Technical Memorandum

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

From: *CDM Smith*

Date: *July 2016*

Subject: *Unimpaired Flow Dataset for the Broad 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 Broad River Basin. The TM references the electronic database, which houses the completed UIF dataset for the Broad 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 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 Broad River Basin, UIFs were calculated at most locations in which a USGS gage has recorded historical flow measurements. The full list of which USGS gages produced viable UIFs can be seen in Table 4.1 of **Attachment A.** Note, since the release of Attachment A, two gages were removed for backwater effects: BRD52 and BRD58. 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 1929-2013 (coinciding with the longest, continuously recorded streamflow in the basin). As a final step, the UIFs in ungaged basins were estimated from UIFs in gaged basins with similar size, land use, and topography.

UIFs are intended to be used for the following purposes:

a) Headwater input to the SWAM models

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

c) SWAM model calibration

d) Comparison of simulated managed flows to natural flows

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

Figure 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, Broad River Basin, South Carolina (CDM Smith, January 2016)* – 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. Within the Methodology TM are the following:
    - *Guidelines for Standardizing and Simplifying Operational Record Extension (CDM Smith, March 2016)* – Included as Attachment B of the Methodology TM. 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 the Methodology TM.
- *Refinements to the UIF Extension Process, with an Example* – Included as **Attachment C.**

Figure 2.2 illustrates the locations of all UIFs developed for the Broad River Basin, and distinguishes between those computed by adjusting measured streamflow at USGS gages, and those computed for ungaged basins through area transposition. The two black circles indicate the nodes from which OASIS arc flows were extracted (see Section 6.1 of Attachment A for explanation of OASIS boundary condition flows). Additionally, **Attachment F** contains a simplified schematic of the USGS streamflow gages and OASIS nodes.

Several situations arose that required specific adjustments to the UIFs unique to the Broad basin. Each are described as follows:

- BRD01, USGS gage 02153200 on the Broad River near Blacksburg, SC requires model output from the North Carolina OASIS model. Specifically, this is arc flow from Node 500 near the state line, upstream of Gaston Shoals Reservoir from 1929-2009. In order to complete UIF calculations for BRD01, both modeled UIF and managed flows from North Carolina are needed from this node. However, these flows end 9/30/2009 and require extension to 12/31/2013. For managed flows, the 2009-2013 period was created from the USGS gage 02151500 on the Broad River near Boiling Springs, approximately 8 miles upstream of the state line. Managed flows for 2009-2013 were predicted from a linear regression of the Boiling Springs flows, and given evidence of change in flow regime, the linear regression uses only 2005-2009 data. For unimpaired flows, area-prorated BRD10 (02154500 on North Pacolet River at Fingerville, SC) filled the 2009-2013 period. Though nearly a tenth in total drainage area compared to BRD01, BRD10 has well-correlated flows (~94% on log-transformed flows using Pearson's coefficient), relatively few impairments, similar land use characteristics, and a continuous flow record back to 1930.
- BRD02, USGS gage 02153500 on the Broad River near Gaffney, SC, includes flows from the major tributary Buffalo Creek—a stream which predominantly has North Carolina drainage. These flows are represented by the NC OASIS model Node 610 near the state line on Buffalo Creek. Like with Node 500, these are managed and unimpaired flows from 1929-2009 and 2009-2013 flows need estimation. According to OASIS model documentation, the Buffalo Creek unimpaired flows were originally estimated from USGS gage 02143500 on Indian Creek near Laboratory, NC. Given the Indian Creek gage is active 2009-2013, prorating its flows forms the UIFs at Node 610. However, unlike with Node 500, there is not a USGS gage upstream on Buffalo Creek from which managed flows can be estimated. For lack of better data, the 2009-2013 managed flows were estimated using a linear regression which predicts impairments given unimpaired flow.
- BRD12, USGS gage 02155500 on the Pacolet River near Fingerville, SC, has a unique situation in that performing calculated UIFs with historic reservoir data would have required accounting for the connected Spartanburg reservoirs of Lake Bowen and Municipal Reservoir #1. As Lake Bowen only has measured elevations for part of its record, calculating historical changes in storage would have required elevation hindcasting and several years of gap-filling. Lake Bowen is controlled to maintain hydropower operations in Reservoir #1, which does

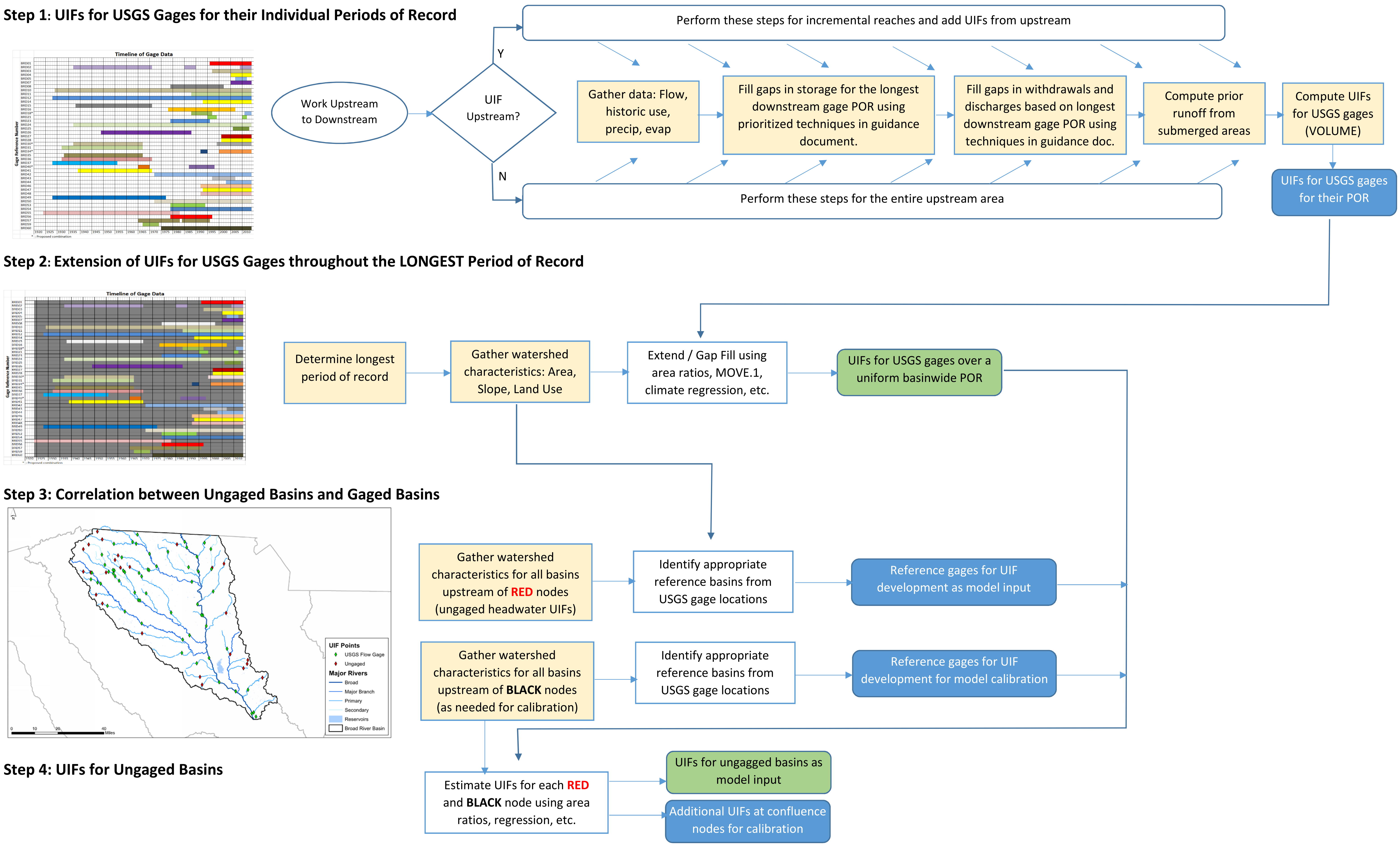
not have recorded elevations. However, given Lake Bowen was constructed in 1960 and that Reservoir #1 has been historically operated as run-of-river, UIFs can be reliably calculated for BRD12 before 1960. As BRD10 (02154500 on North Pacolet River at Fingerville, SC) offers nearly the same period of record as BRD12, is immediately upstream on the North Pacolet, has similar land use and highly correlated flows, area-prorated UIFs from BRD10 is an appropriate alternative to calculating UIFs at BRD12 after 1960. After comparing area-prorated BRD10 with BRD12's UIFs before 1960 and using linear regression to predict BRD12 using BRD10 UIFs, only a slight modification to the slope of regression provides a robust estimation of BRD12's post-1960 UIFs.

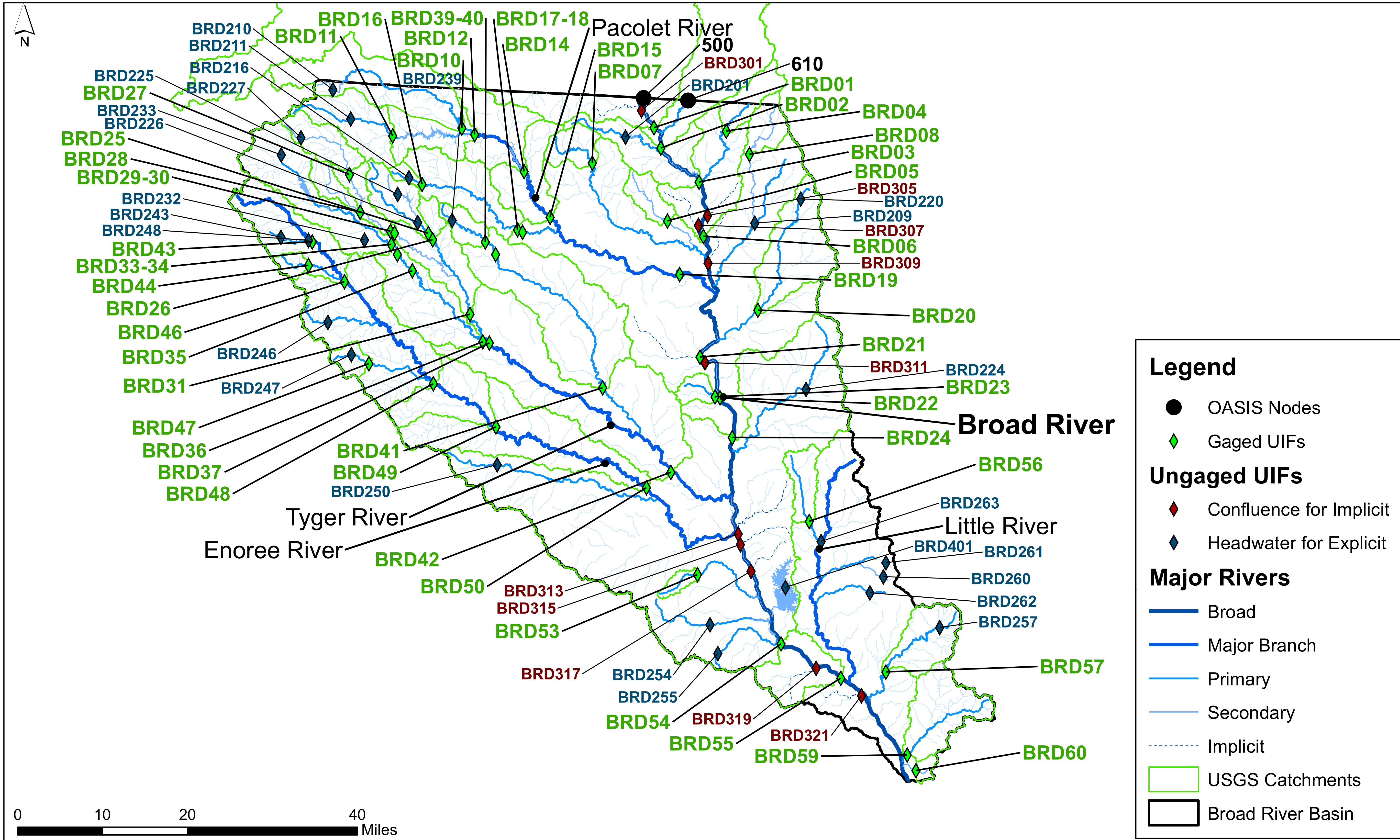
- BRD14, USGS gage 021556525 on the Pacolet below Lake Blalock, had another complicated scenario. Lake Blalock underwent several years of construction including repairs and raising of the dam. During these years, there was not a consistent stage-storage-elevation relationship. Additionally, USGS elevations are not available for all years of the lake's existence, thus operational hindcasting and multiple-year gap filling would have been needed. As BRD14 is downstream of BRD12 on the Pacolet, using area-prorated BRD10 flows was a viable alternative for similar reasons as with BRD12. Unlike BRD12, BRD14 does not have a long period of record and does not have flows before the construction of Lake Blalock, thus the same type of early-record comparisons as with BRD12 could not be performed. However, given lake operations stabilized from 2010 onward, calculated UIFs for BRD14 were compared with area-prorated BRD10. Similar to BRD12, the resulting linear regression of predicting BRD14 based on prorated BRD10 UIFs needed a slight adjustment, only this time with separate modifiers for low and high flows.

- Two gages on the South Tyger River, BRD35 (02158500), BRD36 (02159000), and BRD37 (02159500) on the Tyger River, required 7-day threshold-based smoothing as their flows exhibited an operational signal. This signal can be attributed to hydropower operations on Berry's Pond, which ended in 1968. Given the period of the signal, a 7-day moving average was applied, unless the flow exceeds 1300 cfs anytime within a 9-day moving window, otherwise the UIF remains as-is. This technique ensures no flattening of large peaks in the hydrograph without adding significant volume. The determination of the 9-day moving was assessed qualitatively based on hydrograph shape on the transitions between smoothed or as-is values.

- Parr Shoals is currently assumed as run-of-river, but flows in the early records of BRD24 (02156500) and BRD55 (02161500) on the Broad River indicate some sort of regulation. Lacking sufficient data to unimpair this regulation, these two gages required a 7-day smoothing before 1960.

Figure 2.1: Stepwise Procedure for UIF Calculation – Broad Basin





CDM Smith

Figure 2.2: Unimpaired Flow Locations in the Broad 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 B**.

The Quality Assurance results are documented in each UIF workbook in the "QAQC" worksheet. Documentation includes the name of the reviewer, requested changes, and changes made. Some review items pertaining to the UIF extension calculations exist separately from the individual UIF workbooks, but are still listed in **Attachment 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 water user. A summary of hindcasting methods used for withdrawals, discharges, and storage are presented in **Table 4.1, Table 4.2** and **Table 4.3**, respectively. Reference Attachment A and for details on the listed methodologies.

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

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
BRD01	02153200	BROAD RIVER NEAR BLACKSBURG, SC	11WS001S02	Gaffney Board of Public Works	1/1/1983 - 12/1/1993	Monthly averages
BRD02	02153500	BROAD RIVER NEAR GAFFNEY, SC	11IN002S01	Milliken & Company	None	All data provided
BRD03	02153551	BROAD RIVER BELOW NINETYNINE ISLAND RESERVOIR,SC	11WS001S01	Gaffney Board of Public Works	1/1/1965 - 12/1/1982	Monthly averages
BRD10	02154500	NORTH PACOLET RIVER AT FINGERVILLE, SC	42WS001S01	Inman Campobello Water District	None	Not in operation yet
			42WS008S01	Spartanburg Commission of Public Works	None	All data provided

Project Gage ID	USGS Number	Stream	Withdrawal Hindcasting			
			User ID	User Name	Time Periods	Method Used
			42WS008S01	City of Landrum	1/1/1925 - 12/1/1982	Monthly averages
			42WS008S02	Spartanburg Commission of Public Works	None	All data provided
BRD12	02155500	PACOLET RIVER NEAR FINGERVILLE, SC	42WS014S01	Spartanburg Commission of Public Works	1/1/1926 - 12/1/1994	Anecdotal information and monthly averages
BRD14	021556525	PACOLET RIVER BELOW LAKE BLALOCK NEAR COWPENS, SC	42WS004S01	Spartanburg Commission of Public Works	1/1/1999 - 12/1/2000	Short term gap filling
BRD19	02156370	PACOLET RIVER NEAR SARATT,SC	42IN075S01	Reflective Recycling	None	Non-responder
			42MI001S01	Vulcan Construction Materials	1/1/1950 - 12/1/2009	Long-term gap filling
			42MI001S02	Vulcan Construction Materials	1/1/1950 - 12/1/2009	Long-term gap filling
BRD20	021563931	TURKEY CREEK NEAR LOWRYS, SC	46WS002S01	City of York	1/1/1956 - 12/1/1982	Anecdotal information, monthly averages, and short term gap filling
BRD22	021564493	BROAD RIVER BELOW NEAL SHOALS RES. NR CARLISLE,SC	44WS001S01	City of Union	1/1/1939 - 12/1/1982	Population data and monthly averages
BRD24	02156500	BROAD RIVER NEAR CARLISLE, SC	12IN002S01	Chemtrade	1/1/1974 - 7/1/1983	Anecdotal information
			12IN002S02	Chemtrade	1/1/1974 - 12/1/1982	Anecdotal information
			44IN003S01	Carlisle Finishing LLC	1/1/1957 - 12/1/1982	Anecdotal information
BRD25	02156999	N. TYGER RIVER BELOW WELLFORD, SC	42WS012S02	Startex Jackson Wellford Water District	None	All data provided
			42WS012S03	Startex Jackson Wellford Water District	None	All data provided

Project Gage ID	USGS Number	Stream	Withdrawal Hindcasting			
			User ID	User Name	Time Periods	Method Used
BRD30	02157510	MIDDLE TYGER RIVER NEAR LYMAN, SC	42IN005S01	Startex Jackson Wellford Water District	None	All data provided
			42IN005S02	Startex Jackson Wellford Water District	1/1/1925 - 12/1/1982	Monthly averages
			42IN005S03	Startex Jackson Wellford Water District	None	All data provided
			42WS012S01	Startex Jackson Wellford Water District	1/1/2001 - 12/1/2001	Short term gap filling
BRD33	02158408	SOUTH TYGER RIVER BELOW DUNCAN, SC	23WS004S01	Greer Commission of Public Works	1/1/1925 - 12/1/1982	Population data and monthly averages
BRD36	02159000	SOUTH TYGER RIVER NEAR WOODRUFF, S. C.	42WS005S02	Woodruff Roebuck Water District	None	All data provided
BRD37	02159500	TYGER RIVER NEAR WOODRUFF, S. C.	42WS005S01	Woodruff Roebuck Water District	None	All data provided
BRD41	02160000	FAIRFOREST CREEK NEAR UNION, S.C.	42GC010S01	The Carolina Country Club	1/1/1997 - 12/1/2001	Long term gap filling
BRD47	02160381	DURBIN CREEK ABOVE FOUNTAIN INN, SC	23GC003S01	Fountain Inn Simpsonville CC	1/1/1986 - 12/1/2000	Long term gap filling
BRD48	02160390	ENOREE RIVER NEAR WOODRUFF, SC	42GC013S01	Willow Creek Golf Club	1/1/1995 - 12/1/2000	Long term gap filling
BRD50	02160700	ENOREE RIVER AT WHITMIRE, SC	30GC003S02	Musgrove Mill Golf Club	1/1/1988 - 12/1/2000	Long term gap filling
			30WS001S01	City of Clinton	None	All data provided
			36WS003S01	Town of Whitmire	1/1/1944 - 12/1/1982	Monthly averages
BRD52	02160750	BROAD RIVER AT BLAIR,SC	30WS001S02	City of Clinton	None	All data provided
			36WS003S02	Town of Whitmire	None	All data provided
BRD54	02161000	BROAD RIVER AT ALSTON, SC	20PN001S01	SCE&G	None	All data provided
			20PN001S02	SCE&G	None	All data provided

Project Gage ID	USGS Number	Stream	Withdrawal Hindcasting			
			User ID	User Name	Time Periods	Method Used
			36GC050S01	Mid Carolina Club	1/1/1968 - 12/1/2000	Annual and monthly averages
BRD58	02162035	BROAD RIVER NEAR COLUMBIA, SC	20WS001S01	Town of Winnsboro	None	All data provided
			20WS001S03	Town of Winnsboro	None	All data provided

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
BRD02	02153500	BROAD RIVER NEAR GAFFNEY, SC	BLACKSBURG/CANOE CREEK	SC0026042-001	None	Combined with SC0047457-001
			BLACKSBURG/CANOE CREEK (NEW)	SC0047457-001	5/1975 - 1/1989	Correlated with monthly withdrawal (Gaffney)
			MILLIKEN/MAGNOLIA FINISHING PLANT	SC0003182-001	1/1983 - 1/1989	Correlated with monthly withdrawal (Milliken)
			COKER WAREHOUSE GAFFNEY	SC0035947-001	2/1984 - 1/1989	Hindcasted to known start date (industrial discharge)
BRD03	02153551	BROAD RIVER BELOW NINETYNINE ISLAND RESERVOIR,SC	GAFFNEY/PEOPLES CREEK	SC0020478-001	None	Combined with SC0047091-001
			GAFFNEY/PEOPLES CRK-BROAD RVR	SC0047091-001	11/1974 - 1/1989	Correlated with monthly withdrawal (Gaffney)
			GAFFNEY/PROVIDENCE CREEK	SC0020508-001	None	Combined with SC0047091-001
BRD10	02154500	NORTH PACOLET RIVER AT	SSSD/PAGE CREEK WWTP	SC0026875-001	10/1925-2/1989	Correlated with monthly withdrawal (Landrum)

Project Gage ID	USGS Number	Stream	Discharge Hindcasting			
			ID	Facility Name	Time Periods	Method Used
		FINGERVILLE, SC	SSSD/PAGE CREEK WWTP	SC0026875-002	None	Combined with SC0026875-001
			MILLIKEN/NEW PROSPECT MILL	SC0023540-001	7/1975-1/1989	Hindcasted to known start date (industrial discharge)
			ONEITA INDUSTRIES/FINGERVILLE	SC0035157-001	None	None
			SWS LANDRUM WTP	SCG64500	10/1925 - 12/2013	Estimated based on permit return (Landrum)
BRD12	02155500	PACOLET RIVER NEAR FINGERVILLE, SC	SIMMS WTP	SCG646049	1/1926 - 12/2006	Estimated based on permit return; directly measured after 2007 (Spartanburg)
BRD14	021556525	PACOLET RIVER BELOW LAKE BLALOCK NEAR COWPENS, SC	CHESNEE WWTF	SC0025763-001	7/1985 - 1/1989	Correlated with monthly withdrawal (Spartanburg)
BRD15	02156000	PACOLET RIVER NEAR CLIFTON, S. C.	R R DONNELLEY AND SONS CO	SC0036102-001	None	None
			AURIGA POLYMERS INC./SPARTANBURG	SC0002798-002	7/1978 - 1/1989	Correlated with monthly withdrawal (Spartanburg)
			SSSD/CLIFTON WWTP	SC0042668-001	1/1926 - 1/1989	Correlated with monthly withdrawal (Spartanburg)
			SSSD/COWPENS-PACOLET RIVER	SC0045624-001	None	Small gap filling
			SSSD/HILLBROOK FOREST SD	SC0029718-001	None	Combined with SC0042668-001
BRD16	02156050	LAWSONS FORK CREEK AT DEWEY PLANT NR INMAN, SC	CITY OF INMAN/LAWSONS FORK CREEK	SC0024414-001	3/1986 - 1/1989	Hindcasted to known start date (historical source too complicated for easy use)

Project Gage ID	USGS Number	Stream	Discharge Hindcasting			
			ID	Facility Name	Time Periods	Method Used
BRD17	02156300	LAWSONS FORK CREEK AT SPARTANBURG SC	INMAN, CITY OF	SC0021601-001	5/1985 - 1/1989	Hindcasted to known start date (historical source too complicated for easy use)
			MILLIKEN/DEWEY PLANT	SC0003581-001	2/1976 - 1/1989	Hindcasted to known start date (historical source too complicated for easy use)
			SPARTAN MILLS/BEAUMONT PLANT	SC0002437-001	None	None
BRD18	02156301	LAWSON FORK CREEK @ TREATMENT PLANT @ SPARTANBURG	SSSD/LAWSON FORK PLANT	SC0020427-001	1/1931 - 1/1989	Correlated with monthly withdrawal (Spartanburg)
BRD19	02156370	PACOLET RIVER NEAR SARATT,SC	CHEVRON USA/CAMP CROFT	SC0040703-001	None	None
			ISG PACOLET FACILITY	SC0002411-002	None	None
			ISG PACOLET FACILITY	SC0002411-003	None	Combined with SC0002411-002
			ISG PACOLET FACILITY	SC0002411-02A	None	Combined with SC0002411-002
			SSSD/FAIRFOREST PLANT	SC0020435-002	None	None
			SSSD/PACOLET MILLS WWTP	SC0044717-001	None	None
			VULCAN MATERIALS - PACOLET Quarry	SCG730293	1/1950 - 12/2013	Estimated based on permitted return (Vulcan)
BRD21	02156409	BROAD RIVER NEAR LOCKHART, SC	GAFFNEY/CLARY WWTF	SC0031551-001	7/1978 - 1/1989	Correlated with monthly withdrawal (Gaffney)
			TIMKEN COMPANY/GAFFNEY BEARING	SC0000949-001	None	None

Project Gage ID	USGS Number	Stream	Discharge Hindcasting			
			ID	Facility Name	Time Periods	Method Used
			LOCKHART TREATMENT FACILITY	SC0003051-001	9/1978 - 1/1989	Correlated with monthly withdrawal (Union)
BRD22	021564493	BROAD RIVER BELOW NEAL SHOALS RES. NR CARLISLE,SC	CITY OF UNION WTP	SCG646042	1/1939 - 12/1013	Estimated based on permitted return (Union)
			UNION/MENG CREEK (NEW)	SC0047236-001	None	None
BRD24	02156500	BROAD RIVER NEAR CARLISLE, SC	CONE MILLS CORP/CARLISLE PLANT	SC0001368-001	1/1957 - 1/1989	Correlated with monthly withdrawal (Carlisle Finishing)
			CHEMTRADE PERF CHEMICALS/LEEDS	SC0022756-001	1/1974 - 7/1989	Correlated with monthly withdrawal (Chemtrade)
BRD31	02158000	NORTH TYGER RIVER NEAR MOORE, S. C.	SPARTAN MILLS/STARTEX MILL	SC0002453-001	7/1974 - 1/1989	Hindcasted to known start date (industrial discharge)
			SPARTAN MILLS/STARTEX MILL	SC0002453-002	None	Combined with SC0002453-001
			LYMAN, CITY OF	SC0021300-001	12/1977 - 1/1989	Correlated with historic purchases (Spartanburg)
			SJWD WTP	SJWD WTP	7/1998 - 12/2004	Estimated based on permit return; directly measured values after 2005 (SJWD)
			SSSD/LOWER N TYGER RIVER WWTP	SC0048143-001	None	None
			SSSD/N TYGER RIVER WWTP	SC0043532-001	None	Combined SC0048143-001
BRD33	02158408		GREER/MAPLE CREEK PLANT	SC0020761-001	None	Combined with SC0046345-001

Project Gage ID	USGS Number	Stream	Discharge Hindcasting			
			ID	Facility Name	Time Periods	Method Used
		SOUTH TYGER RIVER BELOW DUNCAN, SC	GREER/MAPLE CREEK PLANT	SC0046345-001	10/1947 - 1/1989	Correlated with monthly withdrawal (Greer)
			GREER/S. TYGER RIVER PLANT	SC0020770-001	None	Combined with SC0046345-001
			UNITED UTILS/N GREENVILLE COLL	SC0026565-001	None	Small gap filling
			DUNCAN WWTF	SC0021008-001	None	Combined with SC0046345-001
BRD36	02159000	SOUTH TYGER RIVER NEAR WOODRUFF, S. C.	MIDLAND CAPITAL LLC/MOORE PLANT	SC0036145-001	5/1982 - 1/1989	Hindcasted to known start date (industrial discharge)
			SSSD/S. TYGER RV REGIONAL WWTP	SC0047732-001	None	None
BRD39	02159800	FAIRFOREST CREEK AT SPARTANBURG, S. C.	I-85 DISTRIBUTION CENTER SITE	SC0048178-001	None	Small gap filling
			SPARTAN MILLS/SPARTAN PLANT	SC0002445-001	None	Small gap filling
BRD41	02160000	FAIRFOREST CREEK NEAR UNION, S.C.	SSSD/FAIRFOREST PLANT	SC0020435-001	1/1931 - 1/1989	Correlated with monthly withdrawal (Spartanburg)
			JONESVILLE, TOWN OF	SC0024988-001	6/1975 - 1/1989	Correlated with monthly withdrawal (Union)
BRD42	02160105	TYGER RIVER NEAR DELTA, SC	SC DEPT CORR/TYGER RIVER CORRE	SC0036773-001	11/1979 - 12/1991	Hindcasted to known start date (industrial discharge)
			UNION/BELTLINE PLANT	SC0021202-001	None	Combined with SC0047244-001
			UNION/TOSCHS CREEK PLANT	SC0021172-001	None	Combined with SC0047244-001
			UNION/TOSCH'S CREEK WWTP	SC0047244-001	1/1939 - 1/1989	Correlated with monthly withdrawal (Union)

Project Gage ID	USGS Number	Stream	Discharge Hindcasting			
			ID	Facility Name	Time Periods	Method Used
BRD46	02160326	ENOREE RIVER AT PELHAM, SC	WCRSA/PELHAM WWTF	SC0033804-001	1/1978 - 1/1989	Correlated with monthly withdrawal (Greenville)
			WCRSA/TAYLORS AREA PLANT	SC0024309-001	12/1970 - 1/1989	Correlated with monthly withdrawal (Greenville)
			HOECHST CELANESE/GREER	SC0001791-001	10/1975 - 1/1989	Hindcasted to known start date (industrial discharge)
BRD48	02160390	ENOREE RIVER NEAR WOODRUFF, SC	GE/GAS TURBINE MFG OPERATION	SC0003484-001	None	None
			WCRSA/DURBIN CREEK	SC0040002-001	1/1985 - 1/1989	Correlated with monthly withdrawal (Greenville)
			WCRSA/GILDER CREEK	SC0040525-001	5/1986 - 1/1989	Correlated with monthly withdrawal (Greenville)
			WOODRUFF/ENOREE RIVER	SC0045802-001	None	None
BRD52	02160750	BROAD RIVER AT BLAIR,SC	CHESTER/SANDY RIVER WWTF	SC0036081-001	6/1980 - 1/1989	Hindcasted to known start date (Catawba withdrawal not developed yet)
			WHITMIRE, TOWN OF	SC0022390-001	1/1944 - 1/1989	Correlated with monthly withdrawal (Whitmire)
BRD54	02161000	BROAD RIVER AT ALSTON, SC	NCW&SA/CANNONS CREEK WWTP	SC0048313-001	None	None
			SCE&G/V C SUMMER NUCLEAR STAT	SC0030856-001	7/1983 - 1/1989	Correlated with monthly withdrawal (V.C. Summer)
			SCE&G/V C SUMMER NUCLEAR STAT	SC0030856-002	None	Combined with pipe 001

Project Gage ID	USGS Number	Stream	Discharge Hindcasting			
			ID	Facility Name	Time Periods	Method Used
			SCE&G/V C SUMMER NUCLEAR STAT	SC0030856-007	None	Combined with pipe 001
			SCE&G/V C SUMMER NUCLEAR STAT	SC0030856-008	None	Combined with pipe 001
			SCE&G/V C SUMMER NUCLEAR STAT	SC0030856-014	None	Combined with pipe 001
BRD55	02161500	BROAD RIVER AT RICHTEX, S. C.	CHAPIN, TOWN OF	SC0040631-001	11/1986 - 1/1989	Correlated with monthly withdrawal (Columbia)
BRD57	02162010	CEDAR CREEK NEAR BLYTHEWOOD, SC	RIDGEWAY, TOWN OF	SC0022900-001	7/1978 - 1/1989	Correlated with monthly withdrawal (Winnsboro)
BRD58	02162035	BROAD RIVER NEAR COLUMBIA, SC	RICHLAND CO/BROAD RIVER WWTF	SC0046621-001	None	None
			WINNSBORO/JACKSON CREEK PLANT	SC0020125-001	4/1978 - 1/9189	Correlated with monthly withdrawal (Winnsboro)

Table 4.3: Summary of Methods Used for Hindcasting Storage

Project Gage ID	USGS Number	Stream	Storage Hindcasting		
			Reservoir Name	Time Periods	Method Used
BRD01	02153200	BROAD RIVER NEAR BLACKSBURG, SC	Gaston Shoals	10/1925 - 10/1997	Random Forest hindcast; small gaps filled via interpolation
BRD03	02153551	BROAD RIVER BELOW NINETYNINE ISLAND RESERVOIR,SC	Ninety-Nine Islands Lake	None	Assumed run-of-river before observed elevations; small gaps filled via interpolation

Project Gage ID	USGS Number	Stream	Storage Hindcasting		
			Reservoir Name	Time Periods	Method Used
			Lake Whelchel	None	Assumed run-of-river
BRD12	02155500	PACOLET RIVER NEAR FINGERVILLE, SC	Spartanburg Municipal Reservoir #1	None	Assumed run-of-river
			Lake William C. Bowen	None	None
BRD14	021556525	PACOLET RIVER BELOW LAKE BLALOCK NEAR COWPENS, SC	Lake H. Taylor Blalock	None	None
BRD22	021564493	BROAD RIVER BELOW NEAL SHOALS RES. NR CARLISLE,SC	Neal Shoals Reservoir	None	Assumed run-of-river
BRD25	02156999	N. TYGER RIVER BELOW WELLFORD, SC	Lake Cooley	None	Assumed run-of-river
BRD30	02157510	MIDDLE TYGER RIVER NEAR LYMAN, SC	Lyman Lake	None	Assumed run-of-river
BRD34	02158410	SOUTH TYGER RIVER BELOW LYMAN, SC	Lake John A. Robinson	None	Assumed run-of-river
			Lake Cunningham	None	Assumed run-of-river
BRD54	02161000	BROAD RIVER AT ALSTON, SC	Parr Shoals	None	Assumed run-of-river before observed elevations; small gaps filled via interpolation
			Monticello Reservoir and Recreation Lake	1/1978 - 12/2002	Based on monthly averages of pumped/generated flows

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

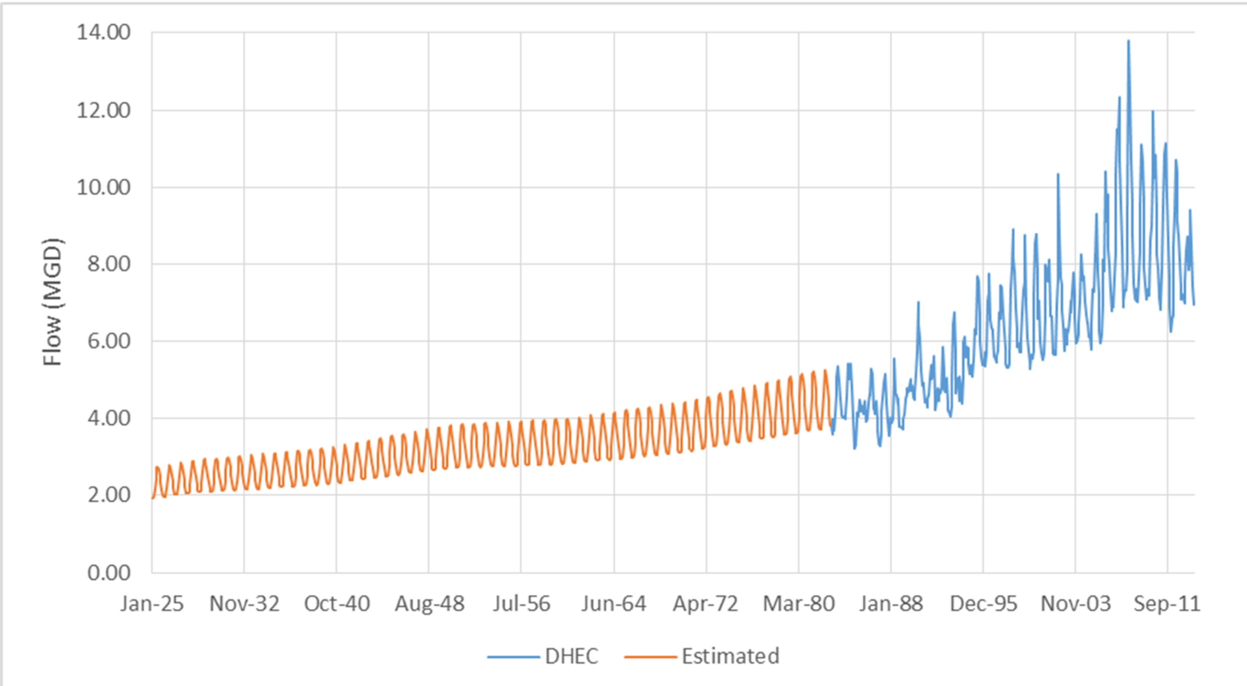


Figure 4.1: Hindcasting Using Anecdotal and Population Information for City of Greer Withdrawals

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

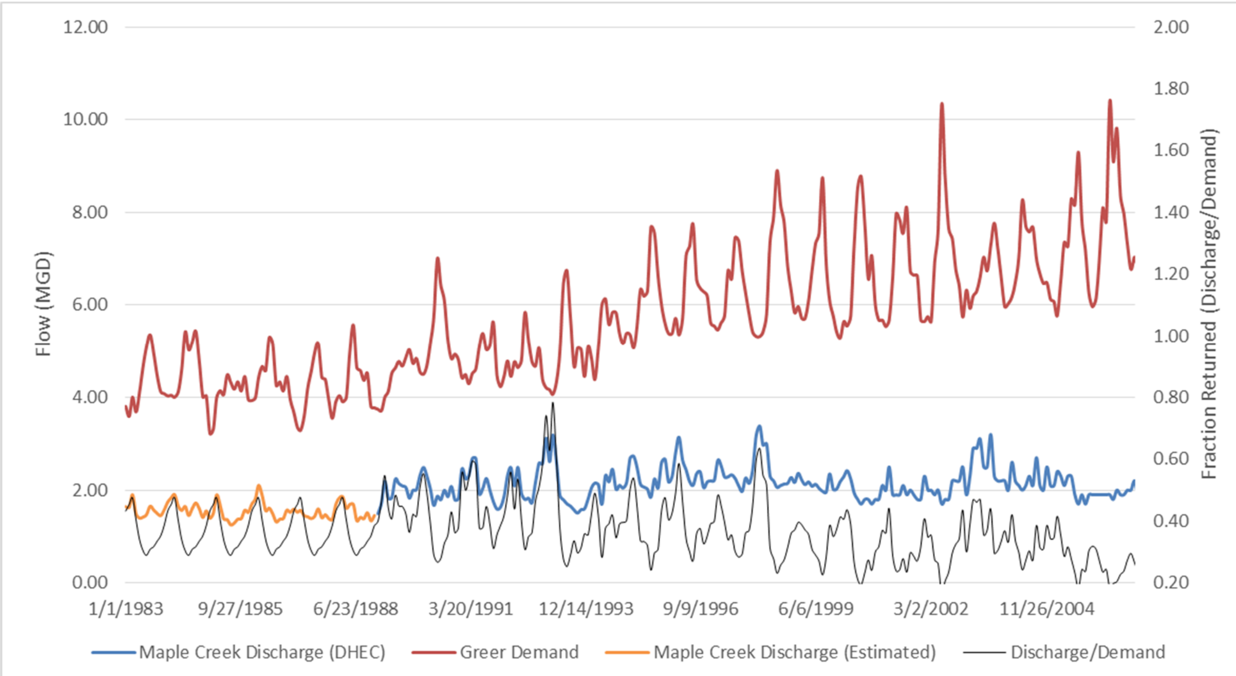


Figure 4.2: Hindcasting Discharge for Maple Creek Plant Based on Withdrawals for City of Greer

Many of the reservoirs on the Broad mainstem can be assumed run-of-river and correspondence with users, such as Duke Energy, supports this. However, the observed elevations for Gaston Shoals, while possibly indicating annual patterns, have too much range in drawdown and recovery to represent standard run-of-river operations. Though there are available reservoir models for Gaston Shoals, they contain current operating rules and may not capture historical reservoir dynamics. In the Saluda, the hindcasting methods developed relied on simple predicted variables such as cumulative precipitation. But, these methods were restricted to a single n-day cumulative amount of precipitation. For this Gaston Shoals, 30-day increments up to 2 years' worth of precipitation were correlated with elevations only to produce marginal results.

Rather than explicitly single out a definitive pattern, a random forest regression was developed to heuristically predict elevations based on observed combinations implicit in historic observations. Instead of picking one n-day sum of precipitation, a matrix of different n-day sums can be used in multivariate prediction. Unlike with parametric regressions, predictors can be correlated, though this can cause some model overfitting. In addition to summed precipitation, n-day totals of evaporation were used as predictors as well. Random forests also allow categorical predictors, and after testing several time classes, the best response appeared from month, but not day of week. A random forest only resamples observed values, thus can never extend beyond the extreme ranges within the fitting period. Additionally, the model may attribute elevation variability that likely occurred due to operator-specific reasons, not necessarily to specific predictor combinations. Thus, the hindcast does not exhibit as much variability compared to the verification period (See Figure 4.3 and Figure 4.4). But, since Gaston Shoals is currently considered run-of-river by Duke, one would not expect much more drawdown and range than already observed.

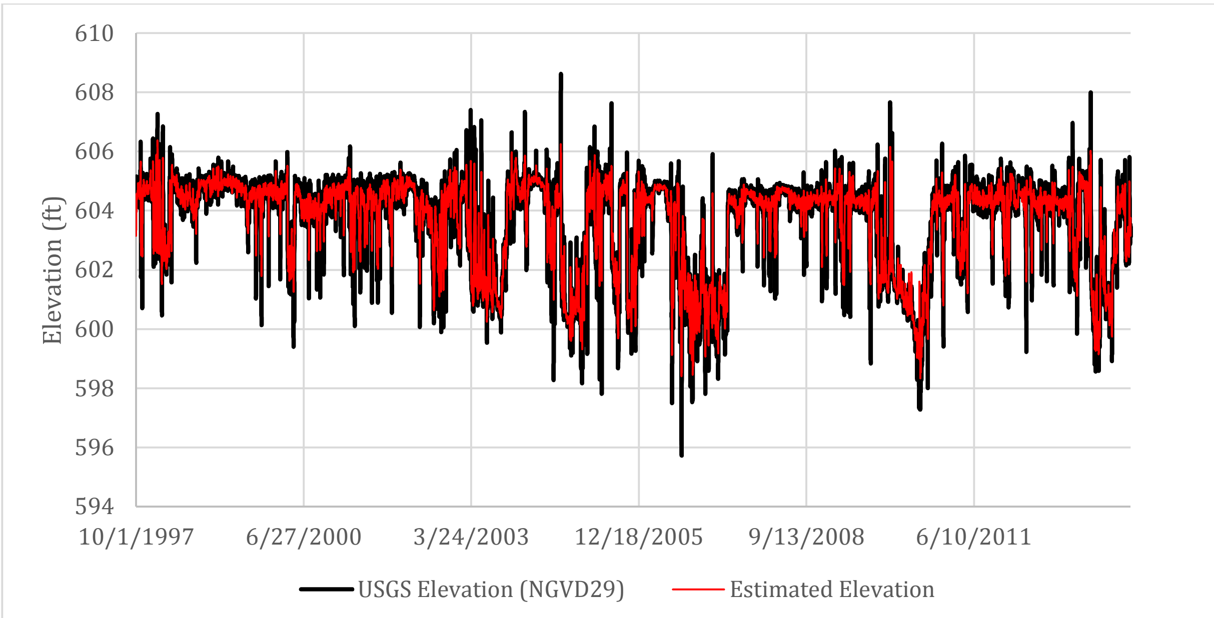


Figure 4.3: Validation of Hindcasting using Random Forest for Gaston Shoals

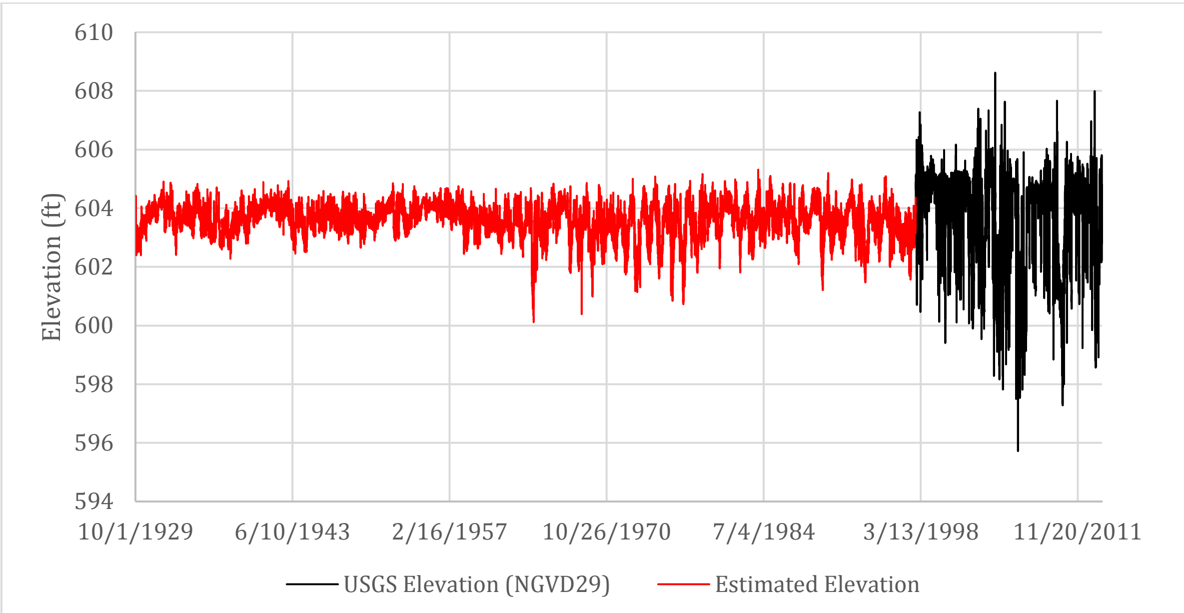


Figure 4.4: Complete Timeseries (Estimated and Observed) for Gaston Shoals

Another unique reservoir situation is the pairing of Parr Shoals and Lake Monticello. Monticello envelops almost the entire Frees Creek watershed and essentially operates as an off-line reservoir. Water is pumped up to Monticello and released from it by the Fairfield pumped storage facility, within the impoundment of Parr Shoals. By performing a mass balance of pumped/generated Fairfield flows, V.C. Summer Nuclear Station consumptive use, local runoff from unsubmerged Frees Creek watershed, and net precipitative/evaporative gains/losses (including increased evaporation from reactor cooling water) the overall change in storage for Monticello can be simplified as a withdrawal term in the Parr Shoals UIF calculations. However, Monticello elevations were only available from 2002 onward and Fairfield flows only available after 2006. For before 2002, the Monticello storage changes are determined by simple monthly averages of pumped/generated Fairfield flows.

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 A. See Attachment C for details pertaining to the decision-making process and **Attachment E** 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 BRD43 and BRD46, the lowest flow is 2.7 cfs. Thus, when MOVE.1 is calculated using BRD43's untransformed flows, any days below 2.7 cfs are replaced with the corresponding flows of that day found from area proration. Note that if a reference gage registers a flow of zero, the extended flow for the partial gage will also be estimated as zero.

UIFs from neighboring basins were considered as well in the record extension process. After evaluating all metrics, ultimately three from the Saluda and two from the Catawba were used. The Saluda UIFs consisted of SLD14 (02165200 on South Rabon Creek near Gray Court, SC), SLD28 (02169550 on Congaree Creek at Cayce, SC), and SLD29 (02169570 on Gills Creek at Columbia, SC). The Catawba UIFs included CAT01 (02145642 on Crowders Creek near Clover, SC) and CAT15 (021473428 on Wildcat Creek below Rock Hill, SC).

The draft UIF dataset initially contained UIFs for BRD52 (02160750 on Broad River at Blair, SC) and BRD58 (02162035 on Broad River near Columbia, SC). It became known that both are impacted by backwater effects from Parr Reservoir and Columbia dam (respectively) and thus both were removed from the final dataset.

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 (mi²)	Project Gage ID	Stream	Basin Area (mi²)	
BRD01	02153200	BROAD RIVER NEAR BLACKSBURG, SC	9/1997 - 12/2013	1317	BRD02	BROAD RIVER NEAR GAFFNEY, SC	1501	MOVE.1: no transform, Area Ratio if MOVE.1 < 251 cfs
					BRD10	NORTH PACOLET RIVER AT FINGERVILLE, SC	114	MOVE.1 (log transform)
					BRD49	ENOREE RIVER NEAR ENOREE S. C.	306	Area Ratio
BRD02	02153500	BROAD RIVER NEAR GAFFNEY, SC	12/1938 - 9/1971 4/1986 - 9/1990 2/2010 - 12/2013	1501	BRD01	BROAD RIVER NEAR BLACKSBURG, SC	1317	MOVE.1: no transform, Area Ratio if MOVE.1 < 302 cfs
					BRD10	NORTH PACOLET RIVER AT FINGERVILLE, SC	114	MOVE.1 (log transform)
					BRD49	ENOREE RIVER NEAR ENOREE S. C.	306	Area Ratio

USGS Gage with Partial Record					USGS Reference Gage(s)			Method of Extension
Project Gage ID	USGS Number	Stream	Periods of Record	Basin Area (mi²)	Project Gage ID	Stream	Basin Area (mi²)	
BRD03	02153551	BROAD RIVER BELOW NINETYNINE ISLAND RESERVOIR,SC	10/1998 - 12/2013	1559	BRD02	BROAD RIVER NEAR GAFFNEY, SC	1501	MOVE.1 (log transform)
					BRD01	BROAD RIVER NEAR BLACKSBURG, SC	1317	Area Ratio
					BRD10	NORTH PACOLET RIVER AT FINGERVILLE, SC	114	MOVE.1 (log transform)
					BRD49	ENOREE RIVER NEAR ENOREE S. C.	306	Area Ratio
BRD04	02153590	KINGS CREEK AT BLACKSBURG, SC	4/2006 - 9/2010 9/2011 - 12/2013	28	BRD07	THICKETTY CREEK AT CNTY ROAD 42 NEAR GAFFNEY, SC	24	MOVE.1 (log transform)
					BRD43	ENOREE RIVER AT TAYLORS, SC	50	MOVE.1 (log transform)
					BRD18	LAWSON FORK CREEK @ TREATMENT PLANT @ SPARTANBURG	76	MOVE.1 (log transform)
					BRD02	BROAD RIVER NEAR GAFFNEY, SC	1501	MOVE.1 (log transform)
					BRD10	NORTH PACOLET RIVER AT FINGERVILLE, SC	114	MOVE.1 (log transform)
					BRD49	ENOREE RIVER NEAR ENOREE S. C.	306	Area Ratio
BRD05	021536097	GILKEY CREEK NEAR WILKINSVILLE, SC	7/2008 - 11/2012	20	BRD02	BROAD RIVER NEAR GAFFNEY, SC	1501	MOVE.1 (log transform)
					BRD47	DURBIN CREEK ABOVE FOUNTAIN INN, SC	13	MOVE.1 (log transform)
					BRD04	KINGS CREEK AT BLACKSBURG, SC	28	MOVE.1 (log transform)
					BRD10	NORTH PACOLET RIVER AT FINGERVILLE, SC	114	MOVE.1 (log transform)
					BRD49	ENOREE RIVER NEAR ENOREE S. C.	306	Area Ratio

USGS Gage with Partial Record					USGS Reference Gage(s)			Method of Extension
Project Gage ID	USGS Number	Stream	Periods of Record	Basin Area (mi²)	Project Gage ID	Stream	Basin Area (mi²)	
BRD06	02153680	BROAD R NR HICKORY GROVE S C	6/2001 - 9/2003	1666	BRD03	BROAD RIVER BELOW NINETYNINE ISLAND RESERVOIR,SC	1559	MOVE.1: no transform, Area Ratio if MOVE.1 < 144 cfs
					BRD01	BROAD RIVER NEAR BLACKSBURG, SC	1317	Area Ratio
					BRD10	NORTH PACOLET RIVER AT FINGERVILLE, SC	114	MOVE.1 (log transform)
					BRD49	ENOREE RIVER NEAR ENOREE S. C.	306	Area Ratio
BRD07	02153700	THICKETTY CREEK AT CNTY ROAD 42 NEAR GAFFNEY, SC	3/2006 - 12/2013	24	BRD11	SOUTH PACOLET RIVER NR CAMPOBELLO, SC	55	MOVE.1: no transform, Area Ratio if MOVE.1 < 0.03 cfs
					BRD02	BROAD RIVER NEAR GAFFNEY, SC	1501	MOVE.1: no transform, Area Ratio if MOVE.1 < 0.03 cfs
					BRD10	NORTH PACOLET RIVER AT FINGERVILLE, SC	114	MOVE.1 (log transform)
					BRD49	ENOREE RIVER NEAR ENOREE S. C.	306	Area Ratio
BRD08	02153780	CLARKS FORK CREEK NR SMYRNA, SC	10/1980 - 9/2002	24	CAT01	CROWDERS CREEK (RD 1104) NEAR CLOVER, SC	89	MOVE.1: no transform, Area Ratio if MOVE.1 < 0 cfs
					BRD04	KINGS CREEK AT BLACKSBURG, SC	28	Area Ratio
					BRD10	NORTH PACOLET RIVER AT FINGERVILLE, SC	114	MOVE.1 (log transform)
					BRD49	ENOREE RIVER NEAR ENOREE S. C.	306	Area Ratio
BRD10	02154500	NORTH PACOLET RIVER AT FINGERVILLE, SC	4/1930 - 12/2013	114	BRD12	PACOLET RIVER NEAR FINGERVILLE, SC	209	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)	
					BRD37	TYGER RIVER NEAR WOODRUFF, S. C.	343	MOVE.1 (log transform)
					BRD49	ENOREE RIVER NEAR ENOREE S. C.	306	MOVE.1 (log transform)
BRD11	02154790	SOUTH PACOLET RIVER NR CAMPOBELLO, SC	1/1989 - 12/2013	55	BRD10	NORTH PACOLET RIVER AT FINGERVILLE, SC	114	MOVE.1 (log transform)
					BRD12	PACOLET RIVER NEAR FINGERVILLE, SC	209	MOVE.1 (log transform)
					BRD49	ENOREE RIVER NEAR ENOREE S. C.	306	Area Ratio
BRD12	02155500	PACOLET RIVER NEAR FINGERVILLE, SC	12/1929 - 9/1996 10/1997 - 9/2006 6/2007 - 12/2013	209	BRD10	NORTH PACOLET RIVER AT FINGERVILLE, SC	114	MOVE.1 (log transform)
					BRD49	ENOREE RIVER NEAR ENOREE S. C.	306	MOVE.1 (log transform)
BRD14	02155652 5	PACOLET RIVER BELOW LAKE BLALOCK NEAR COWPENS, SC	11/1993 - 12/2013	271	BRD12	PACOLET RIVER NEAR FINGERVILLE, SC	209	MOVE.1 (log transform)
					BRD49	ENOREE RIVER NEAR ENOREE S. C.	306	Area Ratio
BRD15	02156000	PACOLET RIVER NEAR CLIFTON, S. C.	10/1939 - 9/1971	323	BRD12	PACOLET RIVER NEAR FINGERVILLE, SC	209	MOVE.1: no transform, Area Ratio if MOVE.1 < 29 cfs
					BRD10	NORTH PACOLET RIVER AT FINGERVILLE, SC	114	MOVE.1 (log transform)
					BRD49	ENOREE RIVER NEAR ENOREE S. C.	306	MOVE.1 (log transform)
BRD16	02156050	LAWSONS FORK CREEK AT DEWEY PLANT NR INMAN, SC	10/1979 - 7/2007	6	BRD26	NORTH TYGER RIVER NEAR FAIRMONT, S. C.	44	MOVE.1 (log transform)
					BRD18	LAWSON FORK CREEK @ TREATMENT PLANT @ SPARTANBURG	76	MOVE.1 (log transform)
					BRD46	ENOREE RIVER AT PELHAM, SC	85	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)	
					BRD12	PACOLET RIVER NEAR FINGERVILLE, SC	209	MOVE.1 (log transform)
					BRD49	ENOREE RIVER NEAR ENOREE S. C.	306	Area Ratio
BRD17-BRD18	02156300 /02156301	LAWSON FORK CREEK @ TREATMENT PLANT @ SPARTANBURG	5/1989 - 9/1997 6/2012 - 12/2013	76	BRD28	BEAVERDAM CREEK ABOVE GREER, SC	16	MOVE.1 (log transform)
					BRD16	LAWSONS FORK CREEK AT DEWEY PLANT NR INMAN, SC	6	MOVE.1 (log transform)
					BRD40	FAIRFOREST CREEK BELOW SPARTANBURG, S.C.	23	MOVE.1 (log transform)
					BRD12	PACOLET RIVER NEAR FINGERVILLE, SC	209	MOVE.1 (log transform)
					BRD49	ENOREE RIVER NEAR ENOREE S. C.	306	Area Ratio
BRD19	02156370	PACOLET RIVER NEAR SARATT,SC	8/2012 - 12/2013	502	BRD14	PACOLET RIVER BELOW LAKE BLALOCK NEAR COWPENS, SC	271	MOVE.1 (log transform)
					BRD12	PACOLET RIVER NEAR FINGERVILLE, SC	209	MOVE.1 (log transform)
					BRD49	ENOREE RIVER NEAR ENOREE S. C.	306	Area Ratio
BRD20	021563931	TURKEY CREEK NEAR LOWRYS, SC	12/2000 - 8/2003	82	CAT15	WILDCAT CREEK BELOW ROCK HILL, SC	30	MOVE.1: no transform, Area Ratio if MOVE.1 < 7 cfs
					SLD14	SOUTH RABON CREEK NEAR GRAY COURT, SC	30	MOVE.1 (log transform)
					BRD42	TYGER RIVER NEAR DELTA, SC	756	MOVE.1 (log transform)
					BRD10	NORTH PACOLET RIVER AT FINGERVILLE, SC	114	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)	
					BRD49	ENOREE RIVER NEAR ENOREE S. C.	306	Area Ratio
BRD21	02156409	BROAD RIVER NEAR LOCKHART, SC	10/1996 - 9/1999 4/2011 - 11/2012	2658	BRD03	BROAD RIVER BELOW NINETYNINE ISLAND RESERVOIR,SC	1559	MOVE.1 (log transform)
					BRD02	BROAD RIVER NEAR GAFFNEY, SC	1501	MOVE.1 (log transform)
					BRD10	NORTH PACOLET RIVER AT FINGERVILLE, SC	114	MOVE.1 (log transform)
					BRD49	ENOREE RIVER NEAR ENOREE S. C.	306	Area Ratio
BRD22	021564493	BROAD RIVER BELOW NEAL SHOALS RES. NR CARLISLE,SC	3/2012 - 12/2013	2730	BRD03	BROAD RIVER BELOW NINETYNINE ISLAND RESERVOIR,SC	1559	MOVE.1 (log transform)
					BRD02	BROAD RIVER NEAR GAFFNEY, SC	1501	MOVE.1 (log transform)
					BRD10	NORTH PACOLET RIVER AT FINGERVILLE, SC	114	MOVE.1 (log transform)
					BRD49	ENOREE RIVER NEAR ENOREE S. C.	306	Area Ratio
BRD23	02156450	NEALS CREEK NR CARLISLE, SC	10/1980 - 9/1996	12	BRD48	ENOREE RIVER NEAR WOODRUFF, SC	249	MOVE.1: no transform, Area Ratio if MOVE.1 < 0.58 cfs
					SLD14	SOUTH RABON CREEK NEAR GRAY COURT, SC	30	MOVE.1 (log transform)
					BRD26	NORTH TYGER RIVER NEAR FAIRMONT, S. C.	44	MOVE.1 (log transform)
					BRD49	ENOREE RIVER NEAR ENOREE S. C.	306	Area Ratio
BRD24	02156500	BROAD RIVER NEAR CARLISLE, SC	10/1938 - 12/2013	2781	BRD55	BROAD RIVER AT RICHTEX, S. C.	4826	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)	
BRD25	02156999	N. TYGER RIVER BELOW WELLFORD, SC	5/2007 - 11/2013	34	BRD26	NORTH TYGER RIVER NEAR FAIRMONT, S. C.	44	Area Ratio
					BRD11	SOUTH PACOLET RIVER NR CAMPOBELLO, SC	55	MOVE.1 (log transform)
					BRD10	NORTH PACOLET RIVER AT FINGERVILLE, SC	114	MOVE.1 (log transform)
					BRD49	ENOREE RIVER NEAR ENOREE S. C.	306	Area Ratio
BRD26	02157000	NORTH TYGER RIVER NEAR FAIRMONT, S. C.	10/1950 - 9/1988	44	BRD25	N. TYGER RIVER BELOW WELLFORD, SC	34	Area Ratio
					BRD37	TYGER RIVER NEAR WOODRUFF, S. C.	343	MOVE.1 (log transform)
					BRD10	NORTH PACOLET RIVER AT FINGERVILLE, SC	114	MOVE.1 (log transform)
					BRD49	ENOREE RIVER NEAR ENOREE S. C.	306	MOVE.1 (log transform)
BRD27	02157470	MIDDLE TYGER RIVER NEAR GRAMLING, SC	2/2002 - 12/2013	33	BRD11	SOUTH PACOLET RIVER NR CAMPOBELLO, SC	55	MOVE.1 (log transform)
					BRD10	NORTH PACOLET RIVER AT FINGERVILLE, SC	114	MOVE.1 (log transform)
					BRD49	ENOREE RIVER NEAR ENOREE S. C.	306	Area Ratio
BRD28	02157490	BEAVERDAM CREEK ABOVE GREER, SC	3/2002 - 12/2013	16	BRD43	ENOREE RIVER AT TAYLORS, SC	50	MOVE.1 (log transform)
					BRD18	LAWSON FORK CREEK @ TREATMENT PLANT @ SPARTANBURG	76	MOVE.1 (log transform)
					BRD30	MIDDLE TYGER RIVER NEAR LYMAN, SC	69	Area Ratio
					BRD10	NORTH PACOLET RIVER AT FINGERVILLE, SC	114	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)	
					BRD49	ENOREE RIVER NEAR ENOREE S. C.	306	Area Ratio
BRD29-BRD30	02157500 /02157510	MIDDLE TYGER RIVER NEAR LYMAN, SC	2/1938 - 9/1967 2/2000 - 12/2013	69	BRD11	SOUTH PACOLET RIVER NR CAMPOBELLO, SC	55	MOVE.1 (log transform)
					BRD37	TYGER RIVER NEAR WOODRUFF, S. C.	343	MOVE.1 (log transform)
					BRD26	NORTH TYGER RIVER NEAR FAIRMONT, S. C.	44	MOVE.1: no transform, Area Ratio if MOVE.1 < 15.5 cfs
					BRD10	NORTH PACOLET RIVER AT FINGERVILLE, SC	114	MOVE.1 (log transform)
					BRD49	ENOREE RIVER NEAR ENOREE S. C.	306	MOVE.1 (log transform)
BRD31	02158000	NORTH TYGER RIVER NEAR MOORE, S. C.	10/1933 - 9/1967	161	BRD37	TYGER RIVER NEAR WOODRUFF, S. C.	343	MOVE.1 (log transform)
					BRD30	MIDDLE TYGER RIVER NEAR LYMAN, SC	69	MOVE.1 (log transform)
					BRD26	NORTH TYGER RIVER NEAR FAIRMONT, S. C.	44	MOVE.1 (log transform)
					BRD49	ENOREE RIVER NEAR ENOREE S. C.	306	MOVE.1 (log transform)
					BRD10	NORTH PACOLET RIVER AT FINGERVILLE, SC	114	MOVE.1 (log transform)
BRD33-BRD34	02158408 /02158410	SOUTH TYGER RIVER BELOW LYMAN, SC	7/1993 - 1/1995 2/2001 - 12/2013	93	BRD30	MIDDLE TYGER RIVER NEAR LYMAN, SC	69	MOVE.1 (log transform)
					BRD43	ENOREE RIVER AT TAYLORS, SC	50	MOVE.1 (log transform)
					BRD48	ENOREE RIVER NEAR WOODRUFF, SC	249	MOVE.1 (log transform)
					BRD26	NORTH TYGER RIVER NEAR FAIRMONT, S. C.	44	Area Ratio

USGS Gage with Partial Record					USGS Reference Gage(s)			Method of Extension
Project Gage ID	USGS Number	Stream	Periods of Record	Basin Area (mi²)	Project Gage ID	Stream	Basin Area (mi²)	
					BRD10	NORTH PACOLET RIVER AT FINGERVILLE, SC	114	MOVE.1 (log transform)
					BRD49	ENOREE RIVER NEAR ENOREE S. C.	306	Area Ratio
BRD35	02158500	SOUTH TYGER RIVER NEAR REIDVILLE, S. C.	10/1934 - 9/1967	101	BRD36	SOUTH TYGER RIVER NEAR WOODRUFF, S. C.	172	MOVE.1 (log transform)
					BRD37	TYGER RIVER NEAR WOODRUFF, S. C.	343	MOVE.1 (log transform)
					BRD30	MIDDLE TYGER RIVER NEAR LYMAN, SC	69	MOVE.1 (log transform)
					BRD26	NORTH TYGER RIVER NEAR FAIRMONT, S. C.	44	Area Ratio
					BRD10	NORTH PACOLET RIVER AT FINGERVILLE, SC	114	MOVE.1 (log transform)
					BRD49	ENOREE RIVER NEAR ENOREE S. C.	306	MOVE.1 (log transform)
BRD36	02159000	SOUTH TYGER RIVER NEAR WOODRUFF, S. C.	10/1933 - 9/1971	172	BRD37	TYGER RIVER NEAR WOODRUFF, S. C.	343	MOVE.1 (log transform)
					BRD30	MIDDLE TYGER RIVER NEAR LYMAN, SC	69	MOVE.1 (log transform)
					BRD49	ENOREE RIVER NEAR ENOREE S. C.	306	MOVE.1 (log transform)
					BRD26	NORTH TYGER RIVER NEAR FAIRMONT, S. C.	44	MOVE.1 (log transform)
					BRD10	NORTH PACOLET RIVER AT FINGERVILLE, SC	114	MOVE.1 (log transform)
BRD37	02159500	TYGER RIVER NEAR WOODRUFF, S. C.	10/1929 - 9/1956	343	BRD31	NORTH TYGER RIVER NEAR MOORE, S. C.	161	MOVE.1 (log transform)
					BRD30	MIDDLE TYGER RIVER NEAR LYMAN, SC	69	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)**	
					BRD26	NORTH TYGER RIVER NEAR FAIRMONT, S. C.	44	MOVE.1 (log transform)
					BRD42	TYGER RIVER NEAR DELTA, SC	756	Area Ratio
					BRD49	ENOREE RIVER NEAR ENOREE S. C.	306	Area Ratio
BRD39-BRD40	02159800/02159810	FAIRFOREST CREEK BELOW SPARTANBURG, S.C.	3/1966 - 9/1970 5/1988 - 4/1998	23	BRD46	ENOREE RIVER AT PELHAM, SC	85	MOVE.1 (log transform)
BRD39-BRD40	02159800/02159810	FAIRFOREST CREEK BELOW SPARTANBURG, S.C.	3/1966 - 9/1970 5/1988 - 4/1998	23	BRD16	LAWSONS FORK CREEK AT DEWEY PLANT NR INMAN, SC	6	MOVE.1: no transform, Area Ratio if MOVE.1 < 6 cfs
BRD39-BRD40	02159800/02159810	FAIRFOREST CREEK BELOW SPARTANBURG, S.C.	3/1966 - 9/1970 5/1988 - 4/1998	23	BRD26	NORTH TYGER RIVER NEAR FAIRMONT, S. C.	44	MOVE.1 (log transform)
BRD39-BRD40	02159800/02159810	FAIRFOREST CREEK BELOW SPARTANBURG, S.C.	3/1966 - 9/1970 5/1988 - 4/1998	23	BRD41	FAIRFOREST CREEK NEAR UNION, S.C.	186	MOVE.1 (log transform)
BRD39-BRD40	02159800/02159810	FAIRFOREST CREEK BELOW SPARTANBURG, S.C.	3/1966 - 9/1970 5/1988 - 4/1998	23	BRD49	ENOREE RIVER NEAR ENOREE S. C.	306	MOVE.1 (log transform)
BRD41	02160000	FAIRFOREST CREEK NEAR UNION, S.C.	7/1940 - 9/1971	186	BRD49	ENOREE RIVER NEAR ENOREE S. C.	306	MOVE.1 (log transform)
BRD41	02160000	FAIRFOREST CREEK NEAR UNION, S.C.	7/1940 - 9/1971	186	BRD26	NORTH TYGER RIVER NEAR FAIRMONT, S. C.	44	MOVE.1 (log transform)
BRD41	02160000	FAIRFOREST CREEK NEAR UNION, S.C.	7/1940 - 9/1971	186	BRD30	MIDDLE TYGER RIVER NEAR LYMAN, SC	69	MOVE.1 (log transform)
BRD41	02160000	FAIRFOREST CREEK NEAR UNION, S.C.	7/1940 - 9/1971	186	BRD10	NORTH PACOLET RIVER AT FINGERVILLE, SC	114	MOVE.1 (log transform)
BRD42	02160105	TYGER RIVER NEAR DELTA, SC	10/1973 - 12/2013	756	BRD49	ENOREE RIVER NEAR ENOREE S. C.	306	MOVE.1 (log transform)
BRD43	02160200	ENOREE RIVER AT TAYLORS, SC	3/1998 - 10/2007	50	BRD46	ENOREE RIVER AT PELHAM, SC	85	MOVE.1 (log transform)
BRD43	02160200	ENOREE RIVER AT TAYLORS, SC	3/1998 - 10/2007	50	BRD11	SOUTH PACOLET RIVER NR CAMPOBELLO, SC	55	MOVE.1: no transform, Area Ratio if MOVE.1 < 2.7 cfs

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)	
					BRD10	NORTH PACOLET RIVER AT FINGERVILLE, SC	114	MOVE.1 (log transform)
					BRD49	ENOREE RIVER NEAR ENOREE S. C.	306	Area Ratio
BRD44	02160325	BRUSHY CREEK NEAR GREENVILLE, SC	8/2004 - 12/2013	9	BRD46	ENOREE RIVER AT PELHAM, SC	85	MOVE.1 (log transform)
					BRD16	LAWSONS FORK CREEK AT DEWEY PLANT NR INMAN, SC	6	MOVE.1 (log transform)
					BRD10	NORTH PACOLET RIVER AT FINGERVILLE, SC	114	MOVE.1 (log transform)
					BRD49	ENOREE RIVER NEAR ENOREE S. C.	306	Area Ratio
BRD46	02160326	ENOREE RIVER AT PELHAM, SC	3/1993 - 12/2013	85	BRD11	SOUTH PACOLET RIVER NR CAMPOBELLO, SC	55	MOVE.1 (log transform)
					BRD30	MIDDLE TYGER RIVER NEAR LYMAN, SC	69	MOVE.1: no transform, Area Ratio if MOVE.1 < 7 cfs
					BRD10	NORTH PACOLET RIVER AT FINGERVILLE, SC	114	MOVE.1 (log transform)
					BRD49	ENOREE RIVER NEAR ENOREE S. C.	306	Area Ratio
BRD47	02160381	DURBIN CREEK ABOVE FOUNTAIN INN, SC	7/1994 - 10/2007 10/2009 - 12/2013	13	BRD48	ENOREE RIVER NEAR WOODRUFF, SC	249	MOVE.1 (log transform)
					BRD50	ENOREE RIVER AT WHITMIRE, SC	443	MOVE.1 (log transform)
					BRD49	ENOREE RIVER NEAR ENOREE S. C.	306	Area Ratio
BRD48	02160390	ENOREE RIVER NEAR WOODRUFF, SC	2/1993 - 12/2013	249	BRD50	ENOREE RIVER AT WHITMIRE, SC	443	MOVE.1 (log transform)
					BRD30	MIDDLE TYGER RIVER NEAR LYMAN, SC	69	MOVE.1: no transform, Area Ratio if MOVE.1 < 14 cfs

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)	
					BRD49	ENOREE RIVER NEAR ENOREE S. C.	306	Area Ratio
BRD49	02160500	ENOREE RIVER NEAR ENOREE S. C.	10/1929 - 1/1977 9/1977 - 9/1997	306	BRD50	ENOREE RIVER AT WHITMIRE, SC	443	MOVE.1 (log transform)
BRD50	02160700	ENOREE RIVER AT WHITMIRE, SC	10/1973 - 12/2013	443	BRD49	ENOREE RIVER NEAR ENOREE S. C.	306	MOVE.1 (log transform)
BRD53	02160775	HELLERS CREEK NR POMARIA, SC	10/1980 - 9/1994	8	BRD56	WEST FORK LITTLE RIVER NR SALEM CROSSROADS, SC	25	MOVE.1 (log transform)
					BRD48	ENOREE RIVER NEAR WOODRUFF, SC	249	MOVE.1 (log transform)
					BRD57	CEDAR CREEK NEAR BLYTHEWOOD, SC	49	MOVE.1 (log transform)
					BRD49	ENOREE RIVER NEAR ENOREE S. C.	306	Area Ratio
BRD54	02161000	BROAD RIVER AT ALSTON, SC	10/1980 - 12/2013	4774	BRD50	ENOREE RIVER AT WHITMIRE, SC	443	MOVE.1 (log transform)
					BRD49	ENOREE RIVER NEAR ENOREE S. C.	306	Area Ratio
BRD55	02161500	BROAD RIVER AT RICHTEX, S. C.	10/1929 - 9/1983	4826	BRD54	BROAD RIVER AT ALSTON, SC	4774	MOVE.1: no transform, Area Ratio if MOVE.1 < 786 cfs
BRD56	02161700	WEST FORK LITTLE RIVER NR SALEM CROSSROADS, SC	10/1980 - 9/1997	25	SLD14	SOUTH RABON CREEK NEAR GRAY COURT, SC	30	MOVE.1 (log transform)
					BRD49	ENOREE RIVER NEAR ENOREE S. C.	306	Area Ratio
BRD57	02162010	CEDAR CREEK NEAR BLYTHEWOOD, SC	12/1966 - 9/1983 2/1985 - 9/1996	49	BRD23	NEALS CREEK NR CARLISLE, SC	12	MOVE.1 (log transform)
					BRD41	FAIRFOREST CREEK NEAR UNION, S.C.	186	MOVE.1 (log transform)
					BRD50	ENOREE RIVER AT WHITMIRE, SC	443	MOVE.1 (log transform)
					BRD49	ENOREE RIVER NEAR ENOREE S. C.	306	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)	
BRD59	02162080	CRANE CREEK AT COLUMBIA, S. C.	1/1968 - 9/1974	66	SLD29	GILLS CREEK AT COLUMBIA, SC	59	MOVE.1: no transform, Area Ratio if MOVE.1 < 0.1 cfs
					BRD57	CEDAR CREEK NEAR BLYTHEWOOD, SC	49	Area Ratio
					BRD49	ENOREE RIVER NEAR ENOREE S. C.	306	MOVE.1: no transform, Area Ratio if MOVE.1 < 0.1 cfs
BRD60	02162093	SMITH BRANCH AT NORTH MAIN ST AT COLUMBIA, SC	7/1976 - 12/2013	6	SLD29	GILLS CREEK AT COLUMBIA, SC	59	MOVE.1 (log transform)
					SLD28	CONGAREE CREEK AT CAYCE,S.C.	119	MOVE.1 (log transform)
					BRD49	ENOREE RIVER NEAR ENOREE S. C.	306	MOVE.1 (log transform)

One way to evaluate the selection of an extension method is comparing frequency curves with flows of the partial record needing extending. A sample plot for BRD15 is shown in **Figure 5.1**.

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 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 D.

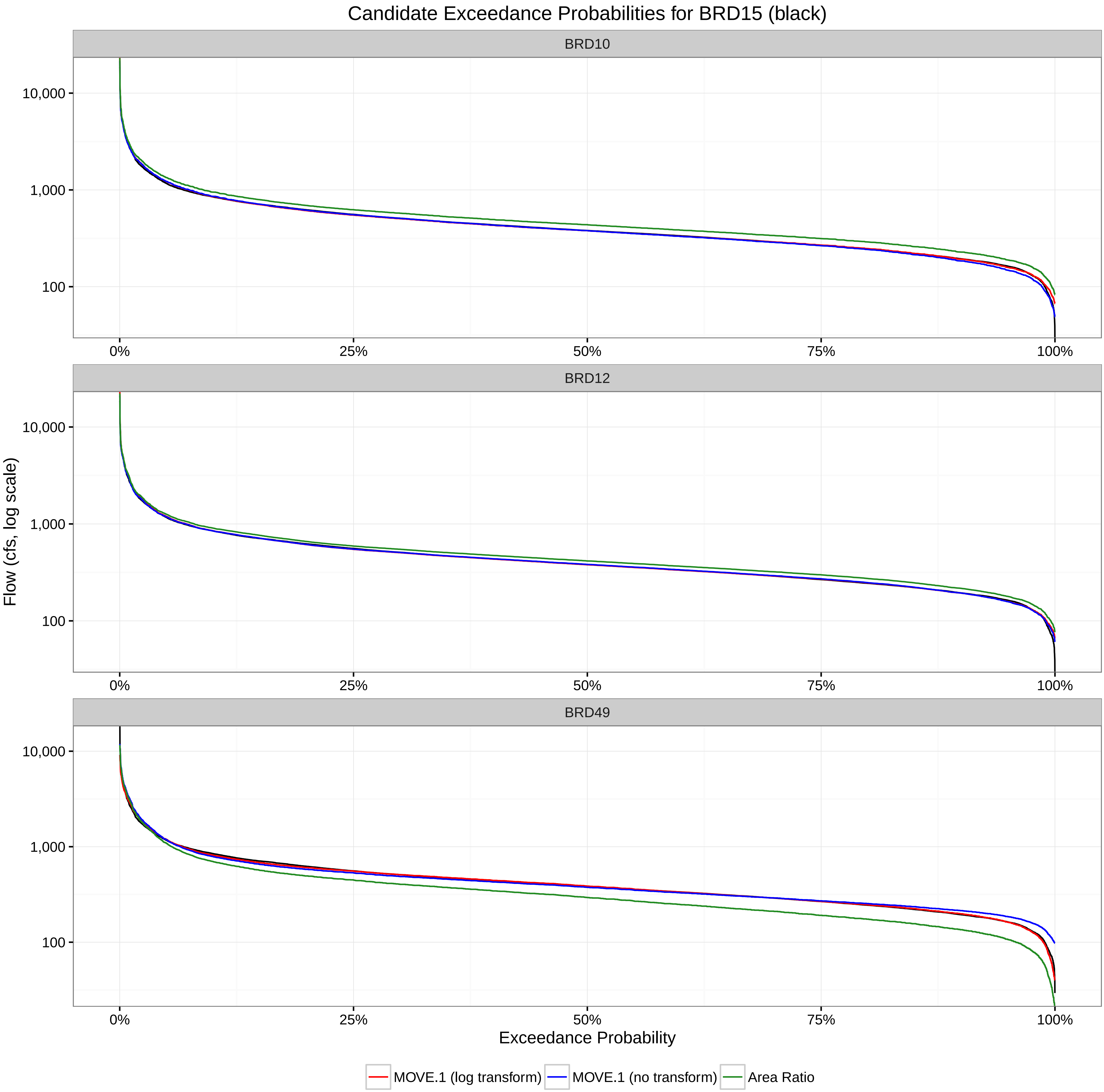


Figure 5.1: Comparison of Exceedance Probabilities for the Computed UIF and Extension Methods

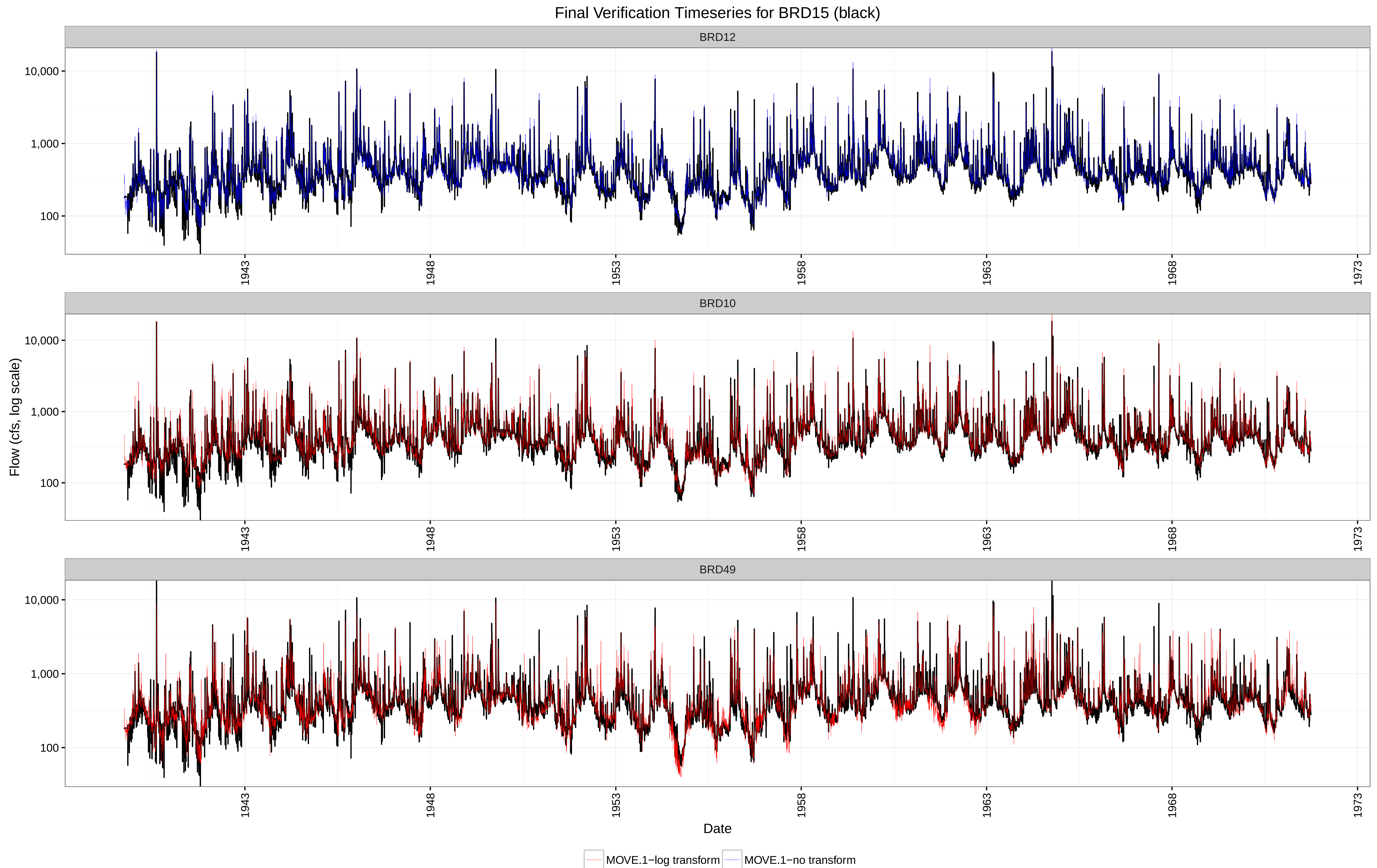


Figure 5.2: Validation Graph for BRD15 with Predicted Flows from Reference Gages

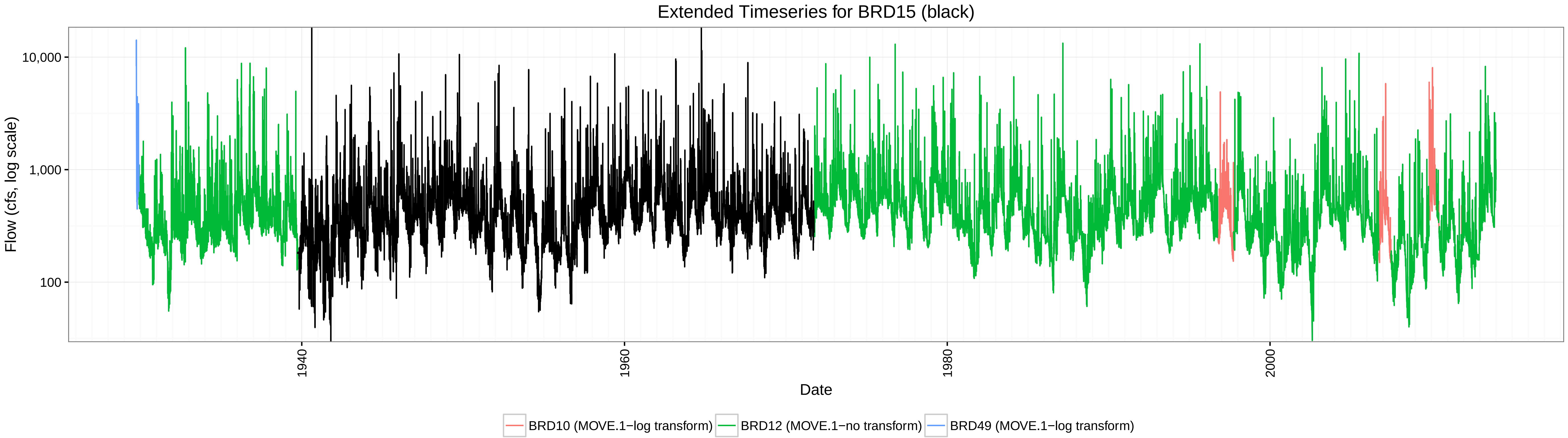


Figure 5.3: Resulting Timeseries for BRD15

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 A. **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)

	Ungaged Basin				USGS Reference Gage[1]				
Project ID	SWAM Usage	Stream	Basin Area (mi²)	% Developed / % Forest	Project Gage ID	USGS Number	Stream	Basin Area (mi²)	% Developed / % Forest
BRD301	Confluence Flow	Ross Creek	17.5	9.4 / 37.8	BRD04	02153590	KINGS CREEK AT BLACKSBURG, SC	27.9	12.7 / 57.2
BRD201	Headwater Flow	Cherokee Creek	11.2	20 / 30.2	BRD07	02153700	THICKETTY CREEK AT CNTY ROAD 42 NEAR GAFFNEY, SC	24.4	10.1 / 44.3
BRD305	Confluence Flow	Guyonmoore Creek	10.4	3.6 / 75.5	BRD08	02153780	CLARKS FORK CREEK NR SMYRNA, SC	24.1	2.5 / 82.1
BRD307	Confluence Flow	Abingdon Creek	13.7	4.4 / 75.7					
BRD309	Confluence Flow	Beaverdam Creek	6.4	4.7 / 56.4					
BRD209	Headwater Flow	Bullock Creek	37.4	4.1 / 56.1					
BRD210	Headwater Flow	Vaughn Creek	2.6	3.9 / 93.4	BRD10	02154500	NORTH PACOLET RIVER AT FINGERVILLE, SC	114.0	12.4 / 61.4
BRD211	Headwater Flow	Pacolet River	13.7	8.5 / 77.6	BRD11	02154790	SOUTH PACOLET RIVER NR CAMPOBELLO, SC	55.4	13.4 / 54.3
BRD216	Headwater Flow	Lawsons Fork Creek	4.2	41 / 27.1	BRD16	02156050	LAWSONS FORK CREEK AT DEWEY PLANT NR INMAN, SC	6.1	44.3 / 27.3

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

	Ungaged Basin				USGS Reference Gage[1]				
Project ID	**SWAM Usage**	**Stream**	**Basin Area (mi²)**	**% Developed / % Forest**	**Project Gage ID**	**USGS Number**	**Stream**	**Basin Area (mi²)**	**% Developed / % Forest**
BRD220	Headwater Flow	Turkey Creek	5.8	14.3 / 37.1	BRD20	021563931	TURKEY CREEK NEAR LOWRYS, SC	82.0	6.4 / 68.5
BRD311	Confluence Flow	Browns Creek	53.1	7.6 / 58.9	BRD23	02156450	NEALS CREEK NR CARLISLE, SC	12.1	2.8 / 82.8
BRD225	Headwater Flow	Jordan Creek	3.0	13.3 / 30.9	BRD25	02156999	N. TYGER RIVER BELOW WELLFORD, SC	34.2	20 / 40.1
BRD226	Headwater Flow	Tyger River	19.2	20.6 / 37.3	BRD25	02156999	N. TYGER RIVER BELOW WELLFORD, SC	34.2	20 / 40.1
BRD227	Headwater Flow	Middle Tyger Creek	4.7	12.2 / 76.9	BRD27	02157470	MIDDLE TYGER RIVER NEAR GRAMLING, SC	32.8	10.3 / 57.5
BRD233	Headwater Flow	South Tyger River	12.3	7 / 64.1	BRD34	02158410	SOUTH TYGER RIVER BELOW LYMAN, SC	92.5	27.7 / 46.1
BRD239	Headwater Flow	Fairforest Creek	3.1	68.3 / 18.6	BRD40	02159810	FAIRFOREST CREEK BELOW SPARTANBURG, S.C.	23.0	74.4 / 19.3
BRD243	Headwater Flow	Mountain Creek	3.8	12.6 / 82.9	BRD44	02160325	BRUSHY CREEK NEAR GREENVILLE, SC	9.1	83.5 / 15
BRD248	Headwater Flow	Enoree River	37.5	24.5 / 50.3	BRD46	02160326	ENOREE RIVER AT PELHAM, SC	84.6	47.6 / 37.1
BRD246	Headwater Flow	Gilder Creek	11.2	78.2 / 14.6	BRD47	02160381	DURBIN CREEK ABOVE FOUNTAIN INN, SC	13.0	41.9 / 30.7
BRD247	Headwater Flow	Durbin Creek	3.8	50.6 / 29					
BRD250	Headwater Flow	Duncan Creek	16.8	14.3 / 50.8					
BRD254	Headwater Flow	Cannons Creek	43.1	10.3 / 62.7	BRD53	02160775	HELLERS CREEK NR POMARIA, SC	8.3	8.1 / 68.5
BRD255	Headwater Flow	Crimms Creek	2.9	6.3 / 64.5					
BRD313	Confluence Flow	Beaver Creek	43.7	2.4 / 76.3	BRD56	02161700	WEST FORK LITTLE RIVER NR SALEM CROSSROADS, SC	25.5	1.8 / 78
BRD315	Confluence Flow	Rocky Creek	11.2	2.9 / 80.8					
BRD317	Confluence Flow	Terrible Creek	11.4	2.2 / 79.9					

	Ungaged Basin				USGS Reference Gage[1]				
Project ID	**SWAM Usage**	**Stream**	**Basin Area (mi²)**	**% Developed / % Forest**	**Project Gage ID**	**USGS Number**	**Stream**	**Basin Area (mi²)**	**% Developed / % Forest**
BRD224	Headwater Flow	Sandy River	35.9	10.1 / 52.1					
BRD263	Headwater Flow	Little River	68.6	2 / 74.8					
BRD401	Headwater Flow	Monticello Local Inflow	6.9	8.1 / 68.5					
BRD257	Headwater Flow	Big Cedar Creek	4.1	3.4 / 67.7	BRD57	02162010	CEDAR CREEK NEAR BLYTHEWOOD, SC	49.1	8.6 / 71.1
BRD260	Headwater Flow	Sand Creek	1.3	6.7 / 21.9					
BRD261	Headwater Flow	Jackson Creek	2.3	28.5 / 16.3					
BRD262	Headwater Flow	Mill Creek	5.5	4 / 34.5					
BRD319	Confluence Flow	Wateree Creek	26.0	10.7 / 72.2					
BRD321	Confluence Flow	Hollinshead Creek	17.1	28.5 / 57.9					

List of Attachments

A. *Methodology for Unimpaired Flow Development, Broad River Basin, South Carolina* (CDM Smith, January 2016). This Technical Memorandum also contains:

   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)

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

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

D. UIF Timeseries Graphs at USGS Gage Locations

E. Discussion on Reference Gage and Method Selection

F. Schematic of USGS Streamflow Gages in Broad River Basin

ATTACHMENT A

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

(CDM Smith, January 2016)

Technical Memorandum

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

From: *CDM Smith*

Date: ***January 2016 (Final)***

Subject: *Methodology for Unimpaired Flow Development*
Broad 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 streamflow 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 Broad River Basin. It describes data needs, methods for filling data gaps, and issues specific to the Broad 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 Broad River Basin will extend from 1925-2013.

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 – Discharge to Reservoirs – Return Flow + Reservoir Surface Evaporation – Reservoir Surface Precipitation + Upstream change in Reservoir Storage + Runoff from previously unsubmerged area*
(Equation 1)

Where reservoirs with large surface areas exist upstream of streamflow gages, UIFs will account for runoff that would have occurred on land that was submerged by reservoirs at the time of streamflow readings. Direct precipitation on the reservoir surface will be replaced by this estimate in Equation 1.

2.0 Overview of the Broad Basin

The Broad River basin covers 5,330 square miles, 3,790 of which falls within South Carolina. Covering 12 percent of the land area of the state, it lies primarily within the Piedmont physiographic province, with edges in the Piedmont and Coastal Plain (**Figure 2-1**). The basin's major watercourse, the Broad River, originates in the Blue Ridge Mountains of North Carolina, flows south-southeastwardly for 60 miles before crossing the state line, and flows another 100 miles before joining the Saluda River to form the Congaree River near Columbia. (**Figure 2-2**). Major tributaries include the Pacolet River, Tyger River, Enoree River, and Little River.

Twenty-six active Unites States Geological Survey (USGS) gaging stations monitor streamflow in the basin, including seven on the Broad River, seven on major branches, and twelve on smaller tributaries. While the Broad River station at Alston (USGS 02161000) offers the earliest period of record beginning in 1896, this gage stopped recording in 1907 and the next earliest gage record does not appear until 1925 at the Broad River station at Richtex (USGS 02161500). As a result of this gap, the Richtex station serves as the starting date for record extension. The Pacolet River station near Fingerville (USGS 02155500) offers the longest, uninterrupted period of record, beginning in 1929. Average annual streamflow[1] in the Broad River varies from 1,680 cubic feet per second (cfs) near Blacksburg (USGS 02153200) to 4,240 cfs near Alston (USGS 02161000). The upper region's higher annual precipitation results in well-sustained and moderately variable streamflow. With downstream progression, rainfall and baseflow decrease and streamflow variability increases. Multiple hydroelectric and municipal water-supply reservoirs affect streamflow not only on the Broad River along its entire length, but also major tributaries.

Chapter 6 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).

[1] Restricted to overlapping calendar years of 1998-2013 between the two gages.

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

Figure 2-2: Broad River Basin Counties and Municipalities

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3.0 Water Users and Dischargers in the Broad 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 Broad 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), **Figure 3-2** (nuclear and hydroelectric), and **Figure 3-3** (agriculture and golf courses). 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 3-4**. Only discharges that typically average over 3 mg/m are listed in the tables and shown on **Figure 3-4**. 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.

Table 3-1. Currently Permitted or Registered Water Users in the Broad Basin

Intake ID	Facility Name	Withdrawal Tributary
Golf Course Users		
23GC003S01	FOX RUN COUNTRY CLUB	Durbin Creek
23GC009S01	HOLLY TREE COUNTY CLUB	Gilder Creek
23GC011S01	PEBBLE CREEK GOLF CLUB	Mountain Creek
23GC011S02	PEBBLE CREEK GOLF CLUB	Mountain Creek
23GC011S03	PEBBLE CREEK GOLF CLUB	Mountain Creek
30GC003S02	MUSGROVE MILL GOLF CLUB	Enoree River
36GC050S01	MID CAROLINA GOLF CLUB	Crimms Creek
42GC005S01	THE COUNTRY CLUB OF SPARTANBURG	Lawsons Fork Creek
42GC010S01	CAROLINA COUNTRY CLUB	Fairforest Creek
42GC013S01	WILLOW CREEK GOLF CLUB	Enoree River
42GC015S01	LINKS O'TRYON	South Pacolet River
Industrial and Mining Users		
11IN002S01	MILLIKEN - MAGNOLIA PLANT	Broad River
12IN002S01	CHEMTRADE	Broad River
12IN002S02	CHEMTRADE	Broad River
42IN075S01	REFLECTIVE RECYCLING LLC	Pacolet River
44IN003S01	CARLISLE FINISHING LLC	Broad River
42MI001S01	VULCAN CONSTRUCTION MATERIALS	Pacolet River

Intake ID	Facility Name	Withdrawal Tributary
42MI001S02	VULCAN CONSTRUCTION MATERIALS	Pacolet River
Hydroelectric and Nuclear Users		
11PH001S01	DUKE ENERGY GASTON SHOALS PEAKING HYDRO	Gaston Shoals Lake (Broad River)
11PH002S01	DUKE ENERGY NINETY-NINE ISLANDS PEAKING HYDRO	Ninety-Nine Islands Res. (Broad River)
20PH001S01	SCE&G FAIRFIELD PUMP STORAGE	Parr Shoals Reservoir (Broad River)
20PH002S01	SCE&G PARR	Parr Shoals Reservoir (Broad River)
42PH001S01	SIMMS HYDRO	Lake Bowen (Pacolet River)
42PH002S01	LOCKHART POWER CO PACOLET HYDRO (LOWER)	Pacolet River
42PH002S02	LOCKHART POWER CO PACOLET HYDRO (UPPER)	Pacolet River
44PH001S01	SCE&G NEAL SHOALS HYDRO	Neal Shoals Res. (Broad River)
44PH002S01	LOCKHART POWER CO LOCKHART HYDRO	Broad River
44PH002S02	LOCKHART POWER CO (MINIMUM FLOW UNIT)	Broad River
20PN001S01	SCE&G - V.C. SUMMER NUCLEAR STATION	Monticello Reservoir
20PN001S02	SCE&G - V.C. SUMMER NUCLEAR STATION	Monticello Reservoir
Drinking Water Users		
11WS001S01	GAFFNEY WTP	Lake Welchel (Cherokee Creek)
11WS001S02	GAFFNEY WTP	Gaston Shoals Lake (Broad River)
20WS001S01	TOWN OF WINNSBORO WTP	Sand Creek
20WS001S03	TOWN OF WINNSBORO WTP	Mill Creek
20WS001S05	TOWN OF WINNSBORO WTP	Broad River
23WS004S01	GREER CPW - WATER TREATMENT PLANT	Lake Cunningham (S. Tyger River)
30WS001S01	CITY OF CLINTON WTP	Enoree River
30WS001S02	CITY OF CLINTON WTP	Duncan Creek
36WS003S01	TOWN OF WHITMIRE WTP	Enoree River
36WS003S02	TOWN OF WHITMIRE WTP	Duncan Creek
40WS054S01	CITY OF COLUMBIA - CANAL WATER PLANT	Broad River
42WS001S01	INMAN CAMPOBELLO N SPARTANBURG PROJECT #1	North Pacolet River
42WS004S01	SPARTANBURG CPW	Lake Blalock (Pacolet River)
42WS005S01	WOODRUFF-ROEBUCK WTP	North Tyger River
42WS005S02	WOODRUFF-ROEBUCK WTP	South Tyger River
42WS008S01	CITY OF LANDRUM (SPARTANBURG CPW)	Vaughn Creek
42WS008S02	CITY OF LANDRUM (SPARTANBURG CPW)	Vaughn Creek
42WS012S01	SJWD MIDDLE TYGER WTP	Middle Tyger River
42WS012S02	SJWD MIDDLE TYGER WTP	North Tyger River
42WS012S03	SJWD MIDDLE TYGER WTP	Lake Cooley (Jordan Creek)
42WS014S01	SPARTANBURG CPW	Lake Bowen/Reservoir #1 (South Pacolet River)
44WS001S01	CITY OF UNION WTP	Broad River

Intake ID	Facility Name	Withdrawal Tributary
46WS002S01	CITY OF YORK WTP	Turkey Creek
Agricultural Users		
23IR002S01	FISHER BROTHERS FARMS	Middle Tyger River
23IR007S01	HYDER AUSTIN FARMS INC	South Pacolet River
23IR007S02	HYDER AUSTIN FARMS INC	Middle Tyger River
23IR007S03	HYDER AUSTIN FARMS INC	South Pacolet River
23IR007S04	HYDER AUSTIN FARMS INC	Middle Tyger River
23IR008S01	FISHERS ORCHARD	Enoree River
36IR010S01	LEWIS NURSERY & FARM	Tyger River
42IR026S01	GILBERTS NURSERY INC	North Pacolet River
42IR026S02	GILBERTS NURSERY INC	North Pacolet River
42IR026S03	GILBERTS NURSERY INC	North Pacolet River
42IR026S04	GILBERTS NURSERY INC	North Pacolet River
42IR026S05	GILBERTS NURSERY INC	North Pacolet River

Table 3-2. Formerly Permitted or Registered Water Users in the Broad Basin

Intake ID	Facility Name	Withdrawal Tributary
Industrial and Mining Users		
23IN032S01	JPS AUTOMOTIVE TAYLORS PLANT 2	Enoree River
30IN004S01	W R GRACE & CO KEARNEY MILL	Enoree River
30IN004S02	W R GRACE & CO KEARNEY MILL	Enoree River
30IN005S01	CLINTON MILLS INC	Duncan Creek
42IN005S01	SJWD WATER DISTRICT WATER TREATMENT PLT	Middle Tyger River
42IN005S02	SJWD WATER DISTRICT WATER TREATMENT PLT	Middle Tyger River
42IN005S03	SJWD WATER DISTRICT WATER TREATMENT PLT	Middle Tyger River
42IN007S01	MAYFAIR MILLS BAILY PLANT	Fairforest Creek
42IN010S01	DRAKE EXTRUSION INC	Fairforest Creek
44IN004S01	MILLIKEN & CO LOCKHART MILL	Broad River
Drinking Water Users		
11WS002S01	BLACKSBURG TOWN OF	Kings Creek
20WS001S02	WINNSBORO TOWN OF	Sand Creek
24WS003S01	WARE SHOALS TOWN OF	South Tyger River
44WS004S01	JONESVILLE TOWN OF	Pacolet River
44WS006S01	CONE MILLS CORPORATION/CARLISLE FINISHING PLANT	Broad River

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

NPDES Pipe ID	Facility Name	Discharge Tributary	Associated Surface Water Permit
SC0047244-001	UNION/TOSCH'S CREEK WWTP	Fairforest Creek	44WS001
SCG646042	CITY OF UNION WTP	Broad River	44WS001
SC0024988-001	JONESVILLE, TOWN OF	Pacolet River	44WS001
SC0001368-001	CONE MILLS CORP/CARLISLE PLANT	Broad River	44IN003
SC0042668-001	SSSD/CLIFTON WWTP	Pacolet River	42WS014/ 42WS004
SC0045624-001	SSSD/COWPENS-PACOLET RIVER	Pacolet River	42WS014/ 42WS004
SC0044717-001	SSSD/PACOLET MILLS WWTP	Pacolet River	42WS014/ 42WS004
SC0020435-001	SSSD/FAIRFOREST PLANT	Fairforest Creek	42WS014
SC0020435-002	SSSD/FAIRFOREST PLANT	Pacolet River	42WS014
SCG646049	SIMMS WTP	Pacolet River	42WS014
SC0048143-001	SSSD/LOWER N TYGER RIVER WWTP	North Tyger River	42WS014/ 42WS012
SC0026875-001	SSSD/PAGE CREEK WWTP	North Pacolet River	42WS008
SCG64500	SWS LANDRUM WTP	Vaughn Creek	42WS008
SC0045802-001	WOODRUFF/ENOREE RIVER	Enoree River	42WS005
SC0002798-002	AURIGA POLYMERS INC./SPARTANBURG	Pacolet River	42WS004
SC0021601-001	INMAN, CITY OF	Lawsons Fork Creek	42WS001
SC0003581-001	MILLIKEN/DEWEY PLANT	Lawsons Fork Creek	42WS001
SCG730293	VULCAN MATERIALS - PACOLET Quarry	Pacolet River	42MI001
SC0049174-002	REFLECTIVE RECYCLING OF SC LLC	Pacolet River	42IN075
SC0022390-001	WHITMIRE, TOWN OF	Duncan Creek	36WS003
SC0046345-001	GREER/MAPLE CREEK PLANT	South Tyger River	23WS004/ 42WS012
SC0047732-001	SSSD/S. TYGER RV REGIONAL WWTP	South Tyger River	42WS012
SCG646023	SJWD WTP	Middle Tyger River	42WS012
SC0021300-001	LYMAN, CITY OF	Middle Tyger River	42WS012
SC0026565-001	UNITED UTILS/N GREENVILLE COLL	South Tyger River	23WS004
SC0030856-001	SCE&G/V C SUMMER NUCLEAR STAT	Monticello Reservoir	20PN001
SC0030856-002	SCE&G/V C SUMMER NUCLEAR STAT	Parr Shoals Reservoir (Broad River)	20PN001
SC0030856-007	SCE&G/V C SUMMER NUCLEAR STAT	Monticello Reservoir	20PN001
SC0030856-008	SCE&G/V C SUMMER NUCLEAR STAT	Monticello Reservoir	20PN001
SC0030856-014	SCE&G/V C SUMMER NUCLEAR STAT	Monticello Reservoir	20PN001
SC0022756-001	CHEMTRADE PERF CHEMICALS/LEEDS	Broad River	12IN002
SC0047457-001	BLACKSBURG/CANOE CREEK (NEW)	Broad River	11WS001
SC0031551-001	GAFFNEY/CLARY WWTF	Thicketty Creek	11WS001
SC0047091-001	GAFFNEY/PEOPLES CRK-BROAD RVR	Ninety-Nine Islands Res. (Broad River)	11WS001

NPDES Pipe ID	Facility Name	Discharge Tributary	Associated Surface Water Permit
SC0020125-001	WINNSBORO/JACKSON CREEK PLANT	Jackson Creek	20WS001
SC0022900-001	RIDGEWAY, TOWN OF	Trib to Cedar Creek	20WS001
SC0025763-001	CHESNEE WWTF	Buck Creek	none
SC0003484-001	GE/GAS TURBINE MFG OPERATION	Enoree River	23IN058G
SC0003051-001	LOCKHART TREATMENT FACILITY	Broad River	none
SC0036145-001	MIDLAND CAPITAL LLC/MOORE PLANT	South Tyger River	none
SC0036773-001	SC DEPT CORR/TYGER RIVER CORRE	Tyger River	none
SC0036081-001	CHESTER/SANDY RIVER WWTF	Sandy River	12WS002
SC0040002-001	ReWa/DURBIN CREEK	Durbin Creek	23W007
SC0040525-001	ReWa/GILDER CREEK	Enoree River	23W007
SC0033804-001	ReWa/PELHAM WWTF	Enoree River	23W007
SC0046621-001	RICHLAND CO/BROAD RIVER WWTF	Broad River	40WS002
SC0040631-001	CHAPIN, TOWN OF	Broad River	40WS002
SC0033804-001	ReWa/PELHAM WWTF	Enoree River	23WS002
SC0040002-001	ReWa/DURBIN CREEK	Durbin Creek	23WS002
SC0040525-001	ReWa/GILDER CREEK	Enoree River	23WS002

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

NPDES Pipe ID	Facility Name	Discharge Tributary
SC0026042-001	BLACKSBURG/CANOE CREEK	Broad River
SC0040703-001	CHEVRON USA/CAMP CROFT	Lawsons Fork Creek
SC0024414-001	CITY OF INMAN/LAWSONS FORK CREEK	Lawsons Fork Creek
SC0035947-001	COKER WAREHOUSE GAFFNEY	Broad River
SC0021008-001	DUNCAN WWTF	South Tyger River
SC0020478-001	GAFFNEY/PEOPLES CREEK	Broad River
SC0020508-001	GAFFNEY/PROVIDENCE CREEK	Cherokee Creek
SC0020761-001	GREER/MAPLE CREEK PLANT	Maple Creek
SC0020770-001	GREER/S. TYGER RIVER PLANT	South Tyger River
SC0001791-001	HOECHST CELANESE/GREER	Enoree River
SC0048178-001	I-85 DISTRIBUTION CENTER SITE	Fairforest Creek
SC0002411-002	ISG PACOLET FACILITY	Pacolet River
SC0002411-003	ISG PACOLET FACILITY	Pacolet River
SC0002411-02A	ISG PACOLET FACILITY	Pacolet River
SC0003182-001	MILLIKEN/MAGNOLIA FINISHING PLANT	Broad River
SC0023540-001	MILLIKEN/NEW PROSPECT MILL	North Pacolet River
SC0035157-001	ONEITA INDUSTRIES/FINGERVILLE	North Pacolet River
SC0036102-001	R R DONNELLEY AND SONS CO	Pacolet River
SC0030856-002	SCE&G/V C SUMMER NUCLEAR STAT	Broad River

NPDES Pipe ID	Facility Name	Discharge Tributary
SC0002437-001	SPARTAN MILLS/BEAUMONT PLANT	Lawsons Fork Creek
SC0002445-001	SPARTAN MILLS/SPARTAN PLANT	Fairforest Creek
SC0002453-001	SPARTAN MILLS/STARTEX MILL	Middle Tyger River
SC0002453-002	SPARTAN MILLS/STARTEX MILL	Middle Tyger River
SC0029718-001	SSSD/HILLBROOK FOREST SD	Pacolet River
SC0020427-001	SSSD/LAWSON FORK PLANT	Lawsons Fork Creek
SC0043532-001	SSSD/N TYGER RIVER WWTP	North Tyger River
SC0026875-002	SSSD/PAGE CREEK WWTP	North Pacolet River
SC0000949-001	TIMKEN COMPANY/GAFFNEY BEARING	Thicketty Creek
SC0021202-001	UNION/BELTLINE PLANT	Tyger Creek
SC0047236-001	UNION/MENG CREEK (NEW)	Broad River
SC0021172-001	UNION/TOSCHS CREEK PLANT	Fairforest Creek
SC0024309-001	WCRSA/TAYLORS AREA PLANT	Enoree River

4.0 UIF Methodology

4.1 UIF Process Diagram

Figure 4-1 illustrates the general UIF development process as a guiding approach. The process involves adding and subtracting known historical management practices from measured streamflow records, and extending records of flow and flow management over periods for which data are not available. In doing so, the impacts of human intervention on the flow in the river can be removed from the historical flow estimates. 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:

- **Step 1: UIFs for USGS Gages for their Individual Periods of Record**: This step "naturalizes" measured daily flow values at each USGS gage in the basin for its individual period of record only, by adding and subtracting known or estimated withdrawals, discharges, and effects of impoundment. See **Section 4.5.1** for details. It includes synthetic extension of operational records (withdrawals, discharges, and reservoir operations) where data records are not available.
- **Step 2: Extension of UIFs for the USGS Gages Throughout the Basin Period of Record:** This step applies statistical techniques to extend or fill unimpaired flow estimates over a uniform period throughout the entire basin, defined by the USGS gage that extends furthest back in time. (See **Section 4.5.2** for details)

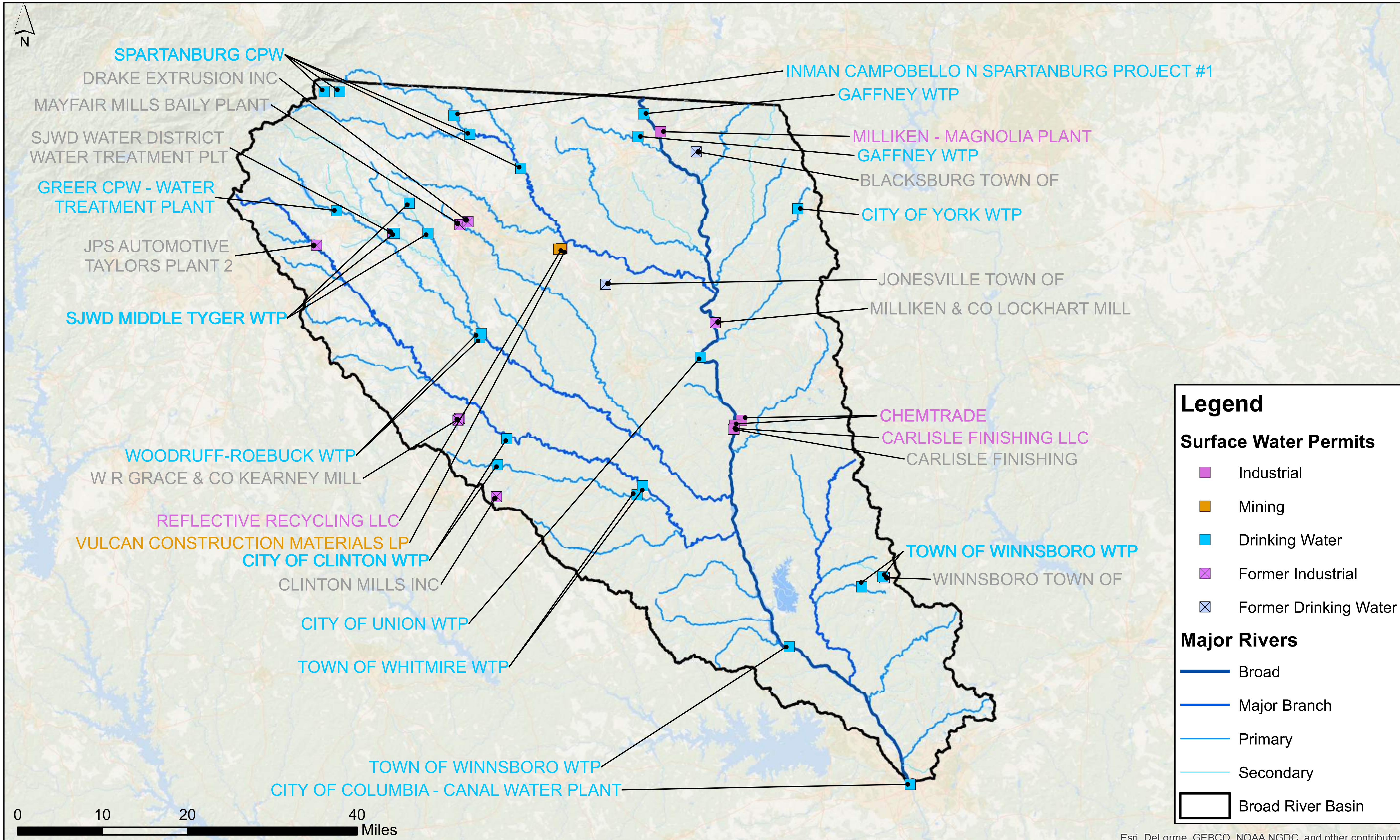

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Figure 3-1: Current and Former Municipal, Industrial, and Mining Surface Water Users

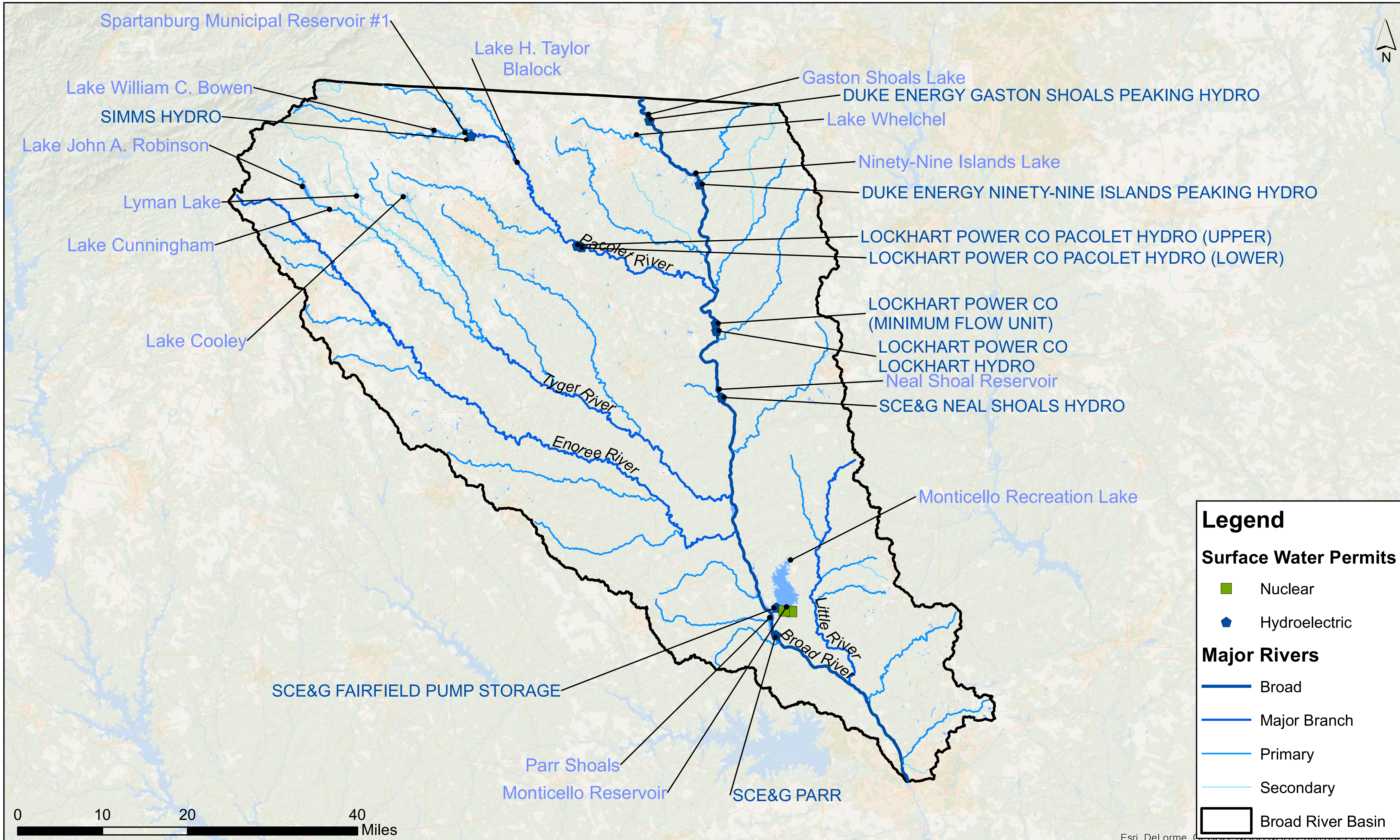

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Figure 3-2: Current Nuclear and Hydroelectric Power Surface Water Users

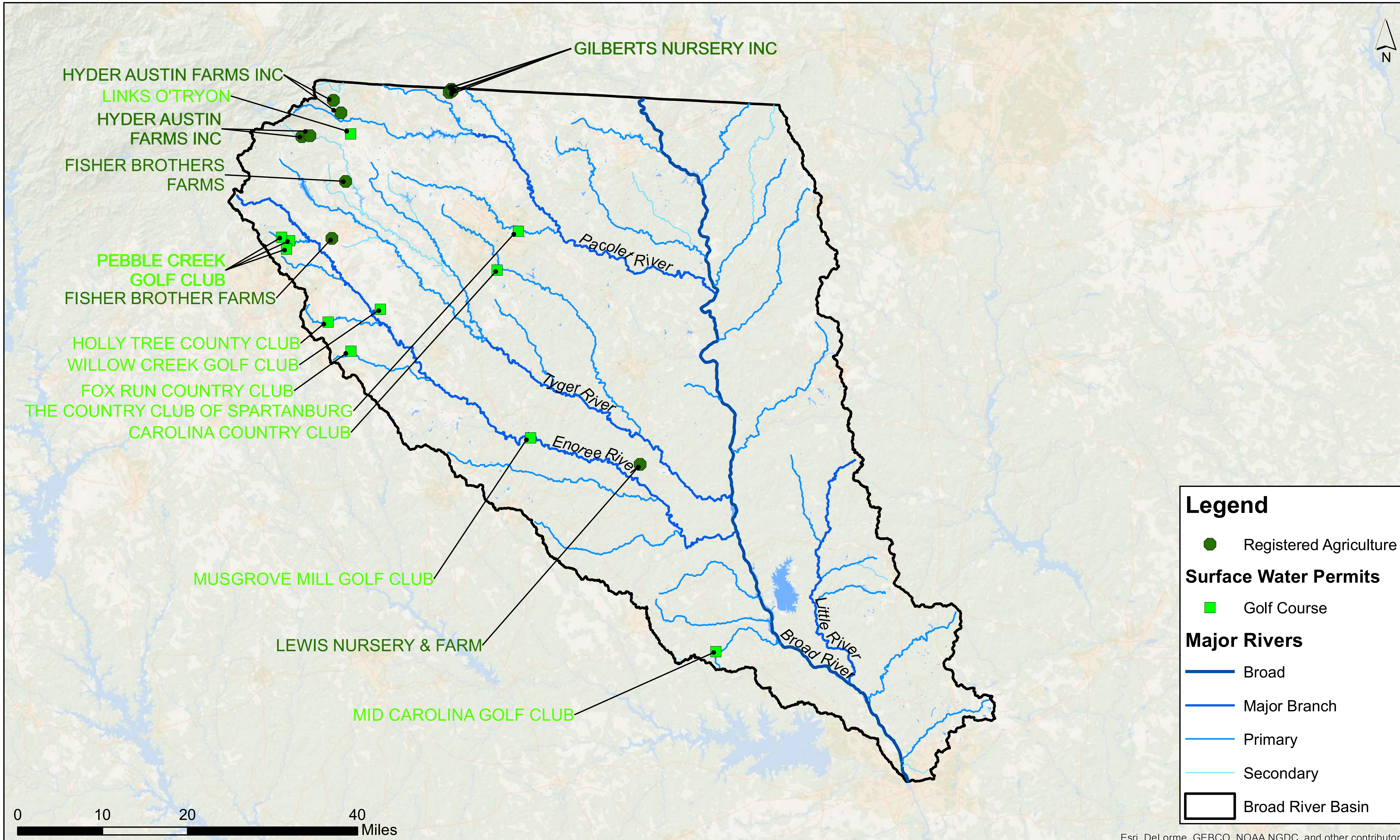

Figure 3-3: Current Agriculture and Golf Course Surface Water Users

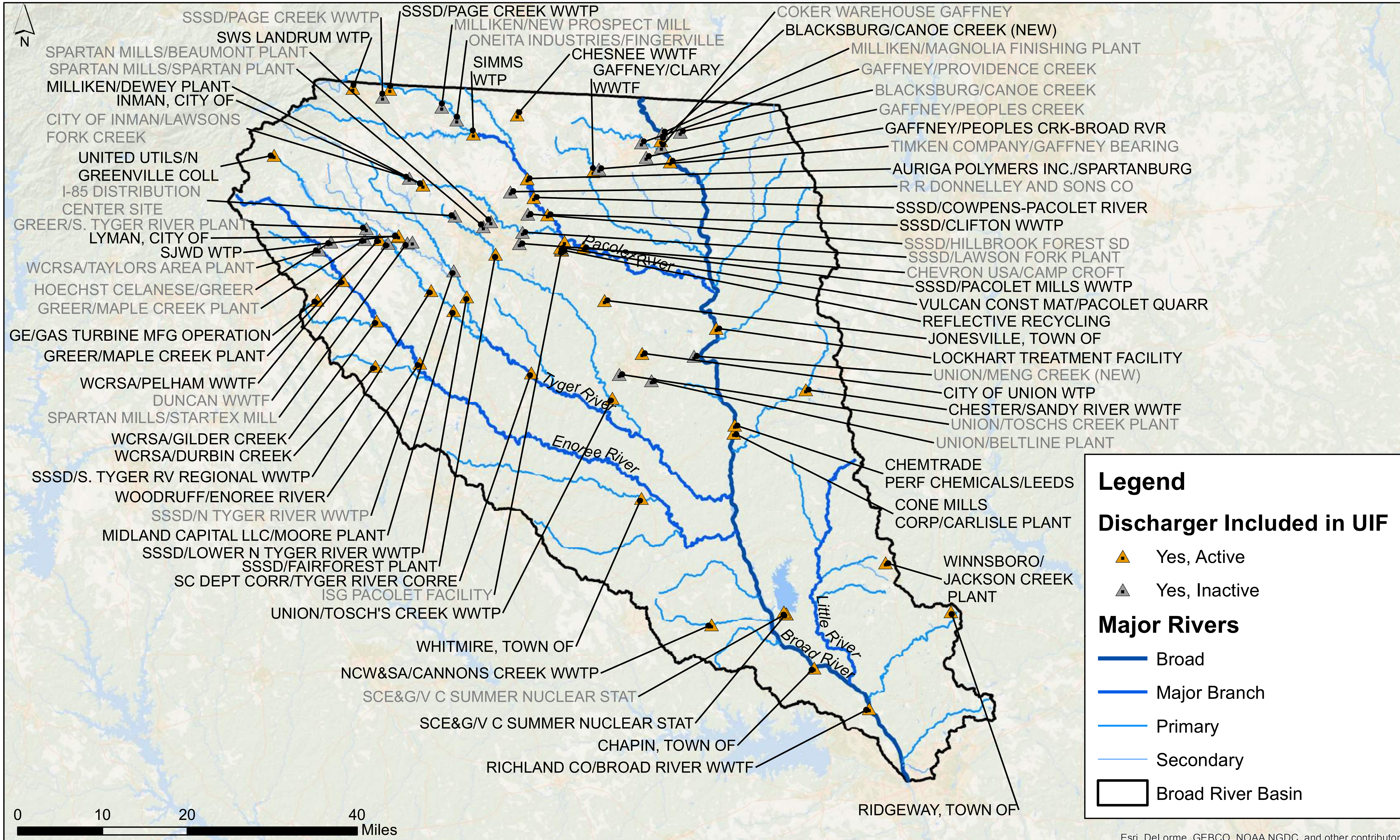

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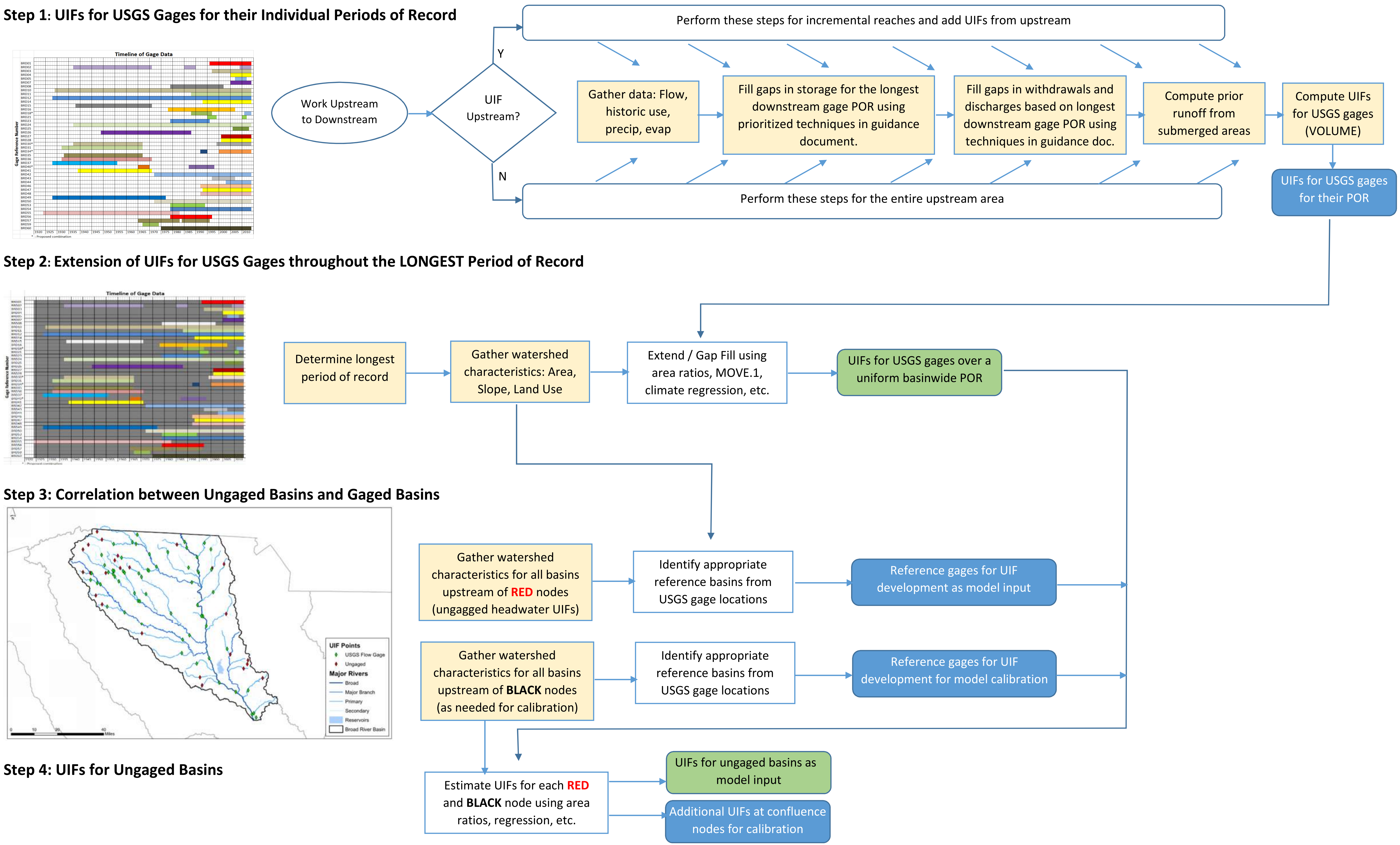
Figure 3-4: Current and Former NPDES Discharges

Figure 4-1. Stepwise Procedure for UIF Calculation – Broad Basin



- **Step 3: Correlation Between Ungaged and Gaged Basins:** This step establishes the framework for estimating unimpaired flow in subbasins without USGS gages. Reference basins with USGS gages and similar hydrologic characteristics as those without USGS basins are identified for use in Step 4. (See **Section 4.5.3** for details)
- **Step 4: UIFs for Ungaged Basins:** This step uses the reference basins in Step 3 to estimate unimpaired flow in ungaged subbasins for the period of record in the basin. (See **Section 4.5.4** for details)

It is important to recognize an adaptation of the UIF process from its original conceptualization. The distinction between "Unregulated Flow" and "Unimpaired Flow" can sometimes be helpful in understanding the different ways in which water management affects streamflow. Unregulated flows represent flow in which the effects of timing due to impoundment are removed. These flows become, effectively, a subset of Unimpaired Flows, and can be particularly useful in hydropower modeling, since other impairments beyond the purview of dam operators can affect expected inflow and the issues are focused more on the impacts of impoundment. Equation 1 in Section 1 includes the effects of streamflow regulation (impoundment) in the UIF calculation. The remaining impairments in Equation 1 represent water management that affects the volume of water, but not the timing of its passage downstream. Together, the impacts on timing due to impoundment and the impacts on flow volume due to withdrawals and discharges (and reservoir surface fluxes such as evaporation) combine to impair flows, and all of these impacts are removed in the calculation of unimpaired flows.

Originally, the proposed process for computing UIFs in South Carolina included a sub-step that computed only the unregulated flows. It was determined that for these models, it was not necessary to separate the effects of impoundment from the effects of withdrawals and discharges. The Saluda Basin Pilot Study confirmed that a more practical approach was to compute the UIFs in one computational step rather than two, as unregulated flows on their own would not be used as input or as calibration targets. The revised procedure accounts for both timing impacts due to impoundments and volume impacts due to withdrawals, discharges, and reservoir surface fluxes. This is reflected in Equation 1, the basis of UIF computation in the Broad River. In summary, the UIFs account for flow regulation due to impoundment and flow increases or decreases due to other management activities, but the data sets do not include a subset of flows that have only had the impacts of impoundments removed.

One other issue on the timing of flows involves hydraulic time lags. There is an important difference between the alteration to flow timing associated with impounding a river, 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, and (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.

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.

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.

4.2 Locations of UIFs

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

- Most sites 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. Stations with less than four years of record will either not be unimpaired or combined with the records of a nearby gage. Where the unimpaired gage records are upstream of management activity in the river, the UIFs will be entered into the model as input. Where the unimpaired gage records are further downstream, either on tributaries or the main stem, the UIFs may be used for model calibration or results comparison, or as input of incremental hydrologic flows. (These are steps 1 and 2 in **Figure 4-1**, further described in **Sections 4.5.1 and 4.5.2**).
- UIFs will also be computed in ungaged basins by transposing records from gaged basins with similar hydrologic characteristics. These UIFs can be used as direct model inputs at tributary and mainstem headwaters. (These are steps 3 and 4 in **Figure 4-1**, further described in **Sections 4.5.3 and 4.5.4**).

4.3 Period of Record

While UIF estimates will begin in 1925 for the Broad Basin, more than half of the stream gages began operation in the 1980s or later. The records for all gages that started tracking flow after 1925 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. Further, the extended range of conditions provides insight into the frequency of various flow conditions historically, and results from the models can be interpreted in a context of "historical likelihood."

Figure 4-3 depicts the length and timing of records available for all USGS gages in the Broad basin, where proposed combinations are highlighted in purple and those likely to not have UIFs in red.

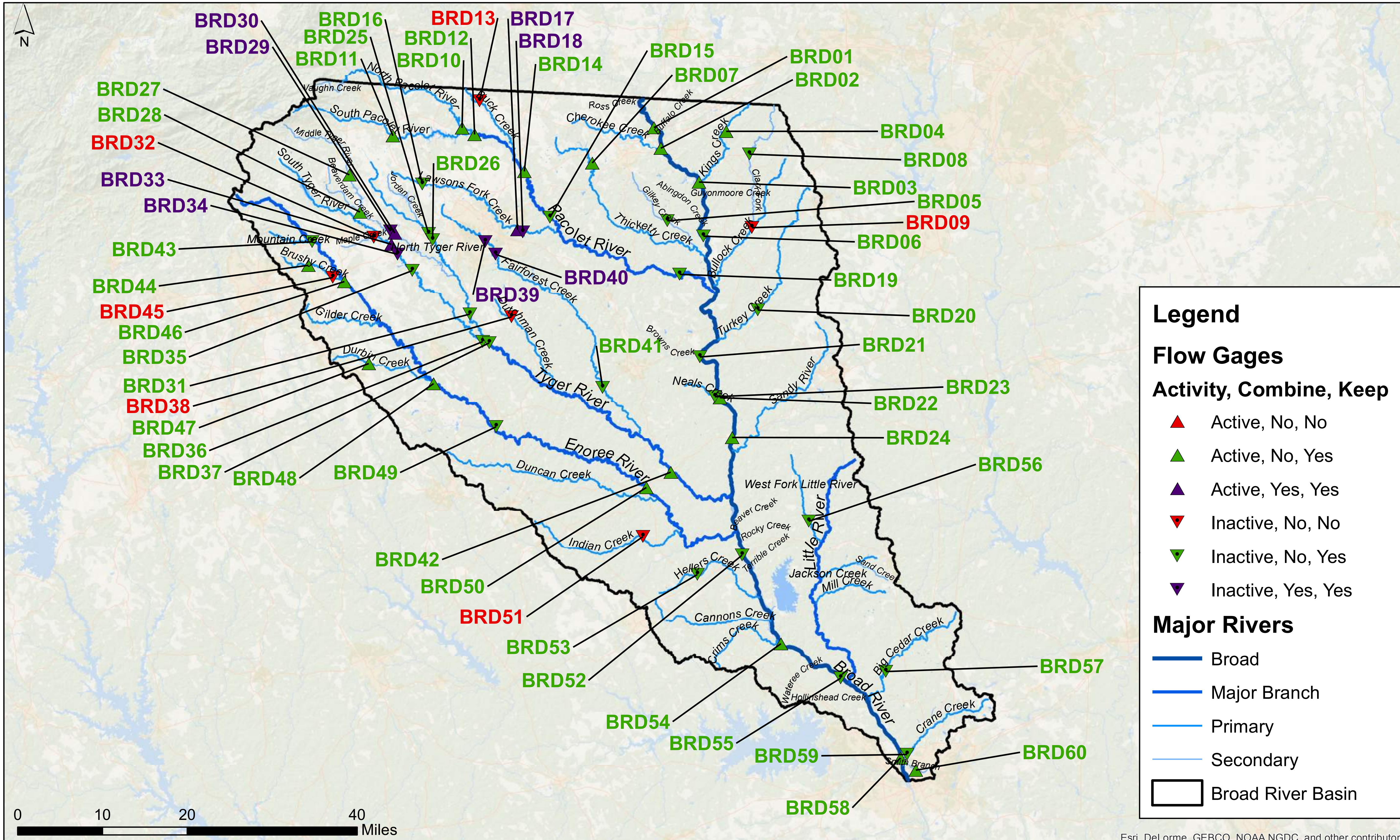


Figure 4-2
Active and Inactive USGS Streamflow Gaging Stations with Proposed Combinations and Deletions

Figure 4-3. Period of record for USGS gages in the Broad Basin

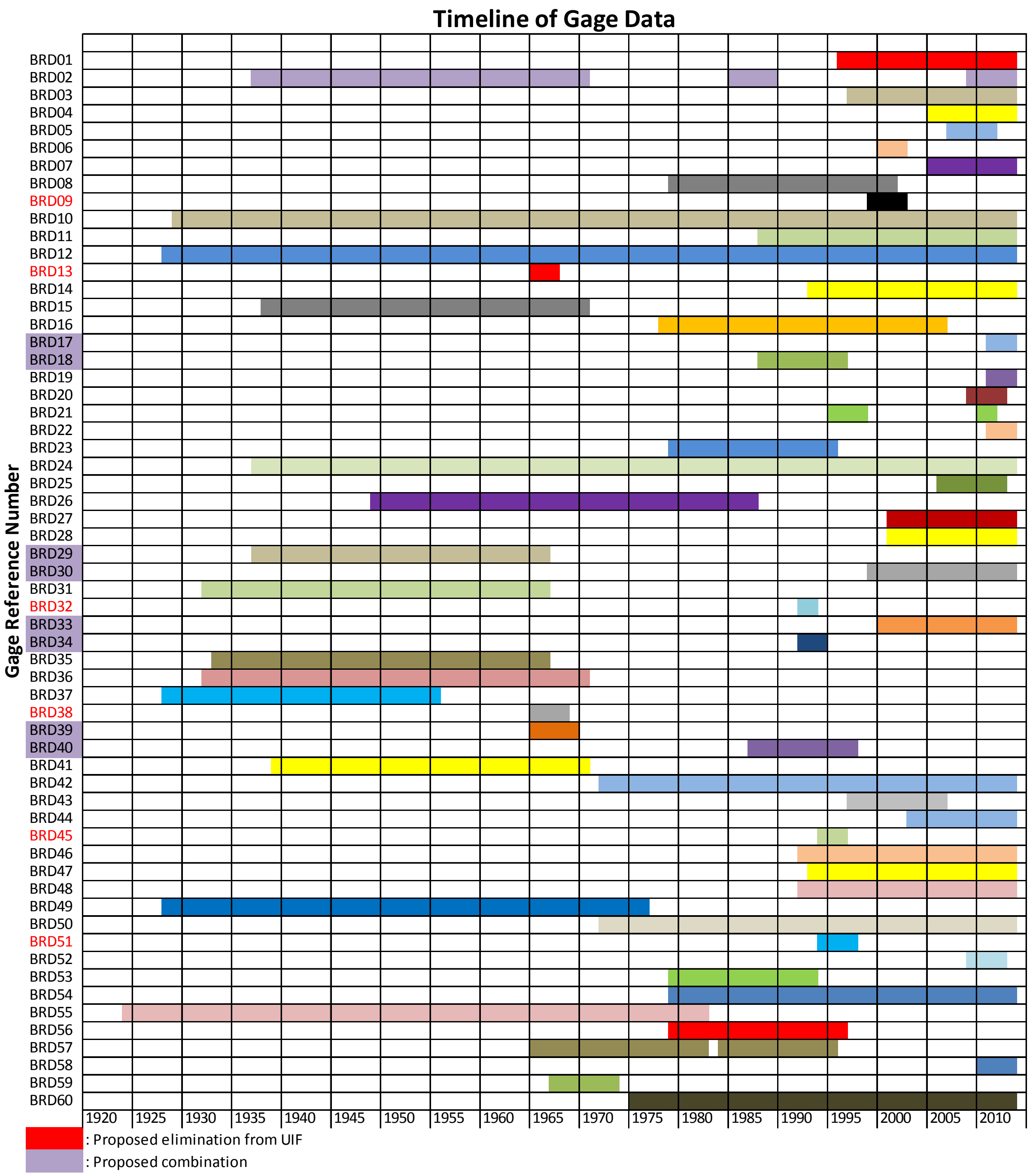


Table 4-1 lists each gage, where combinations are in **bold** and those with insufficient records for UIFs are *italicized*.

4.4 Data Needs

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 (1925 – 2013). Records from other gages are extended to match this duration (described in **Section 4.5.2**).

Data needs, discussion of how the data will be used, and potential sources of the data are presented in **Table 4-2**. 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 once the flows for the available periods of record have been unimpaired (see **Section 4.5.2**). The gap filling techniques may include correlation with other stream gage records, precipitation data, and evaporation data, and may involve 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. Historic streamflow information is gathered and processed as part of Step 1 in **Figure 4-1**, described further in **Section 4.5.1** below).

<u>Reservoir Impacts</u>: Reservoir levels and/or discharges are needed to estimate unregulated flows. A mass balance is performed to convert measured changes in reservoir storage to unregulated flow in the stream, which is used in Equation 1. Reservoir operating rules and records may be used to assist with gap filling. **Table 4-3** outlines the assignments for combining precipitation records and assigning evaporation data for each reservoir accounted for in the UIF process. **Figure 4-4** displays the selected meteorological stations with respect to reservoir locations. Reservoir information is gathered and processed as part of Step 1 in **Figure 4-1**, described further in **Section 4.5.1** below).

<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**. Water use information is gathered and processed as part of Step 1 in **Figure 4-1**, described further in **Section 4.5.1** below).

Table 4-1. USGS gages in the Broad Basin
(Note: Proposed gage combinations are in **bold** and those with insufficient records for UIFs are *italicized*.)

USGS Number	Description	Period of Record						Gage ID (BRD)	Years
		From:	To:	From:	To:	From:	To:		
02153200	BROAD RIVER NEAR BLACKSBURG, SC	9/24/1997	12/31/2013					1	16.3
02153500	BROAD RIVER NEAR GAFFNEY, SC	12/1/1938	9/30/1971	4/18/1986	9/30/1990	2/24/2010	12/31/2013	2	41.0
02153551	BROAD RIVER BELOW NINETYNINE ISLAND RESERVOIR,SC	10/30/1998	12/31/2013					3	15.2
02153590	KINGS CREEK AT BLACKSBURG, SC	4/1/2006	9/30/2010	9/13/2011	12/31/2013			4	6.8
021536097	GILKEY CREEK NEAR WILKINSVILLE, SC	7/30/2008	11/7/2012					5	4.3
02153680	BROAD R NR HICKORY GROVE S C	6/1/2001	9/30/2003					6	2.3
02153700	THICKETTY CREEK AT CNTY ROAD 42 NEAR GAFFNEY, SC	3/31/2006	12/31/2013					7	7.8
02153780	CLARKS FORK CREEK NR SMYRNA, SC	10/1/1980	9/30/2002					8	22.0
02153800	*BULLOCK CREEK NR SHARON, SC*	*11/15/2000*	*10/6/2003*					*9*	*2.9*
02154500	NORTH PACOLET RIVER AT FINGERVILLE, SC	4/1/1930	12/31/2013					10	83.8
02154790	SOUTH PACOLET RIVER NR CAMPOBELLO, SC	1/6/1989	12/31/2013					11	25.0
02155500	PACOLET RIVER NEAR FINGERVILLE, SC	12/1/1929	9/30/1996	10/1/1997	9/30/2006	6/29/2007	12/31/2013	12	81.8
02155600	*BUCK CREEK NEAR FINGERVILLE, SC*	*10/1/1966*	*9/30/1969*					*13*	*3.0*
021556525	PACOLET RIVER BELOW LAKE BLALOCK NEAR COWPENS, SC	11/1/1993	12/31/2013					14	20.2
02156000	PACOLET RIVER NEAR CLIFTON, SC	10/1/1939	9/30/1971					15	32.0
02156050	LAWSONS FORK CREEK AT DEWEY PLANT NR INMAN, SC	10/1/1979	7/8/2007					16	27.8
02156300	**LAWSONS FORK CREEK AT SPARTANBURG SC**	**6/21/2012**	**12/31/2013**					**17**	**1.5**

USGS Number	Description	Period of Record						Gage ID (BRD)	Years
		From:	To:	From:	To:	From:	To:		
02156301	**LAWSON FORK CREEK @ TREATMENT PLANT @ SPARTANBURG**	**5/11/1989**	**9/30/1997**					**18**	**8.4**
02156370	PACOLET RIVER NEAR SARATT,SC	8/23/2012	12/31/2013					19	1.4
021563931	TURKEY CREEK NEAR LOWRYS, SC	12/8/2000	8/3/2003					20	2.5
02156409	BROAD RIVER NEAR LOCKHART, SC	10/1/1996	9/30/1999	4/7/2011	11/1/2012			21	4.5
021564493	BROAD RIVER BELOW NEAL SHOALS RES. NR CARLISLE,SC	3/27/2012	12/31/2013					22	1.8
02156450	NEALS CREEK NR CARLISLE, SC	10/1/1980	9/30/1996					23	16.0
02156500	BROAD RIVER NEAR CARLISLE, SC	10/1/1938	12/31/2013					24	75.3
02156999	N. TYGER RIVER BELOW WELLFORD, SC	5/30/2007	11/7/2013					25	6.4
02157000	NORTH TYGER RIVER NEAR FAIRMONT, SC	10/1/1950	9/30/1988					26	38.0
02157470	MIDDLE TYGER RIVER NEAR GRAMLING, SC	2/15/2002	12/31/2013					27	11.9
02157490	BEAVERDAM CREEK ABOVE GREER, SC	3/7/2002	12/31/2013					28	11.8
02157500	**MIDDLE TYGER RIVER AT LYMAN, SC**	**2/1/1938**	**9/30/1967**					**29**	**29.7**
02157510	**MIDDLE TYGER RIVER NEAR LYMAN, SC**	**2/12/2000**	**12/31/2013**					**30**	**13.9**
02158000	NORTH TYGER RIVER NEAR MOORE, SC	10/1/1933	9/30/1967					31	34.0
021584051	*MAPLE CREEK NEAR DUNCAN, SC*	*10/1/1993*	*12/31/1994*					*32*	*1.3*
02158408	**SOUTH TYGER RIVER BELOW DUNCAN, SC**	**2/17/2001**	**12/31/2013**					**33**	**12.9**
02158410	**SOUTH TYGER RIVER BELOW LYMAN, SC**	**7/14/1993**	**1/10/1995**					**34**	**1.5**
02158500	SOUTH TYGER RIVER NEAR REIDVILLE, SC	10/1/1934	9/30/1967					35	33.0
02159000	SOUTH TYGER RIVER NEAR WOODRUFF, SC	10/1/1933	9/30/1971					36	38.0
02159500	TYGER RIVER NEAR WOODRUFF, S. C.	10/1/1929	9/30/1956					37	27.0

USGS Number	Description	Period of Record						Gage ID (BRD)	Years
		From:	To:	From:	To:	From:	To:		
02159600	*DUTCHMAN CREEK NEAR PAULINE, S.C.*	*7/16/1966*	*9/30/1969*					*38*	*3.2*
02159800	**FAIRFOREST CREEK AT SPARTANBURG, S. C.**	**3/1/1966**	**9/30/1970**					**39**	**4.6**
02159810	**FAIRFOREST CREEK BELOW SPARTANBURG, S.C.**	**5/17/1988**	**4/2/1998**					**40**	**9.9**
02160000	FAIRFOREST CREEK NEAR UNION, S.C.	7/1/1940	9/30/1971					41	31.3
02160105	TYGER RIVER NEAR DELTA, SC	10/1/1973	12/31/2013					42	40.3
02160200	ENOREE RIVER AT TAYLORS, SC	3/1/1998	10/28/2007					43	9.7
02160325	BRUSHY CREEK NEAR GREENVILLE, SC	8/10/2004	12/31/2013					44	9.4
021603257	*BRUSHY CREEK NEAR PELHAM, SC*	*10/1/1995*	*9/30/1997*					*45*	*2.0*
02160326	ENOREE RIVER AT PELHAM, SC	3/10/1993	12/31/2013					46	20.8
02160381	DURBIN CREEK ABOVE FOUNTAIN INN, SC	7/6/1994	12/31/2013					47	17.5
02160390	ENOREE RIVER NEAR WOODRUFF, SC	2/9/1993	12/31/2013					48	20.9
02160500	ENOREE RIVER NEAR ENOREE S. C.	10/1/1929	1/17/1977	9/7/1977	9/30/1977			49	47.4
02160700	ENOREE RIVER AT WHITMIRE, SC	10/1/1973	12/31/2013					50	40.3
021607224	*INDIAN CREEK ABOVE NEWBERRY, SC*	*10/1/1995*	*11/3/1998*					*51*	*3.0*
02160750	BROAD RIVER AT BLAIR,SC	9/11/2010	2/18/2013					52	2.4
02160775	HELLERS CREEK NR POMARIA, SC	10/1/1980	9/30/1994					53	14.0
02161000	BROAD RIVER AT ALSTON, SC	10/1/1896	12/31/1907	10/1/1980	12/31/2013			54	33.3
02161500	BROAD RIVER AT RICHTEX, S. C.	10/1/1925	7/31/1928	10/1/1929	9/30/1983			55	56.9
02161700	WEST FORK LITTLE RIVER NR SALEM CROSSROADS, SC	10/1/1980	9/30/1997					56	17.0
02162010	CEDAR CREEK NEAR BLYTHEWOOD, SC	12/1/1966	9/30/1983	2/26/1985	9/30/1996			57	28.4
02162035	BROAD RIVER NEAR COLUMBIA, SC	7/2/2011	12/31/2013					58	2.5

USGS Number	Description	Period of Record						Gage ID (BRD)	Years
		From:	To:	From:	To:	From:	To:		
02162080	CRANE CREEK AT COLUMBIA, S. C.	1/1/1968	9/30/1974					59	6.8
02162093	SMITH BRANCH AT NORTH MAIN ST AT COLUMBIA, SC	7/12/1976	12/31/2013					60	34.5

Table 4-2. 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.
	Unimpaired Flow Estimates, Broad River	Direct UIF input	CDM Smith	Broad River is tributary to Saluda basin
	North Carolina Unimpaired Flow Estimates		North Carolina	For Broad River basin. USGS gage records near the state line should capture current managed flow conditions from NC. Records may require updating through 2013.
	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.
Flow and Reservoir Impacts	Historic Precipitation (Daily)	Reservoir surface precipitation, correlation for flow estimation	US Historical Climatology Network (USHCN)	30 South Carolina sites
	Historic Pan Evaporation (Monthly)	Reservoir surface evaporation, correlation for flow estimation	DNR	13 sites with data from 1948
Reservoir Impacts	Historic Air Temperature (Daily or Monthly)	Extend evaporation records using temperature as independent variable	National Climatic Data Center (NCDC)	
	Reservoir Operations and Levels	Compute change in volume to develop unregulated flows	Dam operators, Federal Energy Regulatory Commission (FERC)	Includes date reservoir put in service
	Reservoir Storage-Area-Elevation Curves	Compute area for direct rainfall and evaporation and convert changes in reservoir level to volume		

Data Category	Data	Use(s)	Potential Sources	Comments
	Spillway Rating Curves	Compute volume spilled to develop unregulated flows	Licenses, USACE, etc.	
	Reservoir Operating Rules	Compute undocumented historic releases or other changes in reservoir storage		Includes FERC licenses for hydroelectric dams
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	Instream Flow Requirements	Estimate historical reservoir releases	DNR/DHEC	All data gathered as part of model development, but may be utilized for gap filling of UIFs

Table 4-3. Meteorological Stations for Reservoirs in the Broad Basin

Reservoir	Evaporation[2]	Precipitation		Precipitation Period of Record	
		Station ID	Location	From:	To:
Lake William C. Bowen and Spartanburg Municipal Reservoir #1	Chesnee	USC00387113	Rainbow Lake	1928	1978
		USC00387885	Simms WTP	1979	1991
		USC00381625	Chesnee 7 WSW	1992	2004
		None - measured by Spartanburg CPW	Lake Bowen	2004	2013
Lake H. Taylor Blalock	Chesnee	USC00387113	Rainbow Lake	1928	1978
		USC00387885	Simms WTP	1979	1991
		USC00381625	Chesnee 7 WSW	1992	2004
		None - measured by Spartanburg CPW	Lake Blalock	2004	2013
Gaston Shoals Lake	Chesnee	USC00383433	Gaston Shoals	1912	2013
Lake Whelchel	Chesnee	USC00383433	Gaston Shoals	1912	2013
Ninety-Nine Islands Lake	Chesnee	USC00383356	Gaffney 6 E	1893	2012
	Chesnee	USC00386293	Ninety-Nine Islands	1940	2013
Lake John A. Robinson	Chesnee	USC00381804	Cleveland 3S	1943	2013
Lake Cunningham	Chesnee	USC00381804	Cleveland 3S	1943	2013
Lyman Lake	Chesnee	USC00381804	Cleveland 3S	1943	2013
Lake Cooley	Chesnee	USW00003870	Greer	1962	2013
Neal Shoal Reservoir	Union	USC00385232	Lockhart	1926	2013
Parr Shoals	Union	USC00380772	Blair	1905	1982
		USC00386688	Parr	1946	2013
Monticello Reservoir and Recreation Lake	Union	USC00380772	Blair	1905	1982
	Union	USC00386688	Parr	1946	2013

[2] Chesnee refers to an estimated timeseries using pan evaporation from Chesnee USC00381625 and temperature from Greer W03870. Union is estimated from Union USC00388786 and temperature from Union 388786.

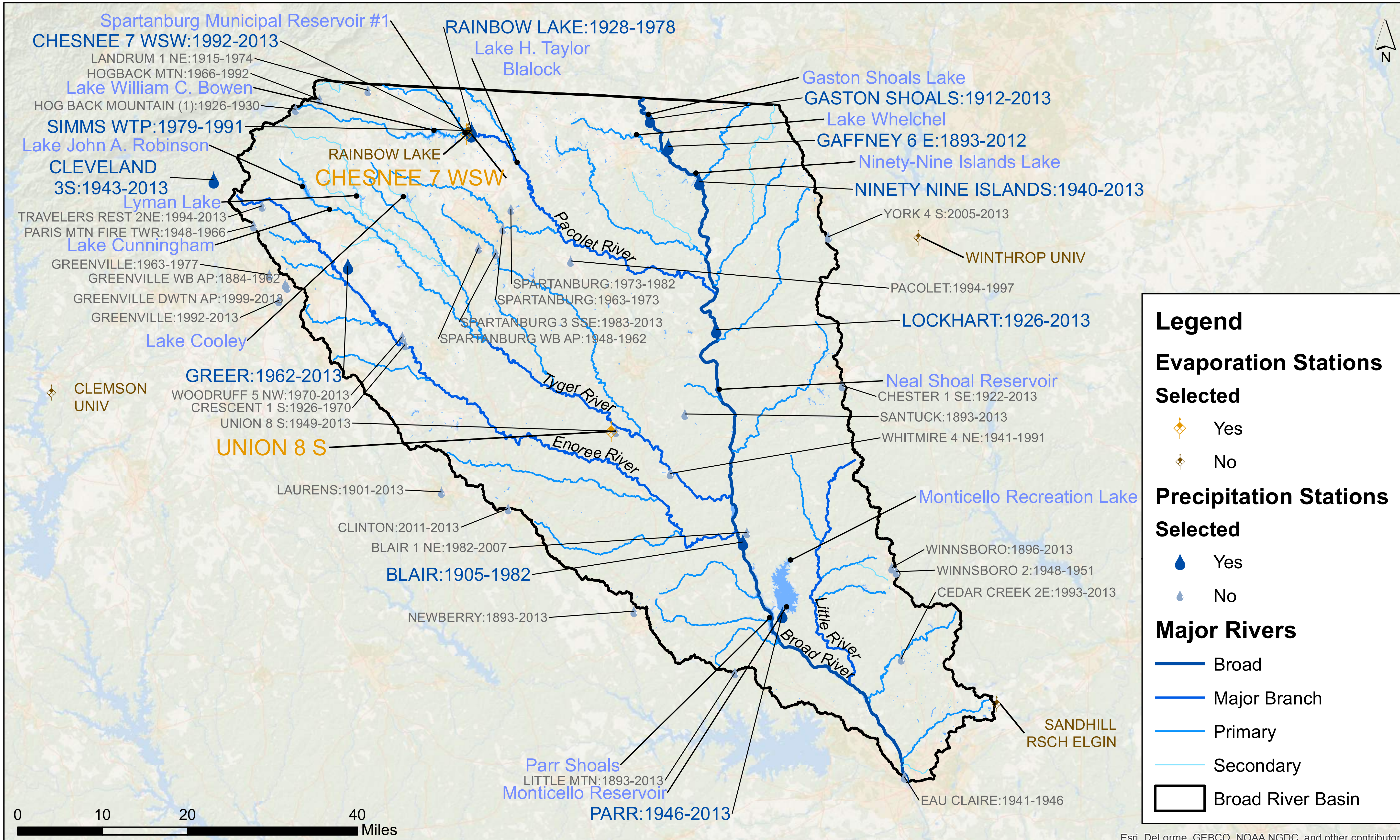


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Figure 4-4: Selected Precipitation and Evaporation Stations

4.5 UIF Development

UIFs are developed on a daily basis so that they may be input into the SWAM models as both daily and monthly timeseries. Development of UIFs requires that historic data be synthesized where it is not available, so that each UIF record spans the entire period of record for the basin. Two types of data filling / hindcasting are discussed in the following sections:

- Hindcasting historical operations such as withdrawals, discharges, and reservoir operations
- Extending fully unimpaired flow records

Operational hindcasting is accomplished first, as part of Step 1 below (see **Section 4.5.1**), in which operating records are synthesized so that they can be used in Equation 1 for the period of record for all downstream gages. Once the UIFs are computed, those for gages that do not span the full period of record for the basin are extended using hydrologic statistical techniques, described in **Section 4.5.2** below.

The following steps are employed in the formulation of UIFs over the period of record for the basin, and for each location in which they are required (tributary headwaters, and points within the river network for either subsequent model calibration or comparison to managed flow results). Refer to **Figure 4-1** for the stepwise diagram that corresponds with **Sections 4.5.1 – 4.5.4**.

4.5.1 Step 1: UIFs for USGS Gages for their Individual Periods of Record

This step includes the collection of available data, extension of operational records to match the USGS periods of record for downstream gages that are affected, and the calculation of UIFs for each USGS gage for its period of record.

Data collection is discussed separately, above, in **Section 4.4** as a precursor to the processing of the data discussed in this and following sections.

Operational data frequently have gaps, and very few data sets are expected to span the range of the period of records for affected USGS gages or the period of record for the basin as a whole. As such, various record extension techniques will be employed to extend operational data over the required periods. These are discussed in detail in the CDM Smith Technical Memorandum entitled, *Guidelines for Standardizing and Simplifying Operational Record Extension,* dated March 2015. It is included as **Attachment B**. A brief summary of the extension techniques is included below. The memorandum is intended to provide guidelines for decision making and procedures for data processing, but is not intended to be an exhaustive list of alternative methods for data extension. Other methods may be found to provide more credible estimates under certain circumstances.

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.

Reservoir operations and responses can be hindcast using statistical techniques, though in the absence of deterministic data, any statistical method will be burdened with inherent uncertainty. Therefore, if existing models of reservoir system are available, and can represent historical practices in the reservoirs covering all or part of the necessary time period, they should be used as a preferred alternative for reservoir record extension. If models are not available, alternative methods are explained in detail in the memo referenced above. Various methods will be preferable in certain situations based on the reservoir size and historic behavior – that is, certain methods will be more applicable to reservoirs that fill and recover each year, while others may be more applicable to those that take several years to draw down and recover.

Once data gaps are filled, UIFs can be developed using Equation 1 for each USGS gage in the basin. As discussed, Equation 1 accounts for the following three categories of impairment:

- Flow regulation due to impoundment (timing of flow downstream)
- Flow change due to withdrawals and discharges (volume of flow downstream)
- Flow change due to alterations in hydrology at impoundments, such as surface evaporation, direct surface precipitation, and water that would have run off on previously unsubmerged land (volume of flow downstream).

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.

4.5.2: Step 2: Extension of UIFs for the USGS Gages Throughout the Basin Period of Record

The period of record for the basin will begin with the first useable date that any USGS gage began recording streamflow. Unimpaired flow records will be extended or filled 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

Note that this data extension is different than the hindcasting and gap filling for the operational records in Step 1 (**Section 4.5.1**). The data extension discussed here is for computed UIFs that already have accounted for measured and synthesized operational impairments, but do not span the full period of record for the basin. The various techniques to fill in gaps in the UIF data sets, or to extend them statistically are described below in **Sections 4.5.2.1** through **4.5.2.2**. 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.

4.5.2.1 Streamflow Transposition by Area Ratios

Where good correlation exists between overlapping periods of unimpaired 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 be 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 Broad, references gages from the Saluda basin may be considered for use in addition to those in the Broad. Guidelines for selecting appropriate reference basins are included in the CDM Smith Technical Memorandum entitled, *"Guidelines for Identifying Reference Basins for UIF Extension or Synthesis,"* dated April 2015. It is included as **Attachment C**.

4.5.2.2 MOVE.1 Technique

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)[3] 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 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

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

which include the gaps to fill. Generally, only the overlapping period of record will be used to calculate statistics; however, in some cases, where the hydrologic statistics are highly variable between gaged and ungagged periods, or where the overlapping period is extremely short, it may improve results to extend the reference gage statistics over a longer period.

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.

4.5.2.3 Combining Area Ratios with MOVE.1

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.

4.5.2.4 Additional Predictive Variables

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.

4.5.2.5 Additional Considerations

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.

4.5.3 Step 3: Correlation Between Ungaged and Gaged Basins

This step is simply the collection of watershed data and the selection of appropriate reference gages for UIFs that must be fully synthesized, either because they are needed in basins that are ungaged, or they are needed at specific calibration points in the river network.

UIFs must be used as inputs to the model at each tributary that will be modeled, either implicitly (flow without management nodes) or explicitly (flow with management nodes) - (Sections 4 and 8 of the *November 2014 South Carolina Surface Water Quantity Models Modeling Plan* discuss explicit and implicit tributaries). The UIF for explicit tributaries will represent the headwater flow of these streams, directly upstream of the first management activity. The UIF for the implicit tributaries can represent flow of the stream at its confluence with the main stem (or other connecting branch). Some of the UIF locations are not gaged, and the UIFs will be synthesized using basin area ratios.

Figure 4-5 illustrates the locations of the ungaged UIF locations. Green diamonds indicate headwater UIFs to be used as model input, and red diamonds represent confluence points of implicit tributaries.

Since there are no partial records to extend, these ungaged UIFs will be developed only with area ratios and carefully selected reference gages. Guidelines for selecting appropriate reference basins are included in the CDM Smith Technical Memorandum entitled, *"Guidelines for Identifying Reference Basins for UIF Extension or Synthesis,"* dated April 2015. It is included as **Attachment C**. The document outlines a series of priorities that can be considered when comparing watershed information to find a reasonably representative reference basin. Fundamentally, the decisions about the most appropriate reference basins will be made collaboratively with DNR and DHEC.

This step does not involve any analysis of the UIFs themselves. Rather, it is a collection of the reference gages and their data that will be used for area transposition into the ungaged sites in Step 4, below.

4.5.4 Step 4: UIFs for Ungaged Basins

This step is the final step in the UIF development process. It transposes the UIFs at the UGSG gage sites, extended through the full period of record for the basin (Step 2, above) into ungaged locations using the reference gages selected in Step 3. **Figure 4-5** above illustrates the locations of the ungaged UIFs that will be developed in this step:

- Any tributary that will be explicitly or implicitly 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).
- Some ungaged sites within the stream network (major confluences, inflow to lakes, etc.) might also benefit from associated UIFs, for subsequent comparison to model results.

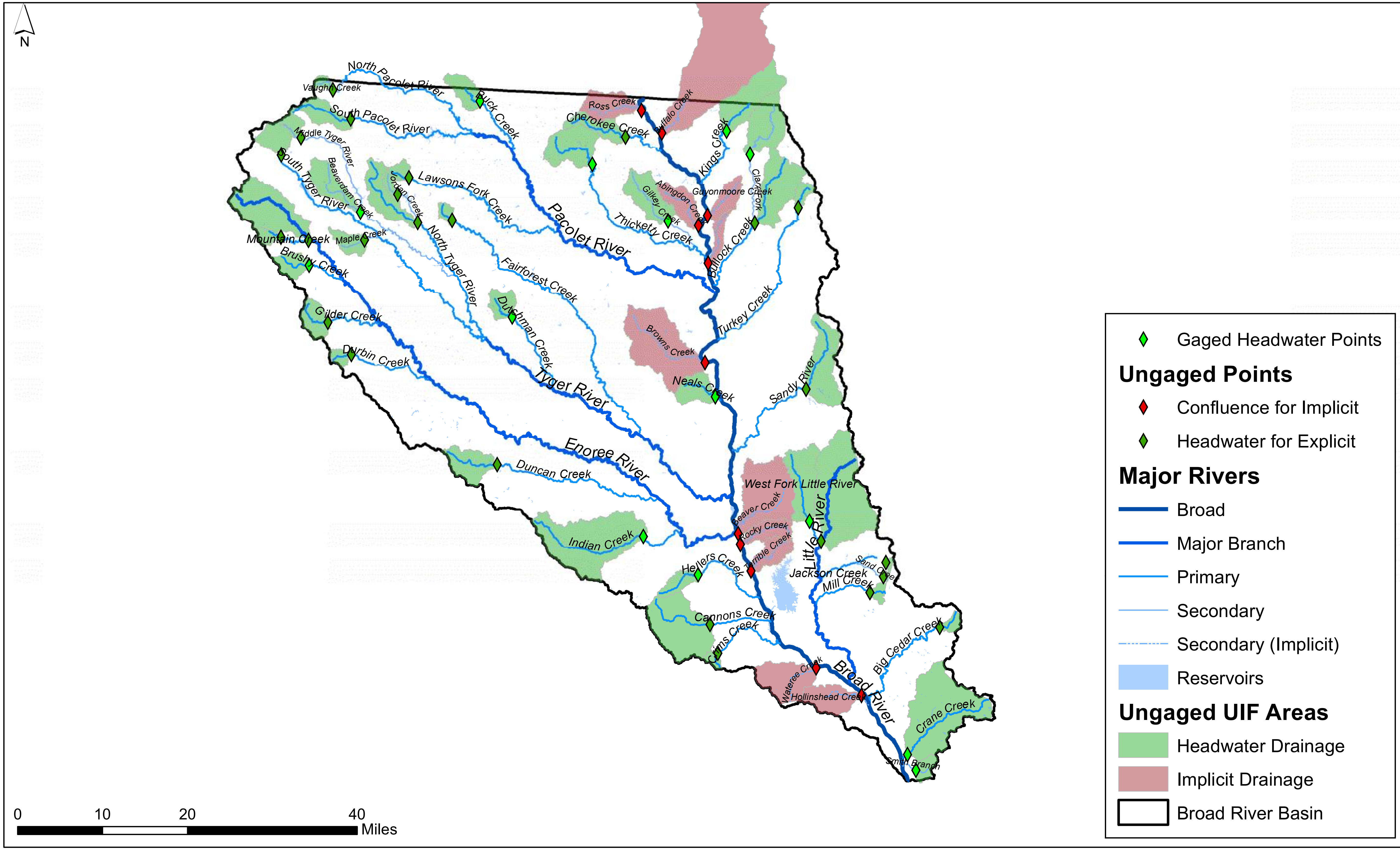

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Figure 4-5: Ungaged UIF Points and Drainage Areas

By combining the reference gages selected in Step 3 with the gaged and extended UIFs developed in Steps 1 and 2, all locations that require UIFs for model input or comparison to results can have the required data. Ungaged UIFs will be computed using area ratios only.

5.0 Gains and Losses Between UIF Nodes

UIFs will be computed for each USGS stream gage 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, if appropriate.

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.

Though losing streams are not likely present in the Broad Basin, 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.

6.0 Issues Specific to the Broad Basin

6.1 Boundary Conditions at the North Carolina State Line

UIFs for basins that originate in North Carolina (Broad, Catawba, and Pee Dee) have already been developed, or will be developed as part of ongoing surface water modeling studies in North Carolina. Where available, CDM Smith will obtain these calculations as boundary condition inputs for the relevant South Carolina models. However, while this will provide a basis for comparing managed flows to natural flows, it may be more practical for future planning to also include managed flows from North Carolina as optional model boundary conditions. The reason is because flows entering South Carolina are based on operating practices regulated by North Carolina, and/or by interstate agreements, neither of which can be controlled by South Carolina. It is recommended that the managed flows from North Carolina be established as the default boundary conditions, but that both data sets (impaired and umimpaired) be available for model users.

CDM Smith will work with NCDNR to utilize the existing OASIS model. Two nodes in the existing OASIS model represent flow near the border between the states, one on the mainstem and one on a major tributary, which will be used as boundary condition flow for the SWAM model, and as necessary for the computation of UIFs in South Carolina. As discussed, unimpaired and impaired boundary condition flows will be developed. Impaired flows will be extracted from the OASIS model using ~2010 operating records). As needed, the difference between the unimpaired and impaired flows at the state line can be used to quantify the total impairments in North Carolina, and these can be used in the computation of mainstem UIFs in South Carolina.

6.2 Existing Broad River UIFs in South Carolina

UIFs for the Broad River Basin in South Carolina were previously developed by DTA under contract to Duke Energy Carolinas, LLC, as reported in the *Broad River Basin Hydrology Report* (DTA, 2007). The UIFs were developed for use in the CHEOPS model, a model that principally simulates hydropower operations in river networks. In support of such a tool, the UIFs were developed to help predict expected flow conditions on the main stem of the Broad River. The UIFs were developed using a "reference basin" approach. Additionally, the Broad River UIFs focused exclusively on flows and flow management in the main stem of the Broad River, since this is where the hydropower facilities are located.

While the UIFs for the Broad River CHEOPS model are well-suited for hydropower simulation by estimating historically available flow, they are not well suited to the Broad River SWAM model currently being developed by CDM Smith for DNR and DHEC. The SWAM model will be used for basin-wide planning and permitting, and requires specific focus on flow management along tributaries, as well as fully unimpaired flows for reference conditions.

They existing UIFs will still have value – they will serve as a good point of comparison for UIFs newly developed for this study, and may help highlight areas that require additional information.

6.3 Groundwater Withdrawals

Registered and permitted (both active and inactive) groundwater withdrawal locations are shown in **Figure 6-1**. 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).

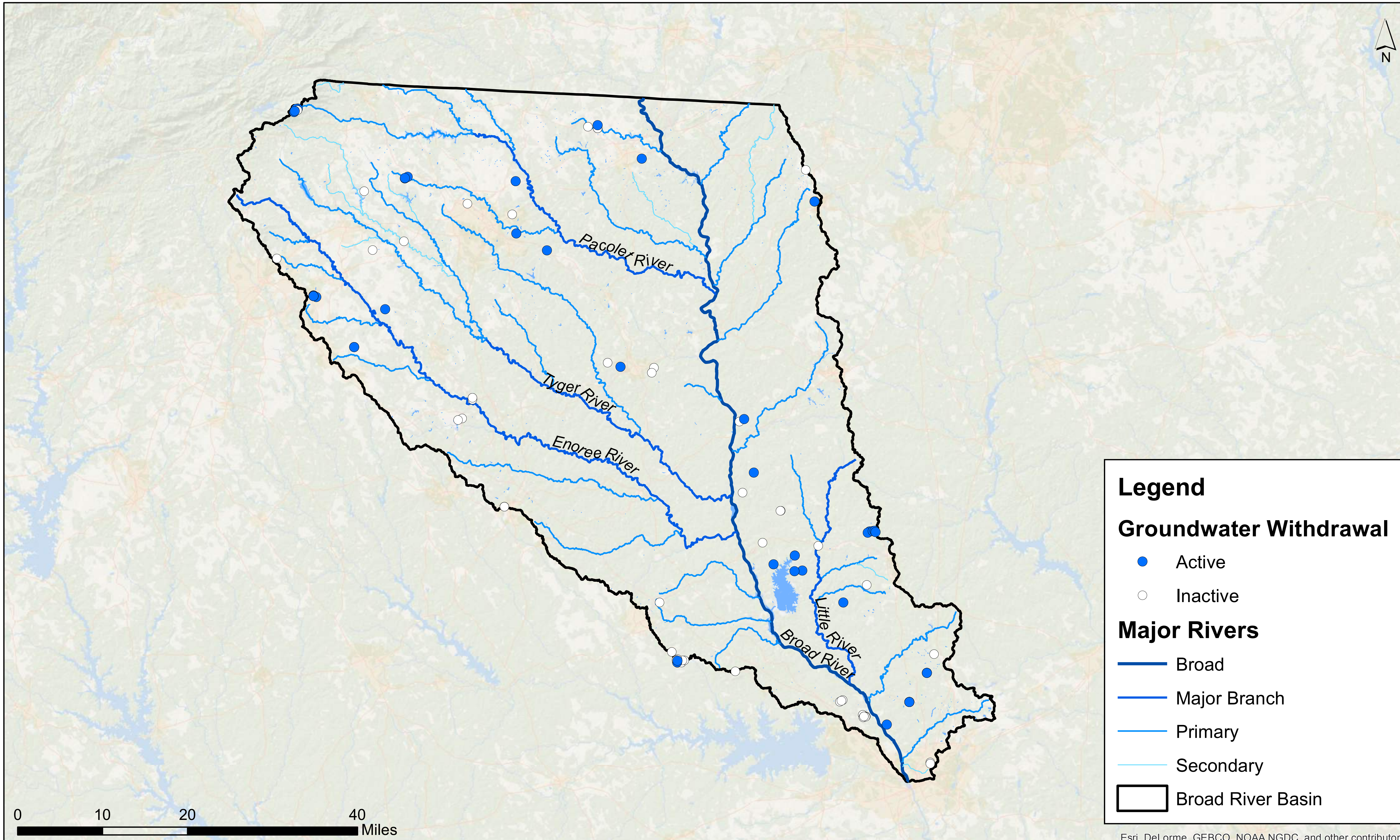


Figure 6-1: Active and Inactive Groundwater Withdrawal Locations

- 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 Broad 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.

6.4 Agriculture

Registered agriculture surface withdrawal locations in the Broad basin were shown in **Figure 3-3.** Of the three registered agricultural surface water users, two 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 percent consumptive. For the UIF calculations, no return flows are assumed.

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.

Additionally, the validity of upstream UIFs will be indirectly assessed as part of the SWAM calibration process. Difficulties in achieving an acceptable calibration at downstream targets may be indicative of problems with upstream UIF inputs to the model. These types of problems, for example, might include poor reference gage selection for estimating upstream ungaged flows. If such problems are identified during the SWAM calibration process, the UIF calculations will be revisited and modified as appropriate.

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. These baseline models could be used, in the same manner described above, to validate downstream UIFs for the full UIF calculation period.

ATTACHMENT A

Methodology for Unimpaired Flow Development – Broad River Basin

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

Script for Water Supply (WS) 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

Methodology for Unimpaired Flow Development – Broad River Basin

Guidelines for Standardizing and Simplifying Operational Record Extension

Guidelines for Standardizing and Simplifying Operational Record Extension

South Carolina Surface Water Quantity Models – Unimpaired Flow Development

CDM Smith, March 2015

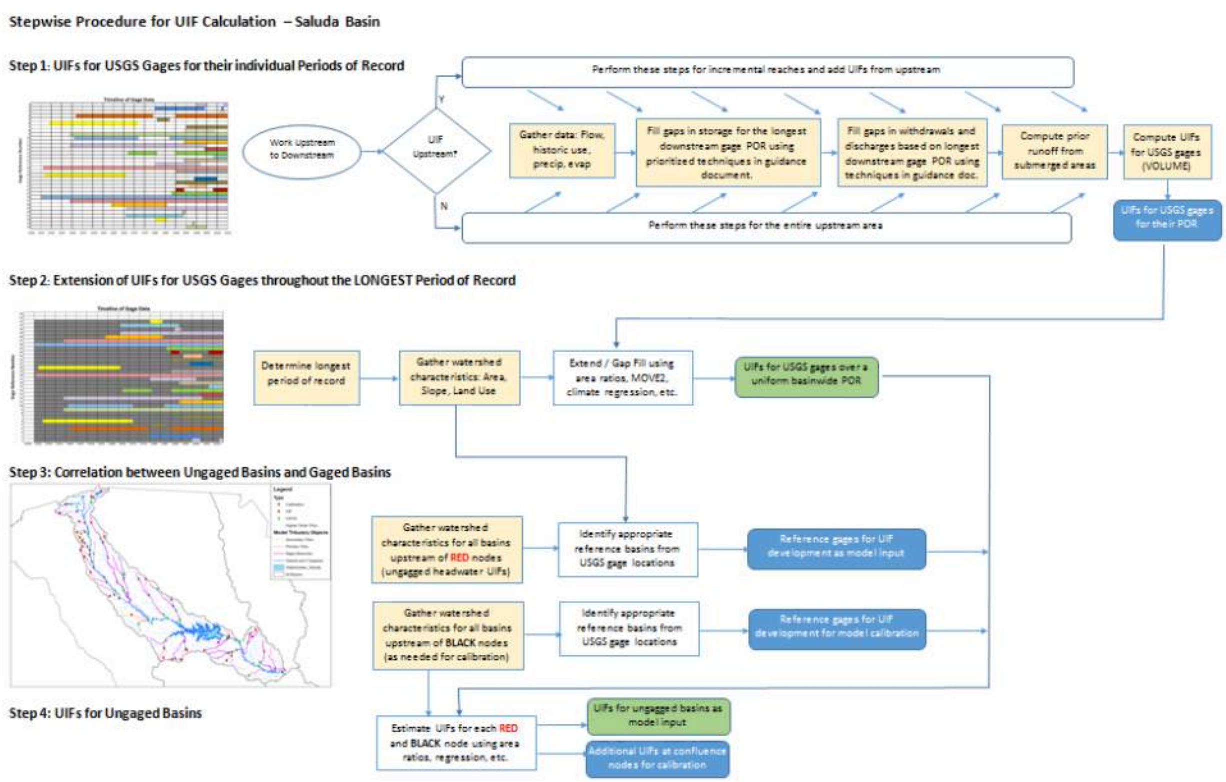
Objective:

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.

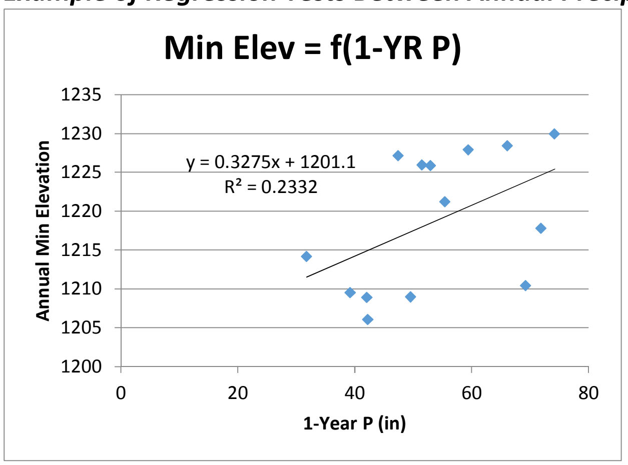
Step 1 - Collect Data: Gather all available information on precipitation and reservoir elevation. Precipitation may be daily, monthly, or annual. Reservoir elevation may be daily or monthly.

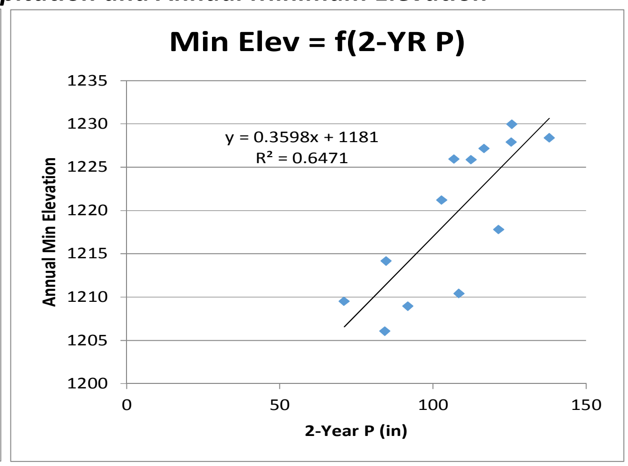
Step 2 - Compute Daily Average Elevation: Over the reservoir period of record, compute a *one-year timeseries* of daily average elevation for each day of the year. For example, the elevation for January 1 would be the average values of all records from January 1 in the period of record. If reservoir 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. *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.* 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.

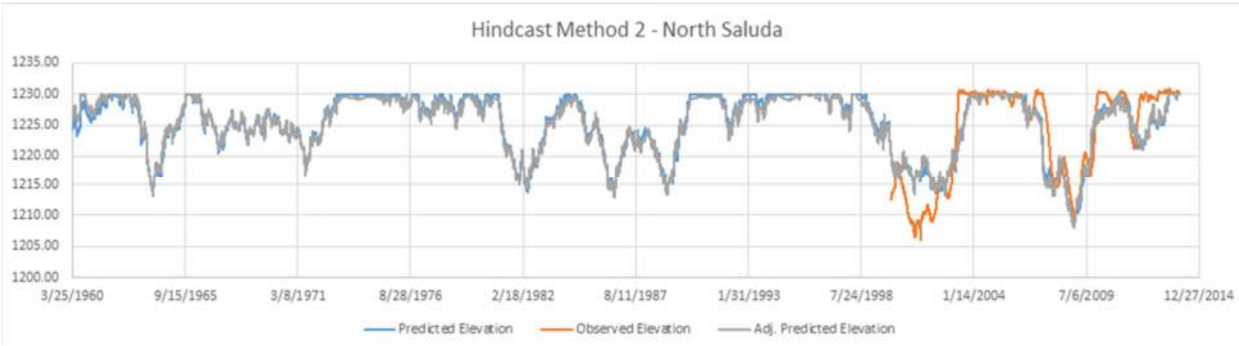
7e) Validate the approach by comparing estimated daily elevation with observed daily or monthly elevation for the period in which the reservoir records exist.

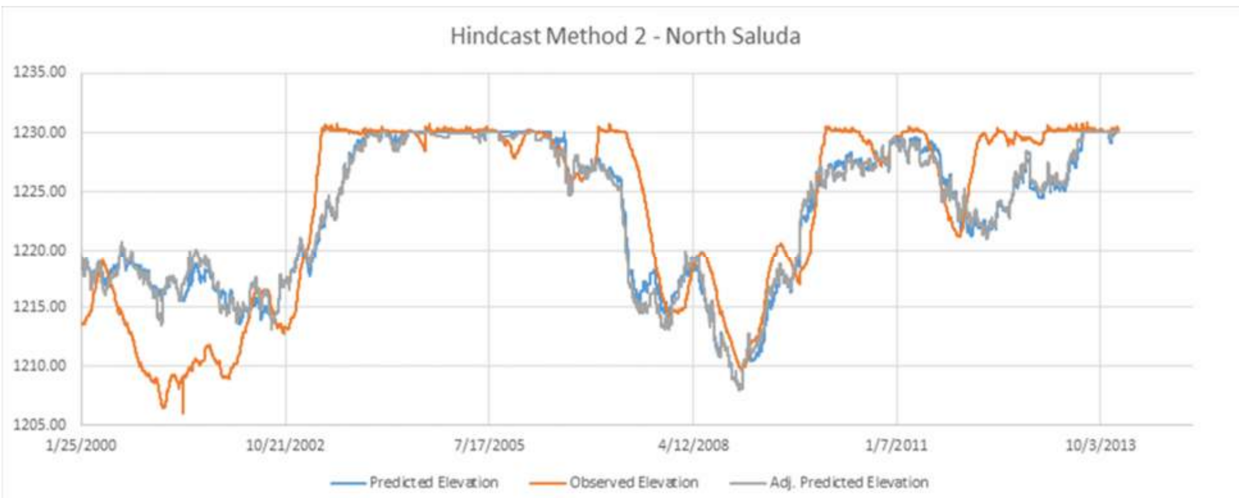
Examples of the Regression Methods:

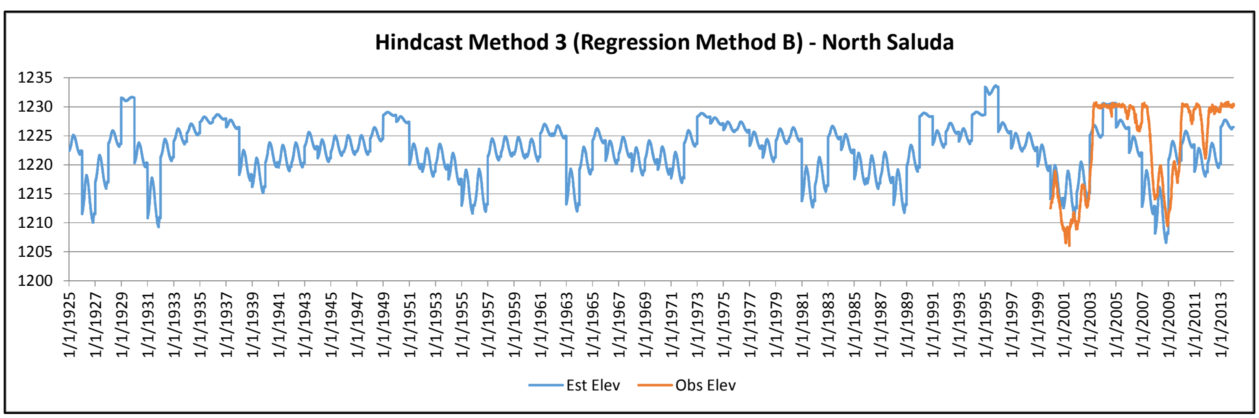
Examples of using these two regression techniques: The two techniques are applied to two reservoirs in the Saluda Basin, and demonstrated below. As noted, this example demonstrates that the best approach may simply be the one with the most obvious predictive ability, but there are some distinguishing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

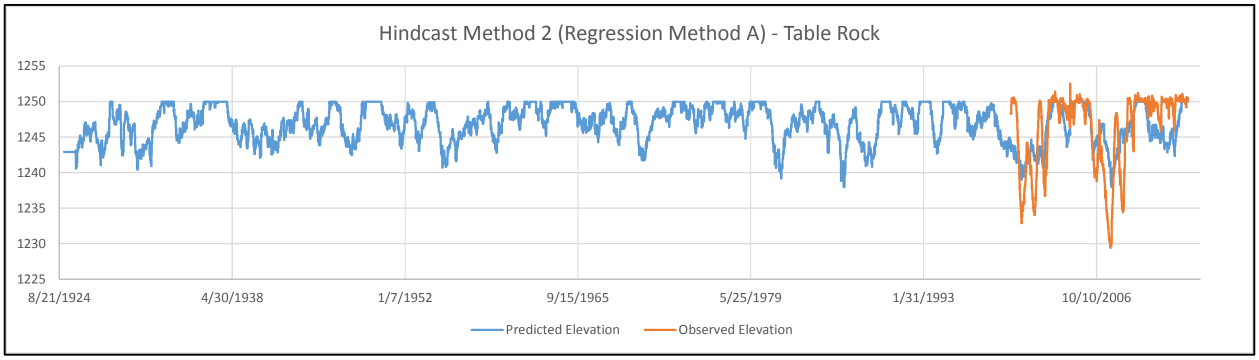


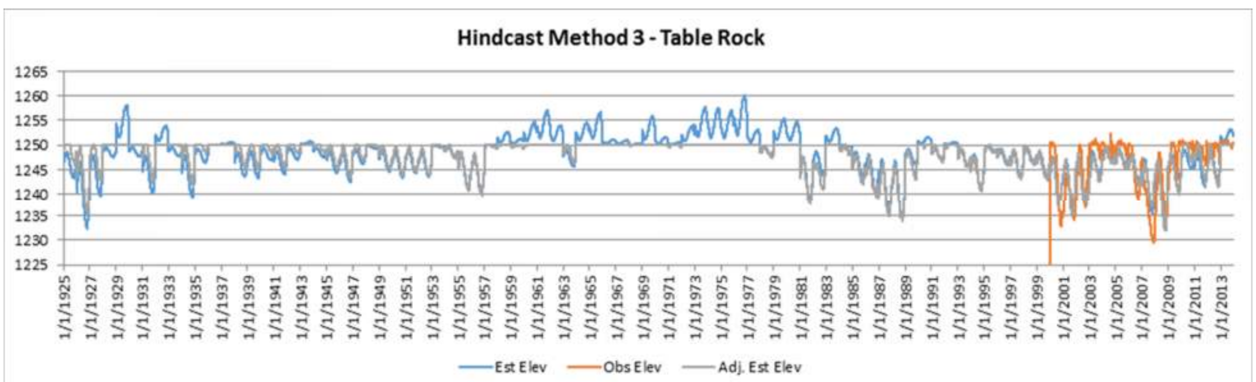


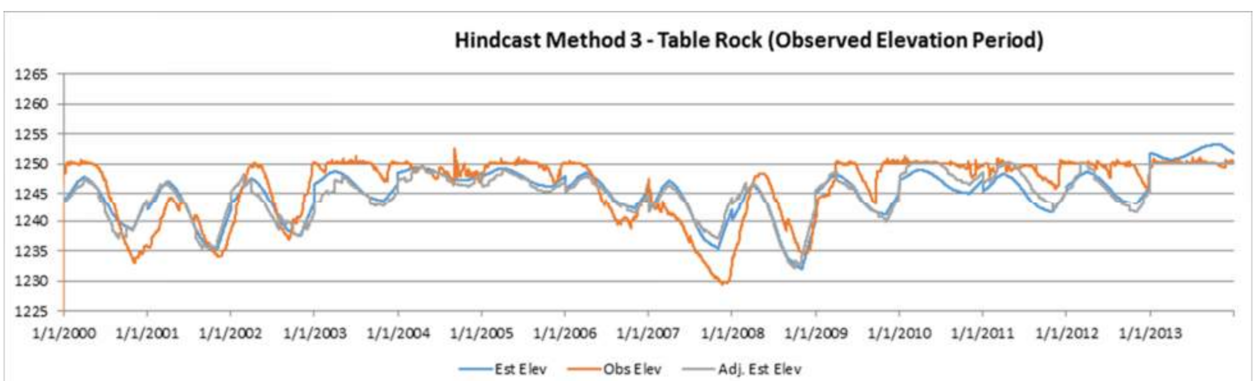


In the second example, the two methods are applied to Table Rock Reservoir.   The data suggest that the reservoir draws down irregularly, and is not usually completely full. **METHOD 3 is preferred in this example** because it appears to better match the magnitude of severe drawdown, the reservoir is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

Methodology for Unimpaired Flow Development – Broad River Basin

Guidelines for Identifying Reference Basins for UIF Extension or Synthesis

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.

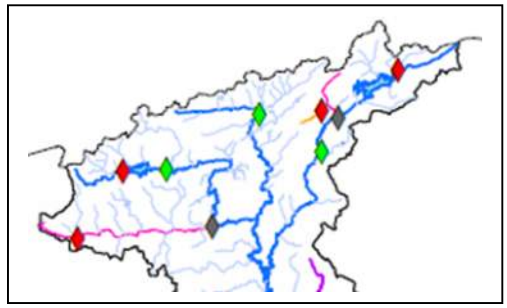
For clarity, we shall refer to ungaged and undergaged sites (needing either full synthesis or gap filling/extension, respectively) all as "ungaged" basins, as opposed to the reference basins, whose gage records will be used for hydrologic transposition.

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**

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

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 B

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

(CDM Smith, April 2015)

Quality Assurance Guidelines

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

Prepared by CDM Smith, April 2015, Adjusted September 2015

Procedural Review

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

Detailed Review

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

Extension Review

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

ATTACHMENT C

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.

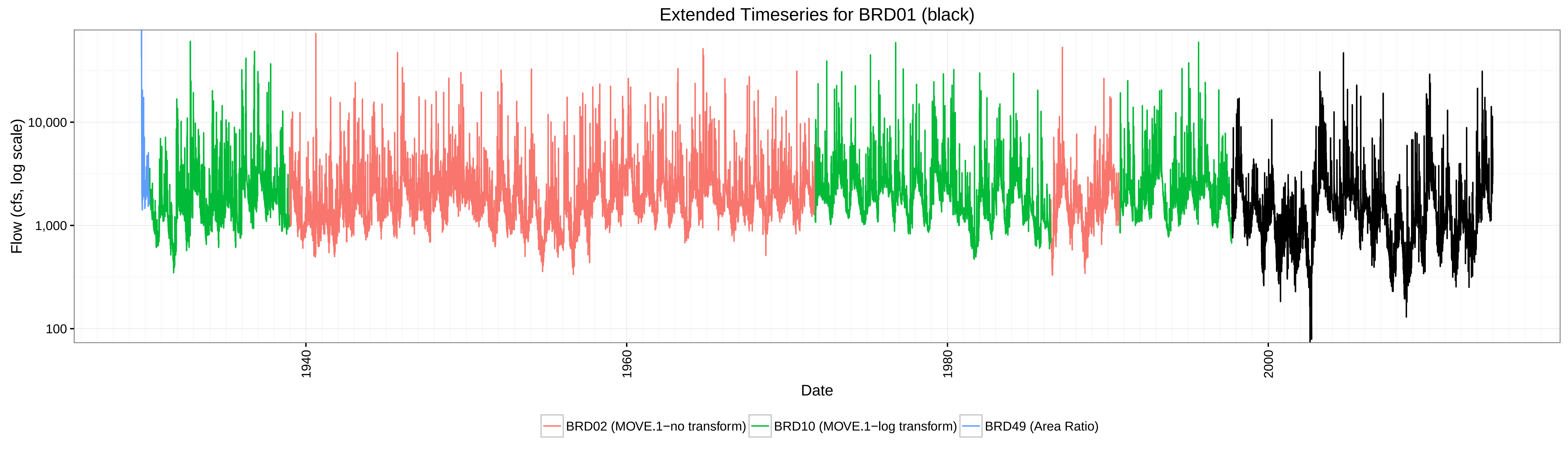
Two quantitative metrics aid the selection of reference gages and methods: root mean square error (RMSE) and predicted residual sum of squares (PRESS). RMSE compares estimated daily values and must be interpreted cautiously as this can be skewed by under or over-predicted flows. As an additional standard,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

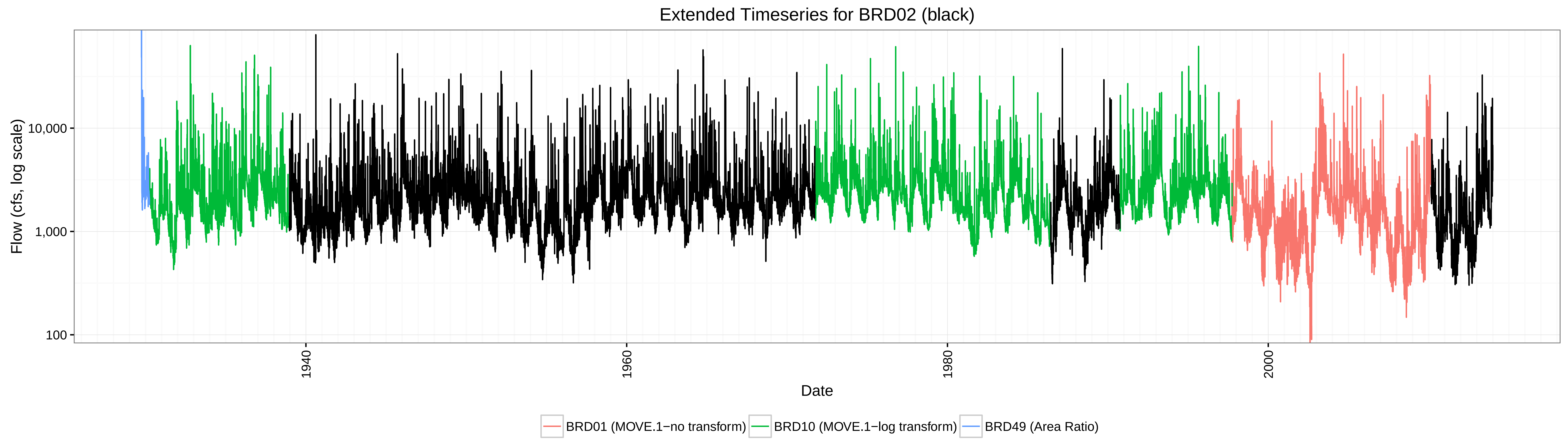
After examining the table and these performance plots, a final decision table is created and fed into another R script that creates the fully-extended record and makes two more plots: 5) verification showing the estimated values for the overlapping record and 6) final flows timeseries for the entire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

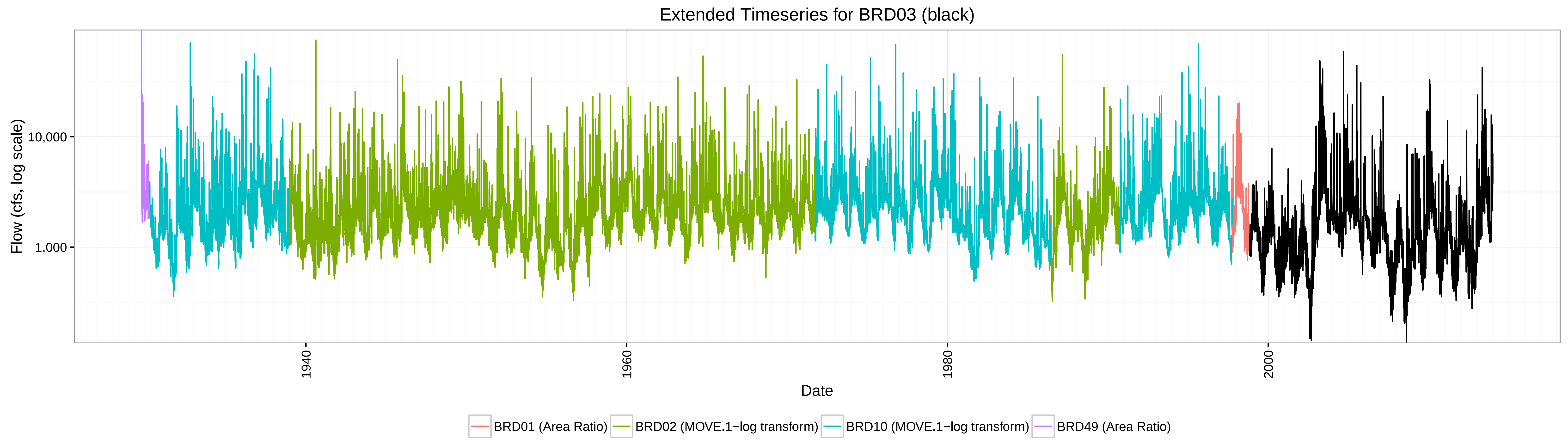
UIF Timeseries Graphs at USGS Gage Locations



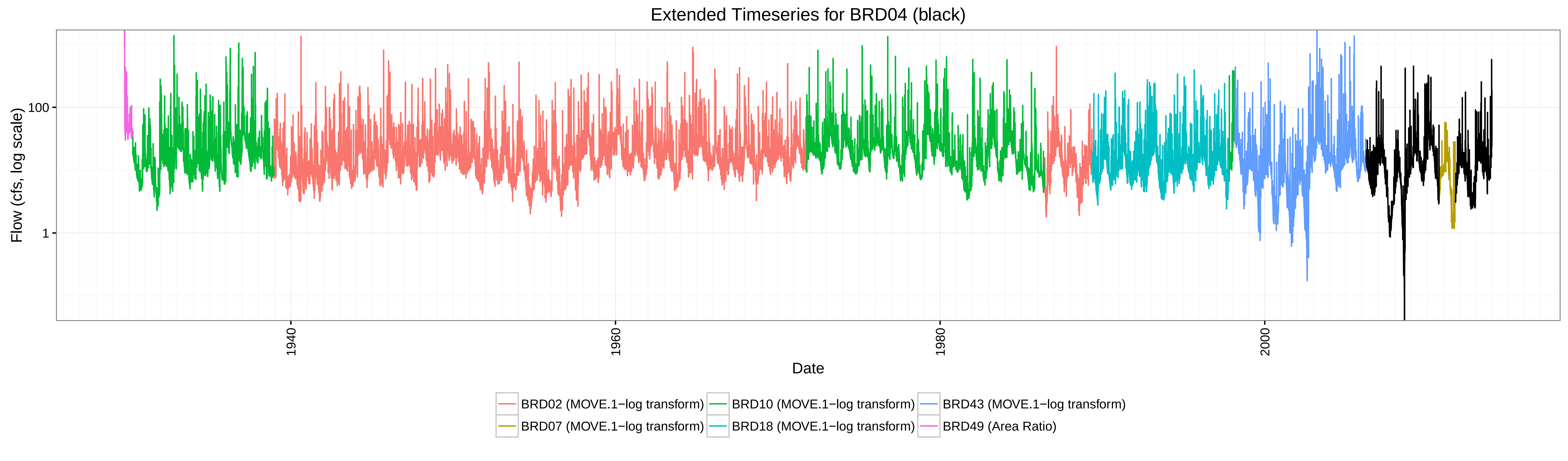
Extended Timeseries for BRD01 (black)
Flow (cfs, log scale)
10,000
1,000
100
1940
1960
1980
2000
Date
BRD02 (MOVE.1−no transform)
BRD10 (MOVE.1−log transform)
BRD49 (Area Ratio)

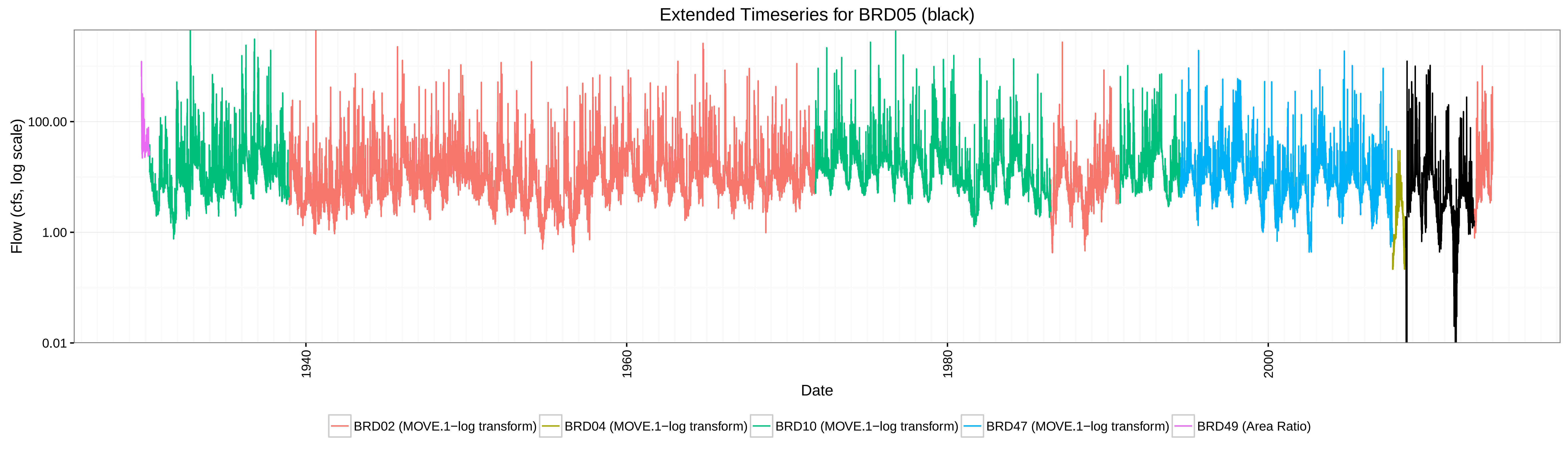


Extended Timeseries for BRD02 (black)
Flow (cfs, log scale)
10,000
1,000
100
1940
1960
1980
2000
Date
BRD01 (MOVE.1−no transform)
BRD10 (MOVE.1−log transform)
BRD49 (Area Ratio)

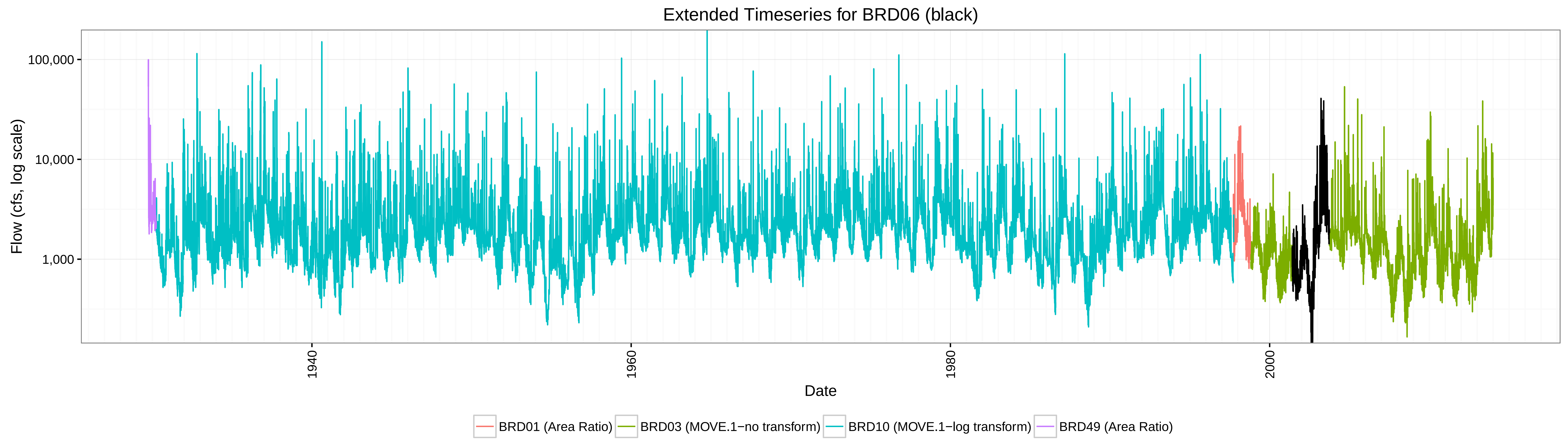


Extended Timeseries for BRD03 (black)
Flow (cfs, log scale)
10,000
1,000
1940
1960
1980
2000
Date
BRD01 (Area Ratio)
BRD02 (MOVE.1−log transform)
BRD10 (MOVE.1−log transform)
BRD49 (Area Ratio)

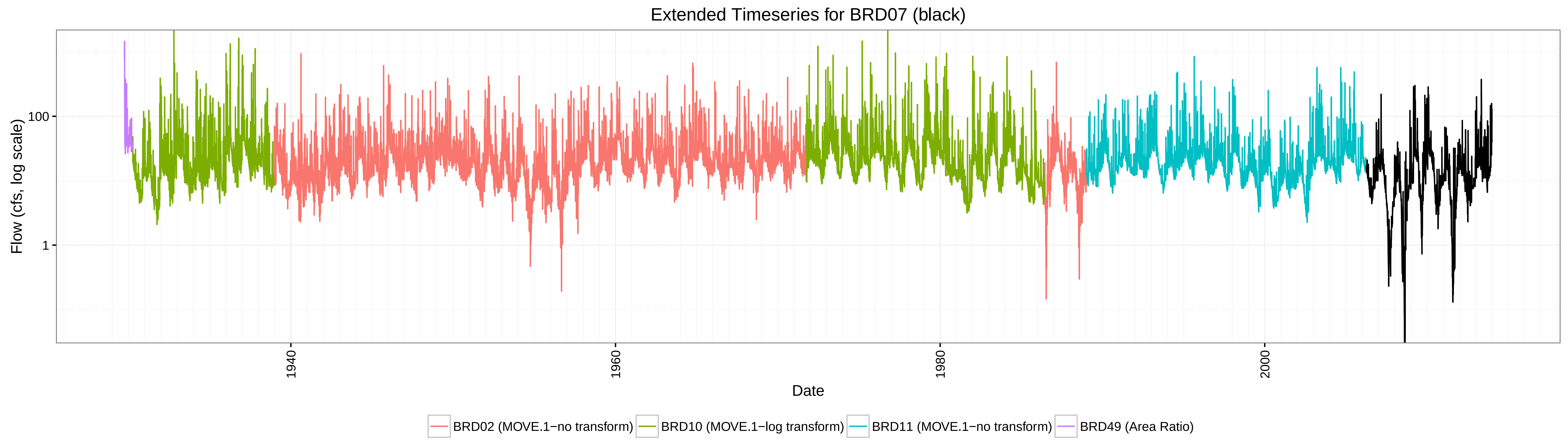

Extended Timeseries for BRD04 (black)
Flow (cfs, log scale)
100
1
1940
1960
1980
2000
Date
BRD02 (MOVE.1−log transform)
BRD10 (MOVE.1−log transform)
BRD43 (MOVE.1−log transform)
BRD07 (MOVE.1−log transform)
BRD18 (MOVE.1−log transform)
BRD49 (Area Ratio)



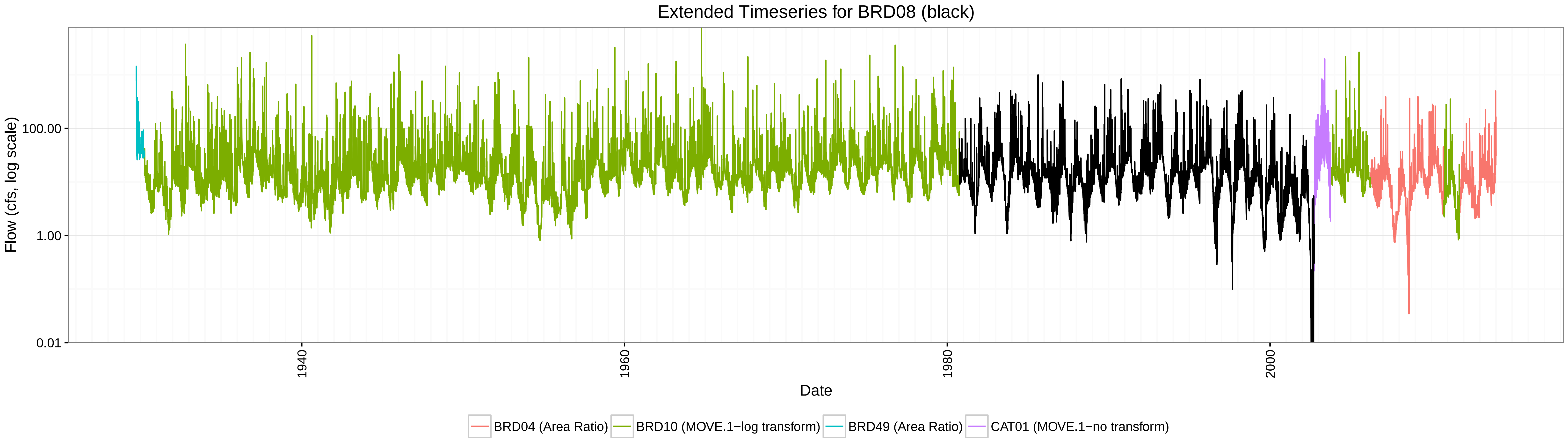
Extended Timeseries for BRD05 (black)
Flow (cfs, log scale)
100.00
1.00
0.01
1940
1960
1980
2000
Date
BRD02 (MOVE.1−log transform)
BRD04 (MOVE.1−log transform)
BRD10 (MOVE.1−log transform)
BRD47 (MOVE.1−log transform)
BRD49 (Area Ratio)



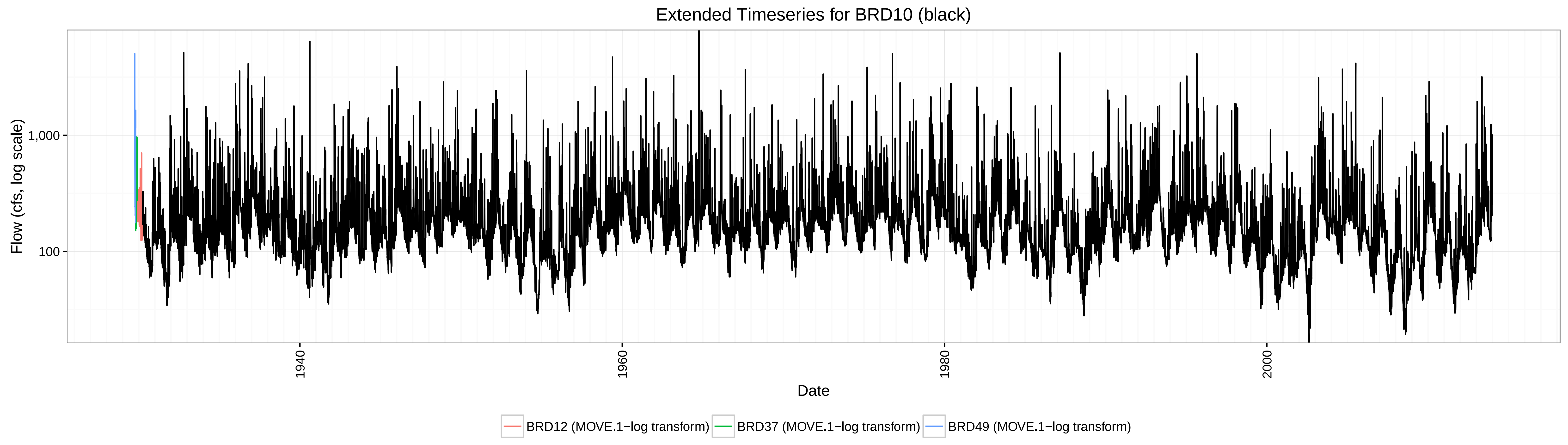
Extended Timeseries for BRD06 (black)
Flow (cfs, log scale)
100,000
10,000
1,000
1940
1960
1980
2000
Date
BRD01 (Area Ratio)
BRD03 (MOVE.1−no transform)
BRD10 (MOVE.1−log transform)
BRD49 (Area Ratio)



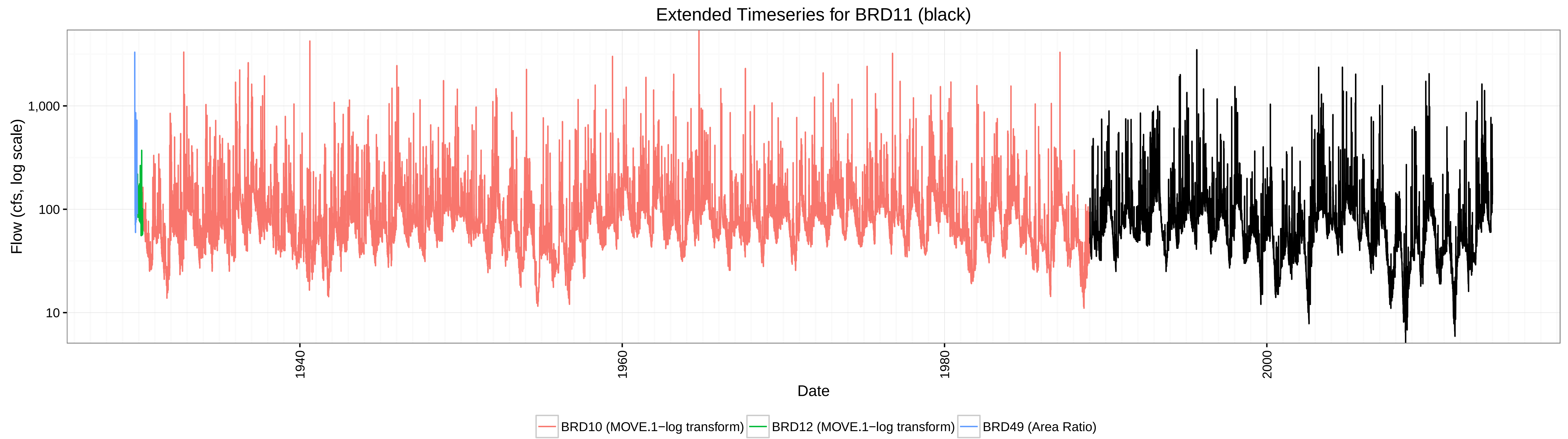
Extended Timeseries for BRD07 (black)
Flow (cfs, log scale)
100
1
1940
1960
1980
2000
Date
BRD02 (MOVE.1−no transform)
BRD10 (MOVE.1−log transform)
BRD11 (MOVE.1−no transform)
BRD49 (Area Ratio)



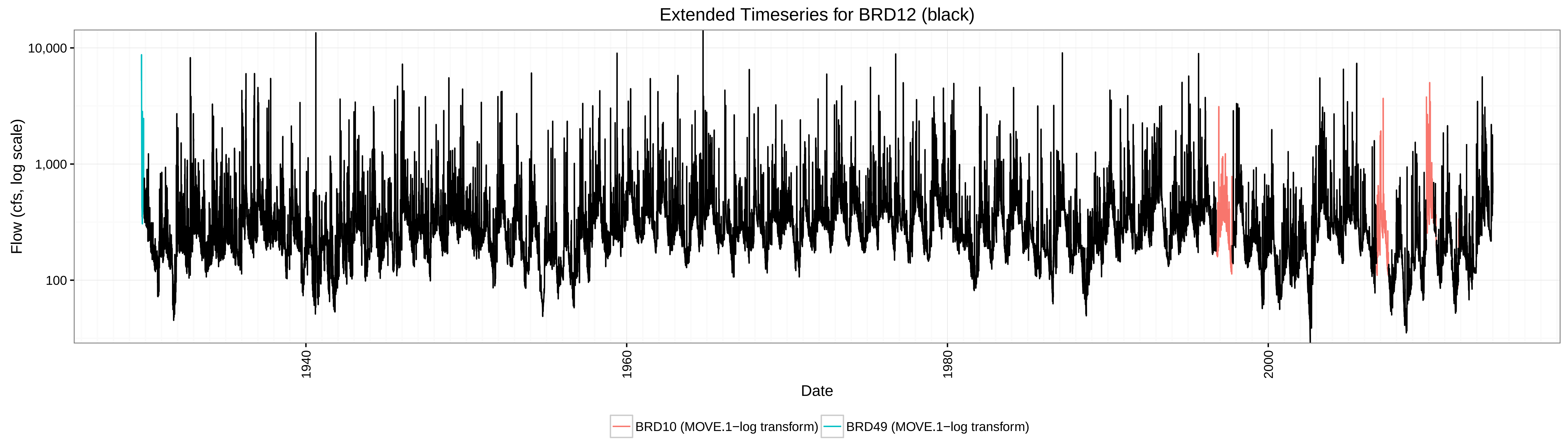
Extended Timeseries for BRD08 (black)
Flow (cfs, log scale)
100.00
1.00
0.01
1940
1960
1980
2000
Date
BRD04 (Area Ratio)
BRD10 (MOVE.1−log transform)
BRD49 (Area Ratio)
CAT01 (MOVE.1−no transform)



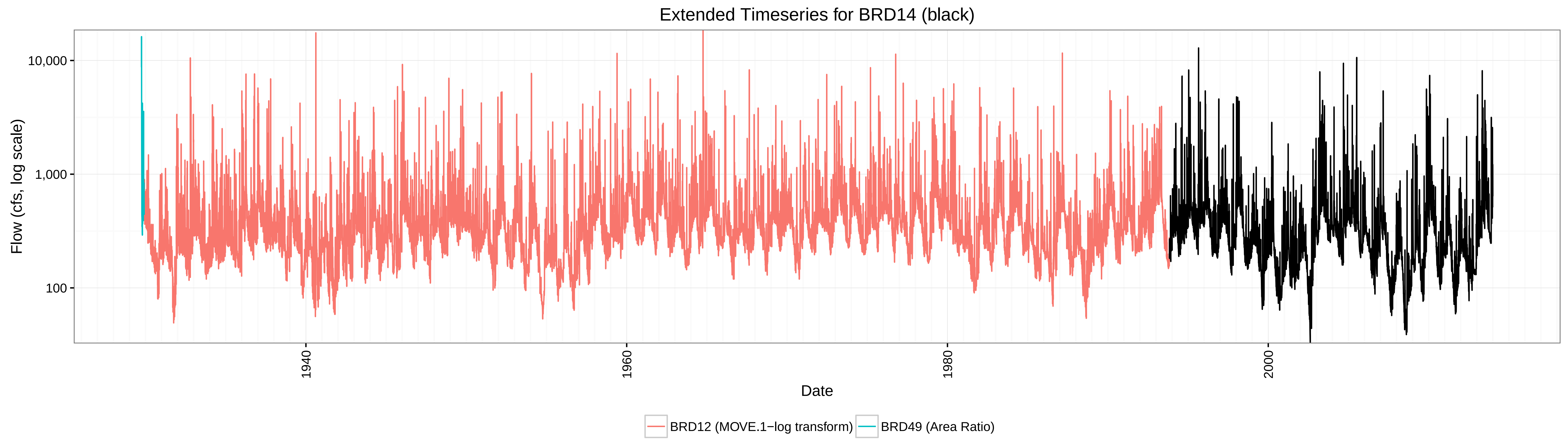
Extended Timeseries for BRD10 (black)
Flow (cfs, log scale)
1,000
100
1940
1960
1980
2000
Date
BRD12 (MOVE.1−log transform)
BRD37 (MOVE.1−log transform)
BRD49 (MOVE.1−log transform)



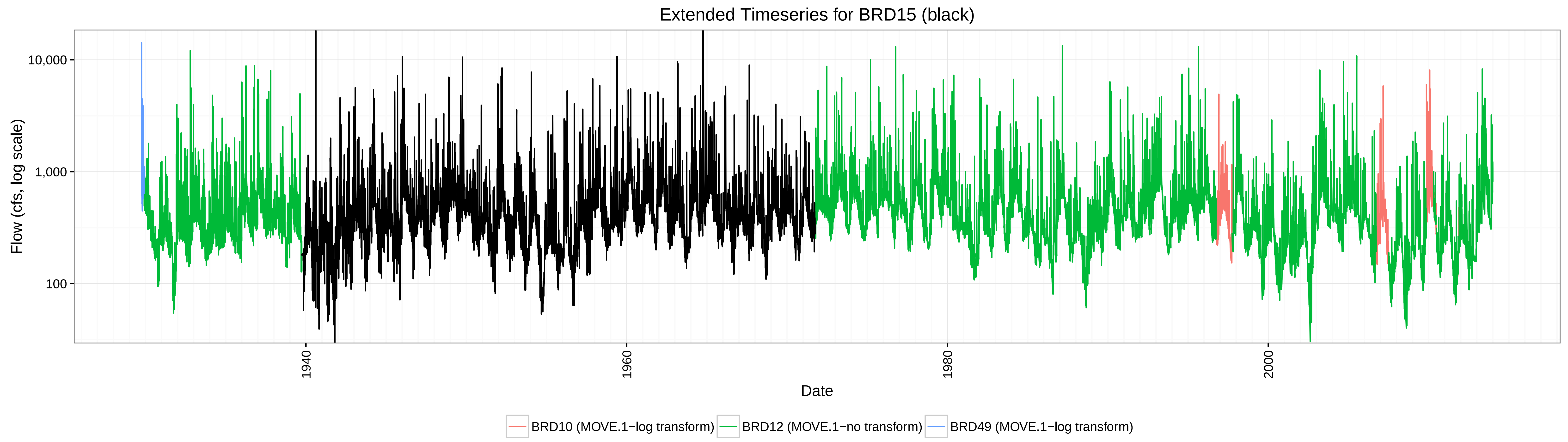
Extended Timeseries for BRD11 (black)
Flow (cfs, log scale)
1,000
100
10
1940
1960
1980
2000
Date
BRD10 (MOVE.1−log transform)
BRD12 (MOVE.1−log transform)
BRD49 (Area Ratio)

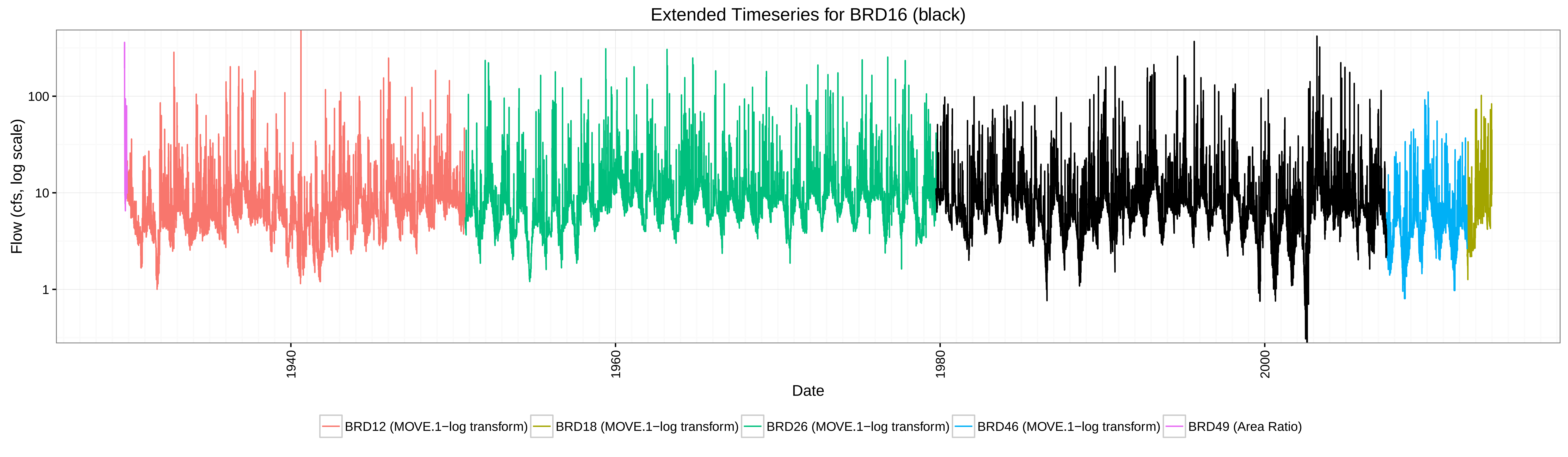


Extended Timeseries for BRD12 (black)
Flow (cfs, log scale)
10,000
1,000
100
1940
1960
1980
2000
Date
BRD10 (MOVE.1−log transform)
BRD49 (MOVE.1−log transform)

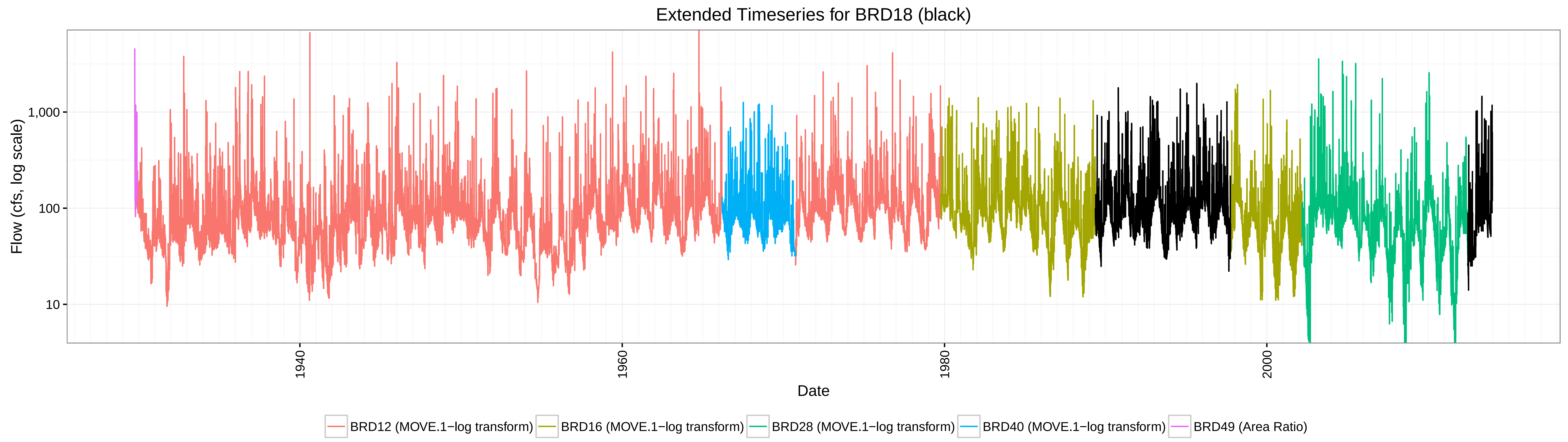


Extended Timeseries for BRD14 (black)
Flow (cfs, log scale)
10,000
1,000
100
1940
1960
1980
2000
Date
BRD12 (MOVE.1−log transform)
BRD49 (Area Ratio)

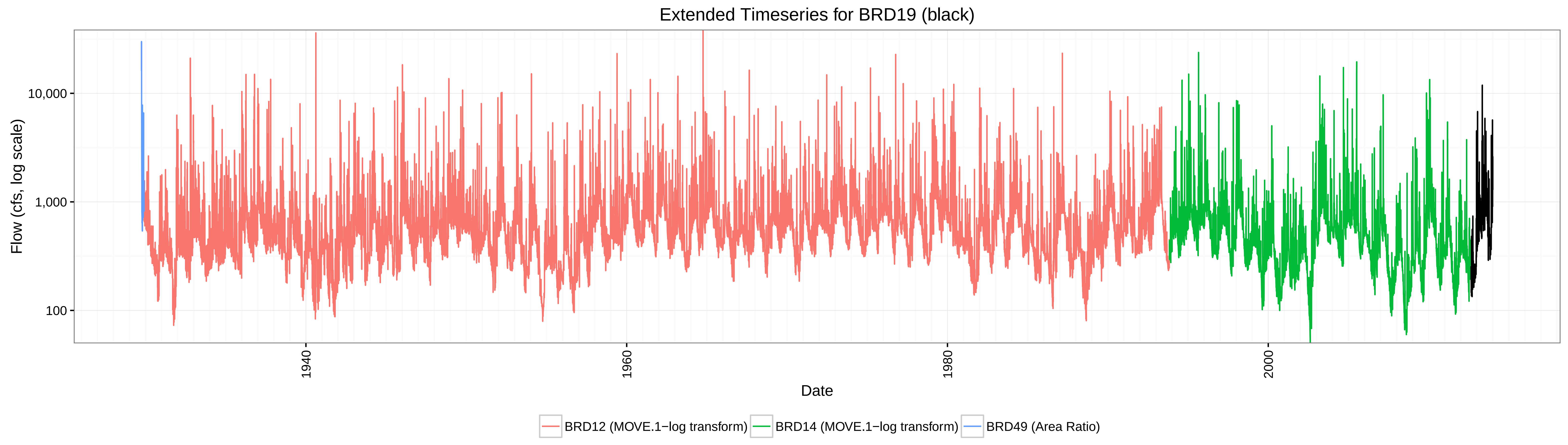

Extended Timeseries for BRD15 (black)
10,000
1,000
100
Flow (cfs, log scale)
1940
1960
1980
2000
Date
BRD10 (MOVE.1−log transform)
BRD12 (MOVE.1−no transform)
BRD49 (MOVE.1−log transform)



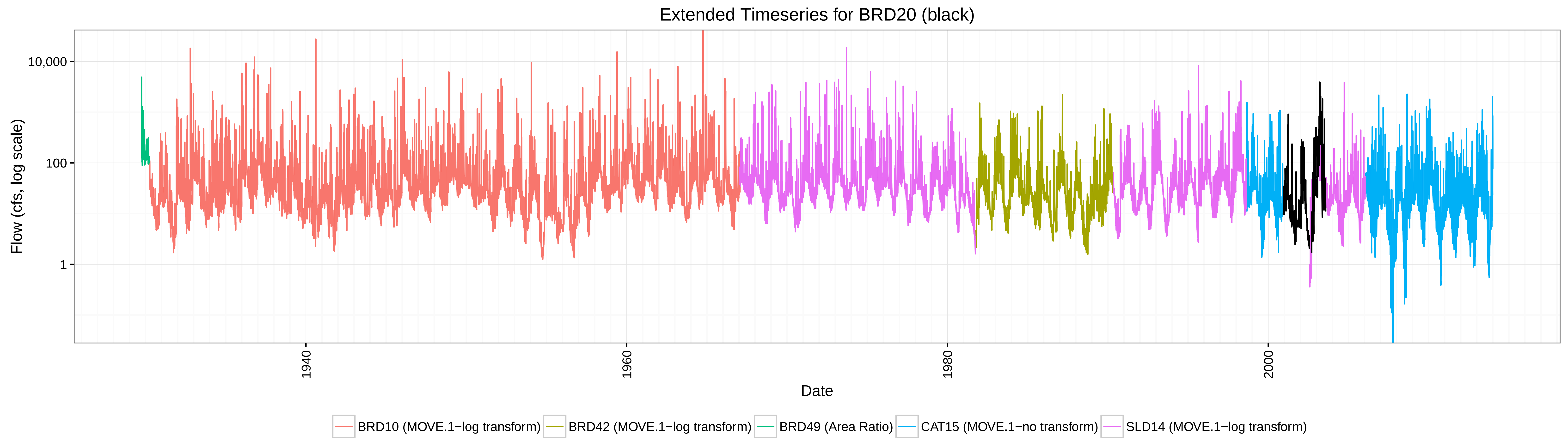
Extended Timeseries for BRD16 (black)
Flow (cfs, log scale)
100
10
1
1940
1960
1980
2000
Date
BRD12 (MOVE.1−log transform)
BRD18 (MOVE.1−log transform)
BRD26 (MOVE.1−log transform)
BRD46 (MOVE.1−log transform)
BRD49 (Area Ratio)

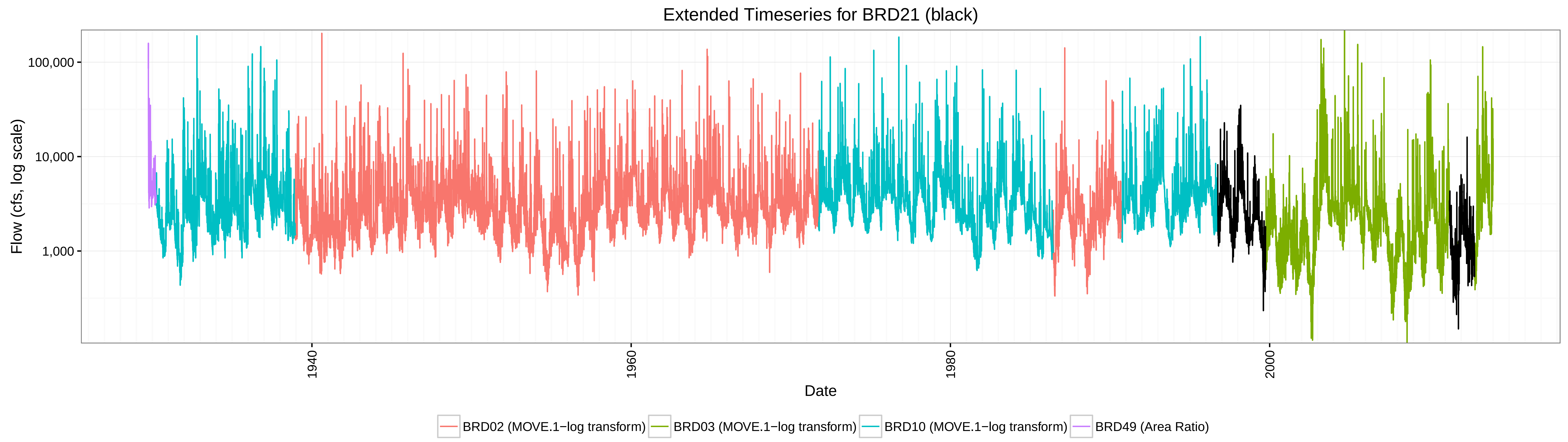


Extended Timeseries for BRD18 (black)
Flow (cfs, log scale)
1,000
100
10
1940
1960
1980
2000
Date
BRD12 (MOVE.1−log transform)
BRD16 (MOVE.1−log transform)
BRD28 (MOVE.1−log transform)
BRD40 (MOVE.1−log transform)
BRD49 (Area Ratio)

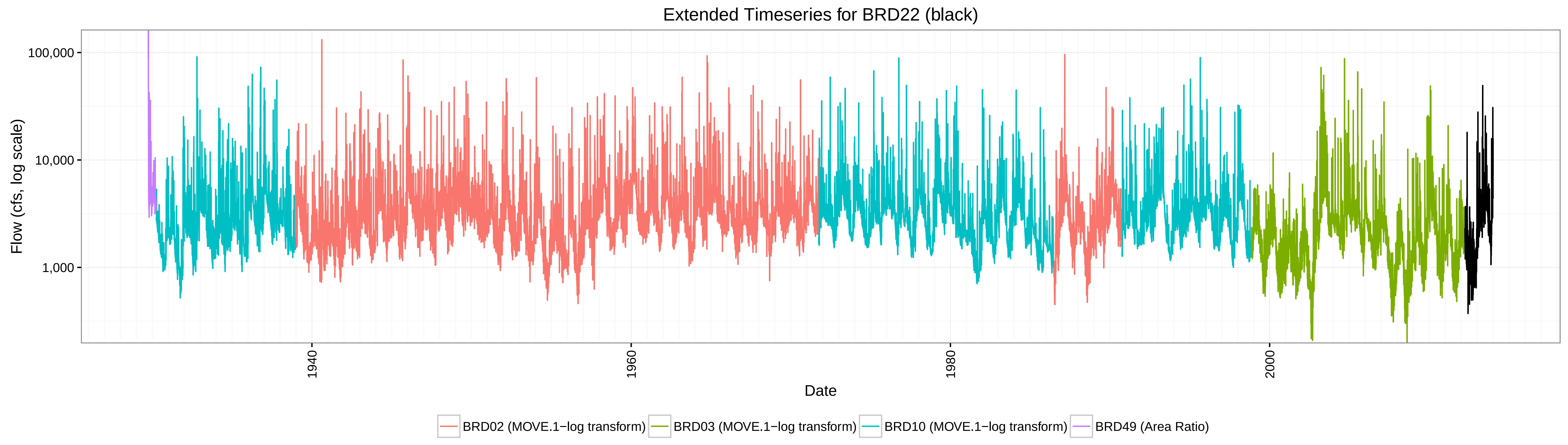


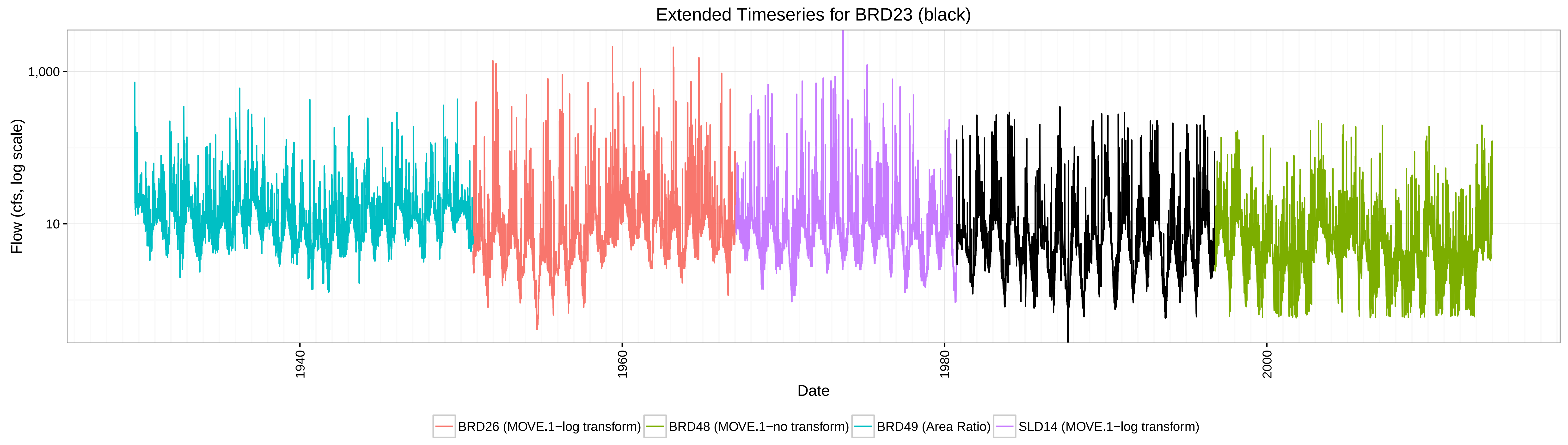
Extended Timeseries for BRD19 (black)
Flow (cfs, log scale)
10,000
1,000
100
1940
1960
1980
2000
Date
BRD12 (MOVE.1−log transform)
BRD14 (MOVE.1−log transform)
BRD49 (Area Ratio)


Extended Timeseries for BRD20 (black)
10,000
100
1
Flow (cfs, log scale)
1940
1960
1980
2000
Date
BRD10 (MOVE.1−log transform)
BRD42 (MOVE.1−log transform)
BRD49 (Area Ratio)
CAT15 (MOVE.1−no transform)
SLD14 (MOVE.1−log transform)

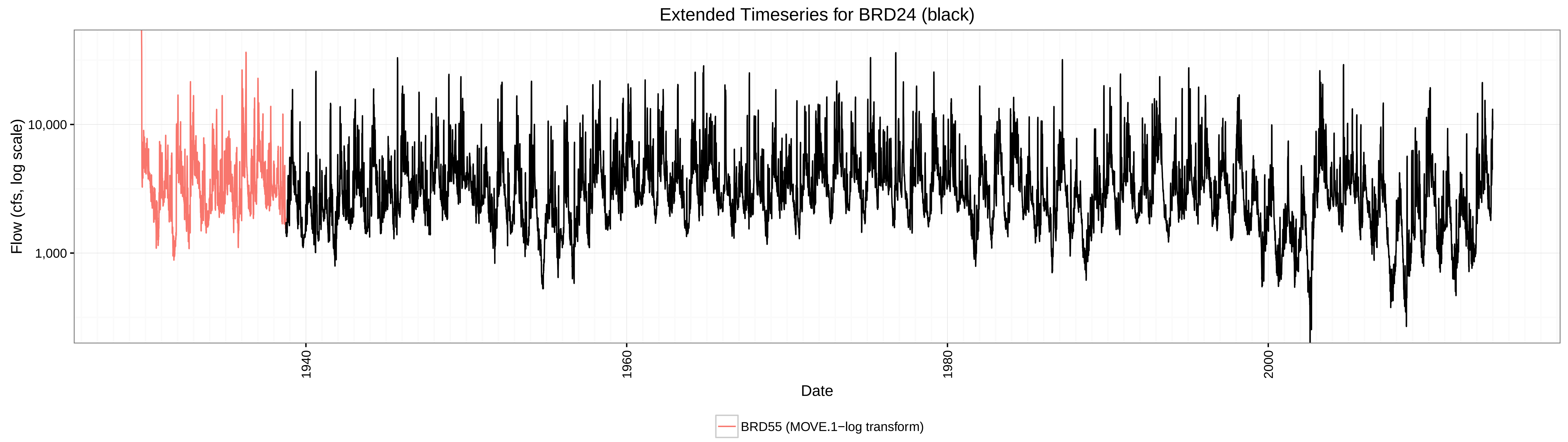


Extended Timeseries for BRD21 (black)
Flow (cfs, log scale)
100,000
10,000
1,000
1940
1960
1980
2000
Date
BRD02 (MOVE.1−log transform)
BRD03 (MOVE.1−log transform)
BRD10 (MOVE.1−log transform)
BRD49 (Area Ratio)

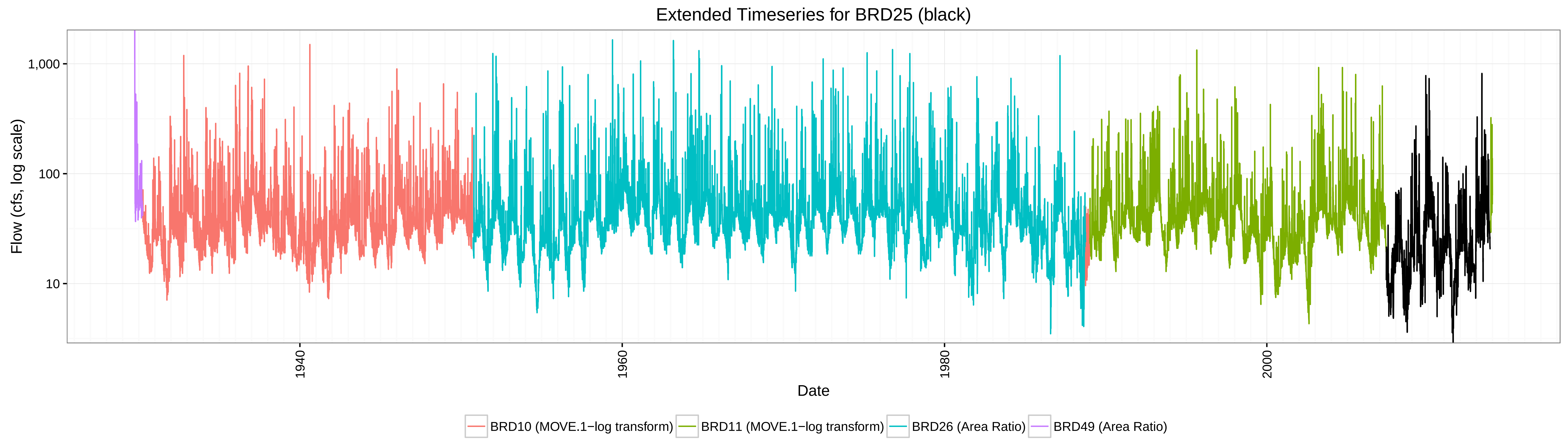

Extended Timeseries for BRD22 (black)
Flow (cfs, log scale)
100,000
10,000
1,000
1940
1960
1980
2000
Date
BRD02 (MOVE.1−log transform)
BRD03 (MOVE.1−log transform)
BRD10 (MOVE.1−log transform)
BRD49 (Area Ratio)



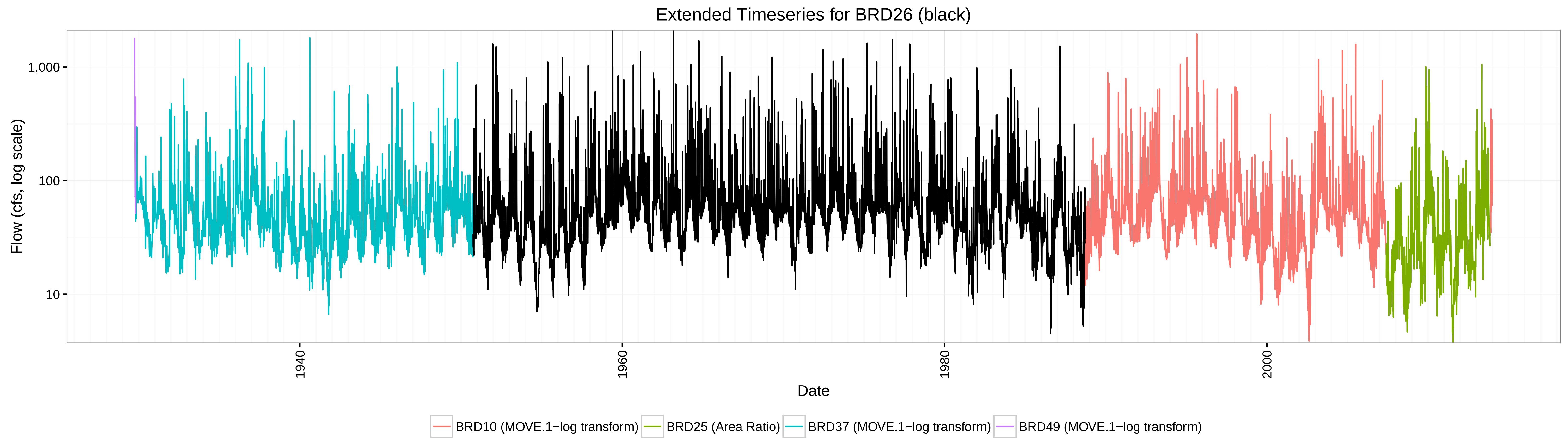
Extended Timeseries for BRD23 (black)
Flow (cfs, log scale)
1,000
10
1940
1960
1980
2000
Date
BRD26 (MOVE.1−log transform)
BRD48 (MOVE.1−no transform)
BRD49 (Area Ratio)
SLD14 (MOVE.1−log transform)

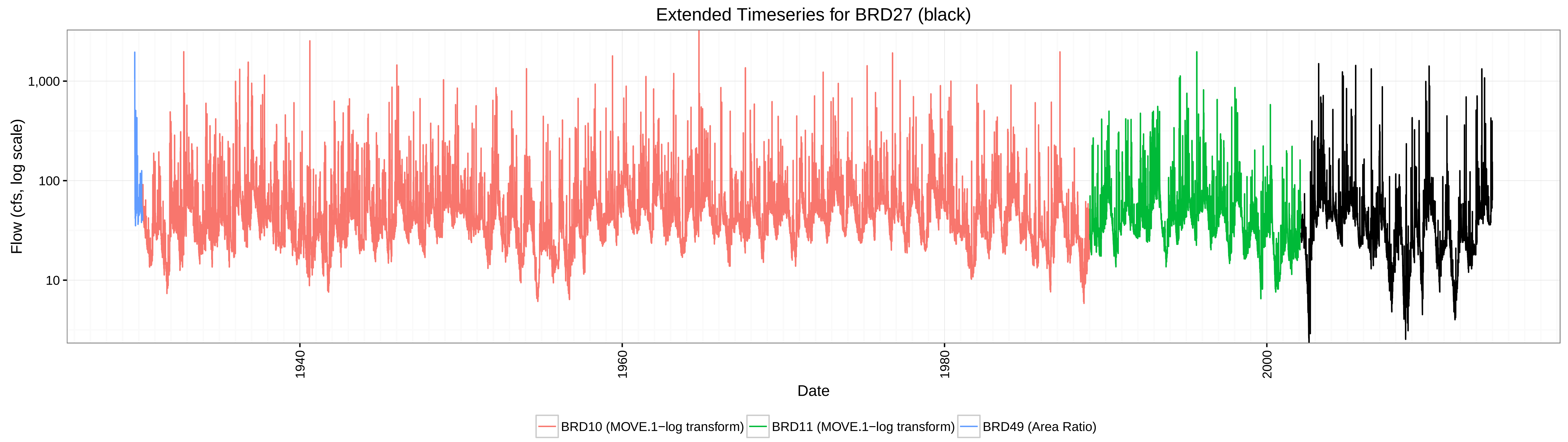


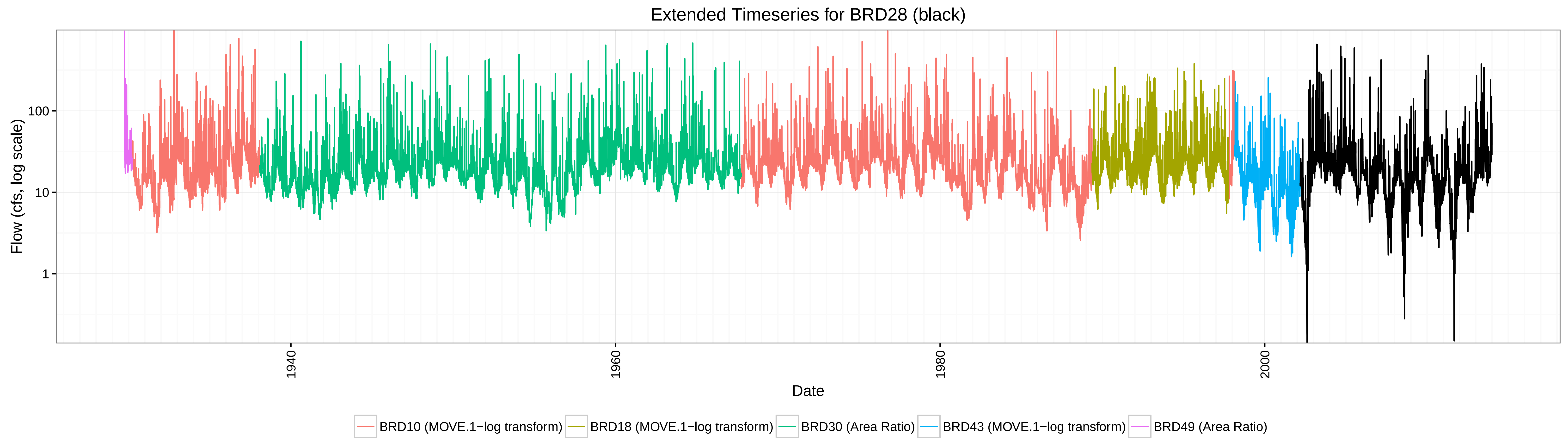
Extended Timeseries for BRD24 (black)
Flow (cfs, log scale)
10,000
1,000
1940
1960
1980
2000
Date
BRD55 (MOVE.1−log transform)



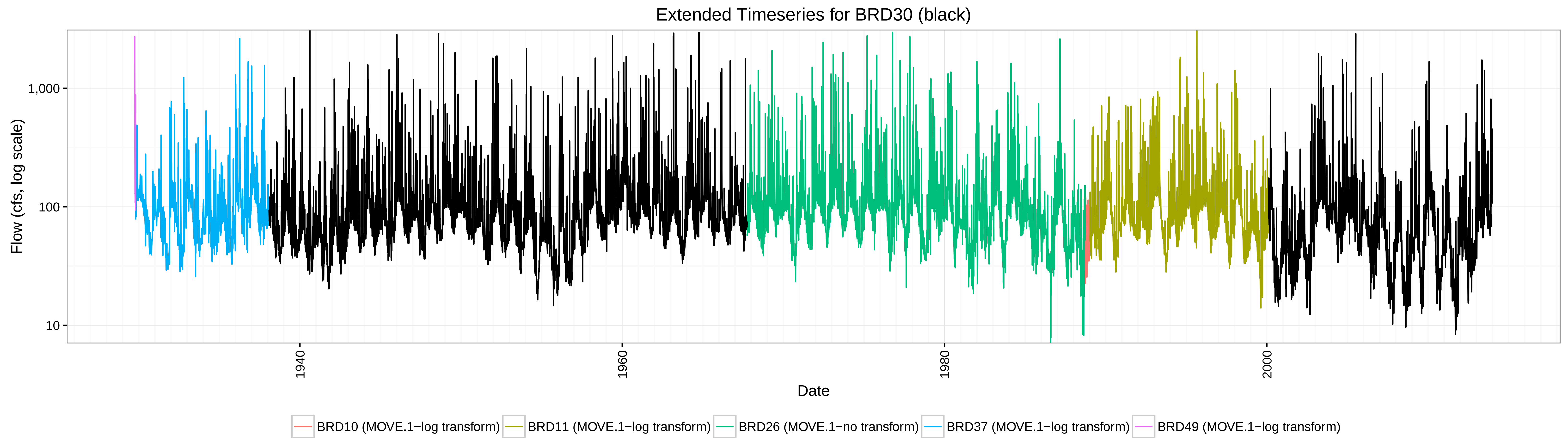
Extended Timeseries for BRD25 (black)
Flow (cfs, log scale)
1,000
100
10
1940
1960
1980
2000
Date
BRD10 (MOVE.1−log transform)
BRD11 (MOVE.1−log transform)
BRD26 (Area Ratio)
BRD49 (Area Ratio)

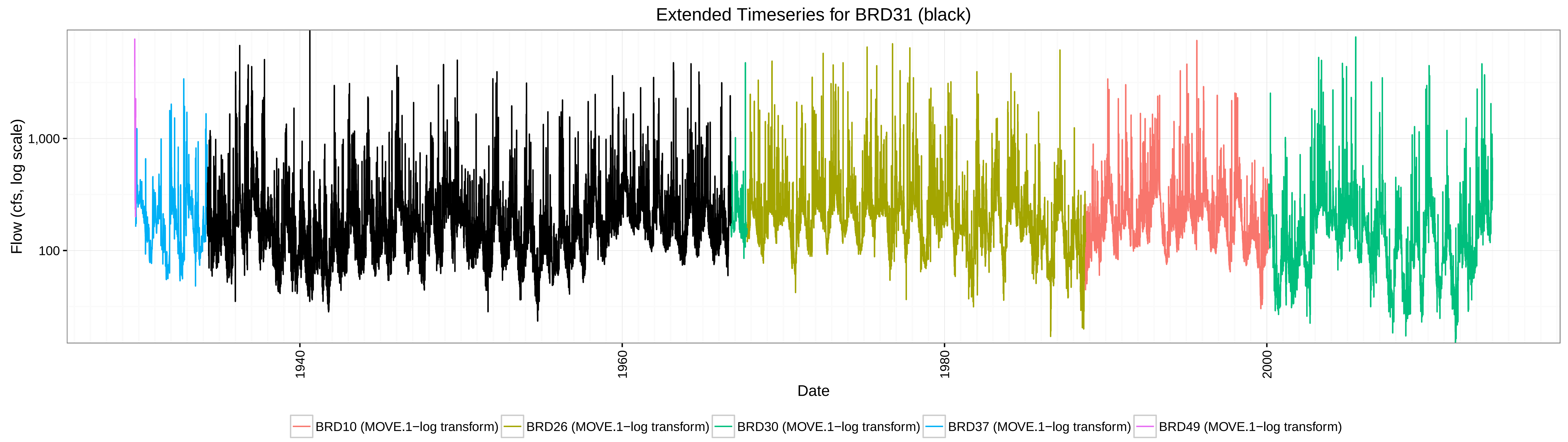

Extended Timeseries for BRD26 (black)
Flow (cfs, log scale)
1,000
100
10
1940
1960
1980
2000
Date
BRD10 (MOVE.1−log transform)
BRD25 (Area Ratio)
BRD37 (MOVE.1−log transform)
BRD49 (MOVE.1−log transform)


Extended Timeseries for BRD27 (black)
Flow (cfs, log scale)
1,000
100
10
1940
1960
1980
2000
Date
BRD10 (MOVE.1−log transform)
BRD11 (MOVE.1−log transform)
BRD49 (Area Ratio)

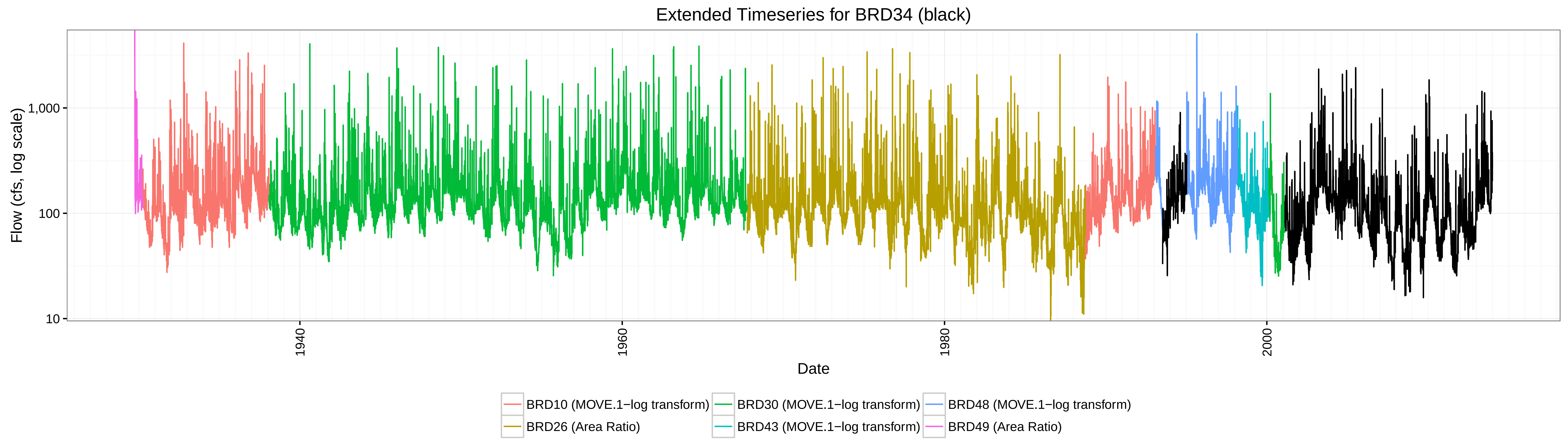


Extended Timeseries for BRD28 (black)
Flow (cfs, log scale)
100
10
1
1940
1960
1980
2000
Date
BRD10 (MOVE.1−log transform)
BRD18 (MOVE.1−log transform)
BRD30 (Area Ratio)
BRD43 (MOVE.1−log transform)
BRD49 (Area Ratio)

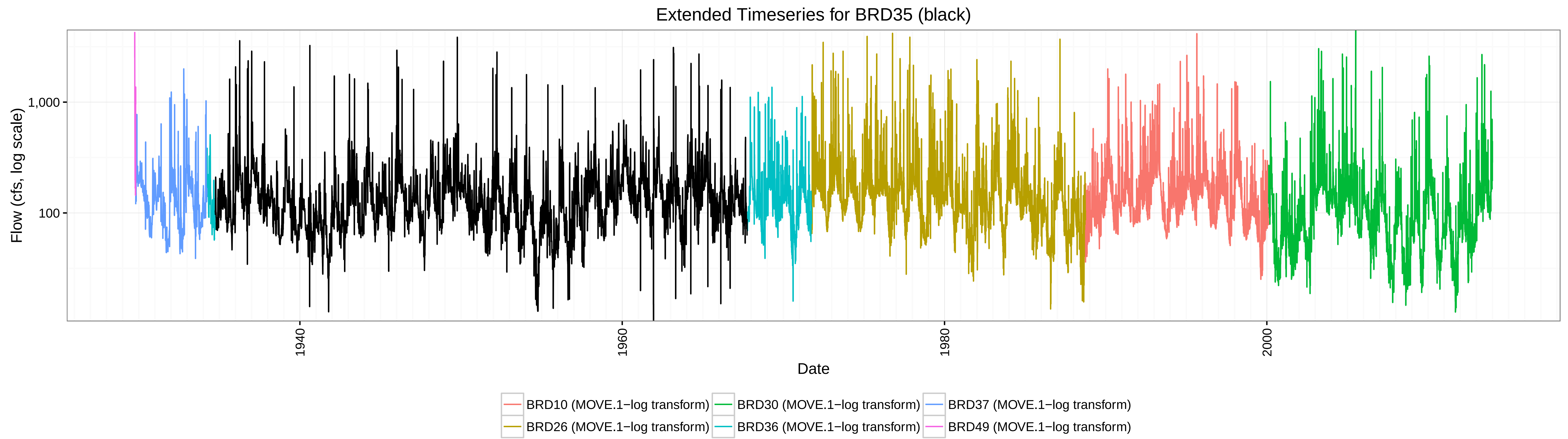

Extended Timeseries for BRD30 (black)
Flow (cfs, log scale)
1,000
100
10
1940
1960
1980
2000
Date
BRD10 (MOVE.1−log transform)
BRD11 (MOVE.1−log transform)
BRD26 (MOVE.1−no transform)
BRD37 (MOVE.1−log transform)
BRD49 (MOVE.1−log transform)



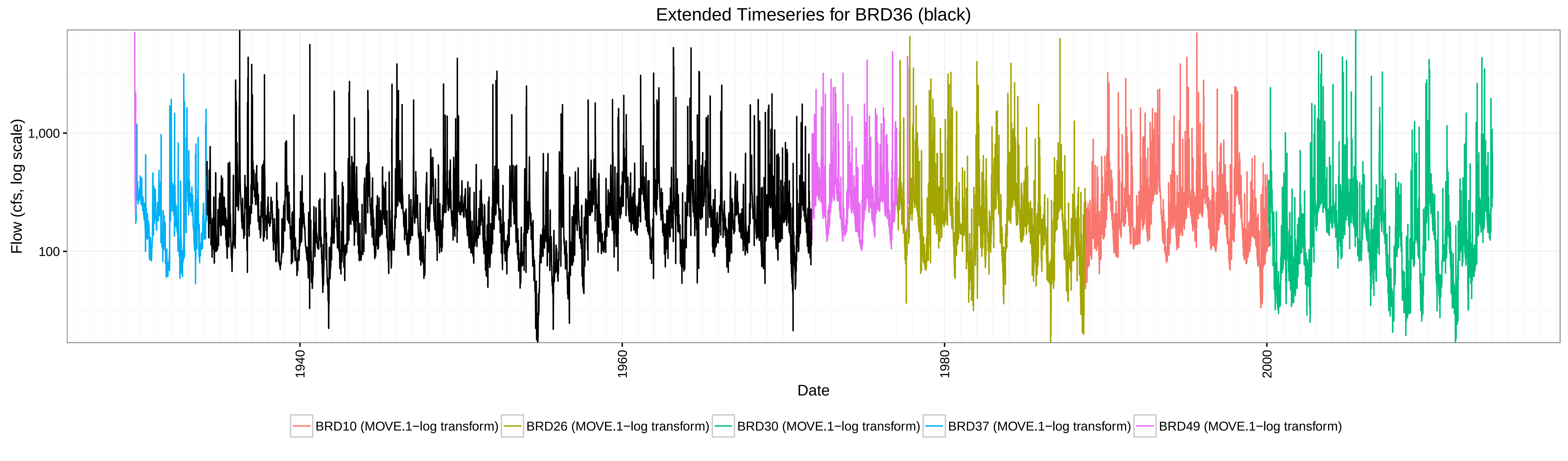
Extended Timeseries for BRD31 (black)
Flow (cfs, log scale)
1,000
100
1940
1960
1980
2000
Date
BRD10 (MOVE.1−log transform)
BRD26 (MOVE.1−log transform)
BRD30 (MOVE.1−log transform)
BRD37 (MOVE.1−log transform)
BRD49 (MOVE.1−log transform)



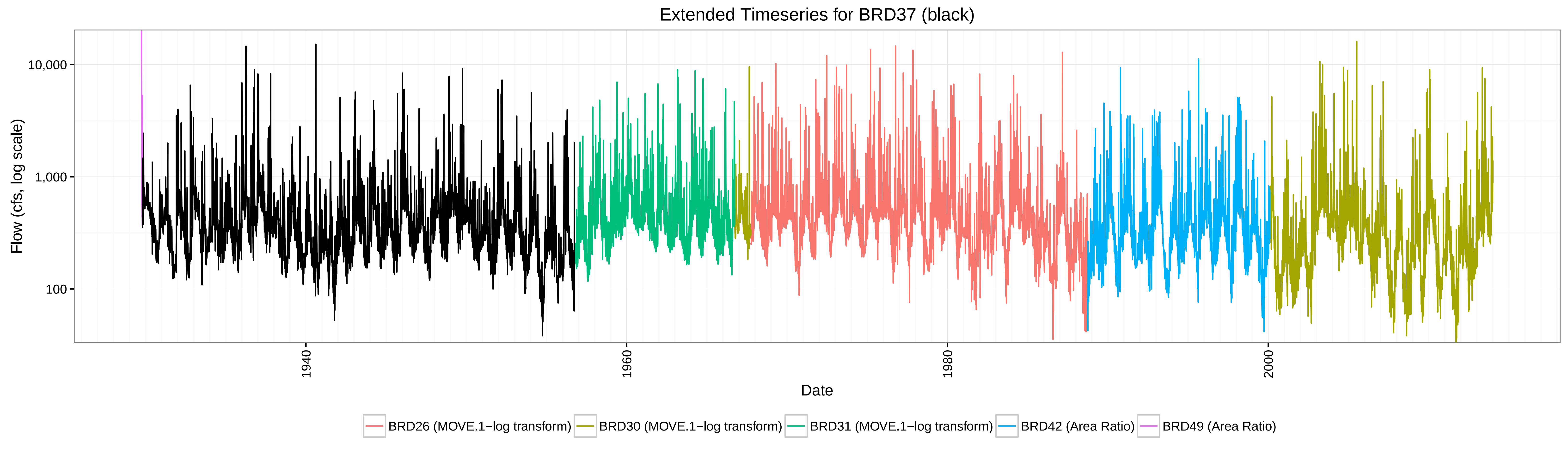
Extended Timeseries for BRD34 (black)
Flow (cfs, log scale)
1,000
100
10
1940
1960
1980
2000
Date
BRD10 (MOVE.1−log transform)
BRD26 (Area Ratio)
BRD30 (MOVE.1−log transform)
BRD43 (MOVE.1−log transform)
BRD48 (MOVE.1−log transform)
BRD49 (Area Ratio)

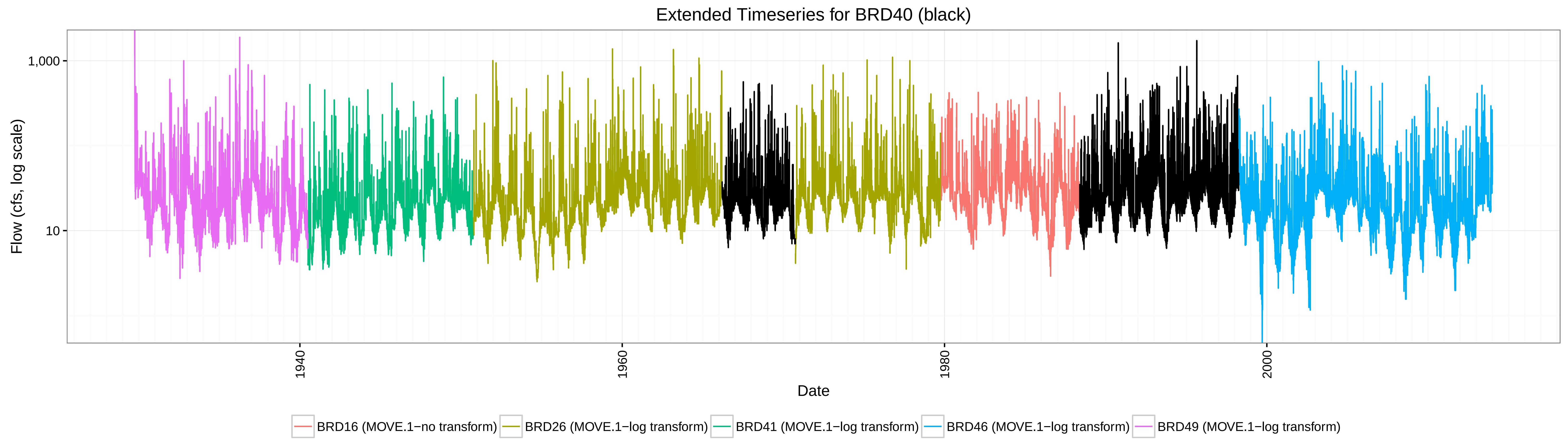


Extended Timeseries for BRD35 (black)
Flow (cfs, log scale)
1,000
100
1940
1960
1980
2000
Date
BRD10 (MOVE.1−log transform)
BRD26 (MOVE.1−log transform)
BRD30 (MOVE.1−log transform)
BRD36 (MOVE.1−log transform)
BRD37 (MOVE.1−log transform)
BRD49 (MOVE.1−log transform)

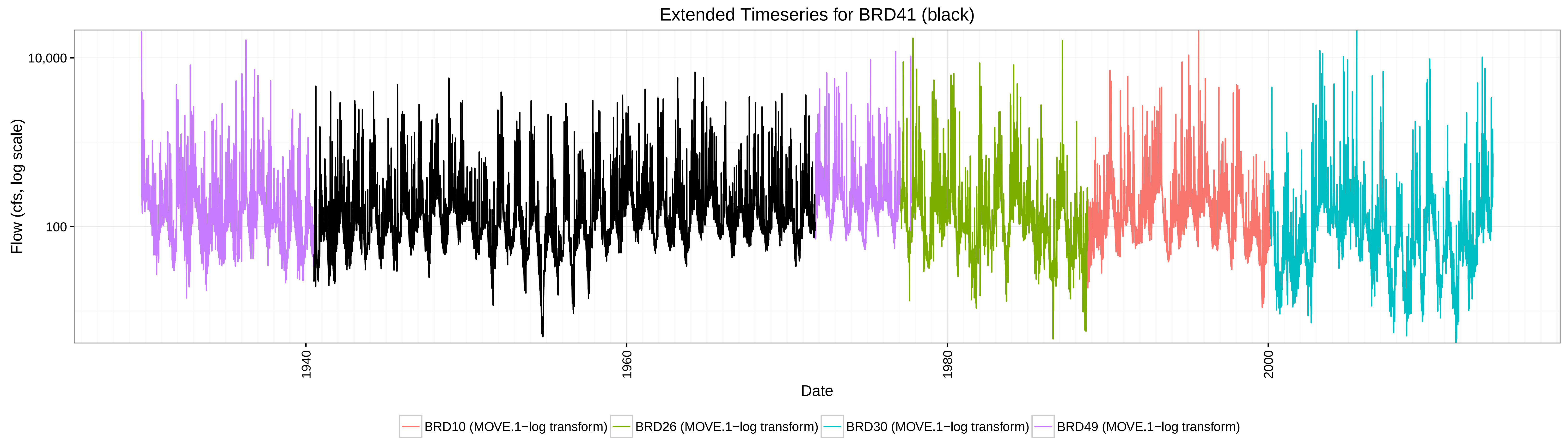


Extended Timeseries for BRD36 (black)
Flow (cfs, log scale)
1,000
100
1940
1960
1980
2000
Date
BRD10 (MOVE.1−log transform)
BRD26 (MOVE.1−log transform)
BRD30 (MOVE.1−log transform)
BRD37 (MOVE.1−log transform)
BRD49 (MOVE.1−log transform)


Extended Timeseries for BRD37 (black)
10,000
1,000
100
Flow (cfs, log scale)
1940
1960
1980
2000
Date
BRD26 (MOVE.1−log transform)
BRD30 (MOVE.1−log transform)
BRD31 (MOVE.1−log transform)
BRD42 (Area Ratio)
BRD49 (Area Ratio)

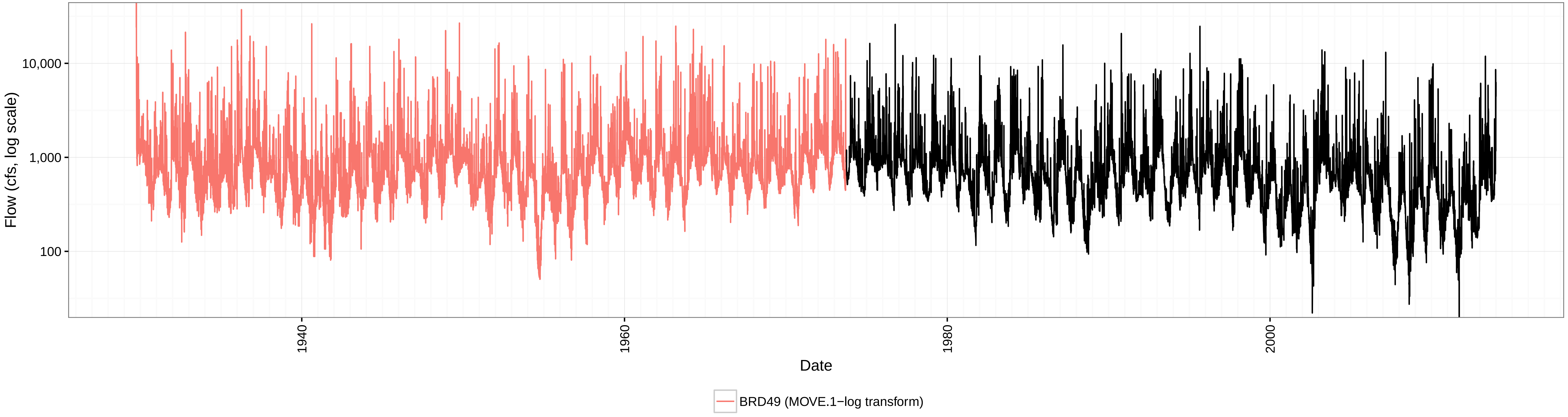


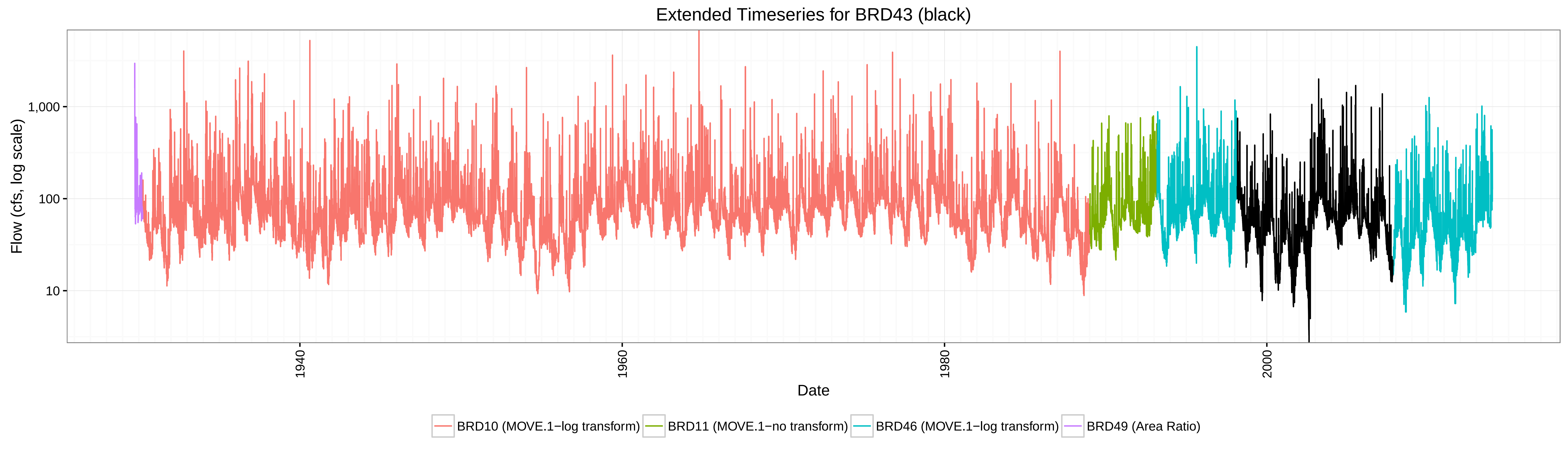
Extended Timeseries for BRD40 (black)
Flow (cfs, log scale)
1,000
10
1940
1960
1980
2000
Date
BRD16 (MOVE.1−no transform)
BRD26 (MOVE.1−log transform)
BRD41 (MOVE.1−log transform)
BRD46 (MOVE.1−log transform)
BRD49 (MOVE.1−log transform)



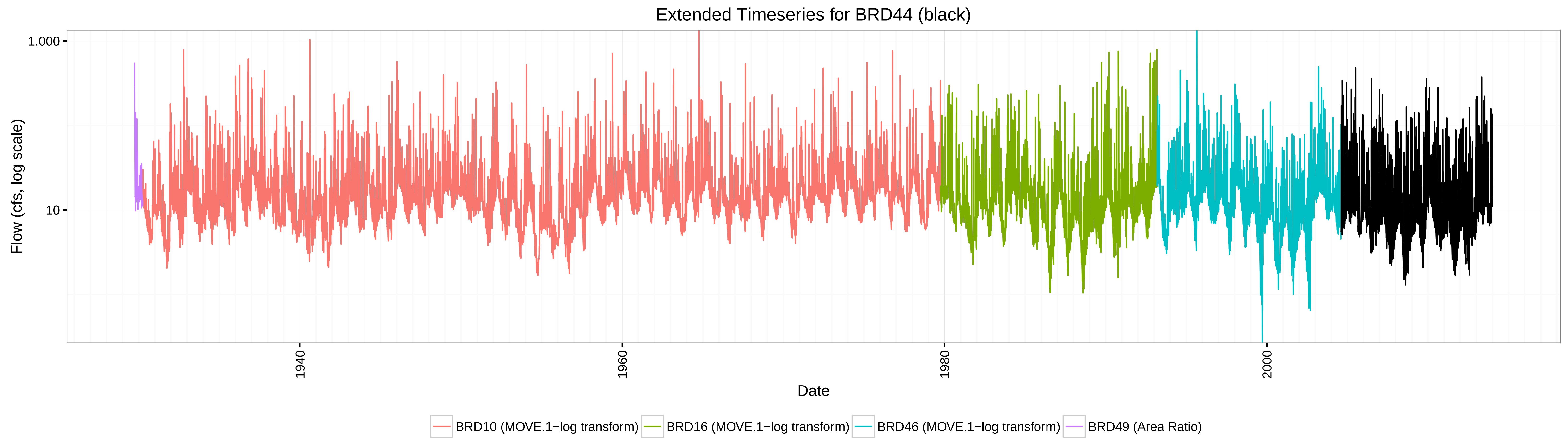
Extended Timeseries for BRD41 (black)
10,000
100
Flow (cfs, log scale)
1940
1960
1980
2000
Date
BRD10 (MOVE.1−log transform)
BRD26 (MOVE.1−log transform)
BRD30 (MOVE.1−log transform)
BRD49 (MOVE.1−log transform)

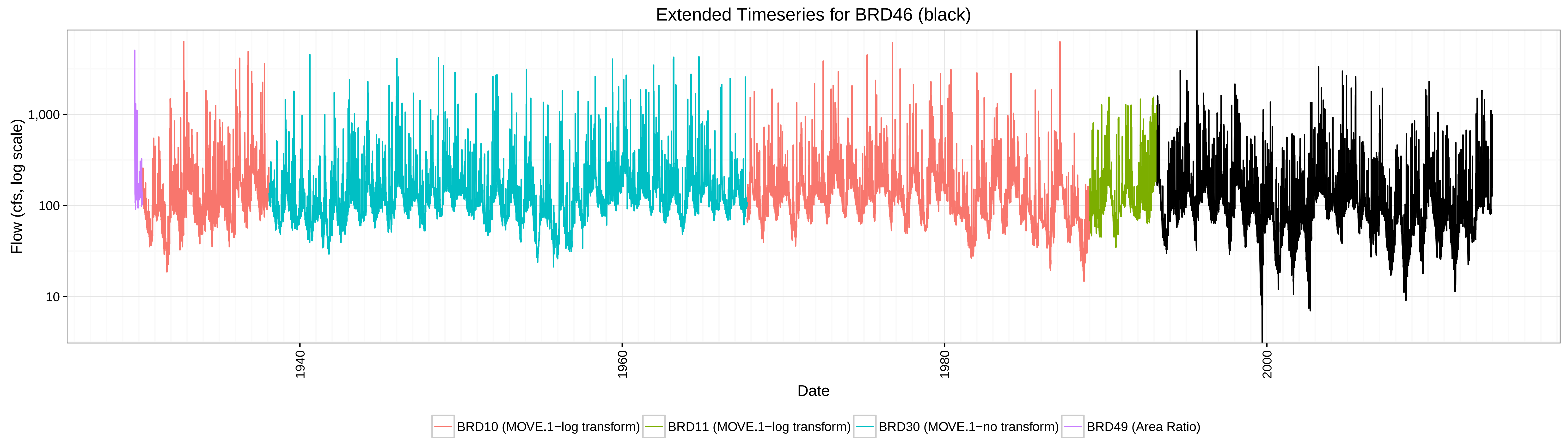
Extended Timeseries for BRD42 (black)



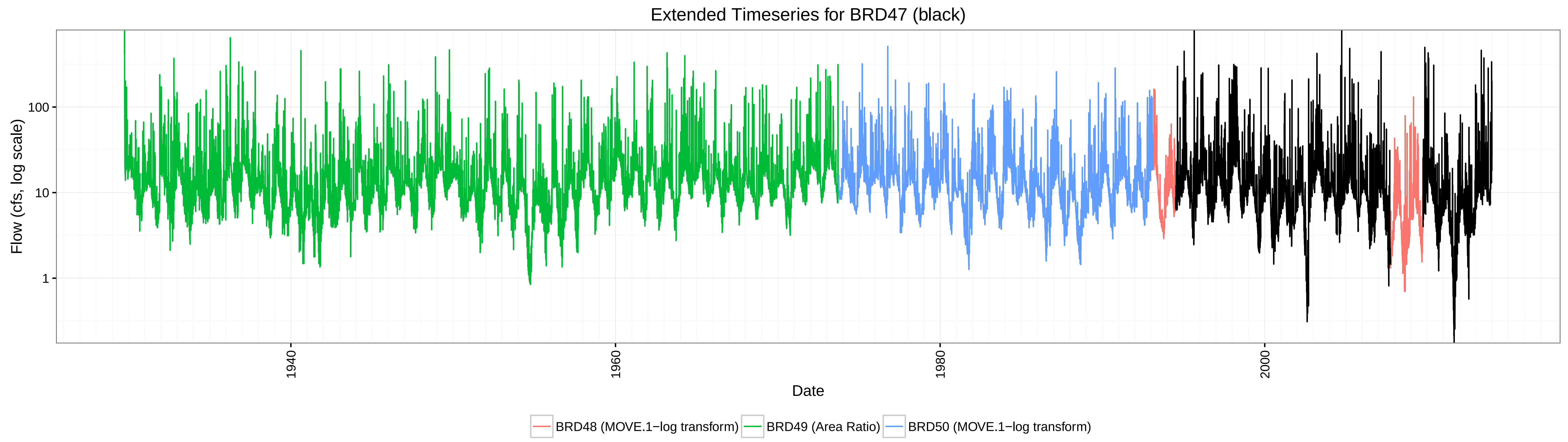


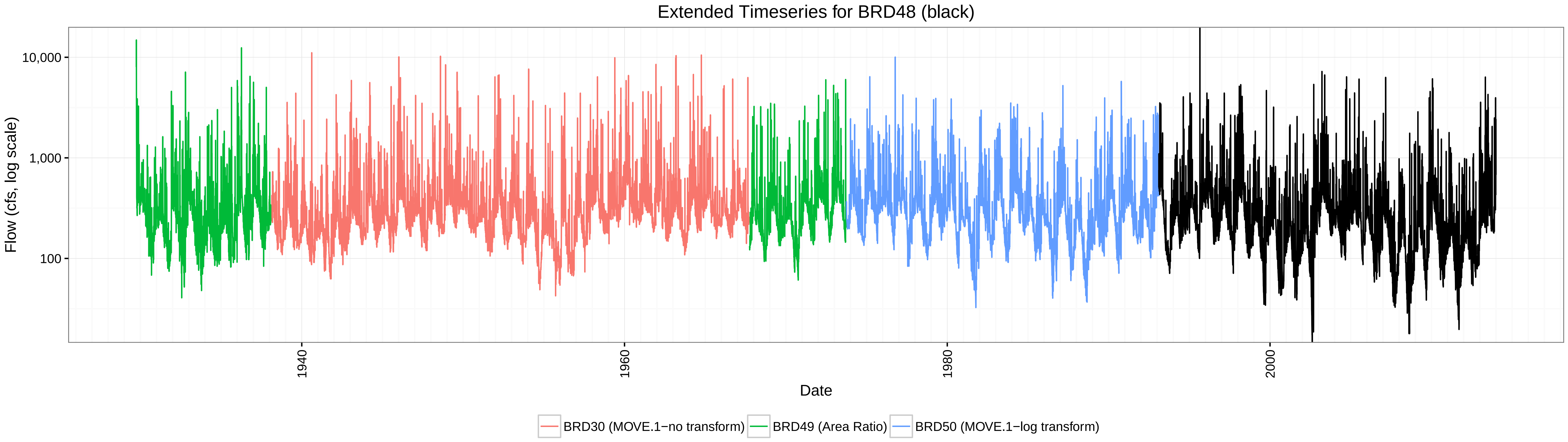
Extended Timeseries for BRD43 (black)
Flow (cfs, log scale)
1,000
100
10
1940
1960
1980
2000
Date
BRD10 (MOVE.1−log transform)
BRD11 (MOVE.1−no transform)
BRD46 (MOVE.1−log transform)
BRD49 (Area Ratio)

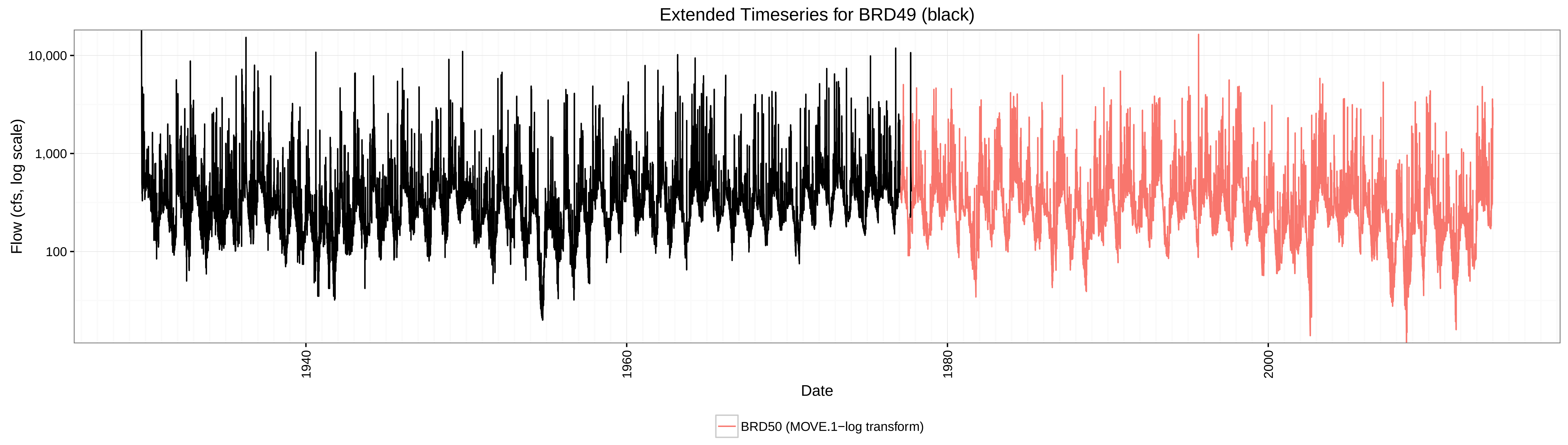

Extended Timeseries for BRD44 (black)
Flow (cfs, log scale)
1,000
10
1940
1960
1980
2000
Date
BRD10 (MOVE.1−log transform)
BRD16 (MOVE.1−log transform)
BRD46 (MOVE.1−log transform)
BRD49 (Area Ratio)

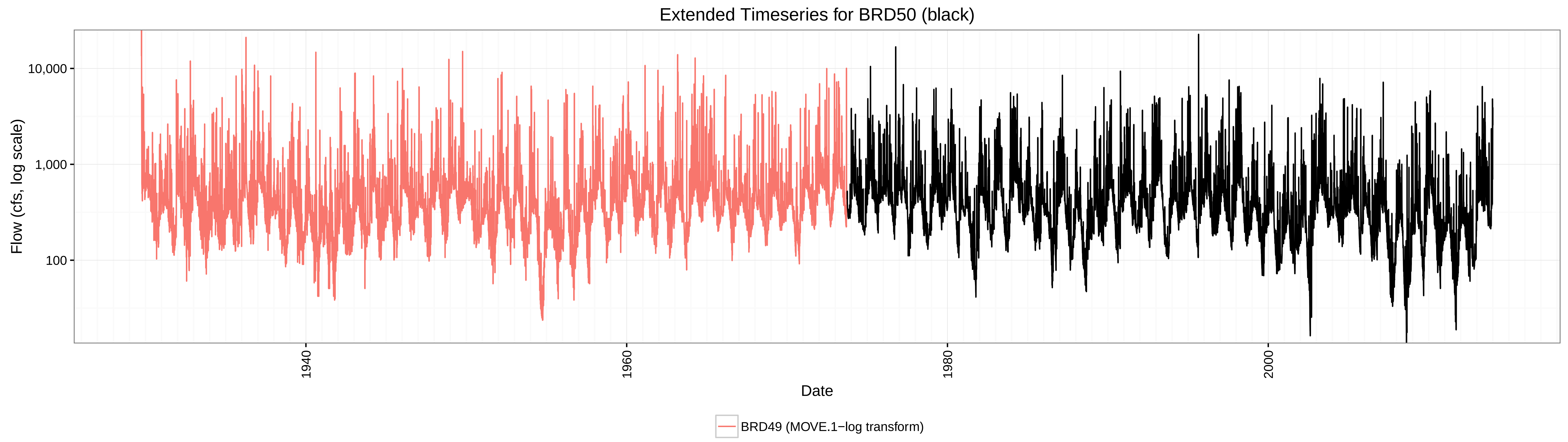


Extended Timeseries for BRD46 (black)
Flow (cfs, log scale)
1,000
100
10
1940
1960
1980
2000
Date
BRD10 (MOVE.1−log transform)
BRD11 (MOVE.1−log transform)
BRD30 (MOVE.1−no transform)
BRD49 (Area Ratio)

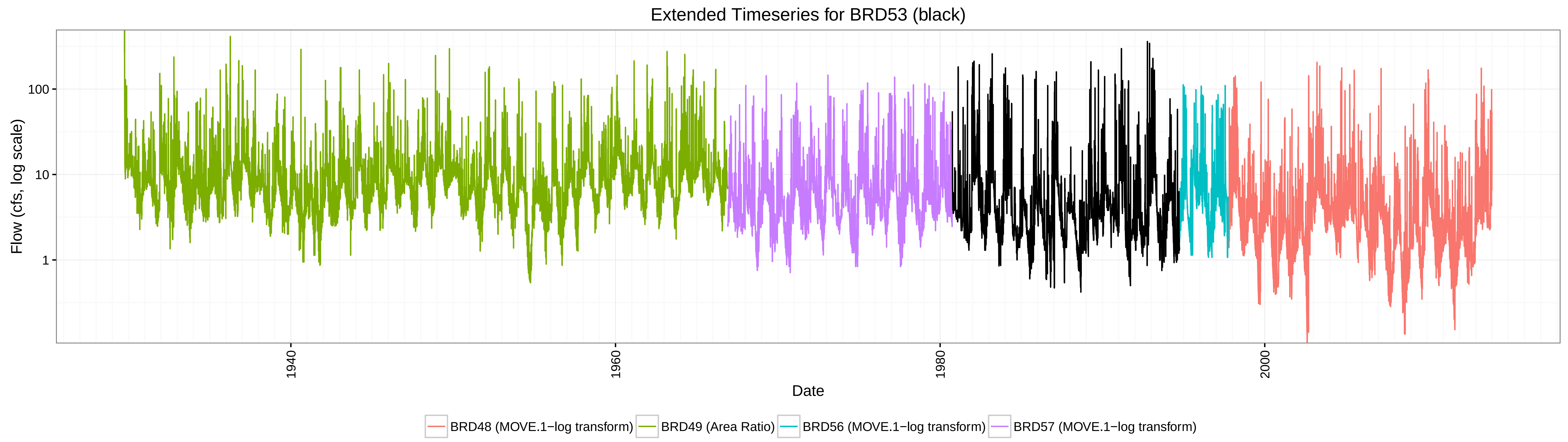

Extended Timeseries for BRD47 (black)
Flow (cfs, log scale)
100
10
1
1940
1960
1980
2000
Date
BRD48 (MOVE.1−log transform)
BRD49 (Area Ratio)
BRD50 (MOVE.1−log transform)


Extended Timeseries for BRD48 (black)
Flow (cfs, log scale)
10,000
1,000
100
1940
1960
1980
2000
Date
BRD30 (MOVE.1−no transform)
BRD49 (Area Ratio)
BRD50 (MOVE.1−log transform)

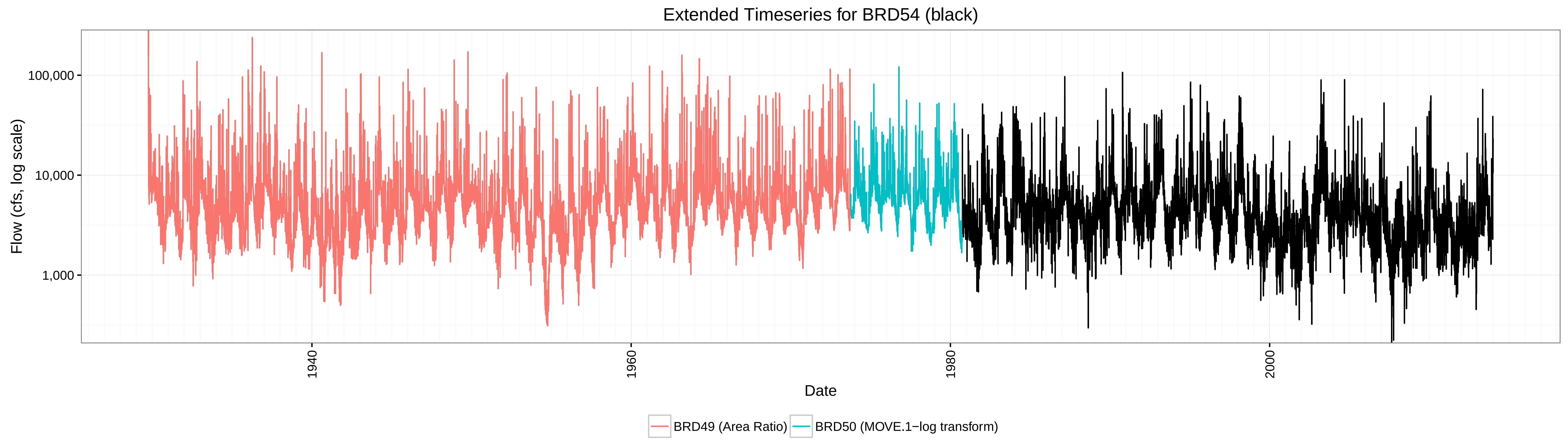

Extended Timeseries for BRD49 (black)
Flow (cfs, log scale)
10,000
1,000
100
1940
1960
1980
2000
Date
BRD50 (MOVE.1−log transform)



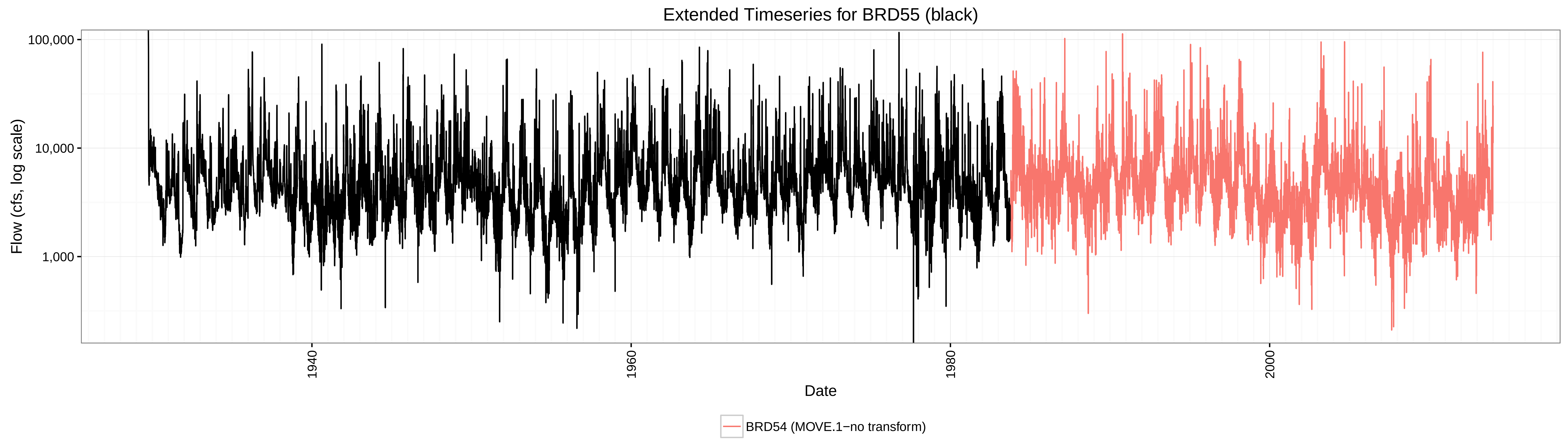
Extended Timeseries for BRD50 (black)
Flow (cfs, log scale)
10,000
1,000
100
1940
1960
1980
2000
Date
BRD49 (MOVE.1−log transform)

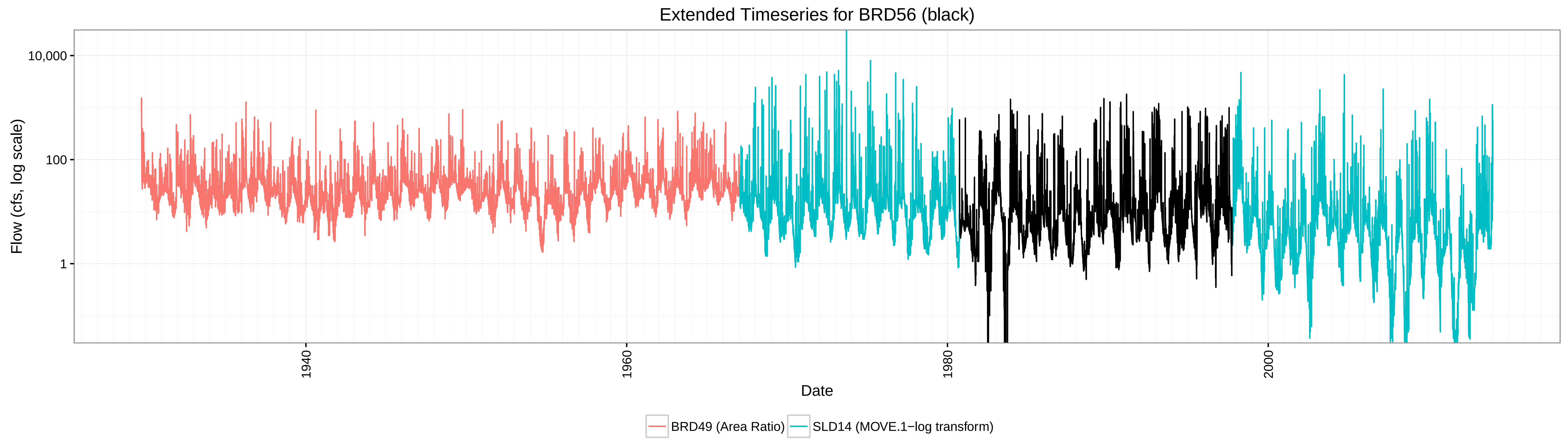


Extended Timeseries for BRD53 (black)
Flow (cfs, log scale)
100
10
1
1940
1960
1980
2000
Date
BRD48 (MOVE.1−log transform)
BRD49 (Area Ratio)
BRD56 (MOVE.1−log transform)
BRD57 (MOVE.1−log transform)

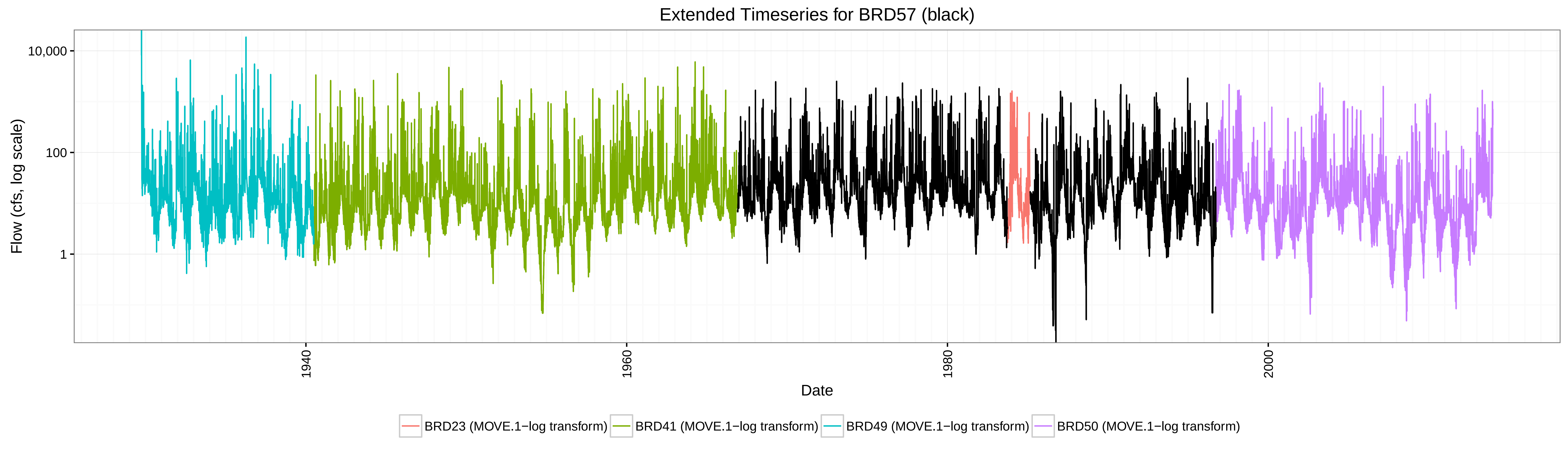


Extended Timeseries for BRD54 (black)
Flow (cfs, log scale)
100,000
10,000
1,000
1940
1960
1980
2000
Date
BRD49 (Area Ratio)
BRD50 (MOVE.1−log transform)

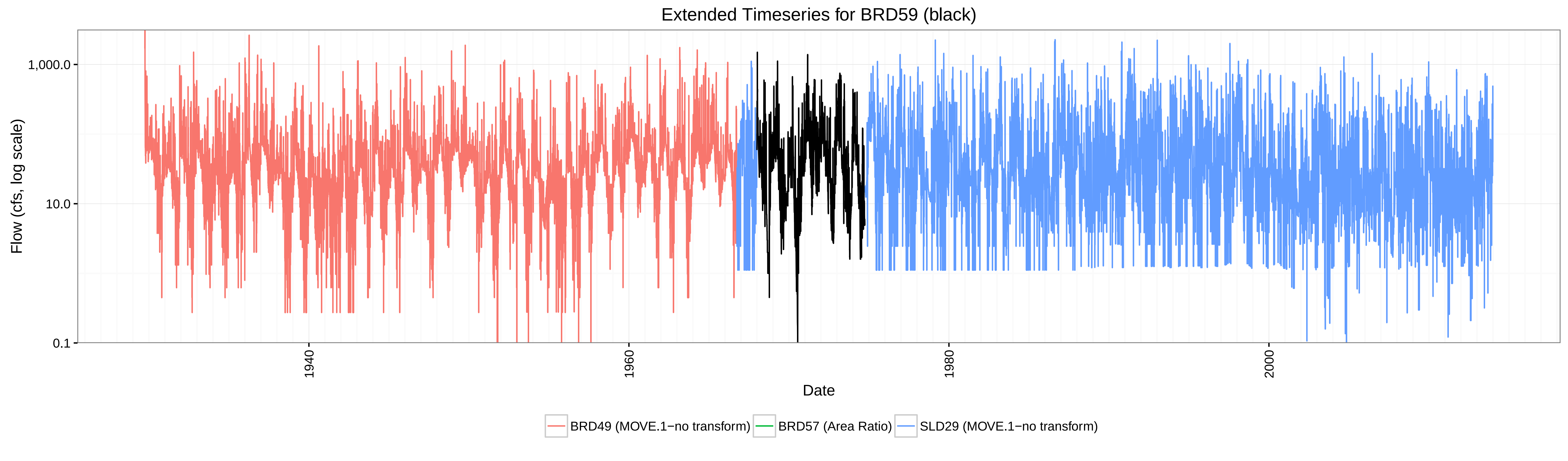

Extended Timeseries for BRD55 (black)
Flow (cfs, log scale)
100,000
10,000
1,000
1940
1960
1980
2000
Date
BRD54 (MOVE.1−no transform)



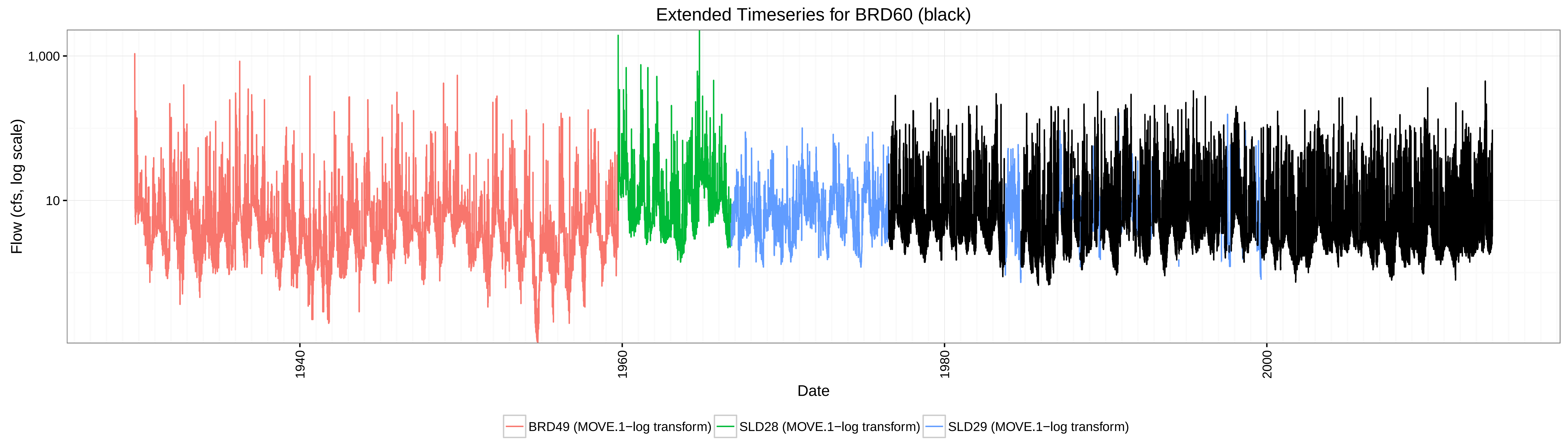
Extended Timeseries for BRD56 (black)
10,000
100
1
Flow (cfs, log scale)
1940
1960
1980
2000
Date
BRD49 (Area Ratio)
SLD14 (MOVE.1−log transform)



Extended Timeseries for BRD57 (black)
Flow (cfs, log scale)
10,000
100
1
1940
1960
1980
2000
Date
BRD23 (MOVE.1−log transform)
BRD41 (MOVE.1−log transform)
BRD49 (MOVE.1−log transform)
BRD50 (MOVE.1−log transform)



Extended Timeseries for BRD59 (black)
Flow (cfs, log scale)
1,000.0
10.0
0.1
1940
1960
1980
2000
Date
BRD49 (MOVE.1−no transform)
BRD57 (Area Ratio)
SLD29 (MOVE.1−no transform)



Extended Timeseries for BRD60 (black)
Flow (cfs, log scale)
1,000
10
1940
1960
1980
2000
Date
BRD49 (MOVE.1−log transform)
SLD28 (MOVE.1−log transform)
SLD29 (MOVE.1−log transform)

ATTACHMENT E

Discussion on Reference Gage and Method Selection

Gage	Reference	Method	Notes
BRD01	BRD02	MOVE.1-no transform	Best overall statistics, low-flow behavior acceptable
BRD01	BRD10	MOVE.1-log transform	
BRD01	BRD49	Area Ratio	No overlap to test, needed to fill first couple years. Previously BRD55
BRD02	BRD01	MOVE.1-no transform	While BRD03 is also highly correlated, does not offer extra extension after using BRD01. Similar choice of transform as with BRD01.
BRD02	BRD10	MOVE.1-log transform	
BRD02	BRD49	Area Ratio	No overlap to test, needed to fill first couple years. Previously BRD55
BRD03	BRD02	MOVE.1-log transform	Changed to log transform
BRD03	BRD01	Area Ratio	Compromise between statistics and low-flow behaviors of the MOVE.1 options.
BRD03	BRD10	MOVE.1-log transform	
BRD03	BRD49	Area Ratio	No overlap to test, needed to fill first couple years. Previously BRD55
BRD04	BRD07	MOVE.1-log transform	
BRD04	BRD43	MOVE.1-log transform	Originally had SLD14, removed per DNR request.
BRD04	BRD18	MOVE.1-log transform	
BRD04	BRD02	MOVE.1-log transform	
BRD04	BRD10	MOVE.1-log transform	Chosen for low-flow behavior despite stats
BRD04	BRD49	Area Ratio	
BRD05	BRD02	MOVE.1-log transform	
BRD05	BRD47	MOVE.1-log transform	
BRD05	BRD04	MOVE.1-log transform	
BRD05	BRD10	MOVE.1-log transform	
BRD05	BRD49	Area Ratio	
BRD06	BRD03	MOVE.1-no transform	Best overall statistics, low-flow behavior acceptable
BRD06	BRD01	Area Ratio	Compromise between statistics and low-flow behaviors of the MOVE.1 options.
BRD06	BRD10	MOVE.1-log transform	
BRD06	BRD49	Area Ratio	
BRD07	BRD11	MOVE.1-no transform	Best overall statistics, low-flow behavior acceptable
BRD07	BRD02	MOVE.1-no transform	Best overall statistics, low-flow behavior acceptable
BRD07	BRD10	MOVE.1-log transform	Chosen for low-flow behavior despite stats
BRD07	BRD49	Area Ratio	
BRD08	CAT01	MOVE.1-no transform	Log transform produces extremely high peaks in final timeseries.
BRD08	BRD04	Area Ratio	Tried both BRD27 & BRD28 as well, but since overlap is so small, can only really test area ratio. Both did not appear suitable in final timeseries.
BRD08	BRD10	MOVE.1-log transform	
BRD08	BRD49	Area Ratio	
BRD10	BRD12	MOVE.1-log transform	Though BRD12 UIFs are prorated UIFs from BRD10 after 1960 and will make statistics appear better, this is still the best reference gage.
BRD10	BRD37	MOVE.1-log transform	Slightly-better than BRD49, only needed to fill couple years.
BRD10	BRD49	MOVE.1-log transform	Only needed for first few weeks.
BRD11	BRD10	MOVE.1-log transform	Area ratio has slightly-better statistics, but log transform has better low-flow performance.
BRD11	BRD12	MOVE.1-log transform	Same as BRD10.
BRD11	BRD49	Area Ratio	No overlap to test, needed to fill first two months
BRD12	BRD10	MOVE.1-log transform	All methods appear good, reference only needed for small gap filling.
BRD12	BRD49	MOVE.1-log transform	Only needed for two months.
BRD14	BRD12	MOVE.1-log transform	Is entirely area-prorated BRD10, will use same decisions as with BRD10.
BRD14	BRD49	Area Ratio	No overlap to test, needed to fill first two months
BRD15	BRD12	MOVE.1-no transform	Best for statistics and most plot behavior.
BRD15	BRD10	MOVE.1-log transform	Only needed for small gaps from BRD12.
BRD15	BRD49	MOVE.1-log transform	Only needed for first few weeks.

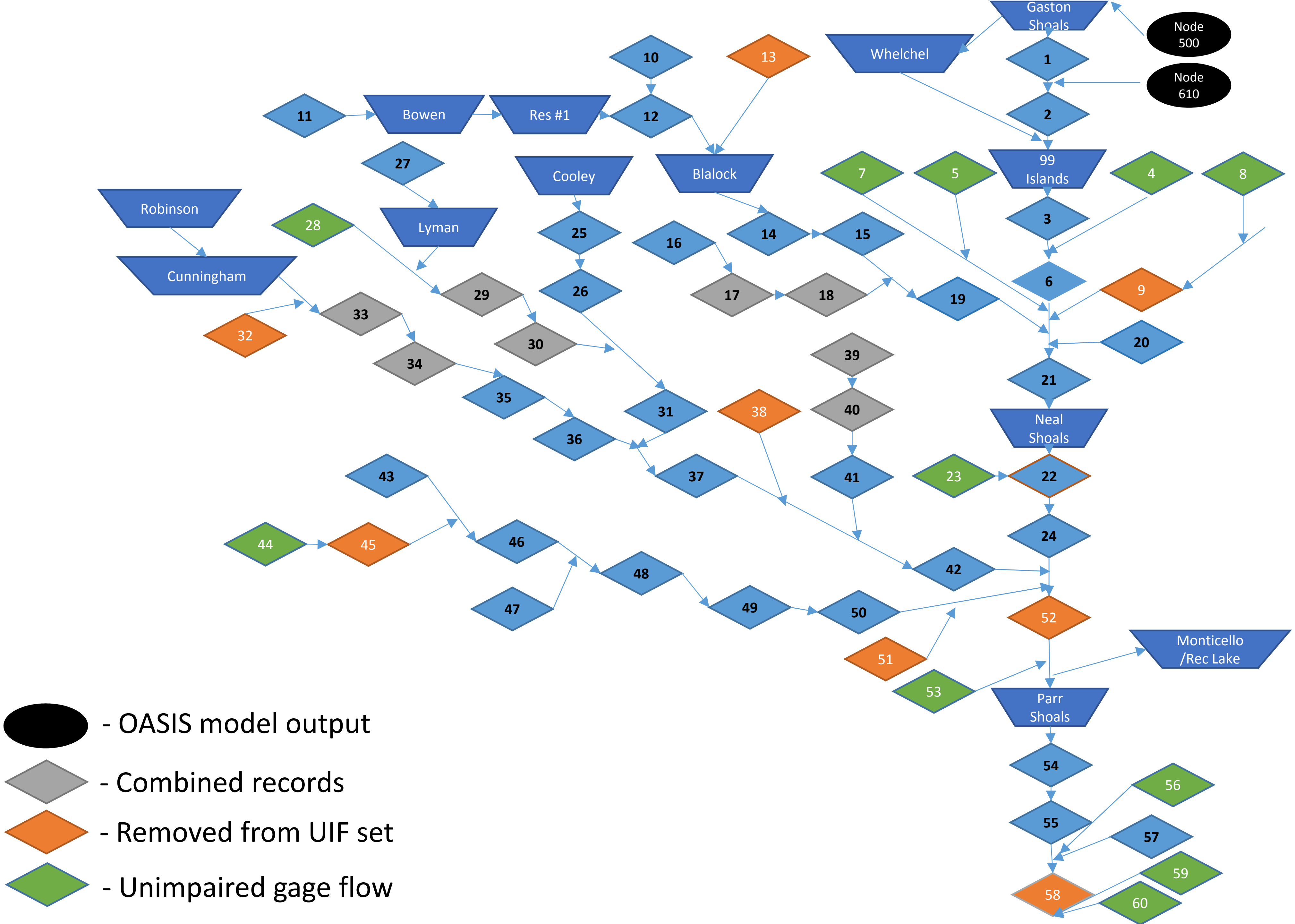
BRD16	BRD26	MOVE.1-log transform	Though no transform has better stats, transform chosen for low-flow behavior.
BRD16	BRD18	MOVE.1-log transform	
BRD16	BRD46	MOVE.1-log transform	
BRD16	BRD12	MOVE.1-log transform	
BRD16	BRD49	Area Ratio	No overlap to test, needed to fill first two months
BRD18	BRD28	MOVE.1-log transform	Choice of log transform versus area ratio is debatable.
BRD18	BRD16	MOVE.1-log transform	
BRD18	BRD40	MOVE.1-log transform	
BRD18	BRD12	MOVE.1-log transform	Though non-transform has overall better statistics, transform chosen for low-flow behavior.
BRD18	BRD49	Area Ratio	No overlap to test, needed to fill first two months
BRD19	BRD14	MOVE.1-log transform	
BRD19	BRD12	MOVE.1-log transform	
BRD19	BRD49	Area Ratio	No overlap to test, needed to fill first two months
BRD20	CAT15	MOVE.1-no transform	CAT14 also good, but offers no extension after using CAT15.
BRD20	SLD14	MOVE.1-log transform	
BRD20	BRD42	MOVE.1-log transform	
BRD20	BRD10	MOVE.1-log transform	May want to revisit during calibration if noticeable effect of high flows.
BRD20	BRD49	Area Ratio	
BRD21	BRD03	MOVE.1-log transform	
BRD21	BRD02	MOVE.1-log transform	
BRD21	BRD10	MOVE.1-log transform	
BRD21	BRD49	Area Ratio	No overlap to test
BRD22	BRD03	MOVE.1-log transform	
BRD22	BRD02	MOVE.1-log transform	
BRD22	BRD10	MOVE.1-log transform	
BRD22	BRD49	Area Ratio	No overlap to test
BRD23	BRD48	MOVE.1-no transform	Too much distortion in high flows
BRD23	SLD14	MOVE.1-log transform	High flow behavior somewhat worrisome.
BRD23	BRD26	MOVE.1-log transform	
BRD23	BRD49	Area Ratio	
BRD24	BRD55	MOVE.1-log transform	
BRD25	BRD26	Area Ratio	No overlap to test, but is logical choice given proximity and similarity.
BRD25	BRD11	MOVE.1-log transform	Though non-transform has overall better statistics, transform chosen for low-flow behavior.
BRD25	BRD10	MOVE.1-log transform	
BRD25	BRD49	Area Ratio	No overlap to test, needed to fill first couple years
BRD26	BRD25	Area Ratio	No overlap to test, but is logical choice given proximity and similarity.
BRD26	BRD37	MOVE.1-log transform	
BRD26	BRD10	MOVE.1-log transform	
BRD26	BRD49	MOVE.1-log transform	Only needed for first few weeks.
BRD27	BRD11	MOVE.1-log transform	
BRD27	BRD10	MOVE.1-log transform	One would expect BRD30 to show better performance, but yet BRD10 is still better.
BRD27	BRD49	Area Ratio	No overlap to test, needed to fill first couple years
BRD28	BRD43	MOVE.1-log transform	
BRD28	BRD18	MOVE.1-log transform	
BRD28	BRD30	Area Ratio	Given statistics, plot behavior excepting extreme low flows, and is directly downstream, area proration is suitable choice.
BRD28	BRD10	MOVE.1-log transform	
BRD28	BRD49	Area Ratio	No overlap to test, needed to fill first couple years.

BRD30	BRD11	MOVE.1-log transform	Case could be made for or against transform.
BRD30	BRD37	MOVE.1-log transform	
BRD30	BRD26	MOVE.1-no transform	Depending on which correlation used, debatable if better than BRD10. Though BRD10 has lower errors, BRD26 is adjacent and has more similar basin characteristics. Non-transform performs well, even at low flows.
BRD30	BRD10	MOVE.1-log transform	
BRD30	BRD49	MOVE.1-log transform	Only needed for first few weeks.
BRD31	BRD37	MOVE.1-log transform	
BRD31	BRD30	MOVE.1-log transform	The non-transform has significantly better performance in the statistics, but transform chosen for low flows.
BRD31	BRD26	MOVE.1-log transform	Priority over BRD49 debatable, but BRD26 selected by virtue of being upstream.
BRD31	BRD49	MOVE.1-log transform	
BRD31	BRD10	MOVE.1-log transform	
BRD34	BRD30	MOVE.1-log transform	
BRD34	BRD43	MOVE.1-log transform	
BRD34	BRD48	MOVE.1-log transform	
BRD34	BRD26	Area Ratio	No overlap to test, but looks good in final timeseries.
BRD34	BRD10	MOVE.1-log transform	
BRD34	BRD49	Area Ratio	No overlap to test, needed to fill first couple years.
BRD35	BRD36	MOVE.1-log transform	
BRD35	BRD37	MOVE.1-log transform	
BRD35	BRD30	MOVE.1-log transform	
BRD35	BRD26	MOVE.1-log transform	
BRD35	BRD10	MOVE.1-log transform	
BRD35	BRD49	MOVE.1-log transform	
BRD36	BRD37	MOVE.1-log transform	
BRD36	BRD30	MOVE.1-log transform	
BRD36	BRD49	MOVE.1-log transform	
BRD36	BRD26	MOVE.1-log transform	
BRD36	BRD10	MOVE.1-log transform	
BRD37	BRD31	MOVE.1-log transform	Not shown in initial candidates, but BRD36 and BRD35 had high correlations, possibly from operational-signal smoothing.
BRD37	BRD30	MOVE.1-log transform	
BRD37	BRD26	MOVE.1-log transform	
BRD37	BRD42	Area Ratio	No overlap to test, but is next gage downstream.
BRD37	BRD49	Area Ratio	Not shown in initial candidates, as only needed for two weeks.
BRD40	BRD46	MOVE.1-log transform	
BRD40	BRD16	MOVE.1-no transform	Log transform has issues at multiple flow regimes.
BRD40	BRD26	MOVE.1-log transform	
BRD40	BRD41	MOVE.1-log transform	
BRD40	BRD49	MOVE.1-log transform	
BRD41	BRD49	MOVE.1-log transform	Transform has noticeable issues with high flows; not using transform comes with some sacrifice of low flow behavior.
BRD41	BRD26	MOVE.1-log transform	Similar to above, but low flows decently reproduced.
BRD41	BRD30	MOVE.1-log transform	Similar to above, but low flows decently reproduced.
BRD41	BRD10	MOVE.1-log transform	Transform has noticeable issues with high flows; not using transform comes with some sacrifice of low flow behavior.
BRD42	BRD49	MOVE.1-log transform	
BRD43	BRD46	MOVE.1-log transform	While BRD34 is next-best candidate, does not offer additional years after using BRD46.
BRD43	BRD11	MOVE.1-no transform	Non-transform has best statistics and reasonable low-flow behavior.

BRD43	BRD10	MOVE.1-log transform	Non-transform has best statistics but perhaps not acceptable low-flow behavior.
BRD43	BRD49	Area Ratio	No overlap to test, needed to fill first couple years.
BRD44	BRD46	MOVE.1-log transform	BRD43 (removed from initial candidates) and BRD47 offer good results, but do not offer any more years after using BRD46.
BRD44	BRD16	MOVE.1-log transform	
BRD44	BRD10	MOVE.1-log transform	
BRD44	BRD49	Area Ratio	No overlap to test, needed to fill first couple years.
BRD46	BRD11	MOVE.1-log transform	
BRD46	BRD30	MOVE.1-no transform	Transform has noticeable issues with high flows; not using transform comes with some sacrifice of low flow behavior.
BRD46	BRD10	MOVE.1-log transform	
BRD46	BRD49	Area Ratio	No overlap to test, needed to fill first couple years.
BRD47	BRD48	MOVE.1-log transform	
BRD47	BRD50	MOVE.1-log transform	
BRD47	BRD49	Area Ratio	No overlap to test, but looks good in final timeseries.
BRD48	BRD50	MOVE.1-log transform	
BRD48	BRD30	MOVE.1-no transform	Non-transform has best statistics and reasonable low-flow behavior.
BRD48	BRD49	Area Ratio	
BRD49	BRD50	MOVE.1-log transform	
BRD50	BRD49	MOVE.1-log transform	
BRD53	BRD56	MOVE.1-log transform	BRD23 produces similar results, but offers no extension after using BRD56.
BRD53	BRD48	MOVE.1-log transform	
BRD53	BRD57	MOVE.1-log transform	
BRD53	BRD49	Area Ratio	No overlap to test
BRD54	BRD50	MOVE.1-log transform	
BRD54	BRD49	Area Ratio	No overlap to test
BRD55	BRD54	MOVE.1-no transform	Log transform has issues at multiple flow regimes.
BRD56	SLD14	MOVE.1-log transform	Good but high flow behavior worrisome.
BRD56	BRD49	Area Ratio	No overlap to test
BRD57	BRD23	MOVE.1-log transform	
BRD57	BRD41	MOVE.1-log transform	
BRD57	BRD50	MOVE.1-log transform	Though SLD14 appears the next-best candidate, tried all three options with unsatisfying results. Not many references offer reasonable extension for this needed period. Using BRD50 until better alternative can be found.
BRD57	BRD49	MOVE.1-log transform	Transform has noticeable issues with high flows; not using transform comes with some sacrifice of low flow behavior.
BRD59	SLD29	MOVE.1-no transform	Non-transform has best statistics and reasonable low-flow behavior.
BRD59	BRD57	Area Ratio	Compromise between statistics and low-flow behaviors of the MOVE.1 options.
BRD59	BRD49	MOVE.1-no transform	Non-transform has best statistics and reasonable low-flow behavior.
BRD60	SLD29	MOVE.1-log transform	
BRD60	SLD28	MOVE.1-log transform	
BRD60	BRD49	MOVE.1-log transform	

ATTACHMENT F

Schematic of USGS Streamflow Gages in Broad River Basin



Gaston Shoals
Node 500
Node 610
Whelchel
10
13
1
2
11
Bowen
Res #1
12
99 Islands
27
Cooley
Blalock
7
5
4
8
Robinson
28
Lyman
25
16
14
15
3
Cunningham
29
26
17
18
19
6
9
33
32
30
20
34
39
21
35
31
38
40
Neal Shoals
36
43
37
41
23
22
44
45
46
24
48
42
47
49
50
52
51
Monticello /Rec Lake
53
Parr Shoals
54
56
55
57
59
58
60
- OASIS model output
- Combined records
- Removed from UIF set
- Unimpaired gage flow