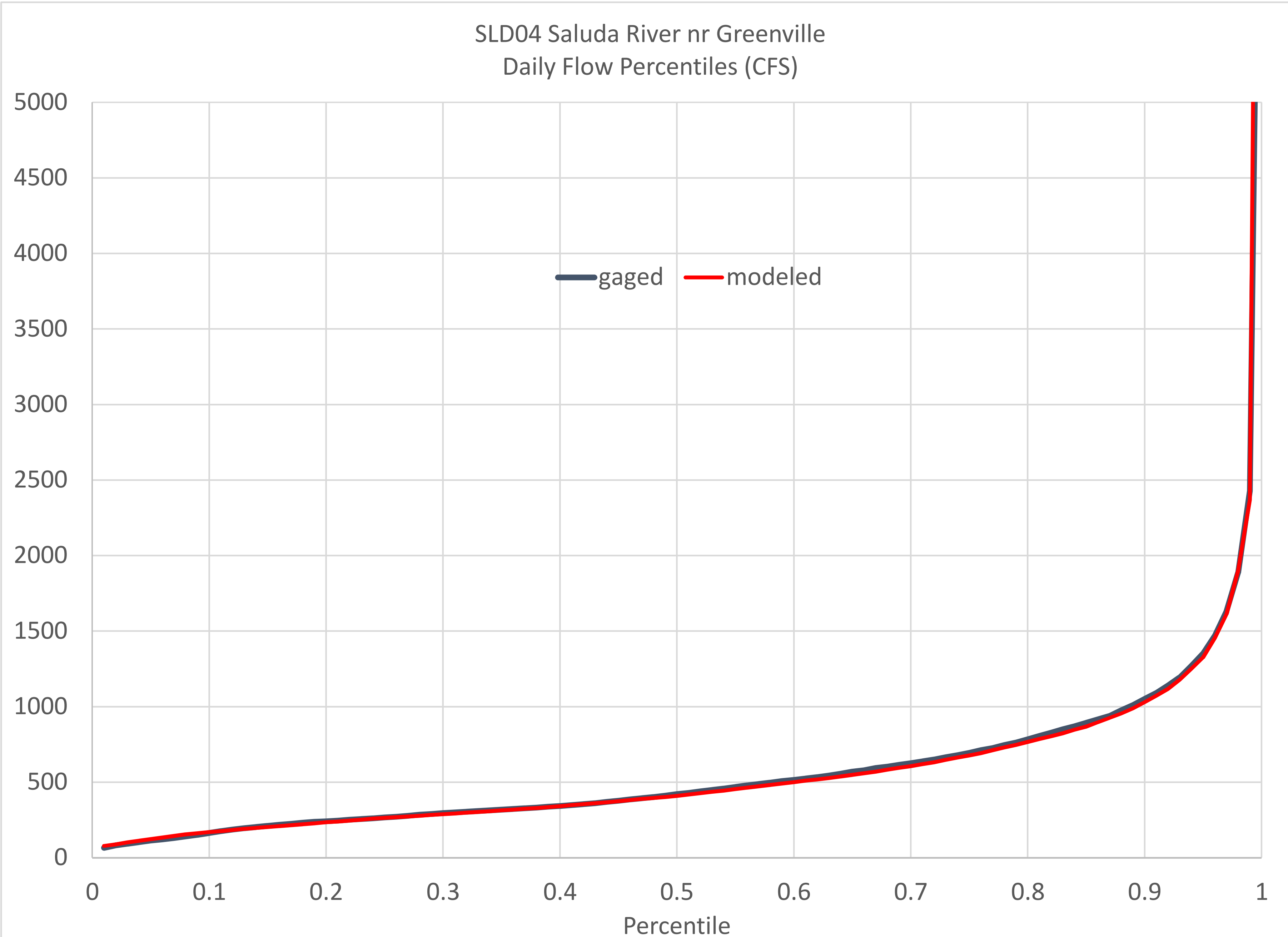
Appendix B

Saluda River Basin Model
Daily Calibration Results

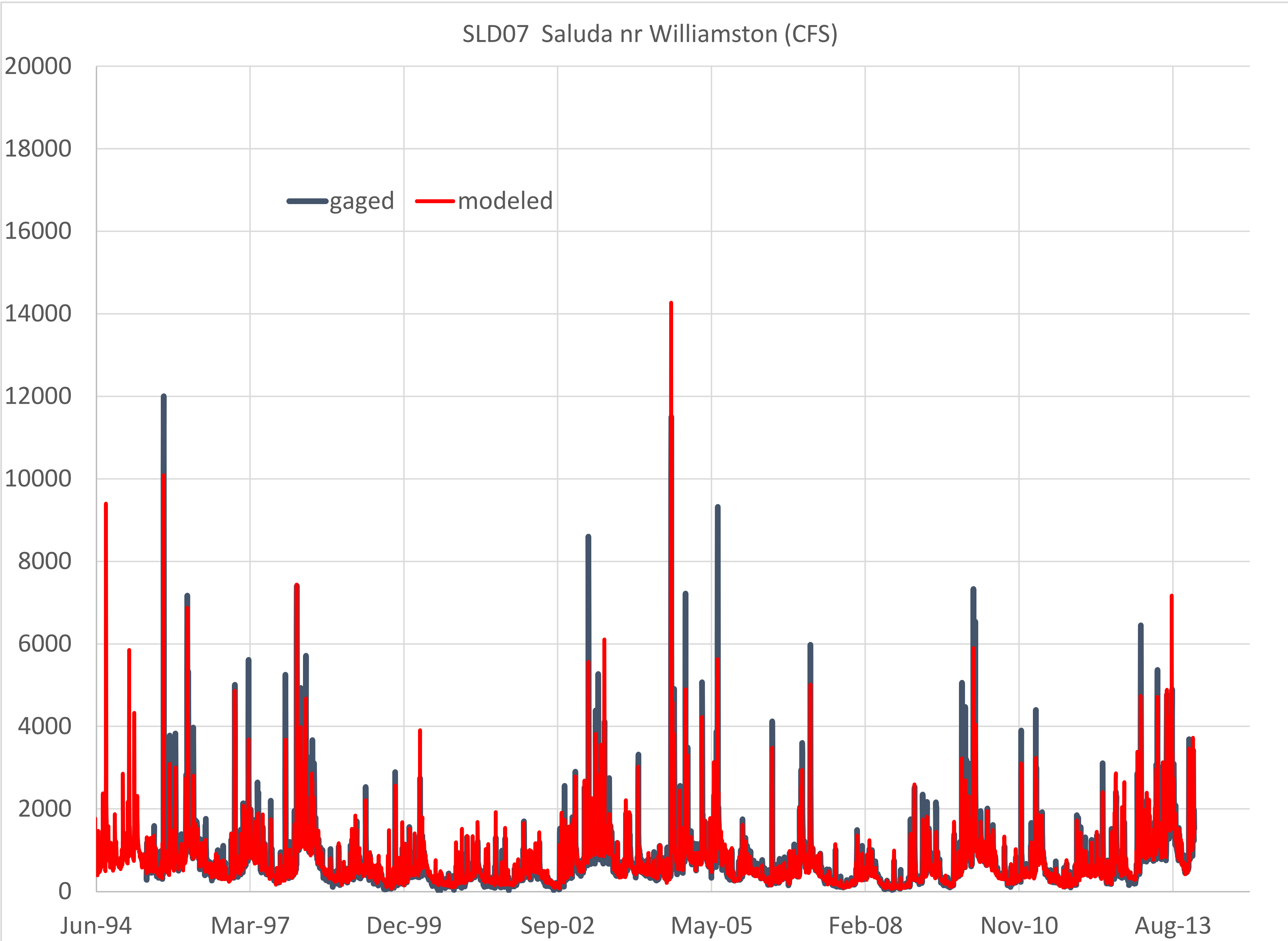
CDM Smith

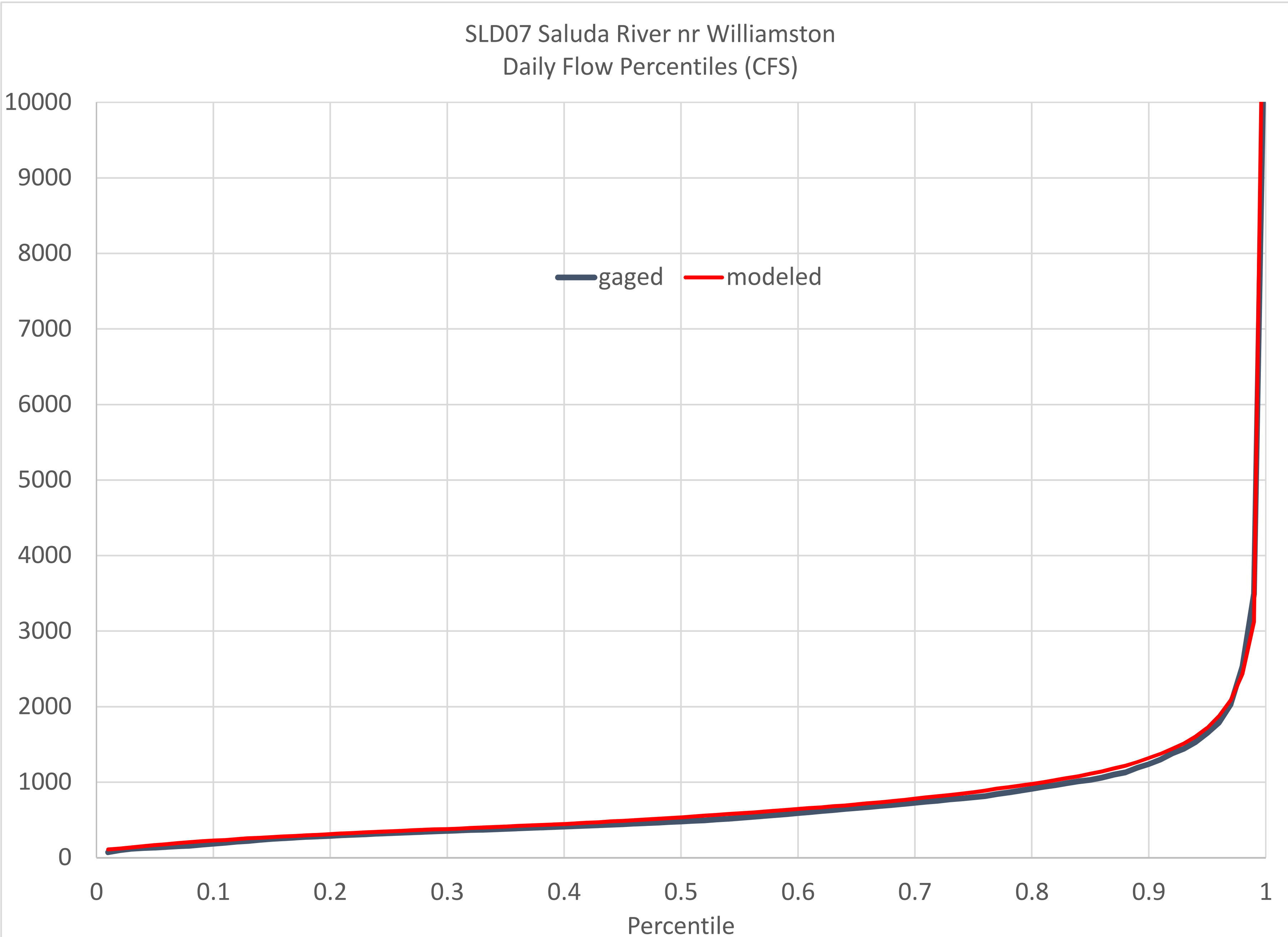

SLD04 Saluda nr Greenville (CFS)
gaged
modeled
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Aug-87
May-90
Jan-93
Oct-95
Jul-98
Apr-01
Jan-04
Oct-06
Jul-09
Apr-12
Dec-14

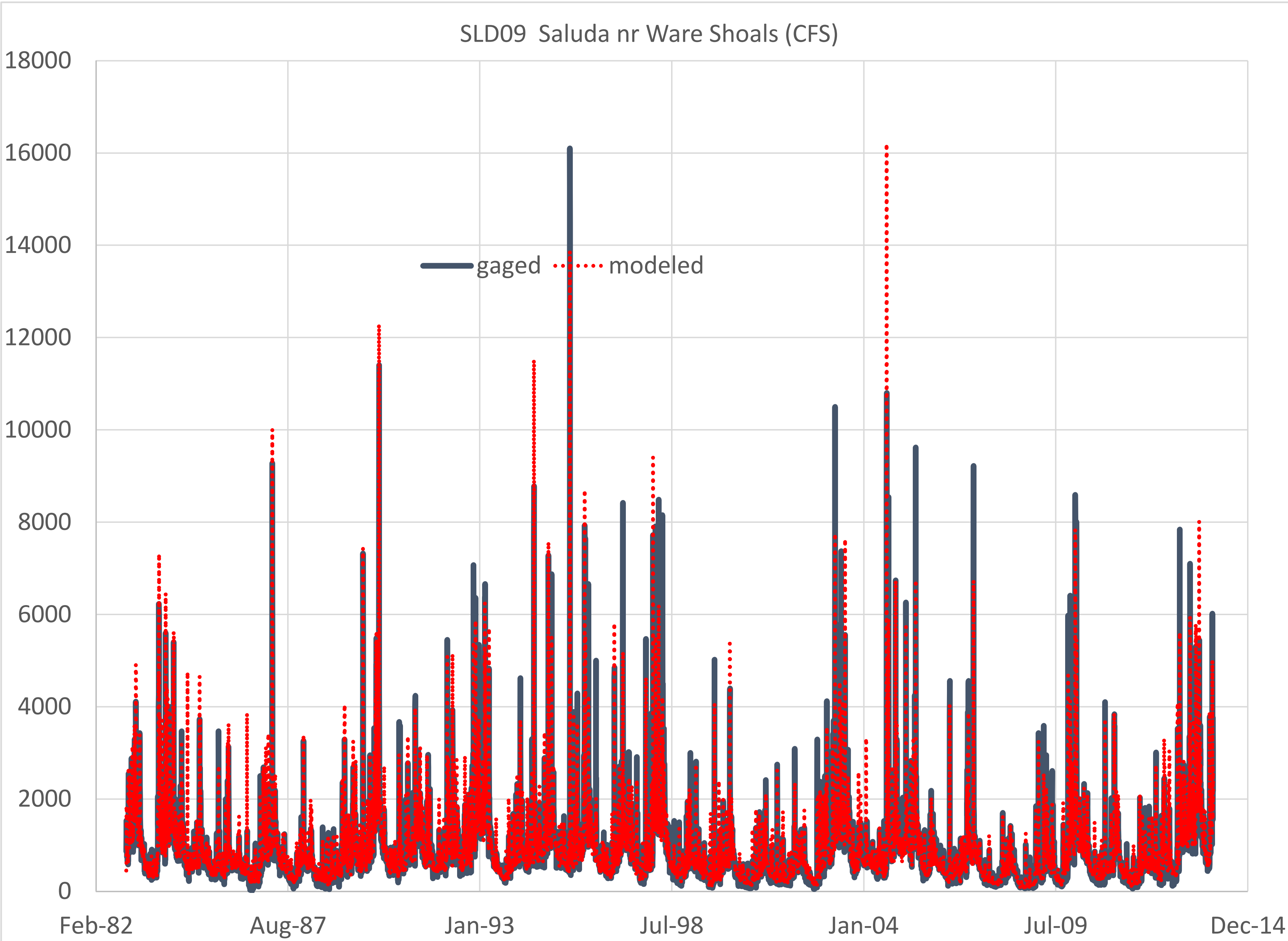

SLD04 Saluda nr Greenville (CFS)
Annual 7 Day Low Flow
gaged
modeled
400
350
300
250
200
150
100
50
0
1980
1985
1990
1995
2000
2005
2010
2015



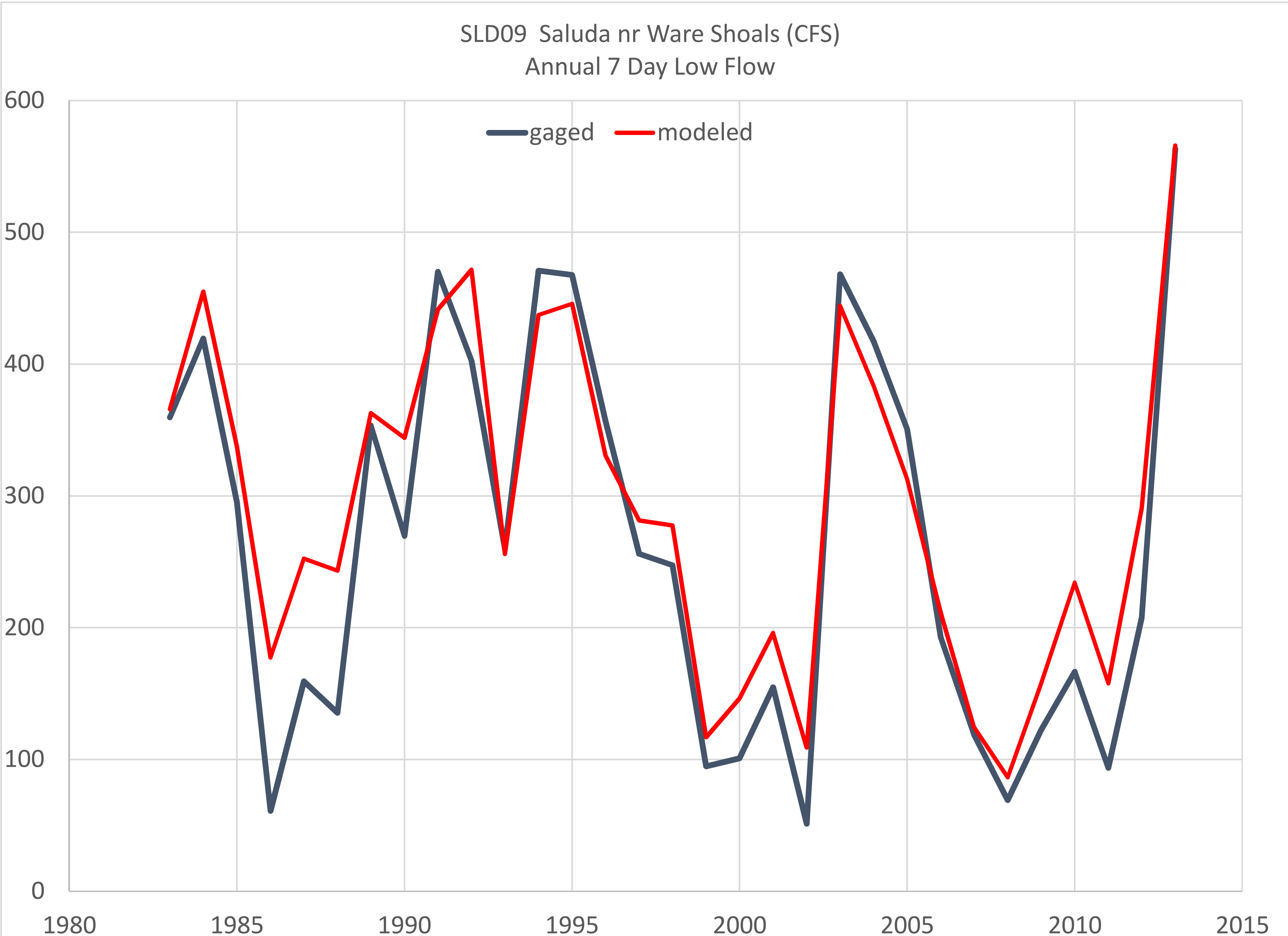
SLD04 Saluda River nr Greenville
Daily Flow Percentiles (CFS)
gaged
modeled
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

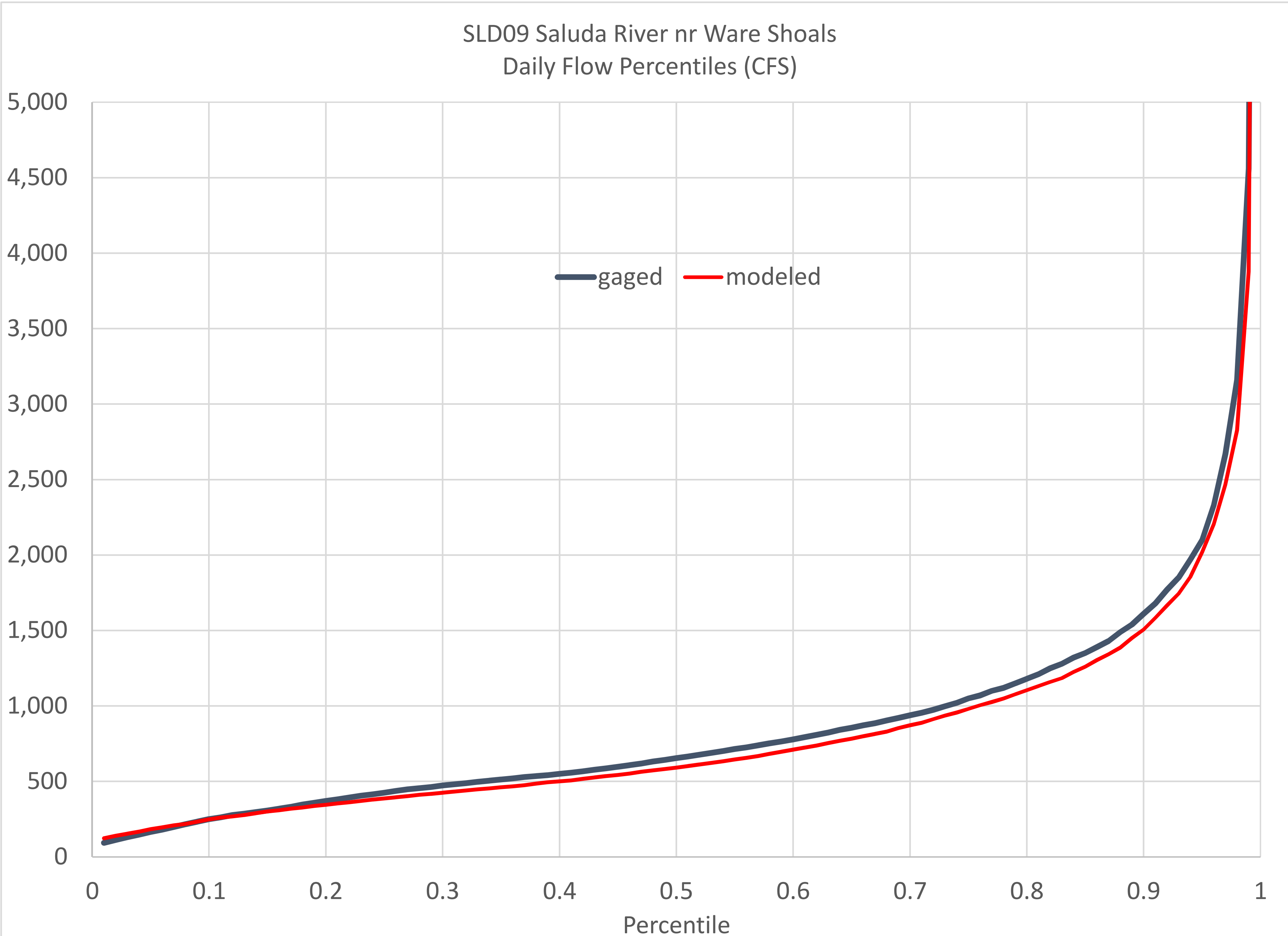

SLD07 Saluda nr Williamston (CFS)
gaged
modeled
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Jun-94
Mar-97
Dec-99
Sep-02
May-05
Feb-08
Nov-10
Aug-13


SLD07 Saluda River nr Williamston
Daily Flow Percentiles (CFS)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
gaged
modeled
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

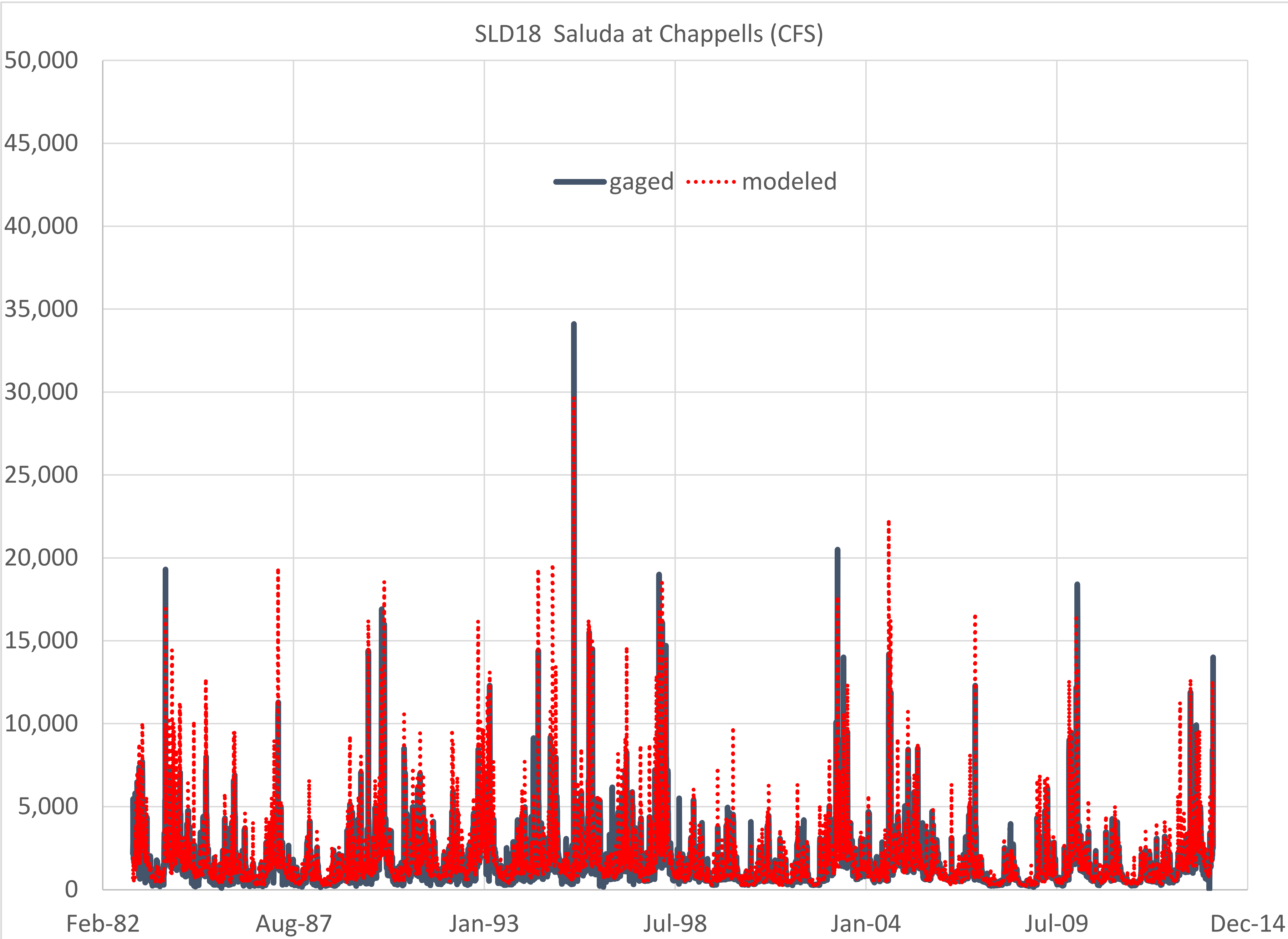


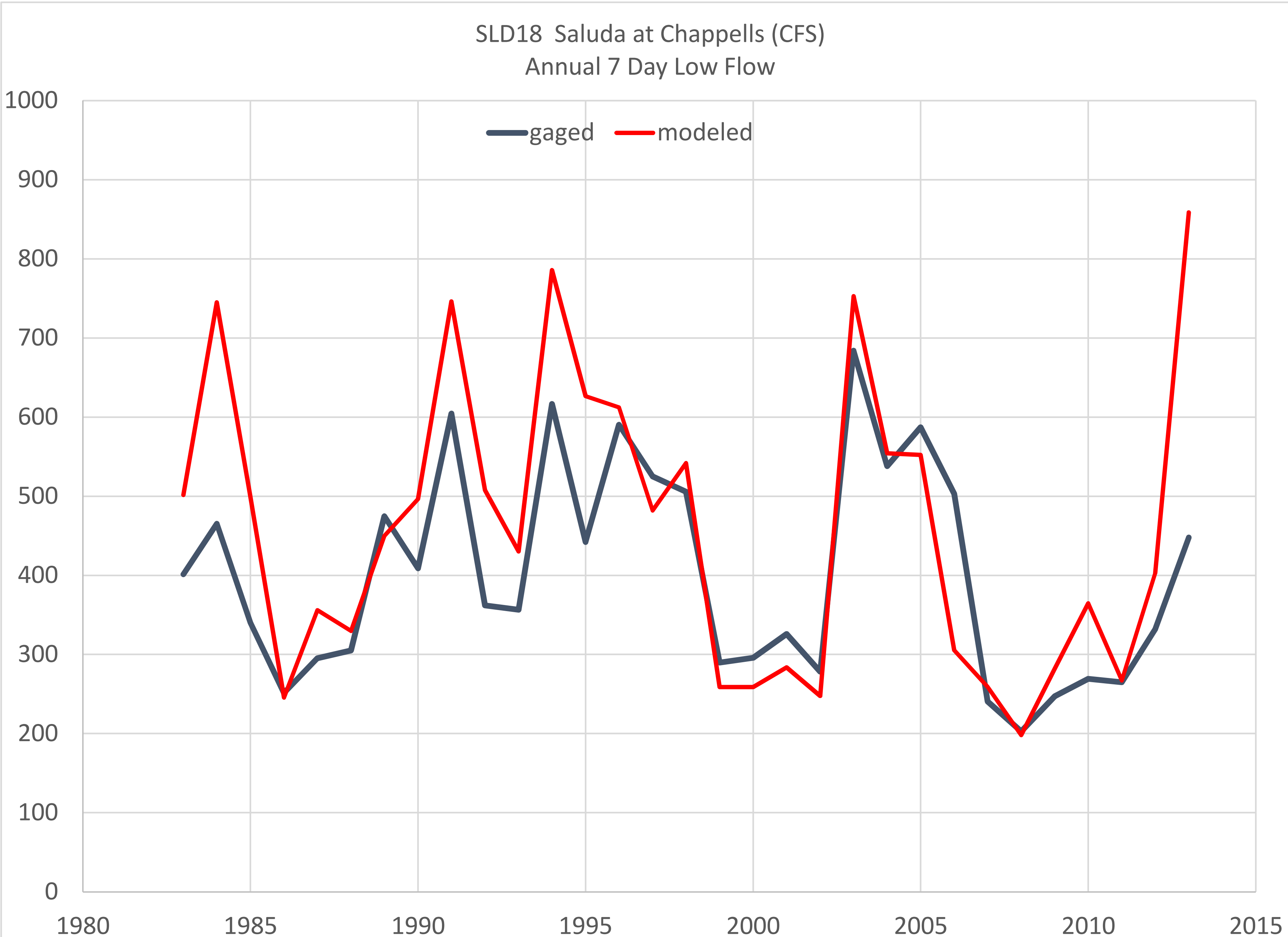
SLD09 Saluda nr Ware Shoals (CFS)
gaged
modeled
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Feb-82
Aug-87
Jan-93
Jul-98
Jan-04
Jul-09
Dec-14

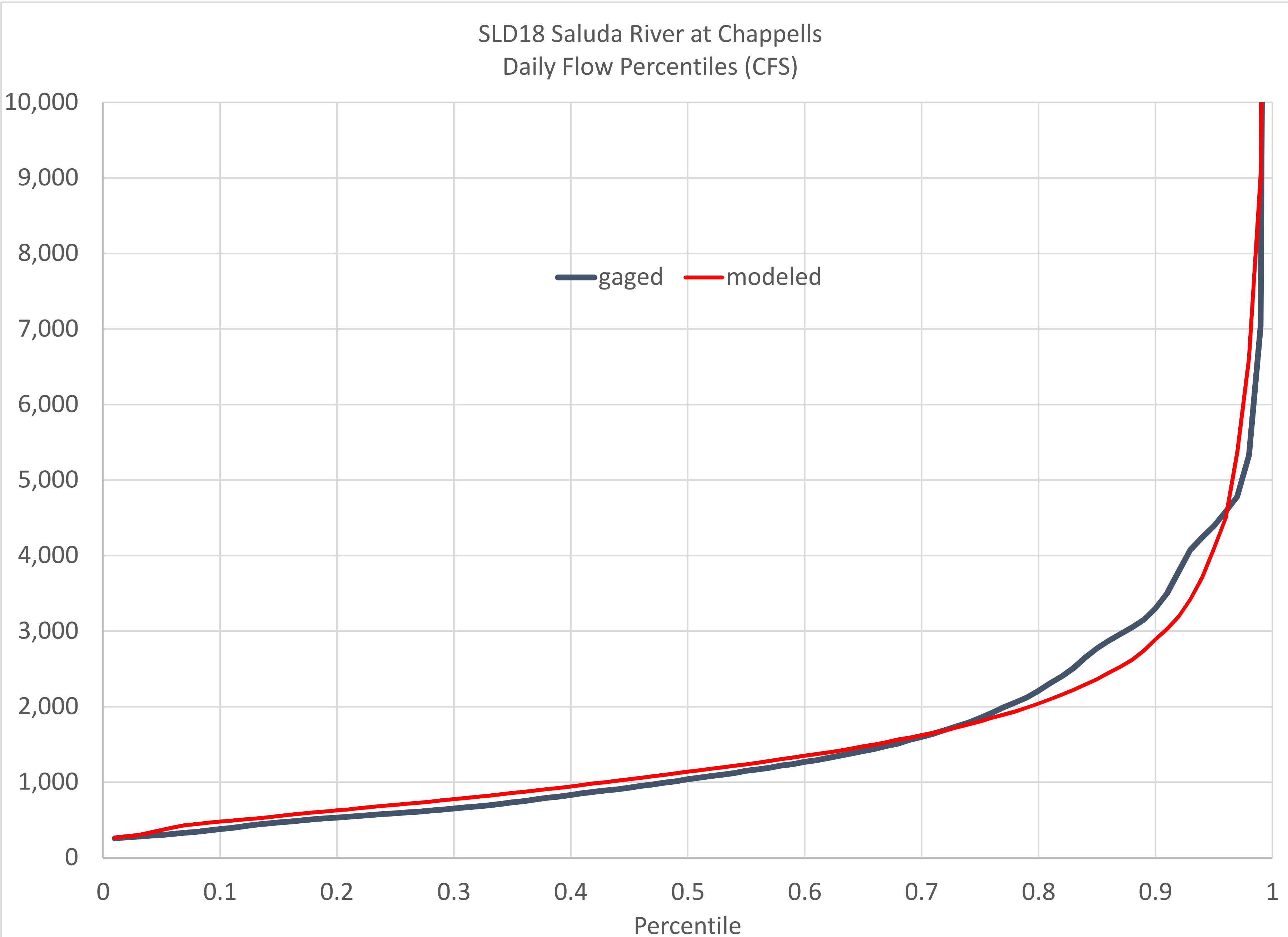

SLD09 Saluda nr Ware Shoals (CFS)
Annual 7 Day Low Flow
gaged
modeled
600
500
400
300
200
100
0
1980
1985
1990
1995
2000
2005
2010
2015

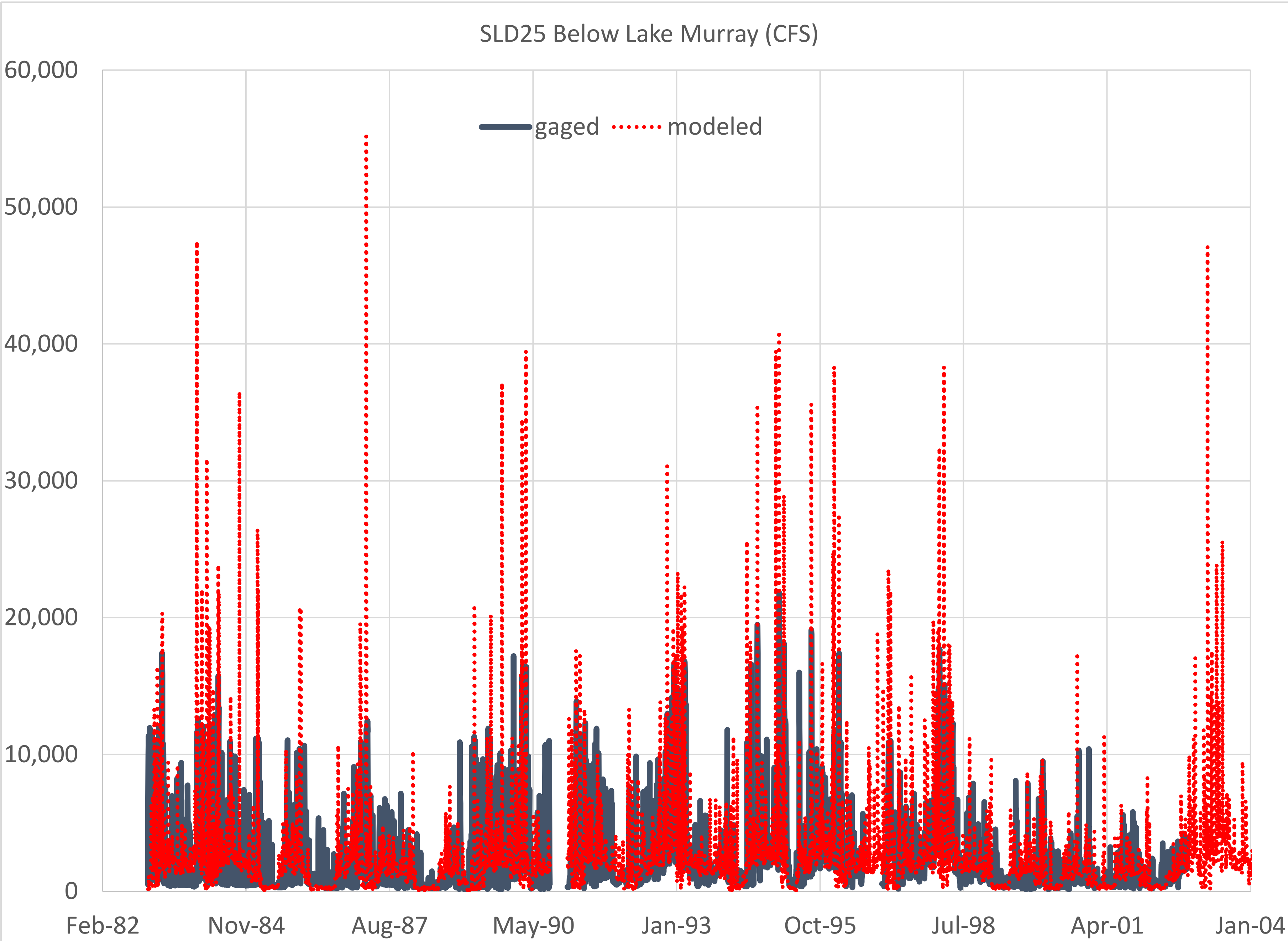


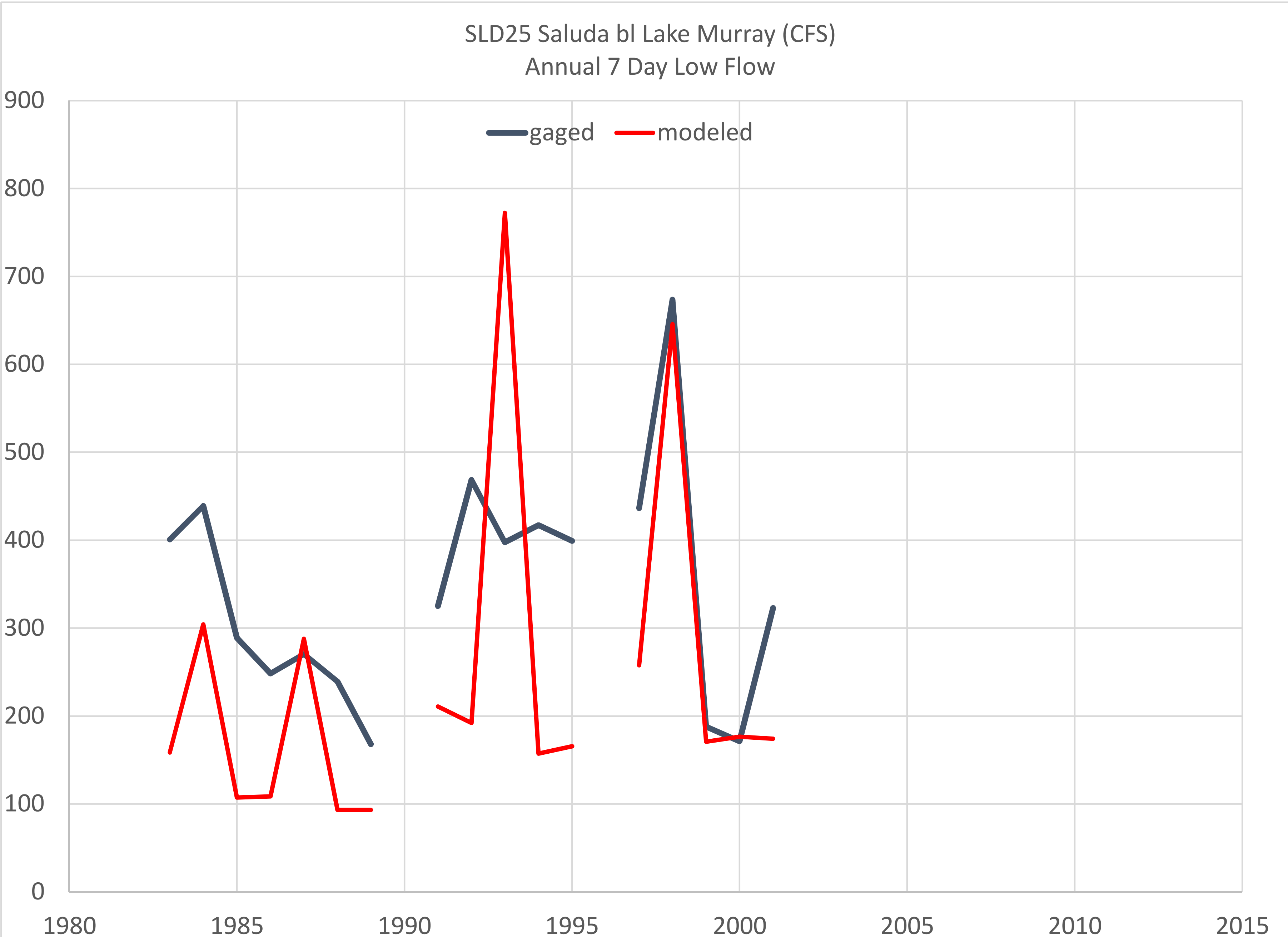
SLD09 Saluda River nr Ware Shoals
Daily Flow Percentiles (CFS)
gaged
modeled
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

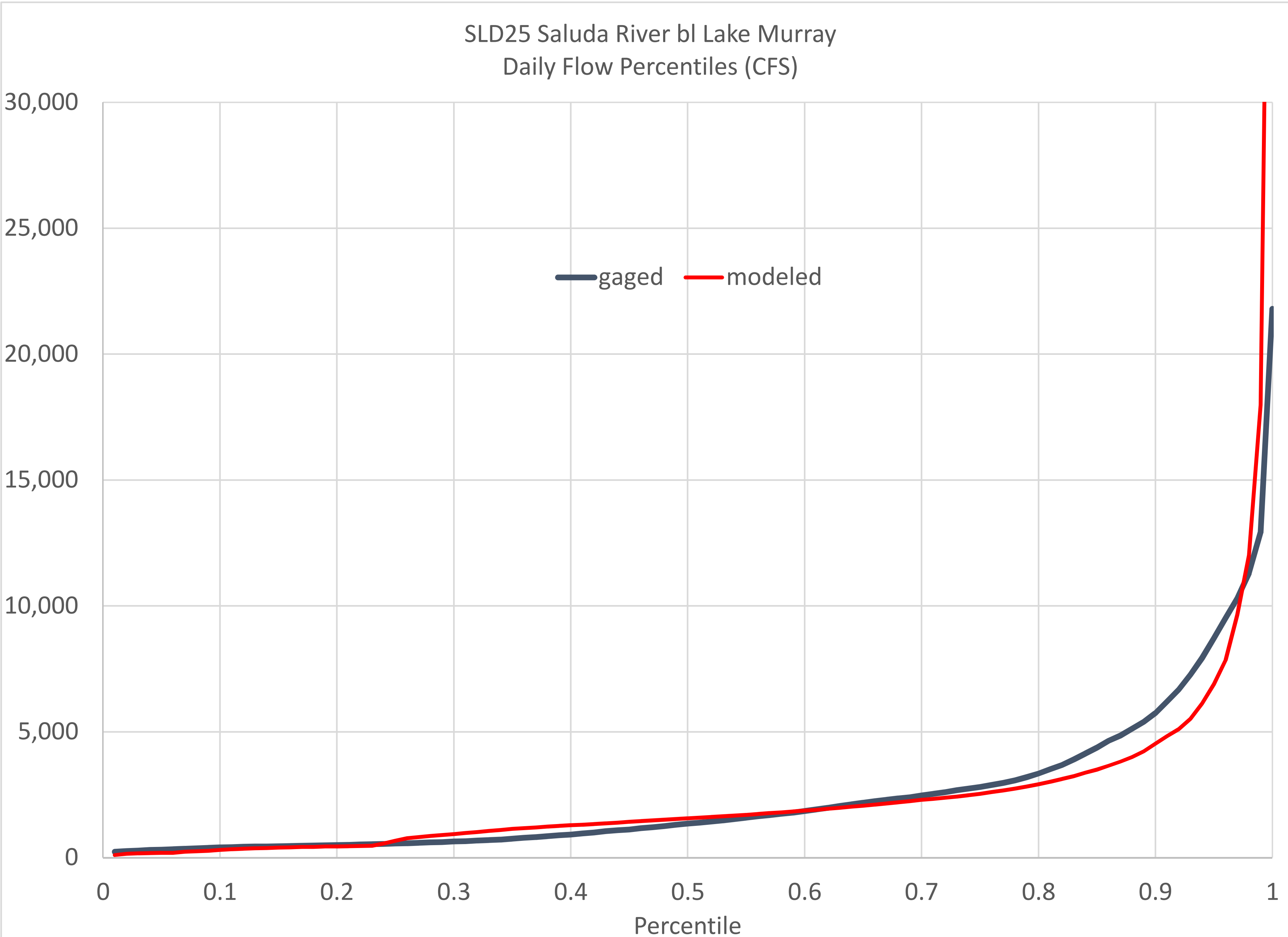

SLD18 Saluda at Chappells (CFS)
gaged
modeled
50,000
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
Feb-82
Aug-87
Jan-93
Jul-98
Jan-04
Jul-09
Dec-14

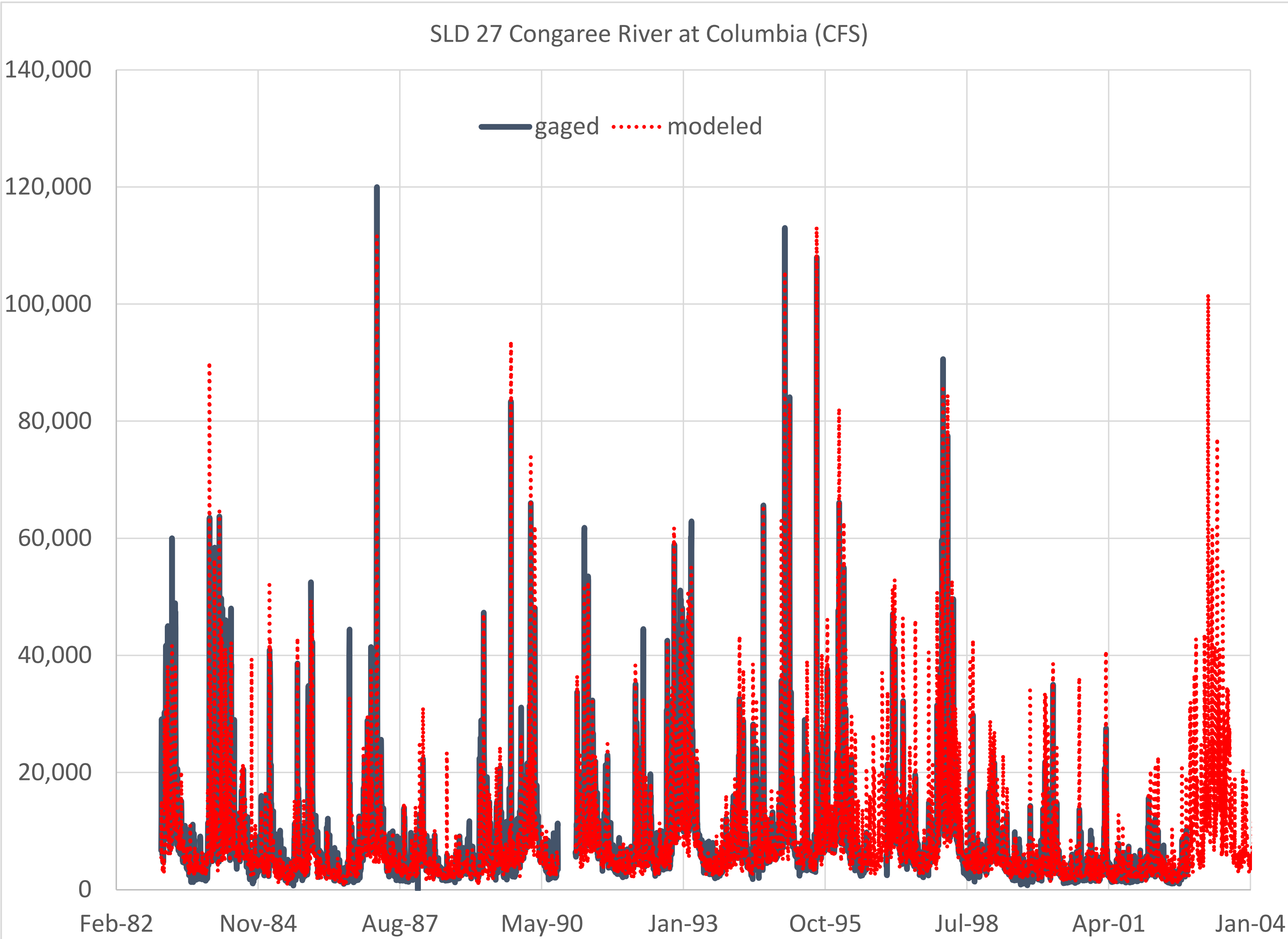

SLD18 Saluda at Chappells (CFS)
Annual 7 Day Low Flow
gaged
modeled
1000
900
800
700
600
500
400
300
200
100
0
1980
1985
1990
1995
2000
2005
2010
2015

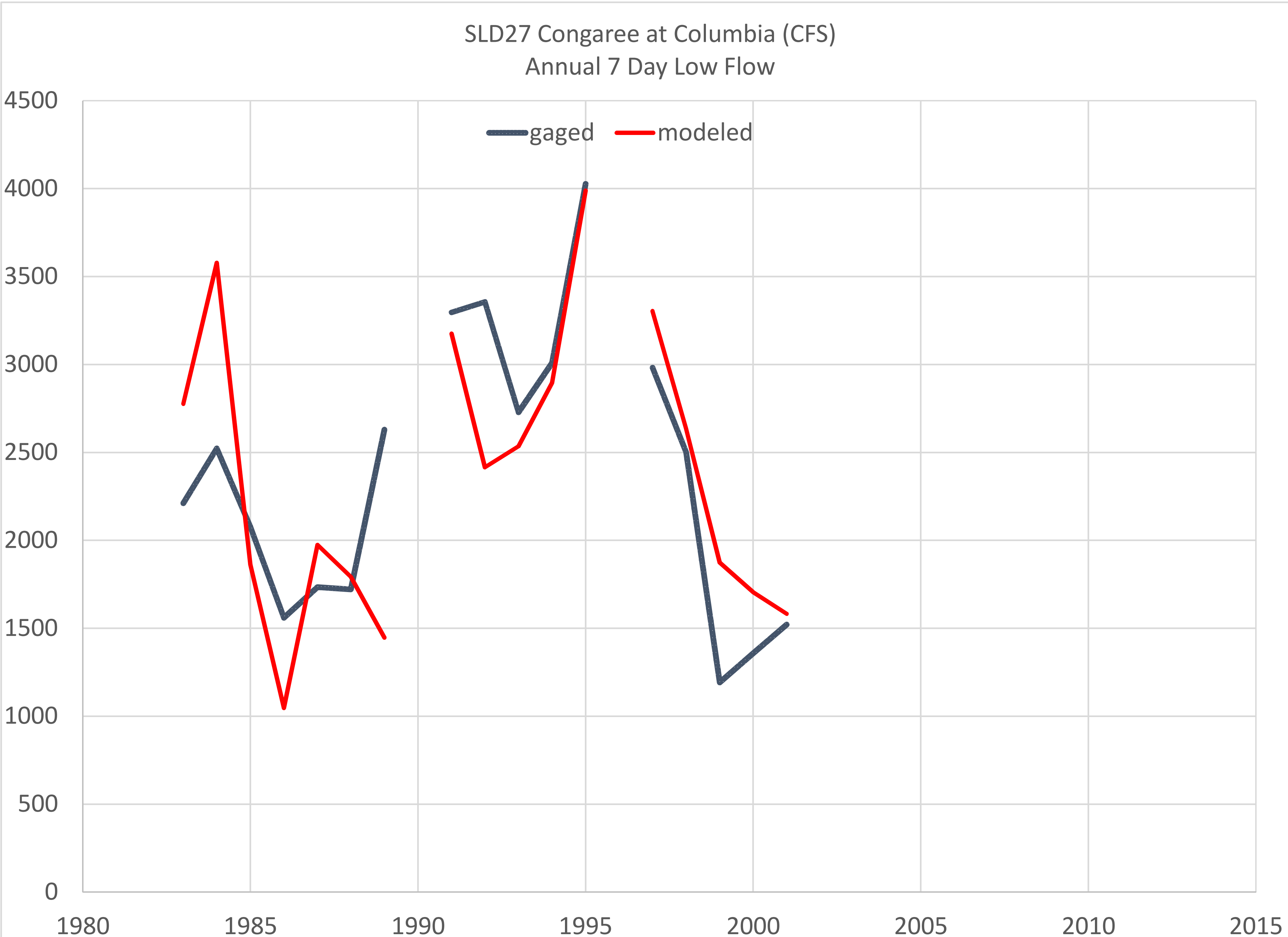

SLD18 Saluda River at Chappells
Daily Flow Percentiles (CFS)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
gaged
modeled
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

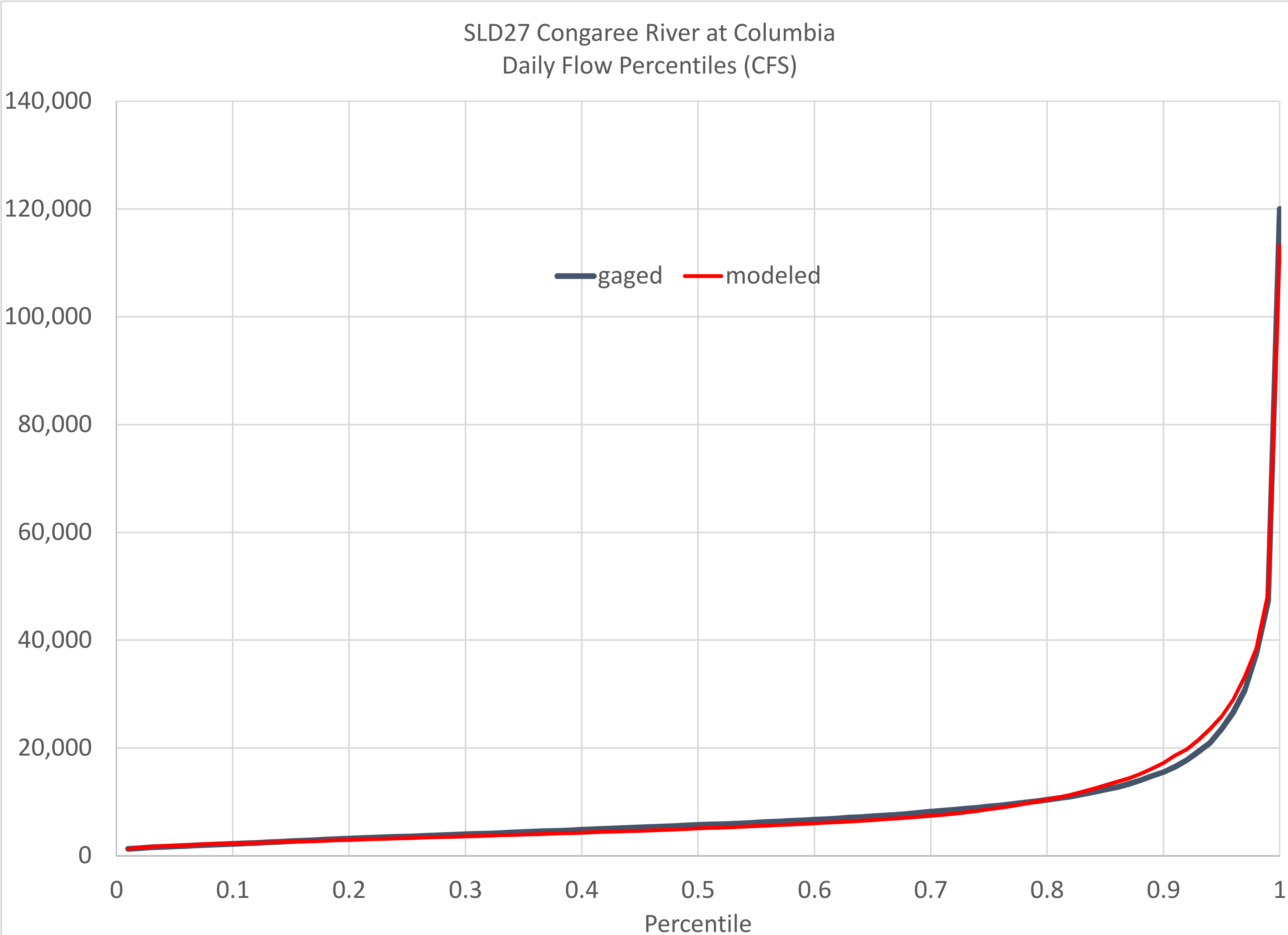

SLD25 Below Lake Murray (CFS)
gaged
modeled
60,000
50,000
40,000
30,000
20,000
10,000
0
Feb-82
Nov-84
Aug-87
May-90
Jan-93
Oct-95
Jul-98
Apr-01
Jan-04

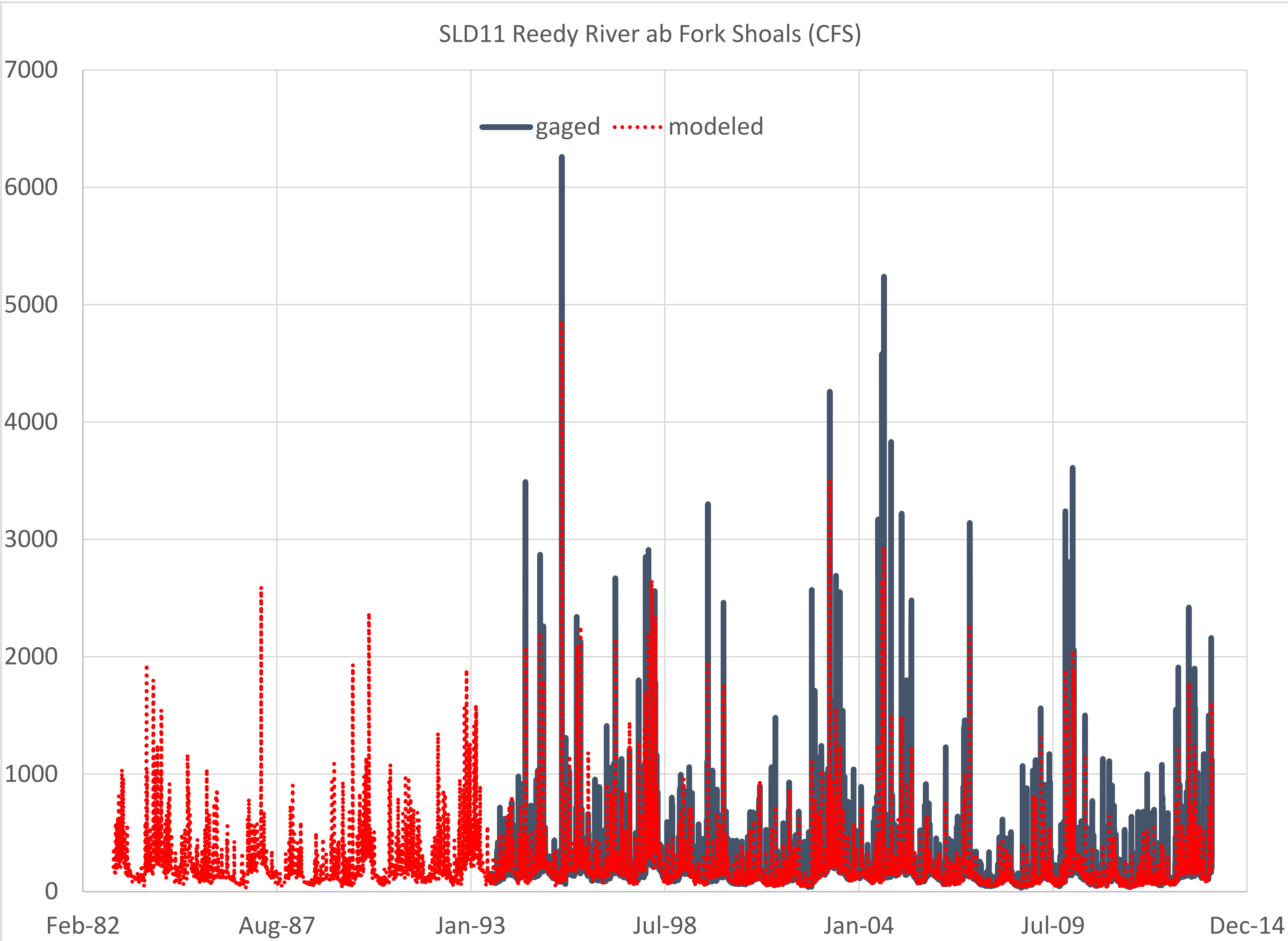

SLD25 Saluda bl Lake Murray (CFS)
Annual 7 Day Low Flow
gaged
modeled
900
800
700
600
500
400
300
200
100
0
1980
1985
1990
1995
2000
2005
2010
2015

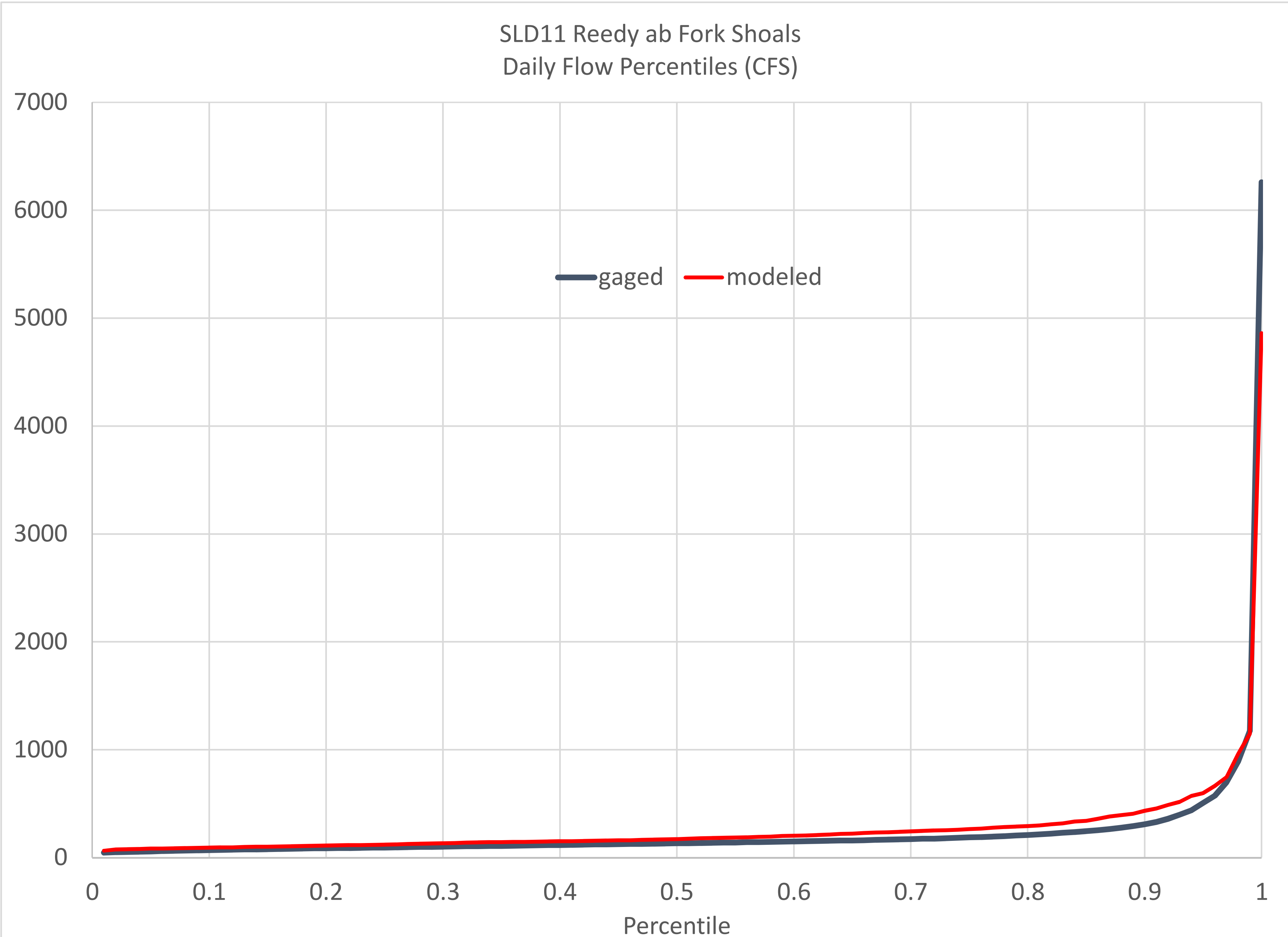

SLD25 Saluda River bl Lake Murray
Daily Flow Percentiles (CFS)
gaged
modeled
30,000
25,000
20,000
15,000
10,000
5,000
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

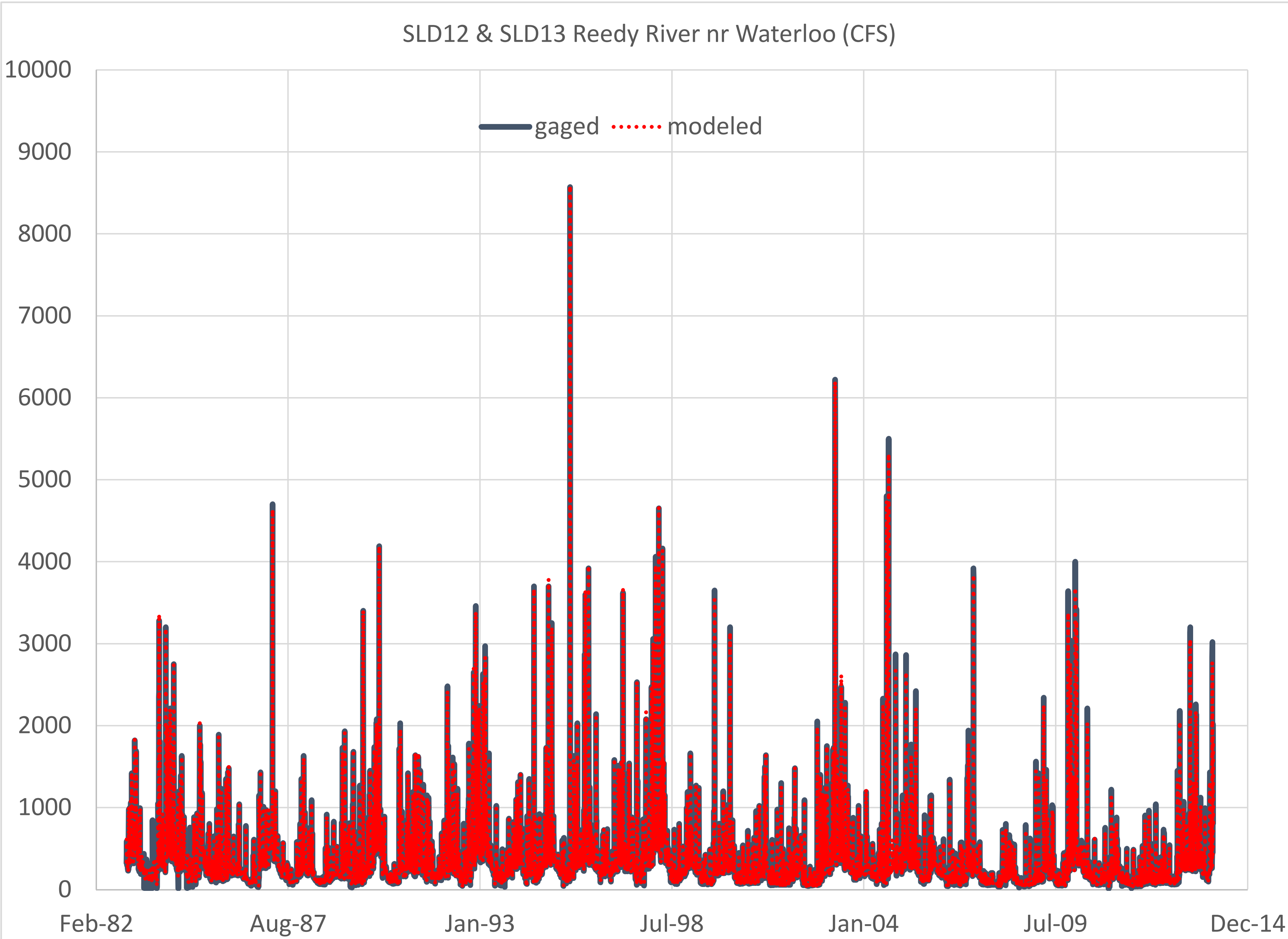

SLD 27 Congaree River at Columbia (CFS)
gaged
modeled
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
Feb-82
Nov-84
Aug-87
May-90
Jan-93
Oct-95
Jul-98
Apr-01
Jan-04

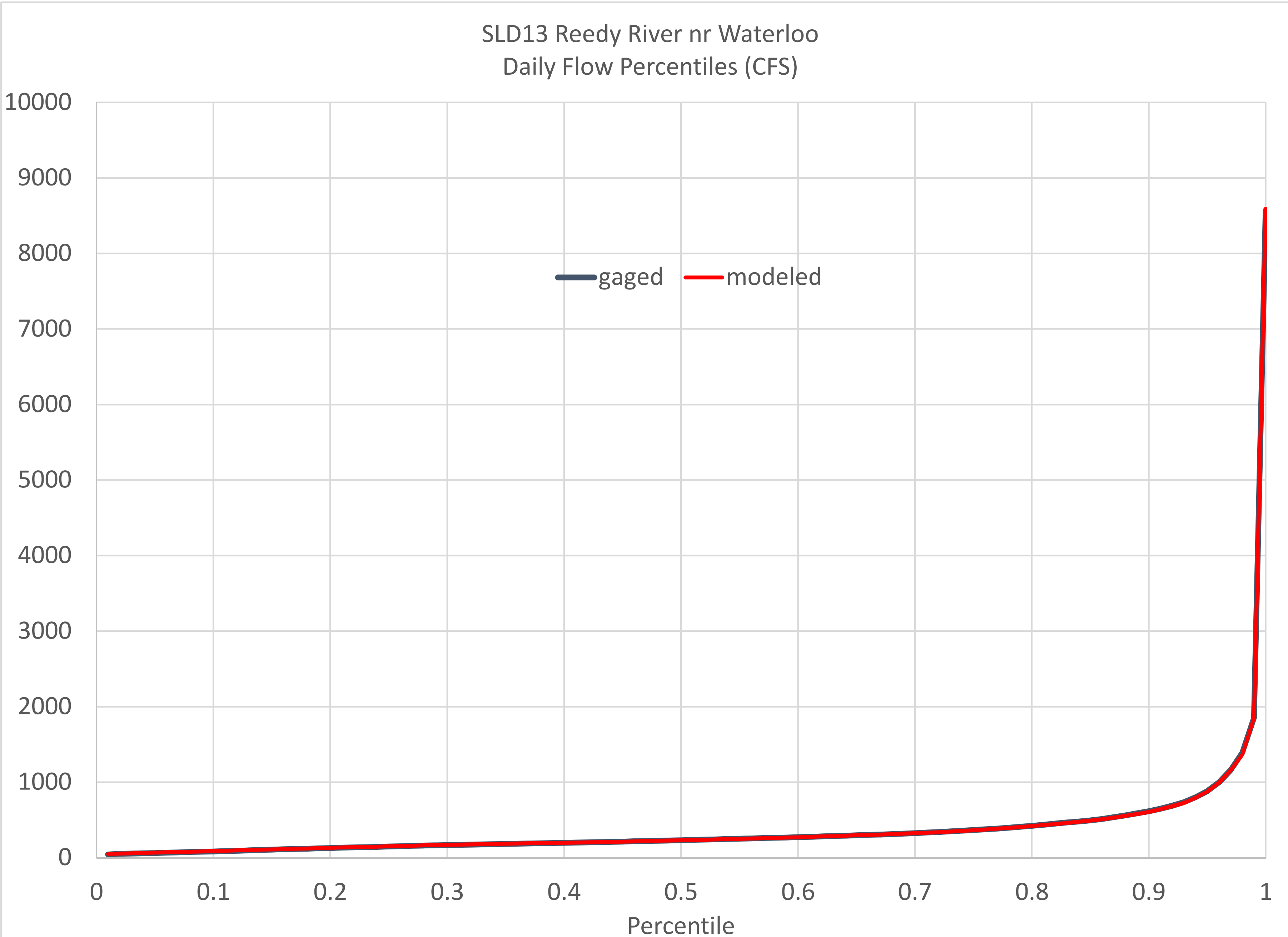

SLD27 Congaree at Columbia (CFS)
Annual 7 Day Low Flow
gaged
modeled
0
500
1000
1500
2000
2500
3000
3500
4000
4500
1980
1985
1990
1995
2000
2005
2010
2015

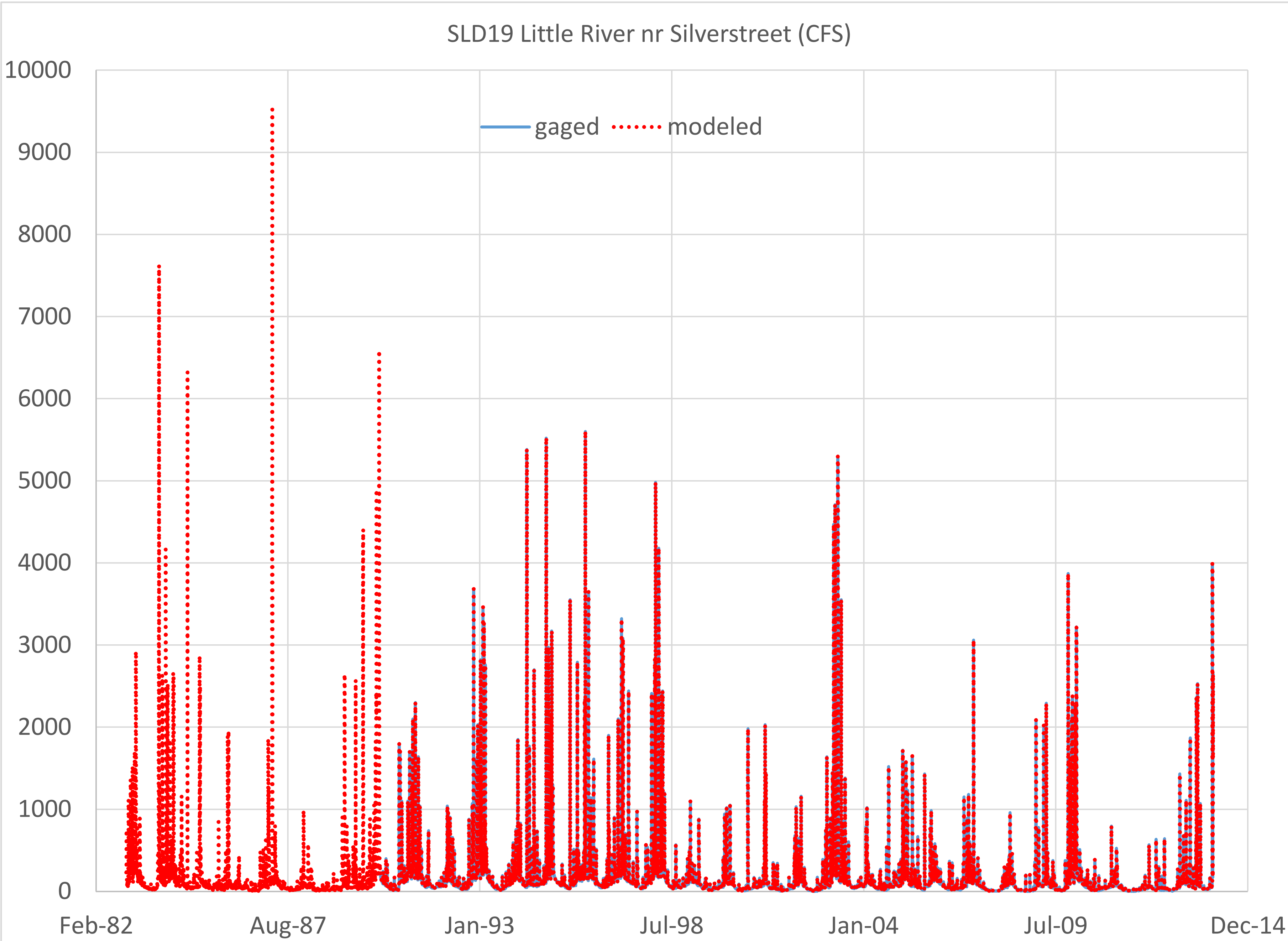

SLD27 Congaree River at Columbia
Daily Flow Percentiles (CFS)
gaged
modeled
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile


SLD11 Reedy River ab Fork Shoals (CFS)
gaged
modeled
7000
6000
5000
4000
3000
2000
1000
0
Feb-82
Aug-87
Jan-93
Jul-98
Jan-04
Jul-09
Dec-14

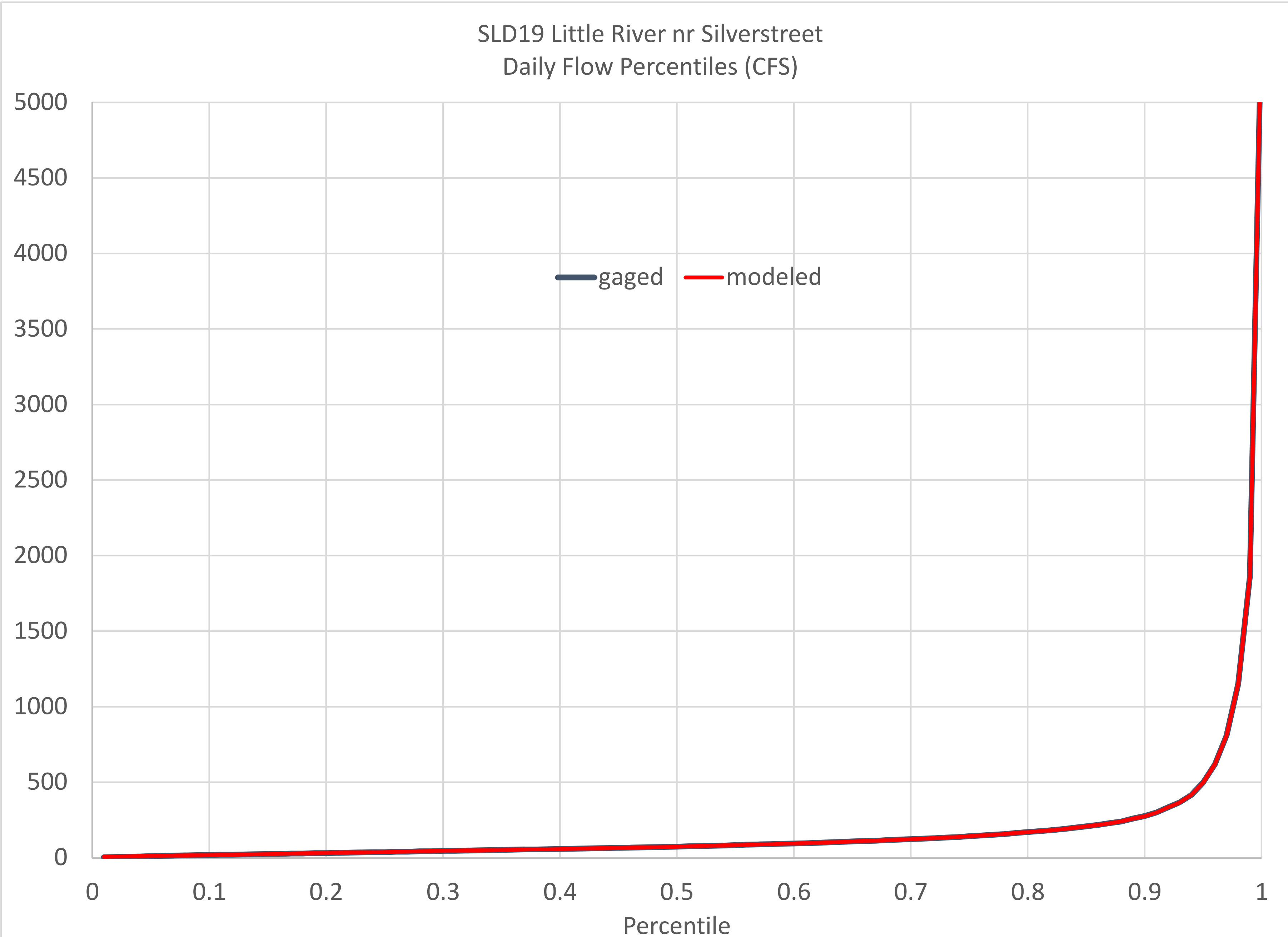

SLD11 Reedy ab Fork Shoals
Daily Flow Percentiles (CFS)
7000
6000
5000
4000
3000
2000
1000
0
gaged
modeled
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile


SLD12 & SLD13 Reedy River nr Waterloo (CFS)
gaged
modeled
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Feb-82
Aug-87
Jan-93
Jul-98
Jan-04
Jul-09
Dec-14

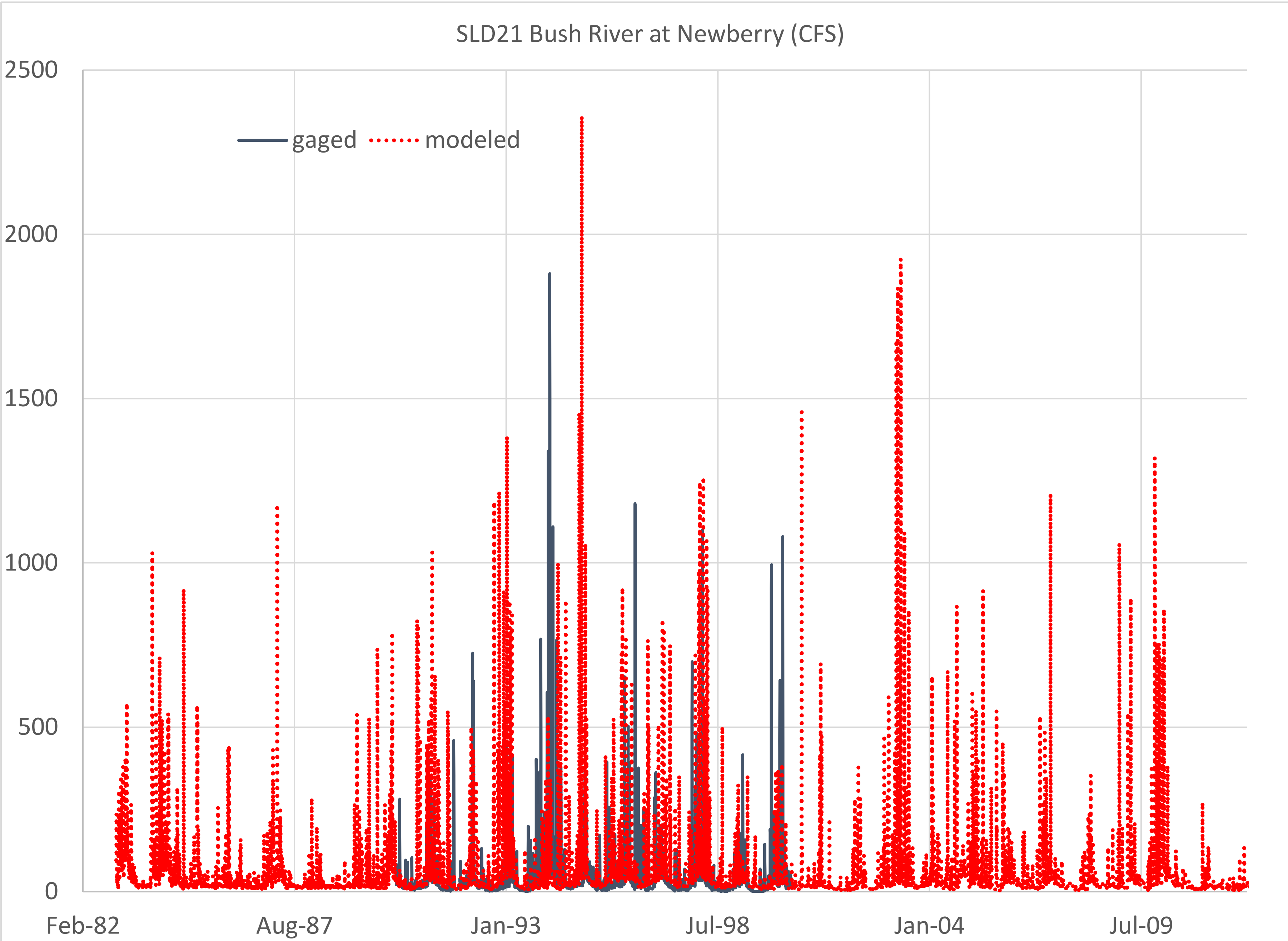

SLD13 Reedy River nr Waterloo
Daily Flow Percentiles (CFS)
gaged
modeled
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile



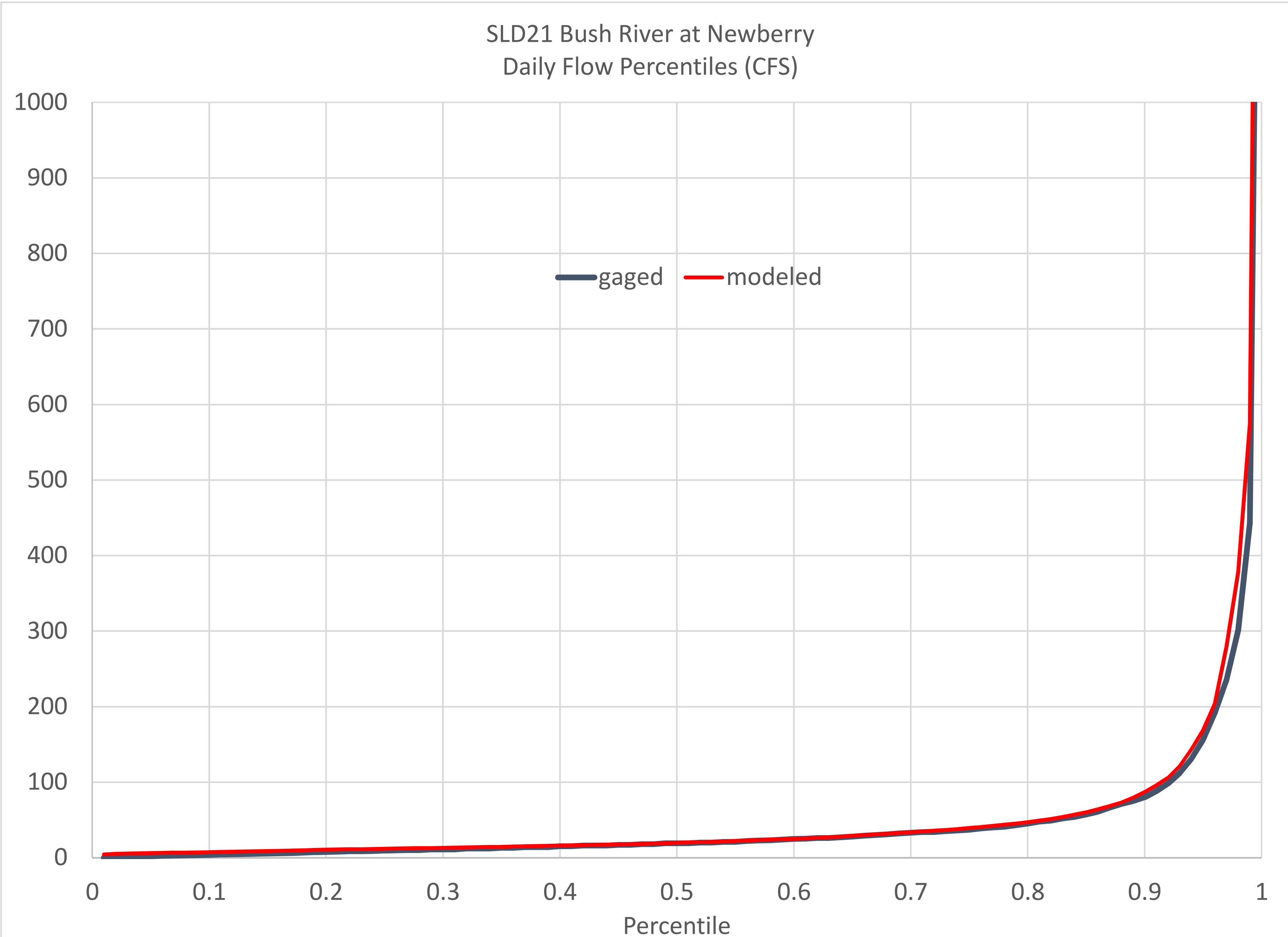
SLD19 Little River nr Silverstreet (CFS)
gaged
modeled
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Feb-82
Aug-87
Jan-93
Jul-98
Jan-04
Jul-09
Dec-14

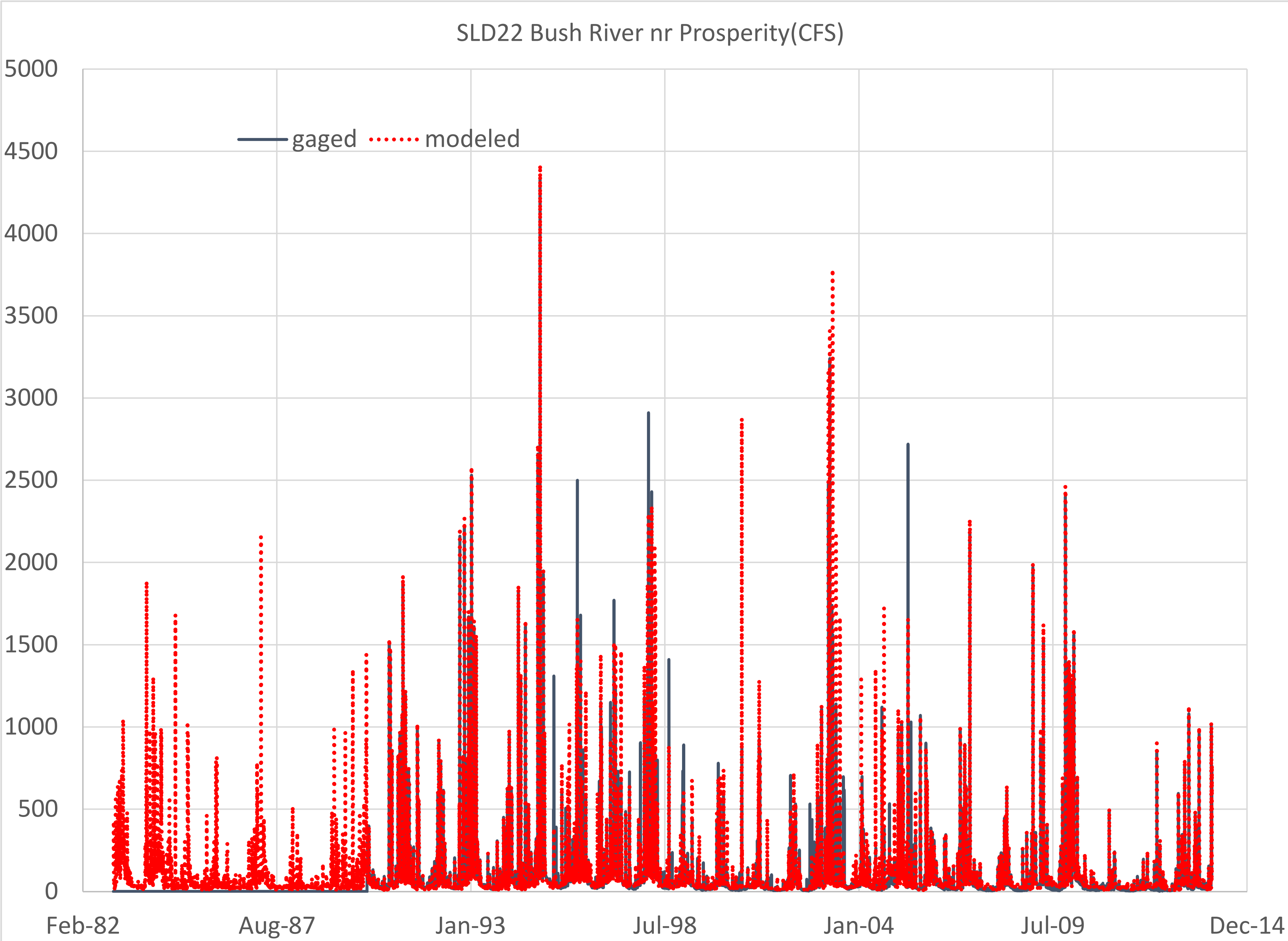


SLD19 Little River nr Silverstreet
Daily Flow Percentiles (CFS)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
gaged
modeled
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

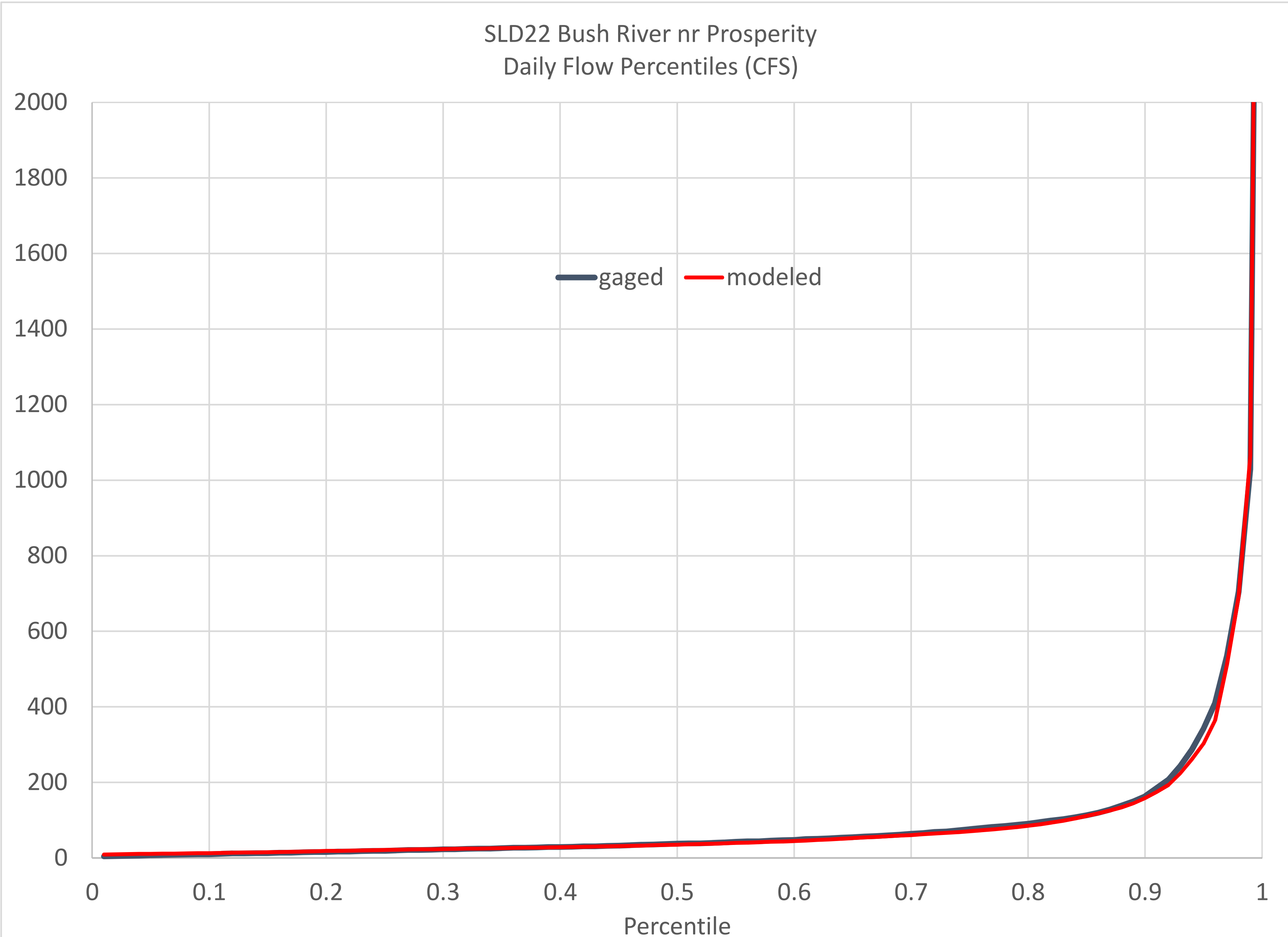


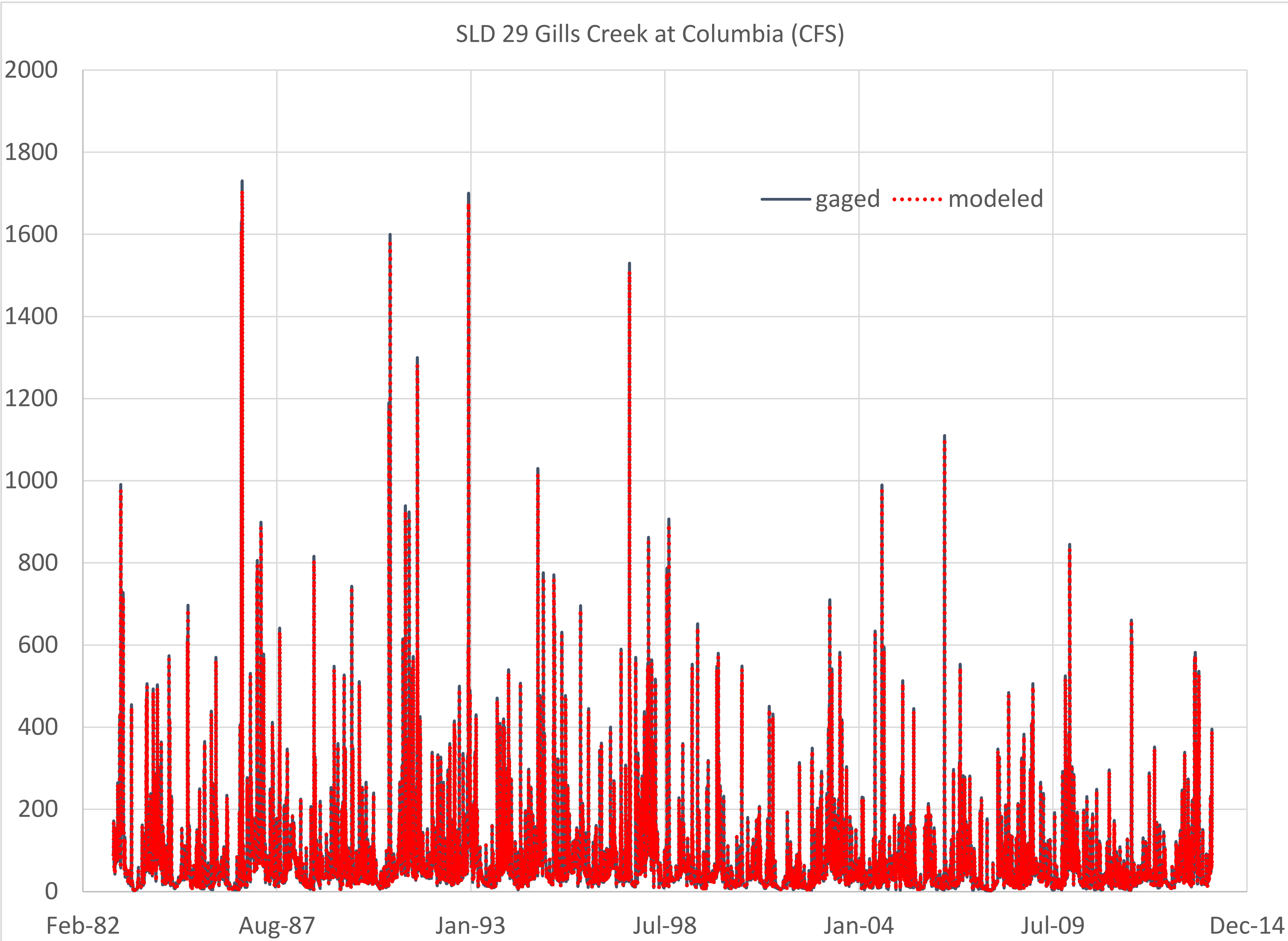
SLD21 Bush River at Newberry (CFS)
2500
2000
1500
1000
500
0
gaged
modeled
Feb-82
Aug-87
Jan-93
Jul-98
Jan-04
Jul-09


SLD21 Bush River at Newberry
Daily Flow Percentiles (CFS)
gaged
modeled
1000
900
800
700
600
500
400
300
200
100
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

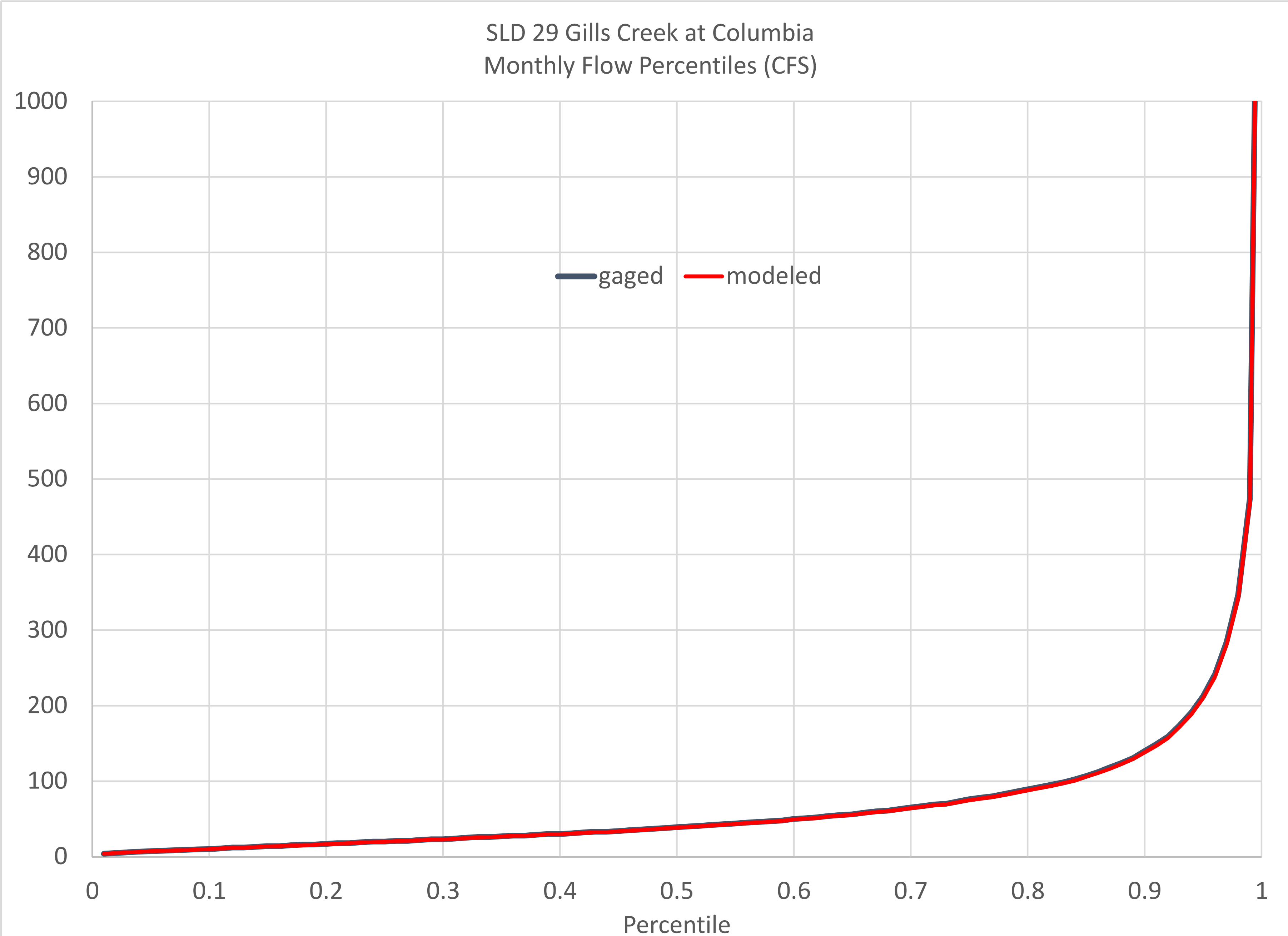


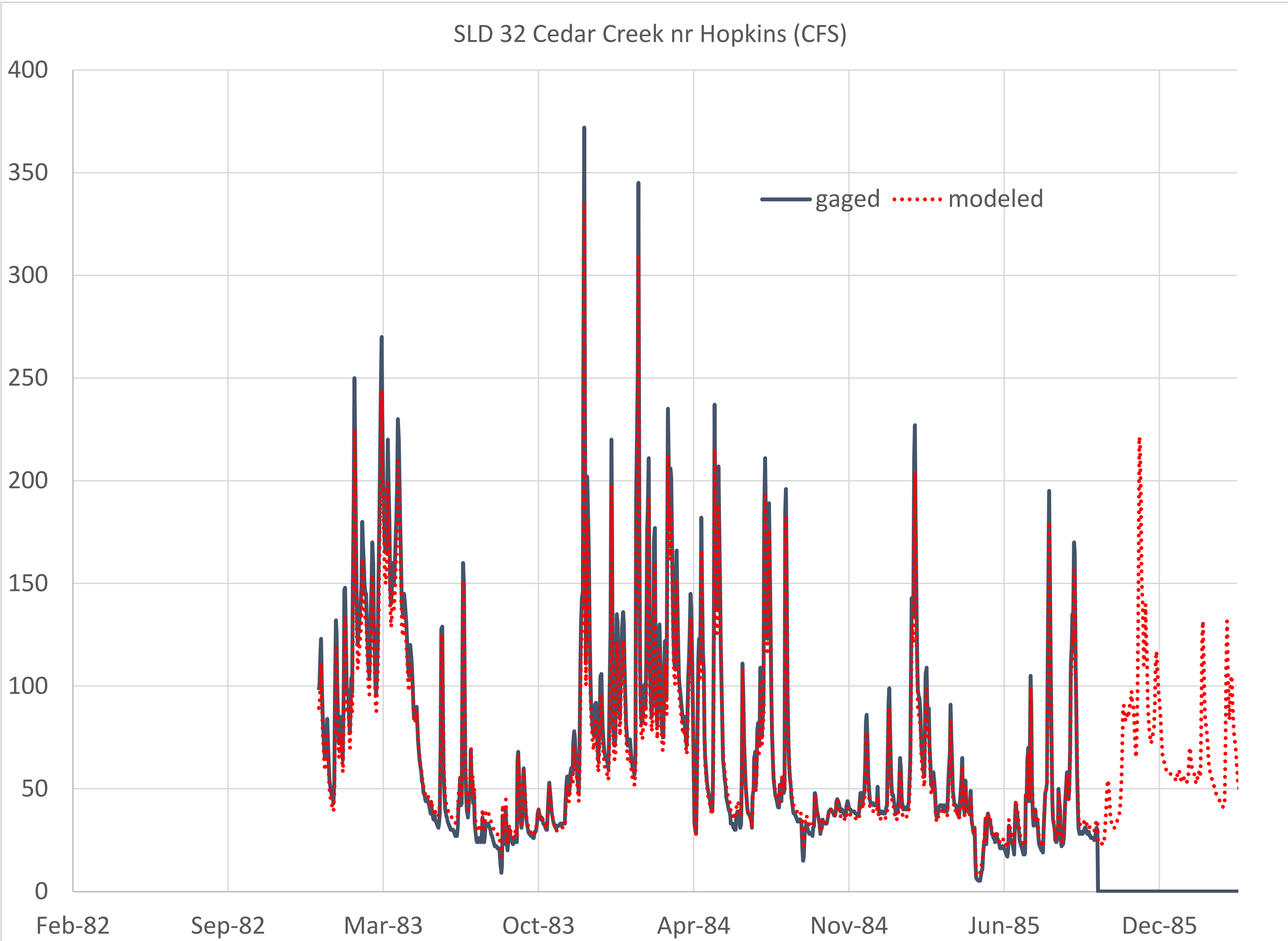
SLD22 Bush River nr Prosperity(CFS)
gaged
modeled
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Feb-82
Aug-87
Jan-93
Jul-98
Jan-04
Jul-09
Dec-14

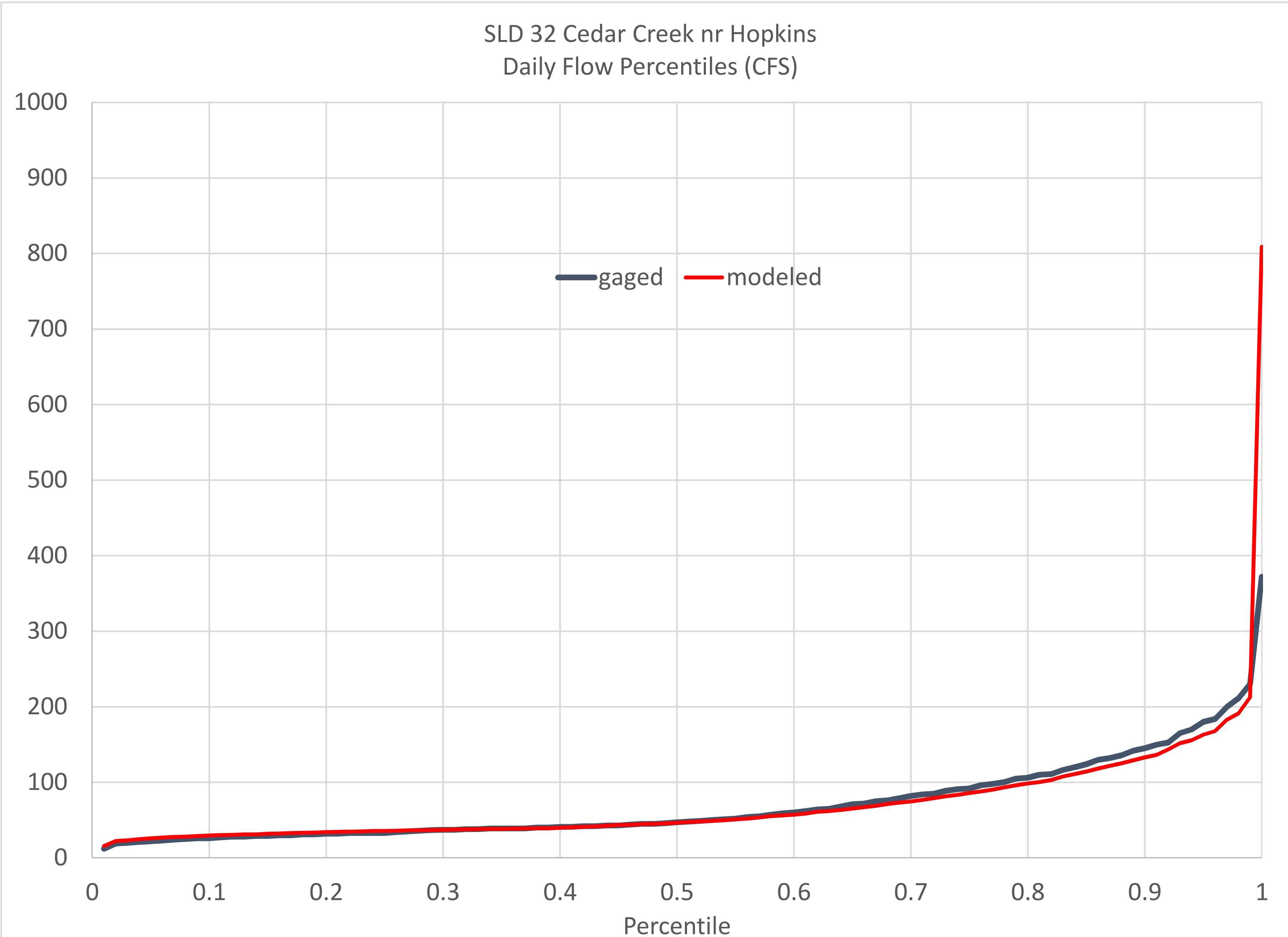

SLD22 Bush River nr Prosperity
Daily Flow Percentiles (CFS)
gaged
modeled
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

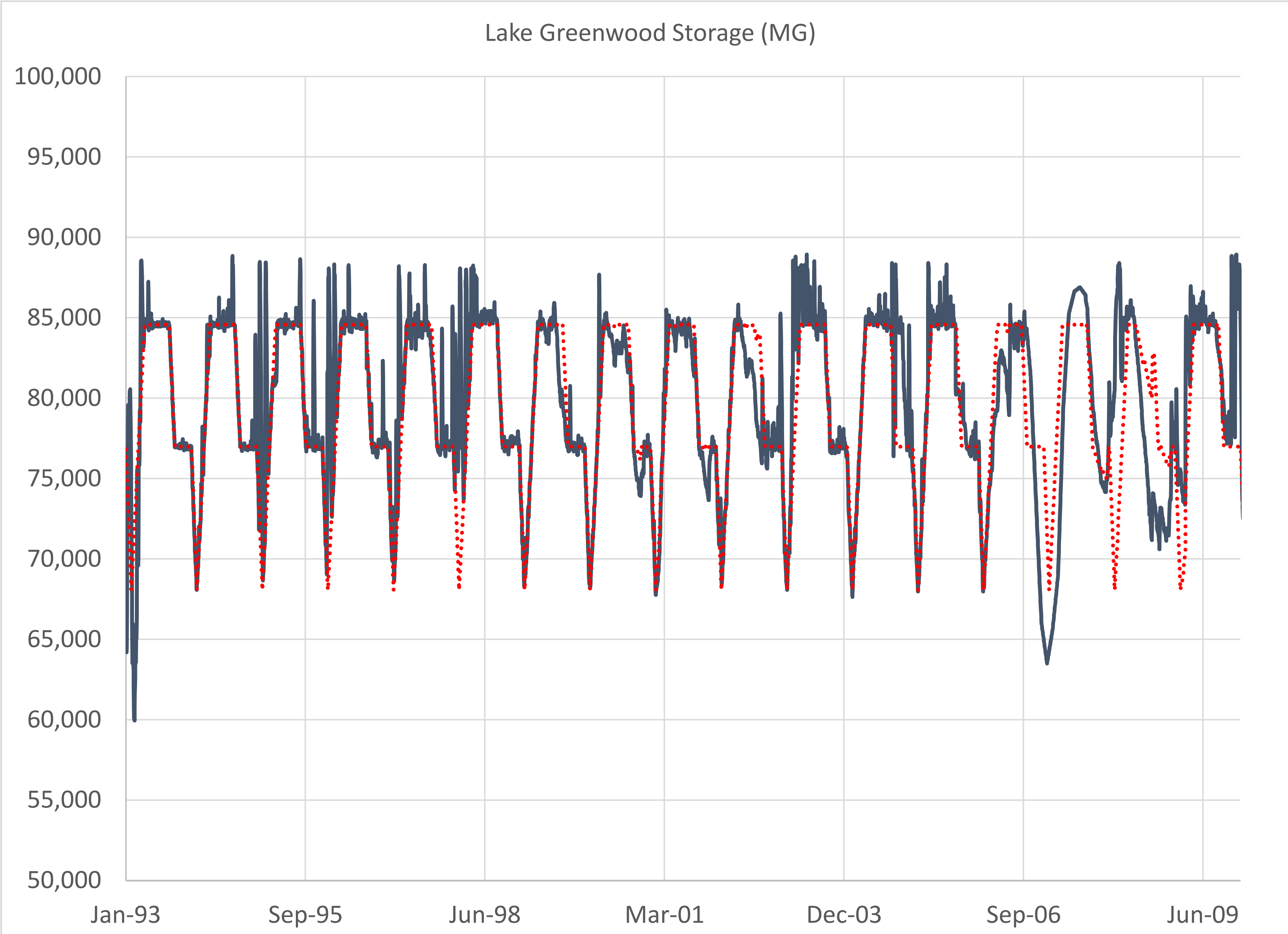


SLD 29 Gills Creek at Columbia (CFS)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
gaged
modeled
Feb-82
Aug-87
Jan-93
Jul-98
Jan-04
Jul-09
Dec-14

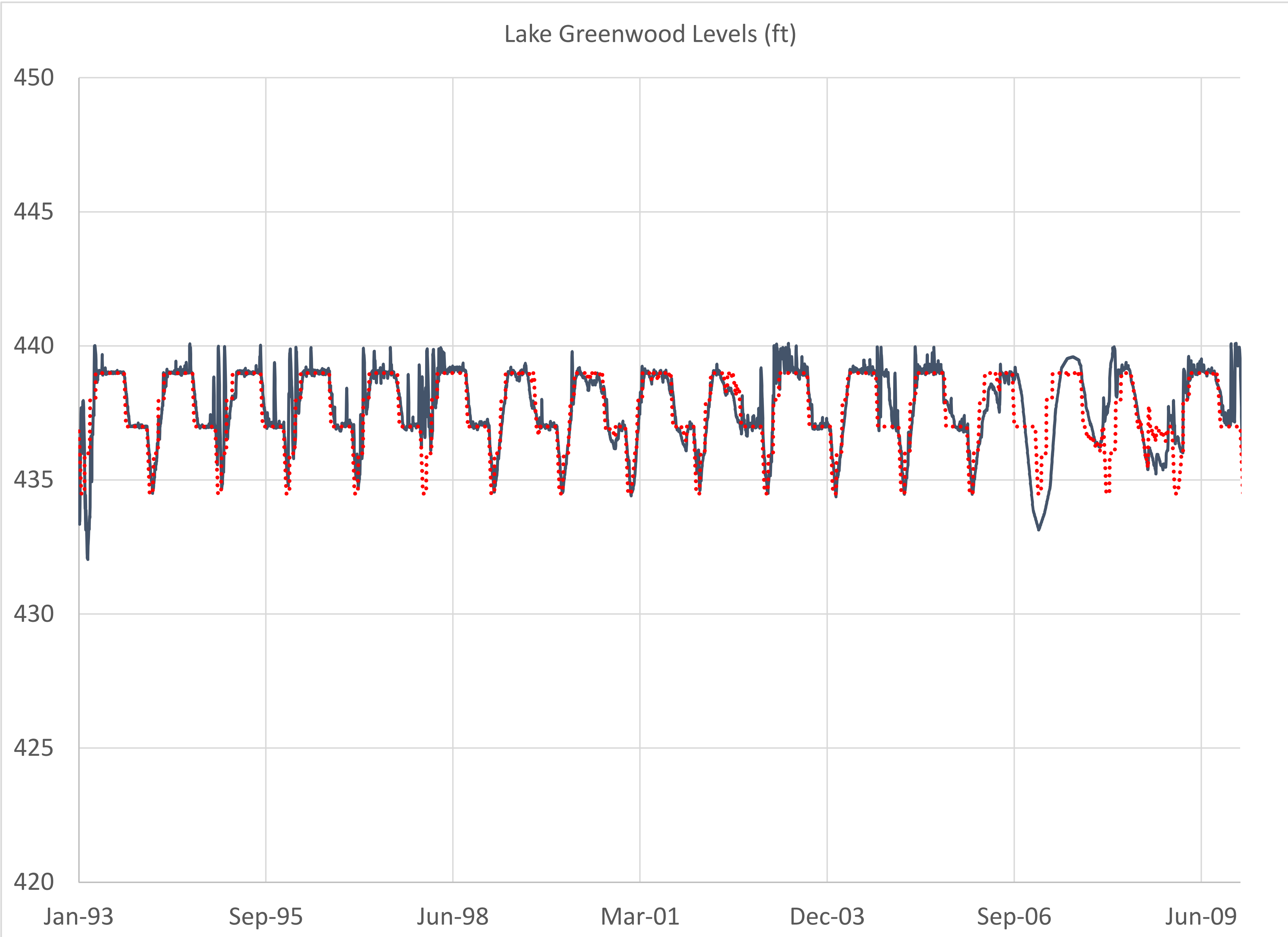

SLD 29 Gills Creek at Columbia
Monthly Flow Percentiles (CFS)
1000
900
800
700
600
500
400
300
200
100
0
gaged
modeled
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

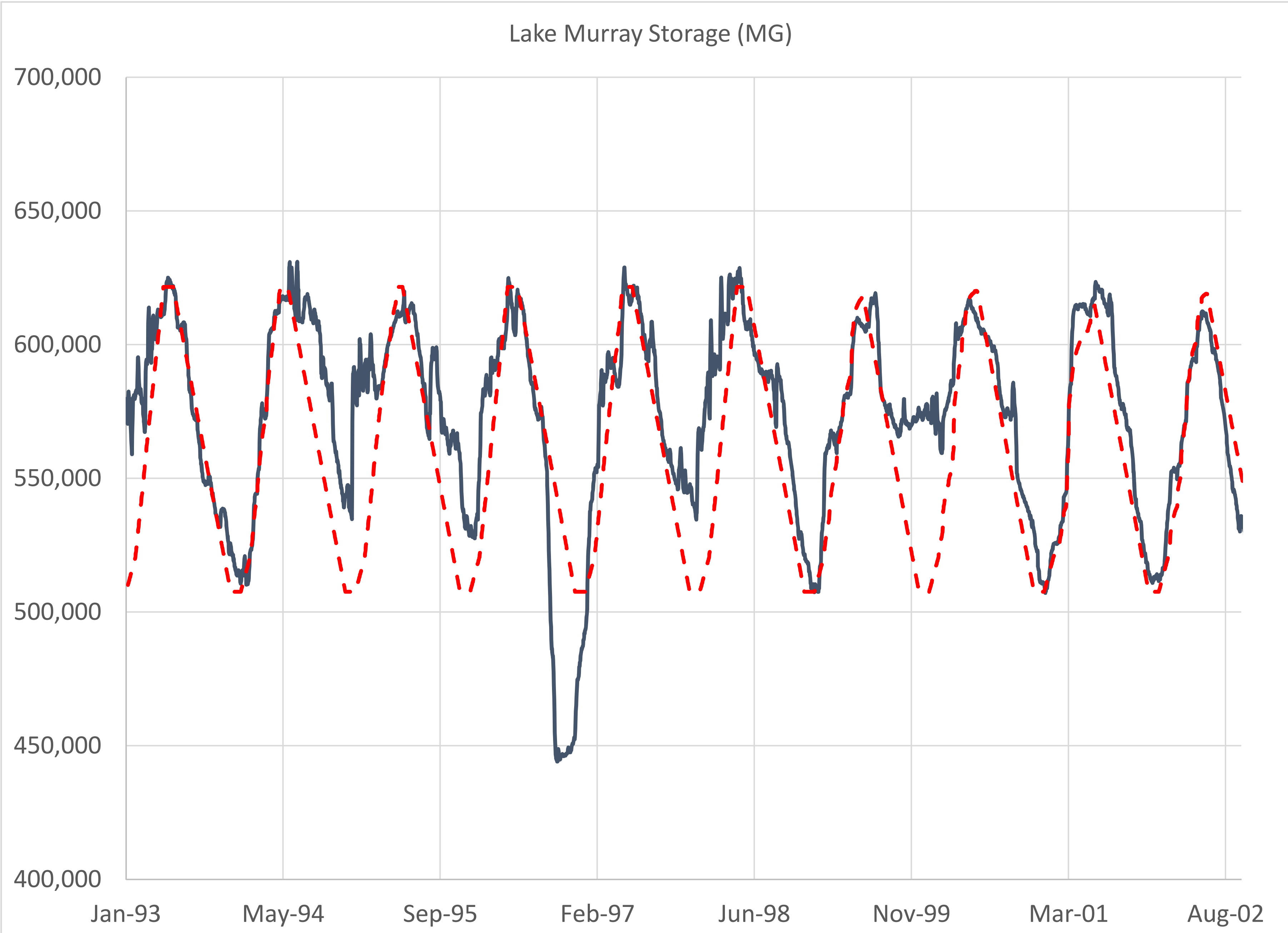

SLD 32 Cedar Creek nr Hopkins (CFS)
400
350
300
250
200
150
100
50
0
gaged
modeled
Feb-82
Sep-82
Mar-83
Oct-83
Apr-84
Nov-84
Jun-85
Dec-85


SLD 32 Cedar Creek nr Hopkins
Daily Flow Percentiles (CFS)
1000
900
800
700
600
500
400
300
200
100
0
gaged
modeled
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percentile

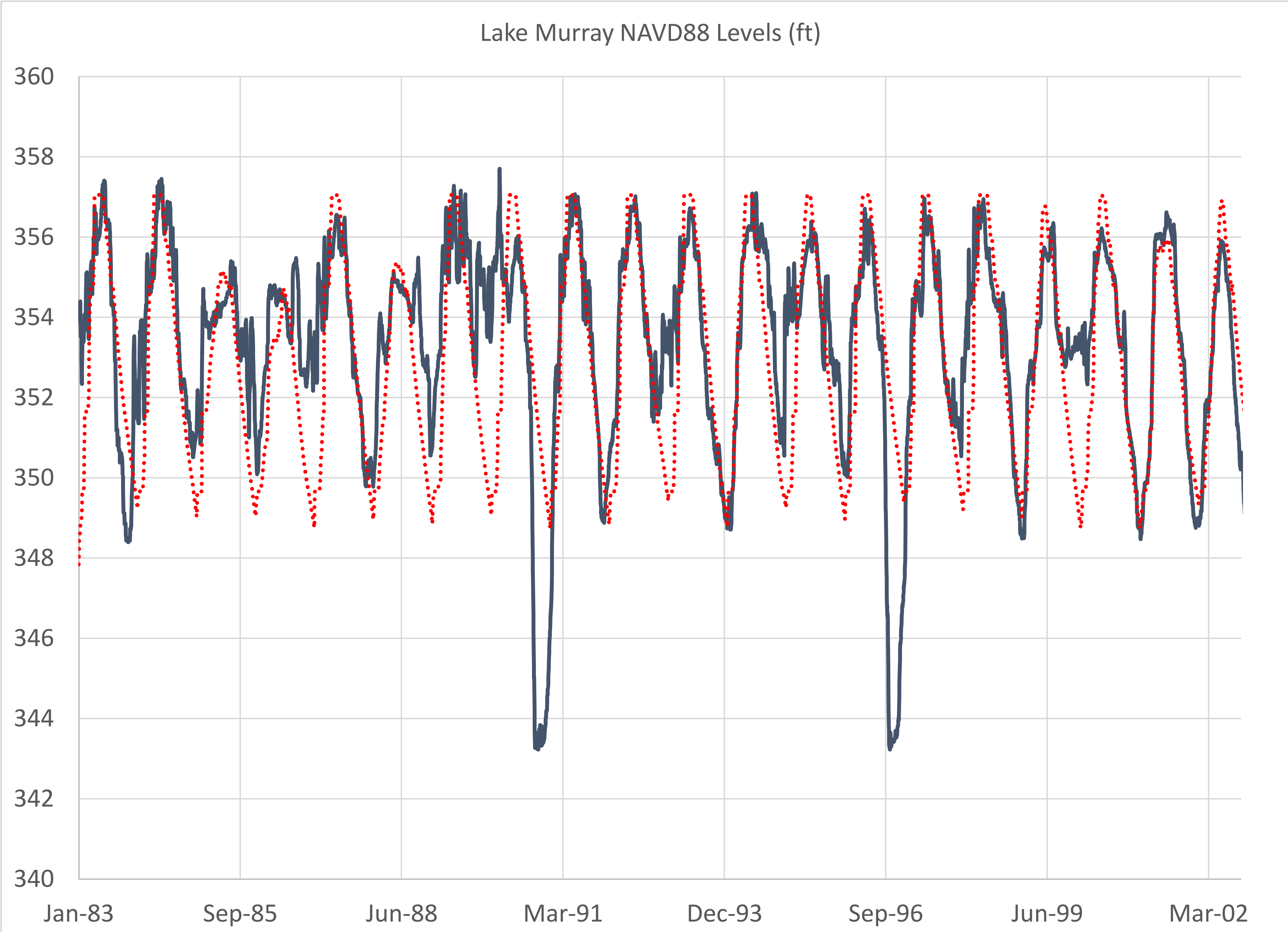


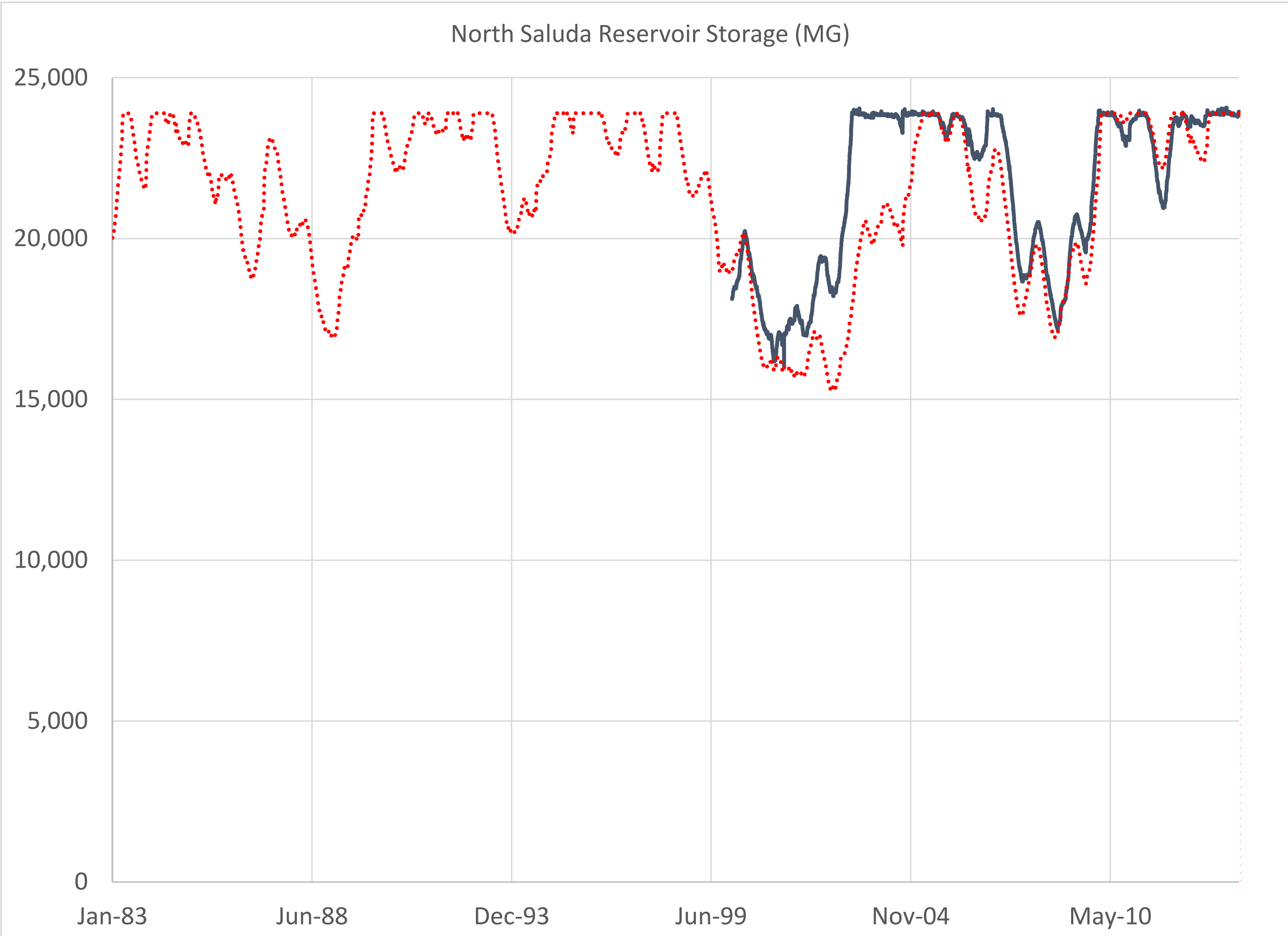
Lake Greenwood Storage (MG)
100,000
95,000
90,000
85,000
80,000
75,000
70,000
65,000
60,000
55,000
50,000
Jan-93
Sep-95
Jun-98
Mar-01
Dec-03
Sep-06
Jun-09

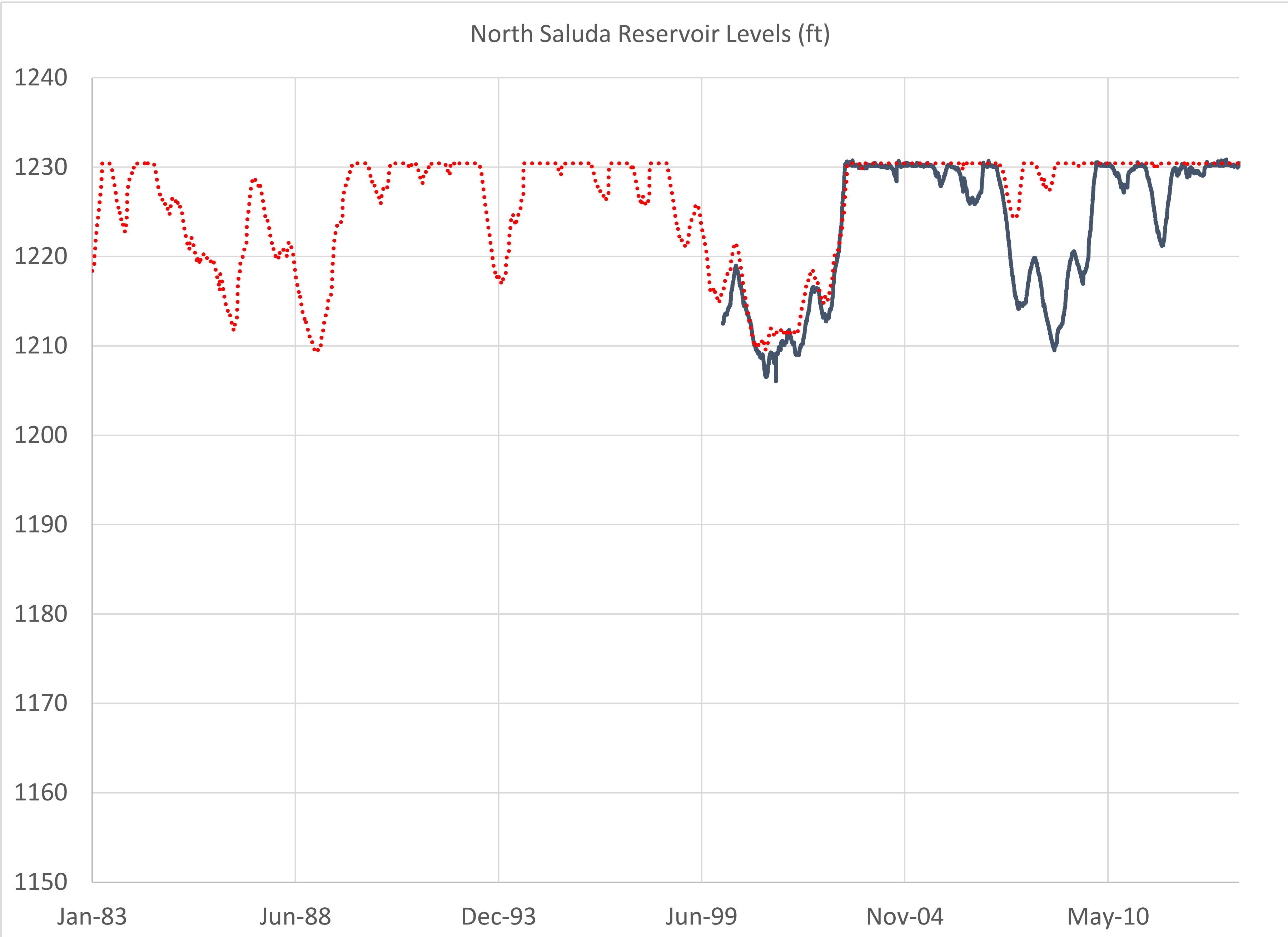

Lake Greenwood Levels (ft)
450
445
440
435
430
425
420
Jan-93
Sep-95
Jun-98
Mar-01
Dec-03
Sep-06
Jun-09



Lake Murray Storage (MG)
700,000
650,000
600,000
550,000
500,000
450,000
400,000
Jan-93
May-94
Sep-95
Feb-97
Jun-98
Nov-99
Mar-01
Aug-02


Lake Murray NAVD88 Levels (ft)
360
358
356
354
352
350
348
346
344
342
340
Jan-83
Sep-85
Jun-88
Mar-91
Dec-93
Sep-96
Jun-99
Mar-02


North Saluda Reservoir Storage (MG)
25,000
20,000
15,000
10,000
5,000
0
Jan-83
Jun-88
Dec-93
Jun-99
Nov-04
May-10


North Saluda Reservoir Levels (ft)
1240
1230
1220
1210
1200
1190
1180
1170
1160
1150
Jan-83
Jun-88
Dec-93
Jun-99
Nov-04
May-10

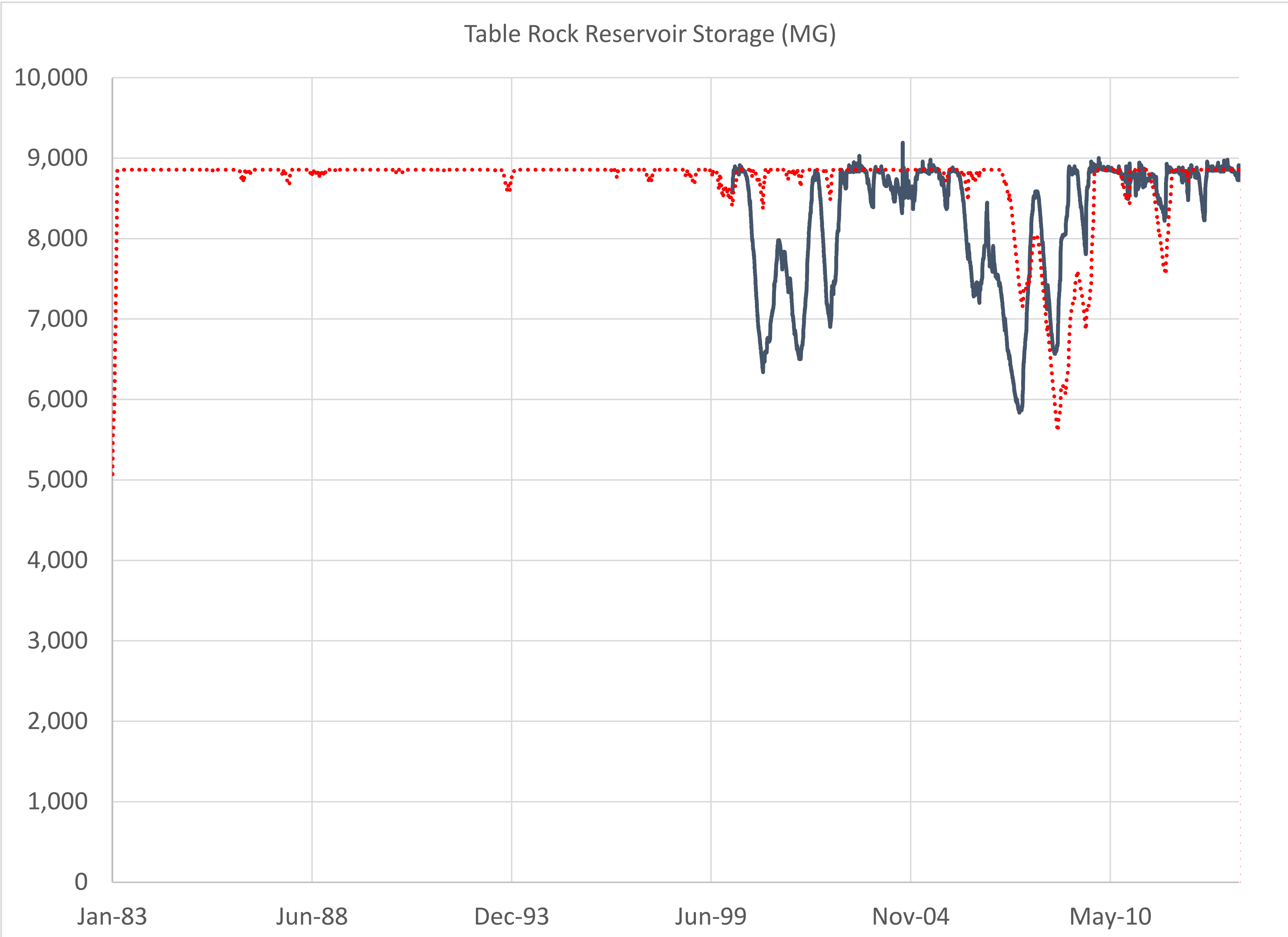


Table Rock Reservoir Storage (MG)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Jan-83
Jun-88
Dec-93
Jun-99
Nov-04
May-10

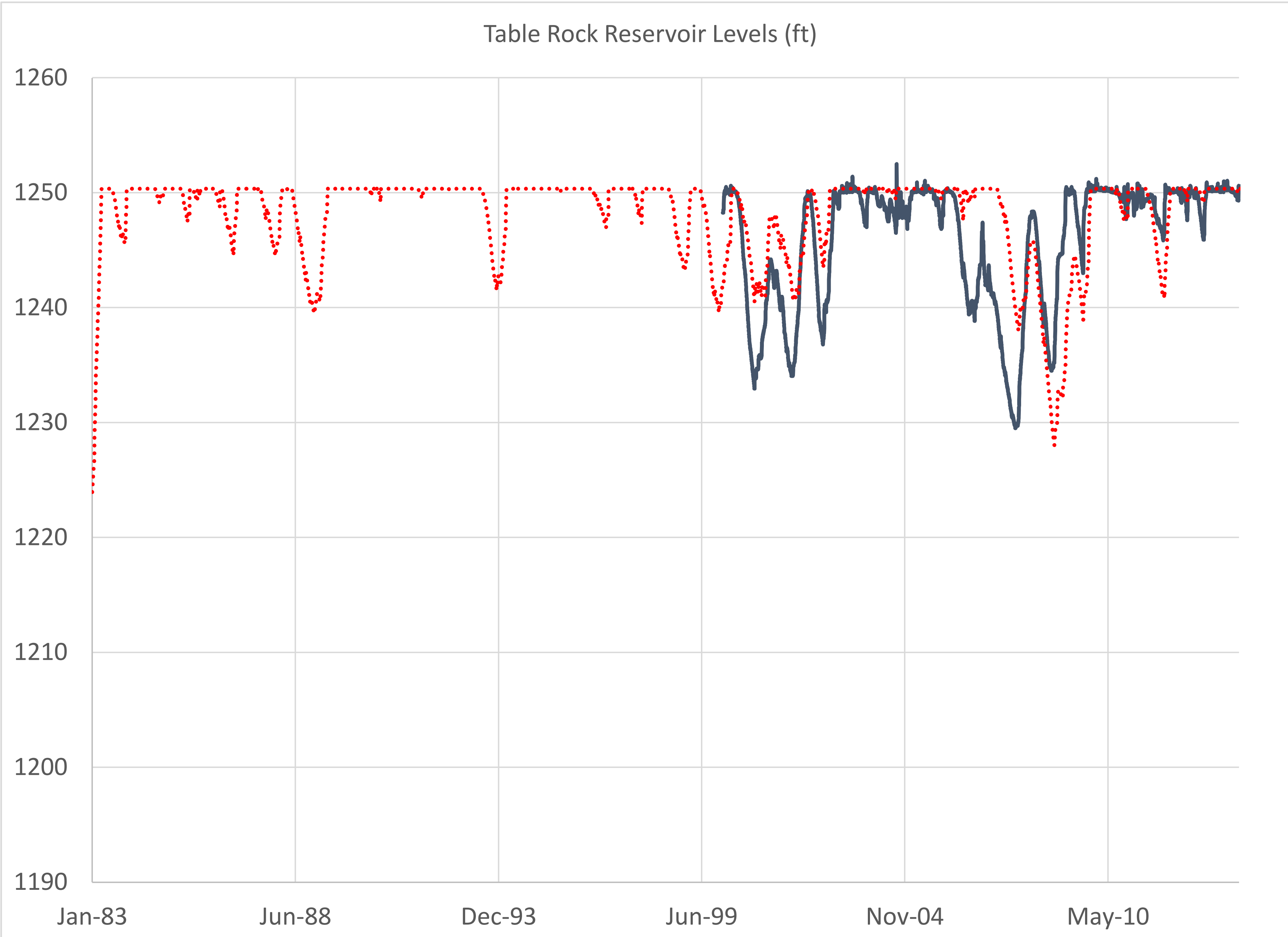
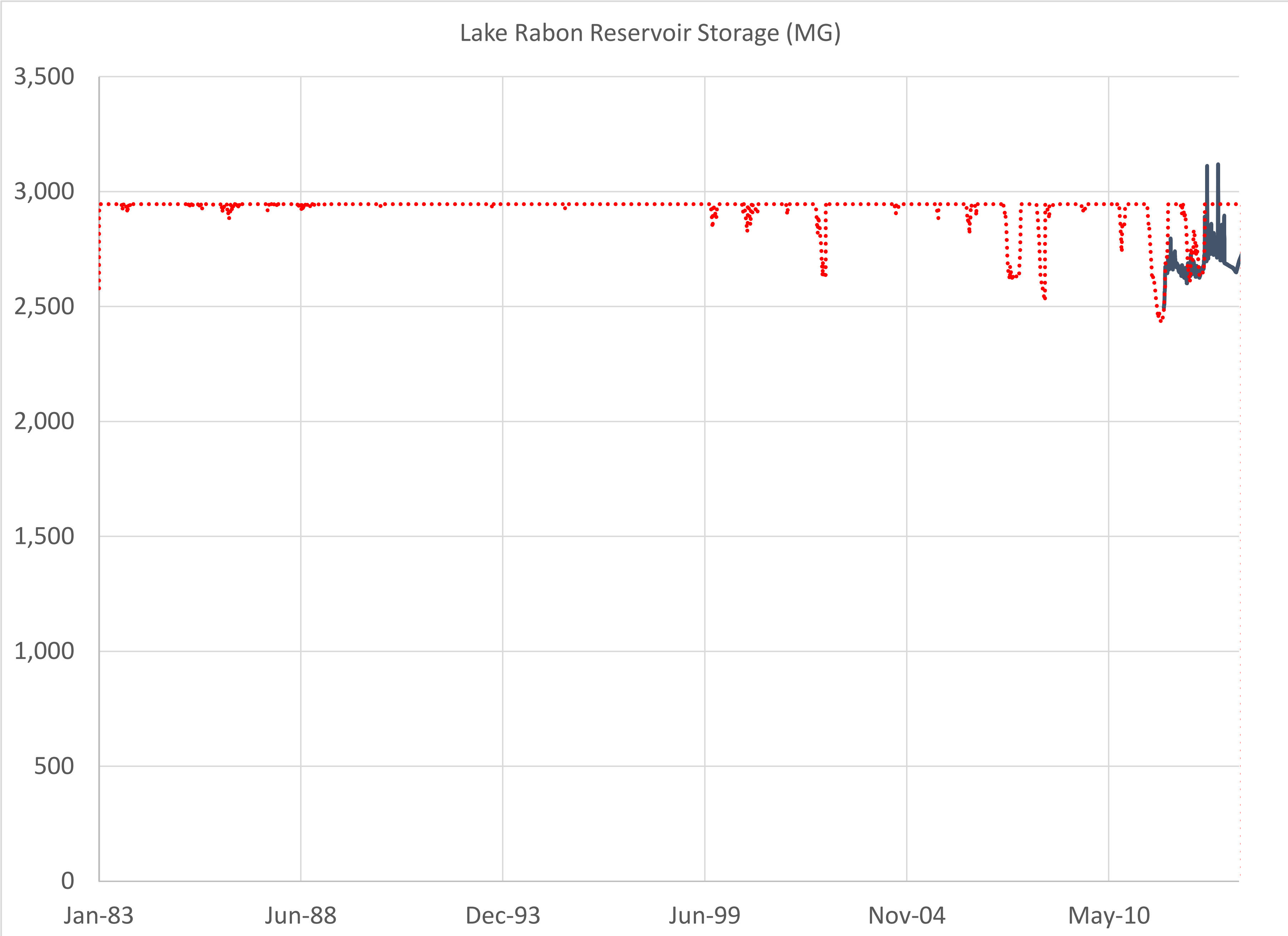
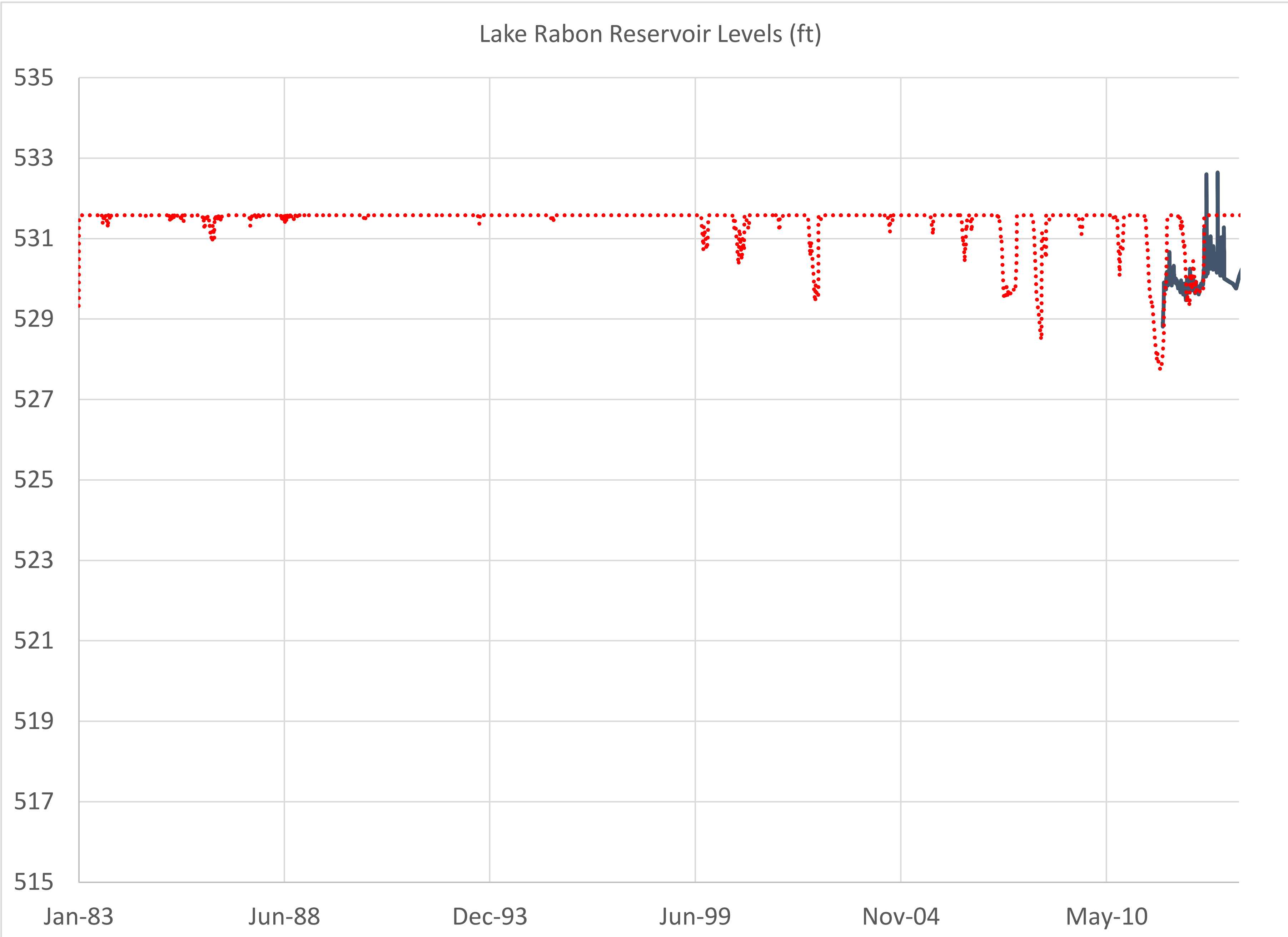


Table Rock Reservoir Levels (ft)
1260
1250
1240
1230
1220
1210
1200
1190
Jan-83
Jun-88
Dec-93
Jun-99
Nov-04
May-10



Lake Rabon Reservoir Storage (MG)
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Jan-83
Jun-88
Dec-93
Jun-99
Nov-04
May-10


Lake Rabon Reservoir Levels (ft)
535
533
531
529
527
525
523
521
519
517
515
Jan-83
Jun-88
Dec-93
Jun-99
Nov-04
May-10

Annual 7 day Low Flows: Modeled

Year	SLD04 Saluda nr Greenville Flow (CFS)	Saluda nr Williamston (SLD07) Flow (CFS)	SLD 09 Saluda nr Ware Shoals Flow (CFS)	SLD11 Reedy ab Fork Shoals Flow (CFS)	SLD 12&13 Reedy nr Waterloo Flow (CFS)	SLD 18 Saluda at Chappells Flow (CFS)	SLD 19 Little Riv nr Silverstreet Flow (CFS)	SLD 21 Bush Riv at Newberry Flow (CFS)	SLD 22 Bush Riv nr Prosperity Flow (CFS)	SLD 25 Saluda bl Lake Murray Flow (CFS)	SLD 27 Congaree at Columbia Flow (CFS)	SLD 29 Gills Crk at Columbia Flow (CFS)	SLD 32 Cedar Creek nr Hopkins Flow (CFS)
1983			366		88	502				159	2,776	2	24
1984			455		142	745				304	3,579	7	30
1985			337		115	499				107	1,862	5	
1986			177		38	246				109	1,047	4	
1987			252		82	356				288	1,975	12	
1988			243		70	330				93	1,793	4	
1989			363		72	450				93	1,447	5	
1990			344		87	497						7	
1991	279		441		155	746	41	7	11	211	3,176	31	
1992	306		472		96	508	26	6	10	192	2,416	16	
1993	151		256		109	430	21	7	10	772	2,535	10	
1994	254		437	86	107	786	52	9	13	157	2,895	7	
1995	292		446	69	119	627	31	13	22	165	3,989	16	
1996	202	269	331	75	151	612	46	11	20			14	
1997	171	229	281	83	140	482	35	14	26	258	3,304	12	
1998	156	217	278	70	127	542	38	11	20	646	2,636	10	
1999	68	95	117	47	77	259	13	8	14	171	1,872	8	
2000	86	118	146	62	75	259	7		10	176	1,706	8	
2001	118	158	196	55	65	284	6		9	174	1,582	6	
2002	71	93	109	47	50	248	4		10			4	
2003	279	363	444	109	148	753	37		17			13	
2004	221	304	383	83		554	16		10			6	
2005	197	260	313	86	99	552	18		9			5	
2006	129	176	211	66	56	305	19		13			5	
2007	77	106	124	56	58	259	5		6			1	
2008	51	74	86	43	41	198	4		12			7	
2009	92	130	157	52	48	282	11		11			4	
2010	146	198	234	55	58	365	13		11			4	
2011	94	131	158	43	40	267	7		8			3	
2012	171	236	291	69	67	403	12		8			8	
2013	366	474	566	110	137	859	24		11			13	

Notes: Blank cells indicate years when gaged flows were not availalable for comparison.

Shaded cells indicate years when Lake Murray was not operated using the same guide curve as in the calibration model, and therefore are excluded from comparison.

Annual 7 day Low Flows: Measured

Year	SLD04 Saluda nr Greenville Flow (CFS)	Saluda nr Williamston (SLD07) Flow (CFS)	SLD 09 Saluda nr Ware Shoals Flow (CFS)	SLD11 Reedy ab Fork Shoals Flow (CFS)	SLD 12&13 Reedy nr Waterloo Flow (CFS)	SLD 18 Saluda at Chappells Flow (CFS)	SLD 19 Little Riv nr Silverstreet Flow (CFS)	SLD 21 Bush Riv at Newberry Flow (CFS)	SLD 22 Bush Riv nr Prosperity Flow (CFS)	SLD 25 Saluda bl Lake Murray Flow (CFS)	SLD 27 Congaree at Columbia Flow (CFS)	SLD 29 Gills Crk at Columbia Flow (CFS)	SLD 32 Cedar Creek nr Hopkins Flow (CFS)
1983			360		28	401				401	2,211	2	17
1984			419		105	465				439	2,523	7	25
1985			295		110	340				289	2,077	5	
1986			61		33	251				248	1,560	4	
1987			159		77	295				270	1,734	12	
1988			135		65	305				239	1,721	5	
1989			353		67	475				168	2,630	5	
1990			270		84	409				248	1,870	7	
1991	298		470		150	605	39	2	24	330	3,296	32	
1992	289		403		95	362	24	2	16	469	3,356	17	
1993	181		260		104	356	19	0	13	398	2,729	10	
1994	304		471	103	105	617	51	8	23	417	3,009	7	
1995	297		468	72	121	442	30	3	18	399	4,027	16	
1996	227	358	357	85	149	590	46	3	19	480	2,621	14	
1997	168	306	256	79	139	525	35	3	15	436	2,981	12	
1998	124	253	247	87	123	506	39	1	17	674	2,501	10	
1999	72	84	95	88	67	290	13	0	9	188	1,192	8	
2000	53		101	64	73	296	6		6	171	1,357	8	
2001	92	131	155	62	65	326	5		5	323	1,521	6	
2002	55	62	51	41	49	278	1		4	437	1,274	4	
2003	311	429	468	104	144	684	36		14	549	3,703	14	
2004	232	330	417	82		538	16		8	345	2,337	6	
2005	235	283	351	80	95	587	18		13	504	1,957	5	
2006	131	211	193	63	52	503	19		11	346	1,764	5	
2007	87	113	119	47	51	241	3		5	267	904	1	
2008	54	49	69	36	37	203	1		4	235	810	7	
2009	93	131	122	50	49	247	7		6	242	1,419	4	
2010	150	188	167	50	58	269	6		5	470	1,290	4	
2011	85	128	94	40	33	265	0		3	297	916	3	
2012	181	214	208	63	64	332	6		3	279	1,280	8	
2013	355	489	563	102	143	448	23		14	701	3,546	13	

Notes: Blank cells indicate years when gaged flows were not availalable for comparison.

Shaded cells indicate years when Lake Murray was not operated using the same guide curve as in the calibration model, and therefore are excluded from comparison.

Approximate 7Q10 Comparison - Modeled vs. Gaged

	SLD04 Saluda nr Greenville Flow (CFS)	Saluda nr Williamston (SLD07) Flow (CFS)	SLD 09 Saluda nr Ware Shoals Flow (CFS)	SLD11 Reedy ab Fork Shoals Flow (CFS)	SLD 12&13 Reedy nr Waterloo Flow (CFS)	SLD 18 Saluda at Chappells Flow (CFS)	SLD 19 Little Riv nr Silverstreet Flow (CFS)	SLD 21 Bush Riv at Newberry Flow (CFS)	SLD 22 Bush Riv nr Prosperity Flow (CFS)	SLD 25 Saluda bl Lake Murray Flow (CFS)	SLD 27 Congaree at Columbia Flow (CFS)	SLD 29 Gills Crk at Columbia Flow (CFS)	SLD 32 Cedar Creek nr Hopkins Flow (CFS)
Modeled:	72	94	124	47	48	259	5.4	6.6	8.6	102	1,528	3.7	25
Gaged:	58	75	94	41	37	251	1.6	0.0	3.9	181	1,456	3.8	18
%Diff:	24%	26%	33%	16%	30%	3%	242%	*	121%	33%	7%	-1%	*

** Relatively few years (<10) available to make comparison*

Appendix C

Guidelines for Representing Multi-Basin Water Users in SWAM

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

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

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

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

Appendix D

Summary of Lake Murray Maintenance, Emergency, and Low Inflow Protocol Rules

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Appendix D

Summary of Lake Murray Maintenance, Emergency, and Low Inflow Protocol (MELIP)

From Appendix A-13 of FERC License Application Settlement Agreement, found at:
http://www.saludahydrorelicense.com/resources/documents/Settlement%20Docs/Appendix%20A-13%20Saluda%20Hydroelectric%20Project%20Maintenance,%20Emergency.pdf

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Definitions

1. ***Seasonal minimum flows*** are:

Jan 1 – Mar 31	700 cfs
Apr 1 – May 10	Striped Bass Enhancement Flow Regime (aka ***STB Flow Request***)
May 11 – May 31	1,000 cfs
Jun 1 – Dec 31	700 cfs

2. ***Net Inflow*** to Lake Murray is calculated as:
   a. ***Net Inflow*** = Scaled Gaged Flow - Estimate Municipal Usage, where:
      i. Scaled Gaged Flow = (1.02)($Q_{\text{Chappells SLD18}}$) + (1.233($Q_{\text{Little R. SLD19}}$) + (6.515)($Q_{\text{Bush R. SLD22}}$)
      ii. Estimated Municipal Usage is 60 cfs in Jan, Feb Mar, Nov and Dec; 90 cfs in Apr; 100 cfs in May and Oct; and 120 cfs in Jun, Jul, Aug and Sept.

3. **STB Flow Request** is calculated as:
   a. IF previous day average flow at Broad River Alston gage >2,500 and <8,000, THEN continuous target flow release from Lake Murray is the lesser of:
      i. 45% of the previous day's daily average flow at Broad River Alston gage; or
      ii. The balance of what's required to create 9,000 CFS flow in the Congaree River
   b. IF previous day average flow at Broad River Alston gage <2,500 or >8,000, THEN continuous target flow release from Lake Murray is 1,000 cfs.

Appendix D

Summary of Lake Murray Maintenance, Emergency, and Low Inflow Protocol (MELIP)

From Appendix A-13 of FERC License Application Settlement Agreement, found at:
http://www.saludahydrorelicense.com/resources/documents/Settlement%20Docs/Appendix%20A-13%20Saluda%20Hydroelectric%20Project%20Maintenance,%20Emergency.pdf

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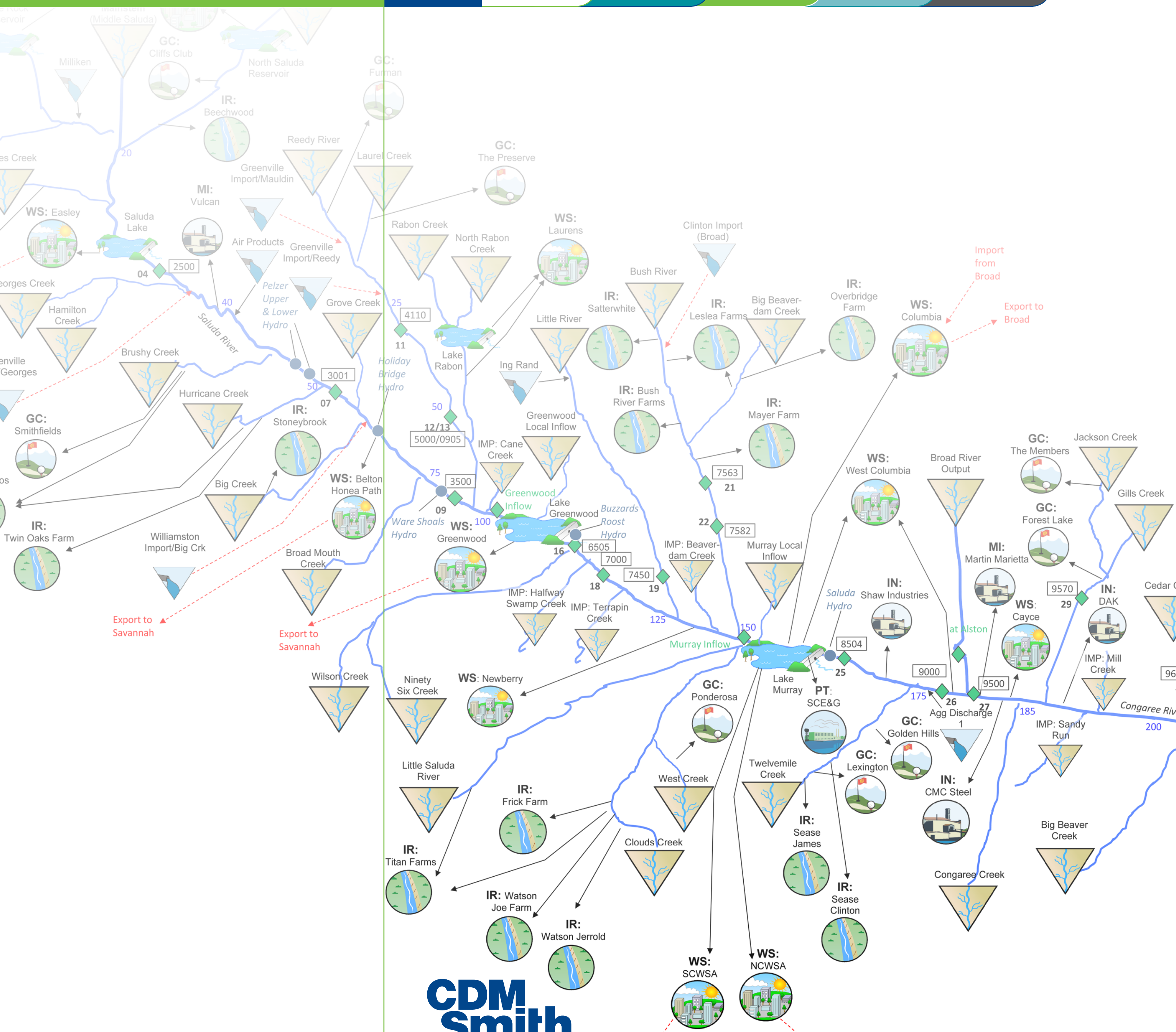
LIP Rules as interpreted from pages A-13-6 and -7

1. IF 14 day average ***net inflow*** < ***seasonal minimum flow***, THEN:
    a. water stored in Lake Murray will be released to provide the normal ***seasonal minimum flow*** until the reservoir elevation is < 1 or 2 ft (TBD by FERC) below current target elevation. Once that occurs, THEN
        i. IF May 11 – Mar 31 (not STB period), THEN minimum target flows will be:
            1. IF 14-day average ***net inflow*** < 1,000 cfs, THEN 700 cfs
            2. IF 14-day average ***net inflow*** < 700 cfs, THEN 500 cfs, with 400 cfs minimum flow.
        ii. IF Apr 1 – May 10 (STB period), THEN minimum target flows will be:
            1. IF 14-day average ***net inflow*** < ***STB flow request***, THEN 1,000 cfs
            2. IF 14-day average ***net inflow*** < 1,000 cfs, THEN 700 cfs
            3. IF 14-day average ***net inflow*** < 700 cfs, THEN 500 cfs, with 400 cfs minimum flow.
2. IF 14 day average ***net inflow*** < ***seasonal minimum flow***, AND IF Dec 16 – Jan 17 AND IF reservation elevation is >351.5' (NAVD88), the reservoir will not be required to drop below current target elevation before reducing minimum flow.
3. IF 14 day average ***net inflow*** < ***seasonal minimum flow***, AND IF Dec 1 – Feb 1 AND IF reservation elevation is >350.5' (NAVD88), the reservoir will not be required to drop below current target elevation before reducing minimum flow.
4. IF 14 day average ***net inflow*** < ***seasonal minimum flow***, AND IF reservation elevation is <352.5' (NAVD88), the minimum flow will be reduced to a target flow of 500 CFS, with 400 cfs minimum flow, until reservoir elevation >352.5' (NAVD88).

Note: Reduction of scheduled recreation flows, releases for the Columbia Fire Department and safety training flows specific in the MELIP are not summarized here.



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