Technical Memorandum

To: *South Carolina Department of Natural Resources (DNR)*
South Carolina Department of Health and Environmental Control (DHEC)

From: *CDM Smith*

Date: *May 2017*

Subject: *Unimpaired Flow Dataset for the Savannah River Basin*
(Prepared as part of the South Carolina Surface Water Quantity Modeling Program)

1.0 Introduction

Unimpaired Flows (UIFs) represent the theoretical historical rate of flow at a location in the absence of all human activity in the river channel, such as water withdrawals, discharges, and impoundments. They will be used as boundary conditions and calibration targets for natural hydrology in the computer simulation models of the 8 major river basins in South Carolina. As such, they represent an important step in the South Carolina Surface Water Quantity Modeling project.

This technical memorandum (TM) summarizes the completion of the UIF dataset for the Savannah River Basin. The TM references the electronic database, which houses the completed UIF dataset for the Savannah Basin and summarizes the techniques and decisions pertaining to synthesis of data where it is unavailable, which may be specific to individual locations.

2.0 Overview of the Savannah Basin

The Savannah River, which forms the border between South Carolina and Georgia, is around 300 miles long and has nearly 11,000 square miles of drainage. The Savannah River Basin is commonly divided into the Upper Savannah and Lower Savannah subregions. The headwaters of the Upper Savannah originate in the Blue Ridge mountains of North Carolina and Georgia, with the Savannah River officially forming at the confluence of the Tugaloo and Seneca Rivers—a confluence now submerged by Lake Hartwell. Flow in the Piedmont region of the Savannah River is heavilyregulated by five large reservoirs: Jocassee, Keowee, Hartwell, Russell, and Thurmond. Below the Fall Line, flows in the Lower Savannah River are primarily controlled by releases from Lake Thurmond. The only developments in the Lower Savannah consist of navigation projects from Augusta to the Savannah Harbor, and the Savannah River becomes a large estuary at the coast of the Atlantic Ocean. **Figure 2-1** shows the full length of the Savannah River Basin, and its span of physiographic provinces from the Blue Ridge to Lower Coastal Plain.

Chapter 8 of The South Carolina State Water Assessment (SCDNR, 2009) describes the basin's surface water and groundwater hydrology and hydrogeology, water development and use, and water quality. A summary is also provided in An Overview of the Eight Major River Basins of South Carolina (SCDNR, 2013).

A detailed discussion of water users and dischargers is presented in the Savannah Framework Memorandum (CDM Smith, 2016). The South Carolina DHEC has provided information and data regarding current (active) and former (inactive) water users and dischargers throughout the state. The Framework Memorandum summarizes the current water users and dischargers for the purposes of the model.

3.0 Overview of UIF Methodology

Fundamentally, UIFs are calculated by removing known impacts from measured streamflow values at places in which flow has been measured historically. An alternate method sometimes employed utilizes rainfall-runoff modeling to estimate natural runoff tendencies, but this technique is often uncertain, and its only sure footing is in calibration to measured (and frequently impaired) streamflow records. Typically, UIFs are calculated at most locations in which a United States Geological survey (USGS) gage has recorded historical flow measurements. The Savannah River Basin has over seventy active or former streamflow gaging stations within South Carolina or on its border. **Attachment A** discusses the selection of UIF locations, which due to existing UIFs along the Savannah River (GA EPD, 2015), led to UIF development only on South Carolina tributary gages. The full list of which USGS gages produced viable UIFs can be seen in Table 4.1 of Attachment A**.** Note that four inactive gages included in Attachment A were removed because of complications caused by incomplete or missing operational data needed for calculations: SAV15, SAV18, SAV40, and SAV41.

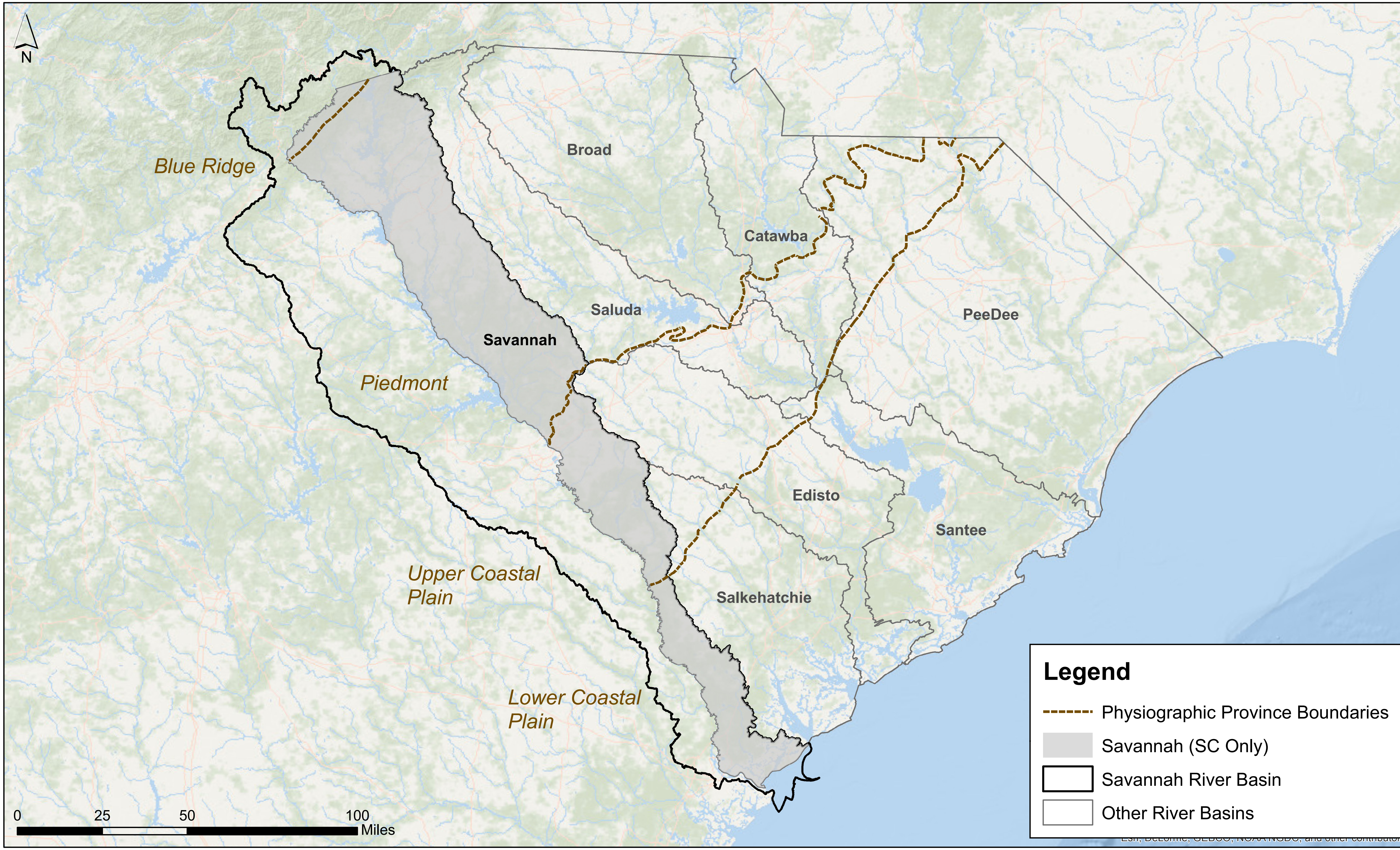

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Figure 2-1
South Carolina's Savannah River Basin and Other Major River Basins

Measured and estimated impacts of withdrawals, discharges, and impoundments were included as linear "debits" or "credits," and the measured flow was adjusted accordingly. Where historical data on river operations did not exist and available data was useable, values were hindcasted using various estimation techniques. For the Savannah River Basin, only dischargers required hindcasting given all reservoirs were either on the mainstem or downstream of tributary gages, and all withdrawals were either on the mainstem, downstream of tributary gages, or started operations after creation of a downstream gage. Once the UIFs were developed for each USGS gage, the Period of Record (POR) for each gage was statistically extended (if necessary) to cover the range of 1939-2013 (coinciding with the longest, continuously recorded streamflow in the basin). As a final step, the UIFs in ungaged basins were estimated from UIFs in gaged basins with similar size, land use, and topography.

UIFs are intended to be used for the following purposes:

a) Headwater input to the SWAM models

b) Incremental flow inputs along the mainstem in the SWAM models

c) SWAM model calibration

d) Comparison of simulated managed flows to natural flows

e) Other uses by DNR/DHEC outside of the SWAM models

Figure 3-1 illustrates the step-by-step methodology for computing UIFs. It is supported by the following technical memoranda, which specifically outline the steps and guidelines for UIF computation and decision-making:

- *Methodology for Unimpaired Flow Development, Savannah River Basin, South Carolina (CDM Smith, September 2016)* – Included as Attachment A of this report. This includes a list of all USGS gages in the basin;
- *Guidelines for Identifying Reference Basins for UIF Extension or Synthesis (CDM Smith, April 2015)* – Included as **Attachment C** of the Methodology TM; and
- *Refinements to the UIF Extension Process, with an Example* – Included as **Attachment D.**

Figure 3-2 illustrates the locations of all UIFs developed for the Savannah River Basin, and distinguishes between those computed by adjusting measured streamflow at USGS gages, and those computed for ungaged basins through area transposition. The red circles and triangles represent previously-existing UIFs from the GA EPD, with the remaining gages along the mainstem representing gages that will be included in the model framework (see Attachment A).

4.0 Quality Assurance Reviews

Quality Assurance guidelines were developed in an internal CDM Smith memorandum dated April 2015, entitled *"Quality Assurance Guidelines: Unimpaired Flow Calculations (UIFs) for the South Carolina Surface Water Quantity Models."* The document is included in this report as **Attachment B**.

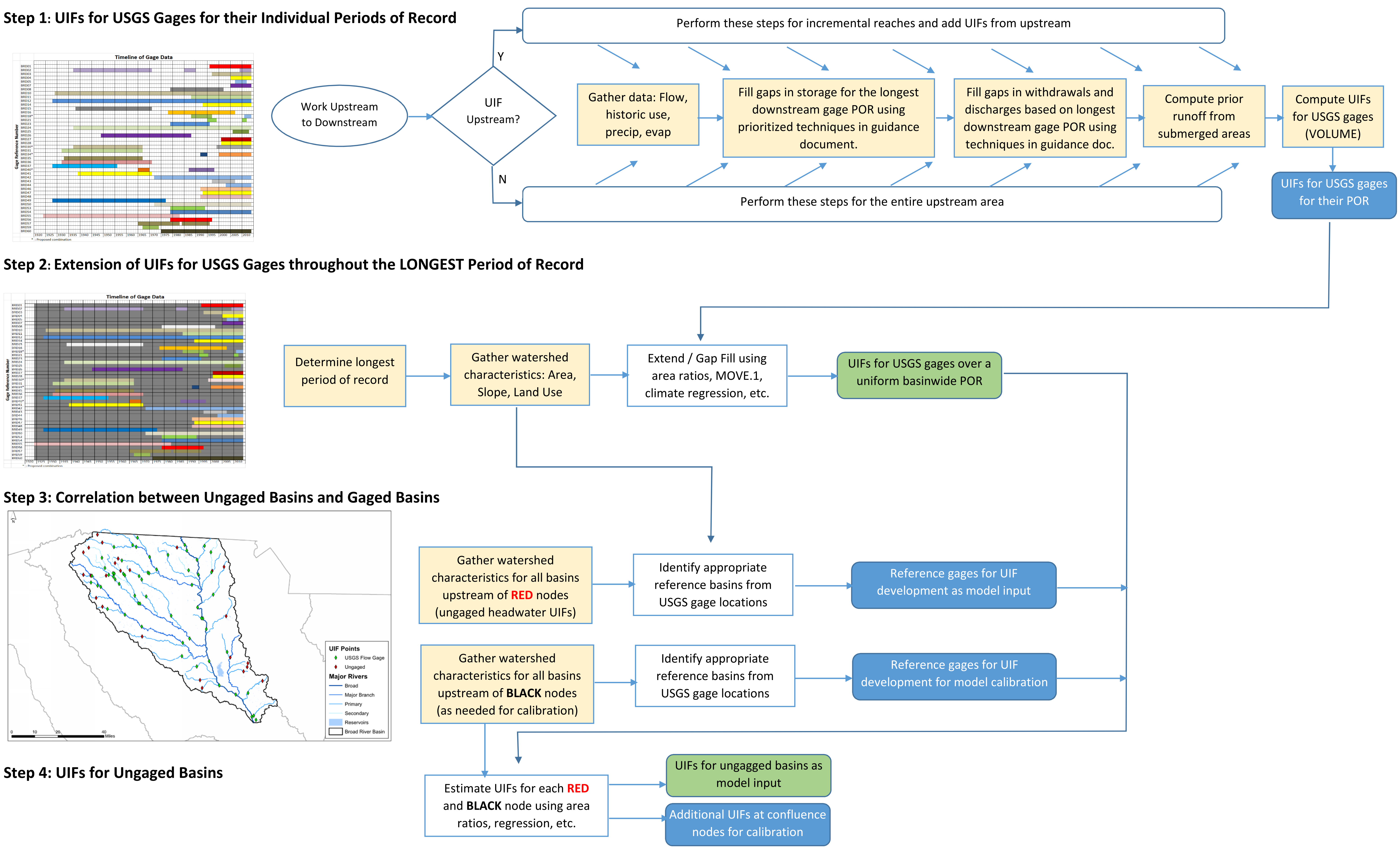
The Quality Assurance results are documented in each UIF workbook in the "QAQC" worksheet. Documentation includes the name of the reviewer, requested changes, and changes made. Some review items pertaining to the UIF extension calculations exist separately from the individual UIF workbooks, but are still listed in Attachment B.

5.0 Summary of Operational Hindcasting

Unique circumstances involving data availability, observable trends, etc. required decisions about how to develop representative hindcast values for each individual water user. Because UIFs were only calculated on tributary gages, as discussed above in **Section 3**, the only operational data that required hindcasting were dischargers. **Table 5-1** lists all dischargers used in the UIF calculations, and whether they required hindcasting.

Hindcasting of agricultural withdrawals in the Savannah Basin was also required for the UIF calculations. Withdrawal data reported to DHEC from 2002 and 2013 was used directly, and prior to that, values from 1950 through 2001 were hindcasted using irrigated acreage estimation techniques. These estimation techniques are described in the CDM Smith memorandum entitled, "*Methodology for Developing Historical Surface Water Withdrawals for Agriculture Irrigation,"* dated July 2015.

Figure 3-1: Stepwise Procedure for UIF Calculation – Savannah Basin



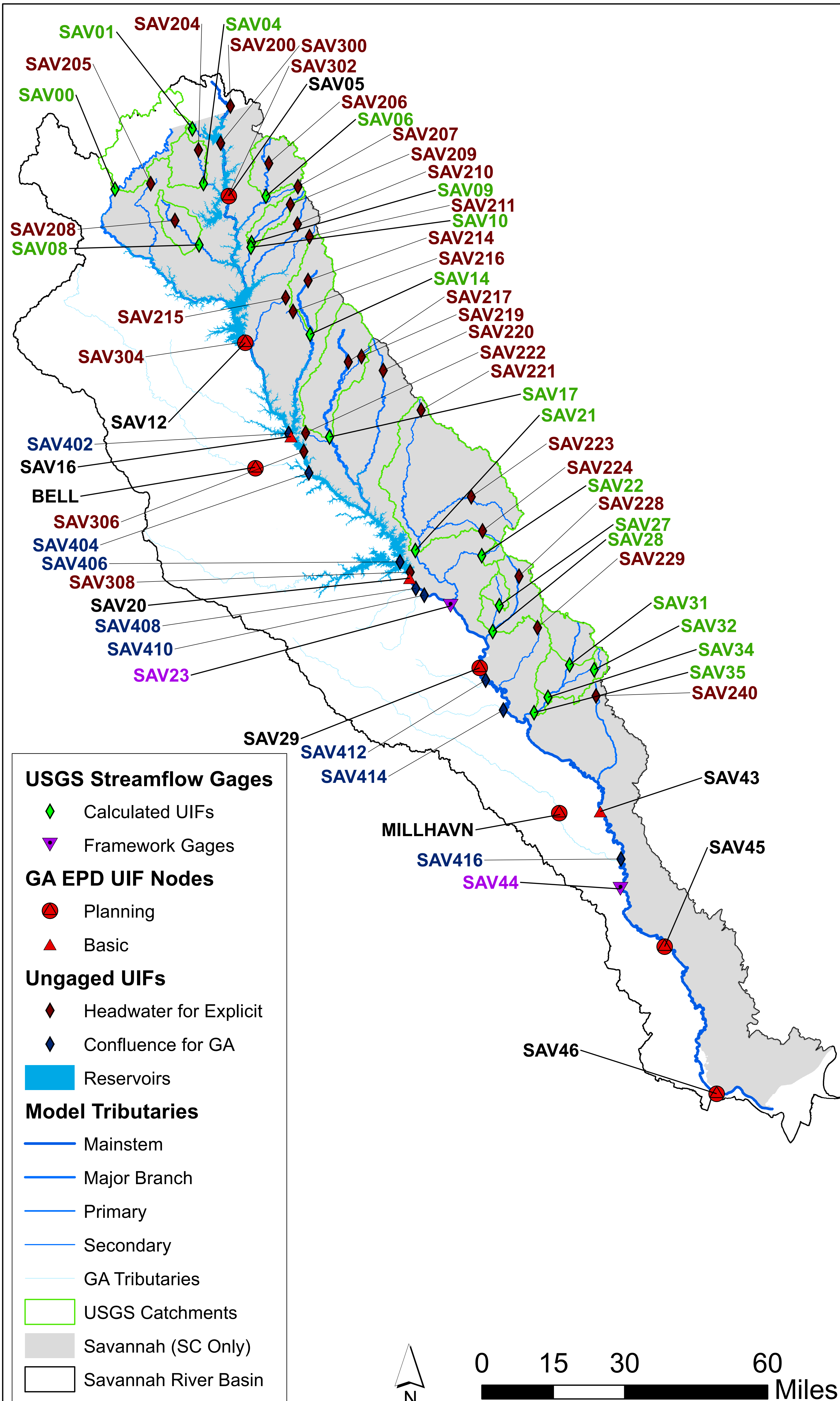


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Figure 3-2
Unimpaired Flow Locations
in the Savannah River Basin

Table 5-1: Summary of Methods Used for Hindcasting Discharges

Project Gage ID	USGS Number	Stream	Discharge Hindcasting			
			ID	Facility Name	Time Periods	Method Used
SAV06	02186000	TWELVEMILE CREEK NEAR LIBERTY, SC	SC0021661-001	PICKENS/TOWN CREEK PLANT	None	Combined with SC0047716-001
			SC0021679-001	PICKENS/WOLF CREEK PLANT	None	Combined with SC0047716-001
			SC0047716-001	PICKENS/12 MILE RV & WOLF CRK	6/1974 - 1/1989	Hindcasted to known start date
SAV08	02186645	CONEROSS CK NR SENECA, SC	SCG641004-001	WALHALLA/CONEROSS CREEK WTP	1/1983 - 12/2013	Estimated based on permit return
SAV09	02186699	EIGHTEENMILE CREEK ABOVE PENDLETON, SC	SC0000264-001	LIBERTY DENIM LLC	4/1978 - 1/1989	Hindcasted to known start date
			SC0026174-001	PICKENS CO-LIBERTY/LUSK	None	Combined with SC0042994-001
			SC0042994-001	PICKENS CO/EIGHTEEN MILE CRK	6/1975 - 1/1989	Hindcasted to known start date
			SC0025003-001	PICKENS CO PSC/CENTRAL-SOUTH	None	Combined with SC0047856-001
			SC0047856-001	PICKENS CO/MIDDLE REG. WWTF	12/1974 - 1/1989	Hindcasted to known start date
SAV10	02186702	EIGHTEENMILE CREEK BELOW PENDLETON, SC	SC0000477-001	MILLIKEN/PENDLETON PLANT	None	None
SAV14	02187910	ROCKY RIVER NR STARR, SC	SC0023744-001	ANDERSON/ROCKY RIVER	4/1978 - 1/1989	Hindcasted to known start date
SAV17	02192500	LITTLE RIVER NEAR MT. CARMEL, SC	SC0020681-001	HONEA PATH/CORNER LAGOON	7/1974 - 1/1989	Hindcasted to known start date
			SC0022403-001	DUE WEST WWTF	9/1984 - 1/1989	Hindcasted to known start date
SAV21	02196000	STEVENS CREEK NEAR MODOC, SC	SC0000396-001	MILLIKEN/MCCORMICK PLANT	10/1981 - 1/1989	Hindcasted to known start date
			SC0022870-001	GREENWOOD/WEST ALEXANDER WWTF	3/1979 - 1/1989	Hindcasted to known start date
			SC0025330-001	ECW&SA/BROOKS STREET WWTP	10/1981 - 1/1989	Hindcasted to known start date
			SC0030783-001	MCCORMICK/ROCKY CREEK WWTF	10/1983 - 1/1989	Hindcasted to known start date
			SCG646029-000	TOWN OF MCCORMICK WTP	1/1983 - 12/2013	Estimated based on permit return

Project Gage ID	USGS Number	Stream	Discharge Hindcasting			
			ID	Facility Name	Time Periods	Method Used
SAV28	02196690	HORSE CREEK AT CLEARWATER, SC	SC0039730-001	CYTEC INDUSTRIES INC	None	None
SAV34	02197310	UPPER THREE RUNS ABOVE ROAD C (SRS), SC	SC0000175-A01	US DOE/SAVANNAH RIVER SITE	None	None
			SC0000175-A11	US DOE/SAVANNAH RIVER SITE	None	Combined with SC0000175-A01
			SC0000175-A1A	US DOE/SAVANNAH RIVER SITE	None	Combined with SC0000175-A01
			SC0000175-M05	US DOE/SAVANNAH RIVER SITE	4/1982 - 1/1989	Hindcasted to known start date
			SC0000175-H02	US DOE/SAVANNAH RIVER SITE	4/1982 - 1/1989	Hindcasted to known start date
SAV35	02197315	UPPER THREE RUNS AT ROAD A (SRS), SC	SC0000175-TH1	US DOE/SAVANNAH RIVER SITE	None	None
			SC0049107-G05	AMERESCO SRS BIOMASS COGENERATION FACILITY	None	None

6.0 Summary of Gaged UIF Flow Record Extension

A summary of the reference gages and methods used to extend the UIFs with partial periods of record is provided in **Table 6-1**. Initial candidates of reference gages are selected following guidelines outlined in Attachment C. See Attachment D for details pertaining to the decision-making process and **Attachment F** for notes associated with each individual decision.

As MOVE.1 without an initial log transform may produce negative or near-zero values, area proration (which is strictly linear and cannot produce negative flows from non-negative reference flows) replaces values below a site-specific minimum threshold determined by the overlapping period between the partial and reference gages. For example, in the overlap between SAV21 and SLD14, the lowest flow is 0.1 cfs. Thus, when MOVE.1 is calculated using SLD14's untransformed flows, any days below 0.1 cfs are replaced with the corresponding flows of that day found from area proration. Note that if a reference gage registers a flow of zero, the extended flow for the partial gage will also be estimated as zero.

UIFs from neighboring basins were considered as well in the record extension process, including several naturally-unimpaired gages from the Georgia side of the basin. After evaluating all metrics, ultimately two from the Saluda River Basin and two from the Edisto River Basin were used. The

Saluda UIFs consisted of SLD14 (02165200 on South Rabon Creek near Gray Court, SC) and SLD17 (02166970 on Ninety-Six Creek near Ninety-Six, SC). The Edisto UIFs included EDO01 (02172300 on McTier Creek near New Holland, SC) and EDO05 (02173000 on South Fork Edisto near Denmark, SC).

Table 6-1: Summary of Extending UIFs with Partial Periods of Record

USGS Gage with Partial Record					USGS Reference Gage(s)			Method of Extension
Project Gage ID	USGS Number	Stream	Periods of Record	Basin Area (mi^2)	Project Gage ID	Stream	Basin Area (mi^2)	
SAV01	02184475	HOWARD CREEK NEAR JOCASSEE, SC	5/1988 - 9/1996	2.2	SAV00	CHATTOOGA RIVER NEAR CLAYTON, GA	203.4	MOVE.1 (log transform)
SAV04	02185200	LITTLE RIVER NEAR WALHALLA, SC	5/1967 - 9/2003	72.1	SAV00	CHATTOOGA RIVER NEAR CLAYTON, GA	203.4	MOVE.1 (log transform)
SAV06	02186000	TWELVEMILE CREEK NEAR LIBERTY, SC	8/1954 - 12/2013	104.2	SAV08	CONEROSS CK NR SENECA, SC	65.4	MOVE.1 (log transform)
					SAV04	LITTLE RIVER NEAR WALHALLA, SC	72.1	MOVE.1 (log transform)
					SAV09	EIGHTEENMILE CREEK ABOVE PENDLETON, SC	46.8	MOVE.1 (log transform)
					SAV00	CHATTOOGA RIVER NEAR CLAYTON, GA	203.4	MOVE.1 (log transform)
SAV08	02186645	CONEROSS CK NR SENECA, SC	4/1989 - 9/2003	65.4	SAV06	TWELVEMILE CREEK NEAR LIBERTY, SC	104.2	MOVE.1 (log transform)
					SAV04	LITTLE RIVER NEAR WALHALLA, SC	72.1	MOVE.1 (log transform)
					SAV00	CHATTOOGA RIVER NEAR CLAYTON, GA	203.4	MOVE.1 (log transform)
SAV09	02186699	EIGHTEENMILE CREEK ABOVE PENDLETON, SC	5/1998 - 7/2008	46.8	SAV08	CONEROSS CK NR SENECA, SC	65.4	Area Ratio
					SAV06	TWELVEMILE CREEK NEAR LIBERTY, SC	104.2	MOVE.1 (log transform)
					SAV04	LITTLE RIVER NEAR WALHALLA, SC	72.1	MOVE.1 (log transform)

USGS Gage with Partial Record					USGS Reference Gage(s)			Method of Extension
Project Gage ID	USGS Number	Stream	Periods of Record	Basin Area (mi²)	Project Gage ID	Stream	Basin Area (mi²)	
					SAV00	CHATTOOGA RIVER NEAR CLAYTON, GA	203.4	MOVE.1 (log transform)
SAV10	02186702	EIGHTEENMILE CREEK BELOW PENDLETON, SC	10/2013 - 12/2013	48.6	SAV09	EIGHTEENMILE CREEK ABOVE PENDLETON, SC	46.8	Area Ratio
					SAV06	TWELVEMILE CREEK NEAR LIBERTY, SC	104.2	MOVE.1 (log transform)
					SAV14	ROCKY RIVER NR STARR, SC	111.2	MOVE.1 (log transform)
					SAV00	CHATTOOGA RIVER NEAR CLAYTON, GA	203.4	MOVE.1 (log transform)
SAV14	02187910	ROCKY RIVER NR STARR, SC	5/1989 - 3/1996 10/1996 - 10/2001 2/2003 - 12/2013	111.2	SLD14	SOUTH RABON CREEK NEAR GRAY COURT, SC	29.5	Area Ratio
					SAV17	LITTLE RIVER NEAR MT. CARMEL, SC	214.6	MOVE.1 (log transform)
					SAV21	STEVENS CREEK NEAR MODOC, SC	543.6	MOVE.1 (log transform)
					SAV00	CHATTOOGA RIVER NEAR CLAYTON, GA	203.4	MOVE.1 (log transform)
SAV17	02192500	LITTLE RIVER NEAR MT. CARMEL, SC	1/1940 - 9/1970 8/1986 - 10/2003 10/2004 - 12/2013	214.6	SAV21	STEVENS CREEK NEAR MODOC, SC	543.6	MOVE.1 (log transform)
					SAV00	CHATTOOGA RIVER NEAR CLAYTON, GA	203.4	MOVE.1 (log transform)
SAV21	02196000	STEVENS CREEK NEAR MODOC, SC	2/1940 - 9/1978 11/1983 - 12/2013	543.6	SLD14	SOUTH RABON CREEK NEAR GRAY COURT, SC	29.5	MOVE.1: no transform, Area Ratio if MOVE.1 0.1< cfs
					SLD17	NINETY-SIX CREEK NR NINETY-SIX, SC	17.4	Area Ratio

USGS Gage with Partial Record					USGS Reference Gage(s)			Method of Extension
Project Gage ID	USGS Number	Stream	Periods of Record	Basin Area (mi²)	Project Gage ID	Stream	Basin Area (mi²)	
					EDO05	SOUTH FORK EDISTO RIVER NEAR DENMARK, SC	733.0	Area Ratio
SAV22	02196250	HORN CREEK NR COLLIERS (EDGEFIELD), SC	10/1980 - 9/1994	14.1	SAV27	LITTLE HORSE CREEK NEAR GRANITEVILLE, SC	26.8	MOVE.1 (log transform)
					SAV21	STEVENS CREEK NEAR MODOC, SC	543.6	MOVE.1 (log transform)
					SLD14	SOUTH RABON CREEK NEAR GRAY COURT, SC	29.5	MOVE.1 (log transform)
					EDO05	SOUTH FORK EDISTO RIVER NEAR DENMARK, SC	733.0	MOVE.1 (log transform)
SAV27	02196689	LITTLE HORSE CREEK NEAR GRANITEVILLE, SC	10/1989 - 12/1999 3/2000 - 4/2001 2/2002 - 7/2002	26.8	SAV28	HORSE CREEK AT CLEARWATER, SC	149.4	Area Ratio
					EDO01	MCTIER CREEK (RD 209) NEAR MONETTA, SC	15.6	MOVE.1 (log transform)
					SAV22	HORN CREEK NR COLLIERS (EDGEFIELD), SC	14.1	MOVE.1 (log transform)
					SAV21	STEVENS CREEK NEAR MODOC, SC	543.6	MOVE.1 (log transform)
					SAV34	UPPER THREE RUNS ABOVE ROAD C (SRS), SC	191.4	Area Ratio
					EDO05	SOUTH FORK EDISTO RIVER NEAR DENMARK, SC	733.0	MOVE.1 (log transform)
SAV28	02196690	HORSE CREEK AT CLEARWATER, SC	4/2005 - 12/2013	149.4	SAV27	LITTLE HORSE CREEK NEAR GRANITEVILLE, SC	26.8	Area Ratio

USGS Gage with Partial Record					USGS Reference Gage(s)			Method of Extension
Project Gage ID	USGS Number	Stream	Periods of Record	Basin Area (mi^2)	Project Gage ID	Stream	Basin Area (mi^2)	
					EDO01	MCTIER CREEK (RD 209) NEAR MONETTA, SC	15.6	MOVE.1 (log transform)
					SAV21	STEVENS CREEK NEAR MODOC, SC	543.6	MOVE.1 (log transform)
					EDO05	SOUTH FORK EDISTO RIVER NEAR DENMARK, SC	733.0	MOVE.1 (log transform)
					SLD14	SOUTH RABON CREEK NEAR GRAY COURT, SC	29.5	MOVE.1 (log transform)
SAV31	02197300	UPPER THREE RUNS NEAR NEW ELLENTON, SC	6/1966 - 9/2002	87.0	EDO01	MCTIER CREEK (RD 209) NEAR MONETTA, SC	15.6	MOVE.1 (log transform)
					EDO05	SOUTH FORK EDISTO RIVER NEAR DENMARK, SC	733.0	MOVE.1 (log transform)
SAV32	021973005	TINKER CREEK ON SRS RD 8-11 AT SRS, SC	10/1992 - 9/1996 12/1998 - 9/2002	14.7	SAV31	UPPER THREE RUNS NEAR NEW ELLENTON, SC	87.0	MOVE.1 (log transform)
					EDO05	SOUTH FORK EDISTO RIVER NEAR DENMARK, SC	733.0	MOVE.1 (log transform)
SAV34	02197310	UPPER THREE RUNS ABOVE ROAD C (SRS), SC	6/1974 - 1/1998 12/1998 - 9/2002	191.4	EDO01	MCTIER CREEK (RD 209) NEAR MONETTA, SC	15.6	MOVE.1 (log transform)
					SAV31	UPPER THREE RUNS NEAR NEW ELLENTON, SC	87.0	MOVE.1 (log transform)
					EDO05	SOUTH FORK EDISTO RIVER NEAR DENMARK, SC	733.0	MOVE.1 (log transform)
SAV35	02197315	UPPER THREE RUNS AT	6/1974 - 1/1978 10/1978 - 9/2002	201.4	EDO01	MCTIER CREEK (RD 209) NEAR MONETTA, SC	15.6	MOVE.1 (log transform)

USGS Gage with Partial Record					USGS Reference Gage(s)			Method of Extension
Project Gage ID	USGS Number	Stream	Periods of Record	Basin Area (mi^2)	Project Gage ID	Stream	Basin Area (mi^2)	
		ROAD A (SRS), SC			SAV31	UPPER THREE RUNS NEAR NEW ELLENTON, SC	87.0	MOVE.1 (log transform)
					EDO05	SOUTH FORK EDISTO RIVER NEAR DENMARK, SC	733.0	MOVE.1 (log transform)

One way to evaluate the selection of an extension method is comparing frequency curves with flows of the partial record needing extending. A sample plot for SAV08 is shown in **Figure 6-1**.

Validation graphs are available for each USGS gage. Each validation graph shows the period of record for a computed UIF and the predicted flows from reference gages during that same period. A sample validation graph is shown in **Figure 6-2**. The usage of each reference gage over different ungaged periods for the target gage (prioritized by hydrologic similarity and available record) is illustrated in **Figure 6-3**. Graphs for each UIF timeseries developed at a USGS gage site are presented in **Attachment E**.

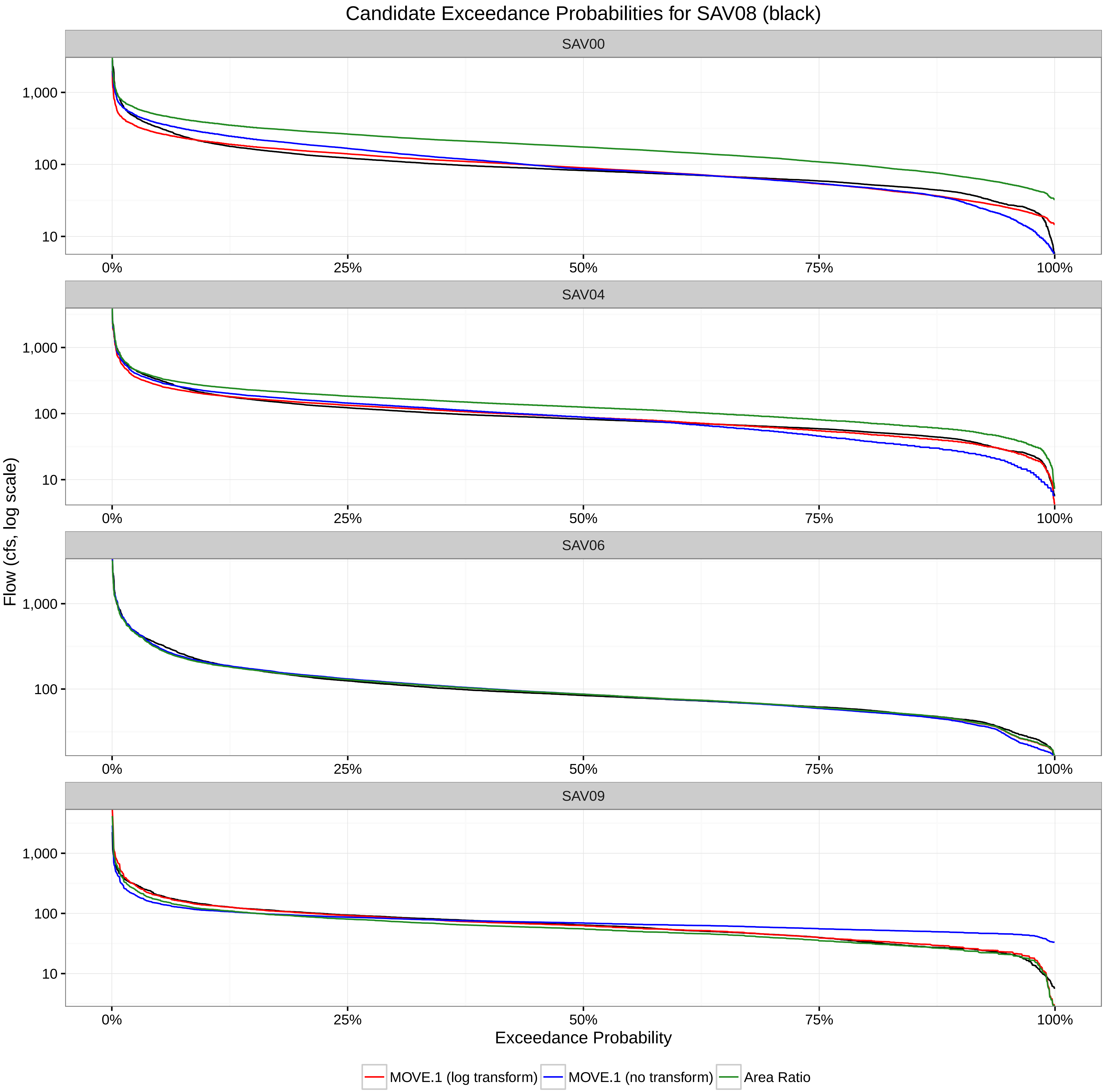


Figure 6.1: Comparison of Exceedance Probabilities for the Computed UIF and Extension Methods

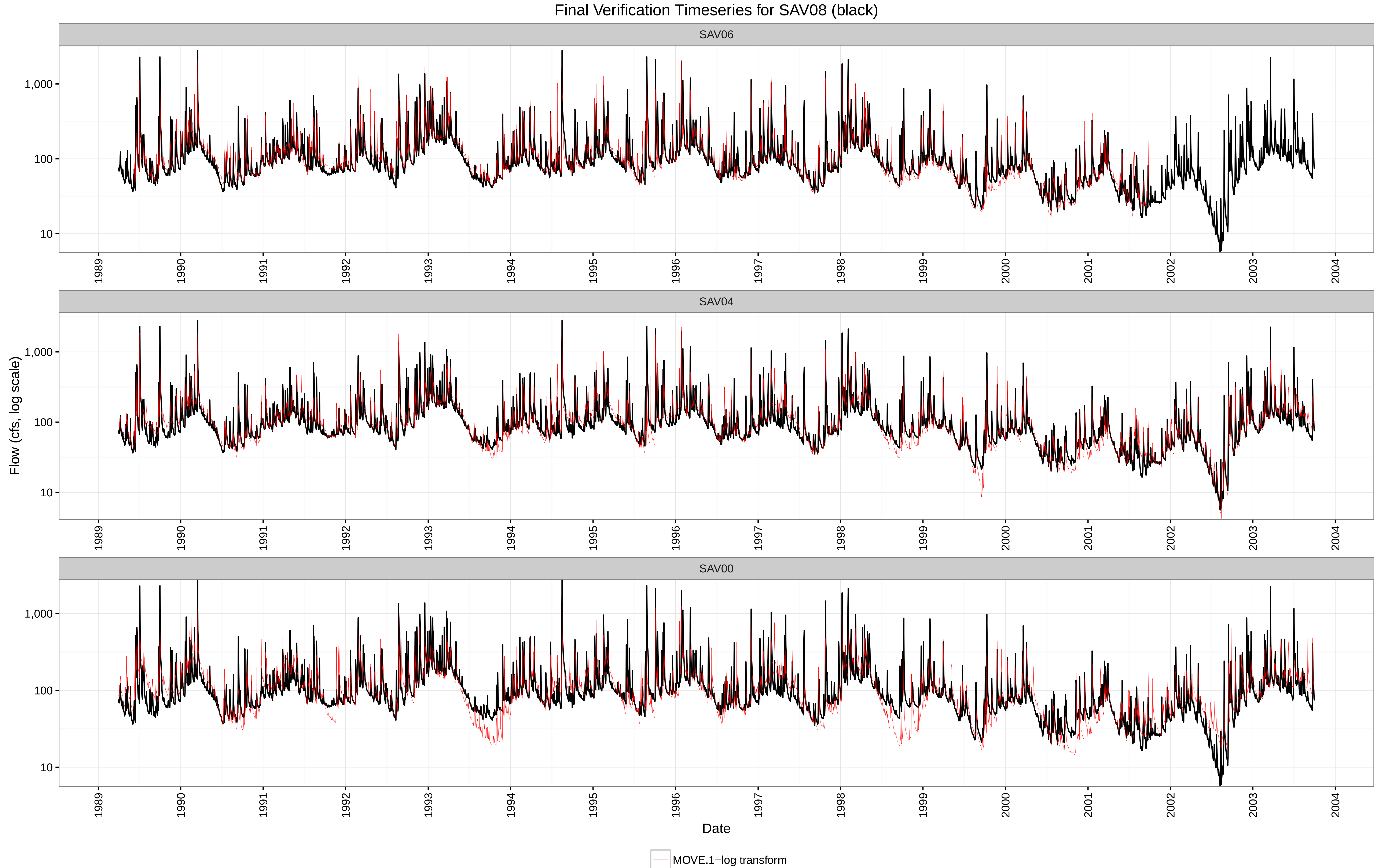


Figure 6.2: Validation Graph for SAV08 with Predicted Flows from Reference Gages

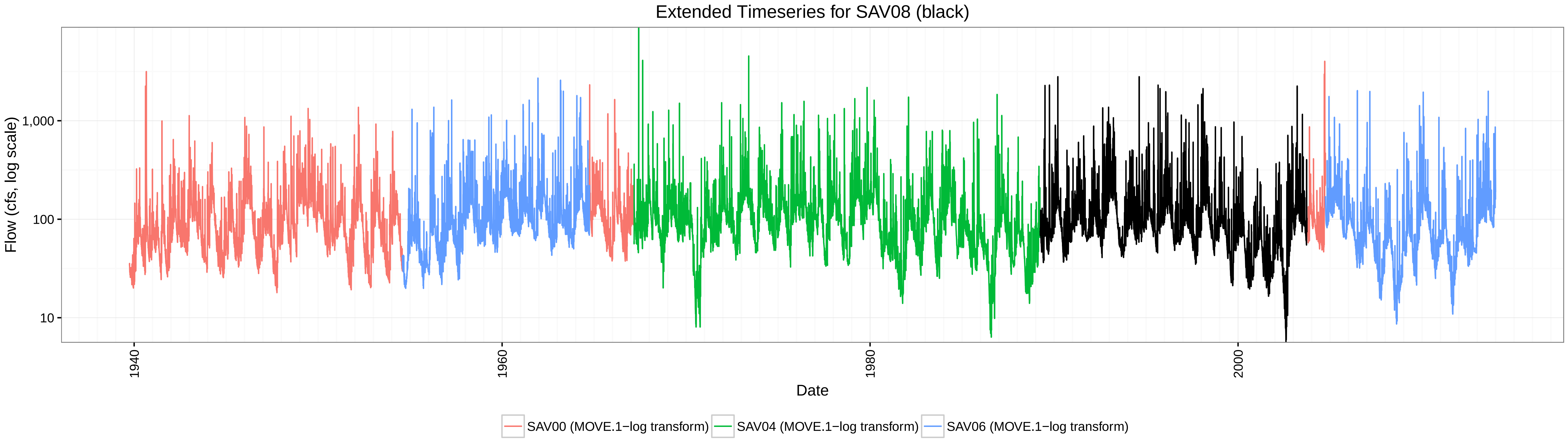


Figure 6.3: Resulting Timeseries for SAV08

7.0 Summary of Ungaged UIF Transposition

Area proration was used to transpose the UIF timeseries from gaged basins to ungaged basins. Selection of reference gages follows guidelines established in Attachment C. **Table 7-1** summarizes the information for the ungaged basins and the gaged basins used as reference. Headwater flows are used as input for each explicitly modeled tributary in SWAM whereas GA tributary flows are used for tributaries on the Georgia side of the basin, treated similarly as implicit confluence flows in other basins. All Georgia tributary flows were estimated using the two-available tributary UIFs from the GA EPD dataset, BELL and MILLHAVN.

Table 7-1: UIFs in Ungaged Basins (Area Ratio Method Only)

	Ungaged Basin				USGS Reference Gage				
Project ID	SWAM Usage	Stream	Basin Area (mi^2)	% Developed / % Forest	Project Gage ID	USGS Number	Stream	Basin Area (mi^2)	% Developed / % Forest
SAV205	Headwater Flow	Chauga River	25.8	5.4 / 83.3	SAV00	02177000	CHATTOOGA RIVER NEAR CLAYTON, GA	203.4	3.8 / 93.1
SAV200	Headwater Flow	Mainstem	24.5	9.2 / 84.8					
SAV204	Headwater Flow	Little River - Lake Keowee	2.8	1.1 / 91	SAV04	02185200	LITTLE RIVER NEAR WALHALLA, SC	72.1	5.8 / 80.2
SAV207	Headwater Flow	Golden Creek	1.1	51.7 / 34.5	SAV06	02186000	TWELVEMILE CREEK NEAR LIBERTY, SC	104.2	15.5 / 53.1
SAV206	Headwater Flow	Twelvemile Creek	18.7	6.2 / 72.2					
SAV300	Headwater Flow	Lake Jocassee Local Inflow	65.7	10.3 / 79.9					
SAV302	Headwater Flow	Lake Keowee Local Inflow	112.7	8 / 82.2					
SAV304	Headwater Flow	Lake Hartwell Local Inflow	138.4	18.6 / 52					
SAV208	Headwater Flow	Coneross Creek	13.3	7.6 / 69.3	SAV08	02186645	CONEROSS CK NR SENECA, SC	65.4	18.5 / 49.5
SAV211	Headwater Flow	Six and Twenty Creek	3.1	14.3 / 45.8	SAV09	02186699	EIGHTEENMILE CREEK ABOVE PENDLETON, SC	46.8	29 / 46
SAV210	Headwater Flow	Three and Twenty Creek	26.2	19.8 / 42.7					
SAV209	Headwater Flow	Eighteenmile Creek	7.6	44.8 / 33.8					
SAV216	Headwater Flow	Beaver Creek	1.7	46.9 / 21.5	SAV14	02187910	ROCKY RIVER NR STARR, SC	111.2	25.5 / 37.2

	Ungaged Basin				USGS Reference Gage				
Project ID	SWAM Usage	Stream	Basin Area (mi²)	% Developed / % Forest	Project Gage ID	USGS Number	Stream	Basin Area (mi²)	% Developed / % Forest
SAV215	Headwater Flow	Big Generostee Creek	6.1	88.4 / 9.2					
SAV214	Headwater Flow	Rocky River	33.3	18.2 / 34.4					
SAV222	Headwater Flow	Sawney Creek	0.9	74.4 / 14.6	SAV17	02192500	LITTLE RIVER NEAR MT. CARMEL, SC	214.6	7 / 50.5
SAV220	Headwater Flow	Long Cane Creek	26.5	6.7 / 47.6					
SAV219	Headwater Flow	Park Creek	3.0	17.7 / 40.5					
SAV217	Headwater Flow	Little River - Savannah River	45.2	10.9 / 40.9					
SAV306	Headwater Flow	Lake Russell Local Inflow	231.2	7.9 / 54.2					
SAV224	Headwater Flow	Beaverdam Creek	9.5	17.5 / 49.7	SAV21	02196000	STEVENS CREEK NEAR MODOC, SC	543.6	6 / 68.6
SAV223	Headwater Flow	Turkey Creek	38.0	5.4 / 70.7					
SAV221	Headwater Flow	Hard Labor Creek	2.9	59.4 / 22.4					
SAV308	Headwater Flow	Lake Thurmond Local Inflow	362.3	6 / 65.1					
SAV228	Headwater Flow	Horse Creek	6.8	3.9 / 55.3	SAV28	02196690	HORSE CREEK AT CLEARWATER, SC	149.4	20.3 / 46.5
SAV229	Headwater Flow	Hollow Creek	0.5	80.8 / 15.4	SAV31	02197300	UPPER THREE RUNS NEAR NEW ELLENTON, SC	87.0	10.9 / 38.4
SAV240	Headwater Flow	Lower Three Runs	8.5	0.2 / 81.3	SAV32	021973005	TINKER CREEK ON SRS RD 8-11 AT SRS, SC	14.7	2.8 / 58.9
SAV402	GA Tributary Flow	Beaverdam Creek (GA)	123.2	10.5 / 44.7	BELL	02192000	BROAD RIVER NEAR BELL, GA	1420	-

	Ungaged Basin				USGS Reference Gage				
Project ID	SWAM Usage	Stream	Basin Area (mi²)	% Developed / % Forest	Project Gage ID	USGS Number	Stream	Basin Area (mi²)	% Developed / % Forest
SAV404	GA Tributary Flow	Broad River (GA)	1503.0	8.6 / 54.6					
SAV406	GA Tributary Flow	Little River (GA)	767.7	5.1 / 64	MILLHAVN	02198000	BRIER CREEK AT MILLHAVEN, GA	646.0	-
SAV408	GA Tributary Flow	Kiokee Creek (GA)	110.8	5 / 67.2					
SAV410	GA Tributary Flow	Uchee Creek (GA)	64.5	29.5 / 48.6					
SAV412	GA Tributary Flow	Spirit Creek (GA)	104.7	24.6 / 46.1					
SAV414	GA Tributary Flow	McBean Creek (GA)	86.1	7.2 / 54.2					
SAV416	GA Tributary Flow	Brier Creek (GA)	848.5	4.9 / 36.5					

8.0 References

CDM Smith, August 2016, *Savannah River Basin SWAM Model Framework.*

Georgia EPD, 2015. Personal communication and data provided by Hailian Liang.

List of Attachments

A. *Methodology for Unimpaired Flow Development, Savannah River Basin, South Carolina* (CDM Smith, January 2016).

B. *Quality Assurance Guidelines: Unimpaired Flow Calculations (UIFs) for the South Carolina Surface Water Quantity Models* (CDM Smith, April 2015)

C. *Guidelines for Identifying Reference Basins for UIF Extension or Synthesis* (CDM Smith, April 2015)

D. *Refinements to the UIF Extension Process, with an Example* (CDM Smith, September 2015)

E. UIF Timeseries Graphs at USGS Gage Locations

F. Discussion on Reference Gage and Method Selection

ATTACHMENT A

Methodology for Unimpaired Flow Development, Savannah River Basin, South Carolina

(CDM Smith, September 2016)

Technical Memorandum

To: *South Carolina Department of Natural Resources (DNR)*
South Carolina Department of Health and Environmental Control (DHEC)

From: *CDM Smith*

Date: *September 6, 2016*

Subject: *Unimpaired Flow Development*
Savannah River Basin, South Carolina

1.0 Background and Objectives for Unimpaired Flows

Unimpaired flow (UIF) describes the natural hydrology of a river basin. UIFs quantify streamflows throughout a river basin in the absence of human intervention in the river channel, such as storage, withdrawals, discharges, and return flows. From this basis, modeling and decision making can be compared with pristine conditions.

This memorandum identifies the active and inactive flow gages the Savannah River basin and provides recommendations on where UIF development may occur.

2.0 Overview of the Savannah Basin USGS Gages

There are over seventy Unites States Geological Survey (USGS) active or former streamflow gaging stations in the Savannah River Basin within South Carolina or on its border. At eight gaging stations on the Savannah River (mainstem), the Georgia Environmental Protection Division (GA EPD) has calculated UIFs for the period 1939 through 2013 (GA EPD, 2015). Since mainstem UIFs have already been developed, additional UIF development to support the South Carolina Surface Water Availability Assessment is focusing on gage locations at select South Carolina tributaries to the mainstem.

An overview map of the current and former USGS streamflow gages in the Savannah River Basin is shown in **Figure 1**. Proposed (new) UIF locations on South Carolina tributaries to the mainstem are identified by green triangles. The location of previously calculated UIFs are identified by red triangles (GA EPD “Basic” UIF nodes) and red circles with triangles (GA EPD “Planning” UIF nodes). Other mainstem gaging stations, which will be included in the model framework, but will not be subject to UIF development are identified by purple triangles.

Table 1 matches each project ID with its gage number, location, periods of record, activity, and whether it is on a tributary and thus subject to UIF development. **Figure 2** depicts the length and timing of records for existing and proposed UIFs, and other model framework gages in the Savannah River basin.

3.0 Recommendations for UIF Development

Twenty-one tributary gages are candidates for UIF development. Two situations arose in which a tributary gage was not included:

- USGS gage 02186090 was only active from May 1998 to September 1999. Since no SWAM model objects are upstream of the gage, and given its short period of record, it was excluded.
- A cluster of forty-three gages were installed within the Department of Energy's Savannah River Site (SRS), all of which are currently inactive. A selection of six of these were chosen to represent key tributaries in this region. The remaining inactive gages will be excluded from UIF calculations.

4.0 Summary

Of the almost-eighty USGS gaging stations, twenty-one gages on tributaries have been identified as candidates for UIF development, supplementing the existing eight UIF locations on the mainstem. The two exceptions have either an insufficient period of record or were omitted in order to simplify the SRS site.

5.0 References

GA EPD, 2015. Savannah River Basin Comprehensive Study II: 2009 – 2013 Unimpaired Flow Data Extension (Draft Report).

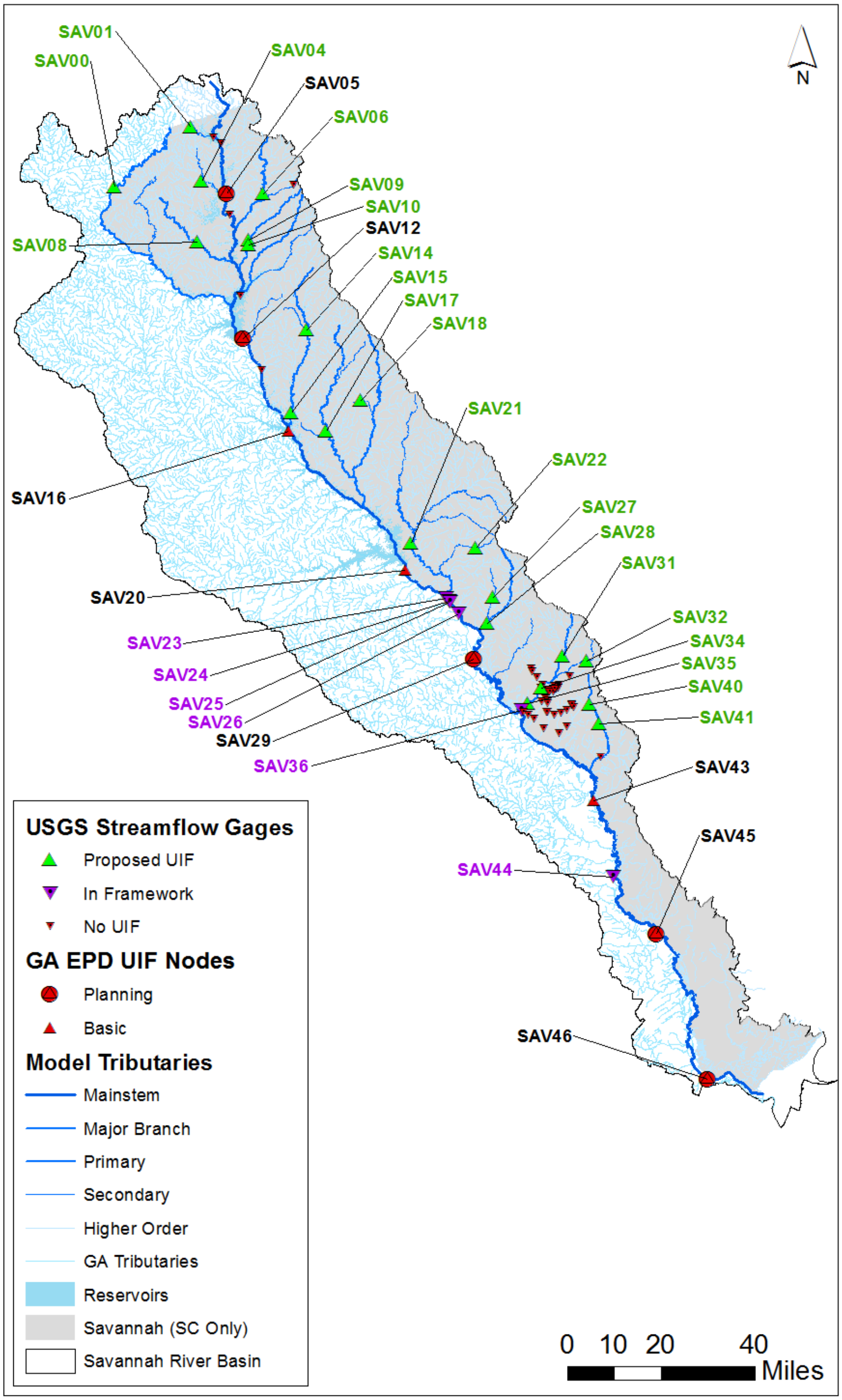


Figure 1: Proposed and Previous UIF Locations

Table 1. Savannah River Basin USGS Streamflow Gages (with project IDs)

Project ID	Tributary UIF	Existing UIF	USGS Number	Description	From:	To:	From:	To:	From:	To:	From:	To:
SAV00	Yes	No	02177000	CHATTOOGA RIVER NEAR CLAYTON, GA	Oct-1939	Dec-2013						
SAV01	Yes	No	02184475	HOWARD CREEK NEAR JOCASSEE, SC	May-1988	Sep-1996						
SAV04	Yes	No	02185200	LITTLE RIVER NEAR WALHALLA, SC	Mar-1967	Sep-2003						
SAV05	No	**Yes**	02185145	LAKE KEOWEE NEAR SIX MILE, SC	Oct-1999	Sep-2000						
SAV06	Yes	No	02186000	TWELVEMILE CREEK NEAR LIBERTY, SC	Aug-1954	Dec-2013						
SAV08	Yes	No	02186645	CONEROSS CK NR SENECA, SC	Apr-1989	Sep-2003						
SAV09	Yes	No	02186699	EIGHTEENMILE CREEK ABOVE PENDLETON, SC	May-1998	Jul-2008						
SAV10	Yes	No	02186702	EIGHTEENMILE CREEK BELOW PENDLETON, SC	Oct-2012	Dec-2013						
SAV12	No	**Yes**	02187252	SAVANNAH RIVER BELOW HARTWELL LK NR HARTWELL, GA	Oct-1984	Sep-1999						
SAV14	Yes	No	02187910	ROCKY RIVER NR STARR, SC	May-1989	Mar-1996	Oct-1996	Oct-2001	Feb-2003	Mar-2004	Oct-2004	Dec-2013
SAV15	Yes	No	02188000	ROCKY RIVER NEAR CALHOUN FALLS, SC	Mar-1950	Sep-1966						
SAV16	No	**Yes**	02189000	SAVANNAH RIVER NEAR CALHOUN FALLS, S. C.	Oct-1896	Sep-1979						
SAV17	Yes	No	02192500	LITTLE RIVER NEAR MT. CARMEL, SC	Jan-1940	Sep-1970	Aug-1986	Oct-2003	Oct-2004	Dec-2013		
SAV18	Yes	No	02192830	BLUE HILL CREEK AT ABBEVILLE, SC	Feb-1998	Aug-2008						
SAV20	No	**Yes**	02195000	SAVANNAH RIVER NEAR CLARKS HILL, S.C.	May-1940	Jun-1954						
SAV21	Yes	No	02196000	STEVENS CREEK NEAR MODOC, SC	Nov-1929	Sep-1931	Feb-1940	Sep-1978	Nov-1983	Dec-2013		
SAV22	Yes	No	02196250	HORN CREEK NR COLLIERS (EDGEFIELD), SC	Oct-1980	Sep-1994						
SAV23	No	No	021964832	SAVANNAH RIVER ABOVE AUGUSTA CANAL NEAR BONAIR,GA	Sep-2011	Dec-2013						
SAV24	No	No	02196484	SAVANNAH RIVER NEAR NORTH AUGUSTA, SC	Oct-1988	Sep-2002						
SAV25	No	No	02196485	AUGUSTA CANAL NR AUGUSTA, GA (UPPER)	Jul-1988	Dec-1992	Oct-1996	Jul-2003	May-2005	Jan-2009	May-2009	Dec-2013
SAV26	No	No	02196500	AUGUSTA CANAL AT AUGUSTA (LOWER)	Nov-1930	Sep-1957	Oct-1988	Sep-1992				
SAV27	Yes	No	02196689	LITTLE HORSE CREEK NEAR GRANITEVILLE, SC	Oct-1989	Dec-1999	Mar-2000	Apr-2001	Feb-2002	Jul-2002		
SAV28	Yes	No	02196690	HORSE CREEK AT CLEARWATER, SC	Apr-2005	Dec-2013						
SAV29	No	**Yes**	02197000	SAVANNAH RIVER AT AUGUSTA, GA	1883-10-01	1891-12-31	1896-01-01	Dec-1906	Jan-1925	Dec-2013		
SAV31	Yes	No	02197300	UPPER THREE RUNS NEAR NEW ELLENTON, SC	Jun-1966	Sep-2002						
SAV32	Yes	No	021973005	TINKER CREEK ON SRS RD 8-11 AT SRS, SC	Oct-1992	Sep-1996	Dec-1998	Sep-2002				
SAV34	Yes	No	02197310	UPPER THREE RUNS ABOVE ROAD C (SRS), SC	Jun-1974	Jan-1998	Dec-1998	Sep-2002				
SAV35	Yes	No	02197315	UPPER THREE RUNS AT ROAD A (SRS), SC	Jun-1974	Jan-1978	Oct-1978	Sep-2002				
SAV36	No	No	02197320	SAVANNAH R. NR JACKSON, SC	Oct-1971	Sep-2002						
SAV40	Yes	No	02197380	LOWER THREE RUNS BELOW PAR POND @ SRS, SC	May-1974	Sep-2002						
SAV41	Yes	No	02197400	LOWER THREE RUNS NEAR SNELLING, SC	Mar-1974	Dec-1996	May-1997	Sep-2002				
SAV43	No	**Yes**	02197500	SAVANNAH R AT BURTONS FERRY BR NR MILLHAVEN, GA	Oct-1939	Sep-1970	Oct-1982	Oct-2003	Oct-2004	Dec-2013		
SAV44	No	No	02198375	SAVANNAH RIVER NEAR ESTILL, SC	Jul-2009	Sep-2014						
SAV45	No	**Yes**	02198500	SAVANNAH RIVER NEAR CLYO, GA	Oct-1929	Sep-1933	Oct-1937	Sep-2014				
SAV46	No	**Yes**	021989773	SAVANNAH RIVER AT USACE DOCK, AT SAVANNAH, GA	Oct-2007	Dec-2013						

Existing UIFs are in ***bold***

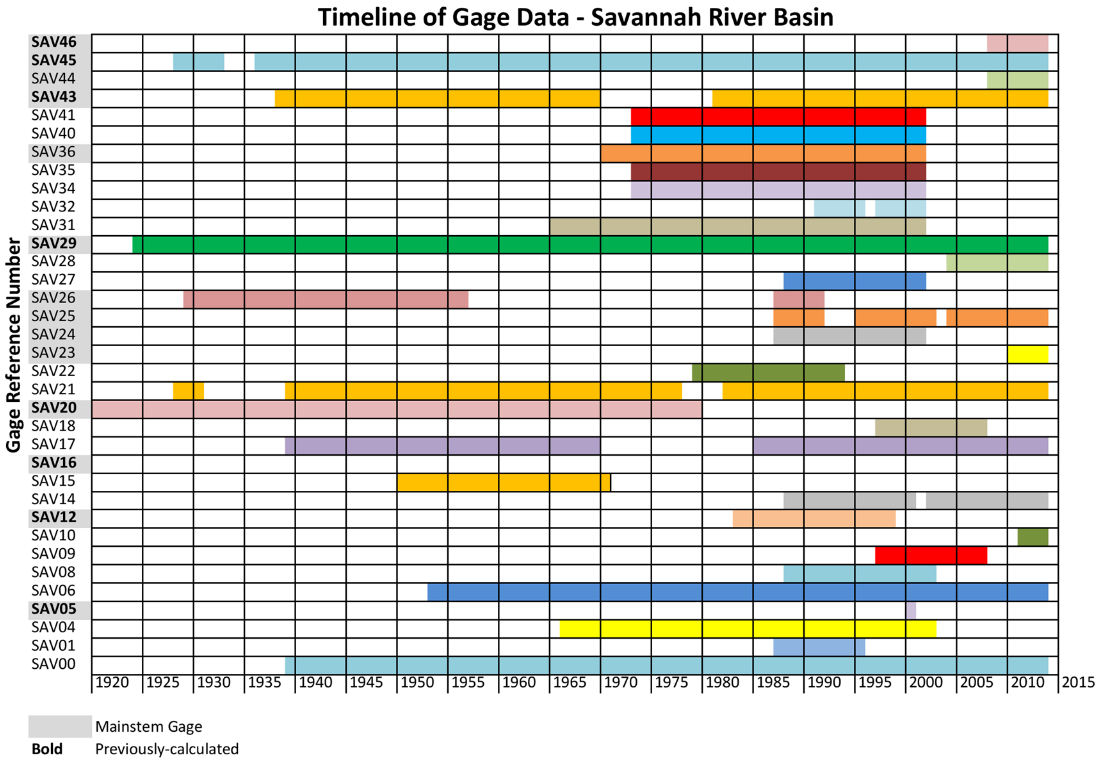


Figure 2. Period of record for proposed UIF USGS gages in the Savannah Basin

ATTACHMENT B

Quality Assurance Guidelines: UIFs for the South Carolina Surface Water Quantity Models

(CDM Smith, April 2015)

Quality Assurance Guidelines

Unimpaired Flow Calculations (UIFs) for the South Carolina Surface Water Quantity Models

Prepared by CDM Smith, April 2015, Adjusted September 2015

Procedural Review

What to Review	How Many UIF Workbooks	How Much Within Each UIF Workbook
Operational Hindcasting and Gap Filling – Appropriate Method?	All	N/A
Approach for negative flow resulting from storage calculations – Major or Minor impact, and Appropriate?	All	Review all UIF entries and required conversions
Overall UIF Equation Correct and Complete	~25%	N/A

Detailed Review

What to Review	How Many UIF Workbooks	How Much Within Each UIF Workbook
All uses included (active and inactive)?	All	N/A
Operational Hindcasting calculations – check math	~50%	Spot check
Operational Hindcasting calculations – visual timeseries evaluation	All	N/A
Hindcast data color-coded through all workbooks and worksheets?	All	Entire workbook
Upstream UIFs (if applicable) accounted for accurately?	All	N/A
Units consistent and accurate?	~25%	Spot check
Overall Mass Balance for reservoirs, if applicable (per example in SLD01 and SLD19)	All	Each Reservoir
Visual comparison of UIF timeseries vs. Gage timeseries	All	N/A

Extension Review

What to Review	R Output Per UIF
DNR recommendations for reference gages applied or justification provided for use of others?	All
All graphs created, labeled correctly, contain correct methods?	All
Any issues regarding noise or minimum values?	All
Selection of UIF Extension Method – Appropriate and Documented?	All
Visual check of final flows graph	All

ATTACHMENT C

Guidelines for Identifying Reference Basins for UIF Extension or Synthesis

(CDM Smith, April 2015)

Technical Memorandum

To: *South Carolina Department of Natural Resources (DNR)*
South Carolina Department of Health and Environmental Control (DHEC)

From: *CDM Smith*

Date: *April 2015*

Subject: *Guidelines for Identifying Reference Basins for UIF Extension or Synthesis*
South Carolina Surface Water Quantity Modeling – Unimpaired Flow Development

1.0 Introduction

These guidelines are developed to help provide a consistent thought process for selecting reference basins (gaged basins) to estimate flow in ungagged or incompletely gaged basins. This applies to the extension of UIFs at USGS gages, and also to the transposition of UIFs into ungaged basins. Naturally, finding a representative basin with similar hydrologic dynamics is partly objective and largely subjective, and many factors can be considered. The following list can be used as a guideline, with the importance of each factor usually decreasing from top to bottom.

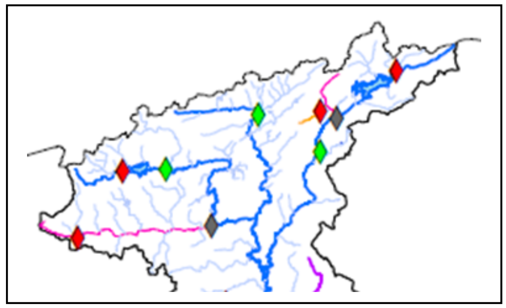
For clarity, we shall refer to ungaged and undergaged sites (needing either full synthesis or gap filling/extension, respectively) all as “ungaged” basins, as opposed to the reference basins, whose gage records will be used for hydrologic transposition.

Consider these factors as guidelines with decreasing importance moving down the list, and refer to the general guidance at the end – There will be cases in which these priorities may need to be adjusted when dealing with certain extreme situations.

2.0 Guidelines

Factor 1: Correlated Overlapping Record: If a candidate reference gage and a basin that has a partial gage requiring extension have overlapping periods of record, test the DAILY correlation between the UIFs (UIFs will be a better indicator of hydrologic similarity than the actual gage records). Note that monthly correlation may be a good indicator of overall water budget characteristics (runoff vs. evap and infiltration), but may not necessarily suggest similar daily hydrologic response patterns, which are important for the UIFs.

Factor 2: **Same Basin**: If the ungaged basin is tributary to a gaged basin (or vice versa) and the area ratios are within a factor of 2x to 4x (approximately), the flows should be highly correlated because one is part of the other. Several examples are shown to the right, where the red nodes indicate ungaged basins, and the green nodes are candidate reference basins. The green nodes downstream of the red nodes should be the first candidates as reference gages.



Factor 3: Measured vs. Estimated Reference Data: In some cases, if a basin would otherwise be a very good candidate as a reference basin but a large percentage of its data have already been synthesized (operational data for UIFs, or a UIF itself synthetically extended), preference should be given to basins with lower amounts of estimated data in the record that would be used for extension.

Factor 4: Basin Area: Because of our daily timestep, this is a critical factor – Large watersheds will exhibit very different daily hydrographs than will small ones in response to the same rain event. It is important that reference basins be comparable in size (generally, within a factor of 2 or 3, if possible).

Factor 5: Land Use: The relative amounts of common land use, and certainly the dominant land use, should be reasonably similar between the reference basin and the ungaged basin to help provide confidence that hydrologic tendencies of the ungaged basin (runoff, infiltration, and evapotranspiration) are well represented by the reference gage.

Factor 6: Basin Slope: The average slope of the basin as determined with DEM's and the stream length in actual river miles can help indicate runoff propensity.

Factor 7: Runoff Curve Number: If the factors above are not sufficient to distinguish several candidate basins, the Soil Conservation Service (SCS) Runoff Curve Number (CN) may be used as a "tie breaker." It can also be used to help determine how adequate the land use similarity (Factor 5) really is as an indicator of runoff propensity.

3.0 General Application of Guidelines

It is not recommended that the six factors above be weighted numerically, nor applied with the exact same priorities in every case. Rather, the determination of a good reference gage is largely subjective, and the factors above should be considered in the selection, but the relative importance may vary depending on certain extremes. For example, if a basin is extremely steep, it would not make sense to choose a reference basin that is nearly flat, even if all the other criteria indicate a good match. Likewise, if a basin is well forested, it would not be wise to use a well-developed basin as a reference, even if all the other criteria indicate a good match. In other words, **while the list**

<u>above provides some general priorities for consideration, we should try to avoid extreme mismatches in any of the criteria.</u>

It is not essential that an ungaged basin use just one reference gage. In fact, it would be impossible to do so unless only the longest gage in the basin were to be used for each ungaged basin. For example, if Basin A is ungaged and must be synthesized back to 1925, and Basin B and C are good candidates for reference basins, we might encounter the following: Basin B is preferred as a reference, but only extends back to 1950, while Basin C is less preferred but extends back to 1925. In this case, use Basin B back to 1950, then Basin C from 1925-1949.

ATTACHMENT D

Refinements to the UIF Extension Process, with an Example

(CDM Smith, September 2015)

Refinements to the UIF Extension Process, with an Example

South Carolina Surface Water Quantity Modeling

September 2015

The following demonstrates an update to the previously-submitted UIF extension process. Previously, all calculations were performed in Excel, but given a need to accelerate the decision process (e.g. reduce time spent making plots by hand), R codes now automate calculations and plot creation. To demonstrate the reliability of the R code, we present an example of the full UIF extension process via Excel for comparison. For the example, we chose SLD15 on North Rabon Creek (USGS gage 2165280). SLD15 provides a solid example as 1) the gage flows required no unimpairing, 2) the best candidate for extension, SLD14, also required no unimpairing, and 3) it has the same overlapping period of record for all candidate extension gages.

Three methods of extension are considered:

1) Standard MOVE.1 – Flow data is transformed into log (base 10) space, mean and standard deviation are determined from this, and the MOVE.1 equation is applied.

2) Untransformed MOVE.1 – Flow data remains untransformed, mean and standard deviation are determined from this, and the MOVE.1 equation is applied.

3) Area proration – Flow is estimated using a simple ratio of areas.

Two main questions arose in prior investigations: 1) Whether mean and standard deviation should be strictly contained to the overlapping record only and 2) Whether flows should be transformed into log space. To adhere to the strict definition of MOVE.1, for current purposes mean and standard deviation are held to the overlapping record. As the choice of using a log transform or not can produce appreciable differences in estimated flows, both options are still considered. In the table below, the first nine rows (excluding overlapping minimum) represent the necessary distributional statistics for performing MOVE.1 in transformed and untransformed space. The following two rows demonstrate initial suitability of candidacy through correlation. To fulfill assumptions of linearity, candidate flows are first transformed into log space before calculating Pearson's correlation coefficient. The rank-based Kendall's Tau is performed on untransformed flows and can provide a more robust standard of correlation given no assumptions of linearity. However, both coefficients typically trend in the same direction in assessing suitability of candidate reference gages.

	SLD14	SLD18	SLD26
Overlapping Mean (Gage)	27.63	27.63	27.63
Overlapping Log Mean (Gage)	1.18	1.18	1.18
Overlapping St. Dev (Gage)	48.99	48.99	48.99
Overlapping Log St. Dev (Gage)	0.47	0.47	0.47
Overlapping Minimum (Gage)	0	0	0
Overlapping Mean (Ref)	21.90	1514.91	2707.93
Overlapping Log Mean (Ref)	1.08	3.03	3.29

Overlapping St. Dev (Ref)	35.79	1687.60	3034.92
Overlapping Log St. Dev (Ref)	0.46	0.35	0.32
Flow Correlation (Kendall's Tau)	0.83	0.61	0.54
Log Flow Correlation (Pearson)	0.94	0.77	0.71
RMSE (MOVE.1-log transform)	15.78	28.10	38.35
RMSE (MOVE.1-no transform)	16.07	27.78	30.32
RMSE (Area Ratio)	16.07	30.66	31.86
PRESS (MOVE.1-log transform)	1.81	16.93	12.15
PRESS (MOVE-no transform)	0.83	12.53	6.14
PRESS (Area Ratio)	0.72	42.37	28.34

A valid concern arising from untransformed MOVE.1 is the possible existence of negative or unrealistically-low flows. In the previous UIF dataset, we offered a hybrid approach where values from area proration substitute these negative values or values below a certain threshold. In Excel, these thresholds were found through trial and error. This threshold is now strictly defined by the overlapping minimum between the partial gage and candidate gage. As SLD15 naturally runs dry, in this example, all untransformed MOVE.1 values that fall below zero are replaced with those from area proration.

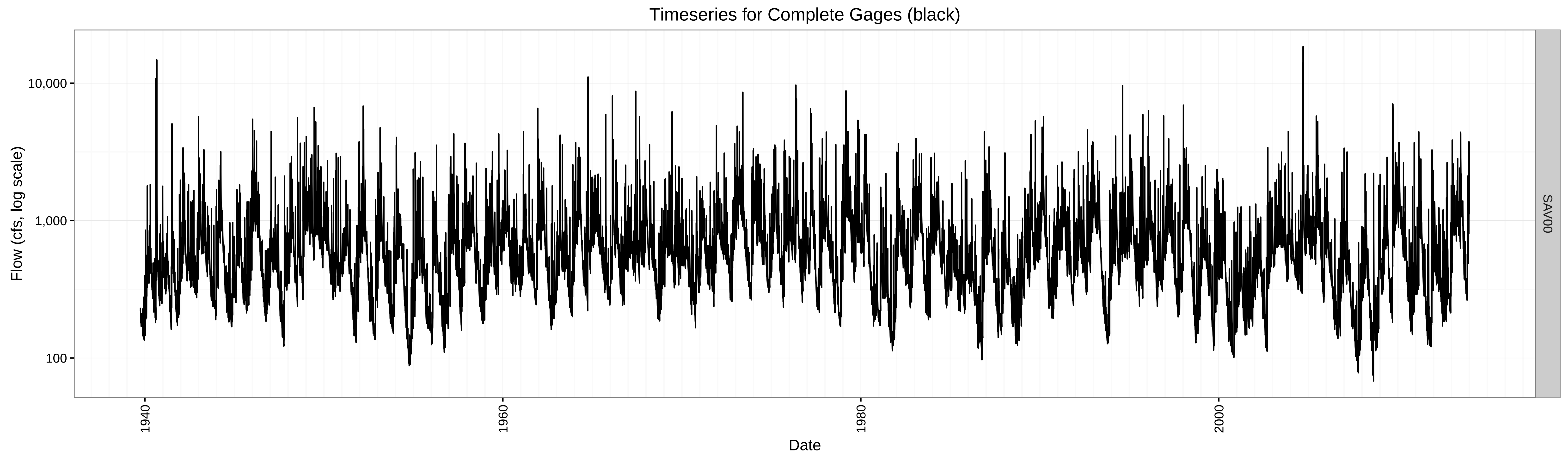
Two quantitative metrics aid the selection of reference gages and methods: root mean square error (RMSE) and predicted residual sum of squares (PRESS). RMSE compares estimated daily values and must be interpreted cautiously as this can be skewed by under or over-predicted flows. As an additional standard, the PRESS metric evaluates *yearly* error. To perform this statistic, one year is iteratively dropped, mean and standard deviation are found from the remaining years, and the dropped year is evaluated from the resulting extension. The values in the table above correspond to total yearly squared error of total volume of water in 1000 acre-ft. While dropping years does not affect the performance of area proration, the final PRESS value is useful in the overall comparison between methods as part of the decision process.

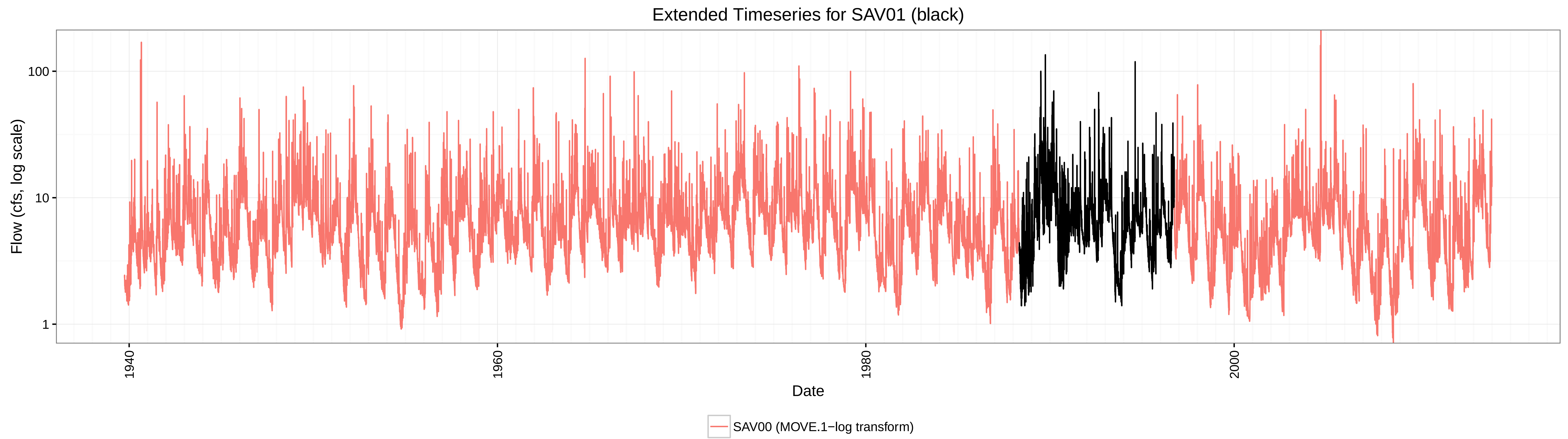
In addition to summary statistics, there are four plots to support to decision-making process: 1) an initial comparison of the original timeseries, 2) timeseries plots of the overlapping record for all methods, 3) scatterplots of the observed versus estimated flows and 4) exceedance frequency curves of the observed and estimated flows. After the first plot, with the y-axis in log-scale, the remaining plots have alternate versions in square root scale. This scale allows for examining low flows without diminishing too much the behavior of higher flows.

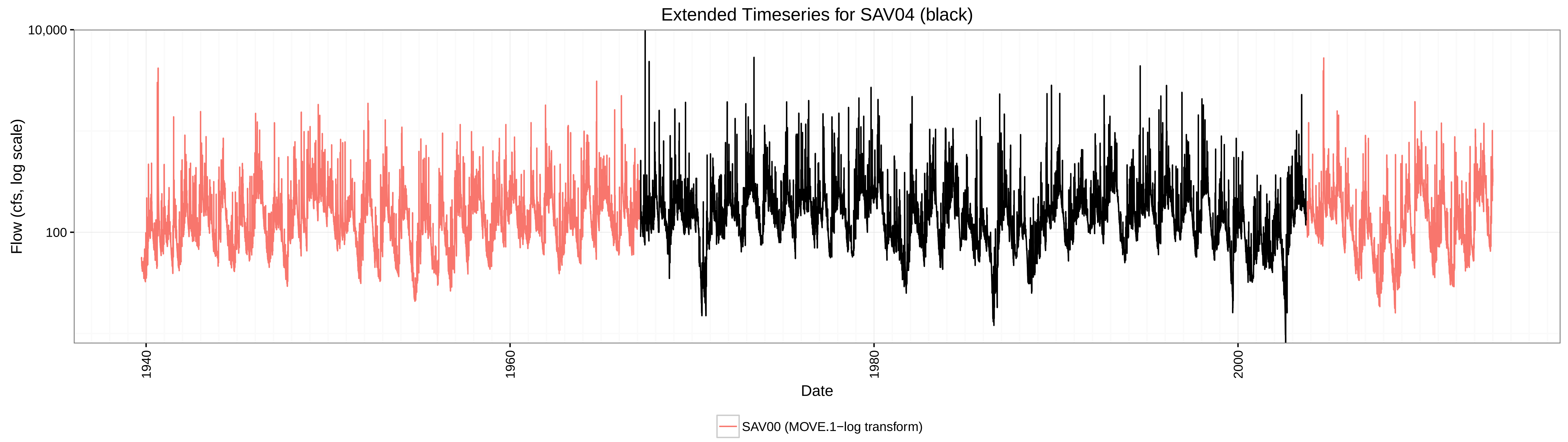
After examining the table and these performance plots, a final decision table is created and fed into another R script that creates the fully-extended record and makes two more plots: 5) verification showing the estimated values for the overlapping record and 6) final flows timeseries for the entire period of record with the use of each reference gage indicated by color. However, this may be an iterative process. The final flow timeseries is still examined and if problems, such as an obvious bias, are evident, the decision table is changed to explore alternate options for problem areas. Lastly, there are timeseries plots contrasting the behavior of immediate upstream/downstream gages.

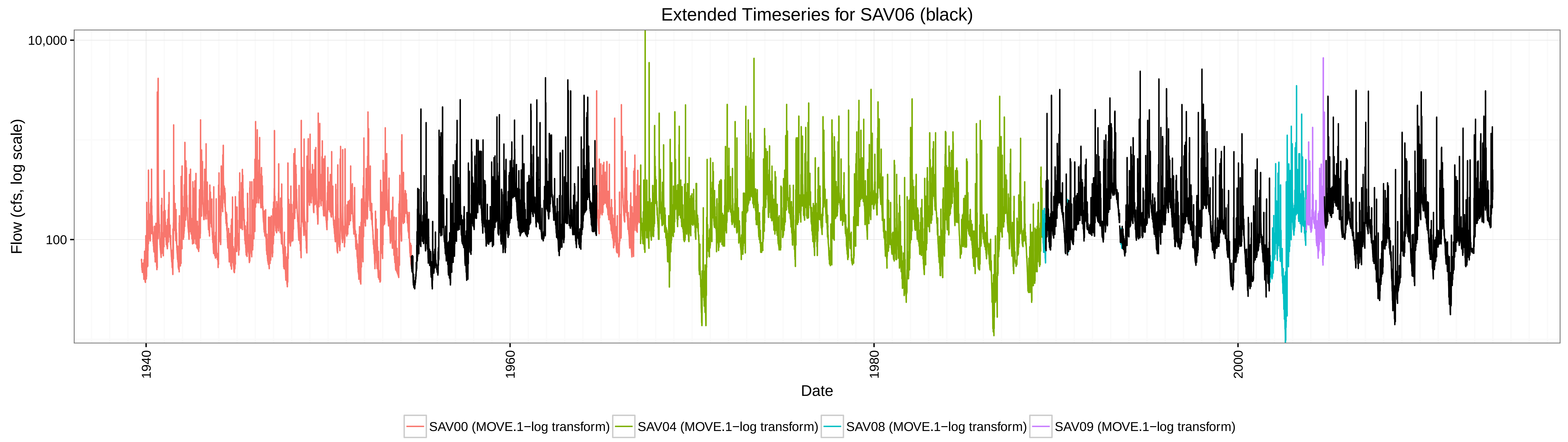
ATTACHMENT E

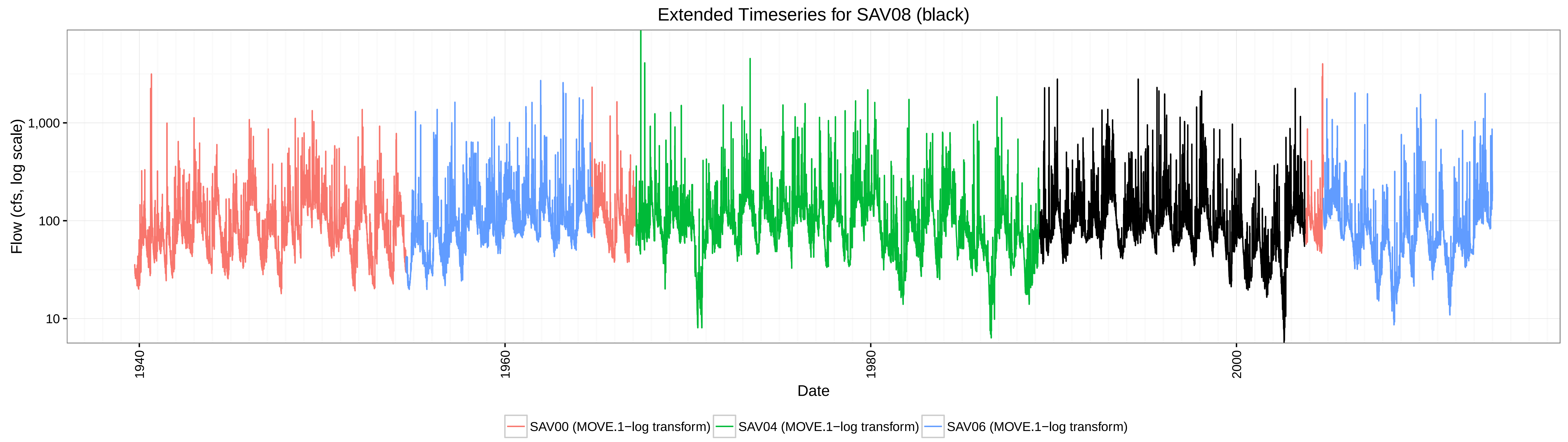
UIF Timeseries Graphs at USGS Gage Locations


Timeseries for Complete Gages (black)
Flow (cfs, log scale)
10,000
1,000
100
1940
1960
1980
2000
Date
SAV00

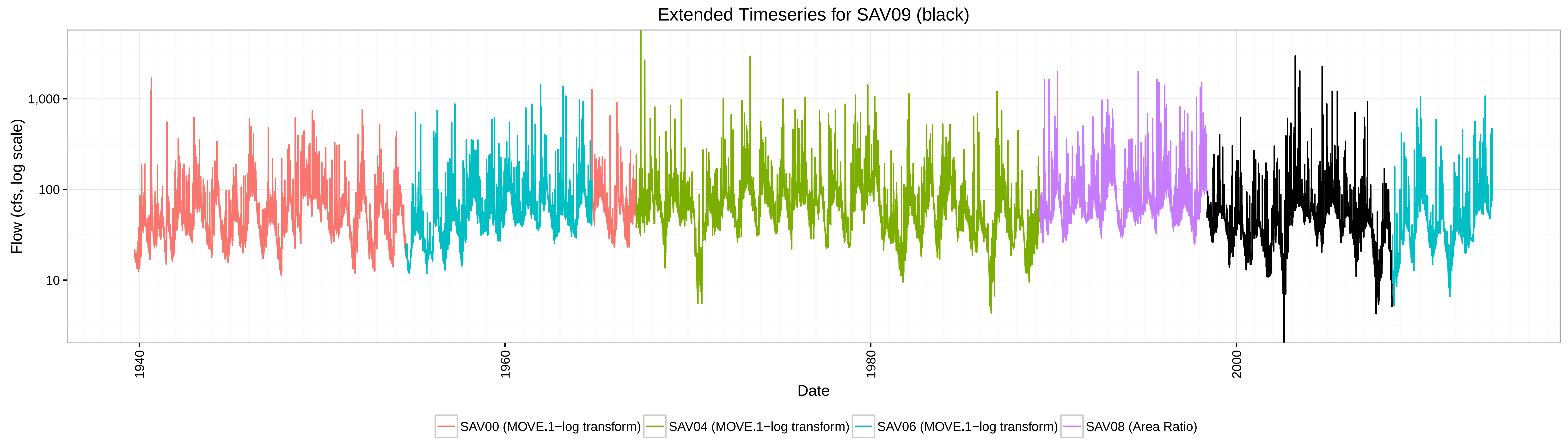

Extended Timeseries for SAV01 (black)
Flow (cfs, log scale)
100
10
1
1940
1960
1980
2000
Date
SAV00 (MOVE.1−log transform)

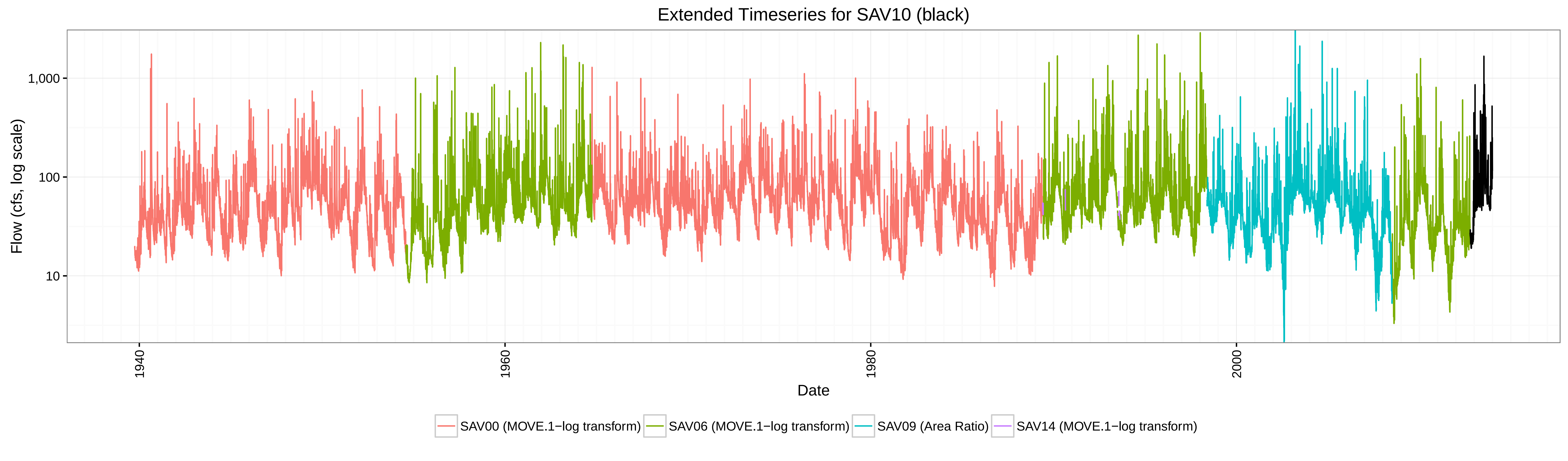

Extended Timeseries for SAV04 (black)
10,000
100
Flow (cfs, log scale)
1940
1960
1980
2000
Date
SAV00 (MOVE.1−log transform)


Extended Timeseries for SAV06 (black)
10,000
100
Flow (cfs, log scale)
1940
1960
1980
2000
Date
SAV00 (MOVE.1−log transform)
SAV04 (MOVE.1−log transform)
SAV08 (MOVE.1−log transform)
SAV09 (MOVE.1−log transform)

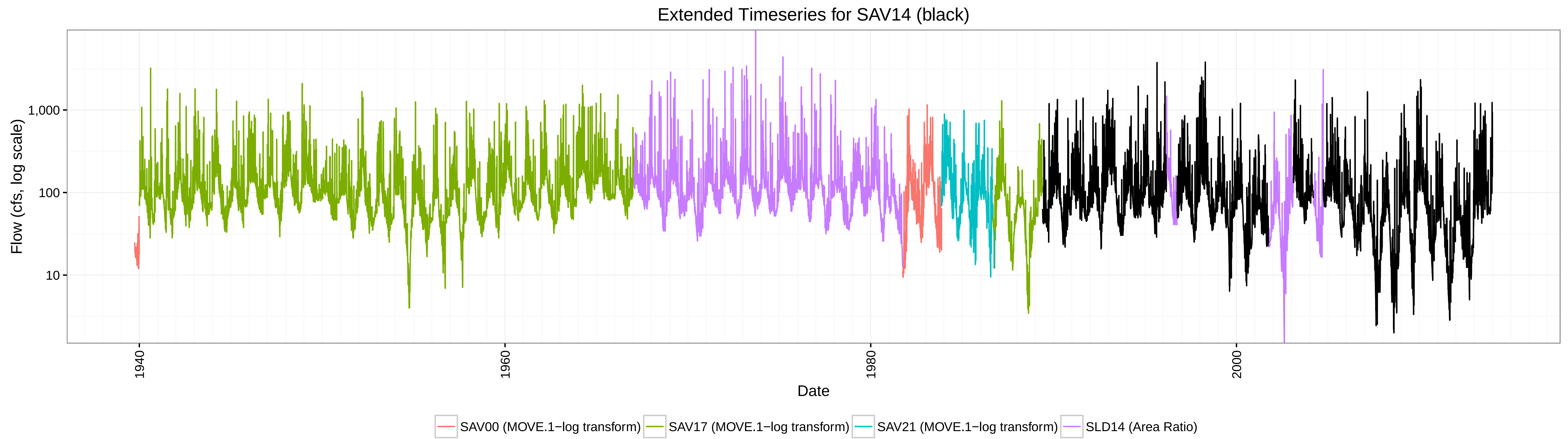


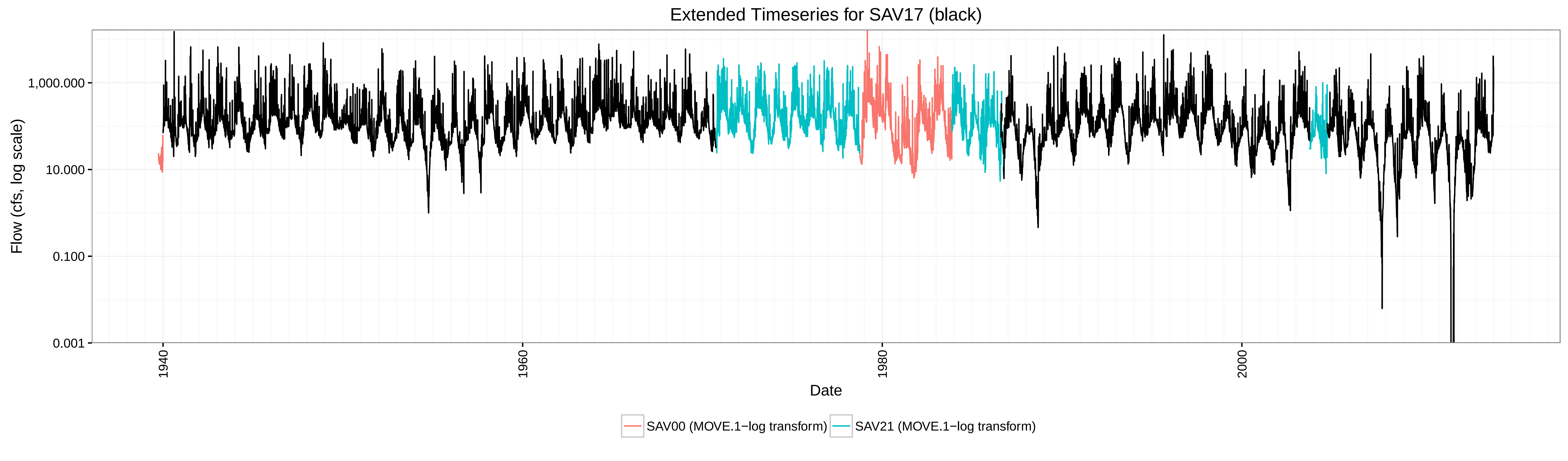
Extended Timeseries for SAV08 (black)
Flow (cfs, log scale)
1,000
100
10
1940
1960
1980
2000
Date
SAV00 (MOVE.1−log transform)
SAV04 (MOVE.1−log transform)
SAV06 (MOVE.1−log transform)

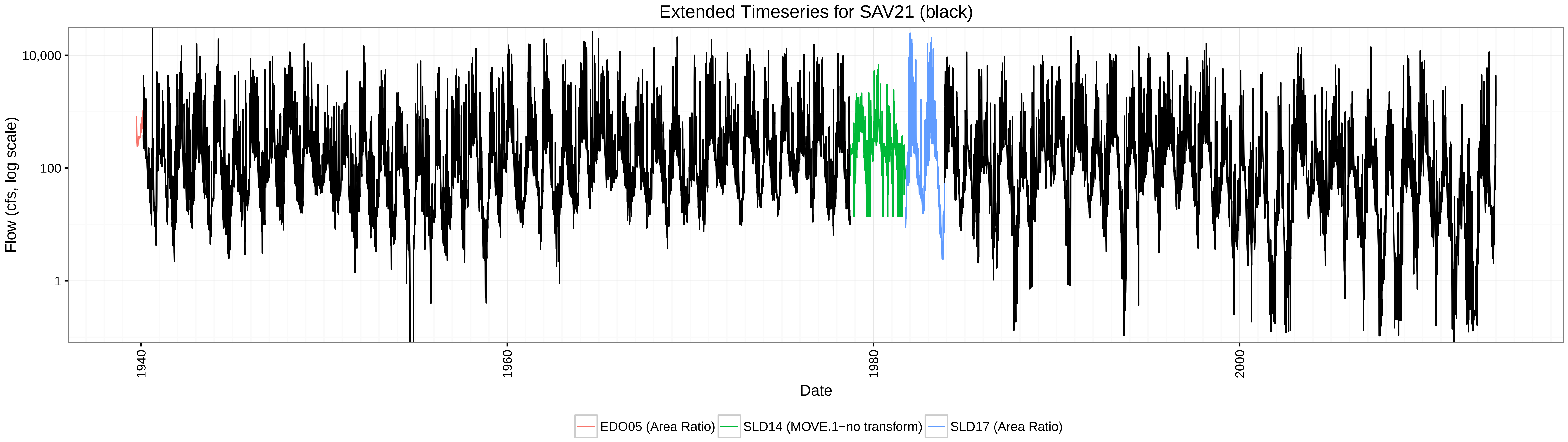

Extended Timeseries for SAV09 (black)
Flow (cfs, log scale)
1,000
100
10
1940
1960
1980
2000
Date
SAV00 (MOVE.1−log transform)
SAV04 (MOVE.1−log transform)
SAV06 (MOVE.1−log transform)
SAV08 (Area Ratio)



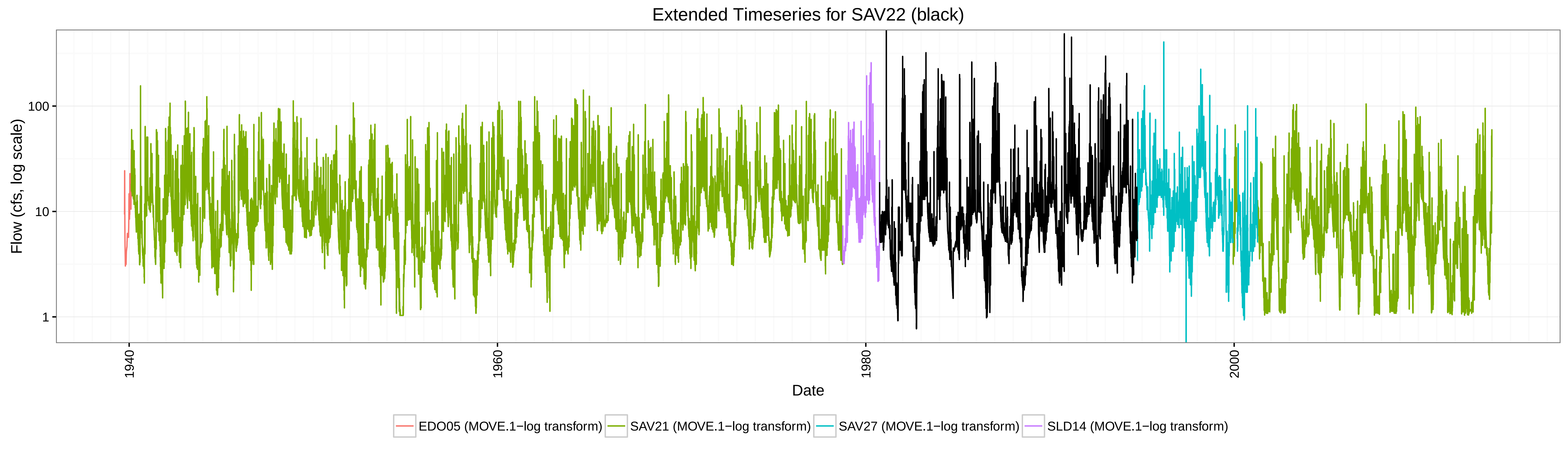
Extended Timeseries for SAV10 (black)
Flow (cfs, log scale)
1,000
100
10
1940
1960
1980
2000
Date
SAV00 (MOVE.1−log transform)
SAV06 (MOVE.1−log transform)
SAV09 (Area Ratio)
SAV14 (MOVE.1−log transform)


Extended Timeseries for SAV14 (black)
Flow (cfs, log scale)
1,000
100
10
1940
1960
1980
2000
Date
SAV00 (MOVE.1−log transform)
SAV17 (MOVE.1−log transform)
SAV21 (MOVE.1−log transform)
SLD14 (Area Ratio)


Extended Timeseries for SAV17 (black)
Flow (cfs, log scale)
1,000.000
10.000
0.100
0.001
1940
1960
1980
2000
Date
SAV00 (MOVE.1−log transform)
SAV21 (MOVE.1−log transform)

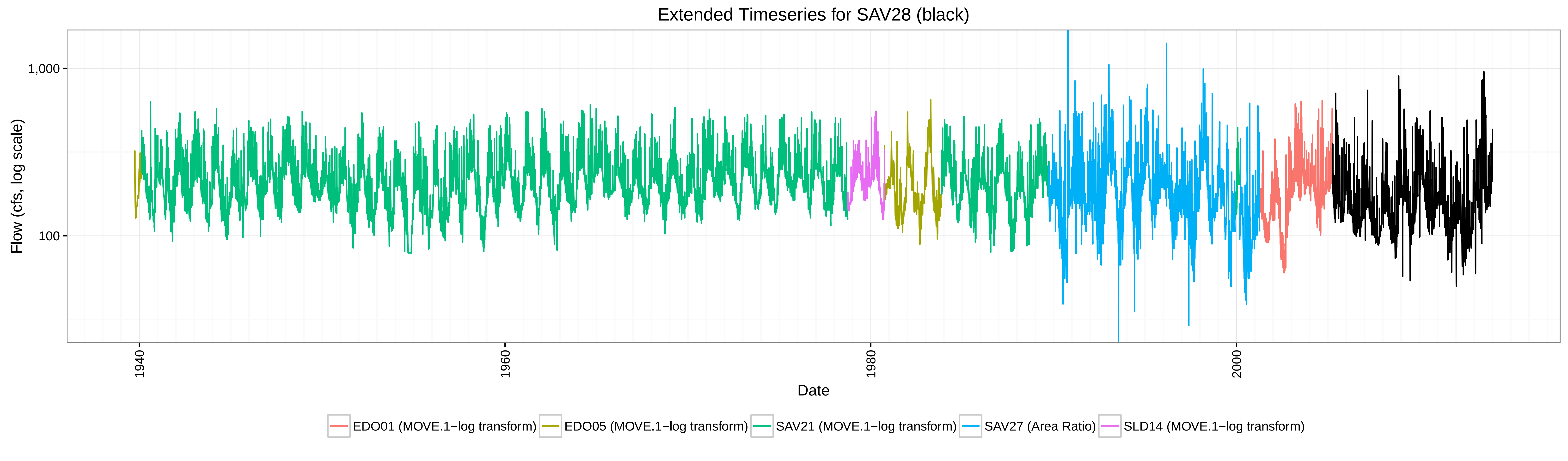


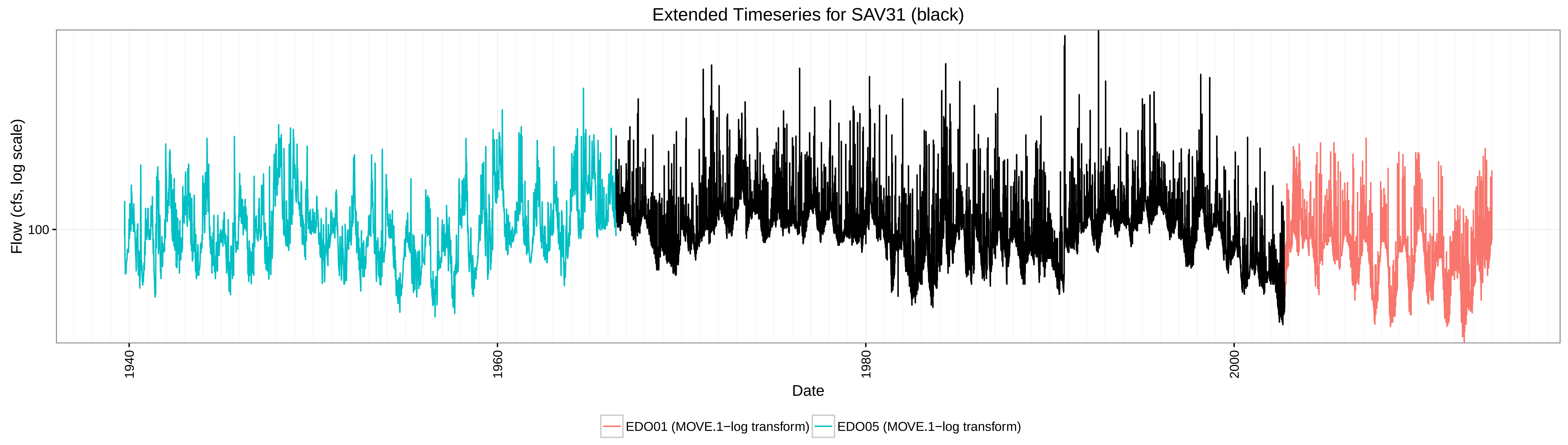
Extended Timeseries for SAV21 (black)
Flow (cfs, log scale)
10,000
100
1
1940
1960
1980
2000
Date
EDO05 (Area Ratio)
SLD14 (MOVE.1−no transform)
SLD17 (Area Ratio)

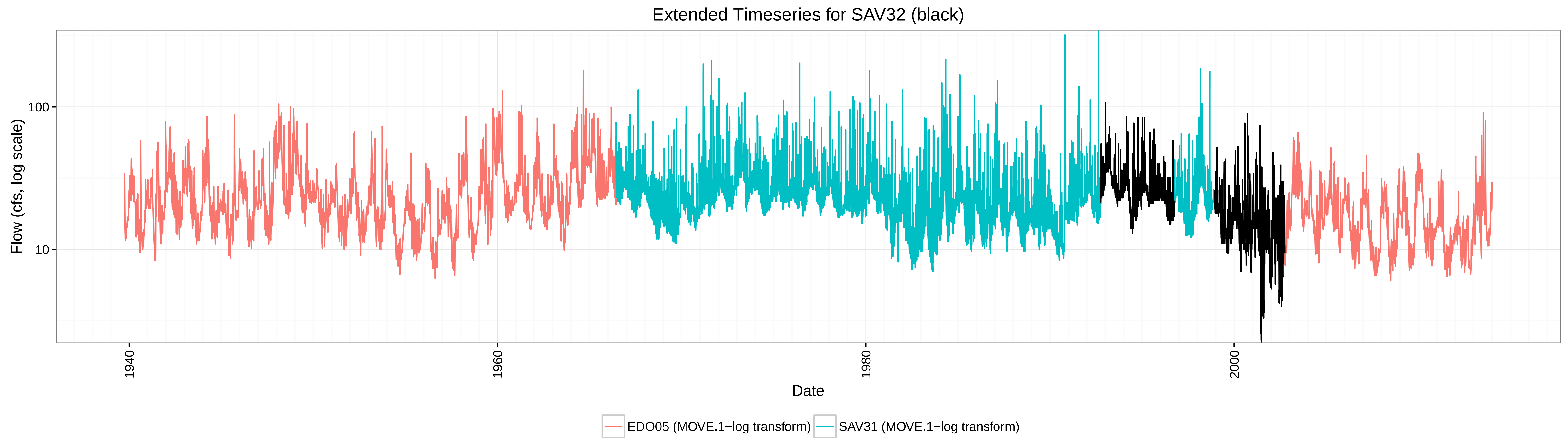


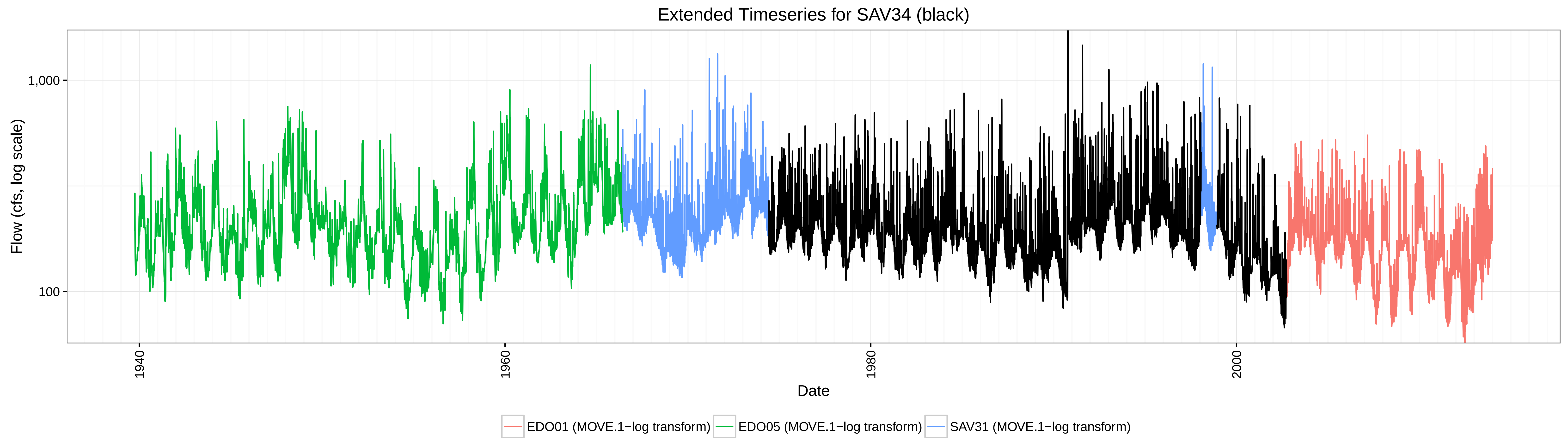
Extended Timeseries for SAV22 (black)
Flow (cfs, log scale)
100
10
1
1940
1960
1980
2000
Date
EDO05 (MOVE.1−log transform)
SAV21 (MOVE.1−log transform)
SAV27 (MOVE.1−log transform)
SLD14 (MOVE.1−log transform)

Extended Timeseries for SAV27 (black)
Flow (cfs, log scale)
100
10
1940
1960
1980
2000
Date
EDO01 (MOVE.1−log transform)
EDO05 (MOVE.1−log transform)
SAV21 (MOVE.1−log transform)
SAV22 (MOVE.1−log transform)
SAV28 (Area Ratio)
SAV34 (Area Ratio)

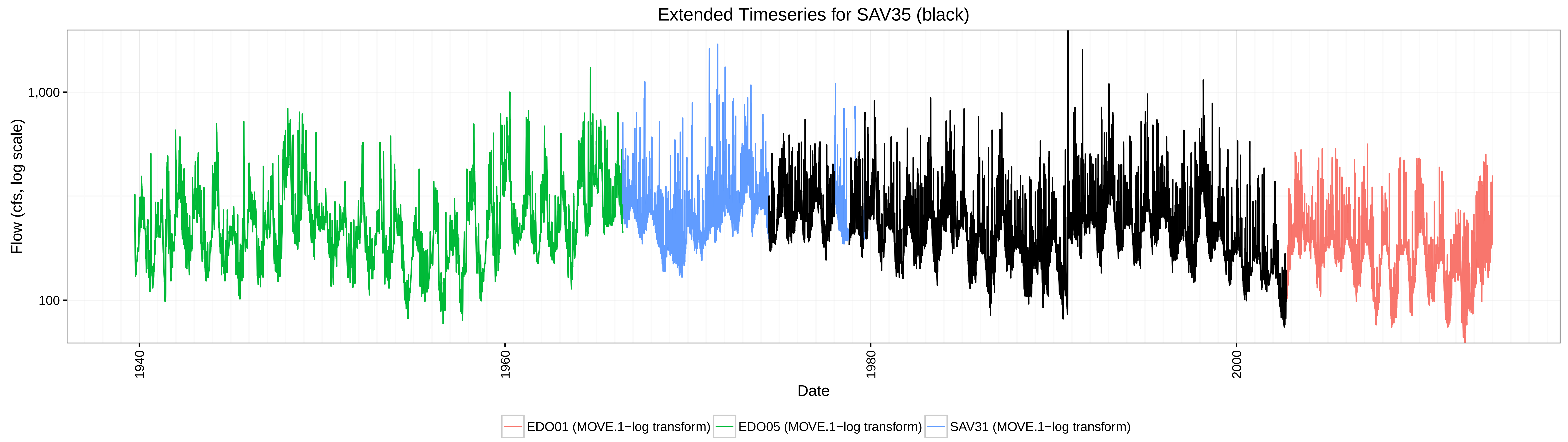

Extended Timeseries for SAV28 (black)
Flow (cfs, log scale)
1,000
100
1940
1960
1980
2000
Date
EDO01 (MOVE.1−log transform)
EDO05 (MOVE.1−log transform)
SAV21 (MOVE.1−log transform)
SAV27 (Area Ratio)
SLD14 (MOVE.1−log transform)


Extended Timeseries for SAV31 (black)
Flow (cfs, log scale)
100
1940
1960
1980
2000
Date
EDO01 (MOVE.1−log transform)
EDO05 (MOVE.1−log transform)


Extended Timeseries for SAV32 (black)
Flow (cfs, log scale)
100
10
1940
1960
1980
2000
Date
EDO05 (MOVE.1−log transform)
SAV31 (MOVE.1−log transform)



Extended Timeseries for SAV34 (black)
Flow (cfs, log scale)
1,000
100
1940
1960
1980
2000
Date
EDO01 (MOVE.1−log transform)
EDO05 (MOVE.1−log transform)
SAV31 (MOVE.1−log transform)



Extended Timeseries for SAV35 (black)
Flow (cfs, log scale)
1,000
100
1940
1960
1980
2000
Date
EDO01 (MOVE.1−log transform)
EDO05 (MOVE.1−log transform)
SAV31 (MOVE.1−log transform)

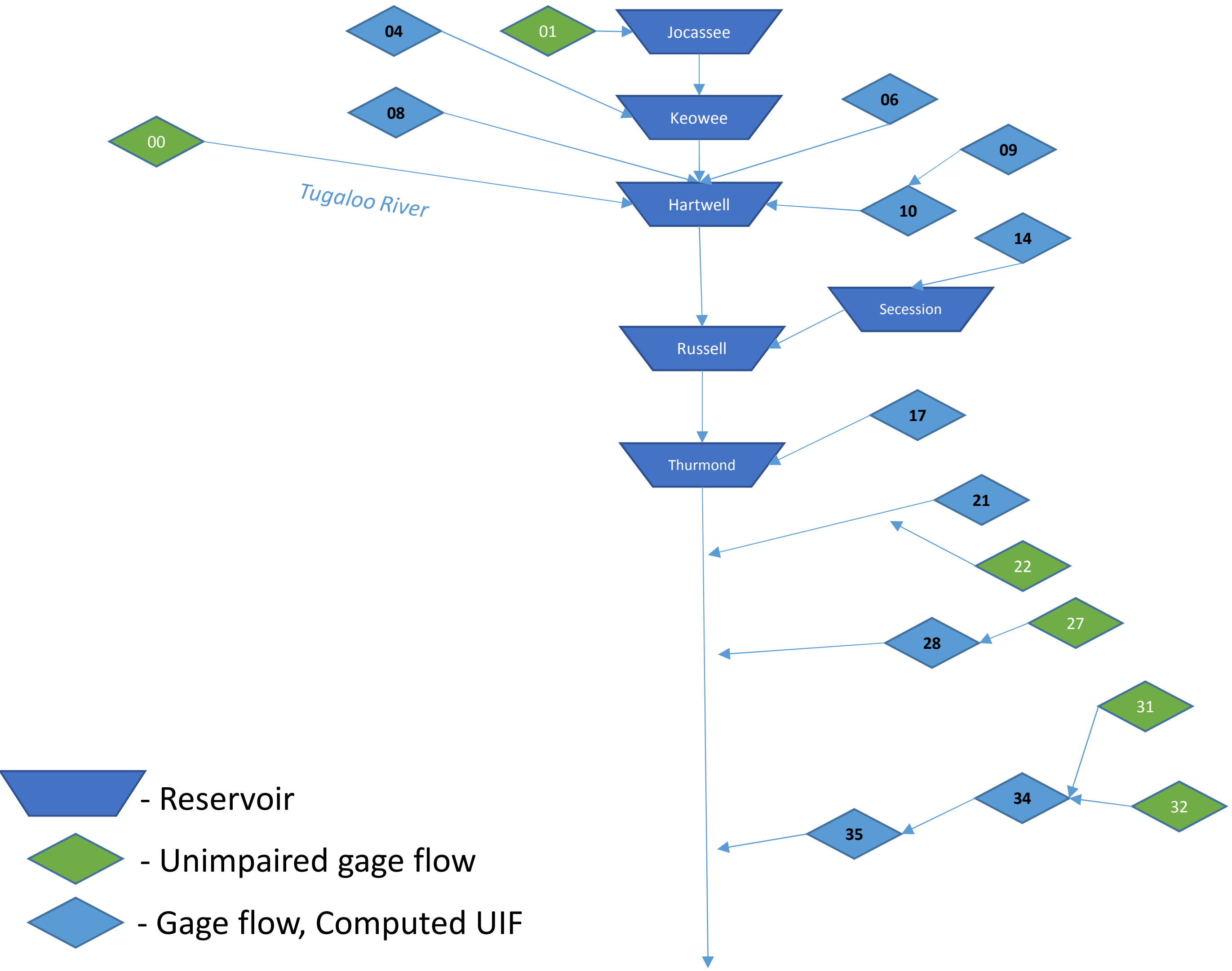
ATTACHMENT F

Discussion on Reference Gage and Method Selection

Gage	Reference	Method	Notes
SAV01	SAV00	MOVE.1-log transform	Best overall statistics and plots, fills all of record
SAV04	SAV00	MOVE.1-log transform	Best overall, SAV06 could be considered as well
SAV06	SAV08	MOVE.1-log transform	Log transform chosen for low flows
SAV06	SAV04	MOVE.1-log transform	Log transform chosen for low flows
SAV06	SAV09	MOVE.1-log transform	Log transform chosen for low flows
SAV06	SAV00	MOVE.1-log transform	Best overall statistics and plots, fills remaining record
SAV08	SAV06	MOVE.1-log transform	Best overall statistics and plots
SAV08	SAV04	MOVE.1-log transform	SAV09 could be used before this one, but has no well-balanced option of extension method
SAV08	SAV00	MOVE.1-log transform	Best overall statistics and plots, fills remaining record
SAV09	SAV08	Area Ratio	Arguable between this method and log-transform
SAV09	SAV06	MOVE.1-log transform	Log transform chosen for low flows
SAV09	SAV04	MOVE.1-log transform	Best overall statistics and plots
SAV09	SAV00	MOVE.1-log transform	Best overall statistics and plots, fills remaining record
SAV10	SAV09	Area Ratio	No overlap to test, but is immediately upstream.
SAV10	SAV06	MOVE.1-log transform	Log transform chosen for low flows
SAV10	SAV14	MOVE.1-log transform	Log transform chosen for low flows
SAV10	SAV00	MOVE.1-log transform	Best overall statistics and plots, fills remaining record
SAV14	SLD14	Area Ratio	Arguable between this method and log-transform
SAV14	SAV17	MOVE.1-log transform	Best overall statistics and plots
SAV14	SAV21	MOVE.1-log transform	Log transform chosen for low flows
SAV14	SAV00	MOVE.1-log transform	Best overall statistics and plots, fills remaining record
SAV17	SAV21	MOVE.1-log transform	SLD17 or SLD14 could be used as well, but despite it the high correlation, no extension method produces well-balanced results
SAV17	SAV00	MOVE.1-log transform	Chosen for low flows, fills remaining record
SAV21	SLD14	MOVE.1-no transform	Compromise method as MOVE with transform has significant issues
SAV21	SLD17	Area Ratio	MOVE methods have notable issues
SAV21	EDO05	Area Ratio	MOVE methods have notable issues; fills remaining record
SAV22	SAV27	MOVE.1-log transform	Best overall statistics and plots
SAV22	SAV21	MOVE.1-log transform	Best overall statistics and plots, mostly
SAV22	SLD14	MOVE.1-log transform	Best overall statistics and plots
SAV22	EDO05	MOVE.1-log transform	Best overall statistics and plots
SAV27	SAV28	Area Ratio	No overlap to test, can only check through final timeseries
SAV27	EDO01	MOVE.1-log transform	Best overall statistics and plots, mostly
SAV27	SAV22	MOVE.1-log transform	Best overall statistics and plots
SAV27	SAV21	MOVE.1-log transform	Log transform chosen for low flows
SAV27	SAV34	Area Ratio	Arguable between this method and log-transform
SAV27	EDO05	MOVE.1-log transform	Best overall statistics and plots
SAV28	SAV27	Area Ratio	No overlap to test, can only check through final timeseries
SAV28	EDO01	MOVE.1-log transform	Best overall statistics and plots
SAV28	SAV21	MOVE.1-log transform	Best overall statistics and plots
SAV28	EDO05	MOVE.1-log transform	Best overall statistics and plots, mostly
SAV28	SLD14	MOVE.1-log transform	Need only to fill small gap in 1970s
SAV31	EDO01	MOVE.1-log transform	Best overall statistics and plots
SAV31	EDO05	MOVE.1-log transform	Best overall statistics and plots, fills remaining record
SAV32	SAV31	MOVE.1-log transform	Best overall statistics and plots
SAV32	EDO05	MOVE.1-log transform	Chosen for low flows, fills remaining record
SAV34	EDO01	MOVE.1-log transform	Best overall statistics and plots
SAV34	SAV31	MOVE.1-log transform	Best overall statistics and plots
SAV34	EDO05	MOVE.1-log transform	Best overall statistics and plots, fills remaining record
SAV35	EDO01	MOVE.1-log transform	Best overall statistics and plots
SAV35	SAV31	MOVE.1-log transform	Best overall statistics and plots, mostly
SAV35	EDO05	MOVE.1-log transform	Best overall statistics and plots, fills remaining record

ATTACHMENT G

Schematic of USGS Streamflow Gages in Savannah River Basin



Attachment G: Schematic of Tributary UIFs in the Savannah River Basin