Technical Memorandum

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

From: *CDM Smith*

Date: *June 2016*

Subject: *Unimpaired Flow Methodology and Dataset for the Salkehatchie 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 eight 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 methodology and completion of the UIF dataset for the Salkehatchie River Basin. The TM references the electronic database which houses the completed UIF dataset for the Salkehatchie River Basin, and summarizes the techniques and decisions pertaining to synthesis of data where it is unavailable, which may be specific to individual locations.

2.0 Overview of the Salkehatchie River Basin

The Salkehatchie River Basin covers approximately 3,270 square miles in the southern Coastal Plain region of the state (**Figure 2-1**). The major streams are the Salkehatchie River, Coosawhatchie River, and Ashepoo River. The Salkehatchie and Little Salkehatchie rivers join to form the tidally-influenced Combahee River. The western Coosawhatchie River drains into the Broad River, a tidal saltwater river. Near the coast, the tidally-influenced areas of this basin contain the most widespread estuarine water bodies in the State.

Streamflow has been monitored on the Salkehatchie and Coosawhatchie rivers since 1951; however, only two of the Unites States Geological Survey (USGS) gaging stations are currently active, including one on the Salkehatchie and one of the Coosawhatchie. Both the Salkehatchie River

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

station near Miley (USGS 02175500, SLK02) and the Coosawhatchie River station near Hampton (USGS 02176500, SLK05) offer the earliest period of record, beginning in 1951.

Average annual streamflow of the Salkehatchie River near Miley is 337 cfs. Streamflow at this site is relatively stable and well-sustained due to several contributing headwater streams as well as groundwater supplies. Average annual streamflow in the Coosawhatchie River near Hampton is 169 cfs. This flow is more variable and dependent on rainfall and runoff to support streamflow.

Chapter 5 of The South Carolina State Water Assessment (SCDNR, 2009) describes the basin's surface water and groundwater hydrology and hydrogeology, water development and use, and water quality. A summary is also provided in An Overview of the Eight Major River Basins of South Carolina (SCDNR, 2013).

A detailed discussion of water users and dischargers is explained and presented in the *Salkehatchie River Basin SWAM Model Framework* (CDM Smith, 2015). The South Carolina DHEC has provided information and data regarding current (active) and former (inactive) water users and dischargers throughout the state, and these are summarized below in **Tables 2-1 and 2-2**. Former users and dischargers in the tidally influenced portions of the Salkehatchie River Basin are not accounted for in the UIF development. Additionally, individual withdrawal and discharges with less than 3 million gallons per month (mg/m) are generally not accounted for in the UIF calculations or in water quality modeling.

3.0 Overview of UIF Methodology

Fundamentally, UIFs are calculated by removing known impacts from measured streamflow values at places in which flow has been measured historically. An alternate method sometimes employed utilizes rainfall-runoff modeling to estimate natural runoff tendencies, but this technique is often uncertain, and its only sure footing is in calibration to measured (and frequently impaired) streamflow records. For the Salkehatchie River Basin, UIFs were calculated at every non-coastal 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 1951-2013 (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

Table 2-1. Permitted Irrigation Users in the Salkehatchie Basin

Intake ID	Facility Name	Withdrawal Tributary
05IR011S01	Anilorac Farm	Little Salkehatchie River
15IR002S01	Breland Farm	Little Salkehatchie River
05IR007S01	Brubaker Farms Inc	Salkehatchie River
03IR002S02	Chappell Farms	Coosawhatchie River
03IR011S01	Connelly Farms	Salkehatchie River
03IR011S02	Connelly Farms	Miller Swamp
03IR011S03	Connelly Farms	Jackson Branch
03IR004S01	Coosaw Farms	Coosawhatchie River
25IR059S01	Coosaw Land LLC	Coosawhatchie River
06IR007S01	Danny Hege Farm Barnwell	Salkehatchie River
05IR042S01	Diem Aden Farm	Little Salkehatchie River
05IR023S01	Gary Hege Farm	Salkehatchie River
05IR023S02	Gary Hege Farm	Little Salkehatchie River
03IR010S01	JCO Farms	Coosawhatchie River
03IR006S01	Sharp & Sharp Certified Seed	Coosawhatchie River
03IR006S02	Sharp & Sharp Certified Seed	Coosawhatchie River
03IR006S03	Sharp & Sharp Certified Seed	Coosawhatchie River
15IR012S01	Williams Farms Partnership	Little Salkehatchie River
15IR012S02	Williams Farms Partnership	Willow Swamp
15IR012S03	Williams Farms Partnership	Willow Swamp
15IR012S04	Williams Farms Partnership	Willow Swamp
15IR012S05	Williams Farms Partnership	Willow Swamp

Table 2-2. Permitted NPDES Discharges in the Salkehatchie Basin

NPDES Pipe ID	Facility Name	Discharge Tributary
SC0001830-001	Nevamar Company LLC	Coosawhatchie River
SC0021318-001	Hampton, Town of	Coosawhatchie River
SC0025950-001	Yemassee, Town of	Combahee River
SC0040215-001	Denmark, City of	Little Salkehatchie River
SC0040215-002	Denmark, City of	Little Salkehatchie River
SC0047872-001	Barnwell, City of WWTF (New)	Salkehatchie River

c) SWAM model calibration

d) Comparison of simulated managed flows to natural flows

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

Figure 3-1 illustrates the step-by-step methodology for computing UIFs. The same general methodology that has been previously used in the Saluda, Edisto, Broad and Pee Dee river basins was also used in the Salkehatchie. Please refer to the *Methodology for Unimpaired Flow Development* documents prepared for these basins. The methodology is also supported by the following technical memoranda, which specifically outline the steps and guidelines for UIF computation and decision-making:

- *Guidelines for Standardizing and Simplifying Operational Record Extension* (CDM Smith, March 2015) – Included as **Attachment A** 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 B** of this report.
- *Refinements to the UIF Extension Process, with an Example* – Included as **Attachment C.**

Figure 3-2 illustrates the locations of all UIFs developed for the Salkehatchie River Basin, and distinguishes between those computed by adjusting measured streamflow at USGS gages, and those computed for ungaged basins through area transposition. Additionally, **Attachment G** contains a simplified schematic of the USGS streamflow gages.

3.1 Period of Record

The earliest UIF estimates begin in 1951 for the Salkehatchie River Basin. Two of the stream gages began operation in the 1990s or later. The records for all gages that started tracking flow after 1951 are extended using gap filling techniques. Therefore, much of the UIFs are based on estimated flows, but 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 3-3** depicts the length and timing of records available for all USGS gages in the basin.

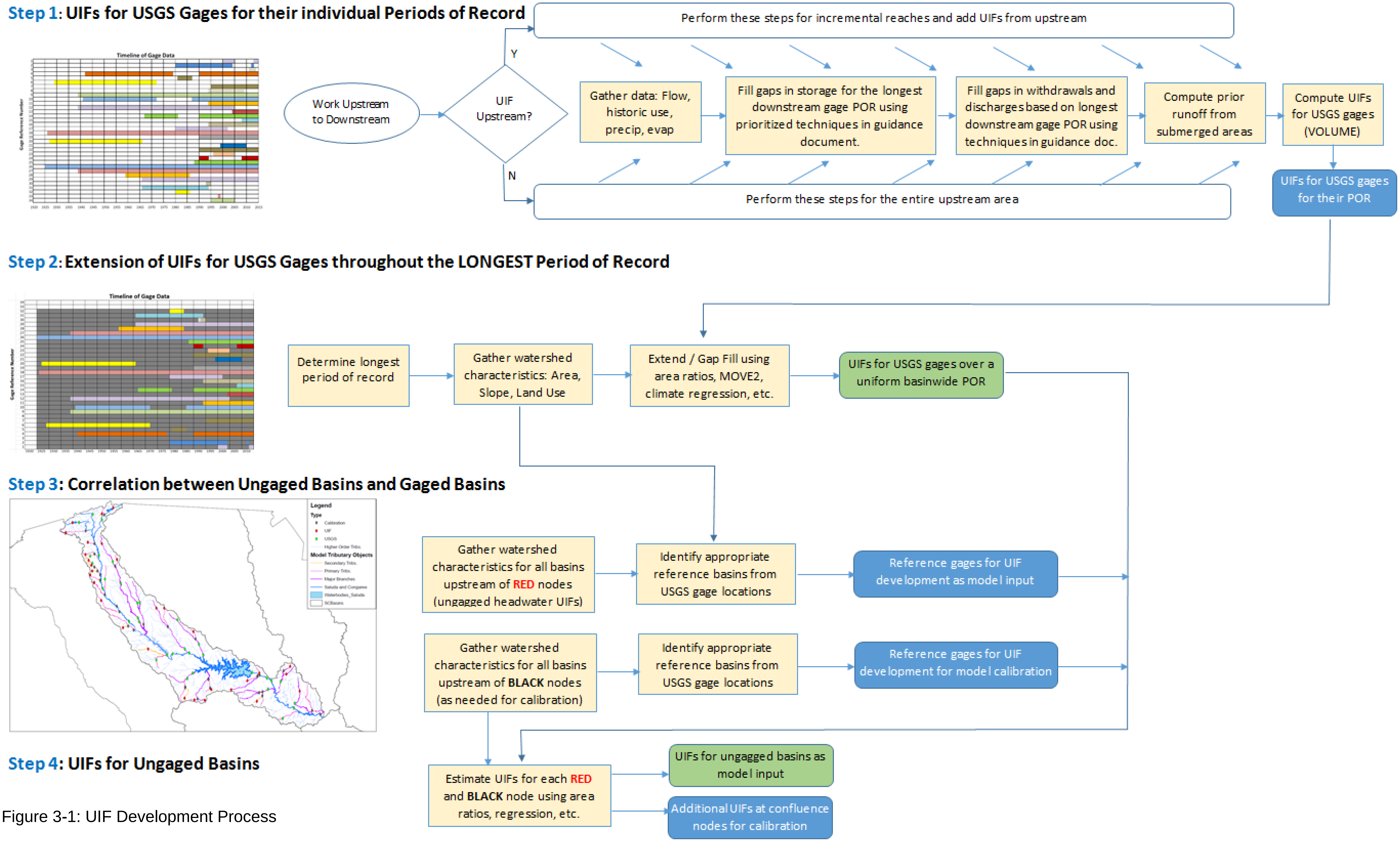

Figure 3-1: UIF Development Process

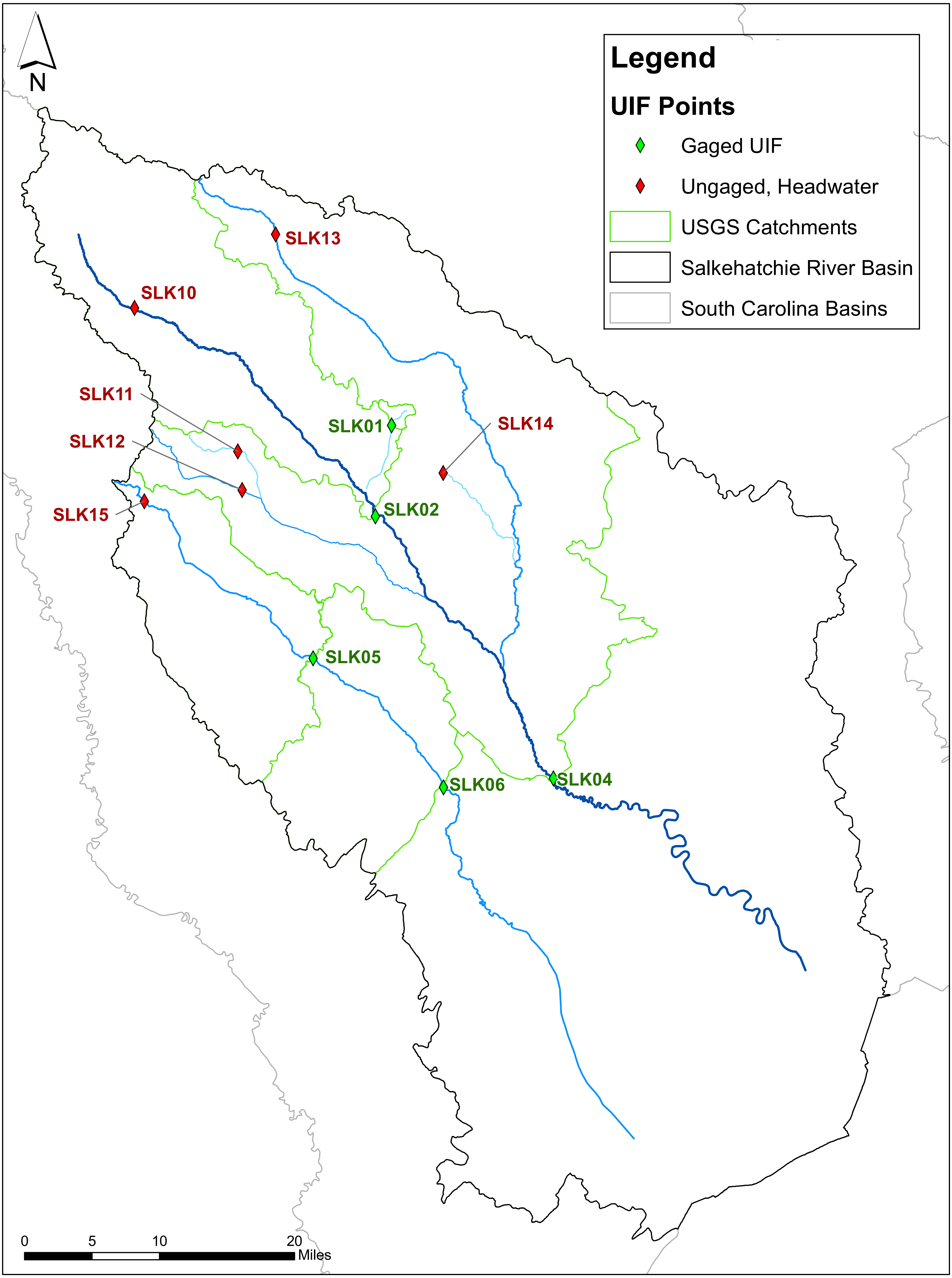

Figure 3-2
Unimpaired Flow Locations in the Salkehatchie River Basin

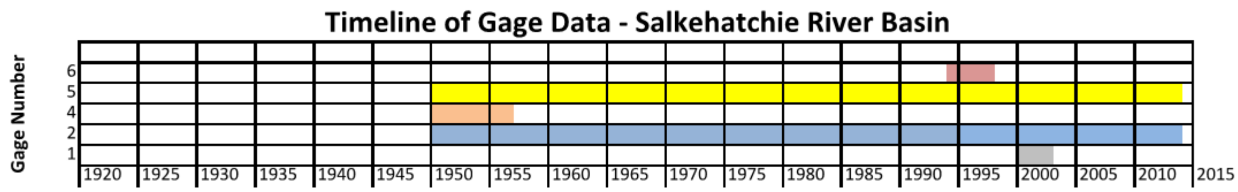

Figure 3-3. Period of record for USGS gages in the Salkehatchie River Basin

3.2 Issues Specific to the Salkehatchie Basin

3.2.1 Coastal Areas

Significant portions of the Salkehatchie River Basin along the coast are tidally influenced. The *Salkehatchie River Basin SWAM Model Framework* (Figure 3) shows a number of golf courses in the tidally influenced area that will not be modeled. No attempt has been made to calculate UIFs in the tidally influenced areas of the basin. Representation of these areas will be limited in SWAM since historical flows and its UIFs cannot be accurately quantified. **Attachment G** shows two of the gages that are considered coastal.

3.2.2 Groundwater

Registered and permitted (both active and inactive) groundwater withdrawal locations are shown in **Figure 3-4**. 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 basin, registered groundwater withdrawals do not meet these conditions, and can therefore be ignored when calculating UIFs; however, larger groundwater withdrawal were reviewed for consideration.

The review showed that 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 not necessary in calculating UIFs.

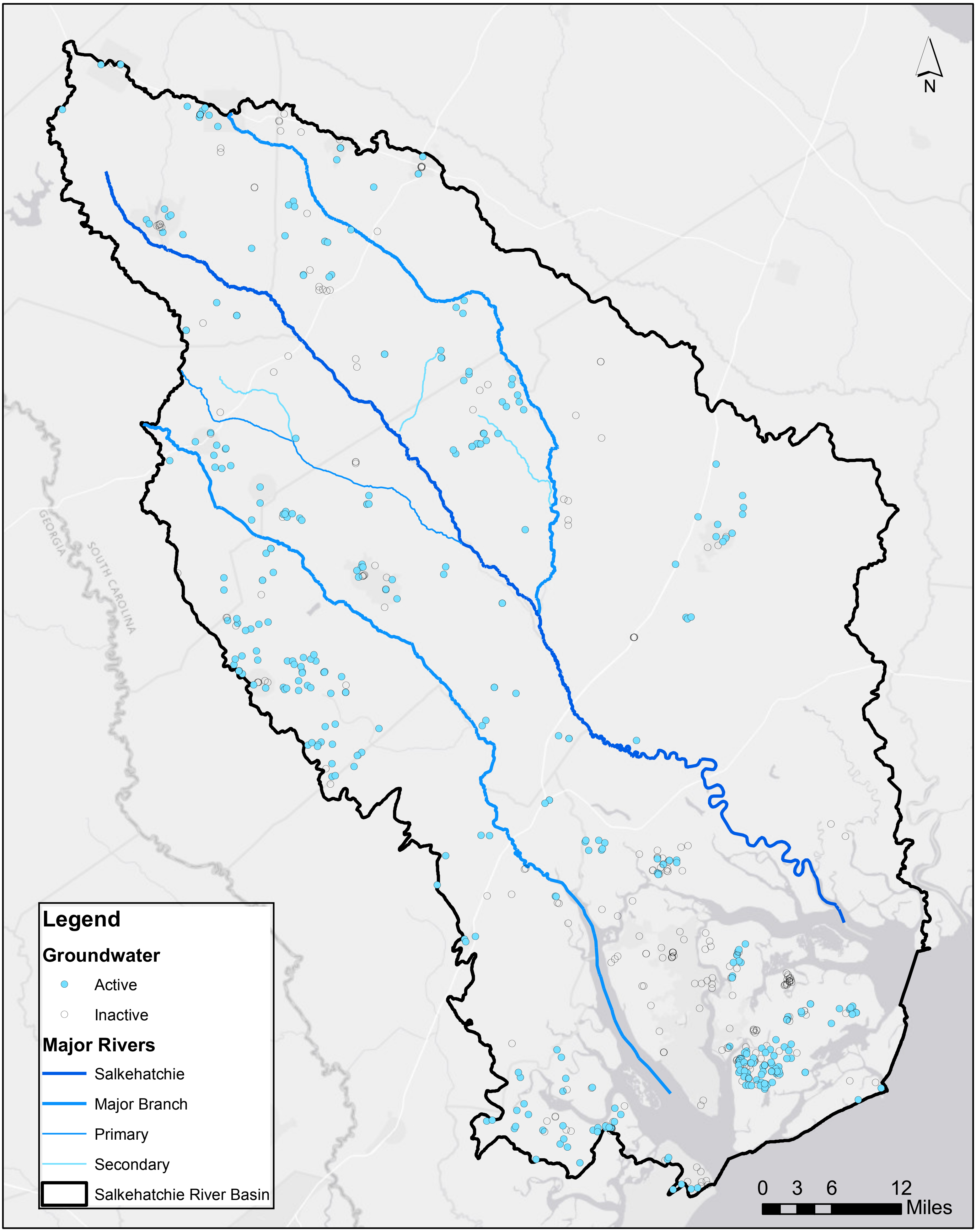

Figure 3-4

Active and Inactive Groundwater Withdrawal Locations

3.2.3 Agriculture

Registered agriculture surface withdrawal locations in the basin are shown in **Figure 3-5.** Withdrawals for agricultural irrigation are currently assumed to be 100 percent consumptive; therefore, no return flows are assumed for the UIF calculations.

4.0 Quality Assurance Reviews

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

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 C**.

5.0 Summary of Operational Hindcasting

Unique circumstances involving data availability, observable trends, etc. required decisions about how to develop representative hindcast values for each individual user. A summary of hindcasting methods used for the discharges are presented in **Table 5-1**. Reference **Attachment A** for details on the listed methodologies. Other than agricultural withdrawals, which are discussed in the next paragraph, there are no other surface water withdrawals in the modeled portion of the Salkehatchie River Basin; therefore, hindcasting for such withdrawals are not discussed.

Hindcasting of agricultural withdrawals in the Salkehatchie River Basin was 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 memorandum entitled, *Methodology for Developing Historical Surface Water Withdrawals for Agriculture Irrigation* (CDM Smith, July 2015).

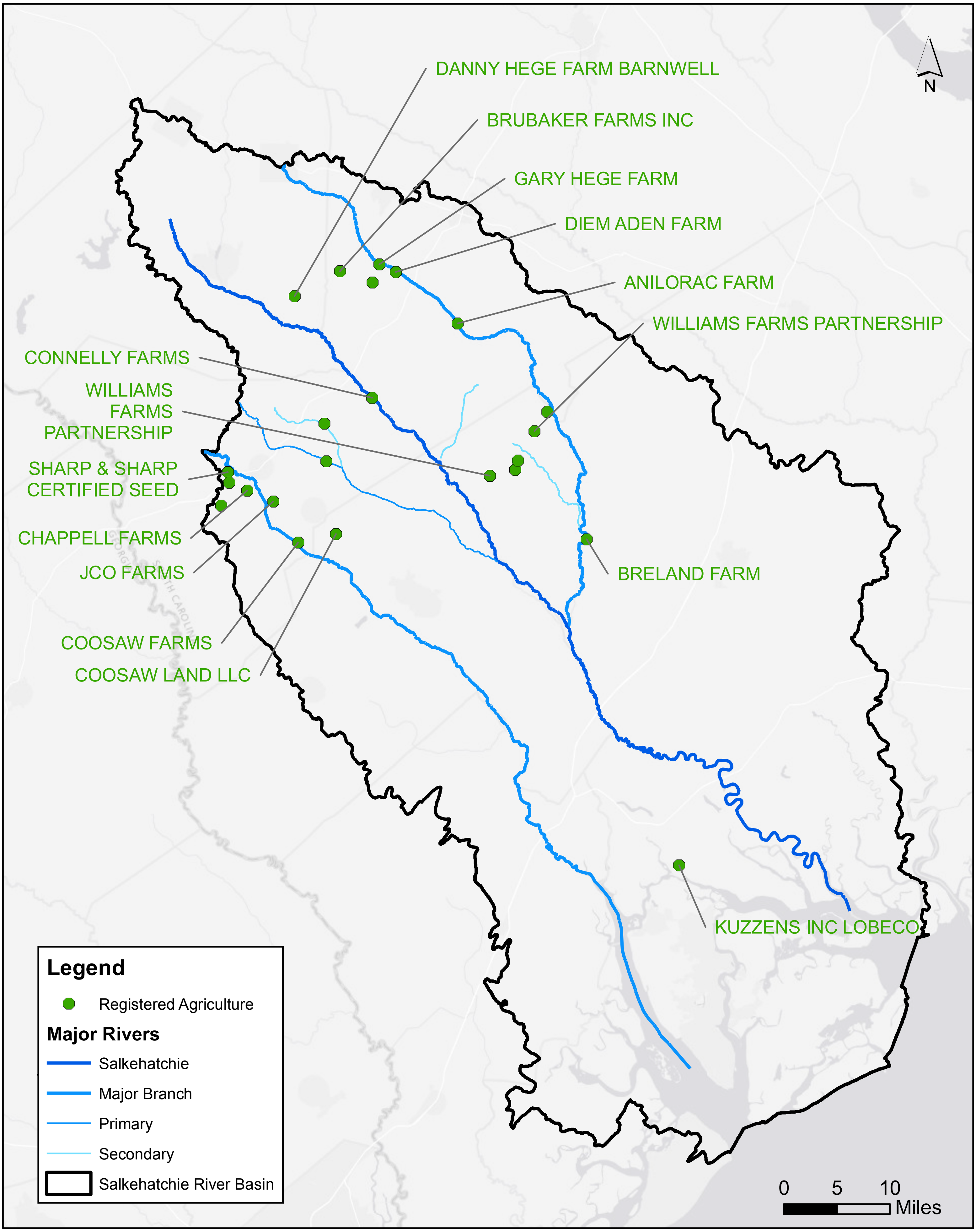

Figure 3-5

Current Agriculture Surface Water Users

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

Project Gage	USGS Number	Stream	Discharge Hindcasting			
			ID	Facility Name	Time Periods	Method Used
SLK02	02175500	SALKEHATCHIE RIVER NEAR MILEY, SC	SC0047872-001	Barnwell WWTF	12/1997 - 3/2002	Extended from anecdotal info.
SLK04	02176000	COMBAHEE RIVER NEAR YEMASSEE, SC	SC0025950-001	Yemassee	9/1979 - 2/1989	Extended from anecdotal info.
			SC0040215-001 SC0040215-002	Denmark	8/1985 - 3/1999	Extended from anecdotal info.
SLK06	02176517	COOSAWHATCHIE RIVER NR EARLY BRANCH, SC	SC0021318-001	Hampton	6/1978 - 1/1989	Extended from anecdotal info.
			SC0001830-001	Nevamar Company LLC	11/1977 - 8/1989	Extended from anecdotal info.

6.0 Summary of Gaged UIF Flow Record Extension

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

As MOVE.1 without an initial log transform may produce negative or near-zero values, area proration (which is strictly linear and cannot produce negative flows from non-negative reference flows) replaces values below a site-specific minimum threshold determined by the overlapping period between the partial and reference gages. Note that if a reference gage registers a flow of zero, the extended flow for the partial gage will also be estimated as zero.

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

USGS Gage with Partial Record					USGS Reference Gage(s)			Method of Extension
Project Gage ID	USGS Number	Stream	Periods of Record	Basin Area (mi²)	Project Gage ID	Stream	Basin Area (mi²)	
SLK01	2175445	SAVANNAH CREEK AT EHRHARDT, SC	3/2001 - 9/2003	3	SLK02	SALKEHATCHIE RIVER NEAR MILEY, SC	342	MOVE.1 (no transform), Area Ratio if MOVE.1 < 0.1 cfs
SLK04	2176000	COMBAHEE RIVER NEAR YEMASSEE, SC	6/1951 - 6/1957	1086				MOVE.1 (log transform)
SLK06	2176517	COOSAWHATCHIE RIVER NR EARLY BRANCH, SC	10/1995 - 9/1998	383	SLK05	COOSAWHATCHIE RIVER NEAR HAMPTON, 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 SLK04 is shown in **Figure 6-1**.

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

7.0 Summary of Ungaged UIF Transposition

Area proration was used to transpose the UIF timeseries from gaged basins to ungaged basins. Selection of reference gages follows guidelines established in **Attachment C**. **Table 7-1** summarizes the information for the ungaged basins and the gaged basins used as reference. Headwater flows are used as input for each explicitly modeled tributary in SWAM whereas confluence flows are used for implicit tributaries needed for model calibration.

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

<table>
<tr><th></th><th colspan="4">Ungaged Basin</th><th colspan="5">USGS Reference Gage</th></tr>
<tr><th>Project ID</th><th>SWAM Usage</th><th>Stream</th><th>Basin Area (mi^2)</th><th>% Developed / % Forest</th><th>Project Gage ID</th><th>USGS Number</th><th>Stream</th><th>Basin Area (mi^2)</th><th>% Developed / % Forest</th></tr>
<tr><td>SLK10</td><td>Headwater Flow</td><td>Salkehatchie River</td><td>105</td><td>8 / 49</td><td>SLK02</td><td>02175500</td><td>Salkehatchie River</td><td>342</td><td>5 / 52</td></tr>
<tr><td>SLK11</td><td>Headwater Flow</td><td>Miller Swamp</td><td>6</td><td>6 / 34</td><td rowspan="4">SLK04</td><td rowspan="4">02176000</td><td rowspan="4">Combahee River</td><td rowspan="4">1087</td><td rowspan="4">5 / 57</td></tr>
<tr><td>SLK12</td><td>Headwater Flow</td><td>Jackson Branch</td><td>26</td><td>6 / 37</td></tr>
<tr><td>SLK13</td><td>Headwater Flow</td><td>Little Salkehatchie River</td><td>27</td><td>5 / 52</td></tr>
<tr><td>SLK14</td><td>Headwater Flow</td><td>Willow Swamp</td><td>19</td><td>5 / 45</td></tr>
<tr><td>SLK15</td><td>Headwater Flow</td><td>Coosawhatchie River</td><td>4</td><td>2 / 55</td><td>SLK05</td><td>02176500</td><td>Coosawhatchie River</td><td>196</td><td>7 / 51</td></tr>
</table>

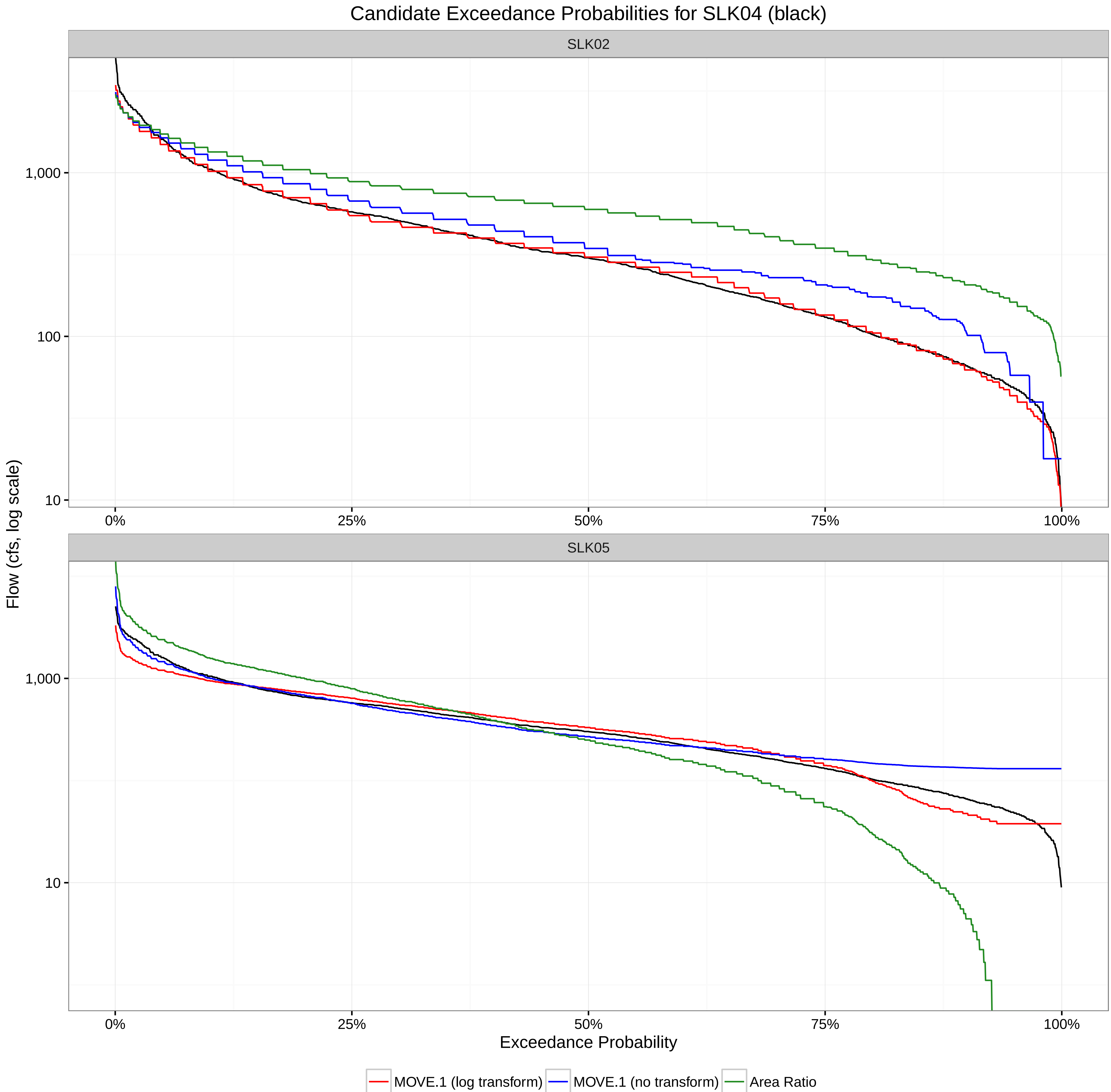


Figure 6-1: Comparison of Exceedance Probabilities for the Computed UIF and Extension Methods

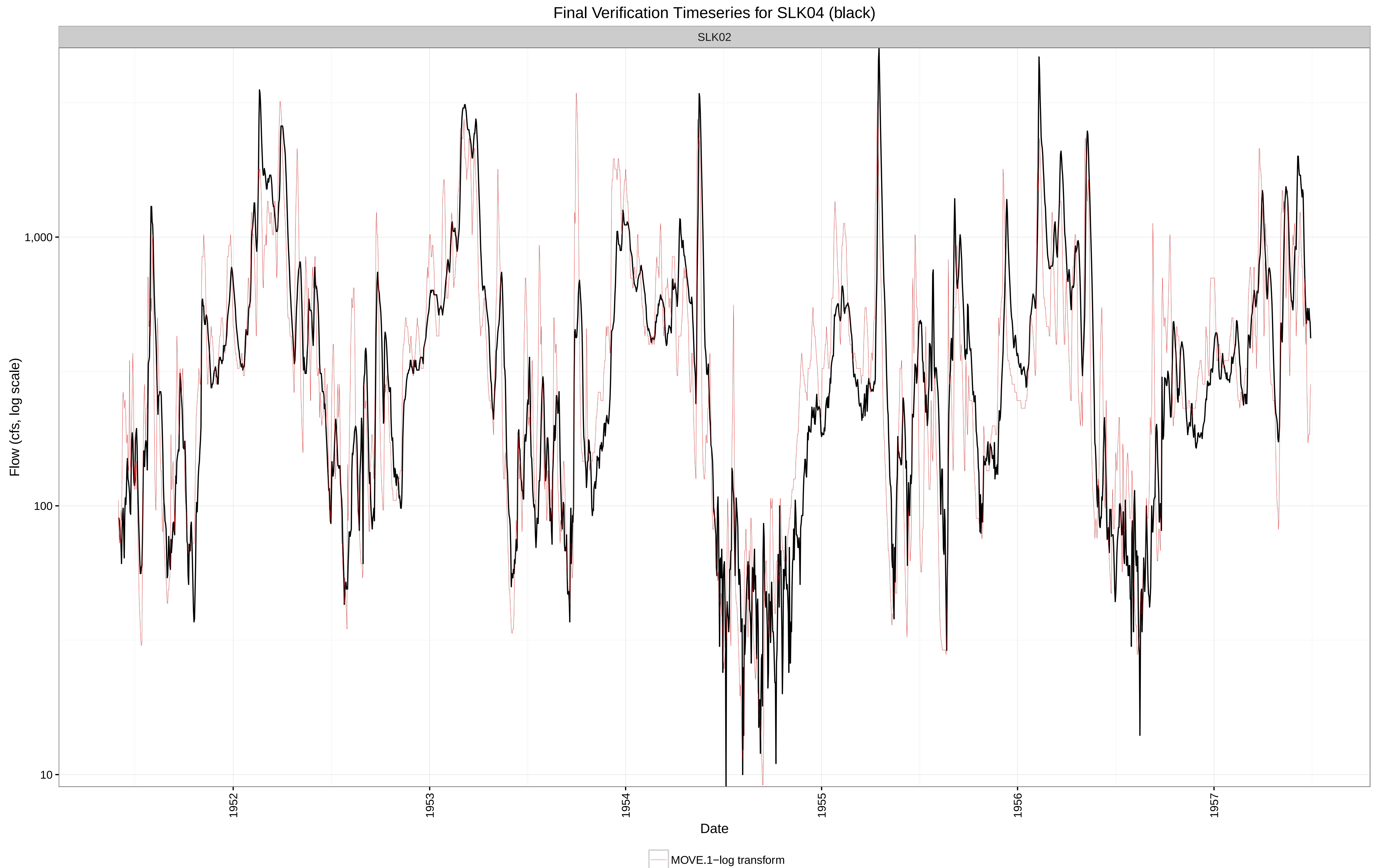


Figure 6-2: Validation Graph for SLK04 with Predicted Flows from Reference Gage SLK02

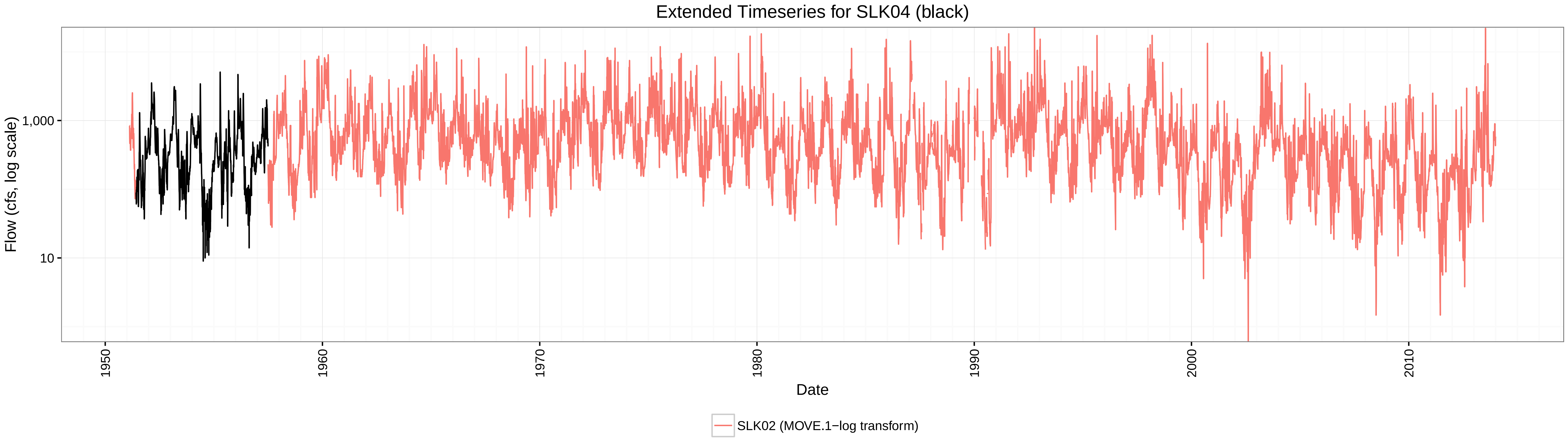


Figure 6-3: Resulting Timeseries for SLK04

8.0 References

CDM Smith, October 2015, *Salkehatchie River Basin SWAM Model Framework.*

CDM Smith, July 2015, *Methodology for Developing Historical Surface Water Withdrawals for* Agriculture *Irrigation*

SCDNR, 2009, *South Carolina State Water Assessment,* Second Edition.

List of Attachments

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

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

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

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

E. UIF Timeseries Graphs at USGS Gage Locations

F. Discussion on Reference Gage and Method Selection

G. Schematic of USGS Streamflow Gages in the Salkehatchie River Basin

ATTACHMENT A

Guidelines for Standardizing and Simplifying Operational Record Extension

(CDM Smith, March 2015) – ***To be included in Final Memo***

ATTACHMENT B

Guidelines for Identifying Reference Basins for UIF Extension or Synthesis

(CDM Smith, April 2015) – *To be included in Final Memo*

ATTACHMENT C

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

(CDM Smith, April 2015) – *To be included in Final Memo*

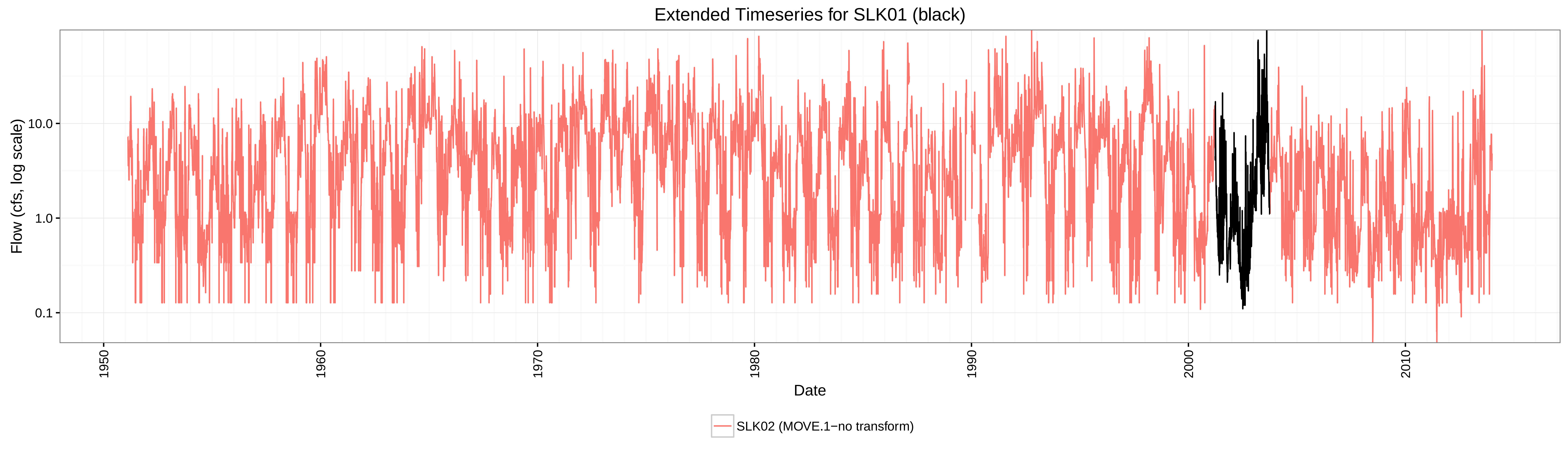
ATTACHMENT D

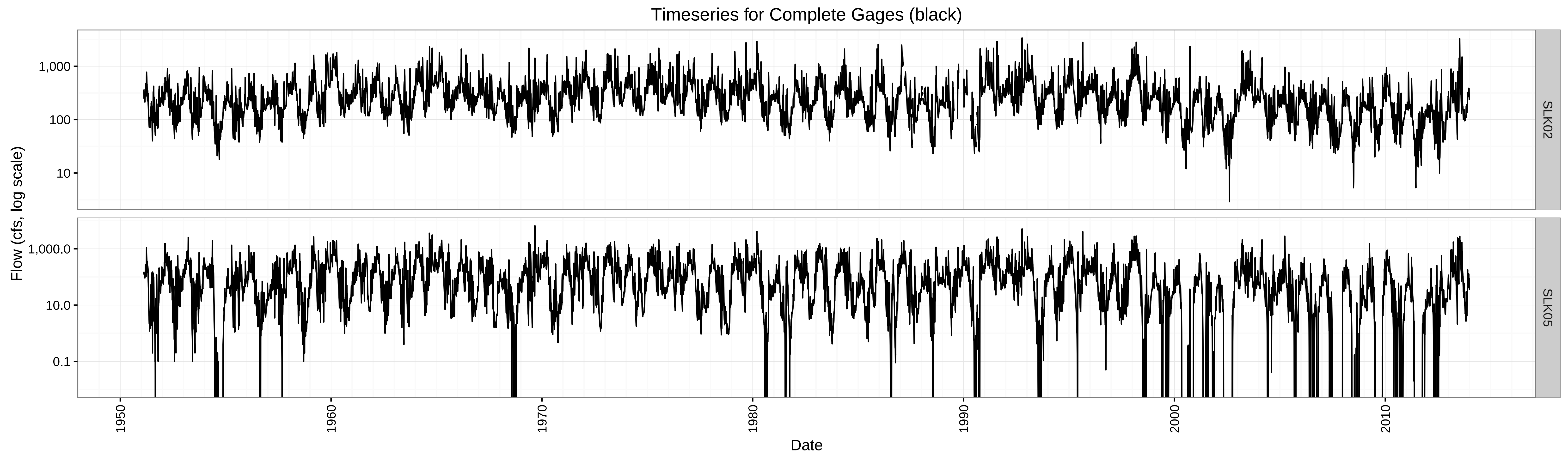
Refinements to the UIF Extension Process, with an Example

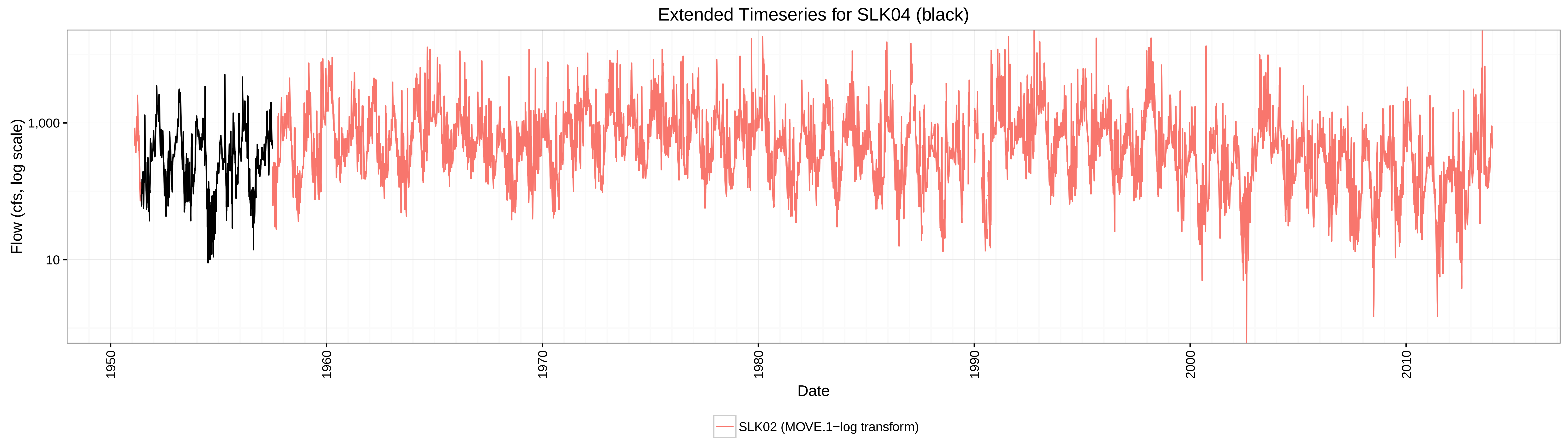
(CDM Smith, September 2015) – *To be included in Final Memo*

ATTACHMENT E

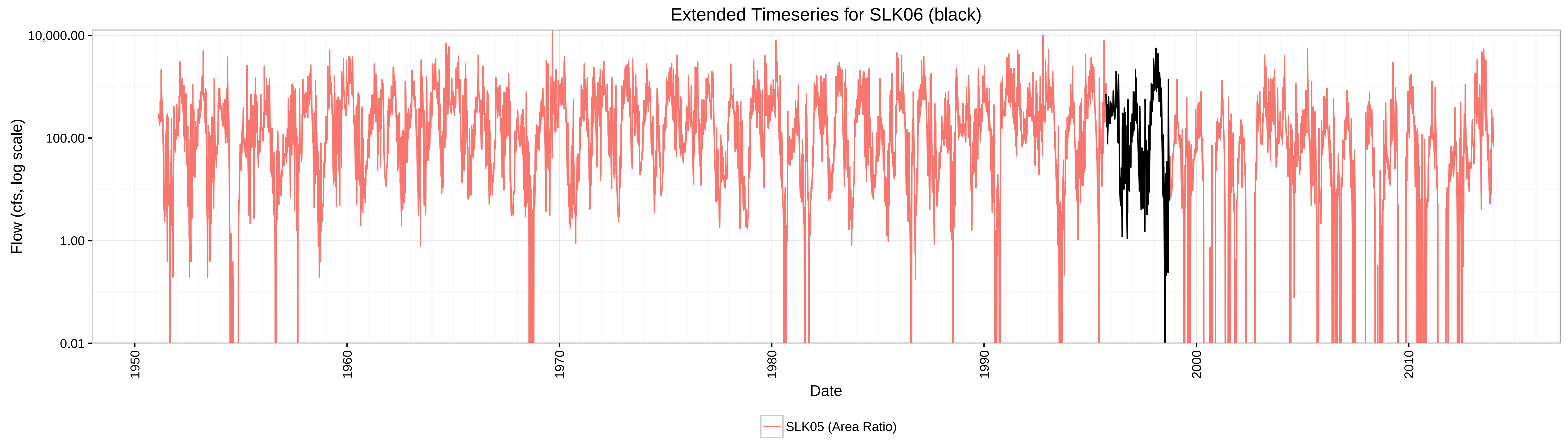
UIF Timeseries Graphs at USGS Gage Locations


Extended Timeseries for SLK01 (black)
Flow (cfs, log scale)
10.0
1.0
0.1
1950
1960
1970
1980
1990
2000
2010
Date
SLK02 (MOVE.1−no transform)


Timeseries for Complete Gages (black)
Flow (cfs, log scale)
1,000
100
10
SLK02
1,000.0
10.0
0.1
SLK05
1950
1960
1970
1980
1990
2000
2010
Date



Extended Timeseries for SLK04 (black)
Flow (cfs, log scale)
1,000
10
1950
1960
1970
1980
1990
2000
2010
Date
SLK02 (MOVE.1−log transform)


Extended Timeseries for SLK06 (black)
10,000.00
100.00
1.00
0.01
Flow (cfs, log scale)
1950
1960
1970
1980
1990
2000
2010
Date
SLK05 (Area Ratio)

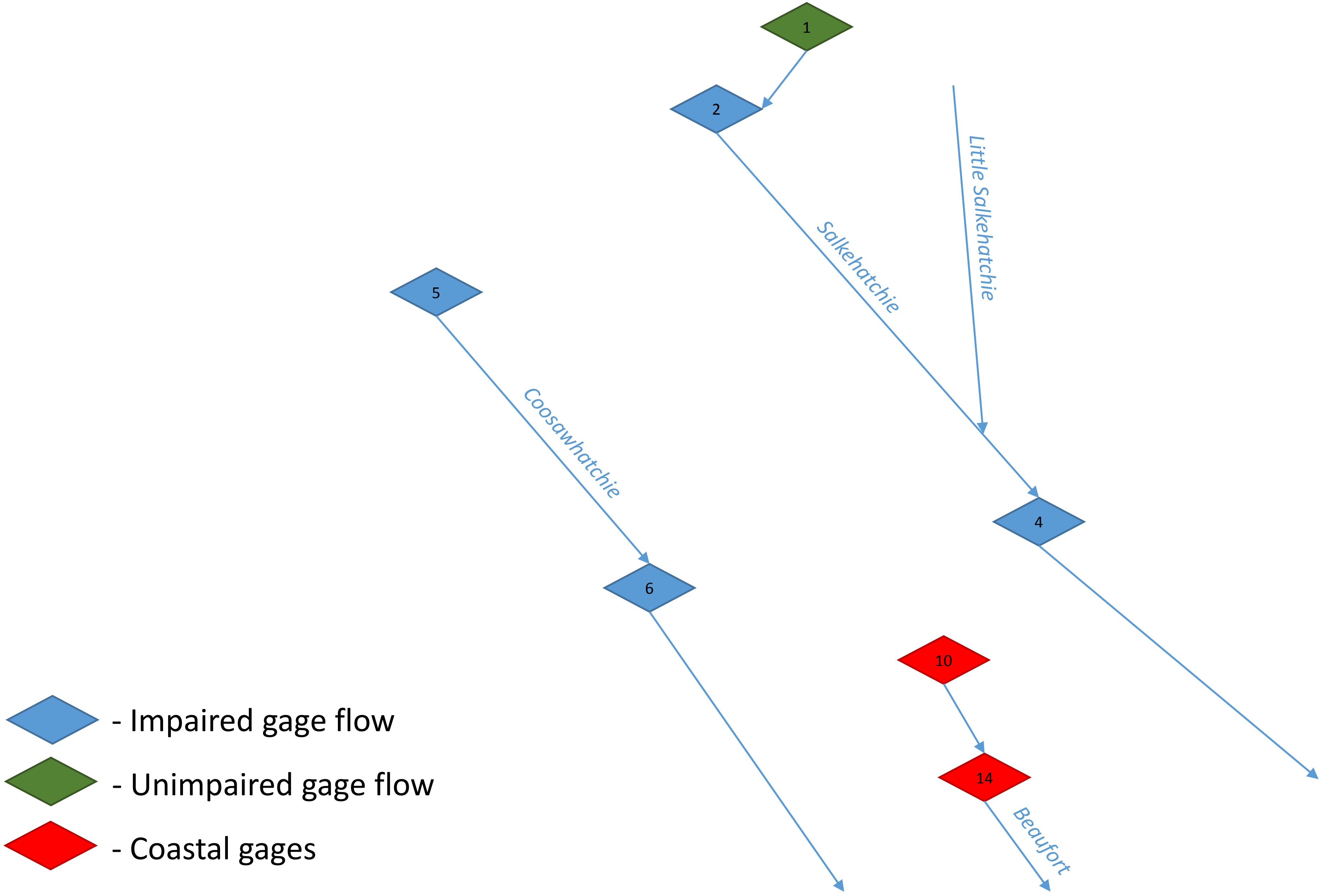
ATTACHMENT F

Discussion on Reference Gage and Method Selection

Gage	Reference	Method	Notes
SLK01	SLK02	MOVE.1-no transform	RMSE and PRESS lowest for MOVE.1-no transform. Matches best in decision plots. No transform matches low flows much better than log transform.
SLK04	SLK02	MOVE.1-log transform	RMSE and PRESS lowest for MOVE.1-log transform. Matches best in decision plots.
SLK06	SLK05	Area Ratio	Statistics for all 3 methods similar. Area ratio captures low flows the best whereas MOVE.1 caps the minimum flow.

ATTACHMENT G

Schematic of USGS Streamflow Gages in the Salkehatchie River Basin



Attachment G: Schematic of USGS Streamflow Gages in the Salkehatchie River Basin