Technical Memorandum

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

From: *CDM Smith*

Date: *March 2016*

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

1.0 Introduction

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

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

2.0 Overview of the Pee Dee Basin

The Pee Dee River basin covers 7,850 square miles, 25 percent of the land area of the State, lying within the Piedmont and Coastal Plain physiographic provinces (**Figure 2-1**). The basin's major watercourses include the Great and Little Pee Dee rivers, the Lynches River, and Black River. The Great Pee Dee River is fed by the Yadkin River in North Carolina, where its flow is heavily regulated by a series of large reservoirs, influencing the downstream behavior of the Great Pee Dee River in South Carolina. Near the coast, each of these branches pass through tidally-influenced areas before draining into the Atlantic Ocean.

Fourteen active Unites States Geological Survey (USGS) gaging stations monitor streamflow in the basin, including three on the Great Pee Dee River, one the Little Pee Dee River, two on the Lynches River, five on Black River, and the rest on coastal tributaries. The Lynches River station at Effingham (USGS 02132000) and the Black River station at Kingstree (USGS 02136000) offer the earliest period of record, both beginning in 1929. Average flow of the Little Pee Dee River is more than 3,000 cfs at Galivants Ferry. Average annual streamflow in the Lynches River is 789 cfs near Effingham and 915 cfs in the Black River near Kingstree.

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

A detailed discussion of water users and dischargers is explained and presented in the Pee Dee Framework Memorandum (CDM Smith, 2015). The South Carolina DHEC has provided information and data regarding current (active) and former (inactive) water users and dischargers throughout the state. The Framework Memorandum summarizes the current water users and dischargers for the purposes of the model. The former user and dischargers are summarized below in **Tables 2-1 and 2-2** as they needed to be accounted for in the UIF development. Individual withdrawal and discharges located in coastal areas or less than 3 million gallons per month (mg/m) are generally not included in UIF calculations or in water quality modeling.

Table 2-1. Formerly permitted or registered surface water users in the Pee Dee Basin

Intake ID	Facility Name	Withdrawal Tributary
Water Supply		
29WS002S01	Town of Kershaw	Little Lynches River
29WS002S02	Town of Kershaw	Hanging Rock Creek
13WS002S01	Jefferson Water Plant	Lynches River
13WS003S01	City of Pageland	Black Creek
13WS004S01	Town of Chesterfield	Thompson Creek
16WS004S01	City of Society Hill	Cedar Creek
Industrial Users		
13IN002S01	Hanson Aggregates - Brewer Facility	Black Creek
29IN002S01	Springs Industries Kershaw Plant	Lynches River
34IN002S01	Delta Mills Market Co Delta Plant	Great Pee Dee River
21IN005S01	Dupont Teijin Films	Great Pee Dee River

Table 2-2. Formerly Permitted NPDES Discharges in the Pee Dee Basin

NPDES Pipe ID	Facility Name	Discharge Tributary
SC0001341-001	AHLSTROM NONWOVENS LLC/BETHUNE	Lynches River
SC0001490-001	REEVES BROTHERS/BISHOPVILLE	Lynches River
SC0002151-001	SCHWARZ WALLACE LLC	Great Pee Dee River
SC0002151-002	SCHWARZ WALLACE LLC	Whites Creek
SC0002500-001	CLEVELAND-CAROKNIT/JEFFERSON	Fork Creek

NPDES Pipe ID	Facility Name	Discharge Tributary
SC0002917-001	DUPONT TEIJIN FILMS/FLORENCE	Great Pee Dee River
SC0002917-002	DUPONT TEIJIN FILMS/FLORENCE	Great Pee Dee River
SC0002917-01A	DUPONT TEIJIN FILMS/FLORENCE	Great Pee Dee River
SC0002925-005	PROGRESS ENERGY/ROBINSON	Black Creek
SC0003042-007	SONOCO PRODUCTS/HARTSVILLE	Black Creek
SC0003042-008	SONOCO PRODUCTS/HARTSVILLE	Black Creek
SC0004162-001	WELLMAN INC/PALMETTO PLANT	Black Creek
SC0004171-001	GE HEALTHCARE/FLORENCE	Jeffries Creek
SC0020257-001	MARION/SOUTH MAIN STREET	Catfish Creek
SC0021351-001	PAMPLICO, TOWN OF	Great Pee Dee River
SC0022471-003	SCPSA/WINYAH STEAM STATION	Turkey Creek (South)
SC0022471-004	SCPSA/WINYAH STEAM STATION	Turkey Creek (South)
SC0022471-01A	SCPSA/WINYAH STEAM STATION	Turkey Creek (South)
SC0022471-01B	SCPSA/WINYAH STEAM STATION	Turkey Creek (South)
SC0024970-003	USAF/SHAW AIR FORCE BASE	Turkey Creek
SC0024970-004	USAF/SHAW AIR FORCE BASE	Turkey Creek
SC0024970-005	USAF/SHAW AIR FORCE BASE	Turkey Creek
SC0024970-006	USAF/SHAW AIR FORCE BASE	Turkey Creek
SC0024970-007	USAF/SHAW AIR FORCE BASE	Turkey Creek
SC0025232-001	CHESTERFIELD/THOMPSON CREEK	Thompson Creek
SC0025356-002	TIMMONSVILLE, TOWN OF	Sparrow Swamp
SC0025755-001	TURBEVILLE WWTF	Pudding Swamp
SC0025755-002	TURBEVILLE WWTF	Pudding Swamp
SC0025755-003	TURBEVILLE WWTF	Pudding Swamp
SC0030732-001	CWS/WHITES CREEK-LINCOLNSHIRE	Sampit River
SC0038164-001	LAKE CITY/LAKE SWAMP WWTF	Lynches River
SC0040088-001	GLASSCOCK TRUCKING COMPANY INC	Pocotaligo River
SC0040088-002	GLASSCOCK TRUCKING COMPANY INC	Turkey Creek
SC0040088-01A	GLASSCOCK TRUCKING COMPANY INC	Turkey Creek
SC0040479-001	HAILE GOLD MINE	Little Lynches River
SC0040479-02A	HAILE GOLD MINE	Little Lynches River
SC0040606-001	CLIO WWTF	Hagins Prong
SC0040606-01B	CLIO WWTF	Hagins Prong
SC0040657-001	BREWER GOLD COMPANY	Little Fork Creek
SC0040657-002	BREWER GOLD COMPANY	Little Fork Creek
SC0040657-01A	BREWER GOLD COMPANY	Little Fork Creek
SC0043281-001	B & M AQUACULTURE FARMS	Little Pee Dee River

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

3.0 Overview of UIF Methodology

Fundamentally, UIFs are calculated by removing known impacts from measured streamflow values at places in which flow has been measured historically. An alternate method sometimes employed utilizes rainfall-runoff modeling to estimate natural runoff tendencies, but this technique is often uncertain, and its only sure footing is in calibration to measured (and frequently impaired) streamflow records. For the Pee Dee River Basin, UIFs were calculated at every location in which a USGS gage has recorded historical flow measurements. Measured and estimated impacts of withdrawals, discharges, and impoundments were included as linear "debits" or "credits," and the measured flow was adjusted accordingly. Where historical data on river operations did not exist, values were hindcasted using various estimation techniques. Once the UIFs were developed for each USGS gage, the Period of Record (POR) for each gage was statistically extended (if necessary) to cover the range of 1929-2013 (coinciding with the longest recorded streamflow in the basin). As a final step, the UIFs in ungaged basins were estimated from UIFs in gaged basins with similar size, land use, and topography.

UIFs are intended to be used for the following purposes:

a) Headwater input to the SWAM models

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

c) SWAM model calibration

d) Comparison of simulated managed flows to natural flows

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

Figure 3.1 illustrates the step-by-step methodology for computing UIFs. The same general methodology that has been previously used in the Saluda, Edisto and Broad river basins was also used in the Pee Dee. Please refer to the *Methodology for Unimpaired Flow Development* documents prepared for these basins. The methodology is also supported by the following technical memoranda, which specifically outline the steps and guidelines for UIF computation and decision-making:

- *Guidelines for Standardizing and Simplifying Operational Record Extension (CDM Smith, March 2015)* – Included as **Attachment A** of this report. This includes guidelines for various techniques for operational gap filling and record extension, and which techniques are most appropriate for various circumstances.
- *Guidelines for Identifying Reference Basins for UIF Extension or Synthesis (CDM Smith, April 2015)* – Included as **Attachment B** of this report.
- *Refinements to the UIF Extension Process, with an Example* – Included as **Attachment C.**

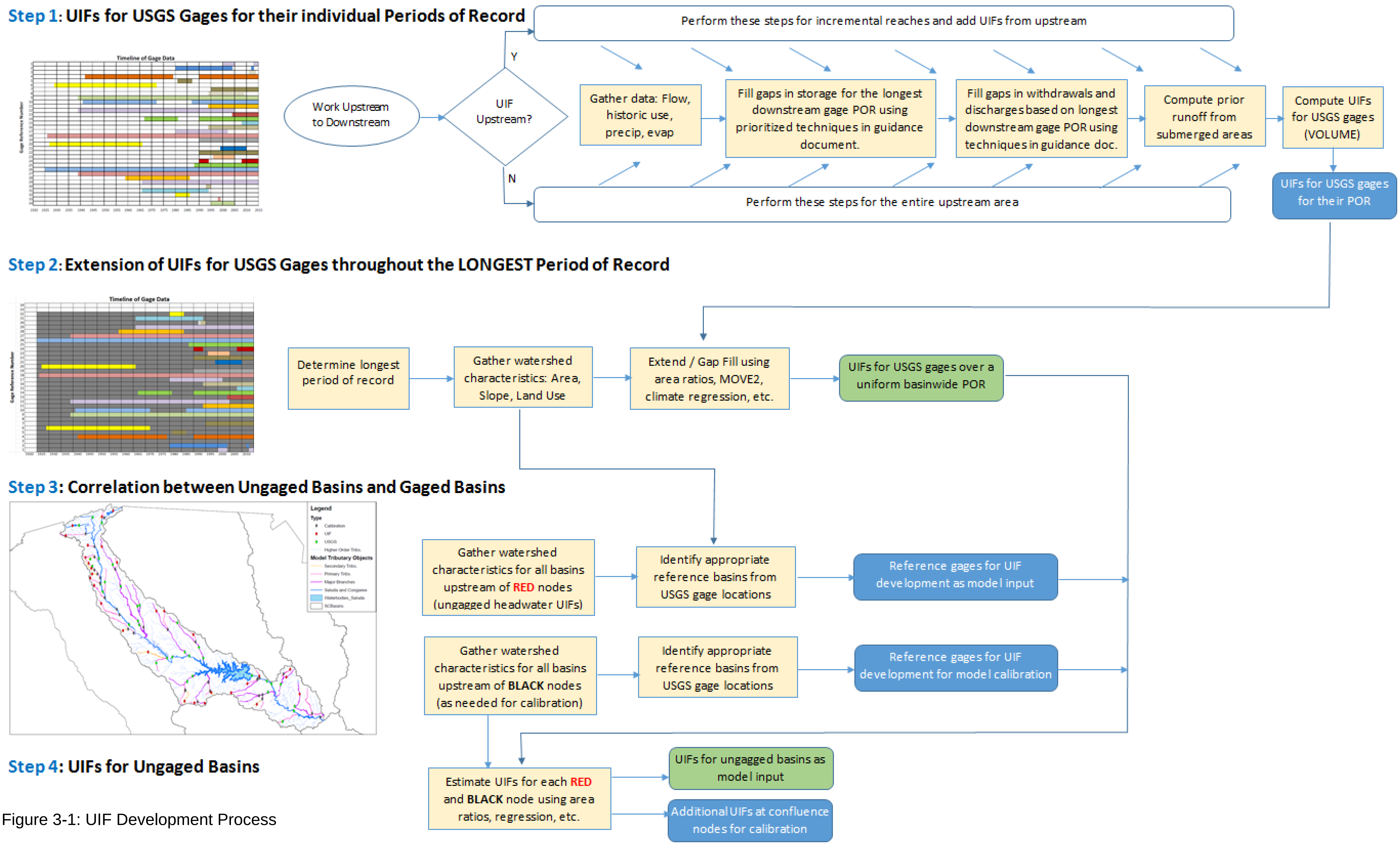

Figure 3-1: UIF Development Process

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

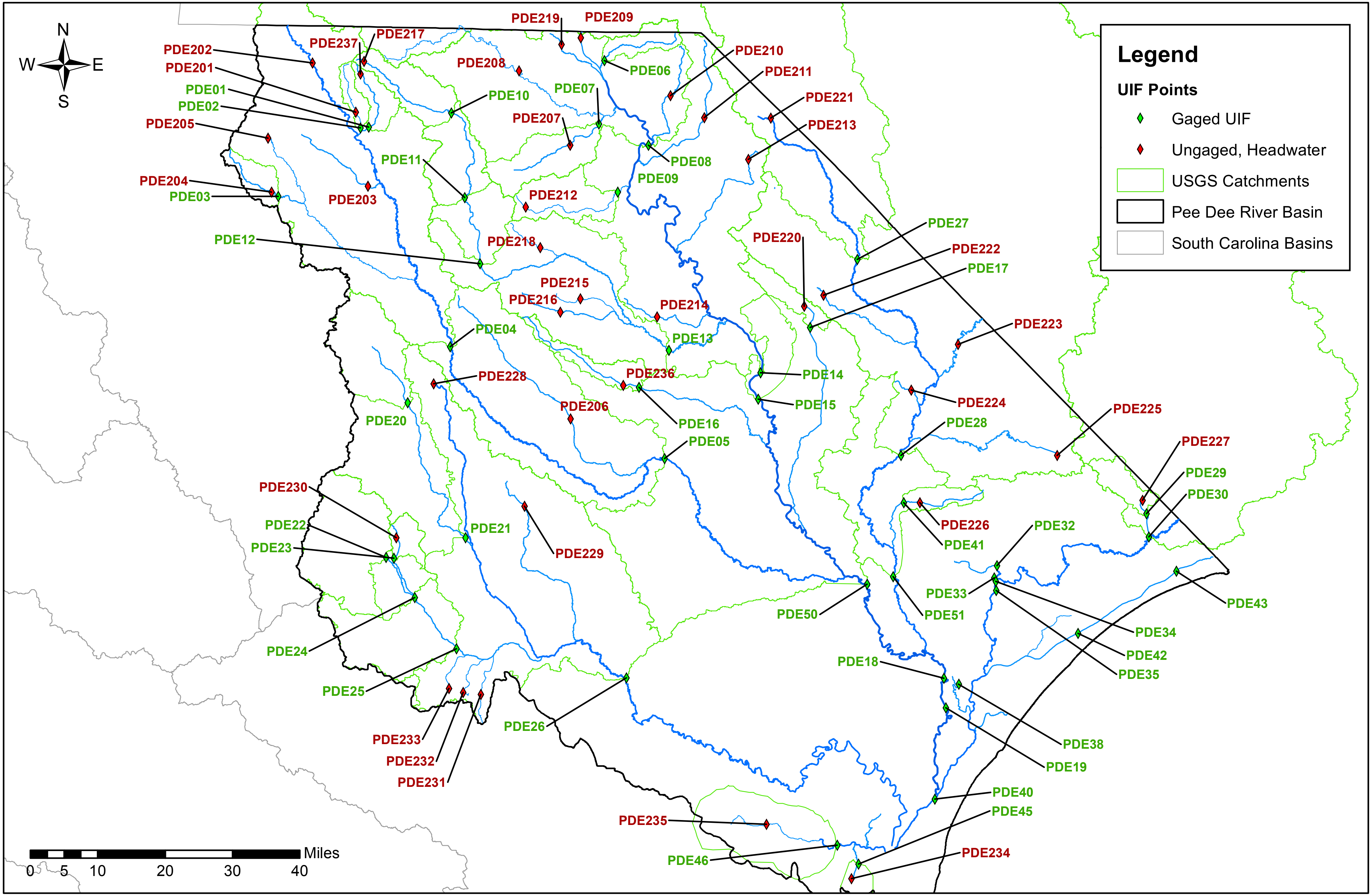

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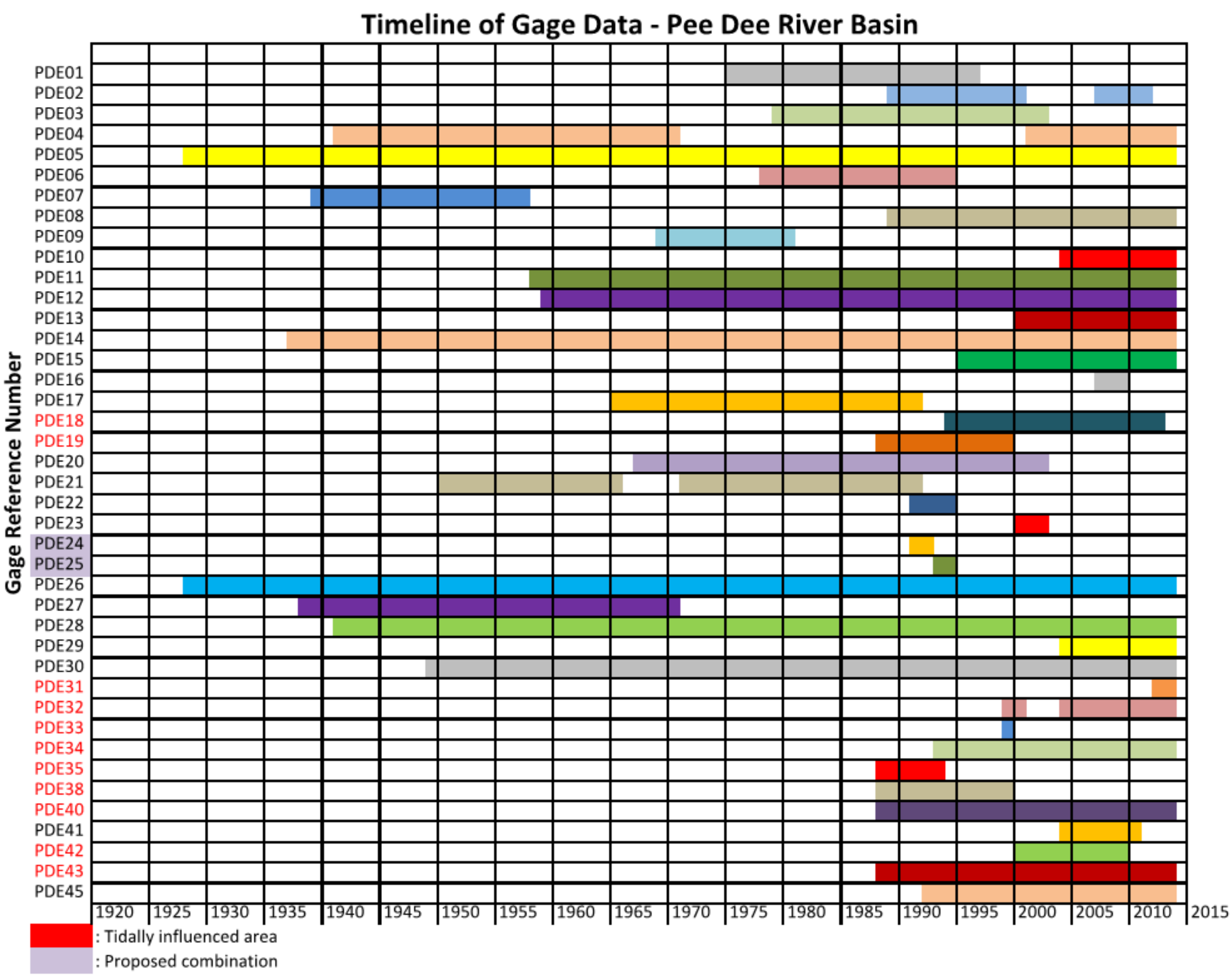
Figure 3-2
Unimpaired Flow Locations in the Pee Dee River Basin

3.1 Period of Record

While UIF estimates begin in 1929 for the Pee Dee 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 1929 will be extended using gap filling techniques. Therefore, much of the UIFs are based on estimated flows, but the value of a lengthy record, even if approximate, is that DNR, DHEC, and other users can evaluate results over a large range of hydrologic and climate conditions. **Figure 3-3** depicts the length and timing of records available for all USGS gages in the Pee Dee basin.

Figure 3-3. Period of record for USGS gages in the Pee Dee Basin



3.2 Issues Specific to the Pee Dee Basin

3.2.1 Coastal Areas

Significant portions of the Pee Dee River Basin along the coast are tidally influenced. The Pee Dee River Basin SWAM Model Framework (**Figure 7** of the Pee Dee Framework Memo) illustrates the extent of the tidally influenced area. No attempt has been made to calculate UIFs in the tidally influenced areas of the basin. Representation of these areas will be limited in SWAM since historical flows and its UIFs cannot be accurately quantified. **Attachment G** illustrates which gages are considered coastal.

3.2.2 Existing Pee Dee River UIFs in North Carolina

Flow enters the Pee Dee River Basin from North Carolina along the Great Pee Dee River and along the Lumber River, tributary to the Little Pee Dee. UIFs from North Carolina to the Great Pee Dee River have been developed by others while UIFs for the Lumber River have not been developed.

UIFs flowing through the Great Pee Dee River Basin from North Carolina were previously developed by HDR Engineering under contract to Duke Energy Carolinas, LLC, as reported in the *Yadkin-Pee Dee Basin Operations Model Study* (HDR, 2014). 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 Pee Dee River. The CHEOPS UIFs along the Great Pee Dee River were verified against the Pee Dee station near Rockingham, NC (USGS 02129000) and found to be well-suited for incorporation into the SWAM model. The overall flow adjustment between the UIFs and a nearby USGS gage was minimal.

UIFs in the Lumber River have not been developed by North Carolina Department of Environmental Quality (NCDEQ). For this tributary, only the managed flows from North Carolina are included. A Lumber station at Boardman, NC (USGS 2134500) represents the flows from North Carolina as a boundary condition. Once UIFs have been developed by NCDEQ for the Lumber River, the UIF dataset may be updated to include these.

3.2.3 Groundwater

Registered and permitted (both active and inactive) groundwater withdrawal locations are shown in **Figure 3-4**. Groundwater withdrawals may lower streamflow to a point that they potentially influence UIF estimates in a significant manner if the following conditions are met:

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

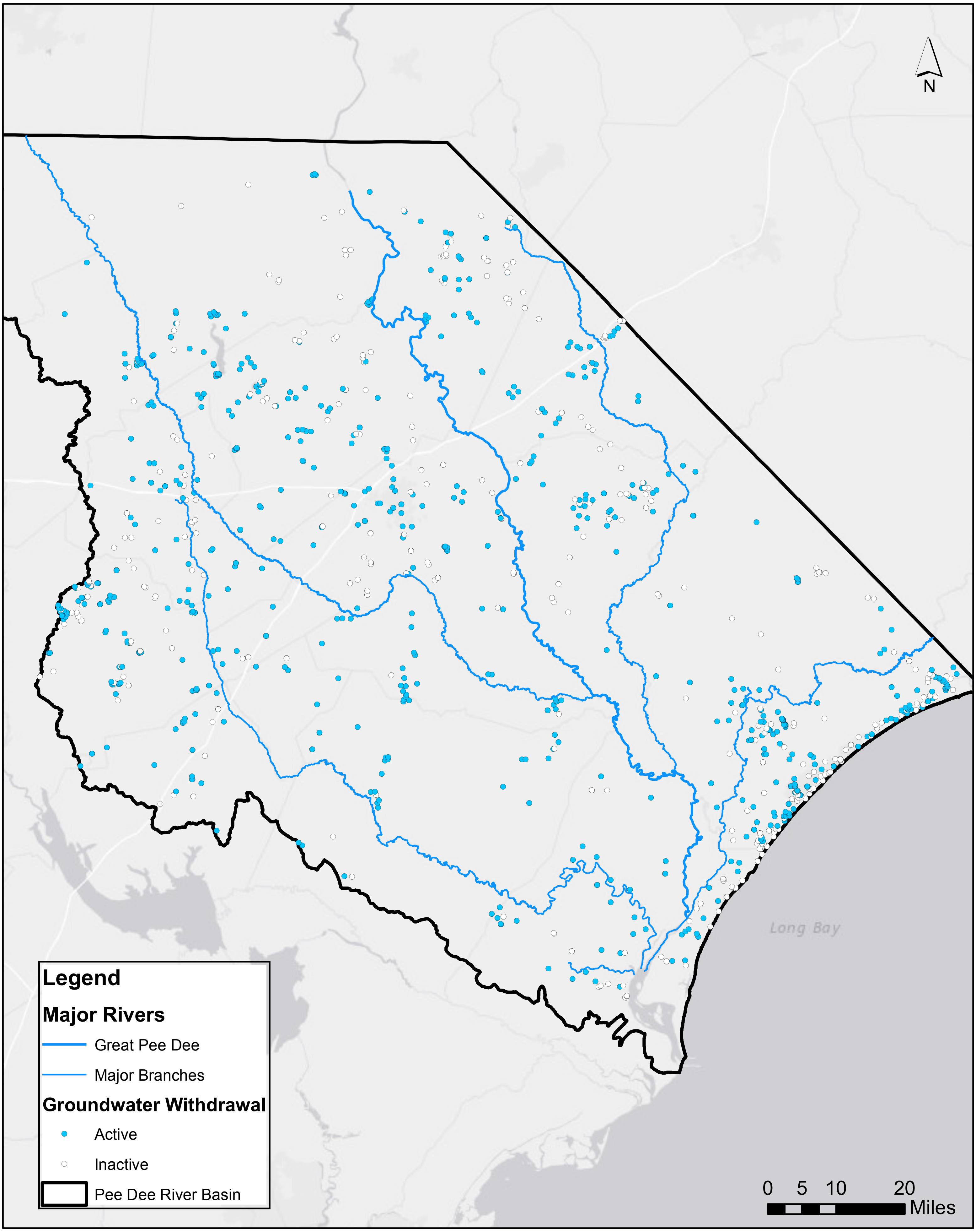


Figure 3-4

Active and Inactive Groundwater Withdrawal Locations

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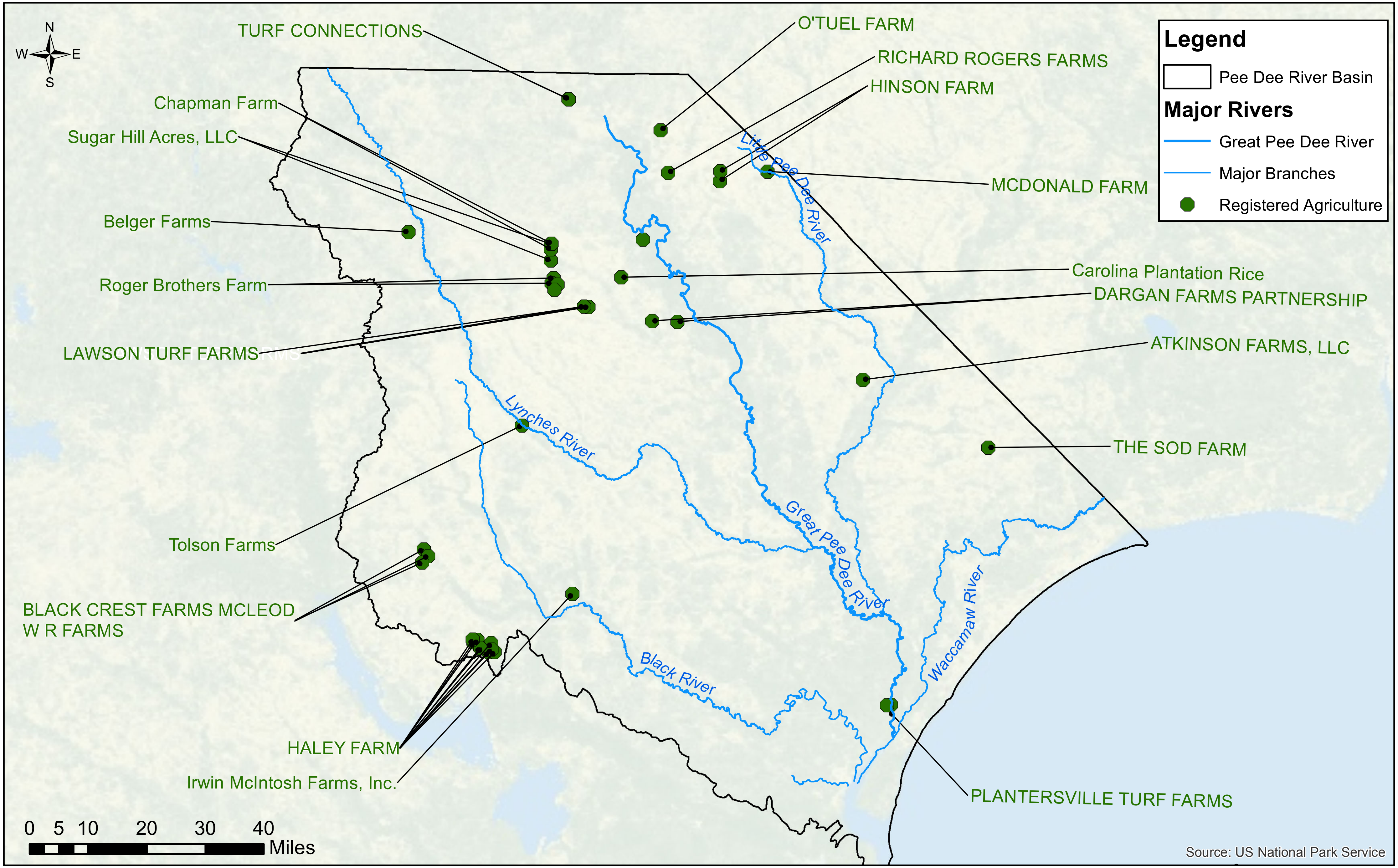

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Figure 3-5
Current Agriculture Surface Water Users

expected to be mostly lost to evapotranspiration. Very little is returned to the stream via direct or indirect runoff.

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

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

3.2.4 Agriculture

Registered agriculture surface withdrawal locations in the Pee Dee basin are shown in **Figure 3-5.** Of the 20 registered agricultural surface water users, thirteen 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; therefore, no return flows are assumed for the UIF calculations.

4.0 Quality Assurance Reviews

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

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

5.0 Summary of Operational Hindcasting

Unique circumstances involving data availability, observable trends, etc. required decisions about how to develop representative hindcast values for each individual user. A summary of hindcasting methods used for withdrawals and discharges are presented in **Table 5.1** and **Table 5.2**, respectively. Reference **Attachment A** for details on the listed methodologies.

Hindcasting of agricultural withdrawals in the Pee Dee Basin was also required for the UIF calculations. Withdrawal data reported to DHEC from 2002 and 2014 was used directly, and prior to that, values from 1950 through 2001 were hindcasted using irrigated acreage estimation techniques. These estimation techniques are described in the memorandum entitled, *Methodology for Developing Historical Surface Water Withdrawals for Agriculture Irrigation* (CDM Smith, July 2015).

Table 5.1: Summary of Methods Used for Hindcasting Withdrawals

Project Gage ID	USGS Number	Stream	Withdrawal Hindcasting			
			User ID	User Name	Time Periods	Method Used
PDE01	02131309	FORK CREEK AT JEFFERSON, SC	13GC003S01	White Plains Country Club	None	All data provided
PDE04	02131500	LYNCHES RIVER NR BISHOPVILLE, SC	13MI003S01	Hanson Aggregates (Jefferson)	1/2006 - 12/2012	Anecdotal information and monthly averages
			28MI001S01	Martin Marietta Materials Plant	None	All data provided
PDE07	02130500	JUNIPER CREEK NEAR CHERAW, SC	13GC001S01	Cheraw State Park	1/1985 - 2/2001	Long term gap filling
PDE08	02130561	PEE DEE RIVER NR BENNETTSVILLE, SC	13WS001S01	Town of Cheraw	None	Non-responder
			34IN005S01	Domtar Paper	11/1990 - 12/2000	Anecdotal information and monthly averages
			34MI001S03	Hanson Aggregates (Marlboro)	None	All data provided
PDE10	02130840	BLACK CREEK BELOW CHESTERFIELD, SC	13IN002S01	Hanson Aggregates (Brewer)	None	All data provided
PDE13	02130980	BLACK CREEK NEAR QUINBY, SC	16IN005S01 16IN005S02	Sonoco Products	1/1920 - 12/1985 1/1989 - 1/2002	Anecdotal information and monthly averages
			16IN006S01	Nucor Corp	None	All data provided
			16PN001S01 16PN001S2	H.B. Robinson Nuclear Plant	1/1971 - 1/1983 1/1985 - 1/1995	Monthly averages
PDE14	02131000	PEE DEE RIVER AT PEEDEE, SC	16IN004S01	Galey & Lord	1/1963 - 12/1982	Monthly averages
			16IN004S02	Galey & Lord	None	All data provided
			21WS002S01	City of Florence SWPTP	None	All data provided

Table 5.2: Summary of Methods Used for Hindcasting Discharges

Project Gage	USGS Number	Stream	Discharge Hindcasting			
			ID	Facility Name	Time Periods	Method Used
PDE02	02131320	LITTLE FORK CREEK AT JEFFERSON, SC	SC0040657-01A to 002	BREWER GOLD COMPANY	10/1986 - 9/1989	Hindcast to known start date (Industrial Discharge).
PDE03	02131472	HANGING ROCK CREEK NR KERSHAW, SC	SC0025798-001	KERSHAW/HANGING ROCK CREEK	6/1975 - 1/1989	Hindcast to known start date

Project Gage	USGS Number	Stream	Discharge Hindcasting			
			ID	Facility Name	Time Periods	Method Used
PDE04	02131500	LYNCHES RIVER NEAR BISHOPVILLE, SC	SC0001341-001	AHLSTROM NONWOVENS LLC/BETHUNE	3/1978 - 1/1989	Hindcast to known start date. Small gap filling
			SC0002500-001	CLEVELAND-CAROKNIT/JEFFERSON	12/1974 - 1/1989	Hindcast to known start date
			SC0040479-02A to 002	HAILE GOLD MINE	none	Minor gap filling.
			SCG730062-000	HANSON AGGR SE/JEFFERSON	1/2006 - 12/2013	Permit estimate of Hanson (Jefferson)
			SC0024767-001	JEFFERSON WWTF	3/1978 - 1/1989	Hindcast to known start date
			SC0021504-001	PAGELAND/NORTHWEST WWTF	10/1981 - 1/1989	Hindcast to known start date
PDE05	02132000	LYNCHES RIVER AT EFFINGHAM, SC	SC0035378-001	BISHOPVILLE WWTF	10/1982 - 1/1989	Hindcast to known start date (town using GW)
			SC0043702-001	LAMAR WWTF	none	none
			SC0042676-001	LYNCHBURG WWTF	none	none
			SC0039284-001 to 01A	MCCALL FARMS INC	11/1983 - 1/1991	Hindcast to known start date (town using GW)
			SC0001490-001	REEVES BROTHERS/BISHOPVILLE	10/1973 - 1/1989	Hindcast to known start date
			SC0025356-001 to 002	TIMMONSVILLE, TOWN OF	4/1980 - 1/1989	Hindcast to known start date (town using GW)
PDE08	02130561	PEE DEE RIVER NR BENNETTSVILLE, SC	SC0020249-001	CHERAW WWTF	1/1983 - 1/1989	Correlated with monthly withdrawal (Cheraw)
			SC0025232-001	CHESTERFIELD/THOMPSON CREEK	5/1985 - 1/1989	Hindcast to known start date
			SC0002151-001 to 002	SCHWARZ WALLACE LLC	10/1977 - 1/1989	Hindcast to known start date
PDE10	02130840	BLACK CREEK BELOW CHESTERFIELD, SC	SCG730286-1AA	HANSON AGGR SE/BREWER	none	Correlated with monthly withdrawal (Hanson (Brewer))
			SC0021539-001	PAGELAND/SOUTHEAST WWTF	10/1981 - 1/1989	Hindcast to known start date
PDE12	02130910	BLACK CREEK NEAR HARTSVILLE, SC	SC0002925-001 to 014	PROGRESS ENERGY/ROBINSON	1/1971 - 1/1995	Correlated with monthly withdrawal (HB Robinson)
PDE13	02130980	BLACK CREEK NEAR QUINBY	SC0039624-001	DARLINGTON/BLACK CREEK WWTF	none	none

Project Gage	USGS Number	Stream	Discharge Hindcasting			
			ID	Facility Name	Time Periods	Method Used
PDE13	02130980	BLACK CREEK NEAR QUINBY, SC	SC0021580-001	HARTSVILLE WWTF	4/1980 - 1/1989	Hindcast to known start date (town using GW)
			SC0003042-001 to 008	SONOCO PRODUCTS/HARTSVILLE	1/1920 - 1/1989	Correlated with monthly withdrawal (Sonoco)
			SC0004162-001	WELLMAN INC/PALMETTO PLANT	3/1973 - 1/1989	Hindcast to known start date
PDE14	02131000	PEE DEE RIVER AT PEEDEE, SC	SC0025178-001	BENNETTSVILLE WWTF	1/1972 - 1/1989	Correlated with monthly withdrawal (Bennettsville)
			SC0040606-01A to 01C	CLIO WWTF	7/1986 - 6/1989	Hindcast to known start date (town using GW)
			SC0042188-001	DOMTAR PAPER CO LLC/MARLBORO MILL	7/2003 - 7/2012	Gap filling
			SC0002704-001	GALEY & LORD/SOCIETY HILL	1/1963 - 1/1989	Correlated with monthly withdrawal (Galey & Lord)
			SC0003018-001 to 002	KOPPERS INC	none	none
			SC0046230-001	MARION/S. MAIN ST. WWTF	10/1994 - 10/1999	Hindcast to known start date (town using GW)
			SC0001996-001 to 003	MOHAWK IND/OAK RIVER PLANT	12/1974 - 8/1989	Hindcast to known start date (industrial discharge)
PDE15	02131010	PEE DEE RIVER BELOW PEE DEE, SC	SC0002917-01A to 002	DUPONT TEIJIN FILMS/FLORENCE	none	Hindcast to known start date
PDE16	02131110	JEFFRIES CREEK ABOVE FLORENCE, SC	SC0004171-001	GE HEALTHCARE/FLORENCE	8/1986 - 1/1989	Hindcast to known start date
PDE22	02135517	POCOTALIGO RIVER AT SUMTER, SC	SC0040088-01A to 002	GLASSCOCK TRUCKING COMPANY INC	9/1986 - 7/1993	Hindcast to known start date
			SC0024970-001 to 007	USAF/SHAW AIR FORCE BASE	4/1985 - 4/1989	Hindcast to known start date
PDE24	02135600	POCOTALIGO R NR SUMTER S C	SC0000795-001 to 002	PILGRIMS PRIDE POULTRY PROC. PLANT	6/1976 - 1/1989	Hindcast to known start date (industrial discharge)
			SC0027707-001	SUMTER/POCOTALIGO RIVER PLANT	10/1977 - 1/1989	Hindcast to known start date
PDE26	02136000	BLACK RIVER AT KINGSTREE, SC	SC0020419-001	MANNING WWTF	6/1975 - 1/1989	Hindcast to known start date (town using GW)

Project Gage	USGS Number	Stream	Discharge Hindcasting			
			ID	Facility Name	Time Periods	Method Used
			SC0003123-001 to 002	MARTEK BIOSCIENCES KINGSTREE	9/1985 - 2/1989	Hindcast to known start date (industrial discharge)
			SC0025755-001 to 003	TURBEVILLE WWTF	6/1975 - 1/1989	Hindcast to known start date
PDE27	02132500	LITTLE PEE DEE RIVER NEAR DILLON, S. C.	SC0041963-001	MCCOLL WWTF	none	none
PDE28	02135000	LITTLE PEE DEE R. AT GALIVANTS FERRY, SC	SC0021776-001 to 004	DILLON/LITTLE PEE DEE	3/1978 - 1/1989	Hindcast to known start date (town using GW)
			SC0025348-001	GSW&SA/LORIS WWTF	9/1978 - 1/1989	Hindcast to known start date
			SC0022284-001	LAKE VIEW WWTF	9/1985 - 2/1990	Hindcast to known start date (town using GW)
			SC0025402-001	LATTA, TOWN OF	6/1975 - 1/1989	Hindcast to known start date (town using GW)
			SC0029408-001	MULLINS/WHITE OAK CREEK WWTF	8/1978 - 1/1989	Hindcast to known start date (town using GW)

6.0 Summary of Gaged UIF Flow Record Extension

A summary of the reference gages and methods used to extend the UIFs with partial periods of record is provided in **Table 6.1**. Initial candidates of reference gages are selected following guidelines outlined in **Attachment B.** See **Attachment D** for details pertaining to the decision-making process and **Attachment F** for notes associated with each individual decision.

As MOVE.1 without an initial log transform may produce negative or near-zero values, area proration (which is strictly linear and cannot produce negative flows from non-negative reference flows) replaces values below a site-specific minimum threshold determined by the overlapping period between the partial and reference gages. For example, in the overlap between PDE04 and PDE11, the lowest flow is 10 cfs. Thus, when MOVE.1 is calculated using PDE11'S untransformed flows, any days below 10 cfs are replaced with the corresponding flows of that day found from area proration. Note that if a reference gage registers a flow of zero, the extended flow for the partial gage will also be estimated as zero.

Additionally, gages from the nearby Catawba River Basin were evaluated as potential reference gages but none were found to be suitable.

Table 6.1: Summary of Extending UIFs with Partial Periods of Record

USGS Gage with Partial Record					USGS Reference Gage(s)			Method of Extension
Project Gage ID	USGS Number	Stream	Periods of Record	Basin Area (mi^2)	Project Gage ID	Stream	Basin Area (mi^2)	
PDE01	02131309	FORK CREEK AT JEFFERSON, SC	8/1976 - 9/1997	24	PDE02	LITTLE FORK CREEK AT JEFFERSON, SC	15	MOVE.1 (no transform), Area Ratio if MOVE.1 < 0.3 cfs
					PDE03	HANGING ROCK CREEK NR KERSHAW, SC	24	MOVE.1 (no transform), Area Ratio if MOVE.1 < 0 cfs
					PDE11	BLACK CREEK NEAR MCBEE, SC	115	MOVE.1 (log transform)
					PDE05	LYNCHES RIVER AT EFFINGHAM, SC	1044	MOVE.1 (log transform)
PDE02	02131320	LITTLE FORK CREEK AT JEFFERSON, SC	10/1990 - 10/2000 3/2001 - 4/2001 3/2008 - 12/2012	15	PDE01	FORK CREEK AT JEFFERSON, SC	24	MOVE.1 (no transform), Area Ratio if MOVE.1 < 0.01 cfs
					PDE03	HANGING ROCK CREEK NR KERSHAW, SC	24	MOVE.1 (no transform), Area Ratio if MOVE.1 < 0.01 cfs
					PDE20	SCAPE ORE SWAMP NEAR BISHOPVILLE, S. C.	95	MOVE.1 (log transform)
					PDE05	LYNCHES RIVER AT EFFINGHAM, SC	1044	MOVE.1 (log transform)
PDE03	02131472	HANGING ROCK CREEK NR KERSHAW, SC	10/1980 - 10/2003	24	PDE01	FORK CREEK AT JEFFERSON, SC	24	MOVE.1 (no transform), Area Ratio if MOVE.1 < 0.1 cfs
					PDE04	LYNCHES RIVER NEAR BISHOPVILLE, SC	661	MOVE.1 (log transform)
					PDE11	BLACK CREEK NEAR MCBEE, SC	115	MOVE.1 (log transform)
					PDE05	LYNCHES RIVER AT EFFINGHAM, SC	1044	MOVE.1 (log transform)
PDE04	02131500	LYNCHES RIVER NEAR BISHOPVILLE, SC	10/1942 - 9/1971 2/2002 - 9/2014	661	PDE11	BLACK CREEK NEAR MCBEE, SC	115	MOVE.1 (log transform)
					PDE05	LYNCHES RIVER AT EFFINGHAM, SC	1044	MOVE.1 (log transform)
PDE06	02129590	WHITES CREEK NEAR WALLACE, SC	10/1979 - 9/1995	27	PDE09	CEDAR CREEK AT SOCIETY HILL, SC	57	MOVE.1 (no transform), Area Ratio if MOVE.1 < 0.1 cfs
					PDE11	BLACK CREEK NEAR MCBEE, SC	115	MOVE.1 (no transform), Area Ratio if MOVE.1 < 0 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)	
					PDE05	LYNCHES RIVER AT EFFINGHAM, SC	1044	MOVE.1 (no transform), Area Ratio if MOVE.1 < 0 cfs
PDE07	02130500	JUNIPER CREEK NEAR CHERAW, S. C.	10/1940 - 9/1958	63	PDE04	LYNCHES RIVER NEAR BISHOPVILLE, SC	661	MOVE.1 (no transform), Area Ratio if MOVE.1 < 0 cfs
					PDE05	LYNCHES RIVER AT EFFINGHAM, SC	1044	MOVE.1 (no transform), Area Ratio if MOVE.1 < 0 cfs
PDE08	02130561	PEE DEE RIVER NR BENNETTSVILLE, SC	11/1990 - 9/2014	443	PDE14	PEE DEE RIVER AT PEEDEE, SC	1474	MOVE.1 (log transform)
					PDE05	LYNCHES RIVER AT EFFINGHAM, SC	1044	MOVE.1 (log transform)
PDE09	02130600	CEDAR CREEK AT SOCIETY HILL, SC	10/1970 - 9/1981	57	PDE06	WHITES CREEK NEAR WALLACE, SC	27	MOVE.1 (log transform)
					PDE04	LYNCHES RIVER NEAR BISHOPVILLE, SC	661	MOVE.1 (log transform)
					PDE11	BLACK CREEK NEAR MCBEE, SC	115	MOVE.1 (log transform)
					PDE27	LITTLE PEE DEE RIVER NEAR DILLON, S. C.	530	MOVE.1 (log transform)
					PDE05	LYNCHES RIVER AT EFFINGHAM, SC	1044	MOVE.1 (log transform)
PDE10	02130840	BLACK CREEK BELOW CHESTERFIELD, SC	9/2005 - 9/2014	52	PDE11	BLACK CREEK NEAR MCBEE, SC	115	MOVE.1 (log transform)
					PDE04	LYNCHES RIVER NEAR BISHOPVILLE, SC	661	MOVE.1 (no transform)
					PDE05	LYNCHES RIVER AT EFFINGHAM, SC	1044	MOVE.1 (log transform)
PDE11	02130900	BLACK CREEK NEAR MCBEE, SC	10/1959 - 9/2014	115	PDE04	LYNCHES RIVER NEAR BISHOPVILLE, SC	661	MOVE.1 (log transform)
					PDE05	LYNCHES RIVER AT EFFINGHAM, SC	1044	MOVE.1 (log transform)
PDE12	02130910	BLACK CREEK NEAR HARTSVILLE, SC	10/1960 - 9/2014	172	PDE04	LYNCHES RIVER NEAR BISHOPVILLE, SC	661	MOVE.1 (log transform)
					PDE05	LYNCHES RIVER AT EFFINGHAM, SC	1044	MOVE.1 (log transform)
PDE13	02130980	BLACK CREEK NEAR QUINBY, SC	10/2001 - 9/2014	446	PDE05	LYNCHES RIVER AT EFFINGHAM, SC	1044	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)	
PDE14	02131000	PEE DEE RIVER AT PEEDEE, SC	10/1938 - 9/2014	1474	PDE05	LYNCHES RIVER AT EFFINGHAM, SC	1044	MOVE.1 (log transform)
PDE15	02131010	PEE DEE RIVER BELOW PEE DEE, SC	10/1996 - 9/2014	1524	PDE14	PEE DEE RIVER AT PEEDEE, SC	1474	Area Ratio
					PDE05	LYNCHES RIVER AT EFFINGHAM, SC	1044	MOVE.1 (log transform)
PDE16	02131110	JEFFRIES CREEK ABOVE FLORENCE, SC	3/2008 - 9/2010	34	PDE41	CHINNERS SWAMP NEAR AYNOR, SC	22	Area Ratio
					PDE13	BLACK CREEK NEAR QUINBY, SC	446	MOVE.1 (no transform), Area Ratio if MOVE.1 < 0.4 cfs
					PDE05	LYNCHES RIVER AT EFFINGHAM, SC	1044	MOVE.1 (no transform), Area Ratio if MOVE.1 < 0.4 cfs
PDE17	02131150	CATFISH CANAL AT SELLERS, SC	11/1966 - 9/1992	28	PDE27	LITTLE PEE DEE RIVER NEAR DILLON, S. C.	530	MOVE.1 (log transform)
					PDE05	LYNCHES RIVER AT EFFINGHAM, SC	1044	MOVE.1 (log transform)
PDE20	02135300	SCAPE ORE SWAMP NEAR BISHOPVILLE, S. C.	7/1968 - 9/2003	95	PDE11	LYNCHES RIVER NEAR BISHOPVILLE, SC	115	MOVE.1 (log transform)
					PDE05	LYNCHES RIVER AT EFFINGHAM, SC	1044	Area Ratio
PDE21	02135500	BLACK RIVER NEAR GABLE, SC	6/1951 - 6/1966 4/1972 - 9/1992	261	PDE05	LYNCHES RIVER AT EFFINGHAM, SC	1044	MOVE.1 (no transform), Area Ratio if MOVE.1 < 0 cfs
PDE22	02135517	POCOTALIGO RIVER AT SUMTER, SC	10/1992 - 1/1995 5/1995 - 9/1995	136	PDE20	SCAPE ORE SWAMP NEAR BISHOPVILLE, S. C.	95	MOVE.1 (log transform)
					PDE05	LYNCHES RIVER AT EFFINGHAM, SC	1044	MOVE.1 (log transform)
PDE23	02135520	TURKEY CREEK (HWY 521) AT SUMTER, SC	1/2001 - 9/2003	19	PDE04	LYNCHES RIVER NEAR BISHOPVILLE, SC	661	MOVE.1 (no transform), Area Ratio if MOVE.1 < 0 cfs
					PDE03	HANGING ROCK CREEK NR KERSHAW, SC	24	Area Ratio
					PDE11	BLACK CREEK NEAR MCBEE, SC	115	MOVE.1 (log transform)
					PDE05	LYNCHES RIVER AT EFFINGHAM, SC	1044	Area Ratio

USGS Gage with Partial Record					USGS Reference Gage(s)			Method of Extension
Project Gage ID	USGS Number	Stream	Periods of Record	Basin Area (mi^2)	Project Gage ID	Stream	Basin Area (mi^2)	
PDE24	02135600	POCOTALIGO R NR SUMTER S C	10/1992 - 9/1993	192	PDE26	BLACK RIVER AT KINGSTREE, SC	1213	MOVE.1 (log transform)
PDE25	02135625	POCOTALIGO RIVER AT MANNING, SC	10/1994 - 2/1995 5/1995 - 9/1995	313				
PDE27	02132500	LITTLE PEE DEE RIVER NEAR DILLON, S. C.	4/1939 - 9/1971	530	PDE28	LITTLE PEE DEE R. AT GALIVANTS FERRY, SC	2806	MOVE.1 (log transform)
					PDE05	LYNCHES RIVER AT EFFINGHAM, SC	1044	MOVE.1 (log transform)
PDE28	02135000	LITTLE PEE DEE R. AT GALIVANTS FERRY, SC	1/1942 - 9/2014	2806	PDE27	LITTLE PEE DEE RIVER NEAR DILLON, S. C.	530	Area Ratio
					PDE05	LYNCHES RIVER AT EFFINGHAM, SC	1044	Area Ratio
PDE41	02135060	CHINNERS SWAMP NEAR AYNOR, SC	10/2005 - 6/2011	22	PDE28	LITTLE PEE DEE R. AT GALIVANTS FERRY, SC	2806	MOVE.1 (log transform)
					PDE14	PEE DEE RIVER AT PEEDEE, SC	1474	MOVE.1 (log transform)
					PDE05	LYNCHES RIVER AT EFFINGHAM, SC	1044	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 PDE08 is shown in **Figure 6-1**.

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

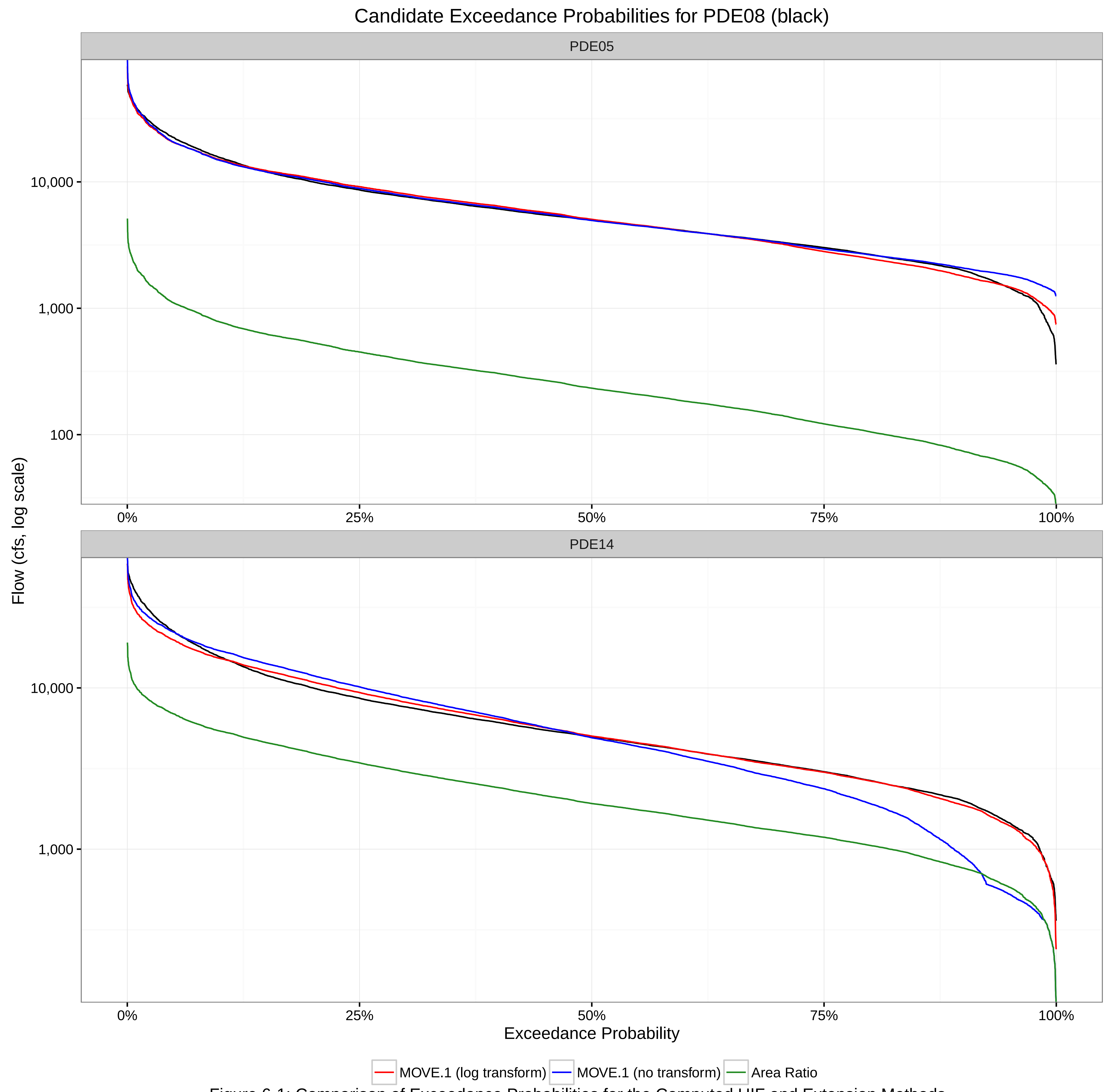


Figure 6-1: Comparison of Exceedance Probabilities for the Computed UIF and Extension Methods

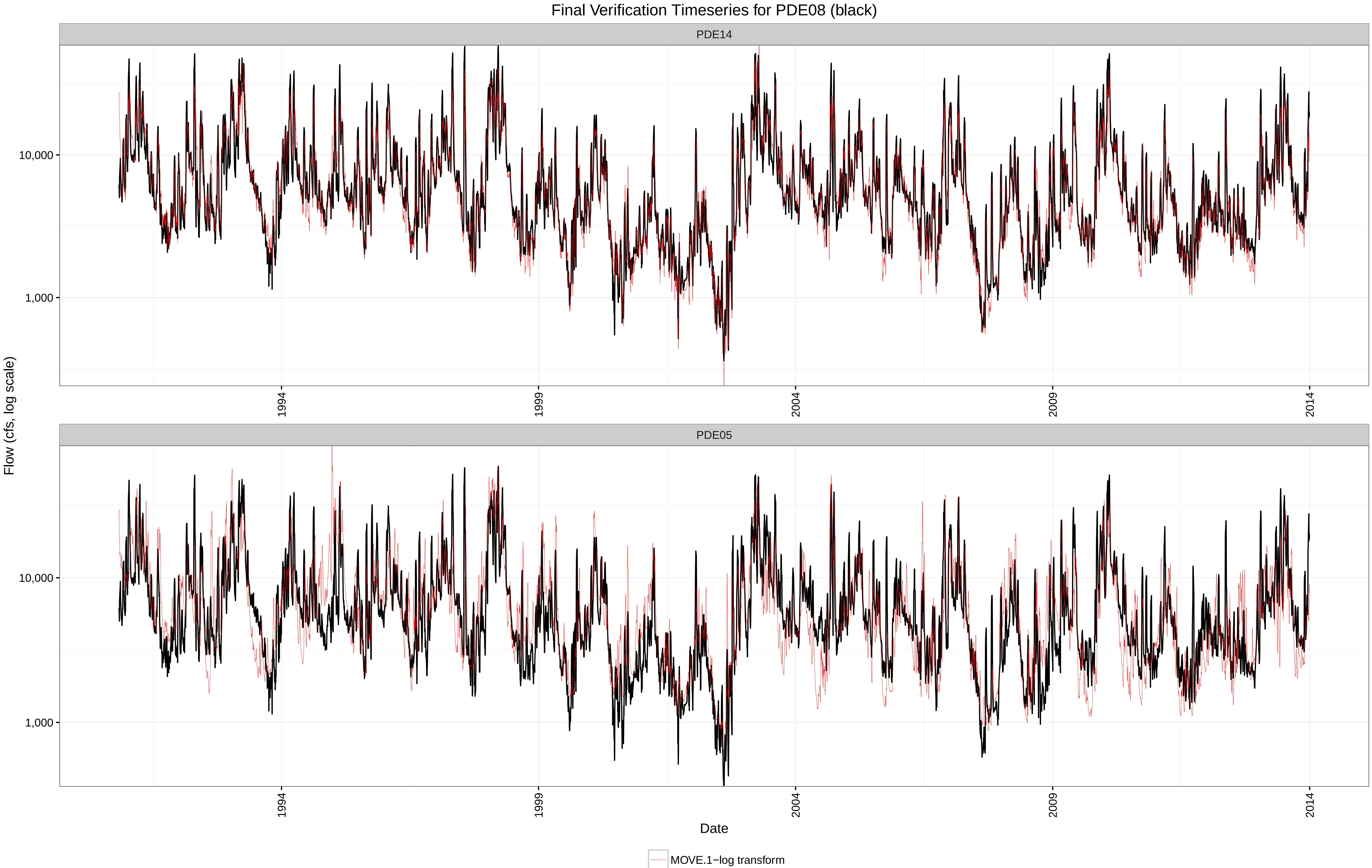


Figure 6-2: Validation Graph for PDE08 with Predicted Flows from Reference Gages PDE14 and PDE05

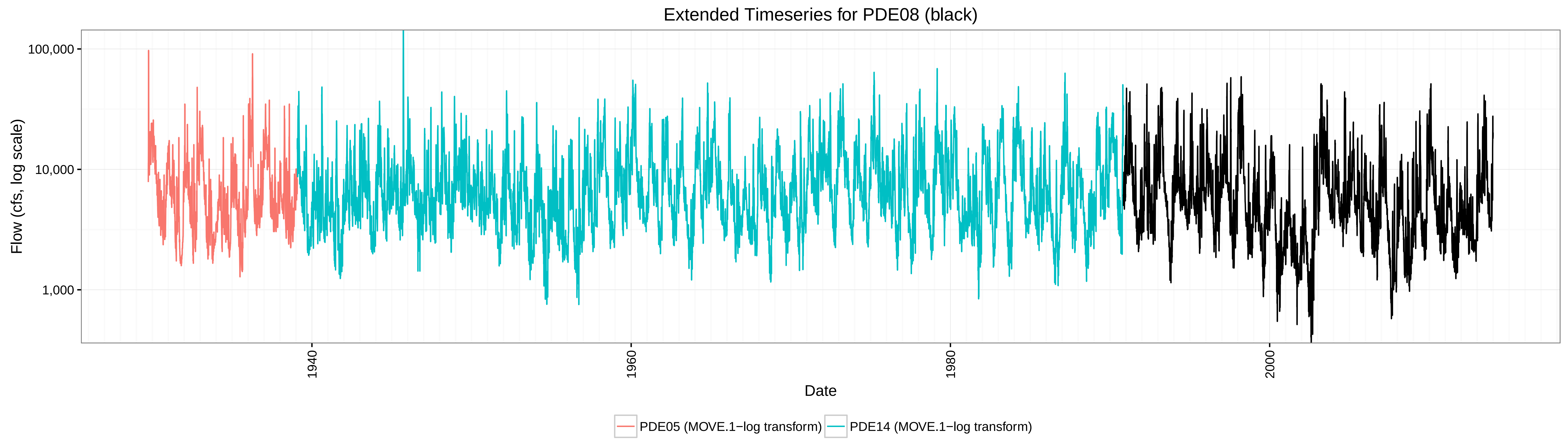


Figure 6-3: Resulting Timeseries for EDO08

7.0 Summary of Ungaged UIF Transposition

Area proration was used to transpose the UIF timeseries from gaged basins to ungaged basins. Selection of reference gages follows guidelines established in Attachment C. **Table 7.1** summarizes the information for the ungaged basins and the gaged basins used as reference. Headwater flows are used as input for each explicitly modeled tributary in SWAM whereas confluence flows are used for implicit tributaries needed for model calibration.

Table 7.1 UIFs in Ungaged Basins (Area Ratio Method Only)

	Ungaged Basin				USGS Reference Gage				
Project ID	SWAM Usage	Stream	Basin Area (mi^2)	% Developed / % Forest	Project Gage ID	USGS Number	Stream	Basin Area (mi^2)	% Developed / % Forest
PDE201	Headwater Flow	Little Fork Creek	10	10 / 53	PDE02	02131320	LITTLE FORK CREEK AT JEFFERSON, SC	15	9 / 69
PDE202	Headwater Flow	Lynches River	51	6 / 50					
PDE217	Headwater Flow	Black Creek	1	22 / 36					
PDE237	Headwater Flow	Fork Creek	1	6 / 69					
PDE203	Headwater Flow	Buffalo Creek	33	6 / 67	PDE03	02131472	HANGING ROCK CREEK NR KERSHAW, SC	24	9 / 71
PDE204	Headwater Flow	Hanging Rock Creek	14	6 / 69					
PDE205	Headwater Flow	Little Lynches River	12	5 / 61					
PDE209	Headwater Flow	Pee Dee River	8	0 / 70	PDE06	02129590	WHITES CREEK NEAR WALLACE, SC	27	4 / 78
PDE210	Headwater Flow	Naked Creek	13	5 / 63					
PDE211	Headwater Flow	Crooked Creek	45	6 / 46					
PDE213	Headwater Flow	Hagins Prong	8	9 / 41					
PDE221	Headwater Flow	Little Pee Dee River	38	10 / 38					
PDE219	Headwater Flow	Westfield Creek	11	7 / 62					
PDE102	Confluence Flow	Phils Creek	27	6 / 57					
PDE101	Confluence Flow	Huckeberry Branch	10	41 / 36					
PDE207	Headwater Flow	Juniper Creek	45	7 / 61	PDE07	02130500	JUNIPER CREEK NEAR CHERAW, S. C.	63	6 / 72
PDE212	Headwater Flow	Cedar Creek	2	9 / 27	PDE09	02130600	CEDAR CREEK AT SOCIETY HILL, S.C.	57	5 / 59
PDE214	Headwater Flow	Back Swamp	6	3 / 51					

<table>
<tr><th></th><th colspan="4">Ungaged Basin</th><th colspan="5">USGS Reference Gage</th></tr>
<tr><th>Project ID</th><th>SWAM Usage</th><th>Stream</th><th>Basin Area (mi²)</th><th>% Developed / % Forest</th><th>Project Gage ID</th><th>USGS Number</th><th>Stream</th><th>Basin Area (mi²)</th><th>% Developed / % Forest</th></tr>
<tr><td>PDE215</td><td>Headwater Flow</td><td>Bellyache Creek</td><td>10</td><td>11 / 54</td><td rowspan="3"></td><td rowspan="3"></td><td rowspan="3"></td><td rowspan="3"></td><td rowspan="3"></td></tr>
<tr><td>PDE216</td><td>Headwater Flow</td><td>Swift Creek</td><td>13</td><td>12 / 33</td></tr>
<tr><td>PDE218</td><td>Headwater Flow</td><td>Boggy Swamp</td><td>7</td><td>6 / 27</td></tr>
<tr><td>PDE208</td><td>Headwater Flow</td><td>Thompson Creek</td><td>1</td><td>8 / 62</td><td>PDE10</td><td>02130840</td><td>BLACK CREEK BELOW CHESTERFIELD, SC</td><td>52</td><td>9 / 68</td></tr>
<tr><td>PDE206</td><td>Headwater Flow</td><td>Sparrow Swamp</td><td>98</td><td>8 / 35</td><td rowspan="4">PDE16</td><td rowspan="4">02131110</td><td rowspan="4">JEFFRIES CREEK ABOVE FLORENCE, SC</td><td rowspan="4">34</td><td rowspan="4">26 / 29</td></tr>
<tr><td>PDE236</td><td>Headwater Flow</td><td>Jeffries Creek</td><td>34</td><td>15 / 38</td></tr>
<tr><td>PDE103</td><td>Confluence Flow</td><td>Rogers Creek</td><td>25</td><td>8 / 37</td></tr>
<tr><td>PDE104</td><td>Confluence Flow</td><td>Hurricane Branch</td><td>16</td><td>5 / 50</td></tr>
<tr><td>PDE105</td><td>Confluence Flow</td><td>Tobys Creek</td><td>61</td><td>5 / 39</td><td>PDE17</td><td>02131150</td><td>CATFISH CANAL AT SELLERS, SC</td><td>28</td><td>6 / 38</td></tr>
<tr><td>PDE228</td><td>Headwater Flow</td><td>Black River</td><td>13</td><td>15 / 33</td><td rowspan="2">PDE20</td><td rowspan="2">02135300</td><td rowspan="2">SCAPE ORE SWAMP NEAR BISHOPVILLE, S. C.</td><td rowspan="2">95</td><td rowspan="2">4 / 72</td></tr>
<tr><td>PDE229</td><td>Headwater Flow</td><td>Pudding Swamp</td><td>19</td><td>4 / 47</td></tr>
<tr><td>PDE231</td><td>Headwater Flow</td><td>Deep Creek</td><td>6</td><td>5 / 50</td><td rowspan="3">PDE22</td><td rowspan="3">02135517</td><td rowspan="3">POCOTALIGO RIVER AT SUMTER, SC</td><td rowspan="3">136</td><td rowspan="3">25 / 38</td></tr>
<tr><td>PDE232</td><td>Headwater Flow</td><td>Bear Creek</td><td>2</td><td>7 / 59</td></tr>
<tr><td>PDE233</td><td>Headwater Flow</td><td>Ox Swamp</td><td>7</td><td>7 / 35</td></tr>
<tr><td>PDE230</td><td>Headwater Flow</td><td>Turkey Creek</td><td>3</td><td>74 / 12</td><td>PDE23</td><td>02135520</td><td>TURKEY CREEK (HWY 521) AT SUMTER, SC</td><td>19</td><td>32 / 41</td></tr>
<tr><td>PDE220</td><td>Headwater Flow</td><td>Catfish Creek</td><td>20</td><td>4 / 34</td><td rowspan="2">PDE27</td><td rowspan="2">02132500</td><td rowspan="2">LITTLE PEE DEE RIVER NEAR DILLON, S. C.</td><td rowspan="2">530</td><td rowspan="2">8 / 50</td></tr>
<tr><td>PDE222</td><td>Headwater Flow</td><td>Buck Swamp</td><td>91</td><td>4 / 47</td></tr>
<tr><td>PDE223</td><td>Headwater Flow</td><td>Lumber River</td><td>17</td><td>9 / 34</td><td rowspan="4">PDE41</td><td rowspan="4">02135060</td><td rowspan="4">CHINNERS SWAMP NEAR AYNOR, SC</td><td rowspan="4">22</td><td rowspan="4">7 / 45</td></tr>
<tr><td>PDE224</td><td>Headwater Flow</td><td>Brown Swamp</td><td>6</td><td>34 / 20</td></tr>
<tr><td>PDE225</td><td>Headwater Flow</td><td>Lake Swamp</td><td>5</td><td>23 / 24</td></tr>
<tr><td>PDE226</td><td>Headwater Flow</td><td>Chinners Swamp</td><td>15</td><td>5 / 40</td></tr>
</table>

8.0 References

CDM Smith, January 2015, *Methodology for Unimpaired Flow Development, Saluda River Basin, South Carolina.*

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

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

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

HDR., Inc. 2014. Yadkin-Pee Dee Basin Operations Model Study.

List of Attachments

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

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

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

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

E. UIF Timeseries Graphs at USGS Gage Locations

F. Discussion on Reference Gage and Method Selection

G. Schematic of USGS Streamflow Gages in the Pee Dee River Basin

ATTACHMENT A

Guidelines for Standardizing and Simplifying Operational Record Extension

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

ATTACHMENT B

Guidelines for Identifying Reference Basins for UIF Extension or Synthesis

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

ATTACHMENT C

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

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

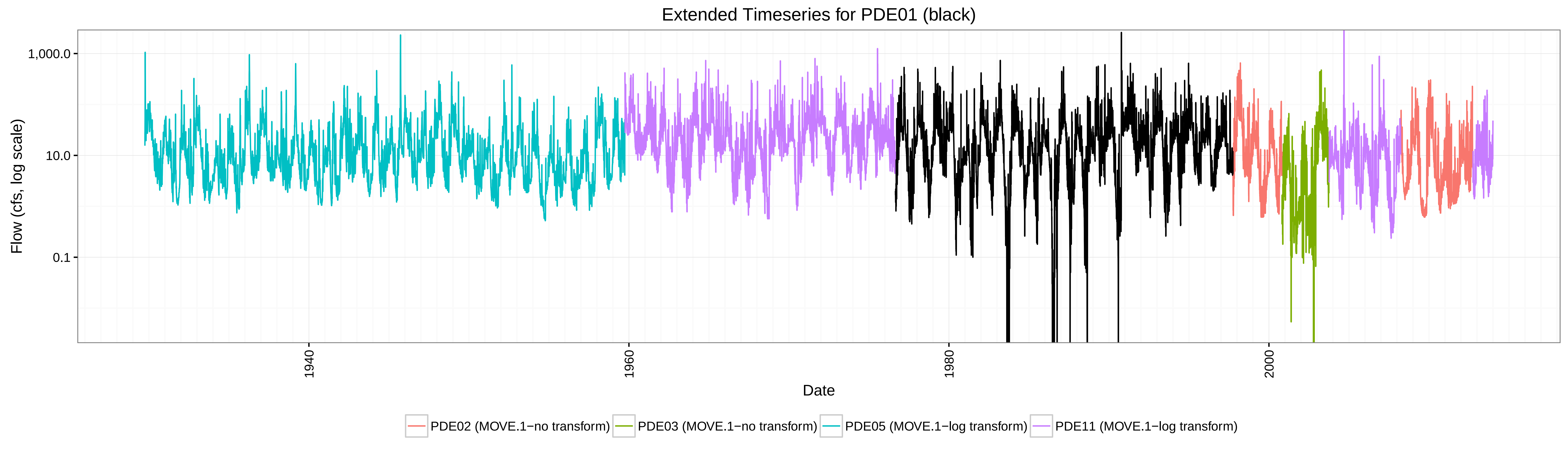
ATTACHMENT D

Refinements to the UIF Extension Process, with an Example

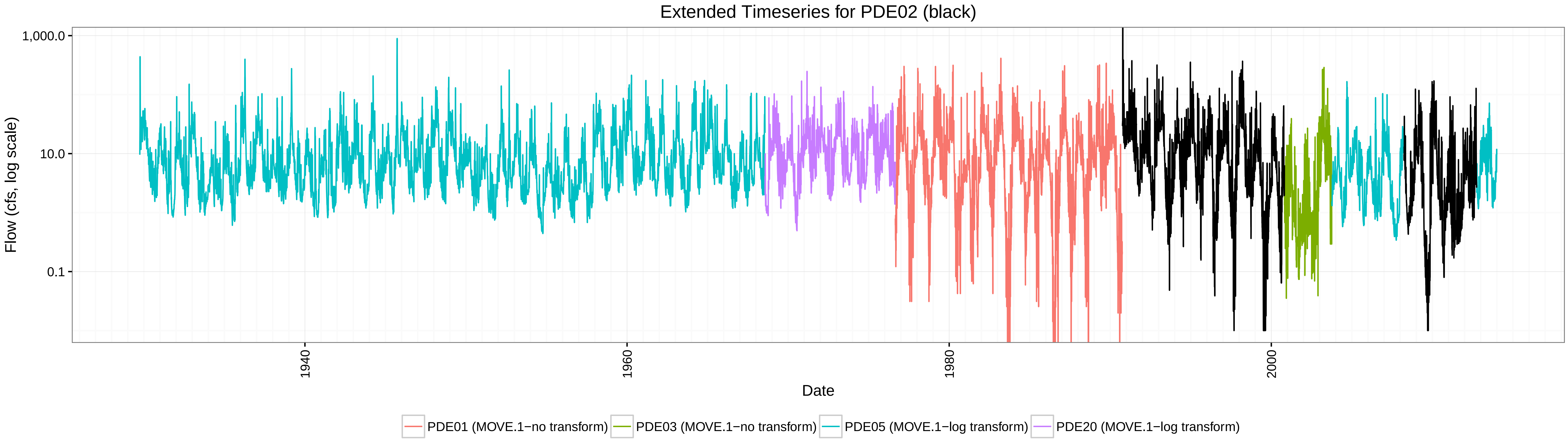
(CDM Smith, September 2015) – *To be included in Final Memo*

ATTACHMENT E

UIF Timeseries Graphs at USGS Gage Locations



Extended Timeseries for PDE01 (black)
Flow (cfs, log scale)
1,000.0
10.0
0.1
1940
1960
1980
2000
Date
PDE02 (MOVE.1−no transform)
PDE03 (MOVE.1−no transform)
PDE05 (MOVE.1−log transform)
PDE11 (MOVE.1−log transform)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Flow (cfs, log scale)
1,000.0
10.0
0.1
1940
1960
1980
2000
Date
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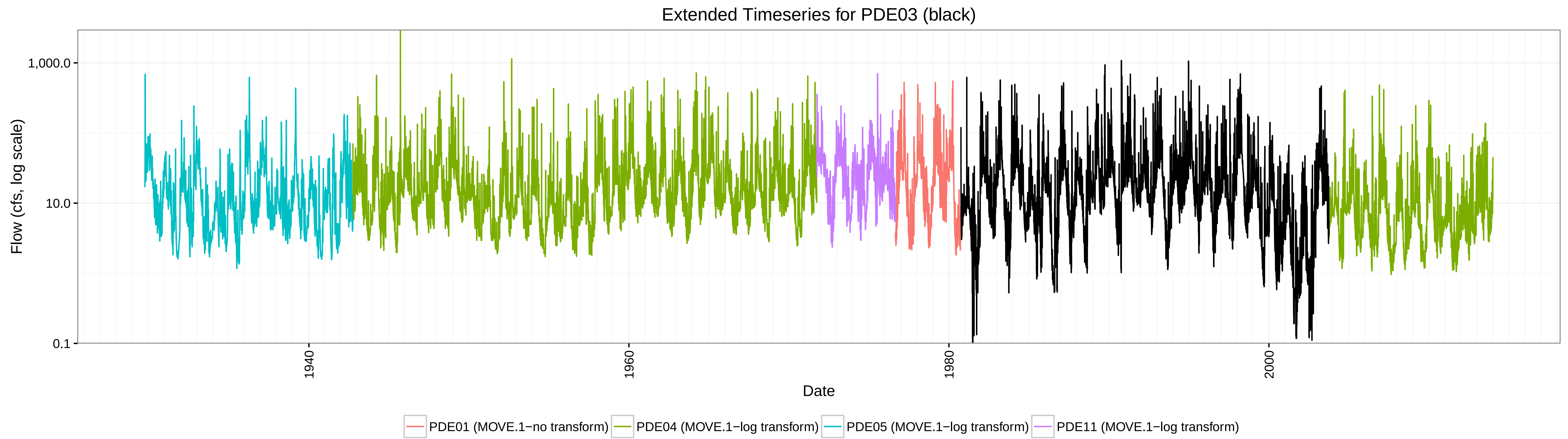
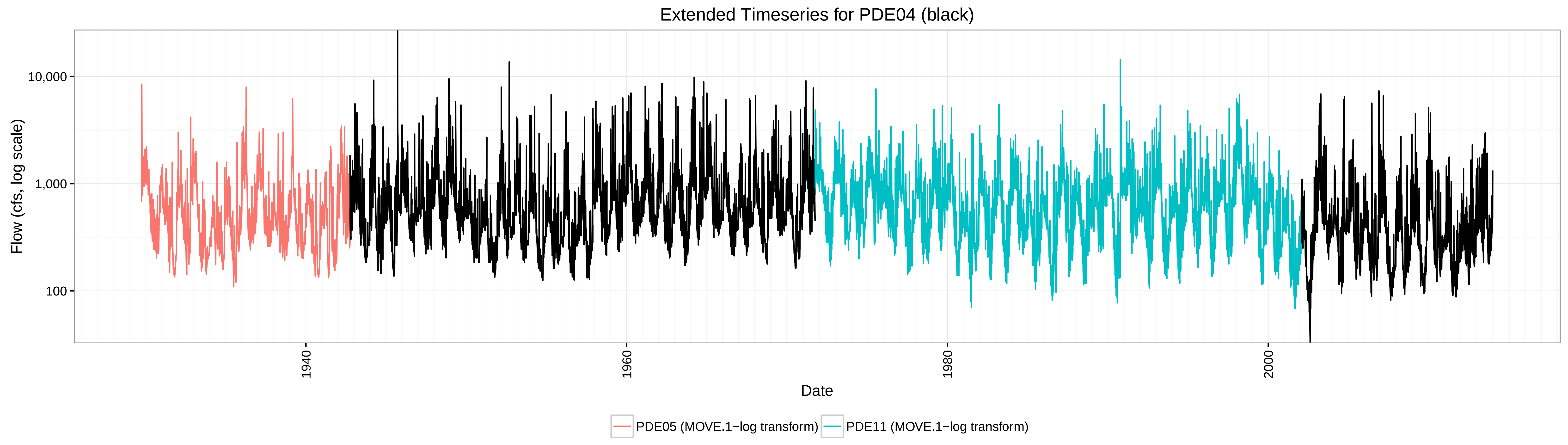
PDE03 (MOVE.1−no transform)
PDE05 (MOVE.1−log transform)
PDE20 (MOVE.1−log transform)



Extended Timeseries for PDE03 (black)
Flow (cfs, log scale)
1,000.0
10.0
0.1
1940
1960
1980
2000
Date
PDE01 (MOVE.1−no transform)
PDE04 (MOVE.1−log transform)
PDE05 (MOVE.1−log transform)
PDE11 (MOVE.1−log transform)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Flow (cfs, log scale)
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1,000
100
1940
1960
1980
2000
Date
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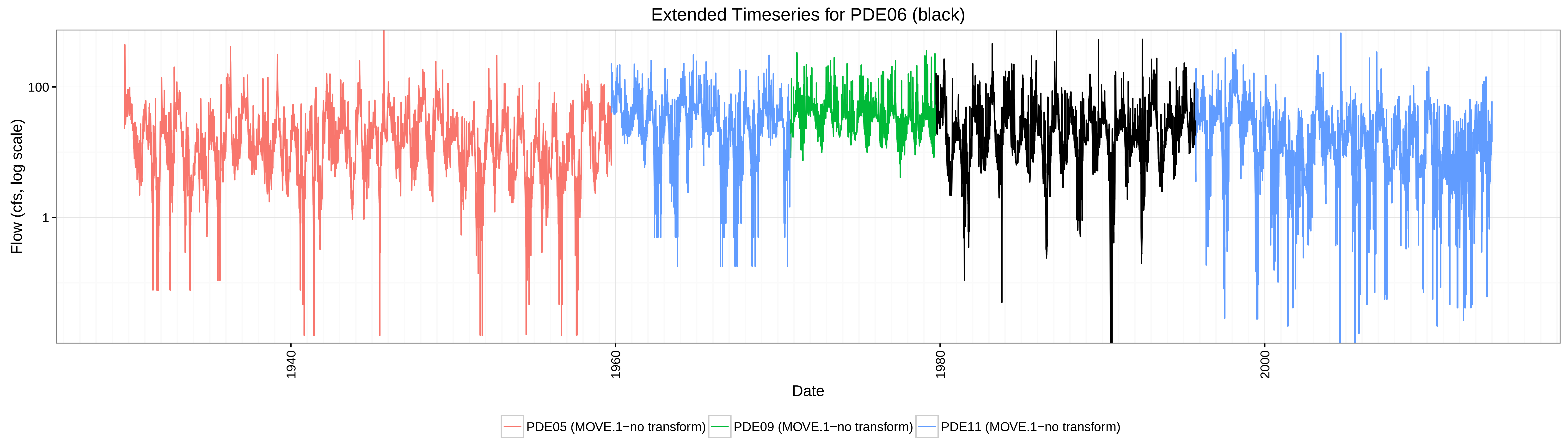
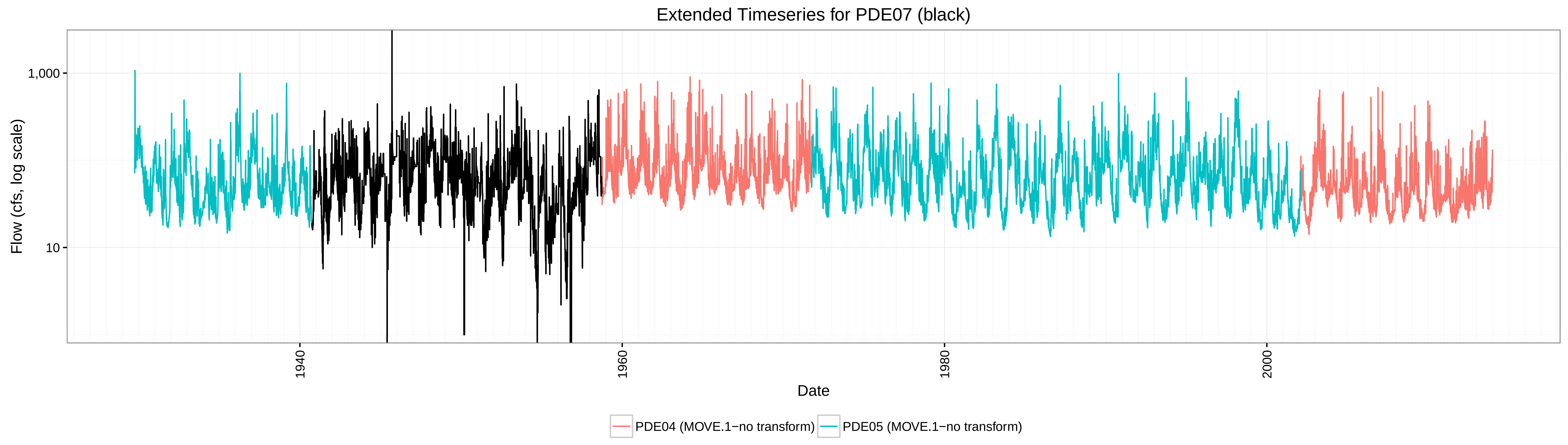
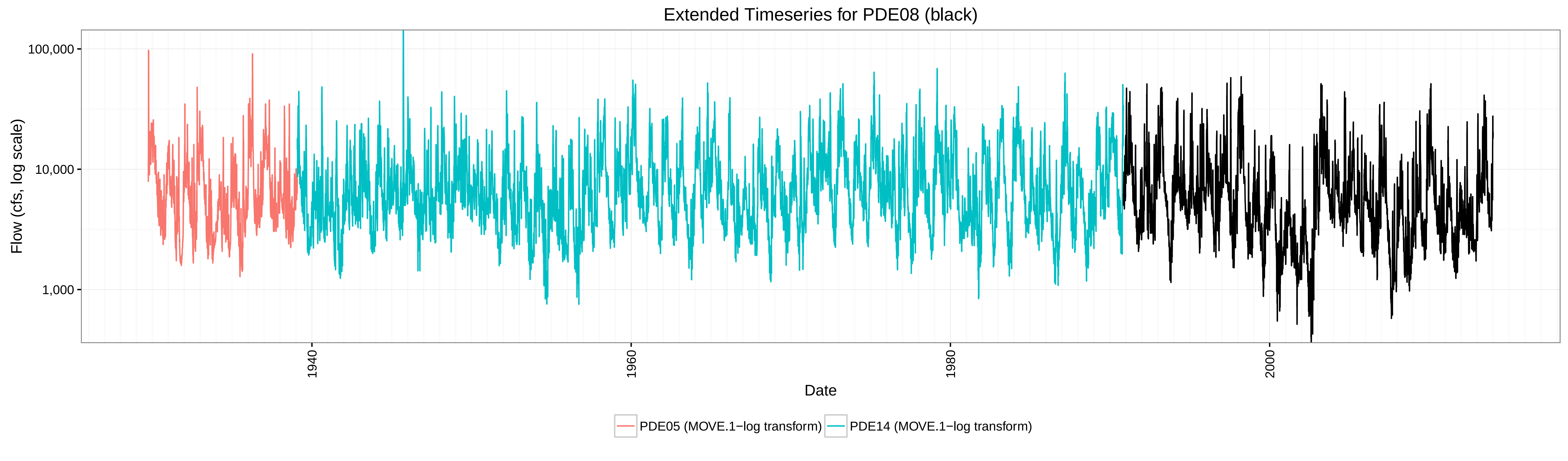
PDE11 (MOVE.1−log transform)

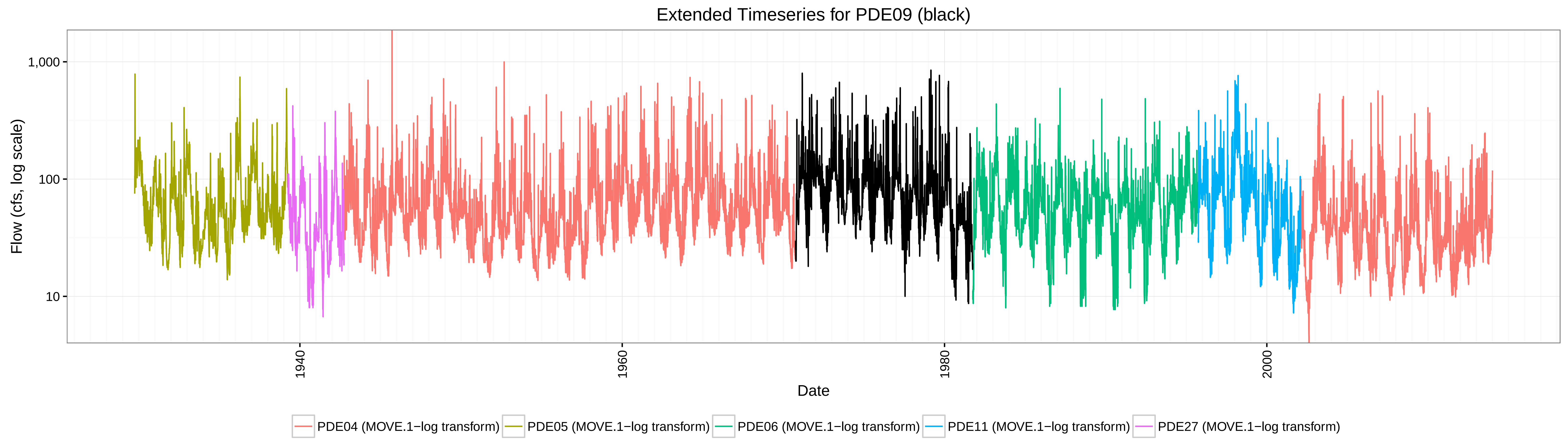


Extended Timeseries for PDE06 (black)
Flow (cfs, log scale)
100
1
1940
1960
1980
2000
Date
PDE05 (MOVE.1−no transform)
PDE09 (MOVE.1−no transform)
PDE11 (MOVE.1−no transform)

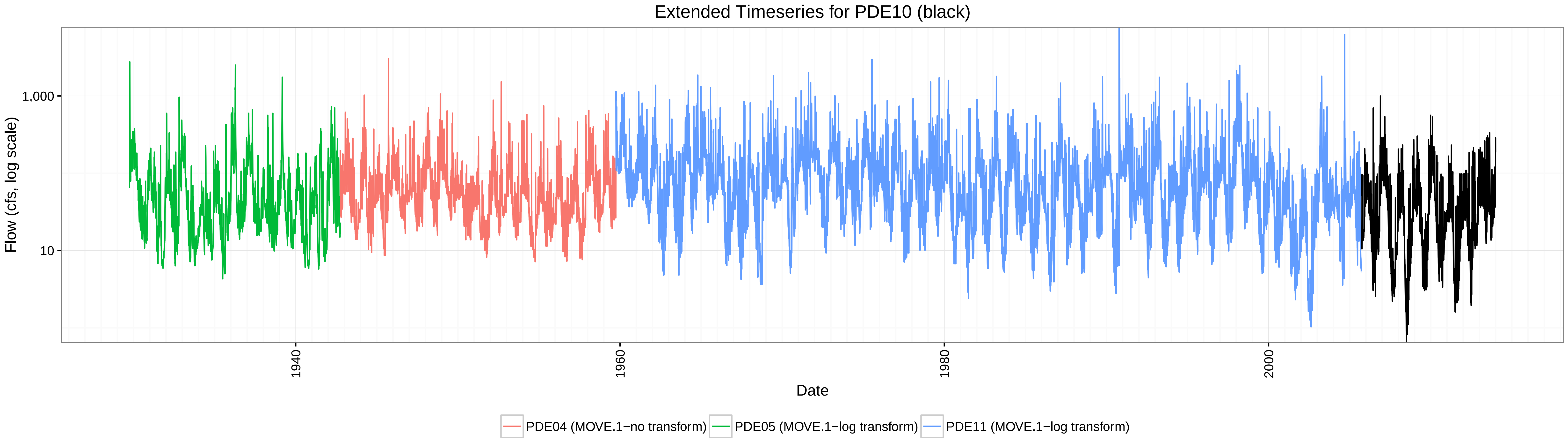

Extended Timeseries for PDE07 (black)
Flow (cfs, log scale)
1,000
10
1940
1960
1980
2000
Date
PDE04 (MOVE.1−no transform)
PDE05 (MOVE.1−no transform)



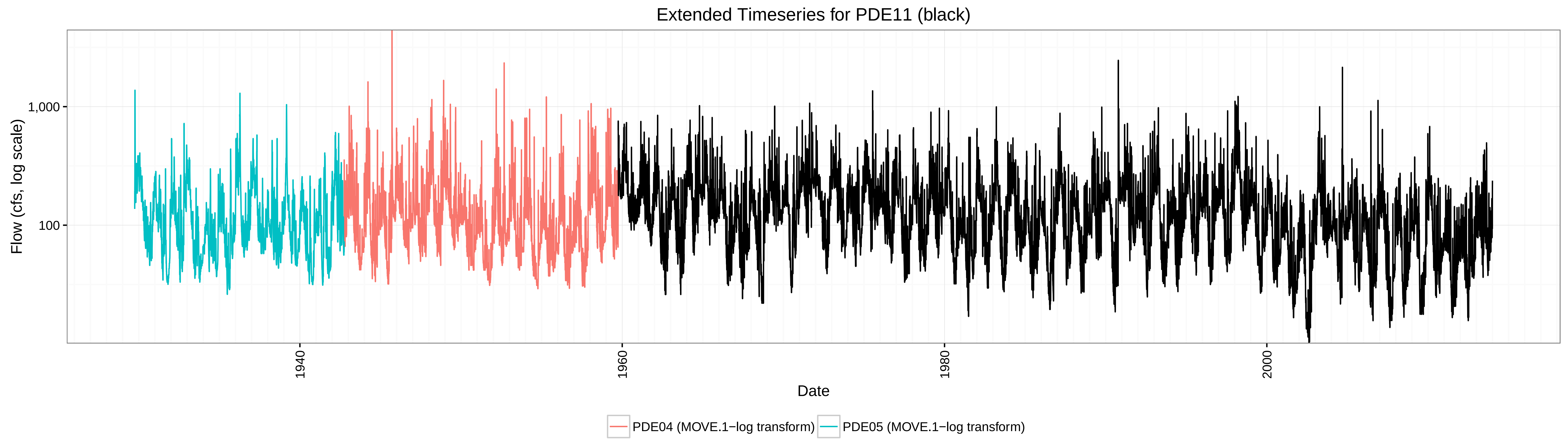
Extended Timeseries for PDE08 (black)
Flow (cfs, log scale)
100,000
10,000
1,000
1940
1960
1980
2000
Date
PDE05 (MOVE.1−log transform)
PDE14 (MOVE.1−log transform)



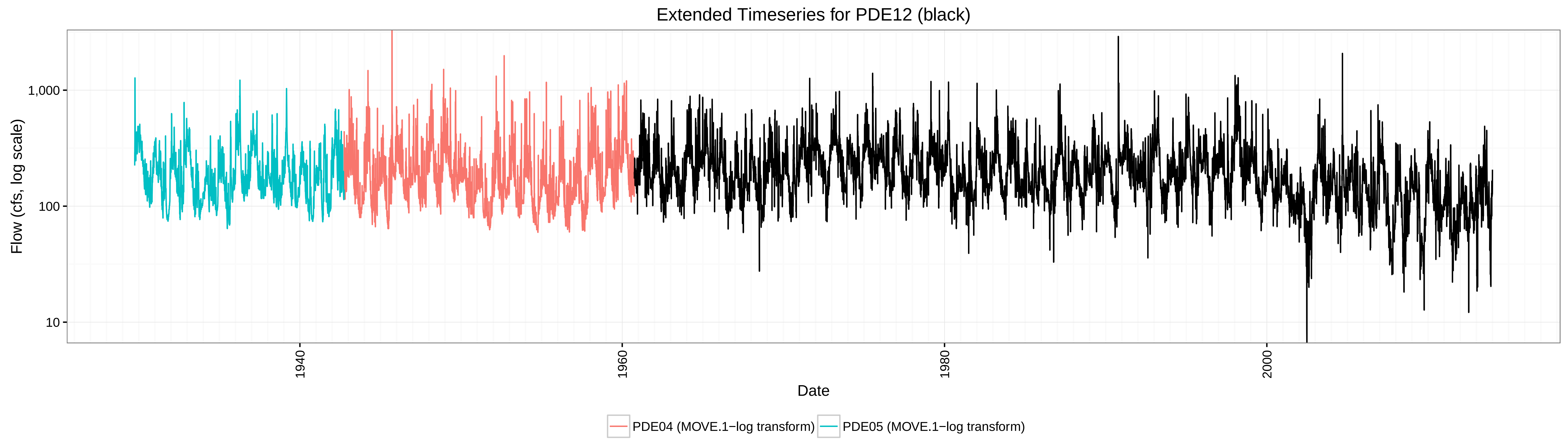
Extended Timeseries for PDE09 (black)
1,000
100
10
Flow (cfs, log scale)
1940
1960
1980
2000
Date
PDE04 (MOVE.1−log transform)
PDE05 (MOVE.1−log transform)
PDE06 (MOVE.1−log transform)
PDE11 (MOVE.1−log transform)
PDE27 (MOVE.1−log transform)

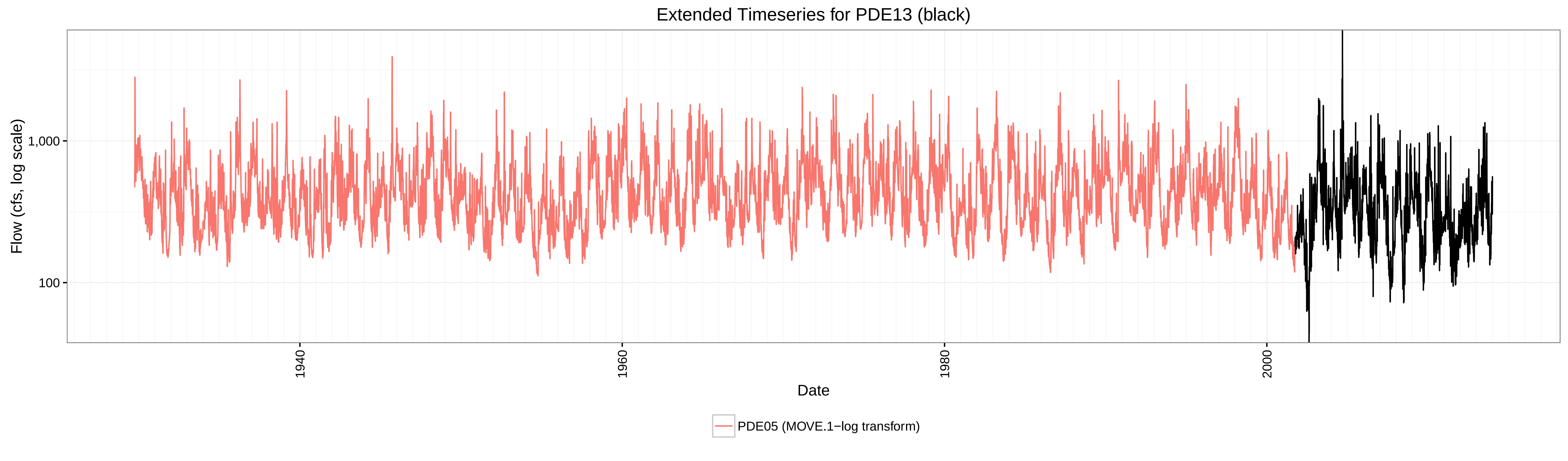


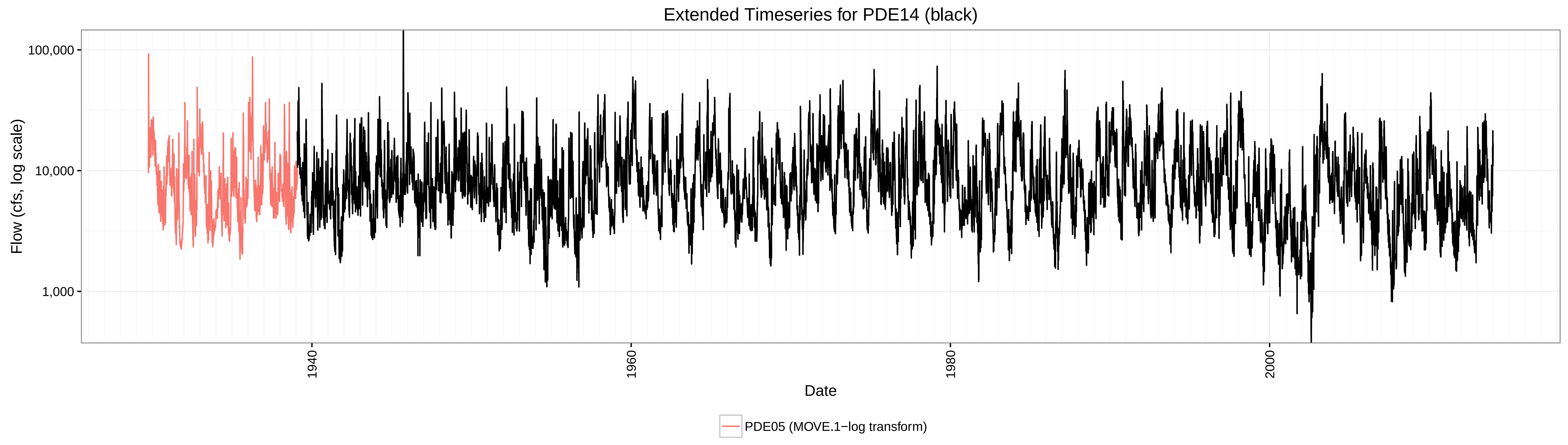
Extended Timeseries for PDE10 (black)
Flow (cfs, log scale)
1,000
10
1940
1960
1980
2000
Date
PDE04 (MOVE.1−no transform)
PDE05 (MOVE.1−log transform)
PDE11 (MOVE.1−log transform)



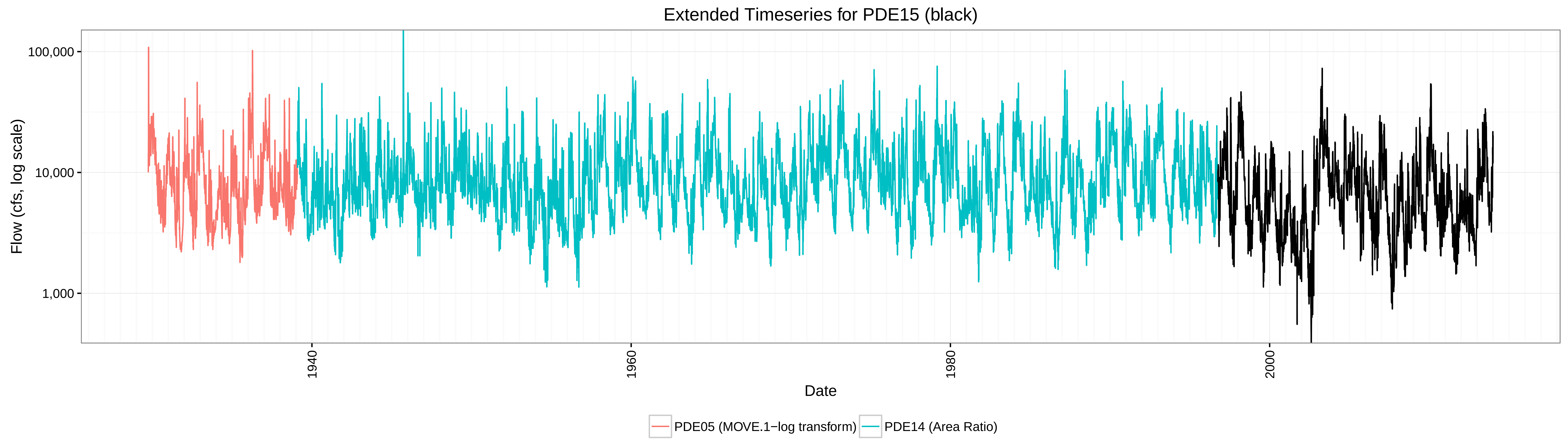
Extended Timeseries for PDE11 (black)
1,000
100
Flow (cfs, log scale)
1940
1960
1980
2000
Date
PDE04 (MOVE.1−log transform)
PDE05 (MOVE.1−log transform)


Extended Timeseries for PDE12 (black)
Flow (cfs, log scale)
1,000
100
10
1940
1960
1980
2000
Date
PDE04 (MOVE.1−log transform)
PDE05 (MOVE.1−log transform)

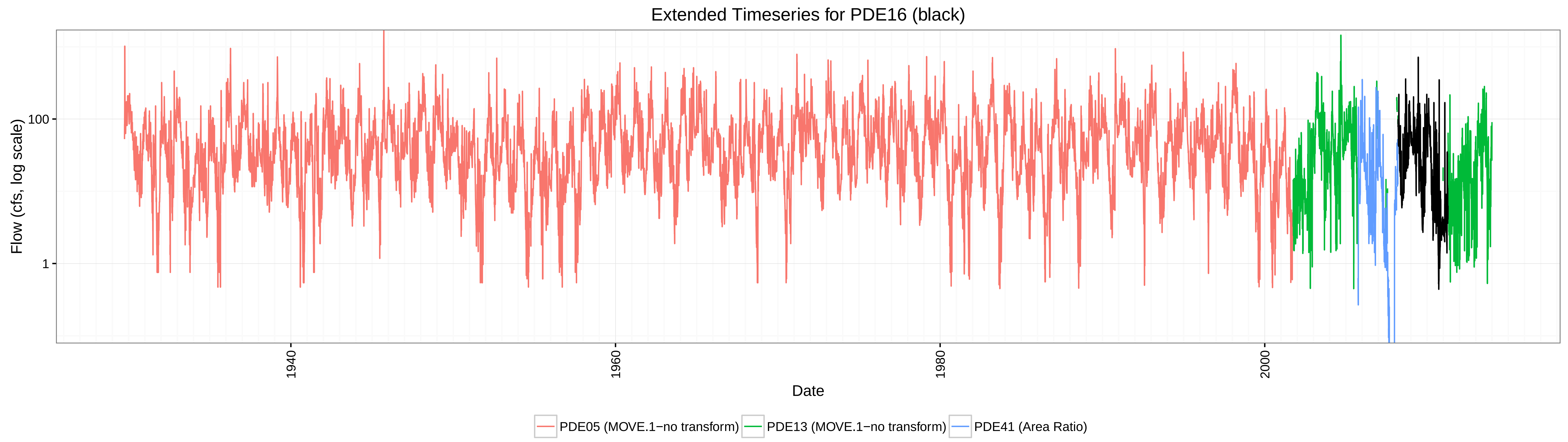

Extended Timeseries for PDE13 (black)
Flow (cfs, log scale)
1,000
100
1940
1960
1980
2000
Date
PDE05 (MOVE.1−log transform)



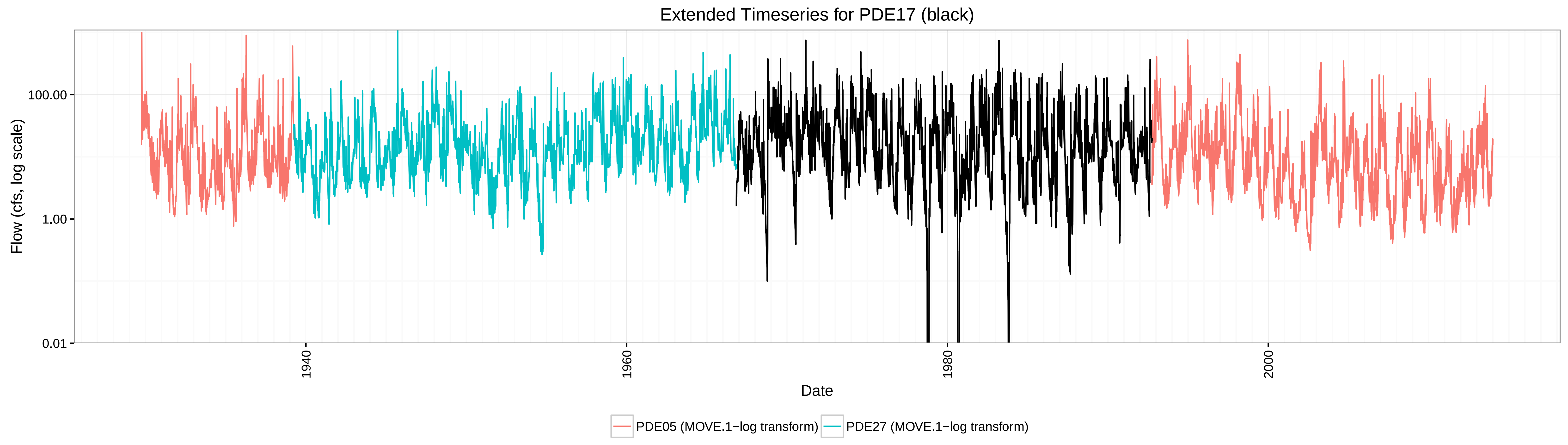
Extended Timeseries for PDE14 (black)
100,000
10,000
1,000
Flow (cfs, log scale)
1940
1960
1980
2000
Date
PDE05 (MOVE.1−log transform)



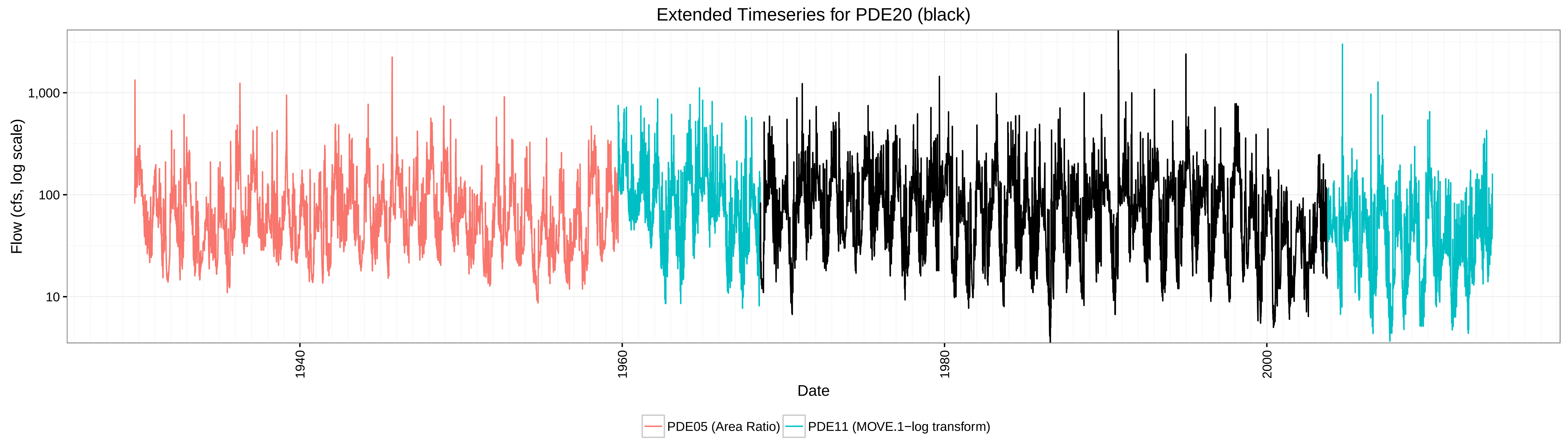
Extended Timeseries for PDE15 (black)
Flow (cfs, log scale)
100,000
10,000
1,000
1940
1960
1980
2000
Date
PDE05 (MOVE.1−log transform)
PDE14 (Area Ratio)

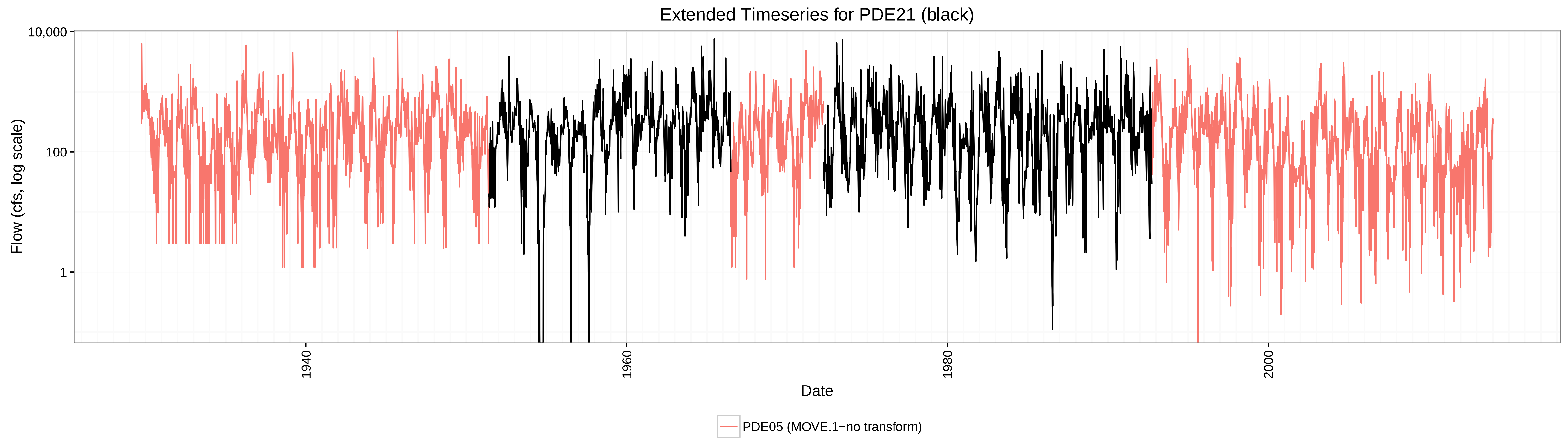


Extended Timeseries for PDE16 (black)
Flow (cfs, log scale)
100
1
1940
1960
1980
2000
Date
PDE05 (MOVE.1−no transform)
PDE13 (MOVE.1−no transform)
PDE41 (Area Ratio)

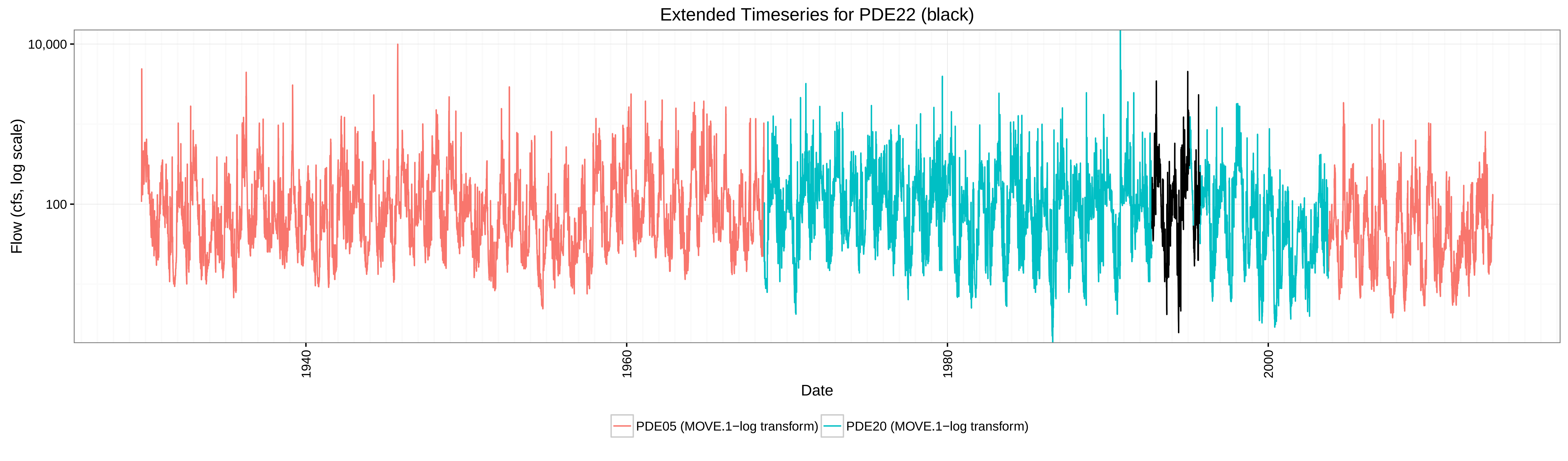


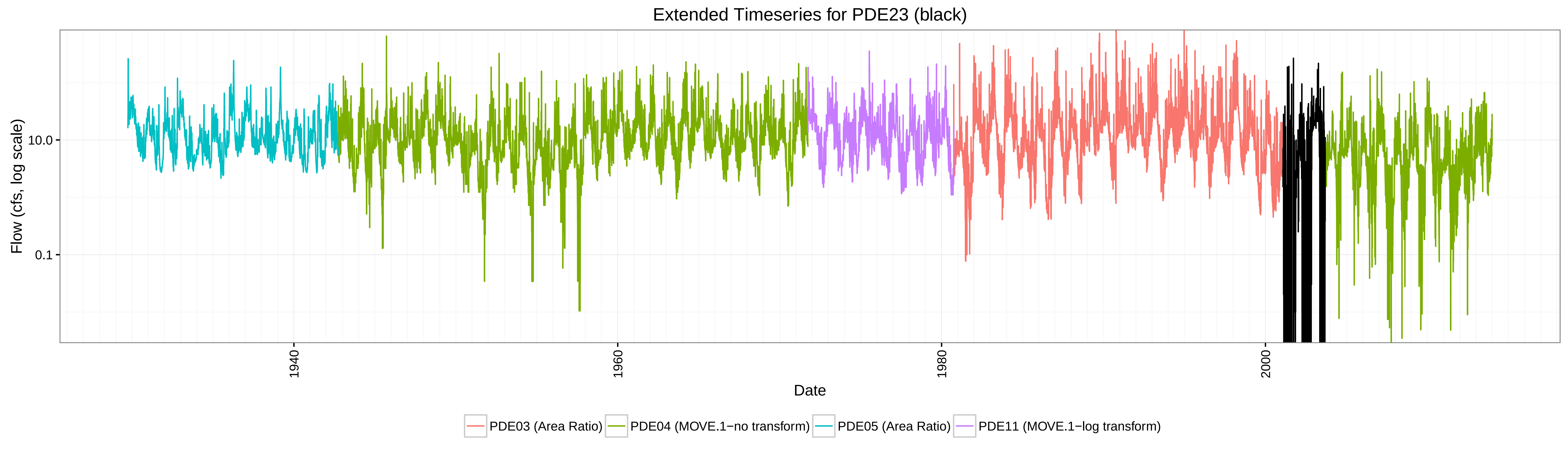
Extended Timeseries for PDE17 (black)
Flow (cfs, log scale)
100.00
1.00
0.01
1940
1960
1980
2000
Date
PDE05 (MOVE.1−log transform)
PDE27 (MOVE.1−log transform)

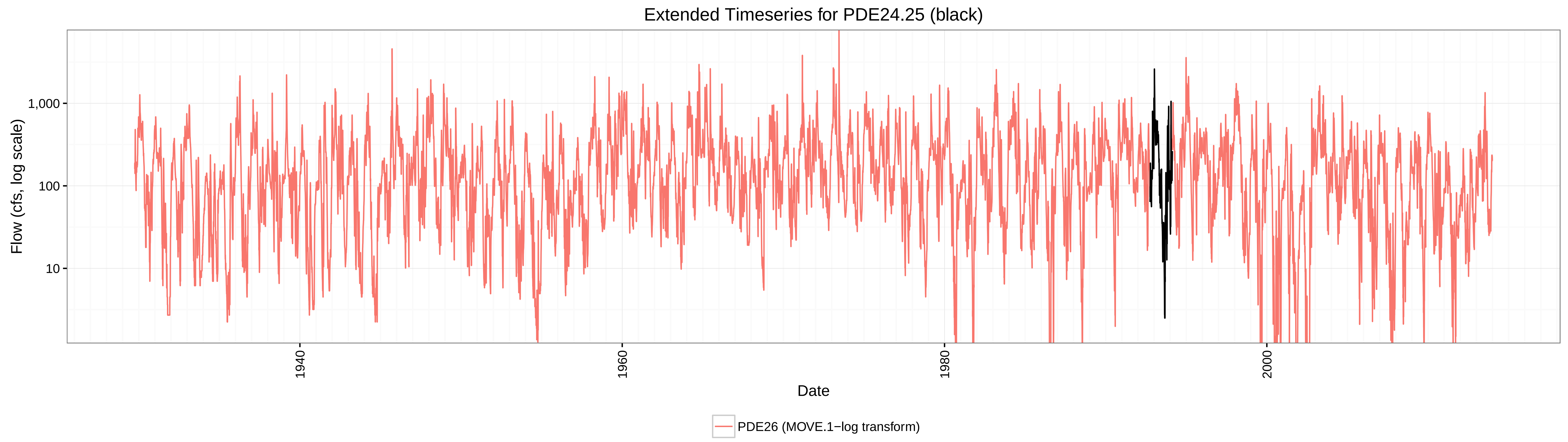

Extended Timeseries for PDE20 (black)
Flow (cfs, log scale)
1,000
100
10
1940
1960
1980
2000
Date
PDE05 (Area Ratio)
PDE11 (MOVE.1−log transform)



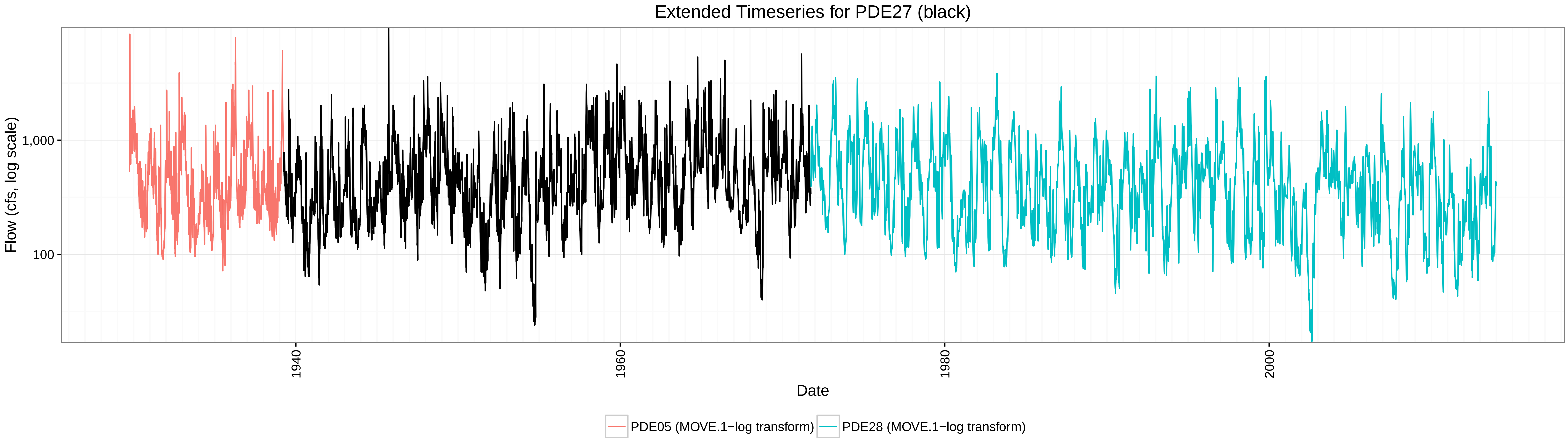
Extended Timeseries for PDE21 (black)
Flow (cfs, log scale)
10,000
100
1
1940
1960
1980
2000
Date
PDE05 (MOVE.1−no transform)

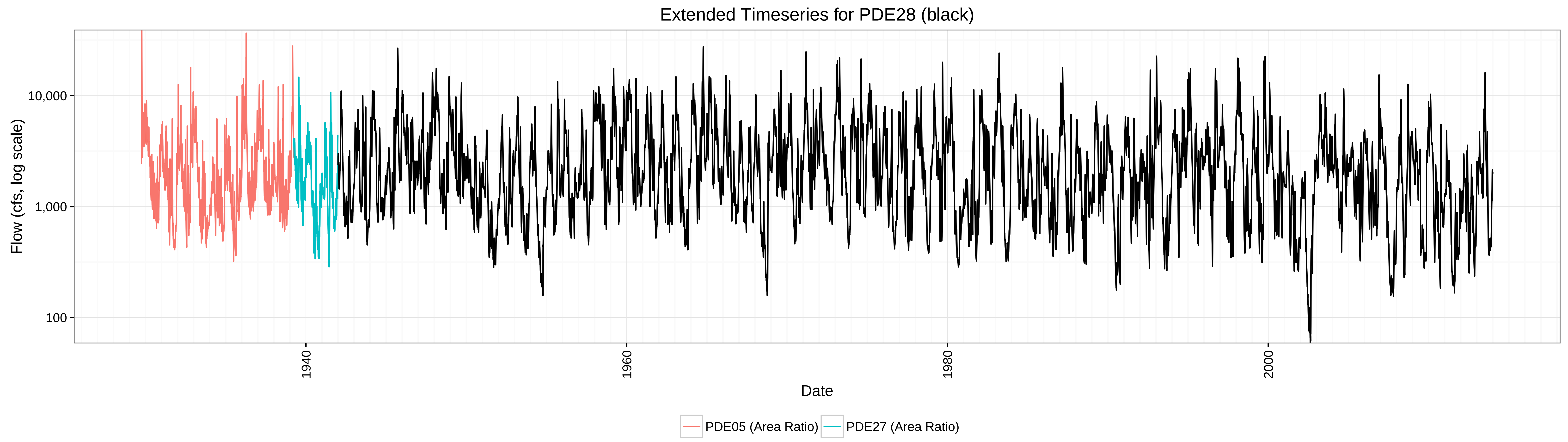

Extended Timeseries for PDE22 (black)
10,000
100
Flow (cfs, log scale)
1940
1960
1980
2000
Date
PDE05 (MOVE.1−log transform)
PDE20 (MOVE.1−log transform)

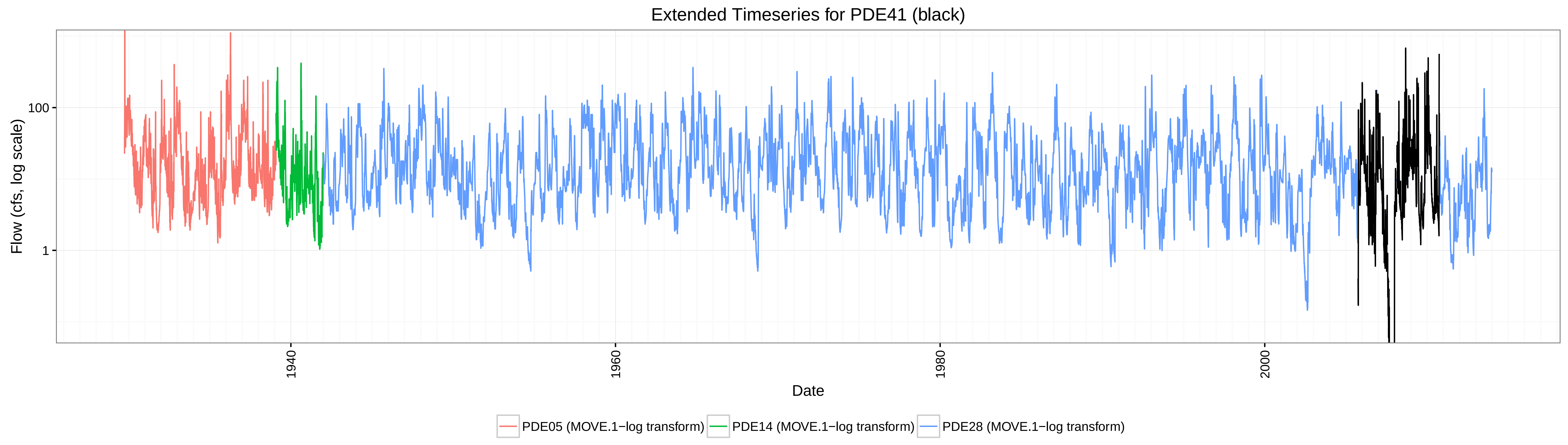

Extended Timeseries for PDE23 (black)
Flow (cfs, log scale)
10.0
0.1
1940
1960
1980
2000
Date
PDE03 (Area Ratio)
PDE04 (MOVE.1−no transform)
PDE05 (Area Ratio)
PDE11 (MOVE.1−log transform)



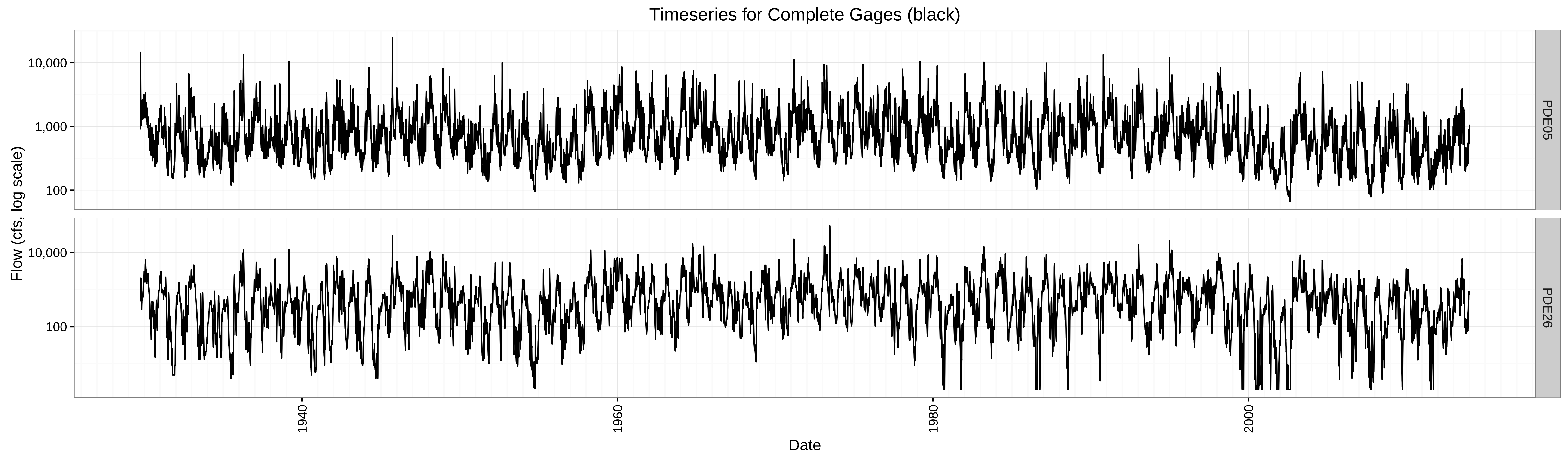
Extended Timeseries for PDE24.25 (black)
Flow (cfs, log scale)
1,000
100
10
1940
1960
1980
2000
Date
PDE26 (MOVE.1−log transform)


Extended Timeseries for PDE27 (black)
Flow (cfs, log scale)
1,000
100
1940
1960
1980
2000
Date
PDE05 (MOVE.1−log transform)
PDE28 (MOVE.1−log transform)


Extended Timeseries for PDE28 (black)
Flow (cfs, log scale)
10,000
1,000
100
1940
1960
1980
2000
Date
PDE05 (Area Ratio)
PDE27 (Area Ratio)



Extended Timeseries for PDE41 (black)
Flow (cfs, log scale)
100
1
1940
1960
1980
2000
Date
PDE05 (MOVE.1−log transform)
PDE14 (MOVE.1−log transform)
PDE28 (MOVE.1−log transform)



Timeseries for Complete Gages (black)
Flow (cfs, log scale)
10,000
1,000
100
PDE05
10,000
100
PDE26
1940
1960
1980
2000
Date

ATTACHMENT F

Discussion on Reference Gage and Method Selection

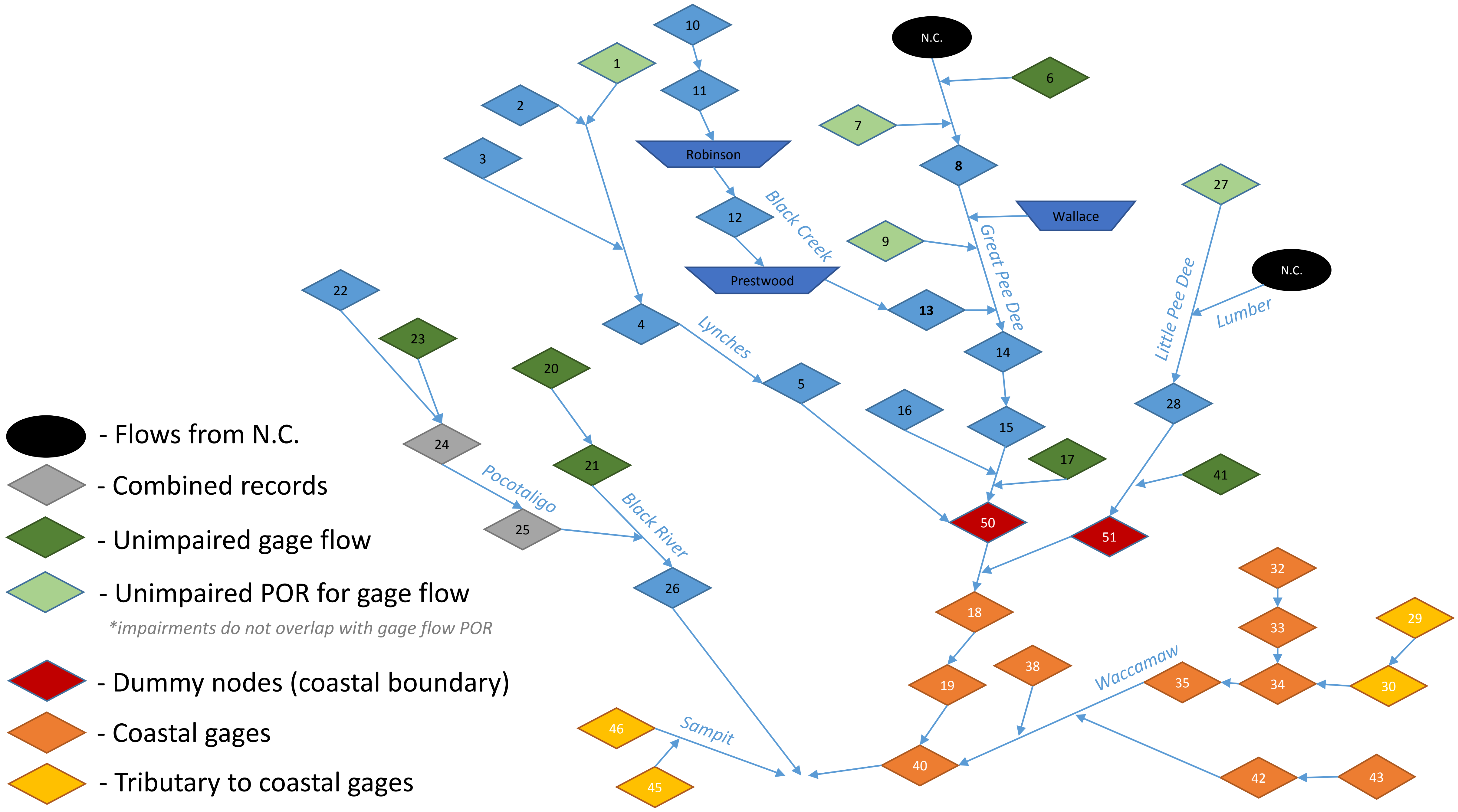
Gage	Reference	Method	Notes
PDE01	PDE02	MOVE.1-no transform	Statistics for all 3 methods similar. No transform matches low flows the best based on exceedence plot.
	PDE03	MOVE.1-no transform	Statistics for no transform and area ratio similarly low. Matches low flows better than area ratio does.
	PDE11	MOVE.1-log transform	Despite being a low flow gage, log transform matches best overall in both statistics and decision plots.
PDE01	PDE05	MOVE.1-log transform	Area-Ratio statistics look better but MOVE.1 log transform matches best in exceedence plots and timeseries.
	PDE01	MOVE.1-no transform	MOVE methods have lowest statistics, no transform's RMSE and PRESS slightly lower. Additionally, the overlapping minimum <1.
	PDE03	MOVE.1-no transform	Statistics for all 3 methods similar. No transform has lowest error and matches low flows the best.
PDE02	PDE20	MOVE.1-log transform	Statistics for all 3 methods similar.. Area ratio has lowest error, but log transform matches best in exceedence plots and timeseries.
	PDE05	MOVE.1-log transform	Statistics for all 3 methods similar. Area ratio has lowest error, but log transform matches best in exceedence plots and timeseries.
PDE03	PDE01	MOVE.1-no transform	Statistics for all 3 methods similar. MOVE methods perform similarly in decision plots. No transform selected due to overlapping minimum <1.
	PDE04	MOVE.1-log transform	Statistics for all 3 methods similar. Log transform matches best in decision plots especially for low flows. Note: minimum flow is <1.
	PDE11	MOVE.1-log transform	Log transform matches best in overal statistics and decision plots. Note: minimum flow is <1.
PDE03	PDE05	MOVE.1-log transform	Log transform matches best in overal statistics and decision plots. Note: minimum flow is <1.
PDE04	PDE11	MOVE.1-log transform	RMSE similar for all methods, but log transform PRESS much lower.
	PDE05	MOVE.1-log transform	RMSE similar for all methods, but log transform PRESS much lower.
PDE06	PDE09	MOVE.1-no transform	No transform and area ratio have lowest errors. No transform captures low flows better.
	PDE11	MOVE.1-no transform	No transform and area ratio have lowest errors. No transform captures low flows better.
PDE06	PDE05	MOVE.1-no transform	No transform and area ratio have lowest errors. No transform captures low flows better.
	PDE04	MOVE.1-no transform	Lowest RMSE and PRESS.
	PDE05	MOVE.1-no transform	Lowest RMSE and PRESS.

Gage	Reference	Method	Notes
PDE08	PDE14	MOVE.1-log transform	Best overall statistics and decision plots.
	PDE06	MOVE.1-log transform	Statistics for all 3 methods similar. Log transform matches best in decision plots and to low flows.
PDE09	PDE04	MOVE.1-log transform	Statistics for all 3 methods similar. Log transform matches best in decision plots.
PDE09	PDE11	MOVE.1-log transform	Statistics for all 3 methods similar. Log transform matches best in decision plots.
	PDE27	MOVE.1-log transform	Area-Ratio statistics look better. Log transform matches best to decision plots.
	PDE05	MOVE.1-log transform	MOVE statistics look similar. Log transform matches best to decision plots.
PDE10	PDE11	MOVE.1-log transform	Log transform overpredicts slightly. Could be either MOVE method.
	PDE04	MOVE.1-no transform	Best overall statistics and decision plots.
PDE10	PDE05	MOVE.1-log transform	Area-Ratio has slightly lower RMSE but underpredicts for high flows and overpredicts for low flows.
PDE11	PDE04	MOVE.1-log transform	Statistics are inconclusive. Log transform matches best in decision plots.
	PDE05	MOVE.1-log transform	Statistics are inconclusive. Log transform matches best in decision plots.
PDE12	PDE04	MOVE.1-log transform	High flows don't look too bad. Best overall method.
	PDE05	MOVE.1-log transform	Best overall.
PDE13	PDE05	MOVE.1-log transform	Lowest RMSE and PRESS.
PDE14	PDE05	MOVE.1-log transform	MOVE methods statistics best. Log chosen as it captures low flows much better and doesn't overpredict high flows too badly.
PDE15	PDE14	Area Ratio	Best overall.
	PDE05	MOVE.1-log transform	MOVE methods statistics best. Log chosen as it captures low flows much better and doesn't overpredict high flows too bad.
PDE16	PDE41	Area Ratio	None of the methods looks too fantastic. MOVE.1 no transform and Area-Ratio have better statistics. Area Ratio Exceedence Probabilities look best, although none of the time-series looks too hot.
	PDE13	MOVE.1-no transform	Between MOVE.1 no transform and Area-Ratio. No transform Exceedence Probabilities look best.
	PDE05	MOVE.1-no transform	Between MOVE.1 no transform and Area-Ratio. No transform Exceedence Probabilities look best.
PDE17	PDE27	MOVE.1-log transform	Statistics for all 3 methods similar. Log transform decision plots match best.
	PDE05	MOVE.1-log transform	Area-Ratio and no transform have slightly lower statistics but Log Transform decision plots match best.

Gage	Reference	Method	Notes
	PDE11	MOVE.1-log transform	Best overall.
PDE20	PDE05	Area Ratio	Best overall.
PDE21	PDE05	MOVE.1-no transform	Best overall.
	PDE20	MOVE.1-log transform	Log transform and area ratio have lowest statistics. Log transform matches best in decision plots.
PDE22	PDE05	MOVE.1-log transform	Area ratio has lowest PRESS but MOVE 1 log transform matches best in decision plots.
	PDE04	MOVE.1-no transform	MOVE.1 no transform and Area-Ratio have lowest errors. Very, very low gage flow. No transform looks better.
	PDE03	Area Ratio	RMSE similar but area ratio PRESS is lowest.
	PDE11	MOVE.1-log transform	Log transform and area ratio have lowest errors.
PDE23	PDE05	Area Ratio	Log transform and area ratio have lowest errors.
PDE24.25	PDE26	MOVE.1-log transform	Between one of the MOVE methods. Log transform chosen as the no-transform didn't capture low flows very well.
	PDE28	MOVE.1-log transform	Statistics for all 3 methods similar. Log transform matches best.
PDE27	PDE05	MOVE.1-log transform	Overpredicts peaks but no transform overpredicts low points.
	PDE27	Area Ratio	Best overall
PDE28	PDE05	Area Ratio	No transform has lowest statistics but area ratio performs better in decision plots.
	PDE28	MOVE.1-log transform	All methods overpredicting low flows.
	PDE14	MOVE.1-log transform	Best overall
PDE41	PDE05	MOVE.1-log transform	PDE14 and PDE05 could both be used as secondary reference gage.

ATTACHMENT G

Schematic of USGS Streamflow Gages in the Pee Dee River Basin



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