Technical Memorandum

To:	*South Carolina Department of Natural Resources (DNR)* *South Carolina Department of Health and Environmental Control (DHEC)*
From:	*CDM Smith*
Date:	*October 2015;* ***Revised May 2016***
Subject:	*Unimpaired Flow Dataset for the Edisto 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 Edisto River Basin. The TM references the electronic database which houses the completed UIF dataset for the Edisto Basin, and also summarizes the techniques and decisions pertaining to synthesis of data where it is unavailable, and which may be specific to individual locations.

2.0 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. For the Edisto River Basin, UIFs were calculated at every location in which a USGS gage has recorded historical flow measurements. 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, values were hindcasted using various estimation techniques. 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 1931-2013 (coinciding with the longest 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 2.1 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, Edisto River Basin, South Carolina (CDM Smith, August 2015)* – Included as **Attachment A** of this report. This includes a list of all USGS gages in the basin, as well as the documented water users whose data were used in computing the UIFs.
- *Guidelines for Standardizing and Simplifying Operational Record Extension (CDM Smith, March 2015)* – Included as **Attachment B** of this report. This includes guidelines for various techniques for operational gap filling and record extension, and which techniques are most appropriate for various circumstances.
- *Guidelines for Identifying Reference Basins for UIF Extension or Synthesis (CDM Smith, April 2015)* – Included as **Attachment C** of this report.
- *Refinements to the UIF Extension Process, with an Example* – Included as **Attachment E.**

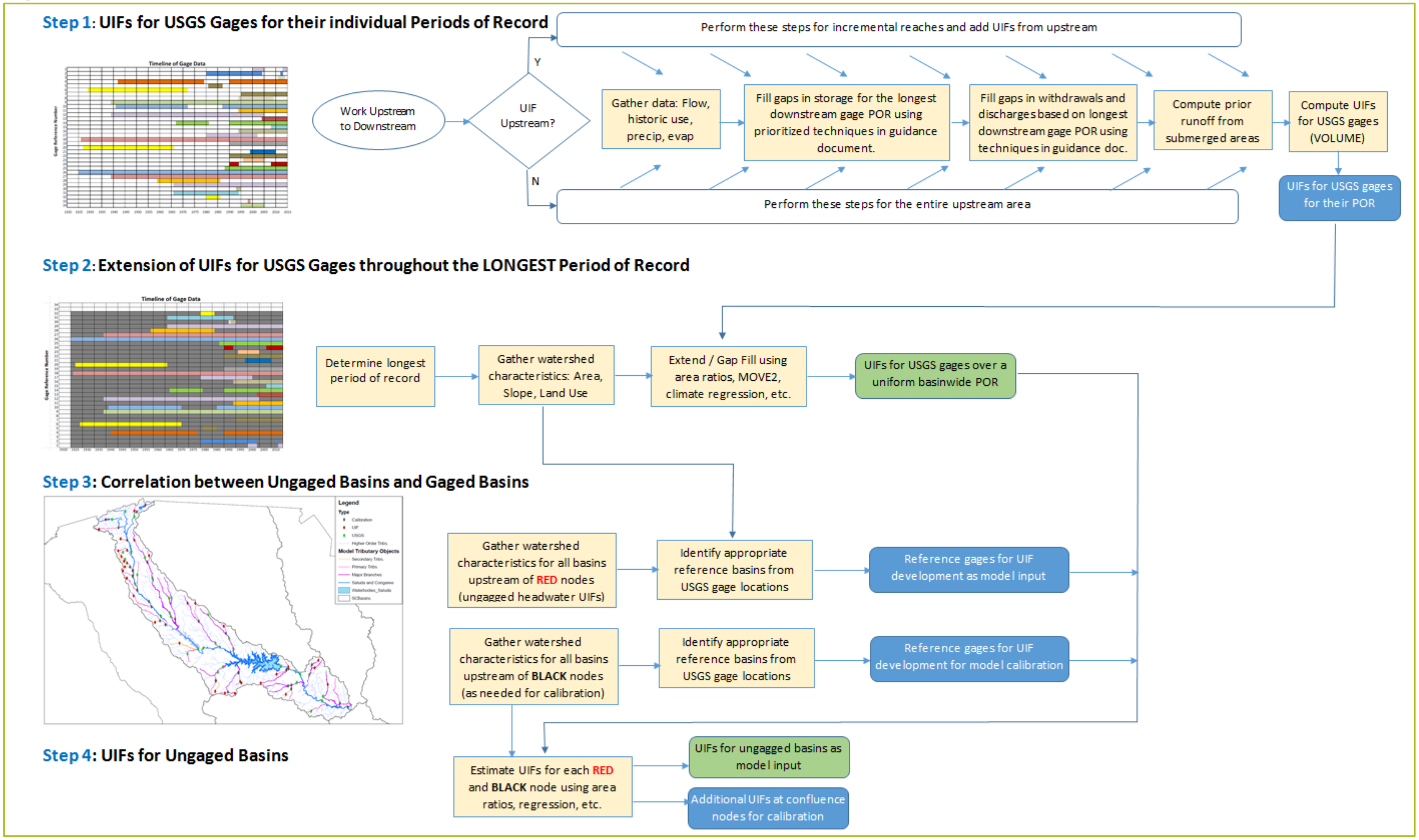
The original guidance document for the UIFs (Attachment A, listed above) distinguished between Unregulated Flows (flows affected by impoundments) and Unimpaired Flows (flows which include the impacts of impoundments in addition to withdrawals and discharges along the river). It was determined that the distinction was not necessary in South Carolina, and so the procedure for computing Unregulated Flows in Section 5.3 of Attachment A was not separated from the rest of the

UIF calculation, but rather, included in a single UIF equation represented by Equation 1 in Attachment A. Generally, the methods employed for the South Carolina UIFs are very similar to those employed for UIFs in North Carolina and Georgia, and include the impacts of impoundments, withdrawals, and discharges.

Figure 2.2 illustrates the locations of all UIFs developed for the Edisto River Basin, and distinguishes between those computed by adjusting measured streamflow at USGS gages, and those computed for ungaged basins through area transposition.

Hindcasting of agricultural withdrawals in the Edisto Basin was also required for the UIF calculations. Withdrawal data reported to DHEC from 2002 and 2014 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 2.1: UIF Development Process



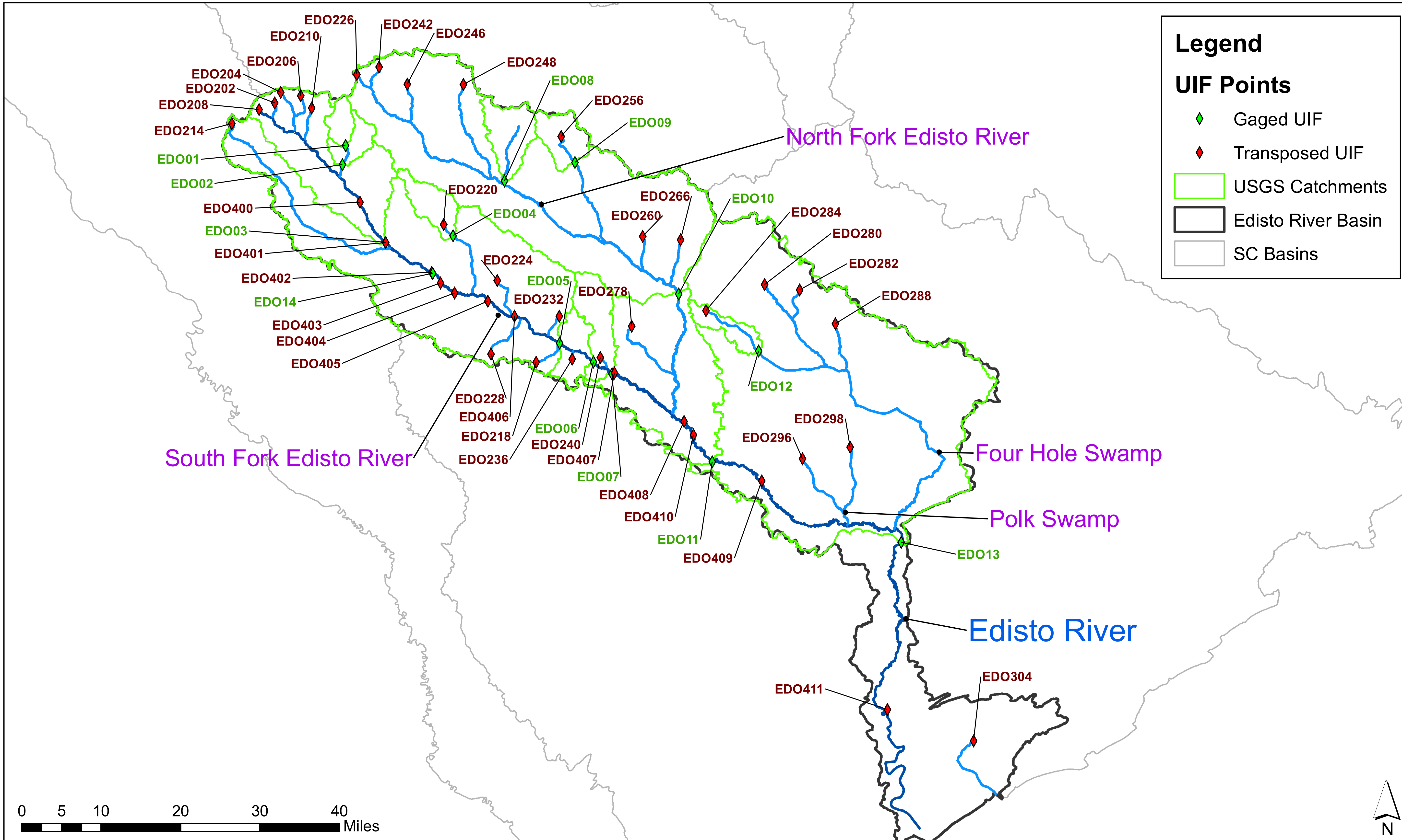


Figure 2.2: Unimpaired Flow Locations in the Edisto River Basin

3.0 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 D**.

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 D**.

4.0 Summary of Operational Hindcasting

Unique circumstances involving data availability, observable trends, etc. required decisions about how to develop representative hindcast values for each individual user. A summary of hindcasting methods used for withdrawals and discharges are presented in **Table 4.1** and **Table 4.2**, respectively. Reference **Attachments A** and **B** for details on the listed methodologies.

Table 4.1: Summary of Methods Used for Hindcasting Withdrawals

Project Gage ID	USGS Number	Stream	Withdrawal Hindcasting			
			User ID	User Name	Time Periods	Method Used
EDO03	02172500	SOUTH FORK EDISTO RIVER NR MONTMORENCI, S. C.	02IN005S01	J M Huber Corp Edisto Plant	None	None (former withdrawal)
			02IN005S02	J M Huber Corp Edisto Plant	None	None (former withdrawal)
EDO05	02173000	SOUTH FORK EDISTO RIVER NEAR DENMARK, SC	02WS002S01	City of Aiken	1/1954 - 6/1981	Anecdotal information
EDO06	02173030	SOUTH FORK EDISTO RIVER NEAR COPE, SC	38PT001S01	SCE&G Cope	None	None
EDO10	02173500	NORTH FORK EDISTO RIVER AT ORANGEBURG, SC	32GC011S01	Indian Trail GC	1/1993 - 12/2000 1/2003 - 12/2003	Monthly averages
			38GC004S01	Orangeburg CC	1/1961 - 12/1984 7/1992 - 9/1994	Monthly averages
			32WS003S01	Town of Batesburg Leesville	1/1963 - 12/2013	Anecdotal information
			32WS003S02	Town of Batesburg Leesville	1/1934 - 12/2013	Anecdotal information

Project Gage ID	USGS Number	Stream	Withdrawal Hindcasting			
			User ID	User Name	Time Periods	Method Used
			38WS002S01 38WS002S02 38WS002S03	City of Orangeburg	All months in: 1940 - 1948 1950 - 1958 1960 - 1968 1970 - 1978 1980 - 1982	Long-term gap filling
EDO11	02174000	EDISTO RIVER NEAR BRANCHVILLE, SC	38IN002S01	SI Group/Albemarle Corp	1/1930 - 6/1983	Anecdotal information
EDO13	02175000	EDISTO RIVER NR GIVHANS, SC	15PT001S01	SCE&G Canadys	1/1962 - 6/1983	Monthly averages
			15PT001S02	SCE&G Canadys	None	None
			10WS004S03	Charleston WS	1/1930 - 12/1933 1/1935 - 12/1937 1/1938 - 6/1983 1/1986 - 12/1987	Short-term gap filling/anecdotal information

Table 4.2: Summary of Methods Used for Hindcasting Discharges

Project Gage ID	USGS Number	Stream	Discharge Hindcasting			
			ID	Facility Name	Time Periods	Method Used
EDO03	02172500	SOUTH FORK EDISTO RIVER NR MONTMORENCI, SC	SC0025691-001	ECW&SA/JOHNSTON #1 PLANT	7/1983-1/1989	Monthly averages/anecdotal information
			SC0024341-001	J M HUBER CORP/EDISTO PLANT	1/1983-1/1991 8/1998-2/2001	Correlated with monthly withdrawal (JM Huber)
			SC0046388-001	KENTUCKY-TENN CLAY/GENTRY PIT	None	None
			SC0022268-001	RIDGE SPRING/S. LAGOON #1	None	Small gap filling
EDO04	02172640	DEAN SWAMP CREEK NR SALLEY, SC	SC0026204-001	WAGENER, TOWN OF	9/1985-1/1989	Hindcast to known start date (town using GW)
EDO05	02173000	SOUTH FORK EDISTO RIVER NEAR DENMARK, SC	SCG641003-001	AIKEN/SHAW CREEK WTP	1/1954-2/1995 7/1995-12/2013	Permit estimate (Aiken)

Project Gage ID	USGS Number	Stream	Discharge Hindcasting			
			ID	**Facility Name**	**Time Periods**	**Method Used**
			SC0026417-001	BLACKVILLE WWTF	6/1975-1/1989	Hindcast to known start date (town using GW)
			SC0045993-001	NORWAY, TOWN OF	None	Small gap filling
EDO07	02173051	SOUTH FORK EDISTO RIVER NEAR BAMBERG, SC	SC0045772-001	SCE&G/COPE POWER PLANT	None	Small gap filling
			SC0045772-002 to 007	SCE&G/COPE POWER PLANT	None	Small gap filling
EDO09	02173351	BULL SWAMP CREEK BELOW SWANSEA, SC	SC0034541-001	GASTON COPPER RECYCLING CORP	3/1984-1/1989	Hindcast to known start date (industrial discharge)
EDO10	02173500	NORTH FORK EDISTO RIVER AT ORANGEBURG, SC	SC0043419-001	ACO DISTRIBUTION & WAREHOUSE INC	none	Small gap filling
			SC0024465-001	BATESBURG-LEESVILLE WWTF	1/1934-12/1988	Correlated with monthly withdrawal (Batesburg-Leesville)
			SC0047821-001	NORTH, TOWN OF	None	Small gap filling
			SC0047821-002	NORTH, TOWN OF	None	Small gap filling
EDO11	02174000	EDISTO RIVER NEAR BRANCHVILLE, SC	SC0001180-001	ALBEMARLE CORP/ORANGEBURG	1/1930-12/1988	Correlated with monthly withdrawal (Albemarle)
			SC0021113-001	BRANCHVILLE, TOWN OF	None	Small gap filling
			SC0047333-001	BRANCHVILLE, TOWN OF	None	Small gap filling
			SC0047023-001	ORANGEBURG NTL FISH HATCHERY	None	Small gap filling
			SC0047023-002	ORANGEBURG NTL FISH HATCHERY	None	Small gap filling
			SC0024481-001	ORANGEBURG WWTF	1/1939-12/1988	Correlated with monthly withdrawal (Orangeburg)
EDO13	02175000	EDISTO RIVER NEAR GIVHANS, SC	SC0040037-001	BOWMAN TOWN OF	1/1985-2/1989	Monthly averages/anecdotal information
			SC0022667-001 to 005	GIANT CEMENT COMPANY INC	6/1975-1/1991	Hindcast to known start date (industrial discharge)

Project Gage ID	USGS Number	Stream	Discharge Hindcasting			
			ID	**Facility Name**	**Time Periods**	**Method Used**
			SC0038504-001	HARLEYVILLE, TOWN OF	6/1985-1/1992	Hindcast to known start date (town using GW)
			SC0002992-001 to 003	HOLCIM (US) INC/HOLLY HILL PLT	12/1974-1/1991	Hindcast to known start date (industrial discharge)
			SC0022586-001	LAFARGE BUILDING MATERIALS INC	7/1985-9/1989	Hindcast to known start date (industrial discharge)
			SC0022586-002	LAFARGE BUILDING MATERIALS INC	7/1985-9/1989	Hindcast to known start date (industrial discharge)
			SC0001147-001	ROSEBURG FOREST PRODUCTS S/HOLLY HILL MDF	None	Small gap filling
			SC0002020-001 to 006	SCE&G/CANADYS STATION	1/1962-12/1988	Correlated with monthly withdrawal (SCE&G Canadys)
			SC0038555-001	SHOWA DENKO CARBON	3/1984-1/1989	Hindcast to known start date (industrial discharge)
			SC0038555-01A	SHOWA DENKO CARBON	3/1984-1/1989	Hindcast to known start date (industrial discharge)
			SC0025844-001	ST. GEORGE, TOWN OF	6/1975-1/1989	Hindcast to known start date (town using GW)

An example of one of the withdrawal hindcasting methods is shown in **Figure 4.1,** which shows withdrawals extended for the City of Orangeburg based on anecdotal information provided by the user.

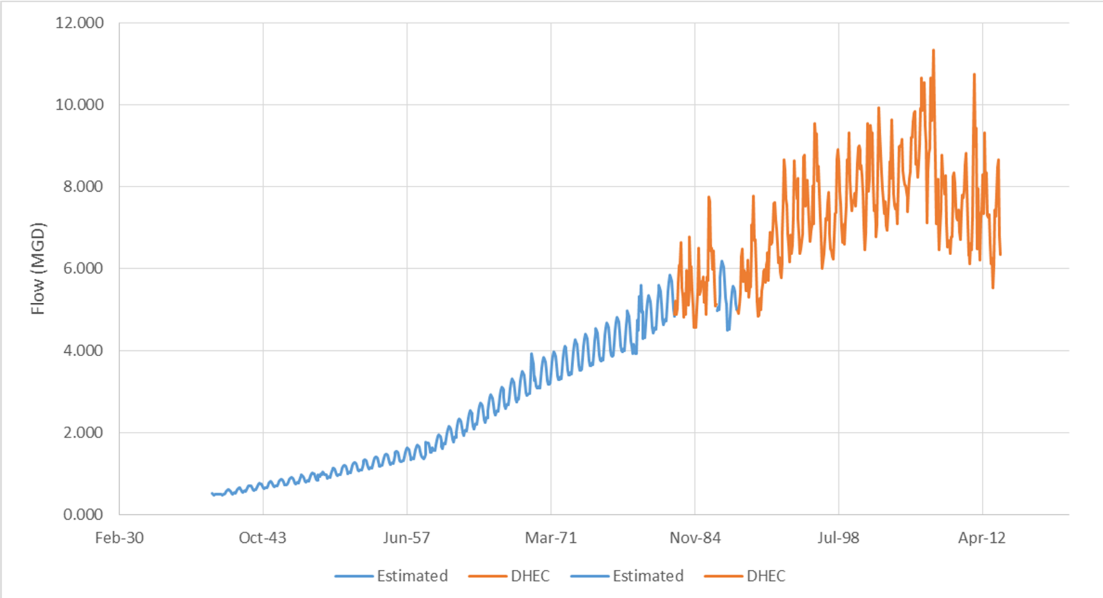


Figure 4.1: Hindcasting Using Anecdotal Information for City of Orangeburg Withdrawals

An example of one of the discharge hindcasting methods is shown in **Figure 4.2,** which shows discharges extended based on withdrawals for Orangeburg.

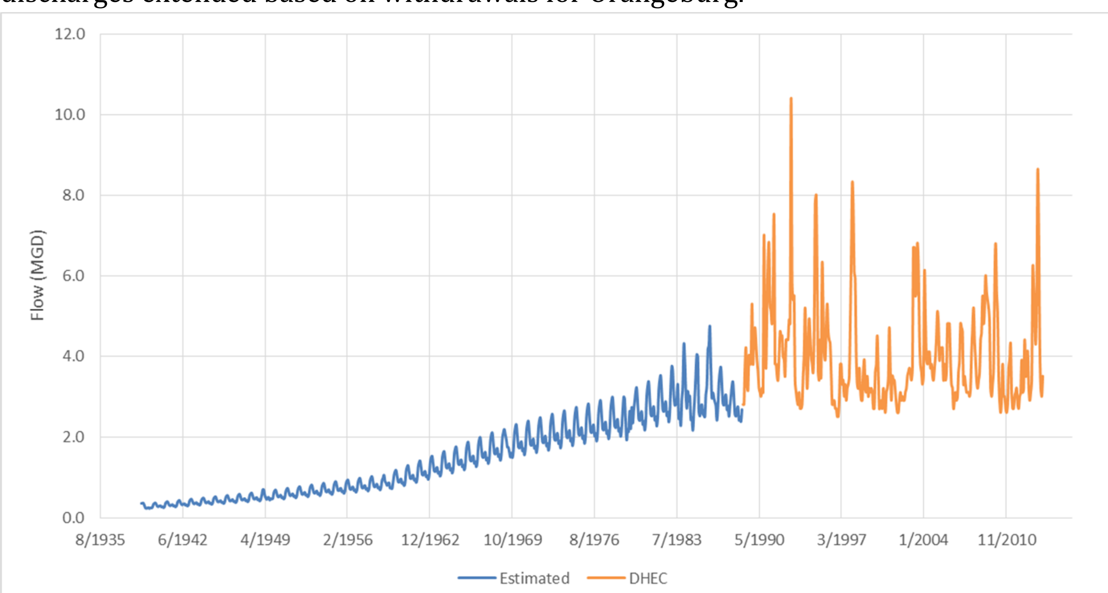


Figure 4.2: Hindcasting Discharge for Orangeburg WWTF Based on Withdrawals for City of Orangeburg

5.0 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 5.1**. Initial candidates of reference gages are selected following guidelines outlined in **Attachment C.** See **Attachment E** for details pertaining to the decision-making process and **Attachment G** 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 EDO04 and EDO05, the lowest flow is 10.9 cfs. Thus, when MOVE.1 is calculated using EDO05's untransformed flows, any days below 10.9 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.

Additionally, two gages from outside the basin are used as reference gages: 02197300 from the Savannah (SAV31) and 02169570 from the Saluda (SLD29). Of special note is the USGS gage EDO14, which started after 2013. Flows before 2013 for this gage are simply calculated using area proration.

Table 5.1: 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)	
EDO01	02172300	MCTIER CREEK (RD 209) NEAR MONETTA, SC	10/1995 - 10/1997 2/2001 - 12/2013	16	EDO04	DEAN SWAMP CREEK NR SALLEY, SC	31	MOVE.1 (log transform)
					EDO05	SOUTH FORK EDISTO RIVER NEAR DENMARK, SC	733	MOVE.1 (log transform)
					EDO10	NORTH FORK EDISTO RIVER AT ORANGEBURG, SC	686	MOVE.1 (log transform)
EDO02	02172305	MCTIER CREEK NEAR NEW HOLLAND, SC	6/2007 - 11/2009	35	EDO01	MCTIER CREEK (RD 209) NEAR MONETTA, SC	16	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)	
					EDO05	SOUTH FORK EDISTO RIVER NEAR DENMARK, SC	733	MOVE.1 (log transform)
					EDO10	NORTH FORK EDISTO RIVER AT ORANGEBURG, SC	686	MOVE.1 (log transform)
EDO03	02172500	SOUTH FORK EDISTO RIVER NR MONTMORENCI, S. C.	4/1940 - 9/1966	196	EDO05	SOUTH FORK EDISTO RIVER NEAR DENMARK, SC	733	MOVE.1 (log transform)
					EDO10	NORTH FORK EDISTO RIVER AT ORANGEBURG, SC	686	MOVE.1 (log transform)
EDO04	02172640	DEAN SWAMP CREEK NR SALLEY, SC	10/1980 - 3/1987 3/1988 - 9/2000	31	EDO01	MCTIER CREEK (RD 209) NEAR MONETTA, SC	16	MOVE.1 (log transform)
					SAV31	UPPER THREE RUNS NEAR NEW ELLENTON, SC	87	MOVE.1: no transform, Area Ratio if MOVE.1 < 10.9 cfs
					EDO05	SOUTH FORK EDISTO RIVER NEAR DENMARK, SC	733	MOVE.1 (log transform)
EDO05	02173000	SOUTH FORK EDISTO RIVER NEAR DENMARK, SC	8/1931 - 9/1971 10/1980 - 12/2013	733	EDO10	NORTH FORK EDISTO RIVER AT ORANGEBURG, SC	686	MOVE.1 (log transform)
EDO06	02173030	SOUTH FORK EDISTO RIVER NEAR COPE, SC	6/1991 - 12/2013	766	EDO05	SOUTH FORK EDISTO RIVER NEAR DENMARK, SC	733	MOVE.1 (log transform)
					EDO10	NORTH FORK EDISTO RIVER AT ORANGEBURG, SC	686	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)	
EDO07	02173051	SOUTH FORK EDISTO RIVER NEAR BAMBERG, SC	4/1991 - 12/2013	813	EDO05	SOUTH FORK EDISTO RIVER NEAR DENMARK, SC	733	MOVE.1 (log transform)
					EDO10	NORTH FORK EDISTO RIVER AT ORANGEBURG, SC	686	MOVE.1 (log transform)
EDO08	02173212	CEDAR CREEK NEAR THOR, SC	4/2008 - 12/2013	44	EDO01	MCTIER CREEK (RD 209) NEAR MONETTA, SC	16	MOVE.1 (log transform)
					EDO10	NORTH FORK EDISTO RIVER AT ORANGEBURG, SC	686	MOVE.1 (log transform)
					EDO05	SOUTH FORK EDISTO RIVER NEAR DENMARK, SC	733	MOVE.1 (log transform)
EDO09	02173351	BULL SWAMP CREEK BELOW SWANSEA, SC	2/2001 - 9/2003	34	SLD29	GILLS CREEK AT COLUMBIA, SC	59	MOVE.1 (log transform)
					EDO05	SOUTH FORK EDISTO RIVER NEAR DENMARK, SC	733	MOVE.1 (log transform)
EDO10	02173500	NORTH FORK EDISTO RIVER AT ORANGEBURG, SC	12/1938 - 12/2013	686	EDO05	SOUTH FORK EDISTO RIVER NEAR DENMARK, SC	733	MOVE.1 (log transform)
EDO11	02174000	EDISTO RIVER NEAR BRANCHVILLE, SC	10/1945 - 9/1996	1728	EDO13	EDISTO RIVER NR GIVHANS, SC	2714	MOVE.1 (log transform)
					EDO10	NORTH FORK EDISTO RIVER AT ORANGEBURG, SC	686	MOVE.1 (log transform)
					EDO05	SOUTH FORK EDISTO RIVER NEAR DENMARK, SC	733	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)	
EDO12	02174250	COW CASTLE CREEK NEAR BOWMAN, SC	10/1970 - 9/1981 10/1995 - 2/2013	24	EDO10	NORTH FORK EDISTO RIVER AT ORANGEBURG, SC	686	MOVE.1 (log transform)
					EDO05	SOUTH FORK EDISTO RIVER NEAR DENMARK, SC	733	MOVE.1 (log transform)
EDO13	02175000	EDISTO RIVER NR GIVHANS, SC	1/1939 - 12/2013	2714	EDO05	SOUTH FORK EDISTO RIVER NEAR DENMARK, SC	733	MOVE.1 (log transform)
EDO14	02172558	SOUTH FORK EDISTO RIVER ABOVE SPRINGFIELD, SC	10/2014 - Current	395	EDO03	SOUTH FORK EDISTO RIVER NEAR DENMARK, SC	196	Area Ratio

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 EDO06 is shown in **Figure 5.1**.

Validation graphs are available for each USGS gage. Each validation graph show the period of record for a computed UIF and the predicted flows from reference gages during that same period of record. A sample validation graph is shown in **Figure 5.2**. 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 5.3**. Graphs for each UIF timeseries developed at a USGS gage site are presented in **Attachment F**.

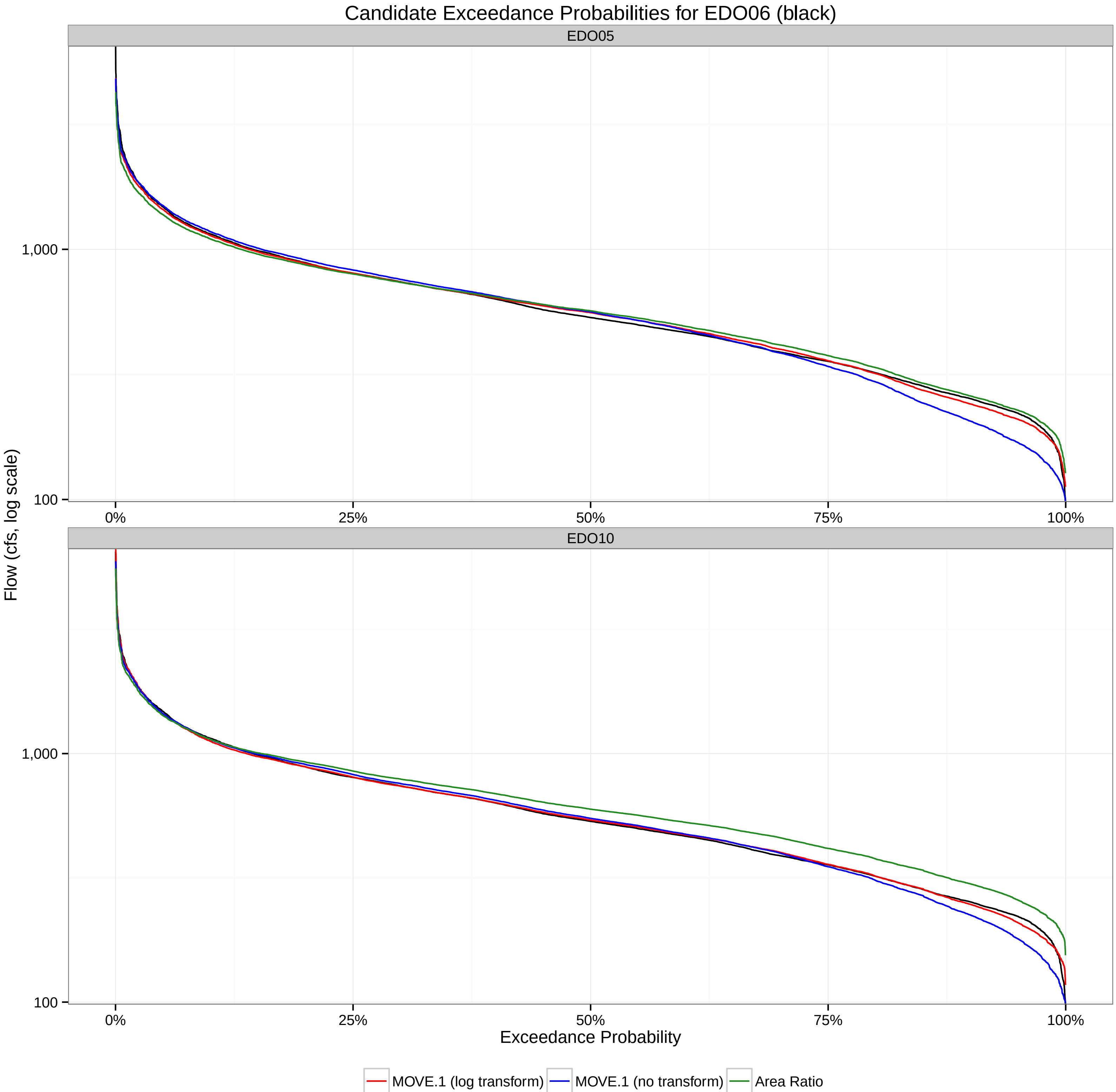


Figure 5.1: Comparison of Exceedance Probabilities for the Computed UIF and Extension Methods

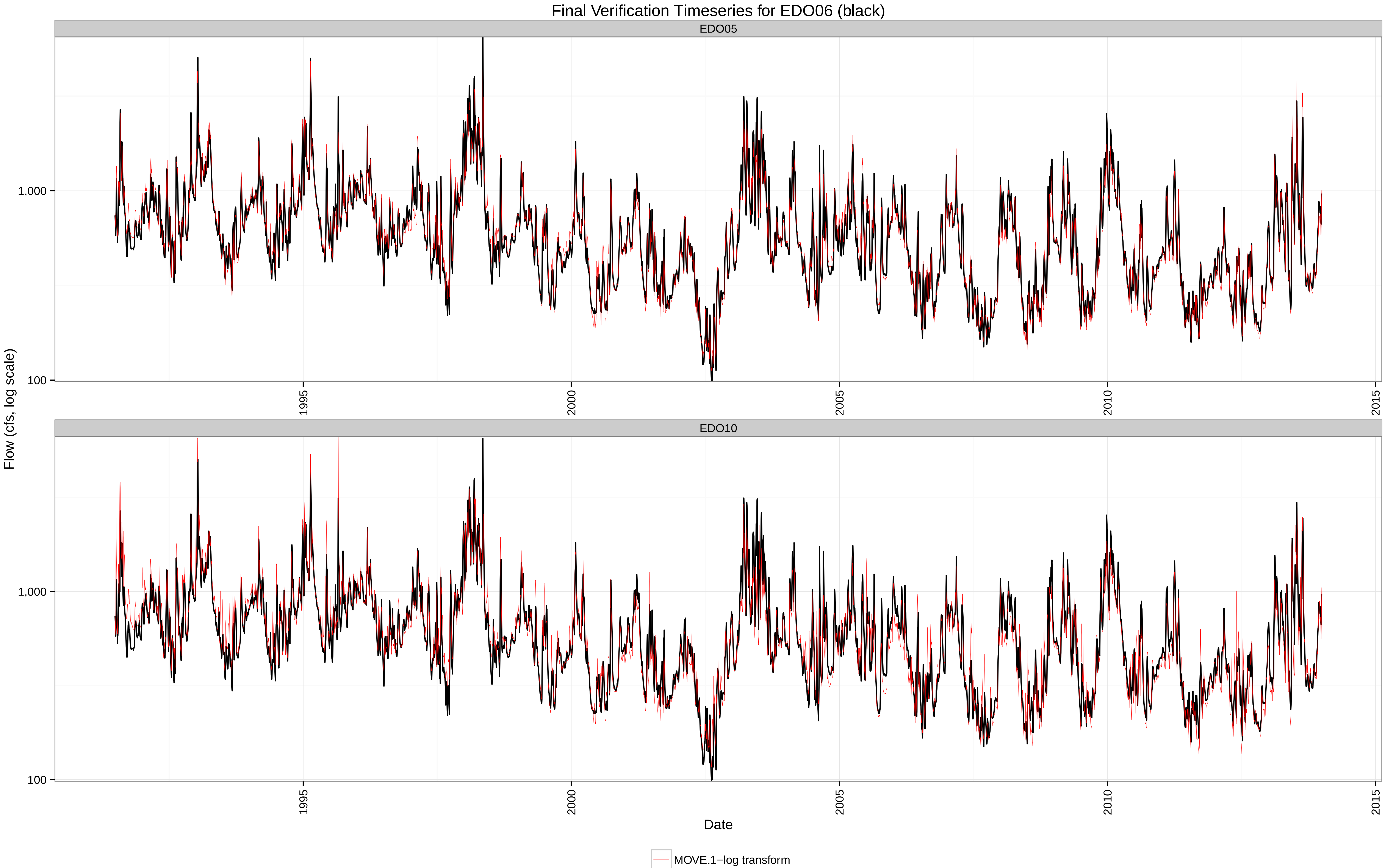


Figure 5.2: Validation Graph for EDO06 with Predicted Flows from Reference Gages EDO05 and EDO10

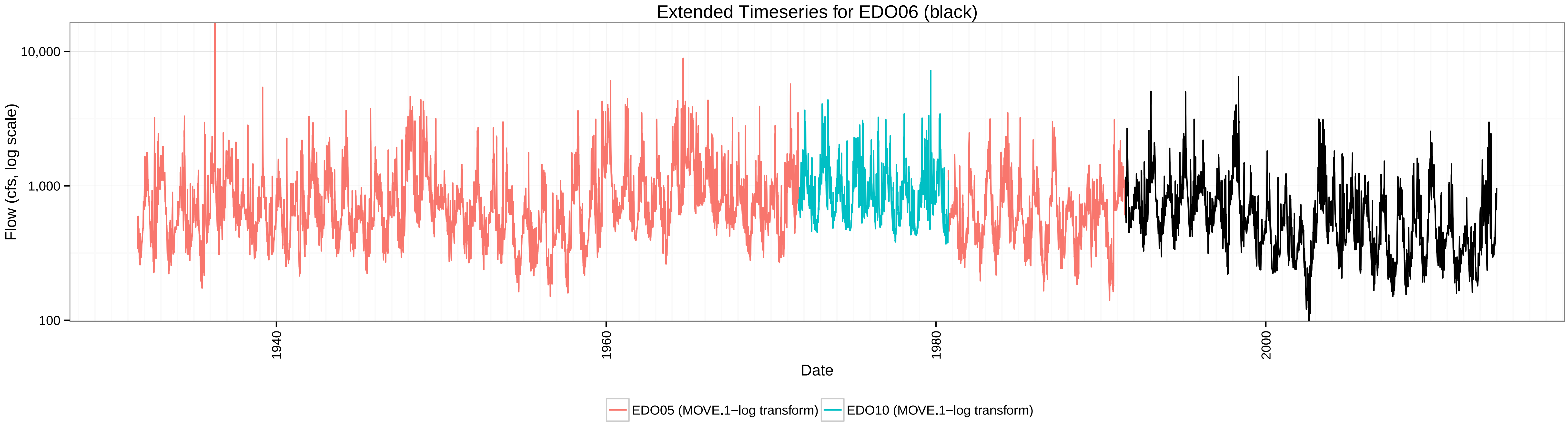


Figure 5.3: Resulting Timeseries for EDO06

6.0 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 6.1** 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 confluence flows are used for implicit tributaries needed for model calibration.

Table 6.1: UIFs in Ungaged Basins (Area Ratio Method Only)

<table>
<tr><th></th><th colspan="4">Ungaged Basin</th><th colspan="5">USGS Reference Gage[1]</th></tr>
<tr><th>Project ID</th><th>SWAM Usage</th><th>Stream</th><th>Basin Area (mi²)</th><th>% Developed / % Forest</th><th>Project Gage ID</th><th>USGS Number</th><th>Stream</th><th>Basin Area (mi²)</th><th>% Developed / % Forest</th></tr>
<tr><td>EDO400</td><td>Confluence Flow</td><td>Rocky Springs Creek</td><td>27.0</td><td>5.2 / 35.7</td><td>EDO03</td><td>02172500</td><td>SOUTH FORK EDISTO RIVER NR MONTMORENCI, S. C.</td><td>196</td><td>5.5 / 47.4</td></tr>
<tr><td>EDO220</td><td>Headwater Flow</td><td>Dean Swamp Creek</td><td>21.9</td><td>5.2 / 33.3</td><td>EDO04</td><td>02172640</td><td>DEAN SWAMP CREEK NR SALLEY, SC</td><td>31</td><td>5.9 / 35.9</td></tr>
<tr><td>EDO202</td><td>Headwater Flow</td><td>Temples Creek</td><td>1.7</td><td>10 / 25</td><td rowspan="14">EDO05</td><td rowspan="14">02173000</td><td rowspan="14">SOUTH FORK EDISTO RIVER NEAR DENMARK, SC</td><td rowspan="14">733</td><td rowspan="14">5.2 / 45.9</td></tr>
<tr><td>EDO204</td><td>Headwater Flow</td><td>Beech Creek</td><td>0.1</td><td>15.6 / 3.6</td></tr>
<tr><td>EDO206</td><td>Headwater Flow</td><td>Bog Branch</td><td>0.5</td><td>22.6 / 8.1</td></tr>
<tr><td>EDO208</td><td>Headwater Flow</td><td>South Fork Edisto River</td><td>0.6</td><td>62.9 / 24.4</td></tr>
<tr><td>EDO210</td><td>Headwater Flow</td><td>Mill Creek</td><td>0.3</td><td>7.5 / 60</td></tr>
<tr><td>EDO214</td><td>Headwater Flow</td><td>Shaw Creek</td><td>0.2</td><td>7.2 / 20.8</td></tr>
<tr><td>EDO218</td><td>Headwater Flow</td><td>Sykes Swamp</td><td>0.9</td><td>2.8 / 43</td></tr>
<tr><td>EDO224</td><td>Headwater Flow</td><td>Goodland Creek</td><td>20.3</td><td>4.6 / 53.7</td></tr>
<tr><td>EDO228</td><td>Headwater Flow</td><td>Windy Hill Creek</td><td>3.7</td><td>10.3 / 47.2</td></tr>
<tr><td>EDO232</td><td>Headwater Flow</td><td>Willow Swamp</td><td>15.6</td><td>8.7 / 40.2</td></tr>
<tr><td>EDO401</td><td>Confluence Flow</td><td>Cedar Creek (Implicit)</td><td>16.5</td><td>3.7 / 35</td></tr>
<tr><td>EDO402</td><td>Confluence Flow</td><td>Hunter Branch</td><td>13.7</td><td>3.2 / 44.4</td></tr>
</table>

[1] Ungaged flows are synthesized from UIFs, not original USGS gage flows

	Ungaged Basin				USGS Reference Gage[1]				
EDO403	Confluence Flow	Pond Branch	34.5	4.3 / 31.1					
EDO404	Confluence Flow	Yarrow Branch	17.9	4.3 / 44.3					
EDO405	Confluence Flow	Spur Branch	21.2	3.6 / 48.4					
EDO406	Confluence Flow	Rocky Swamp Creek	27.7	3.4 / 46.3					
EDO236	Headwater Flow	Hayes Mill Creek	11.0	5.5 / 55.3	EDO06	02173030	SOUTH FORK EDISTO RIVER NEAR COPE, SC	766	5.1 / 46.2
EDO240	Headwater Flow	Roberts Swamp	32.9	3.5 / 42.4	EDO07	02173051	SOUTH FORK EDISTO RIVER NEAR BAMBERG, SC	813	5 / 46.4
EDO256	Headwater Flow	Bull Swamp Creek	8.0	9 / 29.3	EDO09	02173351	BULL SWAMP CREEK BELOW SWANSEA, SC	34	11.8 / 32.3
EDO226	Headwater Flow	Chinquapin Creek	0.2	17.3 / 22.7	EDO10	02173500	NORTH FORK EDISTO RIVER AT ORANGEBURG, SC	686	7.6 / 46.1
EDO242	Headwater Flow	Duncan Creek	1.1	38.7 / 32.5					
EDO246	Headwater Flow	Long Branch	18.4	11.3 / 43.8					
EDO248	Headwater Flow	Black Creek	12.7	8.8 / 45.5					
EDO260	Headwater Flow	Limestone Creek	8.4	2.1 / 57.2					
EDO266	Headwater Flow	Caw Caw Swamp	57.9	6.4 / 41.5					
EDO278	Headwater Flow	Cooper Swamp	2.9	8.3 / 27.7	EDO11	02174000	EDISTO RIVER NEAR BRANCHVILLE, SC	1728	6.3 / 47.8
EDO407	Confluence Flow	Snake Swamp	16.9	5.7 / 38.3					
EDO408	Confluence Flow	Betty Branch	32.5	3.8 / 64.6					
EDO410	Confluence Flow	Pen Branch	16.4	6 / 60.9					
EDO280	Headwater Flow	Four Hole Swamp	78.9	8.5 / 34.9	EDO12	02174250	COW CASTLE CREEK NEAR BOWMAN, SC	24	8.1 / 38.6
EDO282	Headwater Flow	Goodbys Swamp	5.3	5.7 / 23.3					
EDO284	Headwater Flow	Cow Castle Creek	3.6	40.2 / 22					
EDO288	Headwater Flow	Providence Swamp	16.7	8.3 / 27.9					

	Ungaged Basin				USGS Reference Gage[1]				
EDO296	Headwater Flow	Polk Swamp	26.9	5.3 / 47.6					
EDO298	Headwater Flow	Indian Field Swamp	48.0	5.7 / 53					
EDO409	Confluence Flow	Cattle Creek	52.4	3.5 / 56.3					

List of Attachments

A. *Methodology for Unimpaired Flow Development, Edisto River Basin, South Carolina* (CDM Smith, August 2015)

B. *Guidelines for Standardizing and Simplifying Operational Record Extension* (CDM Smith, March 2015)

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

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

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

F. UIF Timeseries Graphs at USGS Gage Locations

G. Discussion on Reference Gage and Method Selection

ATTACHMENT A

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

(CDM Smith, August 2015)

Technical Memorandum

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

From: *CDM Smith*

Date: *August 2015*

Subject: *Methodology for Unimpaired Flow Development*
Edisto River Basin, South Carolina (Prepared as part of the South Carolina Surface Water Quantity Modeling Program)

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 explains the methods that will be employed to develop UIFs for South Carolina's Edisto River Basin. It describes data needs, methods for filling data gaps, and issues specific to the Edisto River basin. Once developed, UIFs will be input to the Simplified Water Allocation Model (SWAM) to evaluate surface water hydrology and operations throughout the basin. The UIFs for the Edisto River Basin will extend from 1931-2013.

UIFs will serve two purposes:

- UIFs will be the **fundamental input** to the model at headwater nodes and tributary nodes upstream of historic management activity, representing naturally occurring water in the riverways. Current and future management practices such as storage, withdrawals, and discharges will be superimposed on the UIFs.
- UIFs will provide a **comparative basis** for model results. The impacts of current and future management practices on flow throughout the river network can be compared to the natural conditions represented by the UIFs, and decisions about relative impacts can be well informed.

UIFs are defined as the addition and subtraction of management impacts on measured, impacted flows. UIFs will be calculated on a daily timestep using Equation 1:

Unimpaired Flow *= Measured Gage Flow + River Withdrawals + Reservoir Withdrawals – Reservoir Discharge – Return Flow + Reservoir Surface Evaporation – Reservoir Surface Precipitation + Upstream change in Reservoir Storage + Runoff from previously unsubmerged area* **(Equation 1)**

2.0 Overview of the Edisto Basin

The Edisto River basin covers 3,120 square miles, 10 percent of the land area of the State, lying within Coastal Plain physiographic province (**Figure 2-1**). The basin's major watercourses include the North and South Fork of the Edisto River; the Edisto River below their confluence near Branchville; and Four Hole Swamp which feeds into the Edisto River (**Figure 2-2**). Near the coast, the North and South branches of the Edisto River drain separately to the Atlantic Ocean.

Eight active Unites States Geological Survey (USGS) gaging stations monitor streamflow in the basin, including four on the South Fork, one on the North Fork, on the Edisto, and two on tributary streams. The North Fork station at Orangeburg (USGS 0217350) offers the earliest period of record, beginning in 1931 (but with a gap between 1971 and 1980). The Edisto River station near Givhans (USGS 0217500) offers the longest, uninterrupted period of record, beginning in 1938. Average annual streamflow in the South Fork Edisto River is 892 cubic feet per second (cfs) near Bamberg. Average annual streamflow in the North Fork Edisto River is 753 cfs near Orangeburg. Average annual streamflow in the Edisto River is 1,991 cfs near Branchville and 2,522 cfs near Ghivans.

In the upper Coastal Plain portion, tributary flows are generally steady, with well-sustained low flows. Comparatively, in the middle and lower Coastal Plain, sustained flow is more dependent on rainfall and direct runoff. Flows in the Edisto River are substantial and fairly consistent as a result of discharge from groundwater reserves in the upper Coastal Plain.

Chapter 7 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).

3.0 Water Users and Dischargers in the Edisto Basin

The South Carolina DHEC has provided information and data regarding current (active) and former (inactive) water users and dischargers throughout the state. Currently permitted or registered water users in the Edisto basin are listed in **Table 3-1**. Former users are listed in **Table 3-2**. Withdrawal locations of current and former water users are shown in **Figure 3-1** (municipal water supply; industrial and mining; thermoelectric, and golf courses) and **Figure 3-2** (agriculture). Individual withdrawals less than 3 million gallons per month (mg/m) will generally not be included in UIF calculations or in water quantity modeling; however, some aggregation of withdrawals that are less than 3 mg/m on a particular reach may occur, and the combined amount included. In other instances, withdrawals that average less than 3 mg/m annually, but are seasonally higher than 3 mg/m may be included.

Current and former wastewater dischargers are listed in **Tables 3-3 and 3-4**, respectively, based on National Pollution Discharge Elimination System (NPDES) permit information. Discharge locations of current and former discharges are shown in **Figure 3-3**. Only active discharges that typically average over 3 mg/m are listed in the tables and shown on Figure 3-3. Discharges that averaged less than 3 mg/m will generally not be considered when performing UIF calculations, except when the cumulative discharge amount from facilities located on the same tributary or portion of the mainstem are deemed significant.

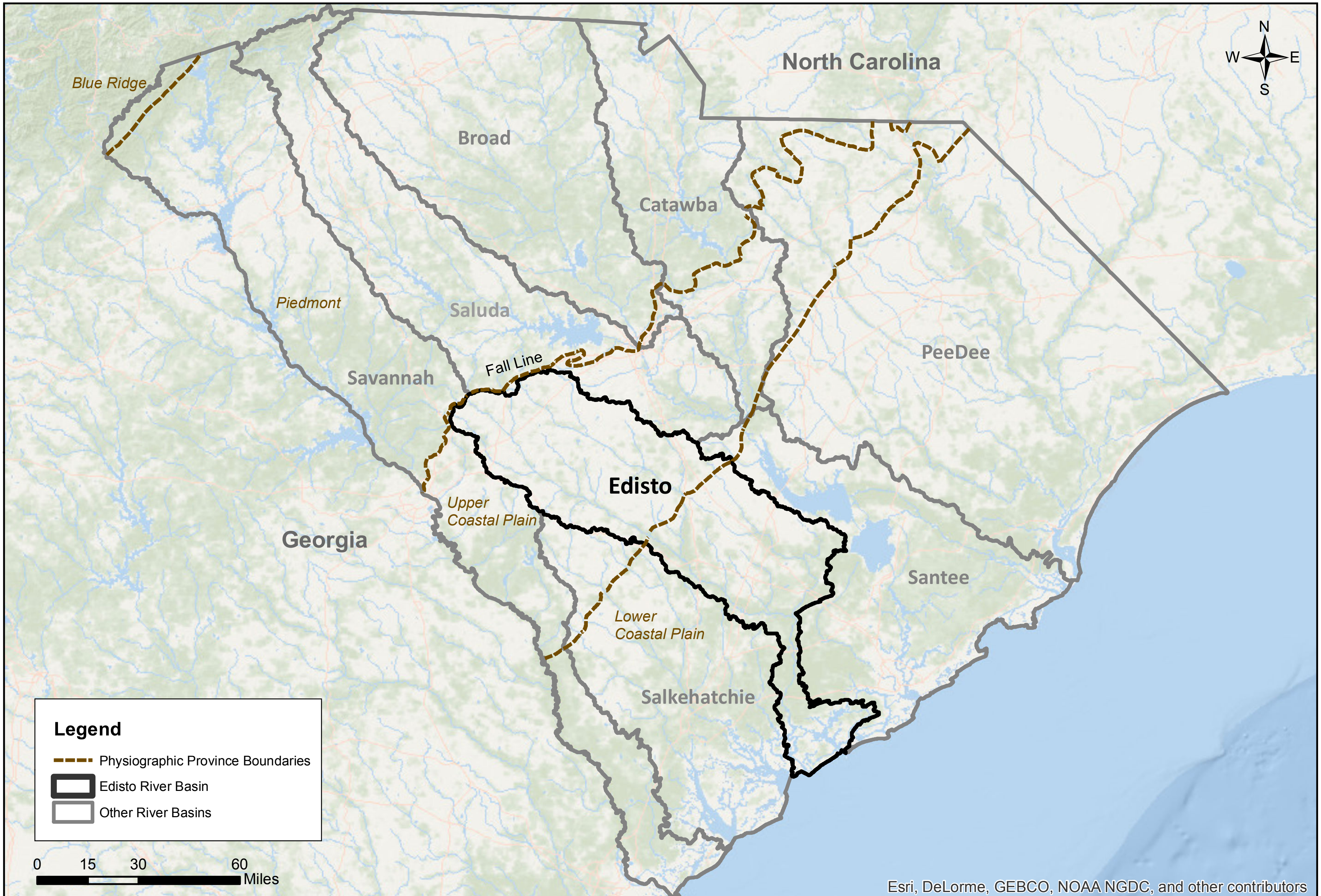


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Figure 2-1
South Carolina's Edisto River Basin and Other Major River Basins

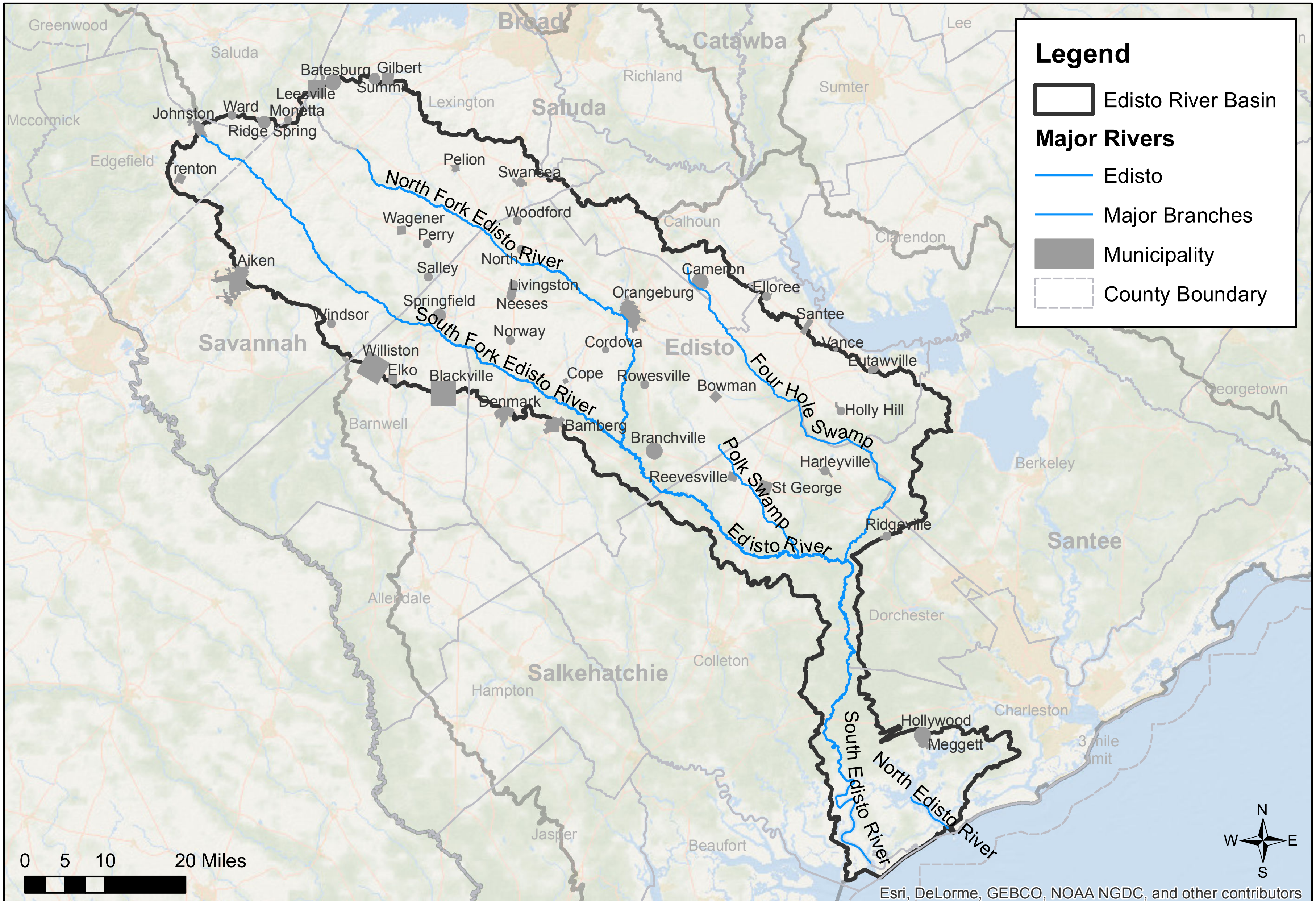

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Figure 2-2
Edisto River Basin

Table 3-1. Currently permitted and registered surface water users in the Edisto Basin

Intake ID	Facility Name	Withdrawal Tributary
Golf Course Users		
32GC011S01	INDIAN TRAIL GOLF CLUB	Duncan Creek
38GC004S01	ORANGEBURG COUNTRY CLUB	North Fork Edisto River
Industrial and Mining Users		
38IN002S01	ALBEMARLE CORP	North Fork Edisto River
Thermoelectric Users		
38PT001S01	SCE&G - COPE STATION	South Fork Edisto River
Drinking Water Users		
02WS002S01	CITY OF AIKEN	Shaw Creek
10WS004S03	CHARLESTON CPW - HANAHAN WTP	Edisto River
38WS002S03	CITY OF ORANGEBURG WTP	North Fork Edisto River
38WS002S01	CITY OF ORANGEBURG WTP	North Fork Edisto River
38WS002S02	CITY OF ORANGEBURG WTP	North Fork Edisto River
32WS003S01	BATESBURG WATER PLANT	Lightwood Knots Creek
32WS003S02	BATESBURG WATER PLANT	Duncan Creek
Agricultural Users		
09IR003S01	COTTON LANE FARMS	Goodby's Swamp
09IR003S02	COTTON LANE FARMS	Goodby's Swamp
09IR003S03	COTTON LANE FARMS	Goodby's Swamp
38IR020S01	BACKMAN FARMS	Willow Swamp
38IR081S01	BOLAND FARM	Dean Swamp Creek
38IR081S02	BOLAND FARM	Dean Swamp Creek
38IR015S01	BROWN FARMS	Willow Swamp
38IR015S02	BROWN FARMS	South Fork Edisto River
38IR014S03	BULL SWAMP PLANTATION	Bull Swamp Creek
38IR014S01	BULL SWAMP PLANTATION	Bull Swamp Creek
38IR014S02	BULL SWAMP PLANTATION	Bull Swamp Creek
09IR004S02	CALHOUN TRADING CO	Limestone Creek
09IR004S01	CALHOUN TRADING CO	Caw Caw Swamp
38IR042S01	GRAY FARM	Cooper Swamp
09IR009S01	HAIGLER FARMS INC	Four Hole Swamp
09IR009S02	HAIGLER FARMS INC	Four Hole Swamp
09IR009S03	HAIGLER FARMS INC	Four Hole Swamp
09IR009S04	HAIGLER FARMS INC	Four Hole Swamp
19IR002S01	HOLMES & SON LEWIS FARM	Shaw Creek
19IR002S02	HOLMES & SON LEWIS FARM	Shaw Creek
32IR004S01	KYZER FARMS	Black Creek
02IR028S01	MAURY FURTICK FARM	Dean Swamp Creek
38IR004S01	MILLWOOD FARM	Limestone Creek
38IR004S02	MILLWOOD FARM	Limestone Creek
38IR004S03	MILLWOOD FARM	Limestone Creek
38IR067S01	NORWAY FARM	Willow Swamp
09IR011S01	OAK LANE FARM HALFWAY SWAMP	Caw Caw Swamp
02IR027S01	PEBBLE CREEK ENTERPRISES	North Fork Edisto River
05IR012S01	PHIL SANDIFER & SONS, LLC	South Fork Edisto River
05IR054S01	RIDDLE DAIRY FARM	Hayes Mill Creek
38IR077S01	RIVER BLUFF SOD FARM	South Fork Edisto River
06IR020S01	ROB BATES FARM	Windy Hill Creek

Table 3-1 (continued). Currently permitted and registered surface water users in the Edisto Basin

Intake ID	Facility Name	Withdrawal Tributary
38IR040S01	SHADY GROVE PLANTATION & NURSERY INC	Cow Castle Creek
05IR005S01	SHIVERS TRADING AND OPERATING COMPANY	Sykes Swamp
19IR012S02	SMITH W G III	Shaw Creek
19IR012S03	SMITH W G III	Shaw Creek
19IR012S04	SMITH W G III	Shaw Creek
38IR066S01	SPRINGFIELD FARM	Goodland Creek
38IR026S02	SPRINGFIELD GRAIN CO BROWN KIRBY & SONS	South Fork Edisto River
38IR026S01	SPRINGFIELD GRAIN CO BROWN KIRBY & SONS	Goodland Creek
38IR026S03	SPRINGFIELD GRAIN CO BROWN KIRBY & SONS	Goodland Creek
32IR050S01	THOMAS C. FINK FARM	Black Creek
41IR014S07	TITAN FARMS	Beech Creek
41IR014S09	TITAN FARMS	Beech Creek
19IR004S03	TITAN FARMS	Beech Creek
19IR004S08	TITAN FARMS	Beech Creek
41IR014S02	TITAN FARMS	Bog Branch
41IR014S06	TITAN FARMS	Bog Branch
19IR004S01	TITAN FARMS	Bog Branch
19IR004S05	TITAN FARMS	Bog Branch
19IR004S06	TITAN FARMS	Bog Branch
19IR004S07	TITAN FARMS	Bog Branch
19IR004S15	TITAN FARMS	Bog Branch
41IR010S01	TITAN FARMS	Chinquapin Creek
41IR014S05	TITAN FARMS	Mill Creek
41IR014S10	TITAN FARMS	Shaw Creek
19IR004S12	TITAN FARMS	Shaw Creek
19IR004S09	TITAN FARMS	South Fork Edisto River
19IR004S13	TITAN FARMS	South Fork Edisto River
19IR004S14	TITAN FARMS	South Fork Edisto River
02IR024S02	TITAN FARMS	South Fork Edisto River
19IR004S02	TITAN FARMS	Temples Creek
19IR004S04	TITAN FARMS	Temples Creek
19IR004S10	TITAN FARMS	Temples Creek
19IR004S11	TITAN FARMS	Temples Creek
19IR004S16	TITAN FARMS	Temples Creek
38IR078S01	TURF CONNECTIONS	Goodland Creek
32IR013S08	WALTER P. RAWL & SONS/WP FARL FARM	Black Creek
02IR025S01	WALTHERS FARMS	South Fork Edisto River
38IR021S01	WILLIAMS & SONS FARMS	South Fork Edisto River
38IR021S02	WILLIAMS & SONS FARMS	South Fork Edisto River
38IR043S01	WILLSHIRE FARMS INC	Providence Swamp
38IR043S02	WILLSHIRE FARMS INC	Providence Swamp
10IR014S01	YELLOW HOUSE FARMS	Wadmalaw River

Table 3-2. Formerly permitted or registered surface water users in the Edisto Basin

Intake ID	Facility Name	Withdrawal Tributary
	Industrial and Mining Users	
02IN005S01	J M HUBER CORP EDISTO PLANT	South Fork Edisto River
	Thermoelectric Users	
15PT001SO1	SCE&G - CANADAYS STATION	Edisto River

Table 3-3. Currently Permitted NPDES Discharges in the Edisto Basin(Average Discharge ≥3 mg/m)

NPDES Pipe ID	Facility Name	Discharge Tributary	Associated Surface Water Permit	Associated Groundwater Withdrawal ID
SCG641003-001	AIKEN/SHAW CREEK WTP	Shaw Creek	02WS002	02WS002G
SC0024465-001	BATESBURG-LEESVILLE WWTF	Duncan Creek	32WS003	32WS002G
SC0001180-001	ALBEMARLE CORP/ORANGEBURG	North Fork Edisto River	38IN002	*none*
SC0045772-001	SCE&G/COPE POWER PLANT	Roberts Swamp	38PT001	38PT001G
SC0045772-002	SCE&G/COPE POWER PLANT	Roberts Swamp	38PT001	38PT001G
SC0045772-003	SCE&G/COPE POWER PLANT	Roberts Swamp	38PT001	38PT001G
SC0045772-005	SCE&G/COPE POWER PLANT	Roberts Swamp	38PT001	38PT001G
SC0045772-006	SCE&G/COPE POWER PLANT	Roberts Swamp	38PT001	38PT001G
SC0024481-001	ORANGEBURG WWTF	North Fork Edisto River	38WS002	*none*
SC0001147-001	ROSEBURG FOREST PRODUCTS S/HOLLY HILL MDF	Four Hole Swamp	*none*	38IN005G
SC0001147-002	ROSEBURG FOREST PRODUCTS S/HOLLY HILL MDF	Four Hole Swamp	*none*	38IN005G
SC0001147-003	ROSEBURG FOREST PRODUCTS S/HOLLY HILL MDF	Four Hole Swamp	*none*	38IN005G
SC0002992-001	HOLCIM (US) INC/HOLLY HILL PLT	Four Hole Swamp	*none*	38IN001G
SC0002992-002	HOLCIM (US) INC/HOLLY HILL PLT	Four Hole Swamp	*none*	38IN001G
SC0002992-003	HOLCIM (US) INC/HOLLY HILL PLT	Four Hole Swamp	*none*	38IN001G
SC0002992-02A	HOLCIM (US) INC/HOLLY HILL PLT	Four Hole Swamp	*none*	38IN001G
SC0022667-001	GIANT CEMENT COMPANY INC	Four Hole Swamp	*none*	18WS014G/18IN001G
SC0022667-002	GIANT CEMENT COMPANY INC	Four Hole Swamp	*none*	18WS014G/18IN001G
SC0022667-003	GIANT CEMENT COMPANY INC	Four Hole Swamp	*none*	18WS014G/18IN001G
SC0022667-004	GIANT CEMENT COMPANY INC	Four Hole Swamp	*none*	18WS014G/18IN001G
SC0022667-004	GIANT CEMENT COMPANY INC	Four Hole Swamp	*none*	18WS014G/18IN001G
SC0022667-005	GIANT CEMENT COMPANY INC	Four Hole Swamp	*none*	18WS014G/18IN001G
SC0022586-001	LAFARGE BUILDING MATERIALS INC	Indian Field Swamp	*none*	18IN0040G
SC0022586-002	LAFARGE BUILDING MATERIALS INC	Indian Field Swamp	*none*	18IN0040G
SC0038504-001	TOWN OF HARLEYVILLE	Indian Field Swamp	*none*	18WS003G
SC0043419-001	ACO DISTRIBUTION & WAREHOUSE INC	North Fork Edisto River	*none*	38IN004G

Table 3-3 (continued). Currently Permitted NPDES Discharges in the Edisto Basin(Average Discharge ≥3 mg/m

NPDES Pipe ID	Facility Name	Discharge Tributary	Associated Surface Water Permit	Associated Groundwater Withdrawal ID
SC0026417-001	BLACKVILLE WWTF	Windy Hill Creek	*none*	06WS002G
SC0047333-001	TOWN OF BRANCHVILLE	Edisto River	*none*	38WS007G
SC0047333-001	TOWN OF BRANCHVILLE	Edisto River	*none*	38WS007G
SC0034541-001	GASTON COPPER RECYCLING CORP	Bull Swamp Creek	*none*	32IN002G
SC0047821-001	TOWN OF NORTH	North Fork Edisto River	*none*	38WS003G
SC0047821-002	TOWN OF NORTH	North Fork Edisto River	*none*	38WS003G
SC0038555-001	SHOWA DENKO CARBON	Four Hole Swamp	*none*	18IN002G
SC0038555-01A	SHOWA DENKO CARBON	Four Hole Swamp	*none*	18IN002G
SC0023272-001	SPRINGFIELD/PLANT #1	South Fork Edisto River	*none*	38WS009G
SC0023281-001	SPRINGFIELD/PLANT #2	Goodland Creek	*none*	38WS009G
SC0025844-001	TOWN OF ST. GEORGE, TOWN	Polk Swamp	*none*	18WS002G
SC0026204-001	TOWN OF WAGENER	Dean Swamp Creek	*none*	02WS001G
SC0045993-001	TOWN OF NORWAY	Willow Swamp	*none*	38WS006G
SC0046388-001	KENTUCKY-TENN CLAY/GENTRY PIT	South Fork Edisto River	*none*	*none*
SC0046388-002	KENTUCKY-TENN CLAY/GENTRY PIT	South Fork Edisto River	*none*	*none*
SC0047023-001	ORANGEBURG NTL FISH HATCHERY	North Fork Edisto River	*none*	*none*
SC0047023-002	ORANGEBURG NTL FISH HATCHERY	North Fork Edisto River	*none*	*none*
SC0047848-001	BEARS BLUFF NATL FISH HATCHERY	Wadmalaw River	*none*	*none*
SC0047848-002	BEARS BLUFF NATL FISH HATCHERY	Wadmalaw River	*none*	*none*
SC0047848-003	BEARS BLUFF NATL FISH HATCHERY	Wadmalaw River	*none*	*none*

Table 3-4. Formerly Permitted NPDES Discharges in the Edisto Basin (Average Discharge ≥3 mg/m)

NPDES Pipe ID	Facility Name	Discharge Tributary
SC0002020-001	SCE&G - CANADAYS STATION	Edisto River
SC0002020-002	SCE&G - CANADAYS STATION	Edisto River
SC0002020-003	SCE&G - CANADAYS STATION	Edisto River
SC0002020-005	SCE&G - CANADAYS STATION	Edisto River
SC0002020-04A	SCE&G - CANADAYS STATION	Edisto River
SC0021113-001	BRANCHVILLE, TOWN OF	Pen Branch
SC0022268-001	RIDGE SPRING/S. LAGOON #1	Flat Rock Creek
SC0024341-001	J M HUBER CORP/EDISTO PLANT	South Fork Edisto River
SC0040401-001	PARADISE SHRIMP FARMS OF SC	North Creek
SC0040401-002	PARADISE SHRIMP FARMS OF SC	North Creek
SC0044270-001	YOUMANS GAS AND OIL CO, INC	Wadmalaw River Trib.

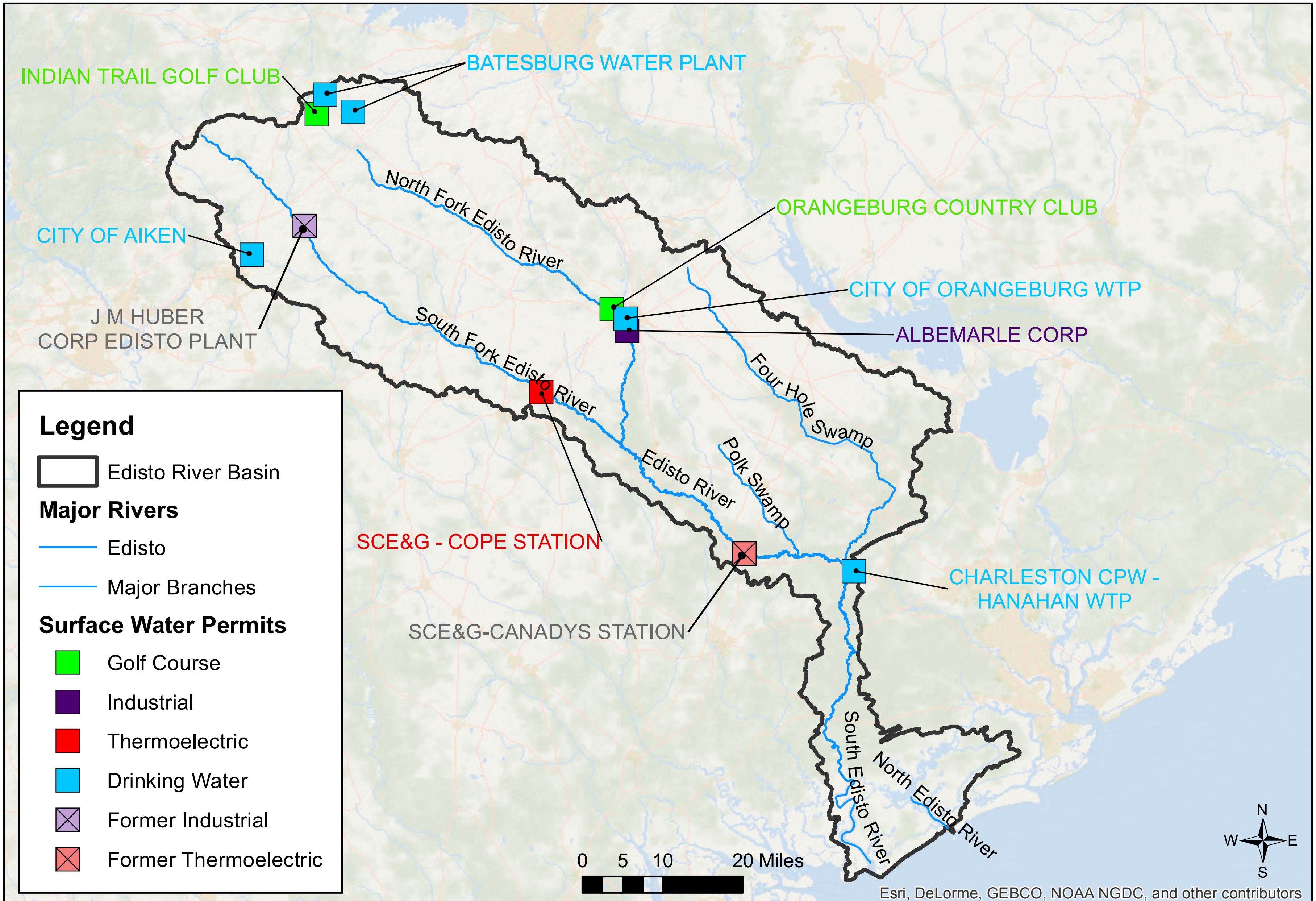

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Figure 3-1
Current and Former Municipal, Industrial, Thermoelectric, and Golf Course Surface Water Users

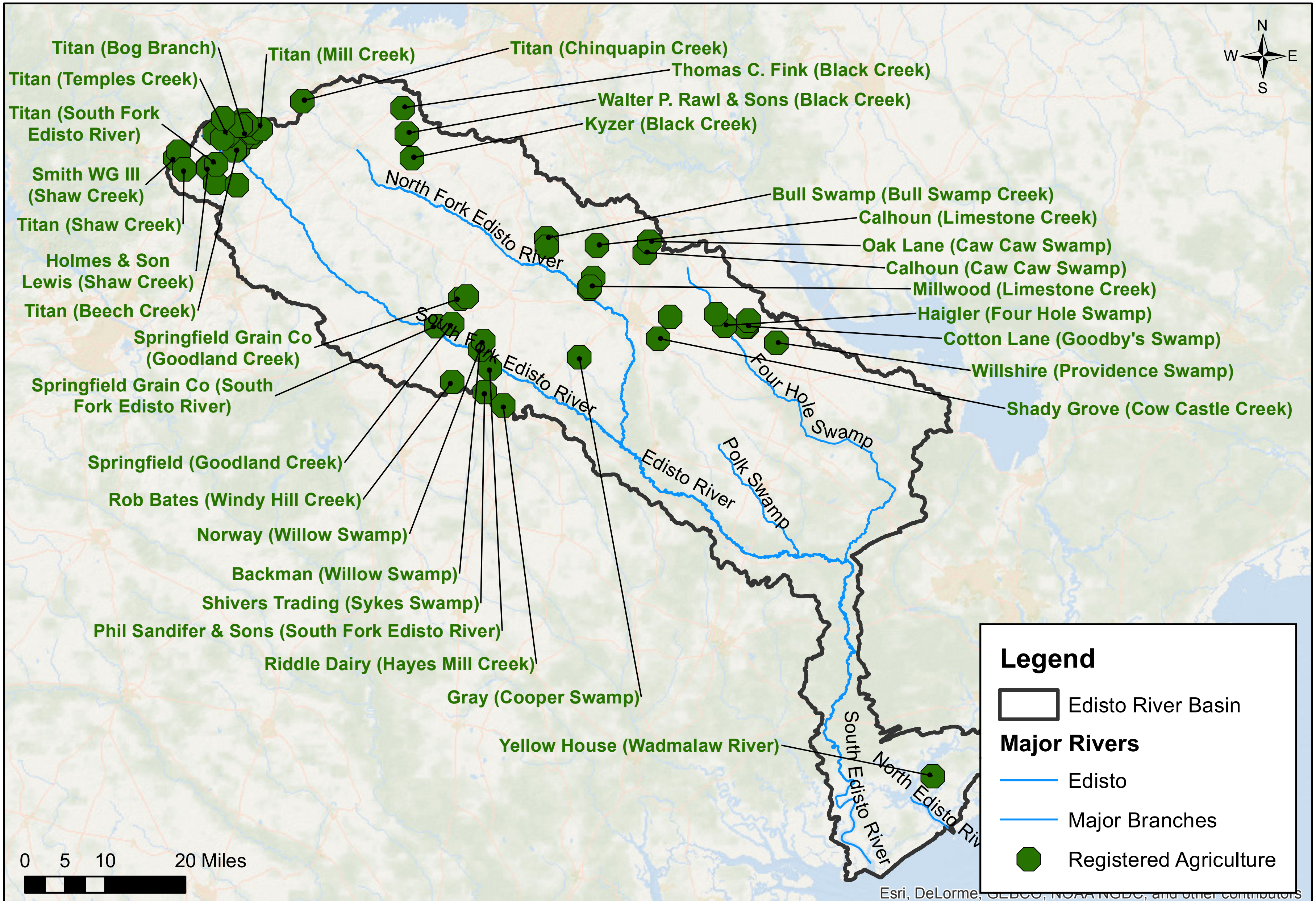

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Figure 3-2
Current Agriculture Surface Water Users

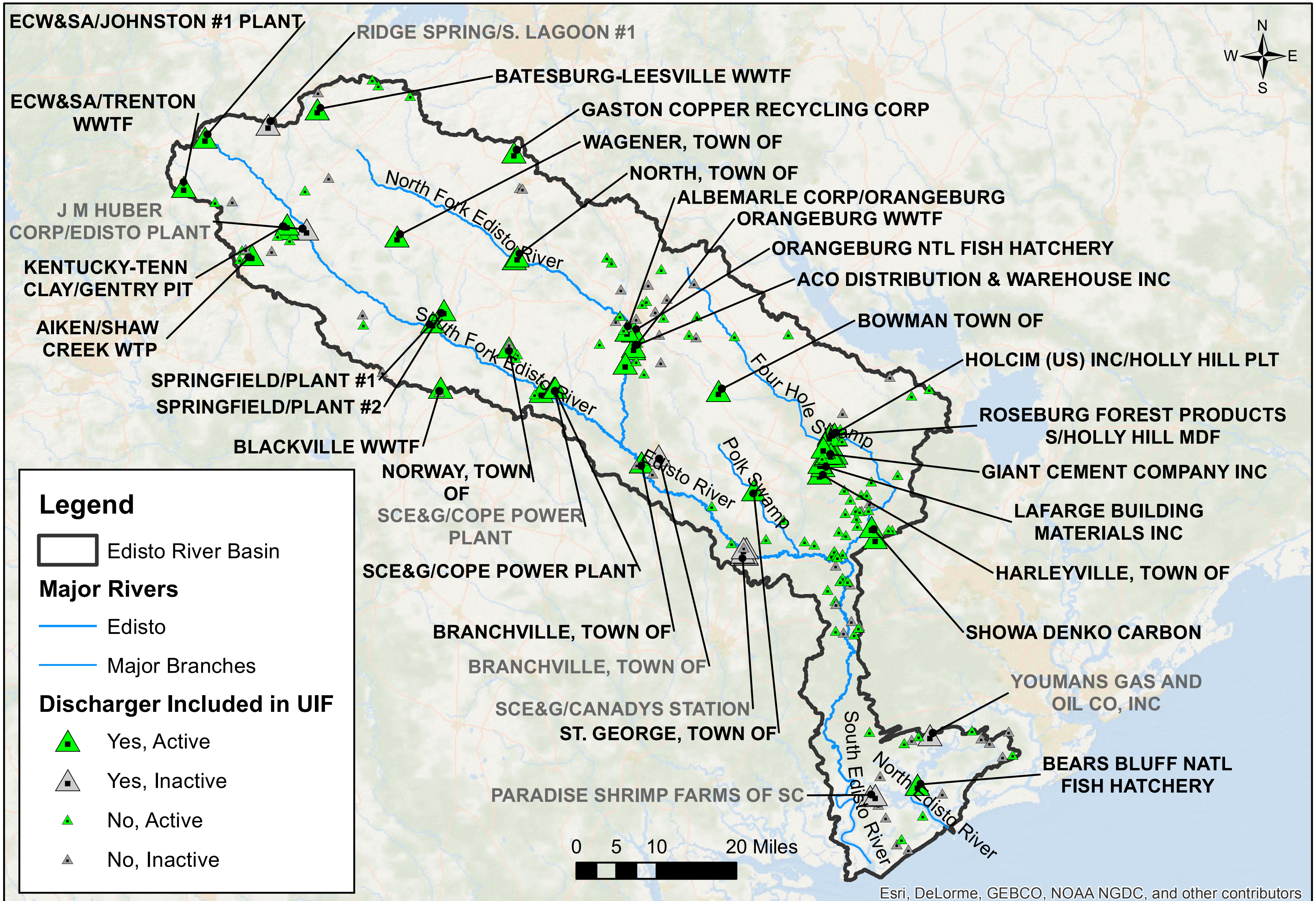

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Figure 3-3
Active and Inactive NPDES Discharges

4.0 Overview of Methodology

4.1 UIF Process Diagram

Figure 4-1 illustrates the general UIF development process, not as a step-by-step procedure, but as a guiding approach. The process involves adding and subtracting known historical management practices from measured streamflow records. In doing so, the impacts of human intervention on the flow in the river can be removed from the historical flow records. Water is added to existing streamflow estimates to account for historic withdrawals and subtracted out to account for historic discharges, and the timing of flows is adjusted to account for impoundment of rivers.

The overarching process can be described in four steps. Each is summarized below and presented in detail in **Section 5.**

Step 1: Data Collection. This step includes collection of available streamflow records, withdrawal records, discharge records, operational records at dams, impoundment features, etc. The duration of the longest available, reliable streamflow record determines the period of record for the basin. Records from other gages are extended to match this duration (described in **Section 5.4**).

Step 2: Unregulated Flow. The distinction between "Unregulated Flow" and "Unimpaired Flow" is helpful in understanding the different ways in which water management affects streamflow, but in the calculations of the UIFs, the two terms are not disaggregated. Unregulated flows represent flow in which the effects of timing due to impoundment are removed, and are, effectively, a subset of Unimpaired Flows. Equation 1 in Section 1 includes the effects of streamflow regulation in the UIF calculation.

As noted, Unregulated Flow refers to flow in which the timing of flow has not been altered by impoundment. In the Edisto, there are no impoundments of significant size, and no impoundments are being included in the SWAM model. Therefore, no adjustments need to be considered to account for the timing of flows from impoundments.

There is an important difference between the alteration to flow timing associated with impounding a river (corrected with unregulated flows), and the timing of flow due to its traverse through the river channel (hydraulic time lags). Currently, it is not expected that hydraulic time lags (also referred to as "travel time") will be necessary for these UIF data sets for the following reasons:

a. At a monthly timestep, the time lags would be inconsequential.
b. At a daily timestep, for long-term simulation, the key metric is frequency of various flow levels and water availability, which would be preserved over time even if shifted by several days.

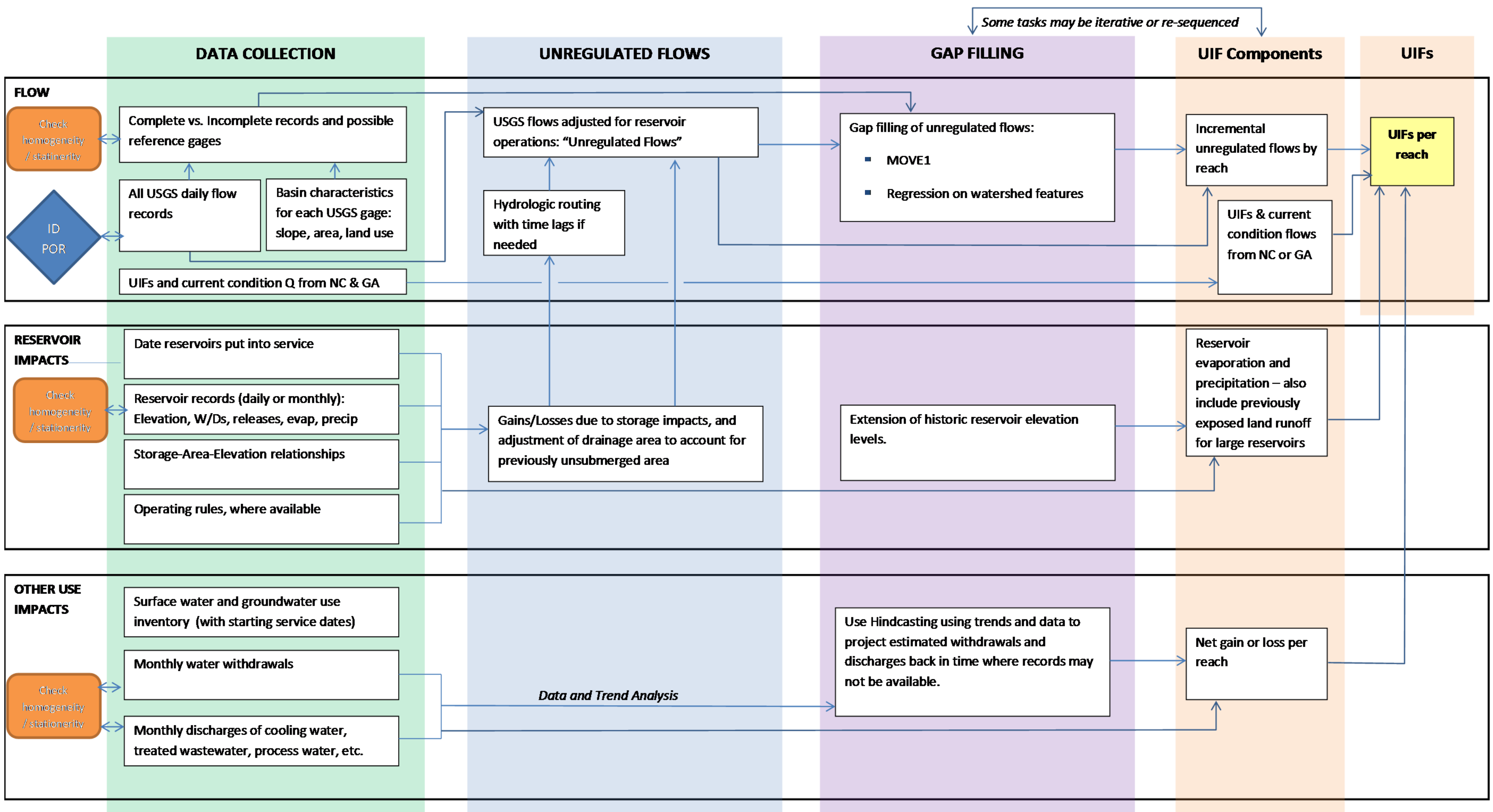


Figure 4-1. Unimpaired Flow Process Diagram

c. Accurate prediction of hydraulic time lags requires channel bathymetry and iterative hydraulic routing equations (HEC-RAS, for example).
d. For UIFs, the observed lags (albeit for impaired flows) are already resident within the USGS streamflow records, so the UIFs will have some of the lag already built in.

If special circumstances warrant rough estimation of hydraulic time lags, flow-based lag equations from USGS could be considered. Note that time lags associated specifically with return flows, e.g. via groundwater, are able to be simulated in SWAM.

*Steps 3 and 4 are presented sequentially in **Figure 4-1**, but may be conducted in either order, and possibly with iteration. It may be preferable to compute UIFs to the greatest extent possible and then fill data gaps using trends observed in documentable UIFs, or it may be preferable to first fill gaps in historic data and then compute uninterrupted UIFs. These decisions will be made on a case-by-case basis, and will likely depend primarily on data availability (see additional detail in **Step 3: Gap Filling**, below).*

Step 3: Gap Filling. As stated under Step 1, the period of record for the basin will begin with the first date that any USGS gage began recording streamflow. All other records will be synthetically extended back to this date if measurements are not available. Likewise, measurement gaps will be filled in synthetically. Two types of synthetic data will be developed: First, the operational data used to compute a UIF over a given period of record for a specific gage will be extended or filled over that period (this includes withdrawals, discharges, and effects of storage). Second, the UIFs for each USGS gage will be extended statistically over the period corresponding with the most complete gage in the basin. Hydrologic flows will be computed using one of a variety of alternative statistical approaches described in **Section 5.4**. Historical management practices, such as withdrawals and discharges, will be filled in to the greatest extent possible with anecdotal information from relevant utilities, supplemented with statistical hindcasting based largely on population.

Where practical, gap filling of the hydrologic flow should occur after UIFs are developed as fully as they can be. This will help preserve the statistical integrity of natural hydrologic relationships. However, the approach is illustrated as flexible for two reasons:

- **Regional Consistency:** It appears that Georgia may have applied some level of gap filling on unregulated flows prior to developing unimpaired flows (see Figure 4-1 of *REVIEW DRAFT: Synopsis of Surface Water Availability Assessment, Georgia Statewide Water Management Plan, Section 4, March 2010*), and we will be using those data sets for the Savannah River Basin.

- **Case-by-Case Decisions:** For basins in which UIFs will be newly developed as part of this study, some flexibility may be important because the timing of when gap filling can be most effective may depend on the type of data sets being filled.

There may be some operational flows that require hind-casting to characterize their impacts over time. It may be beneficial to do this prior to developing the UIFs. In other cases, it may simply be advantageous to extend USGS records synthetically if they can be shown to correlate well with other data so that UIFs can be developed from data sets that are as comprehensive as possible. Not all of the reasons for these decisions are foreseeable at this time, and some will be case-by-case decisions made in collaboration with DNR/DHEC.

<u>For the pure hydrologic timeseries, however, the project team will endeavor to compute UIFs to the greatest extent possible and then fill in gaps *in the UIFs* using statistical techniques</u>. The flexible approach outlined above facilitates the filling in of some operational gaps along the way if the project team (collectively with DNR/DHEC) deems it to be necessary or advantageous to create the most comprehensive datasets with which to compute the UIFs.

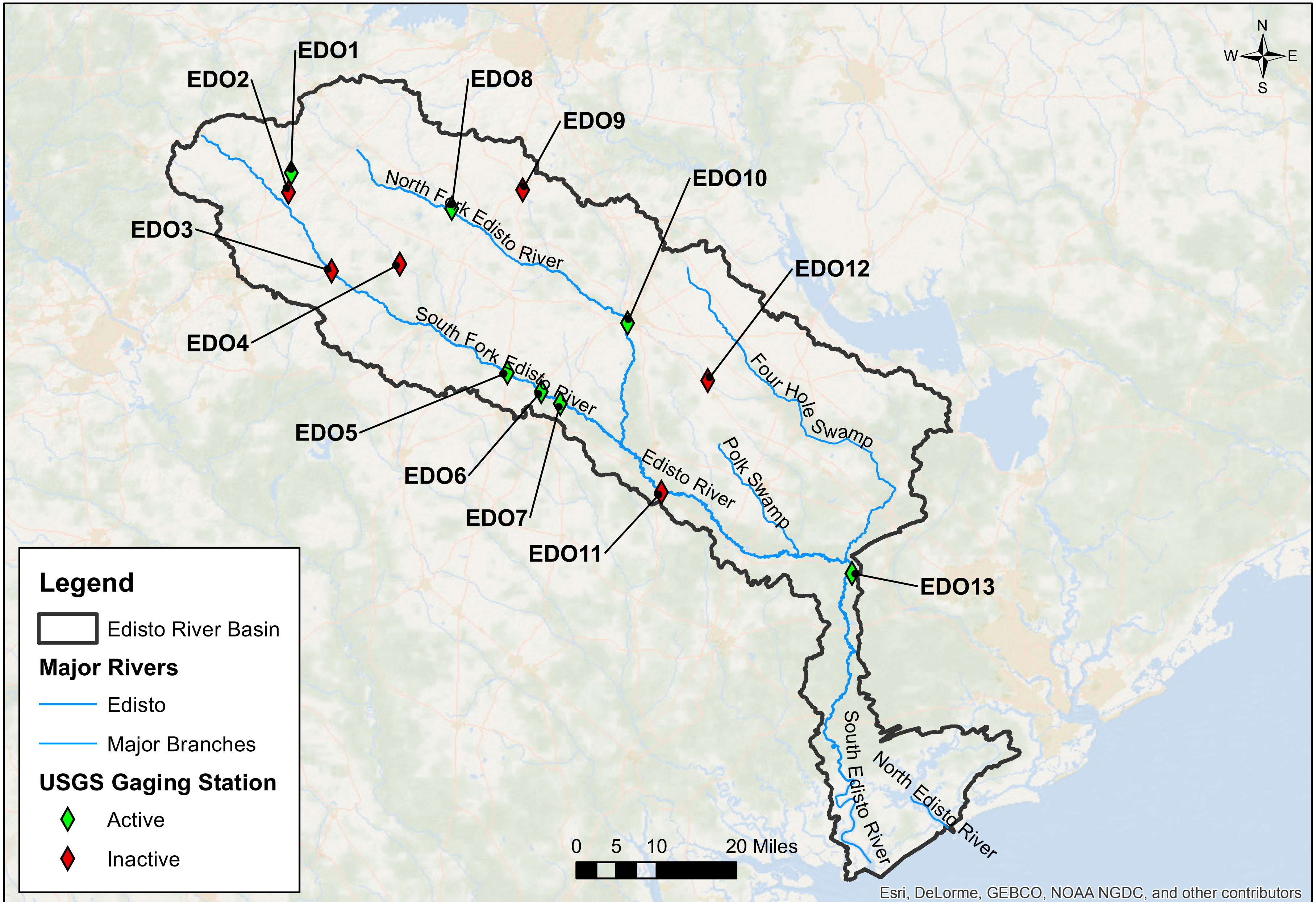
Step 4 – Unimpaired Flow Calculation: UIFs will be computed following Equation 1. Once they are complete for each gage record, two additional steps are needed:

> <u>Step 4a</u>: Extend each UIF record over the period corresponding to the most complete (longest) gage record in the basin,
>
> <u>Step 4b</u>: Using basin area proration, estimate the UIFs in ungaged basins that are deemed necessary for subsequent model input.

4.2 Locations of UIFs

UIFs will be computed at two types of locations throughout the basin:

- Any site where a USGS gage station has recorded streamflow measurements will have calculated UIFs (See **Figure 4-2**). This is because the USGS records provide a necessary "footing" with which to begin the calculation per Equation 1. It will allow model development to proceed with UIFs at upstream sites as input, and at downstream sites for comparative use, or as input of incremental hydrologic flows:
  - Where a gage is located upstream of historical management activity, it will be included in the model as direct input.
  - Where a gage is located on a tributary downstream of a management activity, the management activity will be removed in the calculations and, if necessary, the record can be scaled according to drainage area to estimate an upstream boundary condition UIF for that tributary.
  - Where a gage is located downstream of a management activity on a river mainstem, it will available for comparative purposes, and also used to calibrate reach gains and losses (see Section 4.3 below) or explicit incremental unimpaired flows. Simulated flow at these locations will be computed by the model itself based on upstream UIFs and subsequent river management.



CDM Smith

Figure 4-2
Active and Inactive USGS Streamflow Gaging Stations

- Any tributary that will be explicitly included in the model will require input of unimpaired headwater boundary flow (Sections 4 and 8 of the *November 2014 South Carolina Surface Water Quantity Models Modeling Plan* discuss explicit and implicit tributaries). If USGS gage data is unavailable for an explicitly modeled tributary, a synthetic UIF will be developed using reference gages and statistical methods discussed in **Section 5.4**.

4.3 Gains and Losses Between UIF Nodes

UIFs will be computed for each USGS streamgage in the basin but, as discussed, not all UIFs will be used for model input. UIFs will be used for model inputs at headwater locations, and available in the river network to compare against computed flows as they are affected by storage, withdrawals, and discharges, and to use for model calibration.

During the subsequent model development and calibration process (after the UIFs are input into the model as headwater inputs), there will be reaches in which hydrologic gains or losses are computed. Gains or losses can be simulated in SWAM in one of two ways. As a first option, the gain/loss function available in SWAM for each tributary object could be used and parameterized according to user-specified percent increases (or decreases) per unit length of stream reach. Alternatively, a timeseries calculated in a similar way to the UIFs themselves (using the difference between two UIFs, and simulated as an inflow or withdrawal) could be specified in SWAM using separate tributary or user objects. Note that for losing streams, the modeled losses would not return elsewhere in the model network, and would be assumed to be lost from the river system.

It is understood that losing streams are likely present in the Edisto Basin and so a general methodology for losses is discussed here. If a downstream gage indicates lower flow than an upstream gage (both unimpaired), this would indicate that the reach in between loses water to the ground, and the REACH GAIN/LOSS function in SWAM would be calibrated accordingly. Alternatively, the difference between the daily flows could be added as a withdrawal from the river using a user object (and not returned elsewhere).

Another possibility that may arise is that an upstream flood may not result in downstream flow immediately (due to travel time). In a normally gaining river, simply subtracting the higher upstream flow from the lower downstream flow that hasn't received the flood waters yet could result in negative values. If this is observed, we will apply discretionary correction factors or time shifts to reduce the impact of the perceived time lag and help ensure that the reach does not lose water simply because of the hydraulic routing of floods.

5.0 Unimpaired Flow Methodology

The UIF methodology follows the diagram previously shown in Figure 4-1. In addition to discussion of the period of record, each block (from left to right) is discussed in detail below.

5.1 Period of Record

While UIF estimates will begin in 1931 for the Edisto Basin, more than half of the streamgages began operation in the 1980s or later. The records for all gages that started tracking flow after 1931 will be extended using gap filling techniques. Although much of the UIFs will thus be based on estimated flows, the value of a lengthy record, even if approximate, is that DNR, DHEC, and other users can evaluate results over a large range of hydrologic and climate conditions. **Figure 5-1** depicts the length and timing of records available for all USGS gages in the Edisto basin. **Table 5-1** lists each gage.

Figure 5-1. Period of record for USGS gages in the Edisto Basin

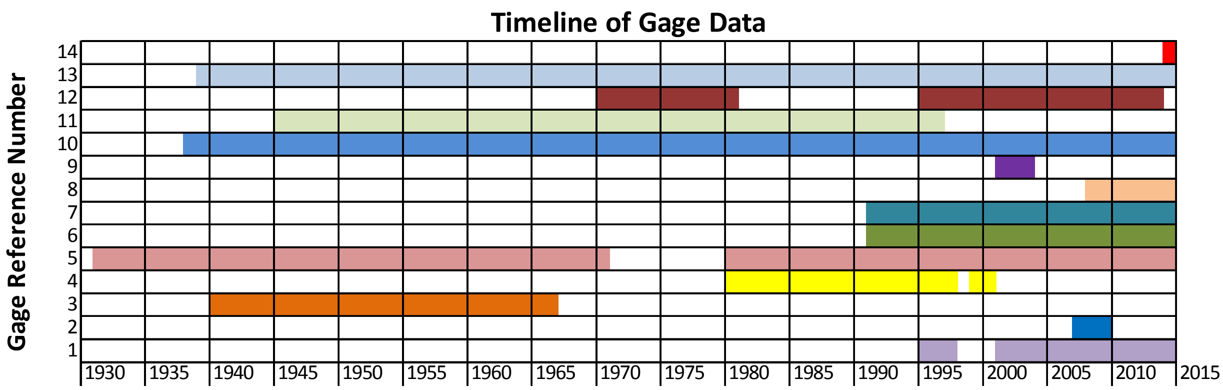


Table 5-1. USGS gages in the Edisto Basin

USGS Number	Description	Period of Record				Gage ID
		From:	To:	From:	To:	
02172300	MCTIER CREEK (RD 209) NEAR MONETTA, SC	10/1/1995	10/1/1997	2/7/2001	12/31/2014	1
02172305	MCTIER CREEK NEAR NEW HOLLAND, SC	6/13/2007	11/30/2009			2
02172500	SOUTH FORK EDISTO RIVER NR MONTMORENCI, S. C.	4/1/1940	9/30/1966			3
02172640	DEAN SWAMP CREEK NR SALLEY, SC	10/1/1980	3/25/1987	3/1/1988	9/30/2000	4
02173000	SOUTH FORK EDISTO RIVER NEAR DENMARK, SC	8/4/1931	9/2/1971	10/1/1980	12/31/2014	5
02173030	SOUTH FORK EDISTO RIVER NEAR COPE, SC	6/29/1991	current			6
02173051	SOUTH FORK EDISTO RIVER NEAR BAMBERG, SC	4/9/1991	current			7
02173212	CEDAR CREEK NEAR THOR, SC	4/8/2008	current			8
02173351	BULL SWAMP CREEK BELOW SWANSEA, SC	2/6/2001	9/30/2003			9
02173500	NORTH FORK EDISTO RIVER AT ORANGEBURG, SC	12/1/1938	current			10
02174000	EDISTO RIVER NEAR BRANCHVILLE, SC	10/1/1945	9/30/1996			11

USGS Number	Description	Period of Record				Gage ID
		From:	To:	From:	To:	
02174250	COW CASTLE CREEK NEAR BOWMAN, SC	10/1/1970	9/30/1981	10/1/1995	2/24/2013	12
02175000	EDISTO RIVER NR GIVHANS, SC	1/1/1939	current			13
02172558	SOUTH FORK EDISTO RIVER ABOVE SPRINGFIELD, SC	10/10/2014	current			14

5.2 Data Needs and Collection

Data needs, discussion of how the data will be used, and potential sources of the data are presented in **Table 5-2**. The majority of data needed are historic records. The categories of data needed include flow, reservoir impacts, and other use impacts. These categories partially overlap. Additional information that needs to be collected as part of developing the SWAM model may also be used to assist with gap filling. Each main category is briefly discussed below.

<u>Flow</u>: All available records of streamflow in the basin need to be gathered, whether they are complete or not. Incomplete records will be filled using the gap filling techniques discussed in **Section 5.4**. The gap filling technique includes correlation with other stream gage records, precipitation data, and evaporation data, which may include gages from outside the basin. As UIF estimates are being prepared across South Carolina, flow data will be gathered from stations statewide to determine the nearest gages from which to correlate flows.

<u>Other Use Impacts:</u> Other impacts include water users, water dischargers, and groundwater withdrawals. Current and historical water users and dischargers are listed in **Section 3**. While daily withdrawal and discharge data would be ideal, such data is unlikely to be available in most cases. Monthly data should be available for most, but the period of record for such data is limited as such data was not required to be maintained before 2000. Water users and dischargers have been contacted by phone to collect additional information on historic usage/discharge patterns to extend the records. Details on the information that was requested is presented in **Attachment A**.

Table 5-2. Data Needs

Data Category	Data	Use(s)	Potential Sources	Comments
Flow	USGS Stream gage Records	UIFs for every available gage	USGS	Provides opportunity to calculate incremental flows between gages.
	Slope, contributing area, and land use for each USGS gage	Correlation for flow estimation	USGS, GIS	USGS provides contributing area, GIS tools and data used to determine slope and land use.
Other Use Impacts	Historical M&I Water Withdrawals	Compute net gain or loss per reach	DHEC databases, Records and anecdotal information from individual users/ permittees	Overlap with UIF data collection and development, but useful in confirming models' ability to recreate historic flows as measured by USGS stream gages.
	Historic Ag Water Withdrawals			
	Historic Industrial / Energy Water Withdrawals			
	Historic Discharges			
	Historic Groundwater Use			
	Historic Interbasin Transfers		DNR/DHEC	
	Historic Population	Estimate historical withdrawals absent data	US Census	Surrogate for actual withdrawal data
Potential Use for Gap Filling	Drought Management Requirements	Estimate changes in water user withdrawals given hydrologic conditions	DNR/DHEC	All data gathered as part of model development, but may be utilized for gap filling of UIFs
	Contingency Plan Requirements	Estimate changes in water user withdrawals given hydrologic conditions		
	Spatially distributed acreage of crop types	Estimate historical agricultural water demand and return flows		

5.3 Unregulated Flow Estimation

Unregulated flows are flows with the timing impacts from reservoirs removed. Unregulated flows are estimated by computing stream flow from changes in reservoir storage. No reservoirs of significant size are present in the Edisto; therefore, unregulated flow estimation is not necessary. Furthermore, the process of UIF calculation has been compressed into a single equation that accounts for flow regulation as one of several types of impairment.

5.4 Gap Filling Techniques

As stated in **Section 4**, the period of record for the basin will begin with the first date that any USGS gage began recording streamflow. Hydrologic records will be extended, filled, or created for sites in the model that meet one or more of the following criteria:

- Sites with USGS gages that began recording after the earliest start date in the basin
- Sites with USGS gages that have gaps in their records

- Ungaged tributaries that will be modeled explicitly in SWAM (Sections 4 and 8 of the November 2014 *South Carolina Surface Water Quantity Models Modeling Plan* discuss explicit and implicit tributaries)

As noted, management practices that have been recorded (withdrawals, discharges, etc.) will likely require record extension using hindcasting approaches. The various techniques to fill in data gaps are described below in **Sections 5.4.1** through **5.4.5**. Decisions on which method to use will be made on a case-by-case basis, based on available data, confidence in the data, and the nature of the incomplete data. In some cases, it may be best to combine methods, or apply more than one for validation purposes.

5.4.1 Streamflow Transposition by Area Ratios *(For extension, gap filling, or full synthesis of historical flows in ungaged or partially gaged basins)*

Where good correlation exists between overlapping periods of streamflow records, or where hydrologic and physical features (drainage area, land use, slope) of an ungaged or incompletely gaged basin correlate well with a nearby gaged reference basin, the correlated reference gage will be used to generate a new synthetic timeseries of flows, or to fill gaps in an existing dataset. Basin area ratios will be applied, and possibly adjusted by correction factors from empirical observations of overlapping periods of record, or literature values related to the magnitude of difference in the area (which may have more of an influence on daily flows than on monthly flows). Reference gages will selected based on proximity to the ungaged or incompletely gaged basin, as well as similarities (to the greatest extent practical based on data availability) in drainage basin land use, size, and slope. For the Edisto, references gages from the Saluda basin may be considered for use in addition to those in the Edisto.

5.4.2 MOVE.1 Technique *(For basins with partial streamflow records)*

Periods of missing streamflow data can be filled based on flow in nearby measured streams using the Maintenance of Variance Extension (MOVE.1) technique (Hirsch, 1982)[1] MOVE.1 is a statistical flow record extension technique that fills missing data in a streamflow record (y) based on flow in a nearby reference stream gage (x) while preserving the statistics in basin *y*. The method, and variations of it, have been employed in other U.S. statewide water plans, such as for the Oklahoma Comprehensive Water Plan 2011 Update. The technique shown in the equation below uses the mean (m) and standard deviation (s) of the two streams (the index 'i' is the daily timestep).

$$y_i = m_y + \frac{s_y}{s_x} \cdot (x_i - m_x) \qquad \textbf{(Equation 2)}$$

The selection of an appropriate reference gage will be an important aspect of applying MOVE.1. It is preferred that only nearby reference gages be used for any given basin. Additionally, reference

[1] R.M. Hirsch, 1982: *A Comparison of Four Streamflow Record Extension Techniques.* Water Resources Research, Volume 18, Issue 4, pages 1081–1088, August 1982.

basins will be selected so that basin size, land use, and slope are similar to the characteristics of the basin whose record is to be extended as closely and as practically as possible, based in large part on data availability. Any overlapping data will be checked for reasonable correlation before final selection of reference gages.

Also, if statistics for the reference basin differ substantially between the periods for which the basin with data gaps has data and is missing data, a determination will be made as to whether to apply statistics for the entire record or just periods over which the statistics are relatively stable, and which include the gaps to fill.

As part of the UIF dataset development for the Saluda River Basin, CDM Smith conducted testing of the MOVE.1 method for record extension, as well as a variation of it which did not include log transformations. Based on the results of the testing, the log transformations generally gave better results; therefore, the MOVE.1 method as described by Hirsch will be followed in most cases, though because of known bias that the log transformation can produce, correlation tests (and subsequent record extension) can also be conducted with the raw flow data if the overlapping period is sufficiently long and broad enough across the hydrologic spectrum to distinguish one method as clearly preferable.

When deciding between using Area Ratio or MOVE.1, if one method is clearly preferred over the other for different hydrologic regimes, and can produce a good fit to observed data, CDM Smith will apply a “hybrid” approach that uses both methods, and define the flow threshold at which to switch from one method to the other. If neither method can reproduce high flows well, CDM Smith will consider MOVE.1 with the entire period of record and straight flows (i.e., without the log transform) for high flows only. Tests confirm that this method may sometimes be best for high flows.

CDM Smith will also endeavor to manually smooth daily flows where run-of-river operations or other stream impairments have produced unnatural “noise”. Moving averages will be applied in instances where it appears that run-of-river operations are creating unrealistic, single day spikes in the record. The smoothing of the data, where appropriate, will eliminate much of the noise that is transferred to downstream UIFs. Generally, smoothing techniques will be applied where it’s possible to identify a likely cause of the sudden spike or dip in UIF estimates, which are not a result of the natural hydrology.

5.4.3 Regression on Overlapping Flow Periods, Precipitation, Temperature, and Watershed Features *(for basins with partial records)*

In some cases, area transposition is not robust enough to cover the full range of hydrologic conditions in a basin, especially on a daily basis. In these cases, regression equations can be developed based on overlapping periods of streamflow record with a longer reference gage, provided there is good correlation between the two. Features such as basin size, level of development, and basin slope may be useful as additional predictive variables for streamflow. It is unlikely that precipitation or temperature will be highly correlated with streamflow on a daily basis, but these records can also be checked for correlation and included in multivariate regression analysis if statistically valid correlation can be demonstrated.

5.4.4 Hindcasting Historical Operations *(For basins with undocumented operations that affect streamflow)*
This method refers to the operational components of UIFs, as opposed to the hydrologic components discussed above. Generally, the operational gaps are filled FIRST in order to calculate UIFs for the period of record corresponding to each individual gage. The project team has contacted water users throughout the Edisto basin to augment historical information on operating practices (withdrawals, discharges, impoundment management, etc.) that may not be recorded in databases extending back as far as the USGS gage records. Based on information collected, historical undocumented operations can be estimated using start dates, trend analysis for hindcasting, relationships to population, etc. These synthetic operating records can then be used in UIF calculation.

5.5 Unimpaired Flow Calculations

Once data gaps are filled, UIFs can be developed by removing the impacts of changes in volume. This includes withdrawals and/or discharges from water users along a river reach. Discharges and withdrawals come from one or more of the water users and dischargers listed in **Section 3**.

Using unregulated flow as a variable, UIFs in the Edisto basin will be computed using the following general equation:

UIF = Measured Gage Flow + River Withdrawals - River Discharges - Irrigation Return Flow – Septic/Other Return Flow

(**Equation 3)**

UIFs will be developed for every stream gage and every major tributary and/or tributary that has managed flows. These particular tributaries will be modeled explicitly. If gage data is not available for such tributaries, synthetic UIFs will be developed to represent these reaches. Smaller tributaries without a gage and without managed flows will be modeled implicitly and do not require development of synthetic UIFs.

Rather than compute UIFs for individual additive reaches from upstream to downstream (a process by which error can accumulate), CDM Smith will compute UIFs for the entire upstream area of each gage, and subtract upstream UIFs to determine incremental UIFs between gages. This avoids accumulation or error or uncertainty by adding calculated UIFs together into a network.

A subsequent report will be issued with the completed UIF datasets to help explain how they were computed, and what assumptions were made. This report will include:

- Data sources
- Specific gap filling measures and where they were applied (and why)
- Examples of each step in the process of computing different types of UIFs, including direct computations from data, operational gap filling, and hydrologic record extension/filling techniques.

6.0 Issues Specific to the Edisto Basin

6.1 Groundwater

Registered and permitted (both active and inactive) groundwater withdrawal locations are shown in **Figure 6-1**. Between 2002 and 2013, total reported groundwater withdrawals for municipal, industrial, mining, golf course, and agricultural purposes in the Edisto basin averaged between 33 and 53 mgd.

Groundwater withdrawals may lower streamflow to a point that they potentially influence UIF estimates in a significant manner if the following conditions are met:

- The withdrawal occurs in an aquifer that contributes baseflow to a stream via direct groundwater discharge.
- The withdrawals are greater than 100,000 gpd.
- A significant portion of the withdrawal is not returned to the stream as a wastewater discharge or to the surficial aquifer via onsite wastewater treatment systems (septic tanks). For example, groundwater withdrawals for irrigation of golf courses or agriculture are expected to be mostly lost to evapotranspiration. Very little is returned to the stream via direct or indirect runoff.

In much of the Edisto basin, registered groundwater withdrawals will likely not meet these conditions, and can therefore be ignored when calculating UIFs; however, larger groundwater withdrawal will be reviewed for consideration.

The combined net amount of groundwater withdrawals from private wells (individual wells not permitted or registered) that is not returned to the surficial aquifer system via onsite wastewater systems is not expected to significantly lower stream baseflow in any area of the basin, such that consideration of these withdrawals is necessary in calculating UIFs.

6.2 Agriculture

Registered agriculture surface withdrawal locations in the Edisto basin were shown in **Figure 3-2. The Edisto basin has the largest number of registered agricultural withdraws of any basin in the state.** Of the 31 registered agricultural surface water users, all six had reported water withdrawals greater than 3 mg/m in any one month over the last 5 years (2009-2013).

Withdrawals for agricultural irrigation are currently assumed to be 100 consumptive. For the UIF calculations, no return flows are assumed.

6.3 Losses of River Flow to Groundwater

Certain reaches of the Edisto River may exhibit hydrologic losses to groundwater as water flows downstream. In such cases, these losses can be included in the SWAM model either as a LOSS function for a particular reach, or as a time history of losses (difference between upstream and downstream UIFs) represented as a withdrawal by a non-user, with no return flow.

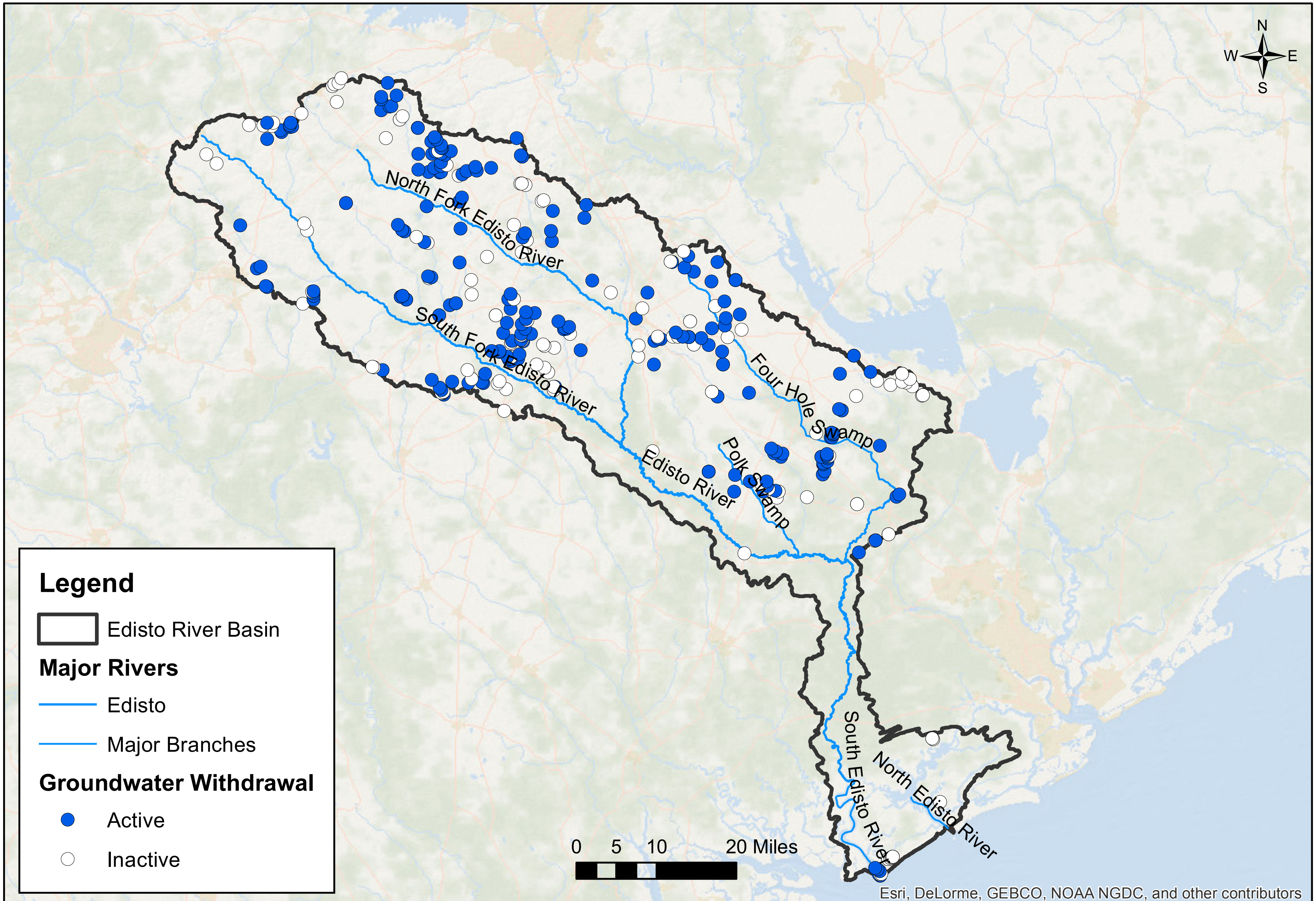
7.0 Validation of UIFs

Independent checks on final calculated unimpaired flows will occur as part of the surface water model calibration and validation task. Basin-specific surface water allocation models constructed using SWAM will include all the same major withdrawals, return flows, storage reservoirs, and tributaries used to calculate the UIFs described above. In contrast to the UIF calculations, however, SWAM will include spatially continuous flow balance calculations that originate with UIF inputs upstream and incorporate the impacts of reach gains/losses and management activity, rather than calculations for specific downstream nodes.

Flow regimes are constructed in the model from the top of a simulated reach to the bottom based on headwater flows, tributary inputs, and calibrated reach gains or losses. Unimpaired flows are used directly in the models in upstream headwater locations, or areas that are not affected by upstream management activity. However, as the stream network develops and management activity is simulated, UIFs at downstream nodes are *not* used directly as inputs to the models, but will be available for comparative purposes to managed flows. Downstream gaged flows, which include existing development and flow impairment, will be used as calibration targets in the modeling.

Reach gains or losses and ungaged tributary flows will serve as the primary calibration parameters. Following calibration, UIFs at downstream nodes can be easily extracted from SWAM by "turning off" upstream water uses and storage and simulating historical periods. The resulting modeled downstream flows essentially represent simulated unimpaired flows for the given historical period. These downstream flows, calculated by removing upstream water users and storage in the model, can be used to confirm and validate the previously calculated UIFs – That is, we will check the comparability between a UIF at a downstream node (calculated per the procedures outlined in previous sections) and the simulated Unimpaired Flow at that location by removing the management objects from the calibrated model. When upstream management activity is removed from the model, the resulting flow at a given node *should* match the calculated UIF for that node. The model and downstream UIF calculations, therefore, can corroborate each other.

It is likely that the SWAM calibration period will not extend as far as the UIF calculation period. The SWAM models will be calibrated using only periods well supported by data and where there is high confidence in the model input data. These periods may or may not exactly coincide with the full UIF calculation periods. Model development (programming and data entry) and calibration are two separate tasks, and it is not possible to predetermine the model calibration periods until all available data has been collected and reviewed. However, once calibrated, “baseline” historical models will be constructed with simulation periods that match the UIF periods.



CDM Smith

Figure 6-1
Active and Inactive Groundwater Withdrawal Locations

ATTACHMENT A

Telephone Questionnaires for Water Users
To Supplement Information on Historical Flow Management

Script for <u>Water Supply (WS)</u> Water User

Contact the water user, following the suggested script below.

Hello, my name is __________ with CDM Smith. As you may be aware, South Carolina DNR and DHEC have begun a two-year project to conduct surface water availability assessment modeling for each of the State's eight major river basins. CDM Smith has partnered with DNR and DHEC to assist with this process.

One of our first responsibilities is to characterize the natural hydrologic conditions in each basin, and we'll do this by blending historic streamflow measurements with historic records of water usage. I'm calling you today to solicit your help in confirming our understanding of the history of your water source(s) and operation, and to collect additional data that may be useful to characterize and quantify your utility's historical water use. You may have recently received a letter from DHEC indicating that we would be contacting you. This should only take about 5 to 10 minutes of your time.

You will hear more about the project in the coming months. DNR is in the process of procuring a facilitator to help engage stakeholders in each basin. The facilitator will be organizing meetings to provide additional information regarding the water quantity modeling and subsequent phases of the state water planning effort.

Do you mind if I ask you a few questions about your utilities water withdrawals, both current and historical, or is there someone else that I should speak with?

As I mentioned, one of the first steps in the process is the development of naturalized flows, which are basically estimates of past river flows without any man-made influences such as withdrawals discharges, and dams. These are based in-part on historical records of withdrawal and discharges.

You have provided DHEC with monthly withdrawal data dating from _________ to _____________.

- *Did your utility withdraw surface water prior to ________?*
- **[if Yes]** *Do you have data quantifying the withdrawal amounts prior to ___________, or if not, can you provide estimated average monthly or annual water use prior to ___________?*
- *Has your water source(s) ever changed?*
- *Have multiple sources ever been used?*
- **[Only if multiple sources are used]** *What are your priorities/rules for withdrawing water if multiple sources are used?*

- *Do you have offline storage reservoirs (*not tanks*)? If yes, is storage/area/elevation data available?*

- *Do you have interconnections with other systems?*

- *Do you purchase water from or sell water to other utilities? Have you historically purchased or sold water (but no longer do so)?*

- **[Only if they do not have a Drought Contingency Plan]** *Have you prepared a Drought Contingency Plan and have you used it?*

- **[If they have a Drought Contingency Plan]** *Have you had to use your Drought Contingency Plan in the past?*

- **[If they have an NPDES permit]** *We have your reported NPDES discharge amounts for your utility dating from _________ to _________. Do you have any records of discharge prior to __________?* **[May not need to ask this depending on the situation. Also, we may need to contact some on the wastewater side of their utility, instead].**

- **[For some utilities which also operate WWTPs, their wastewater is stored in holding ponds when the stream's flow and assimilative capacity are low. Water may be withdrawn from the stream but not returned as wastewater while instream flow remains low. This is a "controlled discharge". Ask them the following question:]** *Does your WWTP ever use controlled discharges?*

- **[Only if they have an interbasin transfer permit]** *Can you describe your interbasin transfer* (e.g. is it a constant transfer, or used only in emergency such as through an interconnection to another utility?*) Do you have records quantifying your historical interbasin transfers?*

Thank you very much for your time. To follow-up, I am going to e-mail to you a memorandum documenting my understanding of the information we have discussed today and listing any additional data needs. If you could review the letter, provide corrections or clarifications, and include any additional withdrawal or other data we discussed within the next 30 days, I would appreciate it. I can be reached by phone at ________________ or e-mail at _________________________.

I have your e-mail address as ____________________________. **[Or if we don't have their e-mail address, ask for it]**

Thanks again for your time.

Script for <u>Golf Course (GC)</u> Water User

Contact the water user, following the suggested script below.

Hello, my name is __________ with CDM Smith. As you may be aware, South Carolina DNR and DHEC have begun a two-year project to conduct surface water availability assessment modeling for each of the State's eight major river basins. CDM Smith has partnered with DNR and DHEC to assist with this process.

One of our first responsibilities is to characterize the natural hydrologic conditions in each basin, and we'll do this by blending historic streamflow measurements with historic records of water usage. I'm calling you today to solicit your help in confirming our understanding of the history of your water source(s) and operation, and to collect additional data that may be useful to characterize and quantify your utility's historical water use. You may have recently received a letter from DHEC indicating that we would be contacting you. This should only take about 5 to 10 minutes of your time.

You will hear more about the project in the coming months. DNR is in the process of procuring a facilitator to help engage stakeholders in each basin. The facilitator will be organizing meetings to provide additional information regarding the water quantity modeling and subsequent phases of the state water planning effort.

Do you mind if I ask you a few questions about your water withdrawals, both current and historical, or is there someone else that I should speak with?

As I mentioned, one of the first steps in the process is the development of naturalized flows, which are basically estimates of past river flows without any man-made influences such as withdrawals discharges, and dams. These are based in-part on historical records of withdrawal and discharges.

You have provided DHEC with monthly withdrawal data dating from _________ to ____________.

- *Did your golf course withdraw <u>surface water</u> prior to ________?*
- **[if Yes]** *Do you have data quantifying the withdrawal amounts prior to ___________, or if not, can you provide estimated average monthly water use prior to ___________?* **[Many golf courses may only irrigate April-October]**
- *Has your water source(s) ever changed?* **[Make sure you develop an understanding of groundwater use vs. surface water use, if both have been used. Often, they may pump groundwater to a pond, then withdraw from the pond to irrigate – which is not considered surface water use.**
- *Have multiple surface water sources ever been used?* **[Not likely]**

Thank you very much for your time. To follow-up, I am going to e-mail to you a memorandum documenting my understanding of the information we have discussed today and listing any additional data needs. If you could review the letter, provide corrections or clarifications, and *include any additional withdrawal or other data we discussed within the next 30 days, I would appreciate it. I can be reached by phone at ________________ or e-mail at ________________________.*

I have your e-mail address as ____________________________. **[Or if we don't have their e-mail address, ask for it]**

Thanks again for your time.

Script for <u>Industrial (IN)</u> and <u>Mining (MI)</u> Water User

Contact the water user, following the suggested script below.

Hello, my name is __________ with CDM Smith. As you may be aware, South Carolina DNR and DHEC have begun a two-year project to conduct surface water availability assessment modeling for each of the State's eight major river basins. CDM Smith has partnered with DNR and DHEC to assist with this process.

One of our first responsibilities is to characterize the natural hydrologic conditions in each basin, and we'll do this by blending historic streamflow measurements with historic records of water usage. I'm calling you today to solicit your help in confirming our understanding of the history of your water source(s) and operation, and to collect additional data that may be useful to characterize and quantify your utility's historical water use. You may have recently received a letter from DHEC indicating that we would be contacting you. This should only take about 5 to 10 minutes of your time.

You will hear more about the project in the coming months. DNR is in the process of procuring a facilitator to help engage stakeholders in each basin. The facilitator will be organizing meetings to provide additional information regarding the water quantity modeling and subsequent phases of the state water planning effort.

Do you mind if I ask you a few questions about your utilities water withdrawals, both current and historical, or is there someone else that I should speak with?

As I mentioned, one of the first steps in the process is the development of naturalized flows, which are basically estimates of past river flows without any man-made influences such as withdrawals discharges, and dams. These are based in-part on historical records of withdrawal and discharges.

You have provided DHEC with monthly withdrawal data dating from _________ to _____________.

- *Did your plant withdraw surface water prior to ________?*
- **[if Yes]** *Do you have data quantifying the withdrawal amounts prior to ___________, or if not, can you provide estimated average monthly or annual water use prior to ___________?*
- *Has your water source(s) ever changed?*
- *Have multiple sources ever been used?*
- *Do you have offline storage reservoirs (*not tanks*)? If yes, is storage/area/elevation data available?*
- *Do you have interconnections with other systems?*

- *Do you also purchase water from a nearby utility? Have you historically purchased or water (but no longer do so)?*

- **[If they have an NPDES permit]** *We have your reported NPDES discharge amounts for your utility dating from _________ to __________. Do you have any records of discharge prior to ___________?* **[May not need to ask this depending on the situation.]**

- **[Only if they have an interbasin transfer permit]** *Can you describe your interbasin transfer* (e.g. is it a constant transfer, or used only in emergency such as through an interconnection a utility?*) Do you have records quantifying your historical interbasin transfers?*

Thank you very much for your time. To follow-up, I am going to e-mail to you a memorandum documenting my understanding of the information we have discussed today and listing any additional data needs. If you could review the letter, provide corrections or clarifications, and include any additional withdrawal or other data we discussed within the next 30 days, I would appreciate it. I can be reached by phone at _________________ or e-mail at _________________________.

I have your e-mail address as ______________________________. **[Or if we don't have their e-mail address, ask for it]**

Thanks again for your time.

Script for Power/Thermal (PT) and Nuclear (PN) Water User

Hello, my name is __________ with CDM Smith. As you may be aware, South Carolina DNR and DHEC have begun a two-year project to conduct surface water availability assessment modeling for each of the State's eight major river basins. CDM Smith has partnered with DNR and DHEC to assist with this process.

One of our first responsibilities is to characterize the natural hydrologic conditions in each basin, and we'll do this by blending historic streamflow measurements with historic records of water usage. I'm calling you today to solicit your help in confirming our understanding of the history of your water source(s) and operation, and to collect additional data that may be useful to characterize and quantify your utility's historical water use. You may have recently received a letter from DHEC indicating that we would be contacting you. This should only take about 5 to 10 minutes of your time.

You will hear more about the project in the coming months. DNR is in the process of procuring a facilitator to help engage stakeholders in each basin. The facilitator will be organizing meetings to provide additional information regarding the water quantity modeling and subsequent phases of the state water planning effort. Do you mind if I ask you a few questions about your facilities water withdrawals, both current and historical, or is there someone else that I should speak with?

As I mentioned, one of the first steps in the process is the development of naturalized flows, which are basically estimates of past river flows without any man-made influences such as withdrawals discharges, and dams. These are based in-part on historical records of withdrawal and discharges.

You have provided DHEC with monthly withdrawal data dating from _________ to _____________.

- *Did your facility withdraw surface water prior to ________?*
- **[if Yes]** *Do you have data quantifying the withdrawal amounts prior to ____________, or if not, can you provide estimated average monthly or annual water use prior to ___________?*
- *We have your reported NPDES discharge amounts for your utility dating from _________ to __________. Do you have any records of discharge prior to ___________?*

Thank you very much for your time. To follow-up, I am going to e-mail to you a memorandum documenting my understanding of the information we have discussed today and listing any additional data needs. If you could review the letter, provide corrections or clarifications, and include any additional withdrawal or other data we discussed within the next 30 days, I would appreciate it. I can be reached by phone at _________________ or e-mail at _________________________.

I have your e-mail address as _____________________________. **[Or if we don't have their e-mail address, ask for it]**

Thanks again for your time.

ATTACHMENT B

Guidelines for Standardizing and Simplifying Operational Record Extension

(CDM Smith, March 2015)

Guidelines for Standardizing and Simplifying Operational Record Extension

South Carolina Surface Water Quantity Models – Unimpaired Flow Development

CDM Smith, March 2015

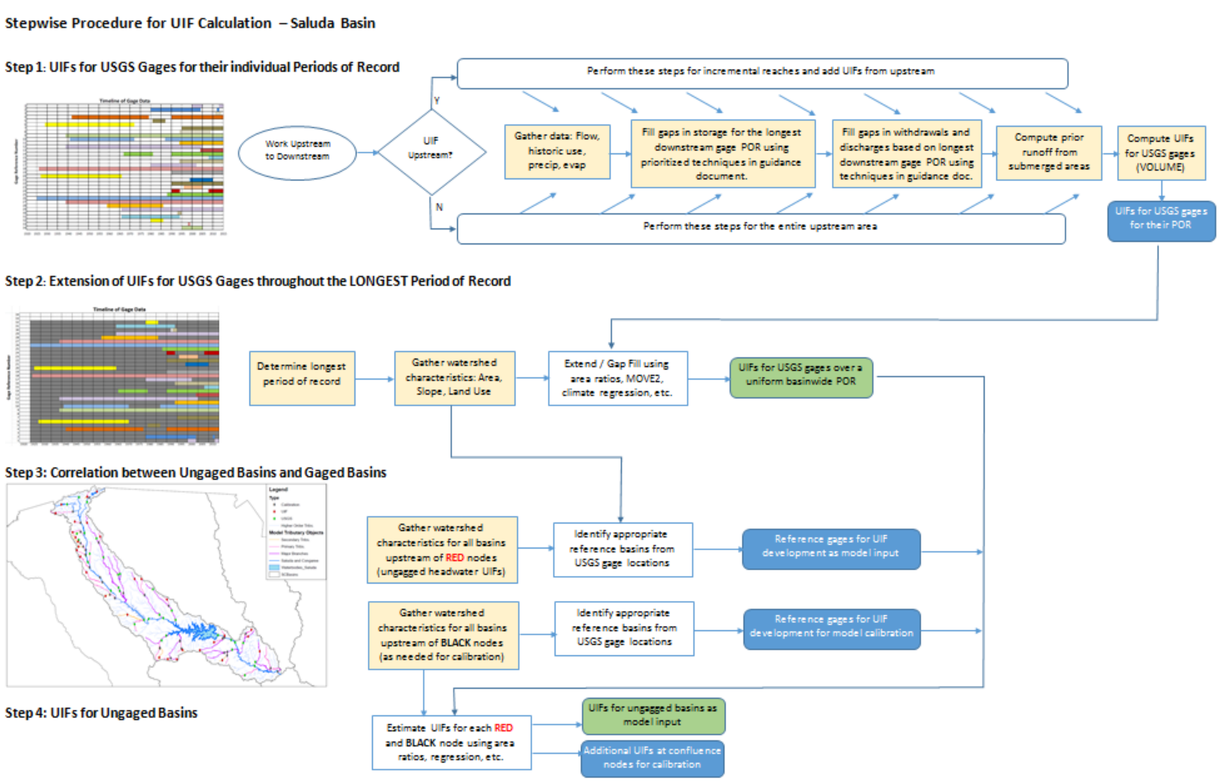
Objective:

This set of guidelines is intended to help simplify and standardize the process of extending and filling gaps in operational records of water **withdrawals, discharges,** and **storage impacts** as part of the process of developing Unimpaired Flows (UIFs) for the South Carolina water quantity models. It is based on the following principles of large-scale water planning:

a) De-emphasize the nuances of specific undocumented local issues (such as matching population trends with service area changes, etc.) and generalize water use trends regionally, and

b) Provide a consistent framework for filling data gaps and extending records

Summary text appears in blue. Note that the recommendations in this document apply only to the synthetic extension of operational records, and not to the extension of the UIFs themselves (the alternative procedures for which are described in the UIF Methodology TM). That is, the guidelines in this document apply to the gap-filling boxes in Step 1 of the overall UIF process below:



While the ultimate UIF data sets in any given basin are required to extend all the way back to the earliest USGS record in the basin, IT IS ONLY NECESSARY TO SYNTHESIZE OPERATIONAL DATA FOR EACH SPECIFIC USE BACK TO THE DATE OF THE EARLIEST **DOWNSTREAM** USGS GAGE RECORD, either on the tributary of use, or downstream on the mainstem. This is because the downstream gages will be the basis for UIFs using upstream impairments, but once each UIF is developed for the period of gaged record at each gage, the UIFs themselves will be statistically extended using other techniques that do not rely on historic use (Step 2 in the diagram above). In other words, if there are no streamflow records for which a given use would be used in unimpairment calculations, we do not need the use record.

> **GENERAL SIMPLIFICATION:** Only extend use data back to the date of the earliest downstream USGS flow record within the basin that would use the data in unimpairment calculations over its period of record.

Specific Guidelines for Water Withdrawals

Water withdrawals may need to be disaggregated into annual and then monthly values (monthly values would be spread evenly across the days in the month). To estimate undocumented water withdrawals on an **ANNUAL** basis (as an example, consider a documented withdrawal from 1990-2013, which requires extension back to 1950):

- **First Priority - Anecdotal Information:** If anectodal information about dates and volumes is available via direct communication from water users, this should be used and interpolated/extrapolated to the greatest extent possible. In the example above, if the water user informs us that the intake came on line in 1962 and started at 2mgd, linearly interpolate usage from 2 mgd in 1962 to the documented value in 1990. *Note: Do not synthesize water use prior to any known date of initiation (in this example, 1962).*

- **Second Priority – Regional Population Trends:** In the example above, if there is a correlation between population and withdrawals from 1990-2013, this correlation can be applied going back in time. Note that the correlation could be as simple as a per capita use rate. DO NOT attempt to fully reconcile local population, county population, and service area, as the relationship between all of these will change over time and would consume too much time to document in every case. Rather, use judgment on whether local, county, or service area estimates (based on availability of data and applicability to the case at hand) will serve as a reasonable indicator of trends in the service area. Note that correlation relationships should be simple – linear if possible, unless there are obvious nonlinearities in the observed trends. In no case should we use anything more than a second order polynomial (because these can exaggerate conditions at the ends of the time spectrum, and sometimes reverse directions inappropriately).

- **Short-Term Gap Filling**: For short-duration periods of missing information between documented periods (up to ~5 years), values may be linearly interpolated between dates of available data. Refer also to the guidelines for monthly estimation below.

To superimpose **SEASONAL OR MONTHLY** withdrawal patterns on these annual averages, compute average monthly multipliers for the documented period of record, and apply these for the period of record extension. Ensure that they average 100%. Do not adjust for the variability in the number of days per month.

Specific Guidelines for Water Discharges

To estimate undocumented discharges, first determine if there is a repeatable monthly pattern of discharge. If not, hindcast using annual values using the guidelines below and apply the discharge as a constant rate throughout the year per below. If there is an observable monthly pattern, refer to the monthly guidelines below the annual guidelines, and choose an option based on the data.

FOR ANNUAL AVERAGE DISCHARGE VALUES:

- **First Priority – Anecdotal Information:** If anectodal information about dates and volumes is available via direct communication from water users, this should be used and interpolated/extrapolated to the greatest extent possible.

- **Second Priority – Correlation with Withdrawal**: If documented discharges can be correlated with documented withdrawals, the correlation can be extended back in time. This actually matches the SWAM model construct, in which discharges are usually specified in terms of corresponding withdrawal percentages.

- **Third Priority – Permit Estimates**: In some cases, discharge permits estimate the discharge volume as a percentage of withdrawal. In such cases, this can be a simple approximation of the historical discharge volumes.

- **Fourth Priority – Regional Population Trends**: If there is a correlation between population and withdrawals during the documented period, this correlation can be applied going back in time. DO NOT attempt to reconcile local population, county population, and service area, as the relationship between all of these will change over time and would consume too much time to trace and document in every case. Rather, assume that either local or county level population (based on availability of data and applicability to the case at hand) will serve as a reasonable indicator of trends in the service area (especially if good correlation exists for the period of documented discharge). Note that correlation relationships should be simple – linear if possible, unless there are obvious nonlinearities in the observed trends. In no case should we use anything more than a second order polynomial (because these can exaggerate conditions at the ends of the time spectrum, and sometimes reverse directions inappropriately).

- **Short-Term Gap Filling**: For short-duration periods of missing information between documented periods (up to ~5 years), values may be linearly interpolated between dates of available data. Refer also to the guidelines for monthly estimation below.

If there is an observable monthly pattern to withdrawals, then use the following guidelines and choose the approach that best matches the situation or available data:

FOR MONTHLY DISCHARGE VALUES (if observed patterns exist):

- **Option 1 – Correlate with Monthly Withdrawal**: If monthly discharge can be well correlated to monthly withdrawal, then it may not be necessary to estimate annual discharge. Rather, develop ratios between observed monthly withdrawal and observed monthly discharge for a period over which records overlap. The ratios would most likely be average values for each month, provided there is not too much scatter. Then apply these ratios to the full (possibly extended) record of withdrawals. Note: Do not use synthesized withdrawal data to establish the ratios – use only documented values. However, it is acceptable to use synthesized withdrawals as the basis for extending the discharge by applying the ratios from the documented values.

- **Option 2** – **Apply observed trends to annual discharge estimates**: If the periods of observed withdrawals and observed discharges do not overlap, or there is poor correlation between withdrawal and discharge, then annual average values will need to be determined per the above procedures, and monthly multipliers applied. Determine average monthly multipliers of discharge, using documented (not extended) annual average as a basis. Ensure that the multipliers average 100%. Then, apply these multipliers to annual average discharge estimates from the procedures above.

FOR INDUSTRIAL DISCHARGES:

For industrial discharges with no withdrawal (groundwater use, for example), simply extrapolate observed data back to the known or estimated date at which operations commenced. This would apply on an annual and/or monthly basis, as deemed appropriate based on the available data.

Specific Guidelines for Storage Impacts

There will be cases in which we need to synthesize the impacts of reservoirs in the absence of documented fluctuations in storage and/or elevation. The presence of reservoirs affects both the timing of flow and the volume of water in the river system. The following guidelines may be applied:

- **Surface Evaporation (volume impact):** Assume full reservoir area for computing surface evaporation in the absence of records of reservoir fluctuations.

- **Surface Precipitation (volume impact):** Assume full reservoir area for computing surface precipitation in the absence of records of reservoir fluctuations.

- **Change in Storage (timing impact)**: Knowing the historic fluctuation in storage is useful because by impounding water, drawing down, and recovering, the timing of when water is released can be affected. Impoundment does not, however, affect the total volume of water in the system, only the distribution of that water as flow over time. To estimate historical water level fluctuations accurately, a calibrated hydrologic and operations model would be needed. This is not always practical, so several alternatives are offered for hind-casting historical reservoir elevation/storage:

    - **First Priority – Published Estimates from Other Modeling Studies**: Many of the basins in South Carolina have been simulated with reservoir operations models (CHEOPS, for example, or HEC-ResSim). As available (without re-running the models), published values from these models can be used to help extend or fill reservoir records.

- **Second Priority – Extrapolation and Correlation with Precipitation**: There are three proposed approaches that can be applied in various conditions. The decision of which method to use should account for the availability and credibility of data, as well as the overall dynamics of the reservoir, per the guidelines below. The 2nd and 3rd methods are described in more detail on the pages that follow, but summarized here. Note that in many cases, it may simply be best to see which of these methods reproduces observed data the best, and rely upon that method purely on its predictive basis. It should be emphasized, though, that hindcasting reservoir storage *does not* account for detailed operational practices, but rather the observed patterns of drawdown, and the apparent dependence the drawdown may have on prior rainfall levels. The graphs that follow the detailed descriptions of the two regression methods illustrate how the two methods may be appropriate for different types of reservoir response patterns. Additionally, following the graphs, a procedure is outlined for adjusting the hindcast timeseries for the potential impacts of variable historical withdrawal rates (if such data are available).

    a) **METHOD 1: Simplest: Monthly Averages*: [To be used only if there is a clear and consistent pattern of drawdown and refill that does not vary significantly from year-to-year].*** Monthly average elevation/storage can be computed for the period of documented record, and these can be applied as estimated hindcasts. Daily values can be interpolated between monthly values. It should be noted with our UIF records that if this method is employed for reservoirs with a great deal of year-to-year variability in water levels, that this is a very approximate technique.

    b) **METHOD 2: Next Simplest: (REGRESSION METHOD A) Correlation Between Daily Elevation and Cumulative Historic Precipitation**: ***[To be used if the reservoir is frequently full, but exhibits irregular drawdown during droughts] – SEE FULL PROCEDURAL DESCRIPTION BELOW FOR REGRESSION METHOD A.***

    c) **METHOD 3: More Complex: (REGRESSION METHOD B) Scaling the Monthly/Daily Averages from (a) above to expected min annual elevation based on historic precip**: ***[To be used if the reservoir experiences significant multi-year or irregular drawdowns during droughts, and is not frequently observed to be full.] - SEE FULL PROCEDURAL DESCRIPTION BELOW FOR REGRESSION METHOD B.***

- **Third Priority – Iteration:** If either of the two methods above are employed for the UIFs, they can be validated or refined once the SWAM models are constructed. This would be a time-consuming process, likely involving iteration between UIFs and model runs, so it should be employed with discretion, and only if truly needed for reservoirs that have pronounced impacts in a basin or a great deal of uncertainty in the hind-casting.

Full Procedure – METHOD 2 - REGRESSION METHOD A:
Hindcasting Reservoir Elevation Using Daily Precipitation Sums
Note: Example spreadsheets are available to assist as reference or templates for this procedure.

This method for developing a historical time series of elevation data for a specific reservoir uses available observed reservoir elevations and daily precipitation records. The precipitation records must cover the entire period of hindcasting and/or gap filling, as they will serve as the independent variable in a regression model. The observed reservoir elevations are needed to develop the regression model, and should cover a multi-year period. The observed reservoir elevations do not need to be continuous, but they must cover an overlapping period with available precipitation data. This procedure may be modified if only average monthly reservoir elevations are available, but will then only be able to hindcast average monthly elevations (or weekly, etc.). The following procedure assumes that daily precipitation data are available for the full hindcast period, and that there is a sufficient multi-year overlap between observed daily reservoir elevations and daily precipitation data.

Step 1: Compile daily observed data. The suggested format for the daily observed data is a continuous time series of dates that span from the 3 years before the earliest reservoir elevation observation to the latest daily reservoir elevation observation, with column headings: Date, Observed Elevation, Daily Precipitation. For example, if the reservoir elevations start on 1/1/2000 and end on 12/31/2010, the time series should span 1/1/1998 to 12/31/2010, and the first 2 years of reservoir observations will be blank.

Step 2: Check linear correlation between preceding daily precipitation sums and reservoir elevation. This step involves calculating the sum of precipitation for the previous X number of days, for each day in the observed data time series. The resulting time series of X-days previous precipitation sum should then be checked for correlation with the reservoir elevation using the RSQ()[1] function in Excel (or similar function to find the linear R-squared correlation in another software). If the table includes precipitation data for 3 years prior to the first reservoir observation, the precipitation sums can go up to the preceding 1,095 days (3 years). The process of computing the preceding X-day precipitation sum and linear correlation value may need to be repeated multiple times to find the best fit precipitation time series. The suggested procedure is to start with the 30-day sum and repeat in 30-day increments until a maximum linear R-squared value is found. For example, the table described in Step 1 is expanded to include the time series of preceding 30-day precipitation total, preceding 60-day precipitation total, preceding 90-day precipitation total, and so on.

Step 3: Use the best-correlated precipitation sums to develop regression equation. The ideal R-squared value is 1.0. If the best linear correlation of all incremental 30-day precipitation sums going back 3 years is not greater than 0.5, this may not be the best method to use to hindcast reservoir elevations. Once the best-linear-fit precipitation sums time series is established, additional regression functions should be explored that relate precipitation sums to reservoir elevation. For example, a logarithmic regression relationship between the 240-day precipitation and observed reservoir elevation may provide a slightly higher R-squared value than the linear regression. Generally, the function types should be limited to linear, logarithmic, exponential, and power. The final hindcast model formula, which uses the X-day preceding precipitation sum to estimate the reservoir elevation, will take the following form:

Elev = min(Max, F(Psum))
Psum: Sum of daily precipitation totals for the X-day period discovered in Step 2
Max: Maximum possible reservoir elevation
Elev: Calculated reservoir elevation
F(Psum): Regression function that produces highest R-squared correlation between Psum and Elev
An example of this model function is:
Elev = min(1230, 32*LN(Psum)+1078)

---

[1] If the precipitation sum time series is in column A, and the reservoir elevation time series is column B, the format for this formula is: RSQ(column B, column A); or more generally: RSQ(known Ys, known Xs)

Where:
Max = 1230, and
F(Psum) = 32*LN(Psum)+1078

Step 4: Check the agreement between observed and modeled reservoir elevations. This step is qualitative. Does the model capture the times when the reservoir is full? Does the model adequately reproduce significant drawdowns? Is the model biased high or low throughout the overlap time period? This step will determine if this method is appropriate for hindcasting elevations for this reservoir. For example, if significant annual drawdowns are not represented by the modeled elevations, another method for hindcasting should be explored.

Step 5: Hindcast the reservoir elevations using the regression model and historic precipitation data. The final step is to calculate estimated reservoir elevation for each day in the full hindcast time series for which there are no observations. This will be done using the X-day precipitation sum time series for the full period, and the model equation developed in Step 3. The suggested format for this step is a daily time series table covering the full hindcast period (e.g. 1/1/1925 to 12/31/2013) with the following columns: Date, Observed Precipitation, X-day precipitation sum, Observed Elevation, Modeled Elevation. The Observed Elevation rows will be blank for days with no reservoir observations. The modeled Elevation rows will be blank for days with reservoir observations. The combination of these time series will be used for the unimpaired flow development.

Full Procedure – METHOD 3 - REGRESSION METHOD B:
Scaling Monthly/Daily Average Elevation to Expected Minimum Annual Elevation Based on Historic Precipitation
Note: Example spreadsheets are available to assist as reference or templates for this procedure. See "Reservoir Hindcasting – Method 2 Example.xlsx"

Like Method 2 above, this method for synthesizing a historical time series of elevation data for a specific reservoir uses available observed daily or monthly reservoir elevations and annual precipitation records. The precipitation records must cover the entire period of hindcasting and/or gap filling, as they will serve as the independent variable in a regression model. The observed reservoir elevations are needed to develop the regression model, and should cover a multi-year period. The observed reservoir elevations do not need to be continuous, but they must cover an overlapping period with available precipitation data. At a minimum, the data should cover a significant drawdown and full recovery of the reservoir to a full condition. This procedure may be applied with either daily or monthly reservoir elevation data, and any form of precipitation data that can be aggregated into annual totals. The following procedure assumes that there is a sufficient multi-year overlap between observed reservoir elevations and precipitation data.

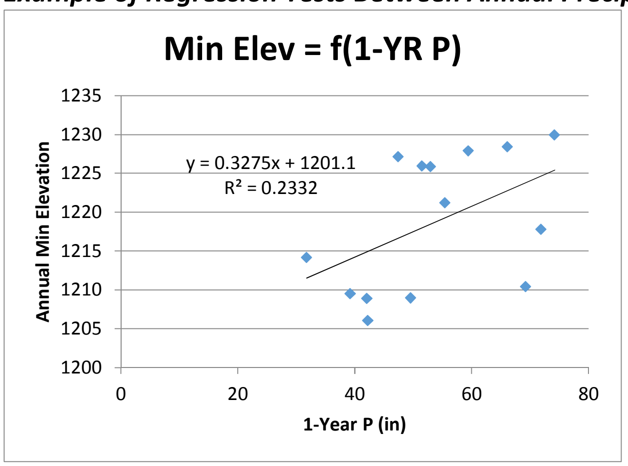
Step 1 - Collect Data: Gather all available information on precipitation and reservoir elevation. Precipitation may be daily, monthly, or annual. Reservoir elevation may be daily or monthly.

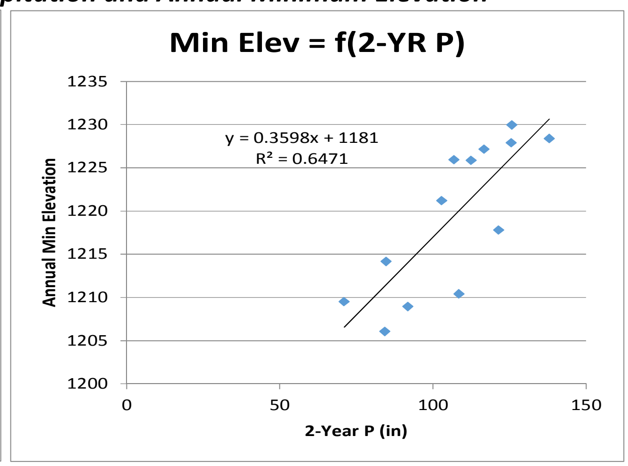
Step 2 - Compute Daily Average Elevation: Over the reservoir period of record, compute a *one-year timeseries* of daily average elevation for each day of the year. For example, the elevation for January 1 would be the average values of all records from January 1 in the period of record. If reservoir elevation is reported monthly, interpolate linearly to approximate daily values. (This is the same as Method 1, above, but it will serve as an interim step in Method 3, here).

Step 3 – Annualize Data from Step 1: Using pivot tables or other means, summarize the recorded data from Step 1 in the form of **Total** Annual Precipitation (summation) and **Minimum** Annual Elevation. For each year in the reservoir's period of record, then, there will be a value of annual precipitation that can be correlated in the next step with the minimum elevation (maximum drawdown) for that year.

Step 4 – Regression Relationship Between Annual Precipitation and Annual Minimum Elevation: Develop a relationship (preferably linear) between Annual Precipitation and Annual Minimum Elevation. In some cases, a relationship may not develop until the past 2 or 3 years of precipitation are added together, so multiple regression tests may be needed to find a good relationship between antecedent rainfall totals and minimum reservoir elevation in a given year. *<u>If a good relationship cannot be clearly developed for the period of record, or if the record does not include a good example of significant drawdown and full recovery, this method may not be appropriate</u>.* The example below shows poor correlation using 1-year total rainfall, but reasonably good correlation using 2-year total rainfall:

Example of Regression Tests Between Annual Precipitation and Annual Minimum Elevation





Step 5 – Extend Minimum Annual Elevation Record: Using the regression relationship from Step 4, extend the annual timeseries of minimum annual elevation over the entire period of record for the basin (defined by the earliest recorded USGS streamflow) using the precipitation statistics as the predictive variable. Also validate the relationship over the period of record for reservoir elevation.

Step 6 – Develop Annual Scaling Factors: For each year in the period for which no reservoir elevation data exist, develop a single annual scaling factor that relates the estimated minimum annual elevation (from Step 5) with the minimum elevation of the Average Year pattern from Step 2. However, before computing these values, convert the minimum elevation into Maximum Drawdown in order to properly scale the relativity of the two values (Full Reservoir Elevation – Minimum Elevation). For example, for a reservoir with a maximum elevation of 1230 feet, if the estimated minimum elevation from Step 5 for year X is 1210 feet, and the minimum elevation of the average year pattern from Step 2 is 1225 feet, the scaling factor would be:

$$Scale\ Factor_{Year\ X} = \frac{Max\ Drawdown_{Year\ X}}{Max\ Drawdown_{Avg\ Year}} \frac{(Full\ Elev - Min\ Elev_{Year\ X})}{(Full\ Elev - Min\ Elev_{Avg\ Year})} = \frac{(1230 - 1210)}{(1230 - 1225)} = \frac{20}{5} = 4$$

The end product of this step will be a timeseries of ANNUAL scaling factors for each year in which no reservoir records exist. It is conceivable that some scale factors could be negative, depending on the regression relationship from Step 4. Consider these carefully, and possibly apply a lower bound of 0 for the scaling factors.

Step 7 – Develop Synthetic Timeseries of Reservoir Drawdown: This is the final step in this procedure, and will result in a DAILY timeseries of estimated reservoir elevation for the entire period of record for the basin.

7a) First, convert the average daily elevations from Step 2 into daily drawdown by subtracting each value from the full reservoir elevation.

7b) Then, copy this annual pattern for every year for which the reservoir record is to be extended or filled.

7c) Next, multiply each value of daily drawdown by the scale factor computed for the corresponding year. *Caution: Do not multiply the actual elevation by the scale factor – rather, multiply the DRAWDOWN (Full Elevation – Daily Elevation) by the scale factor, and then recompute the resulting elevation in 7d.*

7d) Lastly, convert the drawdown values into reservoir elevation values by subtracting them from the full reservoir elevation.

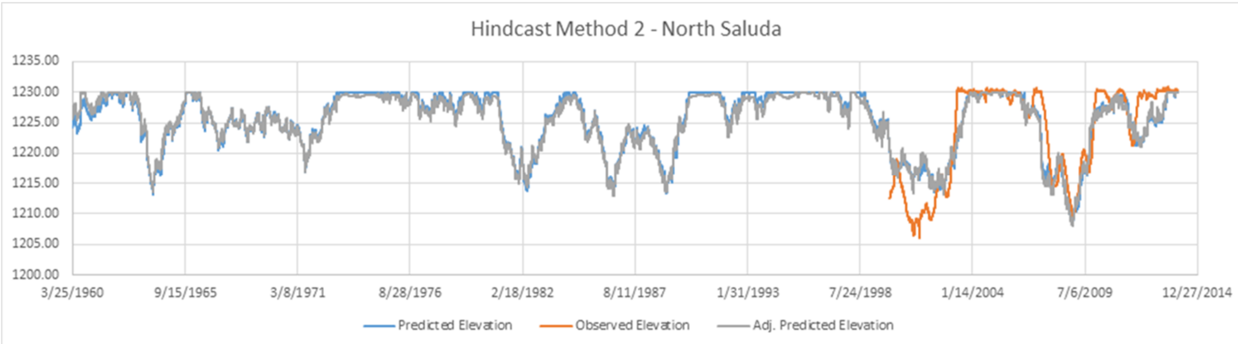
7e) Validate the approach by comparing estimated daily elevation with observed daily or monthly elevation for the period in which the reservoir records exist.

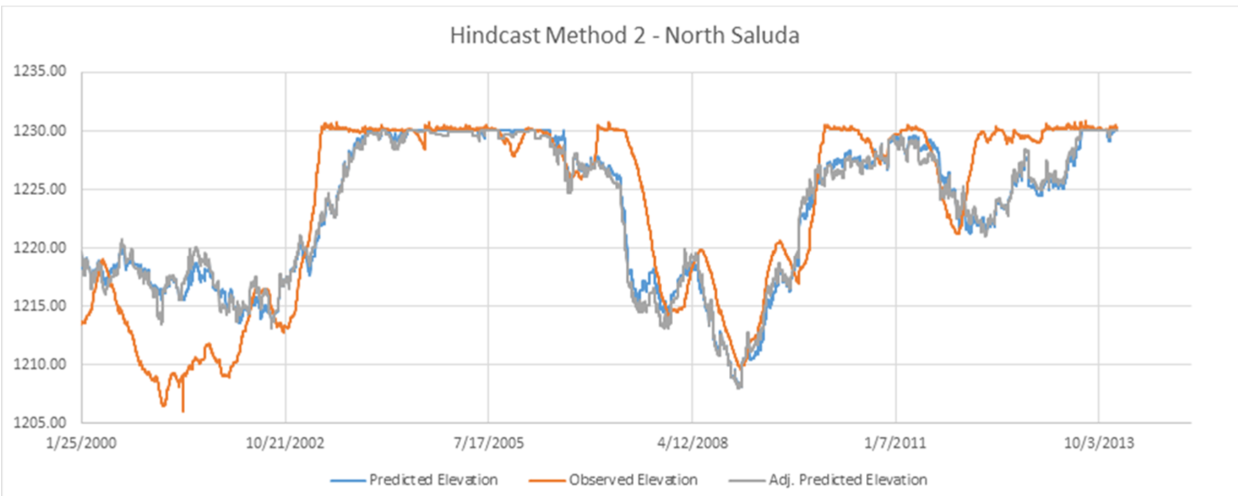
Examples of the Regression Methods:

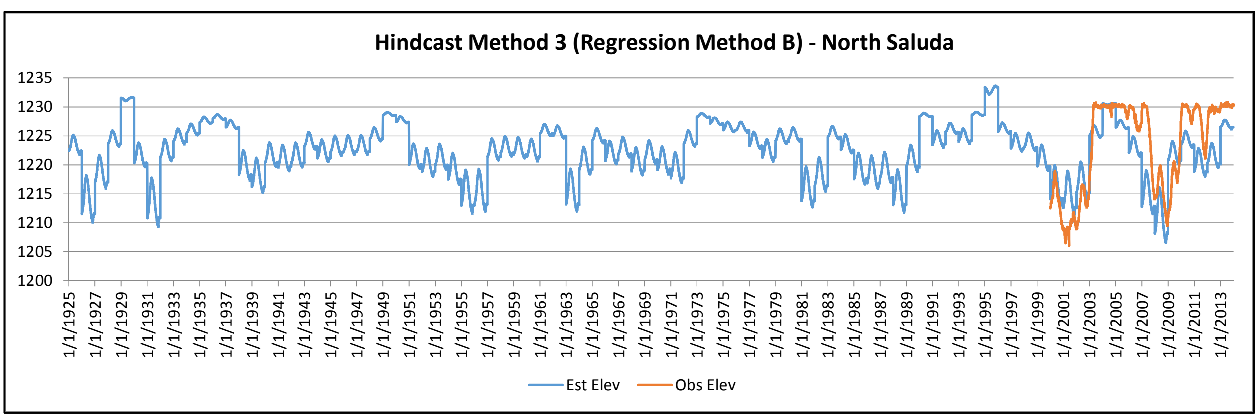
Examples of using these two regression techniques: The two techniques are applied to two reservoirs in the Saluda Basin, and demonstrated below. As noted, this example demonstrates that the best approach may simply be the one with the most obvious predictive ability, but there are some distinguishing features about these two reservoirs that may be important.

In the first example, the two methods are applied to the North Saluda Reservoir. The data suggest that there are extended periods of time over which the reservoir is full, or nearly full, but that it can draw down somewhat irregularly during droughts. **METHOD 2 (Regression Method A) is preferred in this example** because it appears to preserve the full condition more realistically than Method 3, and also simply because it provides a more credible reproduction of the historical drawdown pattern.

First Example: North Saluda Lake

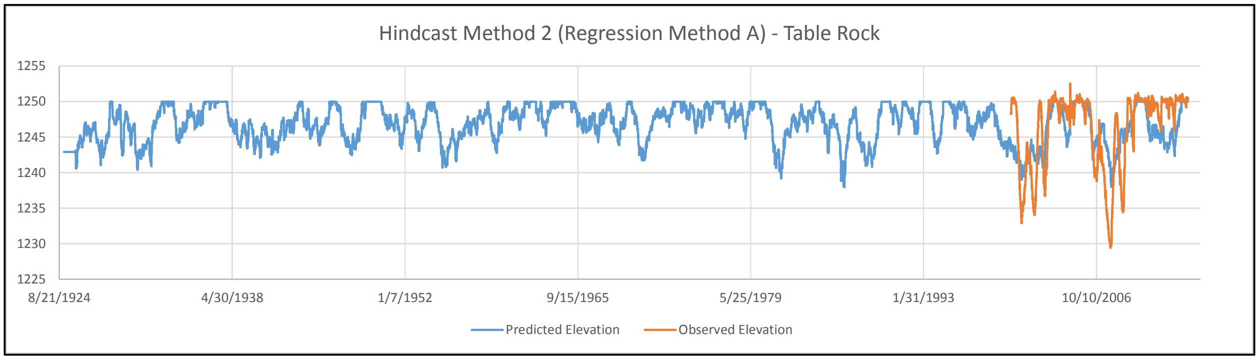


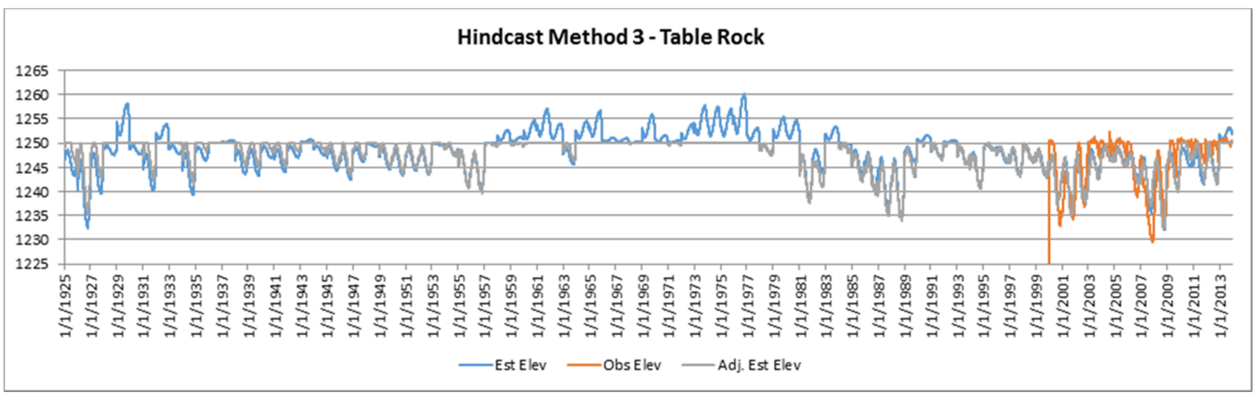


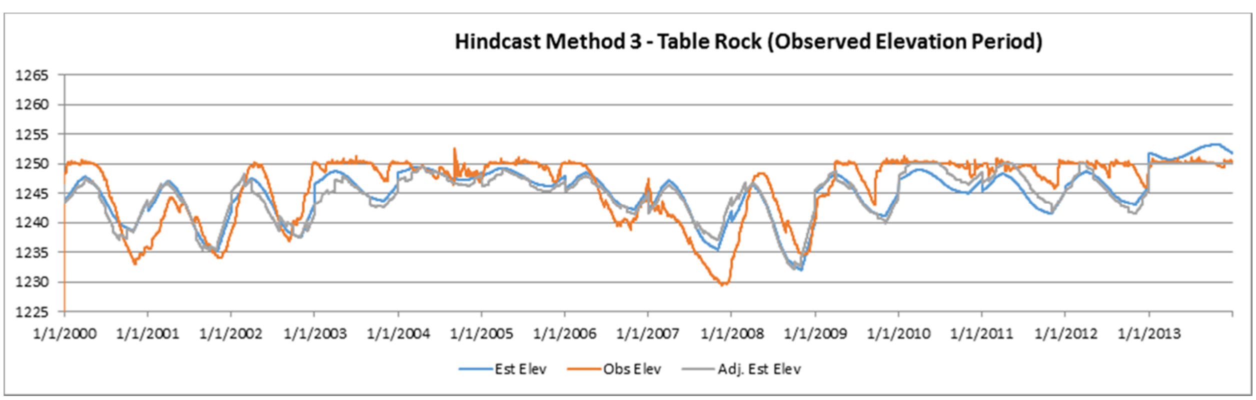


In the second example, the two methods are applied to Table Rock Reservoir.   The data suggest that the reservoir draws down irregularly, and is not usually completely full. **METHOD 3 is preferred in this example** because it appears to better match the magnitude of severe drawdown, the reservoir is not usually full, and because the method provides a more credible reproduction of the overall historical pattern.

Second Example: Table Rock Reservoir







Adjustment for Variable Historic Withdrawal Rates

If data for reservoir withdrawals extend back beyond the available data of reservoir water level, adjustments can be made to the hindcast timeseries of reservoir elevation. This is because the elevation hindcasting assumes an average withdrawal pattern equal to the average withdrawals over the period of elevation records, and is aimed principally at distinguishing drawdown due to severe drought from drawdown due to normal reservoir use and operations. It does not explicitly account for drawdown due to variations in reservoir withdrawals.

In such situations, the following approach may be applied (as a supplement to Method 1, 2, or 3 above):

1. Proceed with the full reservoir hindcast procedures as specified above (Method 1, 2, or 3).

2. Compute the average monthly withdrawal over the period of ELEVATION record for each month (the average of all Januaries, the average of all Februaries, etc.)

3. Convert hindcast elevation into hindcast volume for each month using the storage-elevation relationship for the reservoir.

4. Add or subtract volume for each hindcast month based on the difference between recorded withdrawal for that specific month and average withdrawal for the corresponding months over the period of ELEVATION record (computed in Step 2).

5. Convert the adjusted volume back to elevation (but keep both timeseries, as volume is used in the UIF equation, but elevation is used for validation).

Note that this method should NOT be applied with hindcast withdrawal data. Only apply this adjustment step when there are actual operational records of withdrawals that extend back further than the records of reservoir elevation.

Also note that if the period of elevation record suggests that the reservoir does not exceed spillway elevation for extended periods of time, hindcast elevations should be capped at the spillway elevation as a maximum, with the assumption that spills happen quickly. If the period of elevation record demonstrates extended periods of time above the spillway elevation, then the hindcasting can reflect this as well, but it should not exceed the documented maximum elevation.

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

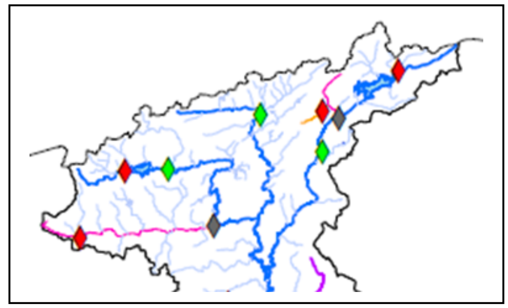
These guidelines are developed to help provide a consistent thought process for selecting reference basins (gaged basins) to estimate flow in ungagged or incompletely gaged basins. This applies to the extension of UIFs at USGS gages, and also to the transposition of UIFs into ungaged basins. Naturally, 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

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 E

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.

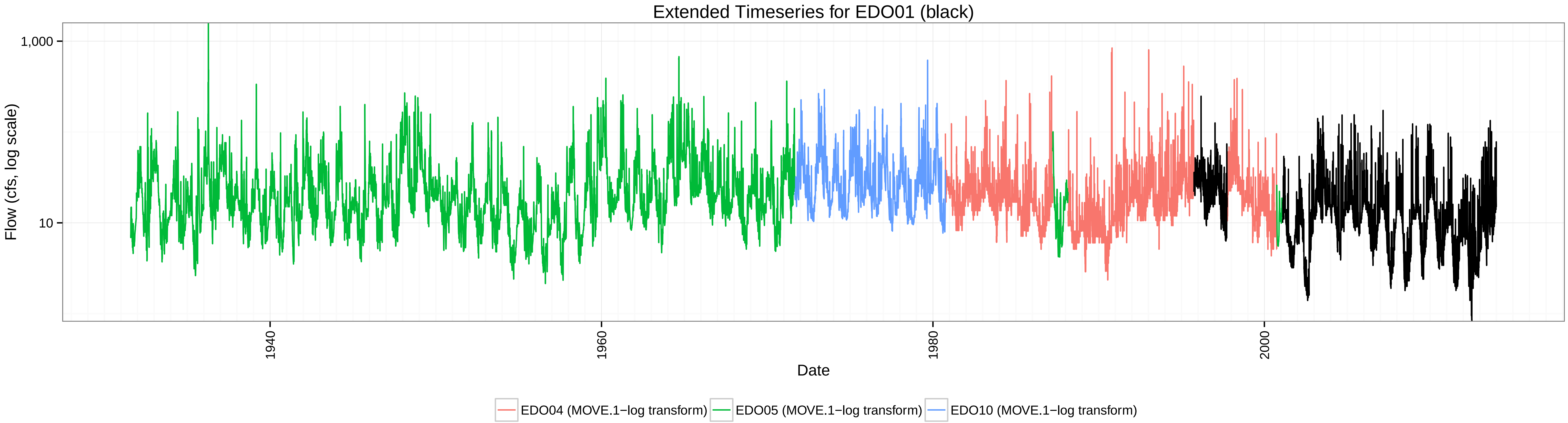
Two quantitative metrics aid the selection of reference gages and methods: root mean square error (RMSE) and predicted residual sum of squares (PRESS). RMSE compares estimated daily values and must be interpreted cautiously as this can be skewed by under or over-predicted flows. As an additional standard, 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.

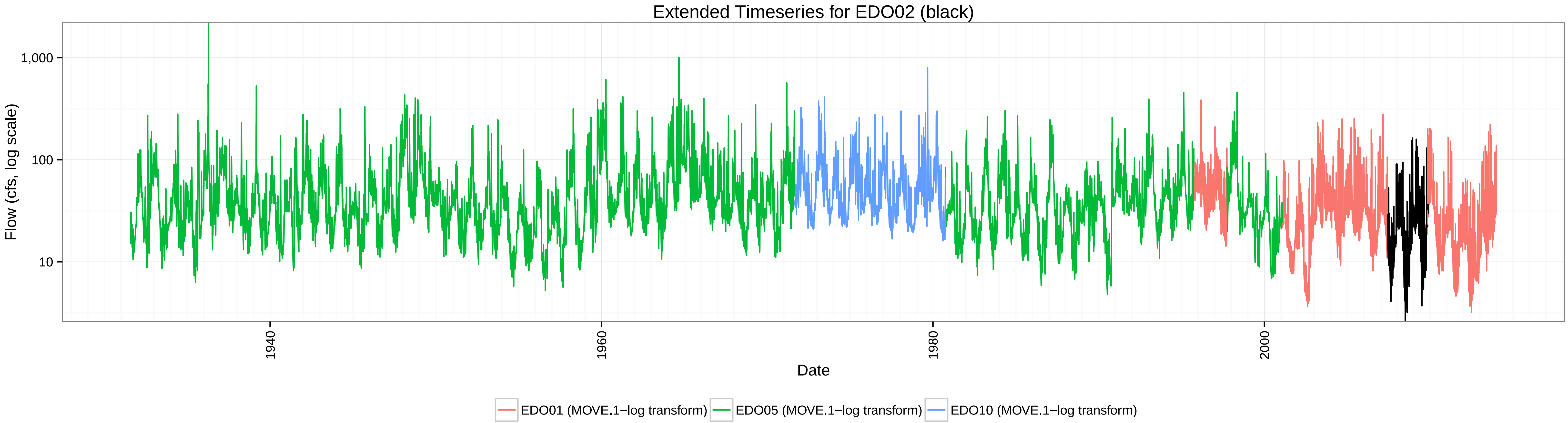
In addition to summary statistics, there are four plots to support to decision-making process: 1) an initial comparison of the original timeseries, 2) timeseries plots of the overlapping record for all methods, 3) scatterplots of the observed versus estimated flows and 4) exceedance frequency curves 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.

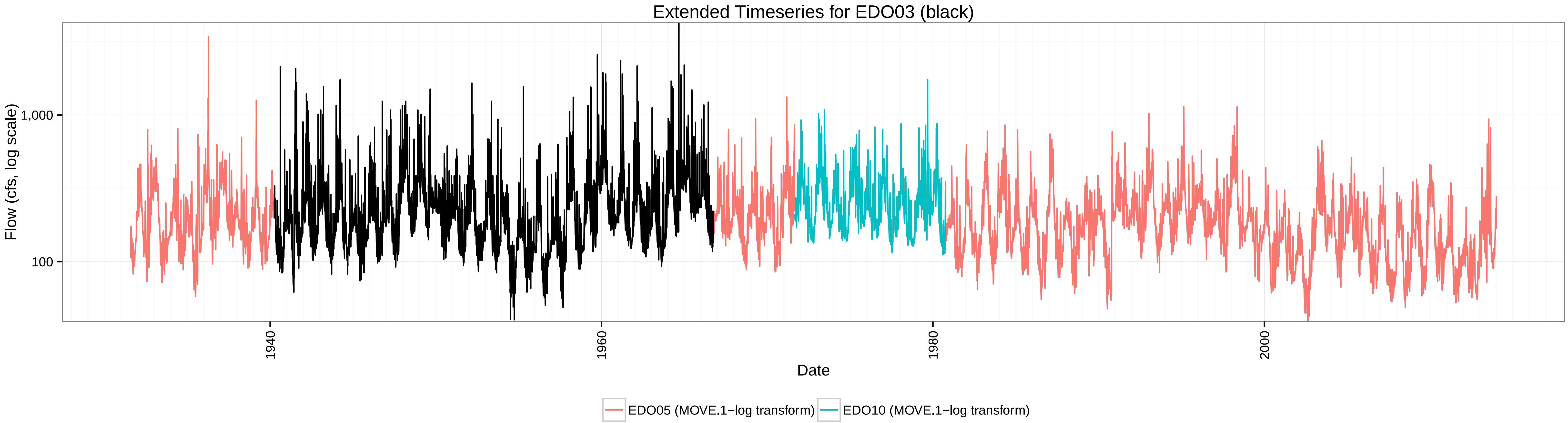
After examining the table and these performance plots, a final decision table is created and fed into another R script that creates the fully-extended record and makes two more plots: 5) verification showing the estimated values for the overlapping record and 6) final flows timeseries for the entire 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.

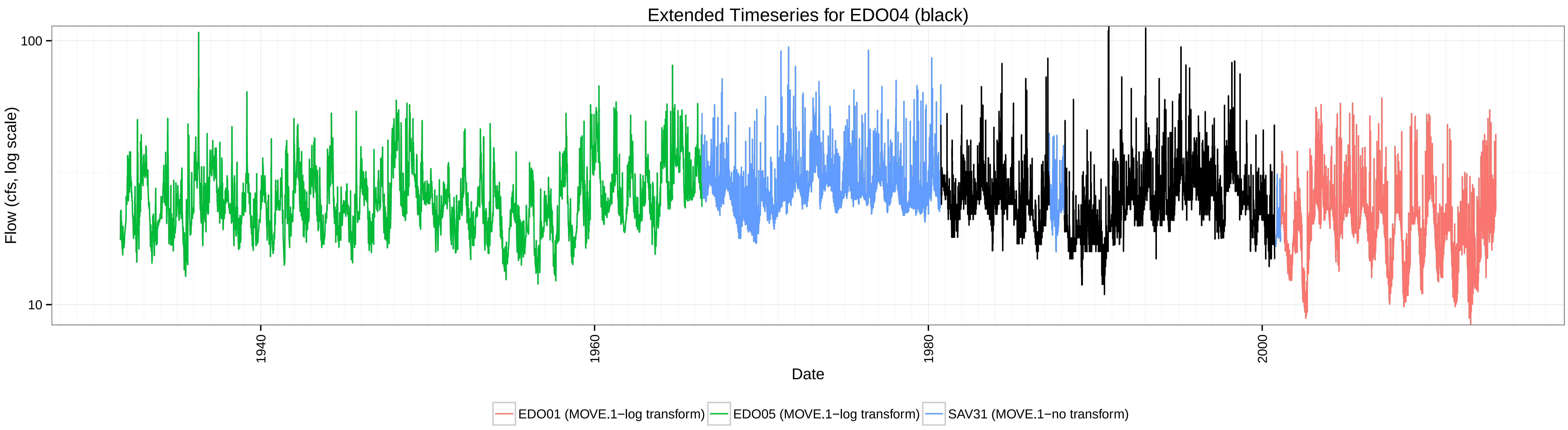
ATTACHMENT F

UIF Timeseries Graphs at USGS Gage Locations

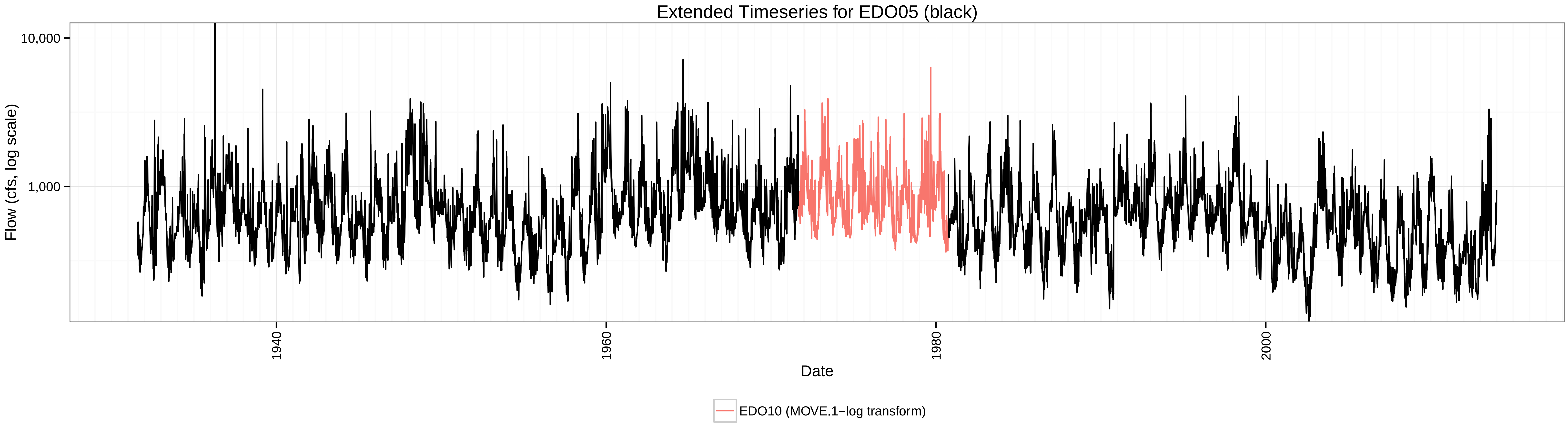

Extended Timeseries for EDO01 (black)
Flow (cfs, log scale)
1,000
10
1940
1960
1980
2000
Date
EDO04 (MOVE.1−log transform)
EDO05 (MOVE.1−log transform)
EDO10 (MOVE.1−log transform)


Extended Timeseries for EDO02 (black)
1,000
100
10
Flow (cfs, log scale)
1940
1960
1980
2000
Date
EDO01 (MOVE.1−log transform)
EDO05 (MOVE.1−log transform)
EDO10 (MOVE.1−log transform)

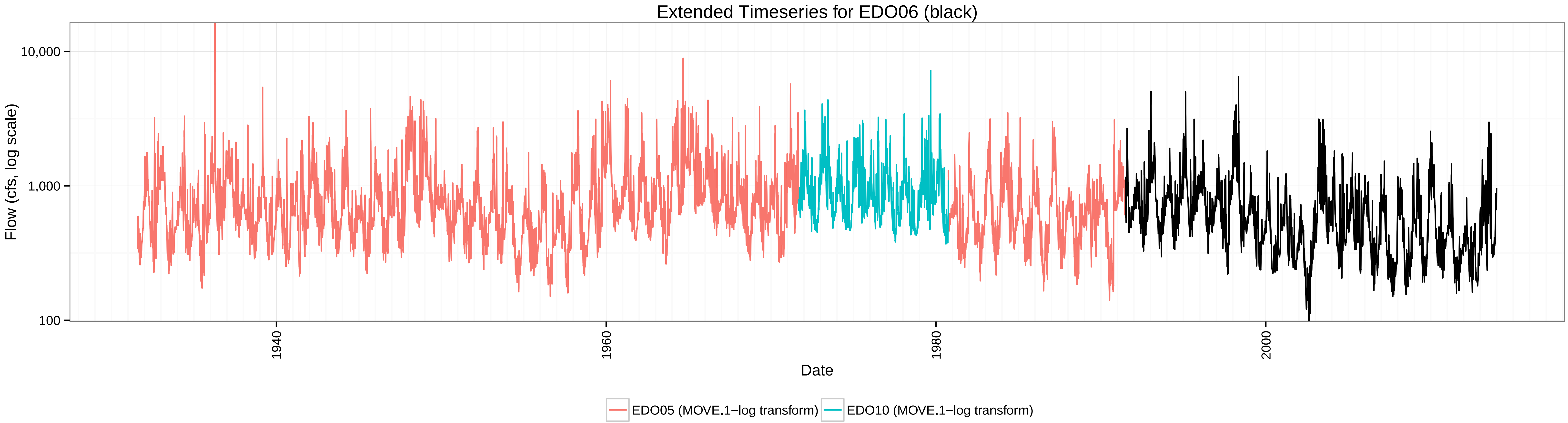

Extended Timeseries for EDO03 (black)
Flow (cfs, log scale)
1,000
100
1940
1960
1980
2000
Date
EDO05 (MOVE.1−log transform)
EDO10 (MOVE.1−log transform)

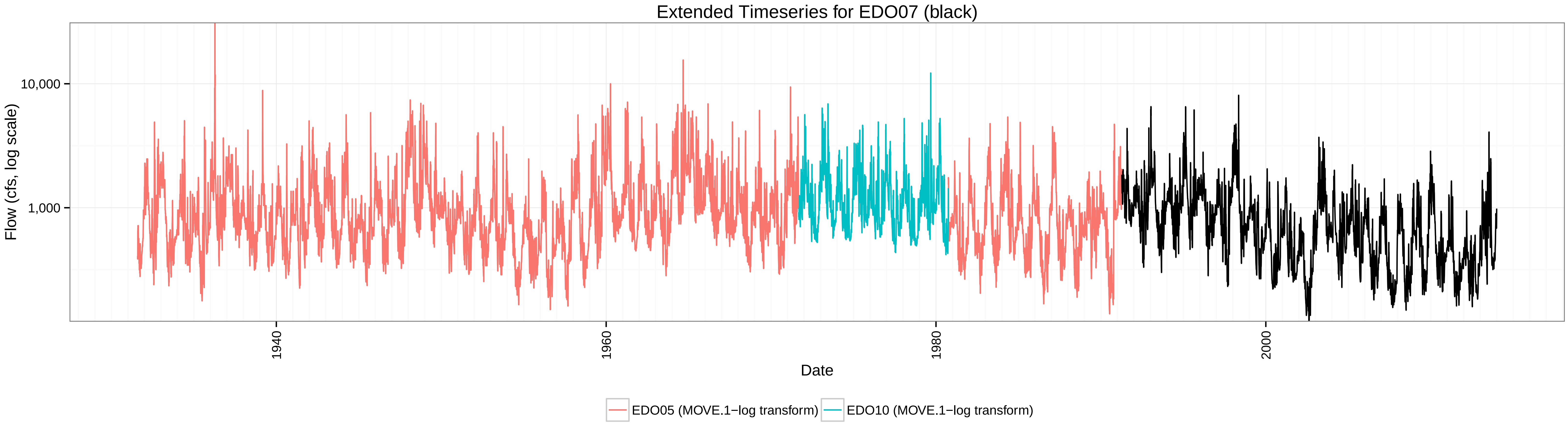


Extended Timeseries for EDO04 (black)
Flow (cfs, log scale)
100
10
1940
1960
1980
2000
Date
EDO01 (MOVE.1−log transform)
EDO05 (MOVE.1−log transform)
SAV31 (MOVE.1−no transform)

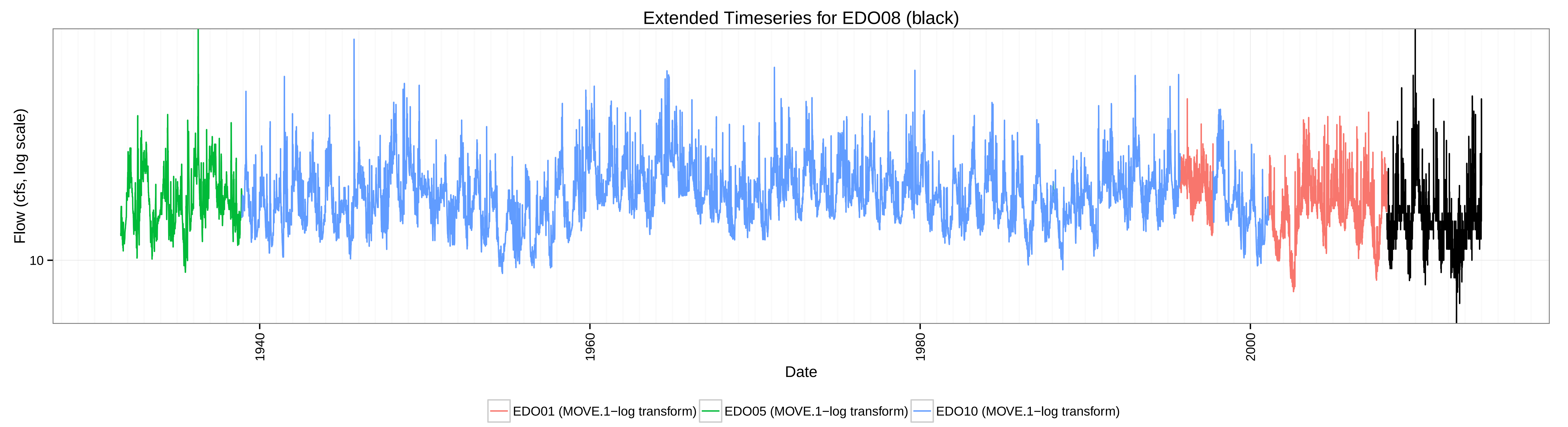


Extended Timeseries for EDO05 (black)
10,000
1,000
Flow (cfs, log scale)
1940
1960
1980
2000
Date
EDO10 (MOVE.1−log transform)

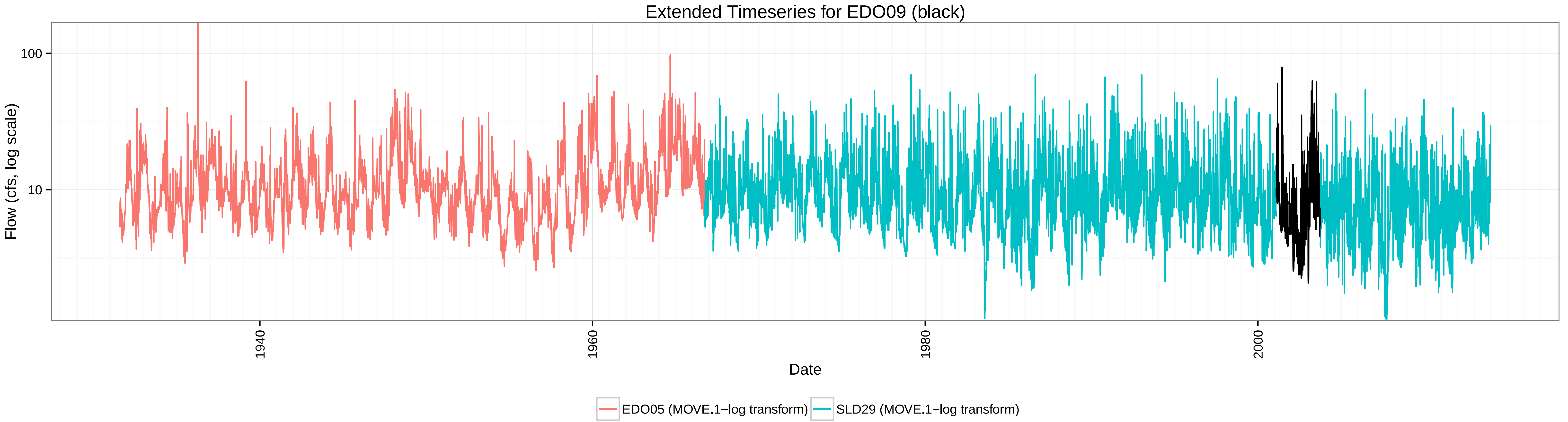

Extended Timeseries for EDO06 (black)
Flow (cfs, log scale)
10,000
1,000
100
1940
1960
1980
2000
Date
EDO05 (MOVE.1−log transform)
EDO10 (MOVE.1−log transform)



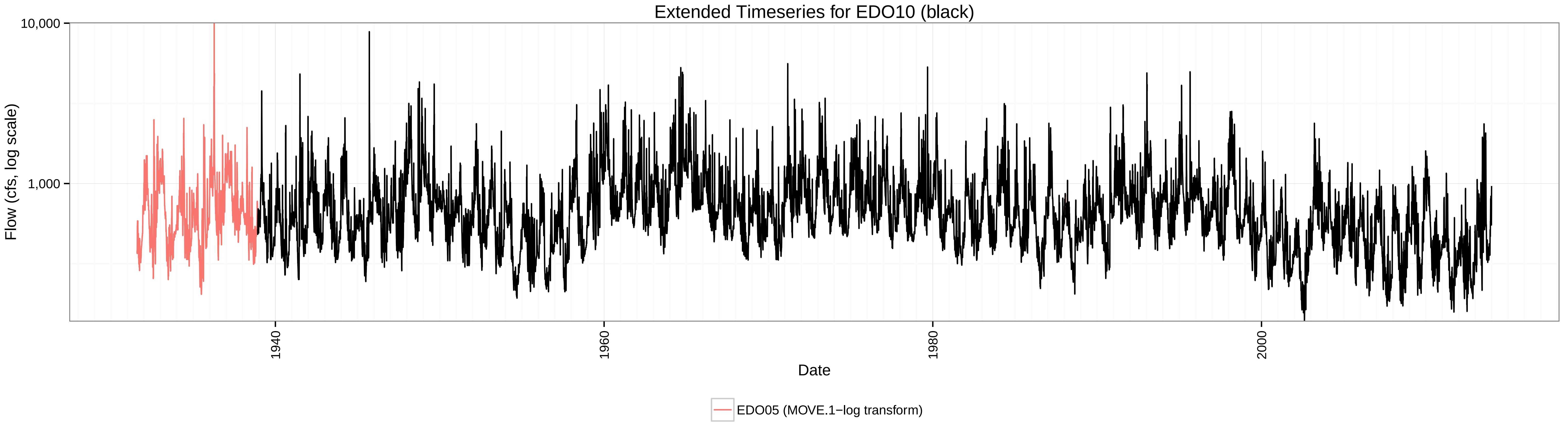
Extended Timeseries for EDO07 (black)
Flow (cfs, log scale)
10,000
1,000
1940
1960
1980
2000
Date
EDO05 (MOVE.1−log transform)
EDO10 (MOVE.1−log transform)

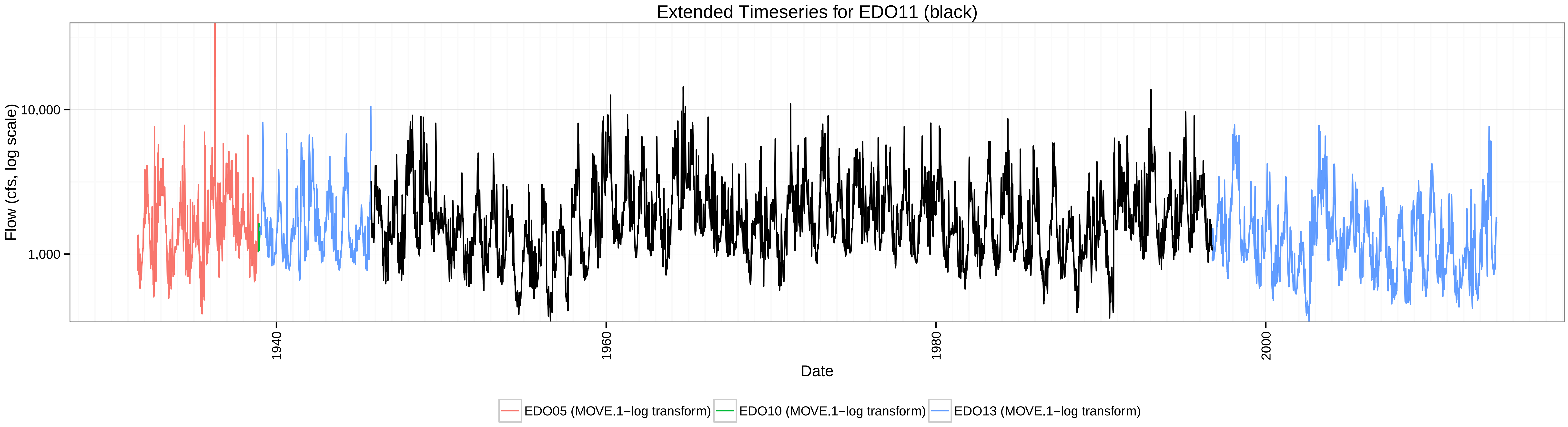


Extended Timeseries for EDO08 (black)
Flow (cfs, log scale)
10
1940
1960
1980
2000
Date
EDO01 (MOVE.1−log transform)
EDO05 (MOVE.1−log transform)
EDO10 (MOVE.1−log transform)

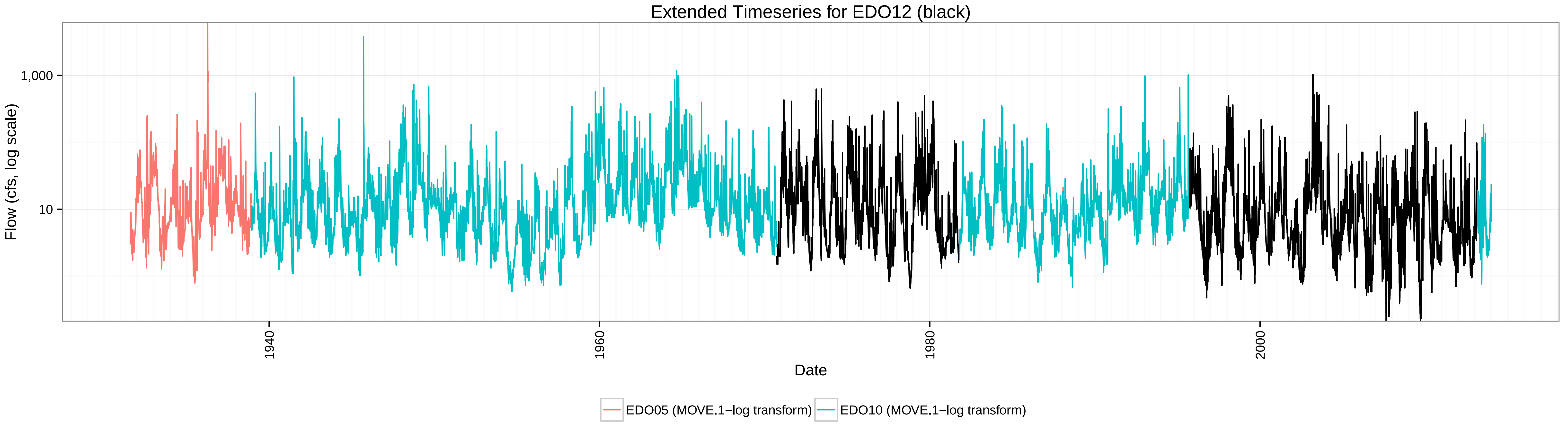


Extended Timeseries for EDO09 (black)
Flow (cfs, log scale)
100
10
1940
1960
1980
2000
Date
EDO05 (MOVE.1−log transform)
SLD29 (MOVE.1−log transform)

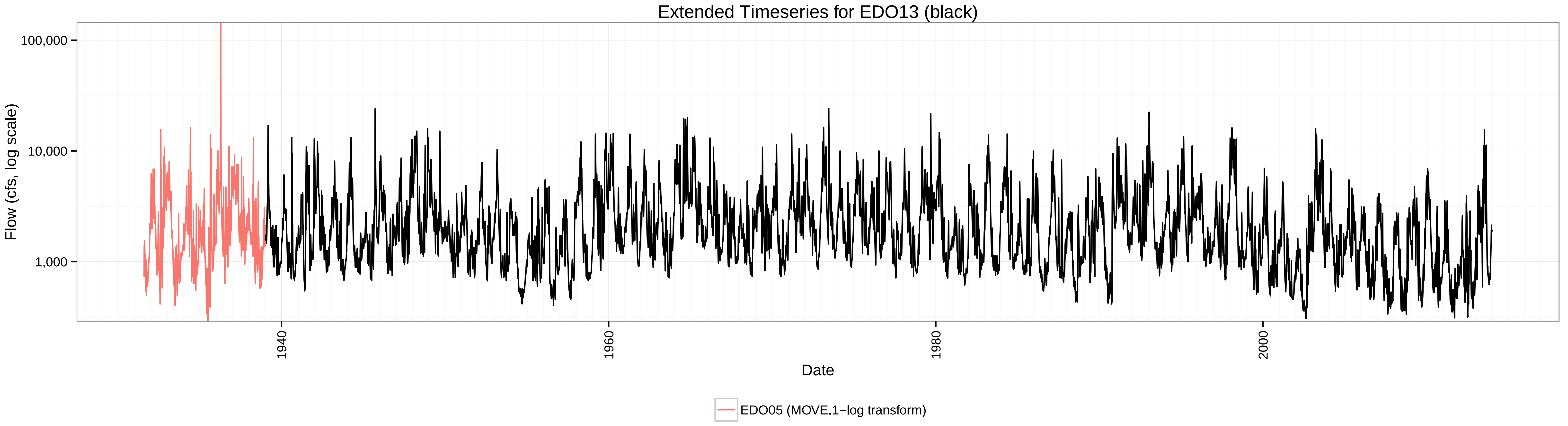

Extended Timeseries for EDO10 (black)
10,000
1,000
Flow (cfs, log scale)
1940
1960
1980
2000
Date
EDO05 (MOVE.1−log transform)



Extended Timeseries for EDO11 (black)
Flow (cfs, log scale)
10,000
1,000
1940
1960
1980
2000
Date
EDO05 (MOVE.1−log transform)
EDO10 (MOVE.1−log transform)
EDO13 (MOVE.1−log transform)



Extended Timeseries for EDO12 (black)
Flow (cfs, log scale)
1,000
10
1940
1960
1980
2000
Date
EDO05 (MOVE.1−log transform)
EDO10 (MOVE.1−log transform)



Extended Timeseries for EDO13 (black)
100,000
10,000
1,000
Flow (cfs, log scale)
1940
1960
1980
2000
Date
EDO05 (MOVE.1−log transform)

ATTACHMENT G

Discussion on Reference Gage and Method Selection

Gage	Reference	Method	Notes
EDO01	EDO04	MOVE.1-log transform	From summary statistics, it's clear EDO04 should be used to the greatest extent possible. Both MOVE variations perform well, but the log transform appears slightly better in the plots, especially with frequency.
	EDO05	MOVE.1-log transform	Judging from stats and plots, it is debatable whether EDO10 or EDO05 should have the higher priority, as both produce similar results. By virtue of EDO05 being downstream, it receives the higher priority. Based on plots, particularly cumulative flow, MOVE.1 with the transform is the prefered choice.
	EDO10	MOVE.1-log transform	For same reason as EDO05, MOVE.1 with transform is chosen. EDO03 has no overlap, but it's role in the final timeseries was examined. Ultimately, EDO03 was not used. Additionally, SLD29 was tested as a possible reference and ultimately not used either.
EDO02	EDO01	MOVE.1-log transform	Best for all statistics and decision plots.
	EDO05	MOVE.1-log transform	While EDO10 appears marginally better, the short overlapping period of record casts some doubt on the stats and plots. As EDO02 is highly-correlated with EDO01, the preference of EDO05 over EDO10 for EDO01 is held here as well. While area ratio has appealing statistics, it has questionable behavior in the low-flow region of the plots, thus MOVE.1 with the transform is chosen.
	EDO10	MOVE.1-log transform	Same method as EDO05 for same reasons. EDO03 and EDO04 have no overlap, but their role in the final timeseries was examined as well. Ultimately, these two were not included for same reasons as EDO01.
EDO03	EDO05	MOVE.1-log transform	Best across all statistics and plots.
	EDO10	MOVE.1-log transform	While area ratio has the best statistics, MOVE.1 with the transform performs the best in all plots.
EDO04	EDO01	MOVE.1-log transform	Best for all statistics and decision plots. Also examined EDO08 and EDO09 with area ratio (have no overlap) but was clear did not fit in final timeseries.
	SAV31	MOVE.1-no transform	Both the Savannah gage and SLD31 provide similarly-appropriate choices, but unfortunately have similar periods of record (thus only one can be used). Both were examined in the final timeseries, but SAV31 was chosen, as SLD31 produces some questionably high flows. This may be attributed to SLD31 having a small drainage area and its own peaks may not scale up appropiately.
	EDO05	MOVE.1-log transform	Both MOVE methods provide reasonable choices. Though MOVE without the transform appears marginally better in the decision plots, especially in higher flows, the transform is chosen to preserve low flows.
EDO05	EDO10	MOVE.1-log transform	Both MOVE methods have robust results. Though MOVE without the transform has slightly-better statistics and performance for most of the plots and flow regimes, the transform is chosen to preserve low flows.
EDO06	EDO05	MOVE.1-log transform	Best across all statistics and plots, though area ratio could be a reasonable choice as well.
	EDO10	MOVE.1-log transform	Best across all statistics and plots.
EDO07	EDO05	MOVE.1-log transform	Without the transform is best for statistics and has most balanced behavior for flow regimes in plots, excepting very low flows. However, transform is chosen to remain consistent with EDO06.
	EDO10	MOVE.1-log transform	Same as with using EDO05.
EDO08	EDO01	MOVE.1-log transform	Best across all statistics and plots (except high flows). Additionally, using area ratio with SLD31 was examined in the final timeseries and had easily-rejected behavior. As EDO08 did not work for EDO03 & EDO04, the reverse can be assumed here and did not merit testing. Tried EDO09 as well, did not fit in final timeseries.

	EDO10	MOVE.1-log transform	Best across all statistics and plots (except high flows). Also tried EDO12, but was worst candidate of all the overlapping candidates.
	EDO05	MOVE.1-log transform	Best across all statistics and plots (except high flows).
EDO09	SLD29	MOVE.1-log transform	Between all candidates, usage and order of priority is debatable (but all should use MOVE.1 with transform). Between using SLD29, EDO10 and EDO12, SLD29 produces the best results. EDO09 does have a small length of record, and overlapping stats and plots must be interpreted with a grain of salt. Additionally, using area ratio with SLD31 was examined in the final timeseries and had easily-rejected behavior. As EDO09 did not work in the final timeseries with EDO03, EDO04, and EDO08 the reverse can be assumed here.
	EDO05	MOVE.1-log transform	See above.
EDO10	EDO05	MOVE.1-log transform	Best across all statistics and plots.
EDO11	EDO13	MOVE.1-log transform	EDO07 is a debatable first choice as well. However, EDO07 provides a much smaller period of overlap, thus its results are not as trustworthy.
	EDO10	MOVE.1-log transform	While area ratio has the best statistics, the frequency and cumulative flow plots indicate otherwise. MOVE with the transform chosen for lows flows.
	EDO05	MOVE.1-log transform	Same reason as above.
EDO12	EDO10	MOVE.1-log transform	EDO04 could have been used as a higher priority, however its small overlap casts some doubt on overlapping statistics and plots, and the MOVE log transform may have odd outliers as a result. EDO10 with the log transform provides a more robust compromise across statistics and plots. EDO08 was considered for the extra year of extension, but the statistics and plots indicate the other gages provide a better fit.
	EDO05	MOVE.1-log transform	Best across all statistics and plots.
EDO13	EDO05	MOVE.1-log transform	EDO10 was considered as a priority for an extra year of extension, but results indicate EDO05 provides an overal fit. MOVE with the transform provides best results across stats and plots.